

HISTORY OF MODERN PHYSICAL SCIENCES – VOL. 3

*Matter*  
*and Spirit*  
in the Universe

Scientific and Religious Preludes  
to Modern Cosmology

Helge Kragh

Imperial College Press

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*and Spirit*  
in the Universe  
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# History of Modern Physical Sciences

## Aims and Scope

The series will include a variety of books dealing with the development of physics, astronomy, chemistry and geology during the past two centuries (1800–2000). During this period there were many important discoveries and new theories in the physical sciences which radically changed our understanding of the natural world, at the same time stimulating technological advances and providing a model for the growth of scientific understanding in the biological and behavioral sciences.

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*Matter*  
*and Spirit*  
in the Universe

Scientific and Religious Preludes  
to Modern Cosmology

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■ To Line and Mikkel

## ■ Preface

The relationship between religion and science has for a long time been a central area in the history of science and ideas. Presently, it is cultivated as actively as ever. During the 20th century and the last half of the 19th century, scholars have in particular focused on evolutionary theory and its implications for religious belief. Cosmology, although distinctly a modern science and undeniably of great relevance to theology, has received curiously little attention. To wit, in John Hedley Brooke's widely acclaimed *Science and Religion: Some Historical Perspectives*, an authoritative introduction and critical guide to the subject, modern cosmology is almost completely ignored. Nor have historians of physics and astronomy paid much attention to how cosmological and religious thought have interacted in the modern period. I believe there is a need for a book on the issue, which is too rich and fascinating not to be dealt with in a comprehensive way.

Being primarily a historian of modern physical science, I am not a specialist in the relationship between science and religious belief. My own interest in the field mostly emerged as a result of my studies in the history of cosmology, such as they appear most fully in my book, *Cosmology and Controversy* from 1996, which analyses in detail the emergence of the big-bang theory and its clash with the rival steady-state model. The present work relies in some respects on the material covered in my earlier book, but is broader in both chronology and scope. The focus of my study is the period between the 1850s and the

1960s. I start with a brief introductory chapter in which I refer to a few earlier ideas and developments, from the high Middle Ages to William Herschel's cosmological ideas of the 1780s. The purpose is solely to introduce certain key concepts in the relationship between cosmology and religion, and also to remind the reader that the relationship is an old one. It has a great past indeed. About its future I dare not prophesy.

Chapter 2 deals comprehensively with the second half of the 19th century, not least with the law of entropy increase and its assumed implications for cosmology and religion. This theme, which involves nothing less than the origin and end of the universe, runs through much of the book. Chapter 3 discusses the religious views of some of the important figures in cosmological research in the early part of the 20th century, including Einstein, Eddington and Jeans. Attention is also directed to Robert Millikan and other scientists who resisted the idea of an expanding universe and favoured, in part for religious reasons, a kind of recurrent cosmology. In earlier writings I have on several occasions drawn attention to George Lemaître, the relatively unknown Belgian who was arguably the single most important cosmologist of the 20th century. Lemaître was also a Catholic priest, and it has sometimes been claimed that his belief in a divine creator served as a motive for the big-bang concept he introduced in 1931. This and other aspects of Lemaître's work form the major part of Chapter 4.

The subsequent chapter is mostly devoted to the cosmo-physical tradition of the interwar period, a tradition characterized by a strong interest in rationalistic and numerological approaches to physics and astronomy. These approaches were in some cases associated with religious beliefs, although the connection was never strong. The main figures of the chapter are Arthur Eddington and Paul Dirac, but I also deal in some detail with Pascual Jordan and Arthur Haas, whose contributions to cosmology are less known and deserve to be recalled. Edward Milne, a prominent cosmo-physicist, is of particular interest, not only because his views were highly original but also because he explicitly linked them to his belief in God. His works and thoughts, such as they culminated in his book, *Modern Cosmology and the Christian Idea of God* from 1952, are described in Chapter 6. This chapter also includes aspects of the controversy in the 1950s between big-bang cosmology and the new steady-state theory of the universe. More details about the controversy can be found in *Cosmology and Controversy*.

My story essentially ends in the mid-1960s, with the emergence of the standard hot big-bang theory, but in a final chapter I indicate some of the later developments, if only in a fragmentary and incomplete way.

The book is a contribution to the history of scientific ideas, but it is neither a systematic account of cosmology's relation to theology nor a personal opinion of how the two fields should relate. It might be tempting to include an analysis of the intense discussion which has

occurred during the last few decades. However, this would require a new book and possibly also an author with a better knowledge of theology.

It should be noted that I use the words "universe," "cosmos" and "world" synonymously, as did most of the actors in the story I recount. What is more significant, I follow a tradition in history of science by writing about "religion" not in the broadest sense but, in most cases, in the sense of Christian belief. This is not an expression of religious intolerance or Euro-chauvinism. It merely reflects the fact that modern scientific cosmology has exclusively been developed in Europe and North America. I am fully aware that the issue also involves other religions, but in so far as it relates to the historical development of modern cosmology, it is a matter of fact that Christianity has occupied (and still occupies) a unique position.

I would like to express my thanks to Simon Rebsdorf, who has kindly gone through the manuscript and pointed out a number of errors.

Helge Kragh



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# 1

## Introduction: Cosmo-theology before Einstein

It is sometimes said that there is nothing new under the sun, which is surely an exaggeration. The proverb generally fails miserably in the history of science—after all, to make new discoveries is the business of science, and a quite successful business it is. On the other hand, for centuries astronomy and cosmology have been concerned with essentially the same kind of questions. These can be identified at the time of Kepler, or even earlier, and 350 years later they were still subjects of debate. Some of the problems were these:

- (i) Has the world always existed, or did it have an origin? And, will it ever come to an end?
- (ii) Is the world finite or infinite in spatial content?
- (iii) What is the relationship between the spatial and the material universe?
- (iv) Is the world static or in a state of evolution?
- (v) From where did matter (and energy) originate? Is it still being created?
- (vi) Are the laws of nature, as known from the local environment, applicable to the universe at large?

There are other questions of a similar cosmic nature, some of them even more comprehensive. Thus, philosophers and theologians may want to know *why* the world exists, or why there is something rather

than nothing. Depending on taste and background, this may be considered either a very deep or a very silly question. Most physicists and astronomers will presumably dismiss it as a question that does not belong in the domain of science. Today, several of the questions listed above have received a scientifically based answer, but this clarification only began about World War I, less than a century ago.

Although none of the questions refer to religion, for a long time they have been considered theologically relevant, either because theology might provide the answers, or because the answers might affect theological doctrines. To put it briefly, cosmology has always been important to theology, and, until fairly recently, *vice versa*. The prelude to and early phase of scientific cosmology occurred in the century between 1860 and 1960, largely the period covered by the present work. As we shall see, there was during the period a significant, if also problematic and controversial, interaction between cosmology and religious belief. To put the relationship in perspective, an impressionistic look at a few earlier episodes may be useful.<sup>1</sup>

### SCENE I: PARIS 1277

The introduction of Aristotelian learning in European universities in the thirteenth century was of the greatest importance to Christian culture and the emergence of science. But the meeting between Christianity and Aristotelianism was not an easy one, for other reasons because aspects of Aristotle's cosmology seemed to flatly disagree with Christian dogmas. According to Aristotle—respectfully named “the philosopher”—there was only, and could only be, one universe. The world was a plenum, spherically shaped and of limited size. Whereas this was not a great problem to medieval theologians, it was most disturbing that Aristotle had unequivocally argued that the universe could not possibly have come into being, nor could it ever cease to be. In sharp contrast to Genesis, and to Christian belief in general, Aristotle's cosmos was eternal.

This and other heresies in the Aristotelian texts led to heated discussions among the scholastics, who did what they could to present

<sup>1</sup> The literature on the historical relationship between religion and the physical sciences is extensive. For a brief and excellent overview, see Jakl 1966, pp. 412–457.

the admired heathen philosopher in a christianized version. Albert the Great, Thomas of Aquinas and other great theologians of the 13th century sought to circumvent the dilemma of choosing between belief and philosophy, between Jerusalem and Athens. Their answer was a "two roads" philosophy according to which Christian theology and Aristotelian philosophy were different but compatible and supplementary roads to truth. Properly understood the two roads could not lead to contradictory truths. Yet it was hard to see how the strategy could be applied to, for example, the question of whether the world was eternal or created in time. It would seem that if the world is eternal, God could not have created it in the past; conversely, if he did create the world, Aristotle must be wrong.

According to Aquinas, who wrote most of his treatises in the 1260s, the question was more involved than simply a choice between Scripture and Aristotle.<sup>2</sup> In his *De Aeternitatis Mundi* from about 1270, he discussed whether something that had always existed can be made; only if this is logically impossible would he concede that God could not have created an eternal universe. But Aquinas argued that since God need not precede his effects in time, there is no contradiction in claiming that a divinely created universe has always existed. Aquinas granted that all change requires some underlying material reality and that nothing can therefore come from nothing. Yet, whereas philosophers deal with changes or processes such as found in the physical world, theologians are concerned with creation, a very different notion which centers on existence as such. Creation is not merely change, it is to give existence to things, to cause them. God does not take "nothing" and transforms it into something, he causes things to exist continually in the radical sense that if they were left to themselves they would return to nothingness.

From this perspective there is no real distinction between creation and preservation. Applying his reasoning to cosmology, Aquinas distinguished between a temporal beginning of the universe and its creation, where the latter concept refers to the existence of the universe as such. From this point of view an eternal, created universe is perfectly possible. Even if the universe had no temporal beginning, it would still depend upon God for its very being. Aquinas repeatedly

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<sup>2</sup> Carroll 1998 (and on [www.nd.edu/Departments/Maritaln/ti/carroll.htm](http://www.nd.edu/Departments/Maritaln/ti/carroll.htm)).

stressed that creation is a metaphysical, not a temporal concept:

Not only does faith hold that there is creation, but reason also demonstrates it . . . . It is to be known, moreover, that the meaning of creation includes two things. The first is that it presupposes nothing in the thing which is said to be created . . . . The second thing is that non-being is prior to being in the thing which is said to be created. This is not a priority of time or of duration, such that what did not exist before does exist later, but a priority of nature, so that, if the created thing is left to itself, it would not exist, because it only has a being from the causality of the higher cause. What a thing has in itself and not from something else is naturally prior in it to that which is has from something else.<sup>3</sup>

Aquinas thought that Aristotle was wrong to contend that the universe is eternal, but he also argued that the question could not be answered on the basis of reason or science alone. As a Christian he believed that the universe was of finite age, but it might well be eternal from a philosophical point of view. What really mattered was that God had created the universe, given its existence, and this involved no contradiction with either reason or faith.

Aquinas was professor in Paris in two periods, 1256–59 and 1269–72. In spite of his elaborate attempt to steer a middle course between Aristotle and Catholic faith, the tensions reached a climax soon after his death. In 1277, the Bishop of Paris, Etienne Tempier, issued a list of forbidden propositions, opinions which were condemned as heretical. Altogether there were 219 such false propositions, including "That the only wise men of the world are philosophers" (where "philosopher" may also be understood to mean "scientist"). Some of the propositions referred to cosmology, such as the erroneous belief in a cyclical universe, "That when all celestial bodies have returned to the same point—which will happen in 36,000 years—the same effects now in operation will be repeated." The Bishop also made clear that God could have made several worlds, had he so wished. Moreover, it was wrong to believe

(87) That the world is eternal as to all species contained in it; and that time is eternal, as are motion, matter, agent, and

<sup>3</sup> *Ibid.*



recipient.... (107) That the elements are eternal. However, they have been made anew in the relationship they now have.... (185) That it is not true that something could be made from nothing, and also not true that it was made in the first creation.... (202) That the elements have been made in a previous generation from chaos; but they are eternal.<sup>4</sup>

In spite of the problems of reconciling Christian faith and the naturalistically oriented philosophy (or science), the ingenious Thomist synthesis did what might seem impossible. In 1323 Aquinas was canonized, and two years later the bishop of Paris revoked the condemned articles. Theology and natural philosophy appeared to have entered a harmonious partnership. Aquinas' system eventually became part of official Catholicism, especially after Pope Leo XIII in 1879 called attention to it as an answer to the intellectual and social challenges of modernity. Since then, Thomism and neo-Thomism have been integrated elements in Catholic thinking.

That medieval philosophers were not always restricted by theological doctrines is illustrated by Nicholas of Cusa, better known as Cusanus, who in *De Docta Inignorantia* from 1440 argued for an infinite and homogeneous universe. According to Cusanus, there was no privileged place in the universe, and all celestial bodies were essentially of the same nature. His radical postulate anticipated what in twentieth-century cosmology became the cosmological principle, the claim that the universe at large is homogeneous and isotropic.

Some of Cusanus' ideas were later developed by Giordano Bruno, who not only suggested that the world is spatially infinite but also that it is eternal. Understandably, his ideas led him into trouble with the Church.

Thomas Aquinas and his contemporaries were principally concerned with theology, not the physical universe, and one may wonder what the learned discussions in the 13th century has to do with modern cosmology. The answer, it seems to me, is: quite a lot. As we shall see in Chapter 6, the distinctions made by medieval theologians were highly relevant to the cosmological controversy in the 1950s. They still are.

<sup>4</sup> Quoted from the selection in Grant 1974, pp. 48-50.

## SCENE II: THE NETHERLANDS 1637

In the early part of the 17th century the relationship between science and theology was still strong, perhaps stronger than ever, but it was no longer harmonious. In particular, Copernicus' heliocentric world system of 1543 caused problems with Christian orthodoxy. In 1633 Galileo had been condemned by the Roman-Catholic church, imprisoned and forced to retract his heretical support of the Copernican universe which so obviously contradicted the Holy Writ. René Descartes, the new star on the firmament of natural philosophy, was shocked, and decided to withhold from publication his *Le Monde*, a cosmology firmly based upon Copernican principles. As he wrote to Marin Mersenne, "I wouldn't want to publish a discourse which had a single word that the Church disapproved of; so I prefer to suppress it rather than publish it in a mutilated form."<sup>5</sup> Descartes was no more an atheist, a materialist or an agnostic (a word still to be invented) than Galileo was. He believed in God as the creator of the universe, but not in a universe which developed according to some plan, teleologically towards the present state of affairs. Descartes' cosmological vision was different, such as he made it clear in his famous *Discours de la Méthode* of 1637, published anonymously in Leiden.

Descartes is one of the fathers of the very idea of natural laws, and he strongly believed not only that law-governed mechanical processes had to replace teleology, but also that his picture of the world was in full agreement with Christian belief. Ultimately, his cosmogony and cosmology were products of matter in motion. God had of course installed the laws, as he had created the material world, but that was that. What followed was a consequence of the laws of motion and the initial conditions. However, in *Discours* and elsewhere he argued that the laws were all-important, not the special initial conditions. These could be anything. What would happen, he asked, if God created a new world and "if He agitated in diverse ways, and without any order, the diverse portions of this matter, so that there resulted a chaos as confused as the poets ever feigned, and concluded His work by merely lending His concurrence to Nature in the usual way, leaving her to act in accordance with the laws which

<sup>5</sup> Quoted in Gaukroger 1995, p. 291.

He had established."<sup>6</sup> According to Descartes, who immodestly claimed his reasoning to rest on no "other principle than the infinite perfection of God," the mechanical laws would eventually lead to the very same world that we inhabit:

Although He had not, to begin with, given this world any other form than that of chaos, provided that the laws of nature had once been established and that He had lent His aid in order that its action should be according to its wont, we may well believe, without doing outrage to the miracle of creation, that by this means alone all things which are purely material might in course of time have become such as we observe them to be at present.

That is, cosmic development is strictly determined by the laws of nature, and there is no further need for God to intervene with any supplementary acts of creation. Descartes effectively limited the omnipotent God's cosmic creativity, not with respect to worlds or matter but to the laws of nature. These, he wrote, "are of such a nature that even if God had created other worlds, He could not have created any in which these laws would fail to be observed." It was not the last time that a cosmologist argued that the divine laws of nature are not subject to God's further manipulation (see Chapter 6).

Descartes believed that the most efficient way to construct a universe would also be God's way, and this way was to start with a chaos and invoke only the laws of mechanics. Any kind of original chaos would do, as it would lead to the same world. What has been called the "indifference principle" was however initially seen as theologically suspect, because it was too mechanistic and seemed to make natural theology redundant. In modern cosmological theory the indifference principle has reappeared in so-called chaotic cosmology and models of the very early, inflationary universe.<sup>7</sup>

### SCENE III: CAMBRIDGE 1692

The first edition of Newton's *Principia*, published in 1687, was silent about God and also included no discussions of cosmological and

<sup>6</sup> Descartes 1996, pp. 26–28.

<sup>7</sup> McMullin 1993.

cosmogonical questions. These only entered in the second edition of 1713, where Newton declared that "to treat of God from phenomena is certainly a part of natural philosophy." His scientific arguments for the existence of God were essentially of two types. For one thing, the wonderful richness and organization of the universe strongly indicated that it was designed by a divine being. In addition to this argument of natural theology, Newton mentioned various phenomena that could not be explained scientifically and therefore required appeal to divine intervention. This was an argument of what would later be called "God of the gaps." Newton wrote:

This most elegant system of the sun, planets, and comets could not have arisen without the design and dominion of an intelligent and powerful being. And if the fixed stars are the centers of similar systems, they will all be constructed according to a similar design and subject to the dominion of *One*, . . . . And so that the systems of the fixed stars will not fall upon one another as a result of their gravity, he has placed them at immense distances from one another.<sup>8</sup>

But even though God originally ordered the stars at immense distances, in itself this would be insufficient to prevent gravitational collapse. God had created the stellar system and his further action was required to preserve it.

Newton's thinking about cosmological problems was indebted to a series of questions from Richard Bentley, chaplain to the Bishop of Worcester. In his correspondence with Bentley in the winter 1692-93, Newton mentioned several astronomical phenomena that could be accounted for only by assuming God's direct intervention. For example, "the Motions which the Planets now have could not spring from any natural Cause alone, but were impressed by an intelligent Agent;" and the adjustment of the velocities, masses and distances of the planets "argues that Cause to be not blind and fortuitous, but very well skilled in Mechanicks and Geometry."<sup>9</sup> The present course of nature could not go on indefinitely. If left to herself, nature would slowly enter a state of decay because of the celestial bodies' friction in the ether and their mutual gravitational perturbations.

<sup>8</sup> Newton 1999, p. 940. On Newton's cosmo-theology, see Hoskin 1982, pp. 71-100.

<sup>9</sup> Newton's letters to Bentley, first published in 1756, are reproduced in Cohen 1978, pp. 279-312.

As to the distribution of matter in the universe, Newton argued that if the world was finite all matter would eventually coalesce in one huge central mass. Even in his favoured universe of infinite size it was hard to imagine how the stars could be arranged in a perfect gravitational equilibrium, but Newton thought it was possible, "at least by a divine power." In his *Confutation of Atheism* of 1693, Bentley repeated what Newton had taught him: "The continuance of this Frame and Order for so long a duration as the known ages of the World must necessarily infer the Existence of God. For though the Universe was Infinite, the Fixt Starrs could not be fixed, but would naturally convene together, and confound System with System."<sup>10</sup> For Newton and Bentley it was important to stress that although the force of gravitation operates throughout the infinite universe, neither it nor other known laws of nature can secure a stable universe. Only divine providence can do that. In his third letter to Bentley, Newton considered the possibility "that there might be other Systems of Worlds before the present ones, and others before those, and so on to all past Eternity." Although he dismissed such a self-generating cyclical universe as "apparently absurd," he granted that it might be accomplished by the will of a divine power.<sup>11</sup>

Newton returned to cosmo-theology in Query 31 of his *Opticks*, where he concluded that it was most "unphilosophical" to believe that the world "might arise out of a Chaos by the mere Laws of Nature." Contrary to Descartes, Newton insisted that the universe cannot be fully understood by the laws of mechanics alone. The wonderful uniformity in the planetary and sidereal systems was only possible because they were constructed and maintained by an intelligent agent. Newton's universe was mechanical but neither deterministic nor free of vital principles and spirits. On the contrary, such non-mechanical principles were all-important to keep the universe going, for "Motion is more apt to be lost than got, and is always upon the Decay." In a passage which may bring to mind much later discussions concerning possible counter-entropic processes, he wrote: "If it were not for these Principles, the Bodies of the Earth, Planets, Comets, Sun, and all things in them, would grow cold and freeze, and

<sup>10</sup> Cohen 1978, p. 351.

<sup>11</sup> On Newton and the cyclical universe, see Kubrin 1967, reprinted in Colln A. Russell, *Science and Religious Belief. A Selection of Recent Historical Studies* (Guildford: Open University Press, 1979), pp. 147-169.

become inactive Masses; and all Putrefaction, Generation, Vegetation and Life would cease, and the Planets and Comets would not remain in their Orbs."<sup>12</sup>

Whereas Descartes' God was constrained by the laws of nature, Newton emphasized God's omnipotence and absolute freedom to create whatever he pleased. The laws of nature were expressions of the way God acted and he could decide to act differently, thereby changing the laws. In *Opticks*, Newton indulged in a remarkable many-worlds speculation. "It may be also allow'd," he wrote, "that God is able to create Particles of Matter of several Sizes and Figures, and in several Proportions to Space, and perhaps of different Densities and Forces, and thereby to vary the Laws of Nature, and make Worlds of several sorts in several Parts of the Universe."<sup>13</sup>

To Leibniz and other critics, the universe created by Newton's God looked suspiciously like a second-rate construction in constant need of repair. They believed that a perfect God would have created a perfect world, at least in the sense of being the best of all possible worlds, a machine in no need of maintenance. But Newton and his protagonists found such a world view to be dangerously close to deism. Samuel Clarke, Newton's spokesman in the controversy with Leibniz, expressed it as follows: "The notion of the world's being a great machine, going on without the interposition of God, as a clock continues to go without the assistance of a clockmaker, is the notion of materialism and fate, and tends...to exclude providence and God's government in reality out of the world."<sup>14</sup>

Leibniz was no less obsessed with God than Newton was. But he conceived of God differently, and his arguments for His existence were different too. For example, Leibniz asked why there is something rather than nothing, and also why things exist as they do and not in some other form. There must, he wrote, be a "sufficient reason, which needs no further reason, must be outside this series of contingent things,.... And this final reason of things is called God."<sup>15</sup> Leibniz's argument is one version among several which are collectively known as the cosmological argument (and which has nothing to do with cosmology in its modern meaning).

<sup>12</sup> Newton 1952, pp. 399–402.

<sup>13</sup> *Ibid.*, pp. 403–404.

<sup>14</sup> Quoted in Hoskin 1982, p. 88.

<sup>15</sup> Leibniz 1934, p. 26.



## SCENE IV: KÖNIGSBERG 1755

Immanuel Kant, a young privatdocent at the University of Königsberg in Prussia, published in 1755 a remarkable work on the development and structure of the universe, *Allgemeine Naturgeschichte und Theorie des Himmels*. Unfortunately his publisher went bankrupt and had his stock impounded, for which reason the work remained practically unknown for a long time. It was only after Helmholtz had praised the theory in a lecture delivered at Königsberg in 1854, that it came to general attention.<sup>16</sup> In spite of its lack of impact, Kant's book marked a new phase in the history of cosmology, primarily because it presented a thoroughly *evolutionary* account of the universe in its totality. It was a grand attempt at a *Universal Natural History and Theory of the Heavens*, as the title reads in English. His world picture was purportedly a scientific theory, solidly based on Newtonian mechanics, but it was a qualitative picture only, and one that rested to a large extent on speculations and hypotheses. Although Kant referred frequently to God and presented his theory as theistic, in reality it was naturalistic, and the references to the Creator largely rhetorical. Contrary to Newton, but in agreement with Leibniz, he found no place for divine miracles in the universe: "A constitution of the world which did not maintain itself without a miracle, has not the character of that stability which is the mark of the choice of God."<sup>17</sup>

Kant started with an original, divinely created chaos of particles at rest, distributed throughout an infinite void. This initial chaos is unstable, he said, and the denser particles will begin to attract the more tenuous, and thus form condensations. With Descartes he claimed that the primary chaos must necessarily evolve into regular and orderly structures—a definite cosmos. As a result of Newtonian gravitation, repulsive forces and collisions, bodies were formed in orbital motion around centers of attraction. In this way he claimed to be able to explain the formation of the solar system, and went on to generalize his system of formation to still larger structures. His great insight was that the Milky Way has a disk-like structure, that it is a flattened conglomerate of a multitude of stars encircling a center.

<sup>16</sup> Helmholtz 1995, pp. 18–45. Helmholtz quoted parts of Genesis and suggested that its account of the creation of the world was consonant with Kant's scenario of a chaos transforming into a cosmos.

<sup>17</sup> Kant 1969, p. 141.

Even more innovatively, he suggested that the nebulous stars were not individual stellar objects, but vast congeries of stars of the same type and structure as the Milky Way. And the enormous nebulae (or galaxies) would themselves be members of even larger structures, the hierarchical arrangement continuing indefinitely throughout the infinite depths of the universe.

Infinitude, evolution and creation were key notions in Kant's dynamical cosmology. He found it imperative that the world must be infinite in space, as only such a universe accords with the attributes of God. "Eternity is not sufficient to embrace the manifestations of the Supreme Being, if it is not combined with the infinitude of space." But God had not created the world in its present state; it had slowly evolved from the primeval chaos governed by the laws of nature: "The arrangement and institution of the universe comes about gradually, as it arises out of the provision of the created matter of nature in the sequence of time."<sup>18</sup>

Kant's cosmic creation was anything but creation once and for all. He wrote of the creation process as a sort of wave propagating from a central area of the universe, bringing life, activity and organization with it. "The sphere of developed nature is incessantly engaged in extending itself. Creation is not the work of a moment.... Millions and whole myriads of millions of centuries will flow on, during which always new worlds and systems of worlds will be formed.... The creation is never finished or complete. It has indeed once begun, but it will never cease."<sup>19</sup>

In Kant's vision, destruction was no less important than creation. Entire worlds perish and are "swallowed up in the abyss of eternity," but in the same time destruction is counteracted by creative processes from which new cosmic formations result. It is in the very nature of finite things, however big, that they will eventually decay. "But we ought not to lament the perishing of a world as a real loss of nature.... The infinitude of the creation is great enough to make a world, or a Milky Way of worlds, look in comparison with it, what a flower or an insect does in comparison with the earth."

Kant even speculated that the entire world, or parts of the world, might return to a chaotic state and then re-emerge, possibly an

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<sup>18</sup> *Ibid.*, p. 140.

<sup>19</sup> *Ibid.*, pp. 145-146.

infinity of times. "Can we not believe that Nature, which was capable of developing herself out of chaos into a regular order and into an arranged system, is likewise capable of re-arranging herself again as easily out of the new chaos into which the diminution of her motions has plunged her, and to renew the former combination?" Kant had no problem with believing such a scenario of "this Phoenix of nature, which burns itself only in order to revive again in restored youth from its ashes, through all the infinity of times and spaces."<sup>20</sup> In this endless cycle of processes, God played no role.

Kant was only 31 years old when he published the ill-fated *Allgemeine Naturgeschichte*. In his later career he came to doubt not only if the design of the universe had anything to do with the existence of God, but also if the notions of age and extent were meaningful when applied to the universe as a whole. In his famous *Kritik der Reinen Vernunft* of 1781, he concluded that the universe cannot be an object of knowledge, and consequently, that cosmology as a science is impossible.

William Herschel was not acquainted with Kant's work, but in some respects his approach to astronomy and cosmology corresponded to that of the philosopher in Königsberg. Astronomy was for Herschel a historical science, a natural history of the heavens. In a remarkable series of papers starting in 1785 and carrying the common title "The Construction of the Heavens" he developed the perspective in a far more fruitful way than Kant. Inspired by Newton, Herschel realized the tendency towards decay and destruction in the universe, yet he was confident that "the great Author of it has amply provided for the preservation of the whole." In perfect agreement with Kant he did not lament "the destruction of now and then a star, in some thousands of ages," for the destructive processes might be the very means by which the universe is preserved and renewed. With a happy phrase he called clusters of stars "the laboratories of the universe."<sup>21</sup>

Herschel's cosmos was not only big; it was "fathomless." With important insight he realized that by observing nebulae very far away he would also observe the distant past of the universe. The temporal and spatial dimensions of the universe were connected by

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<sup>20</sup> *Ibid.*, pp. 153-154.

<sup>21</sup> Hoskin 1963, p. 85.

the finite velocity of light, which meant that observational cosmology was necessarily historical in nature. Although the astronomer could not follow directly the slow evolution of stars and nebulae, he could construct an evolutionary picture of the universe by collecting data from different parts of it, some far away and others closer to earth. In a paper from 1789, the year of the French revolution, he expressed it beautifully:

They [the heavens] now are seen to resemble a luxuriant garden, which contains the greatest variety of productions, in different flourishing beds; and one advantage we may at least reap from it is, that we can, as it were, extend the range of our experience to an immense duration. For, ... is it not almost the same thing, whether we live successively to witness the germination, blooming, foliage, fecundity, fading, withering, and corruption of a plant, or whether a vast number of specimens, selected from every stage through which the plant passes in the course of its existence, be brought at once to our view?<sup>22</sup>

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<sup>22</sup> *Ibid.*, p. 115.



2

# A Thermodynamic Universe





# 2

## A Thermodynamic Universe

### ASPECTS OF 19TH CENTURY COSMOLOGY

Cosmology, in its modern meaning as the endeavour to understand scientifically the universe at large, was rarely considered a legitimate part of 19th century astronomy.<sup>1</sup> Hence we should not be surprised to learn that, to the limited extent that cosmological questions were discussed within a purportedly scientific (as opposed to metaphysical) framework, most contributions came from non-astronomers: either physicists, philosophers, or amateurs of various kinds. And if astronomers wrote about cosmology, it was usually in popular presentations.

In a lecture given in 1832 and published 16 years later, the great German astronomer Friedrich Wilhelm Bessel emphasized that astronomy was an empirical science using mathematical methods, and that its domain was restricted to what could be observed from the earth. It was a business of precise measurements of the positions and orbits of celestial bodies. "Everything else that one may learn about the objects," he wrote to Alexander von Humboldt, "for example their appearance and the constitution of their surfaces, is not unworthy of attention, but is not the proper concern of astronomy."<sup>2</sup>

<sup>1</sup> For 19th century cosmology, see Hoskin 1982, North 1965, pp. 3–51, Crowe 1994, and Merleau-Ponty 1983.

<sup>2</sup> Bessel, *Populäre Vorlesungen über Wissenschaftliche Gegenstände* (Hamburg: Hammerich & Lesser, 1848), pp. 1–34. Felber 1994, p. 14.

Not only did almost all Continental astronomers agree, so did most on the British Isles.

John Herschel's hugely popular book, *Outlines of Astronomy*, appeared in 1849; and by 1865 it had been printed in eight editions. It included chapters on sidereal astronomy, the Milky Way, variable stars, nebulae, and clusters of nebulae, but it had nothing to say about the universe at its largest scale. Indeed, the term "cosmology" did not occur at all within the 731 pages of the edition of 1865. This does not imply that Herschel had no interest in cosmology, or that he did not cover topics that by the standards of the time were considered to be cosmological. But as far as the grander and necessarily speculative aspects were concerned, he preferred not to discuss them publicly. That he was not unconcerned with such aspects can be seen from a letter he wrote in 1869 to Richard Proctor, the popularizer of astronomy. Here Herschel revealed a glimpse of his vision of an infinite, hierarchic universe not unlike the one that Kant had suggested in his book, *Allgemeine Naturgeschichte*. Speaking of the forms of nebulae and clusters of nebulae, he speculated that "if the forms belong to and form part and parcel of the galactic system, then *that system includes within itself miniatures of itself* on an almost infinitely reduced scale; and what evidence then have we that there exists a universe beyond?—unless a sort of argument from analogy that the galaxy, with all its contents, may be *but one* of these miniatures of that vast universe, and so *ad infinitum*; and that in *that* universe there may exist multitudes of other systems on a scale as vast as *our* galaxy, the analog of those other nebulous and clustering forms which are *not* miniatures of our galaxy."<sup>3</sup>

At the end of the century, things had not changed much with respect to cosmology's relationship to astronomy. The French astronomer Hervé Faye published in 1884 a book with the inviting title *Sur l'Origine du Monde*, but he understood the term "universe" (*monde*) in the restricted sense of the ensemble of celestial bodies that astronomers could observe. His universe consisted of millions of "worlds," gravitationally bound systems such as the solar system, star clusters and nebulae. It was such worlds, and the solar system in particular, that Faye was concerned with.

In 1890, in an oft-quoted passage, the Irish astronomer and historian of astronomy Agnes Mary Clerke, made clear that the nebulae

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<sup>3</sup> Hoskin 1987, p. 28.

were parts of the Milky Way, not separate galaxies. And what about the universe beyond the Milky Way? Clerke raised the question only to dismiss it: "With the infinite possibilities beyond, science has no concern."<sup>4</sup> In a later book, the bulky *Problems of Astrophysics* of 1903, she likewise refrained from going beyond the Milky Way, or what she called "the equatorial girdle of a sphere containing stars and nebulae." For, as she wrote,

The whole material creation is, to our apprehension, enclosed within this sphere. We know nothing of what may lie beyond. Thought may wander into the void, but observation cannot follow. And where its faithful escort halts, positive science comes to a standstill. Fully recognising the illimitable possibilities of omnipotence, we have no choice but to confine our researches within the bounds of the visible world.<sup>5</sup>

The great American astronomer Simon Newcomb was not afraid of speculation, but with regard to this question he was at one mind with Clerke. In an essay on unsolved problems in astronomy he asked if the universe was populated with stars all over, or if they were largely contained in the system of the Milky Way, floating in infinite empty space. The question, he wrote, "must always remain unanswered by us mortals.... Far outside of what we call the universe might still exist other universes which we can never see." For all practical purposes, the Milky Way "seems to form the base on which the universe is built and to bind all the stars into a system."<sup>6</sup> In an age of positivism, the general attitude was that theories and hypotheses were put forward in order to explain facts, and hence "when there are no facts to be explained, no theory is required. As there are no observed facts as to what exists beyond the farthest stars, the mind of the astronomer is a complete blank on the subject. Popular imagination can fill up the blank as it pleases."<sup>7</sup>

The unwillingness to go beyond observation was not complete, though; not even among professional astronomers. What is more, the latter half of the 19th century witnessed a number of important discoveries that would eventually transform the field and pave the

<sup>4</sup> Clerke 1890, p. 368.

<sup>5</sup> Clerke 1903, p. 538.

<sup>6</sup> Newcomb 1906, pp. 5–6.

<sup>7</sup> *The Observatory* 30 (1907), p. 362, in an anonymous review of J. Ellard Gore, *Astronomical Essays, Historical and Descriptive* (London: Chatto & Windus, 1907).

way for what may be called the first phase of physical cosmology. These discoveries were in part made outside of astronomy, but they were quickly recognized to be significant also for the science of the sidereal universe.

The nebular hypothesis—the belief that the nebulae, or some of them, are made up of hot gaseous clouds—goes back to William Herschel's observations in the 1790s, and had by 1830 won wide acceptance.<sup>8</sup> It was not only of great interest with respect to the structure of the distant nebulae, but perhaps even more so because it seemed to support Laplace's nebular theory of the origin of the solar system, first proposed in 1796. During parts of the 19th century the nebular hypothesis was often associated with the fashionable view of nature being in a state of continual evolution, and was for this reason, rated highly by evolutionists many years before Darwin gave a new meaning to evolution. The hypothesis figured prominently in the widely read book, *Vestiges of the Natural History of Creation*, published anonymously by Robert Chambers in 1844. *Vestiges* presented a grand, evolutionary world view in which everything, from chemical elements to organic species, had developed from a primordial form of matter.

However, after William Parsons, the Earl of Rosse, had completed his famous giant mirror telescope at Birr Castle, Ireland, the nebular hypothesis began to crumple. The telescope, "the Leviathan of Parsonstown," happened to be ready for use the same year as *Vestiges* was published. The more nebulae the nobleman and amateur astronomer studied with the telescope, the more he was able to resolve into clusters of discrete stars. John Herschel admitted in 1849 that "it may very reasonably be doubted whether there be really any essential physical distinction between nebulae and clusters of stars."<sup>9</sup> And John Nichol, a leading evolutionist and exponent of the nebular hypothesis, felt forced to conclude from Rosse's observations that "every shred of that evidence which induced us to accept as a reality, accumulations in the heavens of matter *not stellar*, is for ever and hopelessly destroyed."<sup>10</sup> But Nichol's conclusion was premature. Thanks to the spectroscope, some 15 years later the nebular hypothesis reappeared

<sup>8</sup> See Brush 1987 and Hoskin 1982, pp. 137–153. On the relation between natural theology and the nebular hypothesis, especially as perceived in the United States, see Numbers 1977.

<sup>9</sup> Herschel 1849, p. 598.

<sup>10</sup> Nichol 1851, pp. 144–145.

as another phoenix from the ashes. What was called the riddle of the nebulae was still a riddle.

And there were other riddles. Due to the absence of reliable distance measurements, the size of the Milky Way remained a matter of educated guesswork, and so did the distances to the nebulae. Although by 1900 the consensus was that practically the entire material universe was concentrated in the Milky Way, such as concluded by Agnes Clerke, the view had no firm foundation in either fact or theory. Is there a finite or an infinite number of shining objects in the universe? Again, nobody really knew. Arguments of mechanical stability accruing back to Newton seemed to require an infinite universe populated with an infinite number of stars, but neither was this view without problems.

One of the problems was the famous Olbers' paradox, named after the German astronomer Wilhelm Olbers, who in 1823 restated what had been known since the days of Newton—namely, that an infinity of stars would cause the night to be shiningly bright.<sup>11</sup> However, during the 19th century, when it was generally assumed that interstellar space is not perfectly transparent to light, it was not seen as much of a paradox. And even those who did not accept interstellar absorption as a solution, could escape the paradox by claiming that the physical universe includes only a finite number of stars and nebulae. This was what Angelo Secchi, an eminent Jesuit astronomer and pioneer in astrospectroscopy, concluded. He curiously argued that "no thing that consists of definite and separate parts can be infinite," to which he added: "If it [the world] were infinite and populated with innumerable stars, the celestial vault should appear to us as brilliant as the whole surface of the sun.... We are therefore stopped by the fact of a finite physical world. And in spite of its finiteness it is already too inconceivable for us; there is therefore no use in aspiring at what we simply cannot comprehend."<sup>12</sup> Secchi briefly mentioned the then popular idea of other worlds of which we will never know "because they are separated from us by an absolutely empty space, missing even the aether necessary for the propagation of light." But such ideas he dismissed as pure speculation.

Only during the early part of the new century did evidence indicate that space was much more transparent than assumed, and

<sup>11</sup> On the complex history of Olbers' paradox, see Jaki 1969.

<sup>12</sup> Secchi 1878, pp. 330–331.

consequently that absorption could not be evoked to solve the problem. So now Olbers' paradox did become paradoxical, as formulated, for example, by Harlow Shapley in 1917: "Either the extent of the star-populated space is finite or 'the heavens would be a blazing glory of light' .... Then, since the heavens are not a blazing glory, and since space absorption is of little moment throughout the distance concerned in our galactic system, it follows that the defined stellar system is finite."<sup>13</sup>

## SEEN AND UNSEEN UNIVERSES

Olbers' optical paradox and related thermodynamic and gravitational problems did not only concern the size of the universe but were also, in a few cases, taken to relate to its spatial geometry. The introduction of non-Euclidean geometries in mathematical thought, as pioneered by Carl Friedrich Gauss, Farkas Bolyai and Nikolai Ivanovich Lobachevsky, was at first unrelated to physical space, but in 1853 Bernhard Riemann gave a famous lecture in which he suggested a deep connection between geometry and physics. Riemann was primarily concerned with microcosmos, not astronomical space, although he briefly discussed "the extension of space-construction to the infinitely great." He noted that an infinite extent does not follow from space being unbounded, but "if we ... ascribe to space constant curvature, it must necessarily be finite provided this curvature has ever so small a positive value." Riemann then left the matter, claiming that "The questions about the infinitely great are for the interpretation of nature useless questions."<sup>14</sup>

Riemann's brief article was studied and translated into English by William Kingdon Clifford, who did much to popularize and extend the idea of a geometrization of physics; but Clifford, too, limited himself to the microworld.<sup>15</sup> Also, Newcomb considered, if only briefly and hesitatingly, non-Euclidean geometry in relation to physical space. Although he admitted a positively curved space to be a possibility, he seems to have preferred an infinite Euclidean universe. In his book, *Popular Astronomy* from 1880, he wrote: "Although this idea

<sup>13</sup> Berendzen, Hart and Seeley 1976, p. 183.

<sup>14</sup> Riemann 1873.

<sup>15</sup> On the contributions of Riemann and Clifford, see Farwell and Knee 1990, and also Boi 1994.

of the finitude of space transcends our fundamental conceptions, it does not contradict them and the most that experience can tell us in the matter is that, though space be finite, the whole extent of the visible universe can be but a very small fraction of the sum total of space."<sup>16</sup> Newcomb was in contact with Charles Sanders Peirce, who shared his interest and possibly took the idea of a non-Euclidean world more seriously. In a letter of December 1891, Peirce wrote to Newcomb that astronomical data did not support the conclusion that space was positively curved. Three years later, in an unpublished address to the American Mathematical Society he concluded that there was empirical evidence for a hyperbolic space.<sup>17</sup> Unfortunately it is unknown what evidence he referred to.

Probably the first person who seriously applied the notions of non-Euclidean geometries to astronomy, and indeed to cosmology, was the German astrophysicist Karl Friedrich Zöllner, a brilliant but also eccentric and polemical scientist. During his later years, Zöllner became increasingly occupied with spiritualism and his own unorthodox theology, an interest which culminated in 1881 with the publication of his book, *Naturwissenschaft und Christliche Offenbarung*. His interest in spiritualism led him to speculate that space has four rather than three dimensions, and that the fourth dimension was connected with a spiritual, Christian reality. A new "transcendental physics" would, he suggested, reveal the fourth dimension and serve to explain psychological phenomena.<sup>18</sup> Zöllner's use of non-Euclidean geometry dated back to 1872, three years before he became engaged with spiritualism, and appeared in a work on the nature of comets. The work also included much else, from philosophy over history of science to wild charges of plagiarism. One of the chapters was an essay "On the Finiteness of Matter in Infinite Space," in which he came up with a new solution to Olbers' paradox, although this was not the primary aim of the essay.<sup>19</sup> Zöllner argued that a finite quantity of matter in the universe would dissolve to zero density in an infinite Euclidean space and in an infinite time. To account for the fact that the matter density is not zero, he subjected the assumptions on which the conclusion rested to close analysis. He found it would not

<sup>16</sup> Quoted in Jaki 1969, p. 165.

<sup>17</sup> Beichler 1988, p. 209.

<sup>18</sup> On Zöllner and his transcendental physics, see Koerber 1899.

<sup>19</sup> Zöllner 1872, pp. 299–312.

do to introduce an infinite quantity of matter, which would only lead to other paradoxes (including Olbers'), and he therefore focused on the assumptions of infinite time and space.

As to the first assumption, he realized that a universe of finite age would solve the problem of the vanishing matter density, but in the end he dismissed the idea, in part for philosophical reasons (see below). Zöllner was then left with the assumption of the infinite Euclidean space, which he was quite willing to modify. As one of the very few contemporary astronomers, he was acquainted with the works of Gauss, Bolyai, Lobachevsky and Riemann, and he also cited the more recent works of Helmholtz and Felix Klein. Contrary to Riemann, whose address of 1854 seemed to have been his chief inspiration, Zöllner believed that non-Euclidean geometry was also highly relevant to the study of astronomy. "It seems to me," he wrote, that

any contradictions will disappear ... if we ascribe to the constant curvature of space not the value zero but a positive value, however small ... The assumption of a positive value of the spatial curvature measure involves us in no way in contradictions with the phenomena of the experienced world if only its value is taken to be sufficiently small.<sup>20</sup>

In this way he made the paradox dissolve without having to assume a limitation of either cosmic time or space. Zöllner's conceptual analysis was truly cosmological and deserves more than a footnote in the history of cosmology. It was subjected to lengthy and critical commentary by the German psychologist Wilhelm Wundt, and also by the philosopher Kurd Lasswitz, but it made no impact on the astronomical community.

Apart from Zöllner, only very few scientists suggested the application of ideas of non-Euclidean geometry to physical or astronomical space. Yet the hypothesis may have been well known, as indicated by a comment made by the German-American positivist philosopher Johann Stallo. In his book, *The Concepts and Theories of Modern Physics* from 1882, he mentioned, rather casually, "the thesis of the meta-geometers" which proposed "that space itself, though unlimited by reason of its inherent curvature, is not infinite, and that, therefore, the mass of the universe must be finite, however diffused."<sup>21</sup> Mention

<sup>20</sup> *Ibid.*, p. 308.

<sup>21</sup> Stallo 1882, p. 274.



should also be made of Auguste Calinon, a French mathematician, who in a paper of 1889 suggested that the curvature of space might vary in time—namely, oscillate between Euclidean and non-Euclidean forms. This was an original suggestion, but his discussion was of a general philosophical nature and he made no attempt to place it within an astronomical context. It has been suggested that Calinon “anticipated the theory of the expanding universe,” but this is to read much too much into his article.<sup>22</sup>

Much better known and of much more interest is an article from 1900 in which the brilliant German astronomer and physicist Karl Schwarzschild sought to determine the curvature of space from astronomical observations.<sup>23</sup> Schwarzschild discussed hyperbolic space as well as elliptic space of positive curvature. In the case of hyperbolic space he concluded that to match observations the curvature radius of space must be at least 4 million astronomical units; whereas, if space is elliptic, the minimal radius of curvature must be about 100 million astronomical units. For philosophical reasons he preferred space to be “closed and finite, and filled, more or less completely, by this stellar system.” For only then would it be possible, at least in principle, to investigate the macroscopic world exhaustively. Or, as he put it, then “a time will come when space will have been investigated like the surface of the earth, where macroscopic investigations are complete and only the microscopic ones need continue.”

Ideas of physical space having a geometry different from that of the ordinary Euclidean model were unusual, but at least they were mathematically well-founded and could in principle be subjected to observational tests. Belonging to a very different tradition were speculations about “hyperspaces” or extra dimensions added to the three known dimensions of space. Such speculations of “other worlds” might have little scientific respectability, but they were nonetheless fairly popular in the Victorian era, both among novelists, amateurs and professional scientists.<sup>24</sup> For example, in 1894 Newcomb entertained the idea of a fourth dimension, but apparently without taking it seriously. “If there is another universe, or a great number of other

<sup>22</sup> Calinon 1898. Capek 1971, p. 380. The first modern cosmologist to pay attention to Calinon's obscure publication may have been H. P. Robertson, in his contribution to the 1949 volume celebrating Einstein's 70-year's birthday. See Schilpp 1959, p. 322.

<sup>23</sup> Schwarzschild 1900. English translation in Schwarzschild 1998.

<sup>24</sup> The subject is covered in considerable detail in Bork 1964 and Beichler 1988. See also Clarke 2001, pp. 172–192.

universes, outside our own, we can only say that we have no evidence of their exerting any action upon our own," he wrote in agreement with what Secchi had earlier stated.<sup>25</sup>

The popularity of the idea of other dimensions or worlds was not due to its potential scientific value but rather to its use in spiritual speculations. As mentioned, such use appealed to Zöllner. Another (and better known) case was *The Unseen Universe*, a book that the physicists Balfour Stewart and Peter Guthrie Tait published anonymously in 1875 and by 1881 had appeared in its 10th edition.<sup>26</sup> The general message of this important and time-typical book was that science and religion were in intimate harmony. Stewart and Tait wanted to base their belief in the immortality of the soul on a scientific basis, and for this purpose they introduced a kind of parallel universe, a spiritual heaven which was connected to the material universe by means of the all-pervading ether. Although the visible universe must come to an end, there must exist an eternal and ethereal "unseen universe" which is the seat of spiritual forces and in contact with the material world. By what they claimed was scientific logic, Stewart and Tait were led to the conclusion that "the visible universe has been developed by an intelligence resident in the Unseen."<sup>27</sup> Contrary to some other ideas of separate universes, it was important here that the spiritual universe was "connected by bonds of energy with the visible universe." They asked, rhetorically, if "we may not regard the ether or the medium as not merely a bridge between one portion of the visible universe and another, but also as a bridge between one order of things and another, forming as it were a species of cement, in virtue of which the various orders of the universe are welded together and made into one?"

But, of course, Stewart and Tait did not intend to have their suggestion of an unseen universe be considered a contribution to science proper, and even less to scientific cosmology. Their frequent use of the term "universe" did not refer to the vast astronomical space filled with stars and nebulae, but in a more general sense to the world in which human beings are situated.

At the end of the 19th century, scientific cosmology had attracted some new interest in connection with a reconsideration of a problem

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<sup>25</sup> Newcomb 1894, p. 329.

<sup>26</sup> Stewart and Tait 1881. See also Heimann 1972.

<sup>27</sup> Stewart and Tait 1881, p. 223.

already discussed by Newton—the mechanical or gravitational stability of an infinite universe. In 1895 the German astronomer Hugo von Seeliger pointed out that an infinite Euclidean universe with a roughly uniform mass distribution cannot be brought into agreement with Newton's law of gravitation.<sup>28</sup> Seeliger's proof was far from simple, but it is easy enough to show that the gravitational force exerted on a body by integration over all the masses in the infinite universe does not lead to a unique result, as the integral diverges. As Seeliger commented, this "leads to insuperable difficulties and irresolvable contradictions." He suggested that one might abandon either the assumption of an infinite matter-filled universe, or else modify Newton's law; and Seeliger chose the latter alternative.

A body moving in the gravitational field of a central mass  $M$  such as the sun, will, according to Newton, experience a gravitational potential  $\varphi(r) = -M/r$ . Seeliger's suggestion was to replace the expression with

$$\varphi(r) = -\frac{M}{r} - \frac{\Lambda r^2}{6}$$

where  $\Lambda$  is a cosmological constant so small that its effects will be unnoticeable except for exceedingly large distances. The body not only experiences an attractive inverse-square force towards the central body, but also a repulsive force given by  $\Lambda r/3$ . In a somewhat different way the slight but significant adjustment of the inverse square law was suggested also by Carl Neumann in 1896, and it reappeared in a very different context in 1917, now as Einstein's famous cosmological constant.

There were other ways to save the spatially infinite Newtonian universe, without modifying the law of gravitation. One such possibility was explored by the Swedish astronomer Carl Charlier in a paper of 1908 with the fascinating title "*Wie eine unendliche Welt aufgebaut sein kann*" (i.e., how an infinite world can be constructed). Charlier's model was ingenious if somewhat contrived. He imagined a hierarchic universe in which matter was grouped locally in clusters, which in turn were grouped in superclusters, these again in super-superclusters, and so on indefinitely. By making this arrangement in

<sup>28</sup> For historical and technical details, see Norton 1999 and Jaki 1979. A short and lucid account is given in Harrison 1986.

a particular way, he obtained a matter distribution with no preferred center and which did not exhibit the gravitational divergencies of the traditional homogeneous model.

Cosmological theories came in many and varied forms, and not all of them from the pens of astronomers or physicists. As an indication of how very different cosmologies around 1900 were, one may compare Seeliger's mathematical theory with the cosmological picture proposed in 1903 by the famous naturalist and evolutionist Alfred Russell Wallace. Having lost his Christian faith as a young man, in the 1860s Wallace was exposed to spiritualism, and soon came to accept the reality of spirit manifestations, a belief he maintained for the rest of his life.<sup>29</sup> His cosmological view was undoubtedly colored by his commitment to spiritualism, but his book, *Man's Place in the Universe* presented a scientific argument and contained only passing references to his metaphysical convictions.<sup>30</sup> Wallace's primary purpose was to challenge pluralism, to show that man as a dignified, spiritual being, is alone in the universe. For this purpose he suggested that the sun is a unique celestial body. Drawing on authorities such as Newcomb, Kapteyn, Lockyer, and John Herschel, he located the sun at the centre of a finite and bounded universe. He took the material universe to be identical to the Milky Way system, the diameter of which he estimated to be only 3,600 light years. Whereas a stellar universe that small was not in radical disagreement with the view of many astronomers, the central sun definitely was. The concept was perceived as a major embarrassment, a return to a pre-Copernican world view, and caused a good deal of controversy and criticism.

Wallace's universe was indeed anthropocentric, and his wish to emphasize the centrality of man guided his interpretation and selection of astronomical data. Although he confirmed that recent discoveries in astronomy "have, of course, no bearing upon the special theological dogmas of the Christian, or of any other religion," he did believe that they lent support to "the view, held by many great thinkers and writers today, that the supreme end and purpose of this vast universe was the production and development of the living soul in the perishable body of man." A universe without man would be an

<sup>29</sup> On Wallace's spiritualism, see Kottler 1974 and Oppenheim 1985, pp. 296–325.

<sup>30</sup> Wallace 1903a, much expanded into Wallace 1903b. The quotations are from Wallace 1903a. For Wallace's cosmology, see Heffernan 1978 and Dick 1999, pp. 36–49.

absurdity, and one with many civilizations would be undignified. "The universe is a manifestation of Mind," he wrote, and

the orderly development of Living Souls supplies an adequate reason why such a universe should have been called into existence, [and I] believe that we ourselves are its sole and sufficient result, and that nowhere else than near the central position in the universe which we occupy could that result have been attained.

Wallace argued that there was overwhelming evidence that the laws and chemical composition of the universe were the same everywhere; and from this he concluded that extraterrestrial biological organisms, if such existed, would evolve in basically the same way as on earth. But contrary to Darwin he did not accept man as merely a product of evolution. The singular existence of the earth as an abode for human beings was no coincidence. For, had there been a multitude of other planets with highly developed life,

It would imply that to produce the living soul in the marvelous and glorious body of man... was an easy matter which could be brought about anywhere, in any world. It would imply that man is an animal and nothing more, is of no importance in the universe, needed no great preparation for his advent, only, perhaps, a secondary demon, and a third or fourth-rate earth.<sup>31</sup>

The major part of *Man's Place in the Universe* was a more standard discussion of astronomical questions, and did not differ significantly from other contemporary works on cosmology. For example, Wallace argued from "telescopic observations and photographic charts" that the stellar universe must be finite, a conclusion he found supported by Olbers' paradox.

## EVOLUTION AND CREATION

As mentioned, around 1850 few astronomers dealt explicitly with cosmology. One exception was John Pringle Nichol, Regius Professor of Astronomy in Glasgow, where he taught the subject to young

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<sup>31</sup> Wallace 1903b, p. 317.

William Thomson, among others.<sup>32</sup> Not only did Nichol speculate about the universe in its widest meaning, he was also a champion of evolutionary astronomy, and his views about cosmology were connected with his theological ideas. Contrary to most Continental astronomers, he claimed that astronomy should not be concerned merely with what can be observed from earth. His cosmo-evolutionary vision covered not only astronomical objects such as stars and nebulae, but the universe *in toto*, an unusual position even among British astronomers.

Nichol assumed that the law of gravity, as well as other laws of nature established from terrestrial observations and experiments, is permanently and universally valid. On the other hand, he also recognized that this is nothing but a postulate, and that statements of a truly cosmological nature must necessarily reflect the uncertainty of the postulate. This was a standard position at the time and also later on. During the 19th century it was commonly accepted that the laws *might* be different in distant corners of the world and that this will forever limit the certainty of cosmological knowledge.

In Nichol's cosmology, evolution was the great and pervasive theme. The emphasis on evolution relied in part on the nebular hypothesis, of which he was a staunch advocate, but it was more than merely a philosophical extrapolation of it. That theological conviction also played an important part, can be seen from the fact that the rejection of the nebular hypothesis in the late 1840s held no consequence at all for his belief in an evolutionary world view. Evolution *à la* Nichol did not merely mean change, but progressive and teleological development—a view that he justified in theological terms. The progress of order, he wrote, should be seen as the result "of an ever-present *creative power*, a power requisite and effective to uphold, to renew the universe every moment, or rather to *prolong* creation by the *persistence* of the creative act."<sup>33</sup> That is, the evolutionary universe was kept going by God's continual creative acts—what theologians refer to as *creatio continua*. This kind of creation could not be meaningfully distinguished from modification by natural law, he stated. Consequently, the latter was as much a sign of the divine mind as was the first. In agreement with this view, in conflict as it was with that of

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<sup>32</sup> My account of Nichol and Challis relies in part on Scheuer 1997.

<sup>33</sup> Nichol 1851, p. 273.

orthodox theology, he rejected the traditional picture of God as the cosmic clockmaker who exerted his power only indirectly, through the laws that he had originally put into existence.

In Nichol's vision of cosmic evolution, the ultimate if unattainable goal was Eternity. Cosmic progressivist as he was, he shared the view of his contemporaries that the solar system, and possibly the entire universe, was decaying. Everything, man included, was seen as transitory. The ultimate dissolution of the solar system had traditionally been resisted by philosophers, but Nichol believed they were mistaken. There was no reason for pessimism, for evolution, not permanence, was the grand design of the universe. In spite of decaying processes, the overall tendency was that "all things are in a state of change and *progress*: here too—on the sky—in splendid hieroglyphics, the truth is inscribed, that the grandest forms of present being are only *germs* swelling and bursting with a life to come!"<sup>34</sup>

Consider next, Nichol's contemporary James Challis, who followed George Airy as Plumian Professor of Astronomy and Experimental Philosophy in Cambridge, the same chair that Eddington would later occupy. Challis is today best known, if known at all, for his unfortunate involvement in the discovery history of Neptune.<sup>35</sup> He was an unrestrained ether unificationist who sought to explain all physical forces, gravity included, in terms of the hydrodynamics of an elastic ether. However, contrary to the advocates of the vortex-atom theory, his ontology was dualistic in that he operated with two separate entities—atoms and ether. In *An Essay on the Mathematical Principles of Physics* of 1873 he developed an ambitious unified theory in which all forces were claimed reduced to ether pressures or waves.

Challis realized that if the attractive gravitational force is all that works between the stars and nebulae, the stellar system cannot be in a state of stable equilibrium. He therefore introduced a very-long-range counteracting force, a repulsive anti-gravity which he managed to construct as certain superpositions of ether waves. His theory was grand and developed in mathematical details, but it failed to win recognition from either physicists or astronomers. In his anonymous

<sup>34</sup> *Ibid.*, p. 298.

<sup>35</sup> Challis is included in the *Dictionary for the History of Science* (vol. 3, 1971, pp. 186–187), where he is described as "a spectacular failure as a scientist ... . At a later time, or under less amiable circumstances, he would be branded as a Charlatan."

review of the book, Maxwell pointed out several grave problems, not the least grave being that the theory violated the principle of energy conservation.<sup>36</sup>

Challis may have been a scientific failure, but in the present context he is of some interest because of the direct connection he made between his physico-cosmological views and those he held with respect to theology. As to the origin of his two basic entities, ether and atoms, he simply referred to "the immediate will and power of the Creator of all things" as a satisfactory explanation. The ethereal waves were ultimately of a spiritual nature, originating from higher intelligent beings, a suggestion he noted was "in conformity with the teaching of the Scriptures respecting *Angels*." Like Stewart and Tait, he operated with two realms or "universes," one heavenly and spiritual, and the other material. Although different, they were connected through the ethereal medium: the spiritual energies of the heavens would activate the ether and then cause the phenomena in the material world that could be studied scientifically. The picture had much in common with that presented in *The Unseen Universe*, but Challis had his reservations because Stewart and Tait were unwilling to consider the direct interference of God.

In fact, according to Stewart and Tait it was "the bounden duty of the man of science to put back the direct interference of the Great First Cause—the unconditioned—as far back as he possibly can in time." Although the universe in its widest sense was believed to be eternal and infinite, "It is perfectly certain ... that the visible universe must have had a beginning in time."<sup>37</sup> Such a first abrupt manifestation of the universe, or just parts of it such as atoms, would however contradict the principle of continuity, which Stewart and Tait held to be sacrosanct. Fortunately the contradiction could be avoided by appealing to the eternal unseen universe as a kind of source for the material one. "We conceive it to be the duty of the man of science to treat the original production of the visible universe in the same way as he would any other phenomenon."<sup>38</sup> Because of the connection to the unseen universe, the two physicists did not have to face the impossible problem of accounting scientifically for the creation of the material world *ex nihilo*.

<sup>36</sup> Maxwell 1965, part 2, pp. 338–342.

<sup>37</sup> Stewart and Tait 1881, p. 94.

<sup>38</sup> *Ibid.*, p. 95.



Stewart and Tait were respected physicists whose scientific—or perhaps scientific—defense of cosmic immortality was meant to be a Christian argument against the scientific naturalists and their materialist metaphysics. It was not intended to be an argument in favour of spiritualism, an ideology none of the authors had any sympathy for. Tait made his stance clear at the 1871 meeting of the British Association in Edinburgh, when he scornfully grouped spiritualists with “Circle-squarers, Perpetual-motionists, Believers that the earth is flat and that the moon has no rotation.” Yet, to many readers of *The Unseen Universe*, the distinction between its message and that of spiritual and occult movements may have seemed insignificant. For example, the notorious Russian émigré Helena Petrovka Blavatsky used it in her theosophical book, *Isis Unveiled* of 1877, characteristically subtitled *A Master-Key to the Mysteries of Ancient and Modern Science and Theology*. According to Blavatsky, theosophy was scientific in method—a synthesis of science, metaphysics, and religion. In her spiritual and pseudoscientific cosmology, the ether played a similarly important role as in *The Unseen Universe*, and she cited passages of Stewart and Tait’s book in support of astral mythology and similar beliefs.<sup>39</sup>

Creation is a most central concept in modern cosmology, but this is a relatively modern feature. In the 19th century it was taken for granted that everything concerning creation and origin, in the strict sense of these terms, was outside the scope and possibility of science. In his book, *Philosophy of the Inductive Sciences* from 1840, William Whewell had emphasized that although science could record and understand the progress of natural occurrences, “we can in no case go back to an origin.” “The thread of induction respecting the natural course of the world snaps in our fingers, when we try to ascertain where its beginning is,” he wrote.<sup>40</sup> Almost all scientists agreed, but this did not mean that beginnings, whether local or global, were excluded from the scientific discourse. Many of these references were related to the second law of thermodynamics, to be considered shortly, but there were also discussions based on other arguments.

The absolute permanence of the building blocks of matter was often seen as an argument for God, who alone had the power to

<sup>39</sup> Clarke 2001, p. 173. Oppenheim 1985, pp. 193–197.

<sup>40</sup> Whewell 1996, vol. 2 (first published 1840), p. 145.

create them or make them disappear. "We might as well attempt to introduce a new planet into the solar system, or to annihilate one already in existence, as to create or destroy a particle of hydrogen," wrote John Dalton in his book, *A New System of Chemical Philosophy*, the work in which he introduced chemical atomism in 1808. Nearly 60 years later, William Thomson pioneered another atomic theory in which atoms were conceived as vortices in the ether. Thomson proved that such vortices were absolutely permanent, a feature which to him meant that they could only have come into existence through "an act of creative power," that is, they must have been created by God. The same point was made by Tait, who at the 1871 meeting of the British Association said about the vortex-atom theory that "its very basis implies the *absolute necessity* of an intervention of Creative Power to form or destroy one atom even of dead matter."<sup>41</sup>

Maxwell confirmed the limitation of natural knowledge in his address on molecules to the British Association in Bradford in 1873. He was impressed by the fact, as revealed by the spectroscope, that molecules of the same chemical species were all alike and had not changed the slightest "since the time when Nature began." Uniformity in time as well as uniformity one-to-another strongly indicated that atoms and molecules were created, by a creator, although Maxwell was careful not to extend his argument to a scientific proof of God's existence. Borrowing an expression from John Herschel, he famously (and with an allusion to natural theology) referred to the molecule as a "manufactured article." He went on:

In tracing back the history of matter Science is arrested when she assures herself, on the one hand, that the molecule has been made, and on the other, that it has not been made by any of the processes we call natural. Science is incompetent to reason upon the creation itself out of nothing. We have reached the utmost limit of our thinking faculties when we have admitted that because matter cannot be eternal and self-existent it must have been created.<sup>42</sup>

<sup>41</sup> Kragh 2002, p. 39, where a detailed account is given of the development of the vortex-atom theory. Tait 1871, p. 6.

<sup>42</sup> Maxwell 1965, part 2, p. 376. See also Harman 1998, pp. 187, 199 and 205. "Manufactured articles" were used by John Herschel in *A Preliminary Discourse on the Study of Natural Philosophy* (London: Cabinet Cyclopædia, 1831), p. 38. Maxwell repeated and amplified his arguments in his article on "Atom" for the *Encyclopedia Britannica*, see Maxwell 1965, part 2, pp. 483-484.

The religious basis of Maxwell's considerations is underlined by his closing remark, that molecules "continue this day as they were created—perfect in number and measure and weight... they are essential constituents of the image of Him who in the beginning created, not only the heaven and the earth, but the materials of which heaven and earth consist." Few readers would have missed the reference to the Wisdom of Solomon (11:20), "Thou hast ordered all things in measure and number and weight."

Maxwell was a committed evangelical in whose thinking science was never far from religion. For example, in his inaugural lecture at Aberdeen in 1856 he confirmed his belief that natural theology was an integral part of the study of science: "But as Physical Science advances we see more and more that the laws of nature are *not* mere arbitrary and unconnected decisions of Omnipresence, but that they are essential parts of one universal system in which infinite Power serves only to reveal unsearchable Wisdom and external Truth."<sup>43</sup> His evangelicalism led him to a position that has been described as anti-deist, anti-utilitarian, and anti-positivist.<sup>44</sup> He believed that science should be kept separate from religion and warned against using the most recent advances in science to change the interpretation of the Bible; on the other hand, he admitted that certain conclusions from science might legitimately enhance the religious sensibility.<sup>45</sup>

Creation of molecules is one thing; the creation of the universe is a very different and much more awesome question. A created universe does not necessarily imply a universe of finite age, but both then and now the identification was usually taken for granted. There was one very general argument in favour of a finite-age universe in agreement with the Bible: namely that if the world is showing signs of gradual decay then it cannot have existed forever—in that case it would already be in a state of total dissolution. The argument became prominent in connection with the second law of thermodynamics, but can be found much earlier. Thus, in a book published in 1757 the astronomer James Ferguson developed an old argument of Newton's—that if gravity remains unchanged the planets will one

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<sup>43</sup> Jones 1973, p. 77.

<sup>44</sup> Theerman 1986.

<sup>45</sup> See the letter to the theologian Charles J. Ellicott in Maxwell 1990–2002, vol. 3, pp. 416–418. Ellicott agreed with Maxwell and replied that "Theologians are a great deal too fond of using up the latest scientific hypotheses they can get hold of."

day collide with the sun. Generalizing this line of reasoning, Ferguson expressed what he called "a strong philosophical argument against the eternity of the World." His strong argument was this:

For, had it [the world] existed from eternity, and been left by the Deity to be governed by the combined actions of the above [Newtonian] forces or powers, generally called Laws, it had been at an end long ago . . . . But we may be certain that it will last as long as was intended by its Author, who ought no more to be found fault with for framing so perishable a world, than for making man mortal.<sup>46</sup>

It is hardly surprising that what is possibly the first attempt to give a naturalistic account of the creation of the universe is to be found in the works of a poet rather than a scientist. Edgar Allen Poe's essay "Heureka" was based on a lecture "On the Cosmogony of the Universe" he gave in New York on 3 February 1848. Although Poe had no scientific training, he had a wide knowledge of astronomical literature and sought to support his scenario with scientific arguments. Among the works he quoted was Nichol's *Architecture of the Heavens*. When Poe's essay merits attention it is not only because his universe was of finite age, but especially because it evolved in a way that resembles the much later big-bang universe.<sup>47</sup>

He imagined that the universe arose from the explosion of a singular state of matter in "one instantaneous flash." From the explosion of the undifferentiated primordial atom followed the entire history of the universe: First the fragments would be diffused by means of radiation in such a way as to fill space homogeneously, and eventually they would form the celestial bodies by gravitational attraction. Poe had philosophical as well as scientific reasons to picture his universe as consisting of only a finite number of stars populating an infinite space. The distance to the stars most far away was so immense that no light rays from them had yet been able to reach the earth, an original solution to Olbers' paradox that made sense because his universe had come into being a finite time ago. Although he repeatedly referred to astronomical authorities, and in part dressed his vision in scientific terms, his essay should not be considered a contribution to

<sup>46</sup> Ferguson 1778, p. 84.

<sup>47</sup> Harrison 1965, vol. 16. For analysis, see Cappi 1994 and, with a different interpretation, Tipler 1988b.

the scientific literature. It rather belongs to the tradition of speculative cosmology with theological overtones. "The Universe is a plot of God," he wrote. And, after having identified the attractive force with Newtonian gravitation and the repulsive force with electricity: "The former is the body; the latter the soul: the one is the material; the other spiritual, principle of the Universe."

Another case of a finite-age universe turned up in astronomical literature in 1858, when the German astronomer Johann Mädler, in his book *Der Fixsternhimmel* discussed Olbers' paradox. Not knowing of Poe's essay, he wrote that one argument had been overlooked, namely: "The world is created, and hence is not eternal. Thus no motion in the universe can have lasted for infinite time; in particular, this applies to a beam of light. In the finite amount of time it could travel before it reached our eye, a light beam could pass through only a finite space no matter how large the speed of light. If we knew the moment of creation, we would be able to calculate its boundary." Three years later, in the popular book, *Der Wunderbau des Weltalls*, Mädler repeated the suggestion of a universe being created a finite time ago, but it failed to make an impact on his colleagues in astronomy. Although he did not relate his idea to theology, he most likely was inspired by his colleague at the University of Dorpat, the theologian and church historian Johann Heinrich Kurtz. In a book on the relationship between astronomy and theology, Kurtz discussed Olbers' paradox and suggested that astronomers should attempt to decide "whether the primeval matter and forces concerned in the production of these [stellar] bodies existed from eternity, or were created in time."<sup>48</sup>

As a last example attention should be called to Zöllner's analysis of 1872, mentioned above, in which he introduced Riemannian geometry to solve various problems of a finite universe. Apparently independent of Mädler, Zöllner considered the possibility that the universe (or rather the matter in it) had not always existed. One could imagine, he wrote,

an act of creation [*eines Schöpfungsakt*] in which had begun, at a time in the finite past, a certain finite initial state of the world, which is ... approaching the several times mentioned end state in which, after an infinite time, the elements of matter are to be

<sup>48</sup> Tipler 1988a. Tipler 1988b.

found in infinitely large distances. From a physical point of view, such a process would be equivalent with a gradual dissolution of the world into nothing or with the annihilation of the world.

However, Zöllner found this scenario unsatisfactory, because it would limit the causal chain arbitrarily. Moreover, he thought it would contradict the Leibnizian principle of sufficient reason. One may perhaps translate his objections as (1) the initial creation cannot be the result of a cause, since a cause must be prior in time to its effect; and (2) there can be given no reason why the universe came into existence a certain time ago rather than at any other time.

With the invention of the spectroscope in 1859, it became possible, for the first time, to make chemical investigations of the stars. Astrospectroscopy would become one of the main sources for the physical cosmology that emerged in the 1930s, but in the 19th century it was largely limited to studies of the sun, the fixed stars, and the nebulae. Yet from an early date the results of astrospectroscopy were discussed in a wider, sometimes cosmological framework. It now became established that the chemical elements known from earth are found also in the stars, thereby confirming the material unity of the world (although for a while it seemed that some elements, such as helium and nebulium, existed in the heavenly bodies only).<sup>49</sup>

In her book, *A Popular History of Astronomy*, Agnes Clerke noted perceptively how astronomy had changed under the impact of spectroscopy. No longer could the science be isolated from the other physical sciences, or be concerned with merely observation and calculation. The modern astronomer had to listen to the chemist, the electrician, the geologist, the meteorologist, even the biologist, she wrote. He "has become, in the highest sense of the term, a physicist; while the physicist is bound to be something of an astronomer." Clerke was a devout Catholic and she wrote her book, at least in part, with the purpose of leading her readers "towards a fuller understanding of the manifold works which have in all ages irresistibly spoken to man of the glory of God." *A Popular History* included many expressions of natural theology, such as when she described the solar system as being shaped "from the beginning by Omnipotent Wisdom." To Clerke, recent advances in astrophysics were indications of "the

<sup>49</sup> On 19th century astrochemistry see, e.g., Brock 1969 and Hirsh 1979.

inscrutable design of the Creator," and the superior purpose of astronomy was "to touch the hem of the garment of the Most High."<sup>50</sup>

Cosmo-theological references also appeared frequently in Clerke's book, *The System of the Stars* from 1890. For example, she wrote about the stars that, "We are perfectly assured, both from reason and revelation, that a time was when they were not, and that at a future date they will not be."<sup>51</sup> Her references to religion sometimes turned up in odd places, as in a review essay on low-temperature physics read to the Royal Institution in 1901. She introduced the subject with some general reflections on laws of nature as expressions of the will of God. Man was able to investigate the world as an intelligible system, and, "by striving to enlarge the limits of its intelligibility, we promote the purpose of the Creator in placing us there, and, following in the track of His primal conceptions, bring our inchoate ideas more and more into harmony with them."<sup>52</sup>

Astrospectroscopy greatly reinvigorated the nebular hypothesis and boosted interest in the complexity of the chemical atom. Foremost among the astrochemists were British researchers Norman Lockyer, William Crookes and William Huggins, who all were in favour of some version of the dissociation hypothesis—that is, the idea that the atoms are broken down in their constituents in the intense heat of the stars. Or, seen in another perspective, that the elements known at present have been formed as a result of "inorganic Darwinism" during the long cosmic history.

J. J. Thomson, the discoverer of the electron, was devoted to what he called "the theory that the different chemical elements have been gradually evolved by the aggregation of primordial units."<sup>53</sup> According to Thomson, atoms lighter than hydrogen had once existed, but by now had formed aggregations, the smallest of which happened to be hydrogen. In 1905 he discussed the opposite hypothesis, that the final stage of the universe would consist of the most simple atoms, that is, free electrons or what Thomson called "corpuscles."<sup>54</sup>

<sup>50</sup> Clerke 1886, citations from pp. vi, 183, 348, 437, and 453. On Clerke and her devotion to Christian belief, see Bruck 2002.

<sup>51</sup> Clerke 1890, p. 82.

<sup>52</sup> Clerke 1901, p. 699. Reprinted in *The Royal Institution Library, Physical Sciences*, 5 (1970), 453–475. The address was sponsored by a large donation to the Royal Institution to further "investigation of the relations and co-relations existing between man and his Creator."

<sup>53</sup> Thomson 1904, p. 101.

<sup>54</sup> Thomson 1905.

According to Crookes, astrospectroscopy was able to throw light on cosmological questions in a way very different from that traditionally followed by astronomers, physicists, and philosophers. He developed this perspective in a most remarkable address that he gave to the British Association in 1886.<sup>55</sup> Anticipating later ideas in cosmology, he invited his audience to "picture the very beginnings of time, before geological ages, before the earth was thrown off from the central nucleus of molten fluid," and "to imagine that at this primal stage all was in an ultragaseous state, at a temperature inconceivably hotter than anything now existing in the visible universe; so high, indeed, that the chemical atoms could not yet have been formed, being still above their dissociation point." And this was not all, for Crookes also ventured to look into the distant past before any matter existed:

Let us start at the moment when the first element came into existence. Before this time matter, as we know it, was not. It is equally impossible to conceive of matter without energy, as of energy without matter; from one point of view the two are convertible terms.... Coincident with the creation of atoms all those attributes and properties which form the means of discriminating one chemical element from another start into existence fully endowed with energy.

Crookes' universe was chemical rather than astronomical, and it was necessarily full of life and never-ending creativity. He was unable to accept the physicists' gloomy predictions of a heat death, and consequently looked for mechanisms that would counteract the dissipation of energy. At the time he gave his address, he had for long nurtured an interest in spiritualism and similar occult systems of thought, and in 1883 he had joined Madame Blavatsky's Theosophical Society. However, his cosmic scenario did not include any spiritual world, and in his address to the British Association he referred to neither spiritualism nor orthodox theology.

As thermodynamics was often misused for spiritual purposes, so the new science of astrochemistry was occasionally used in support of views with little or no scientific foundation. For example, the French revolutionary anarchist Louis Auguste Blanqui wrote in his prison cell a speculative book, *L'Éternité par les Astres*, in which he

<sup>55</sup> Crookes 1886. DeKosky 1972-73.



argued for a cyclical universe that eternally repeats itself, a doctrine he claimed was "a simple deduction from spectral analysis and from the cosmogony of Laplace."<sup>56</sup> His argument was that the universe is infinite in space and time, whereas there is only a small number of chemical elements throughout the universe, and therefore duplication must constantly occur. Although Blanqui's fantasies were not taken seriously, ideas of a similar kind can also be found in the writings of respected astronomers. For example, Secchi concluded from the near-similarity of spectral types on earth and stars that life was abundant all over the universe.<sup>57</sup>

## THE HEAT DEATH

The thermodynamical theory that emerged in the mid-19th century almost immediately became of cosmological importance, although in a way that astronomers at first paid little attention to, and which was mostly discussed outside the astronomical community. The cosmic significance of heat phenomena was occasionally discussed before 1840, notably by Jean-Baptiste-Joseph Fourier in his analytical theory of heat. One may say that Fourier established a "new cosmology of heat,"<sup>58</sup> but if so it is in a more restricted meaning of the term cosmology than adopted here. Fourier and a few others of his generation used the theory of heat in attempts to understand the physics of the earth and sun, but they did not apply it to the universe at large. Such attempts had to await the introduction of the concepts of energy conservation and entropy increase.

Spiritual and religious reflections based on the new thermodynamics relied on the second law in particular, but in some cases the law of energy conservation was enough to serve as an argument for theism. A case in point is the Danish engineer and physicist Ludvig Colding, who in 1843 had suggested the conservation and correlation

<sup>56</sup> Crowe 1986, pp. 407–408.

<sup>57</sup> Secchi 1878, p. 332. One area of astronomical thought where religious ideas were very influential, was the question of "pluralism," i.e., whether or not there are intelligent life elsewhere in the universe. In general, there was no simple connection between astronomers' religious views and their position in the pluralist debate. During the period 1840–1914 it was often argued that extraterrestrial life is incompatible with Christian belief; but the opposite position was argued as well. See Crowe 1986 and Crowe 2001. Because pluralism was mostly concerned with planetary and stellar astronomy, and only rarely with cosmology proper, I shall refer to the subject only occasionally.

<sup>58</sup> Cardwell 1971, pp. 118–119. On Fourier's "cosmological" theory of heat, see also Merleau-Ponty 1983, pp. 212–225.

of "forces." Colding believed that spiritual activity was a higher form of energy and that the law of energy conservation proved not only the immortality of the soul but also that God has created the world out of nothing. "It was the religious philosophy of life which led me to the concept of the imperishability of forces," he admitted.<sup>59</sup>

The English chemist and physicist William Groves was equally convinced of the religious implications of energy conservation, a message he spelled out in his widely read book, *Correlation of Physical Forces*, first published in 1846. He concluded from the interconnectedness of the forces of nature that "neither matter nor space can be created or annihilated, and that an essential cause is unattainable—Causation is the will, Creation the act, of God."<sup>60</sup> Robert Mayer, too, generally credited as the discoverer of the law of conservation of energy, considered the principle a weapon against materialism and atheism, but he was reluctant to link his scientific work directly to religion and metaphysics.<sup>61</sup> Yet he believed, like Colding, that the existence and immortality of the soul followed from the new science of heat.

The two fundamental laws of thermodynamics were framed cosmologically in the sense that they were claimed to be universally valid, to work not only for steam engines and test tube reactions but also for the universe at large. Moreover, the second law implied a unidirectionality of all natural processes in harmony with the evolutionary worldview, and it had consequences for both extremes of the cosmic time-scale. If extrapolated to the far future, it told that the world would come to an end; and it indicated that the past could not be pushed indefinitely back in time, that the world had not always existed but perhaps had been created by some agent outside the universe. Neither of the predictions could be tested, but they both concerned states of the world that were traditionally seen as parts of religion.<sup>62</sup>

The second law of thermodynamics was formulated only a few years after Helmholtz had written the definitive essay on the principle of energy conservation.<sup>63</sup> In his seminal paper of 1850, Rudolf

<sup>59</sup> The essay "Scientific Reflections on the Relationship Between the Activity of Spiritual Life and the General Forces of Nature" was published in Danish in 1856. An English translation by Per Dahl appears in Colding 1972, pp. 105–128. See also Caneva 1997.

<sup>60</sup> Quoted in Hiebert 1966, p. 1052.

<sup>61</sup> See Caneva 1993.

<sup>62</sup> For religious, ideological and social aspects of thermodynamics, see the surveys in Hiebert 1966, Seeger 1967, Meyerson 1930, pp. 259–290, and Myers 1986.

<sup>63</sup> The literature on early thermodynamics is extensive. For helpful introductions, see Harman 1982 and Brush 1986.

Clausius stressed the natural tendency of heat to equalize temperature, or the impossibility for a self-acting cyclic machine to transfer heat from a body of a certain temperature to a body at a higher temperature. Four years later, he reformulated his theory and based it on a function that in 1865 reappeared under the new name "entropy." (He had initially referred to the function as *Verwandlungseinhalt*, meaning content of transformation.) The entropy difference between two states A and B was defined as

$$S_A - S_B = \int_A^B \frac{\delta q}{T}$$

T is the absolute temperature;  $\delta q$  an infinitesimal change in heat; and the path of integration corresponds to a reversible transformation from A to B. Armed with his entropy concept, Clausius famously stated the second law of thermodynamics as "the entropy of the world tends towards a maximum," and similarly expressed the first law globally, as "the energy of the world is constant."

Although Clausius' formulations referred to *die Welt*—the world or universe—in his later works he only rarely phrased the thermodynamical principles in such global terms. The cosmological connection was cultivated more fully in William Thomson's alternative route to the second law, the first result of which was "On the Dynamical Theory of Heat" from 1851. Thomson never used the concept of entropy, but instead spoke of dissipation of heat or energy, a concept that roughly corresponds to a change in entropy. Not only were the cosmic aspects always in Thomson's mind; so were the theological aspects. In a draft to his 1851 paper, he referred to the impossibility of the world to return to any previous state "without a creative act or an act possessing similar power."<sup>64</sup> The draft included several references to the Bible, including "the earth shall wax old & c.," a reference to the 102nd Psalm (or perhaps to Isaiah 51:6, "The heavens shall vanish away like smoke, and the earth wax old like a garment.") Not only was it God alone who could create or annihilate energy (as well as matter), it was also only Him who could reverse the transformations of energy in nature. In another paper, of 1852, Thomson amplified what he meant by a universal tendency toward dissipation of energy, including the sentence, "As it is most certain that Creative Power

<sup>64</sup> See Smith 1998, pp. 110–112. The draft is transcribed in Smith 1976.

alone can either call into existence or annihilate mechanical energy, the 'waste' referred to cannot be annihilation, but must be some transformation of energy."<sup>65</sup>

At the Liverpool meeting of the British Association in 1854, Thomson went a step further and gave a sweeping survey of his cosmo-energetic ideas. Inviting his audience to trace backwards in time the actions of the laws of physics, he speculated that the source of mechanical energy in the universe might be sought in "some finite epoch [with] a state of matter derivable from no antecedent by natural laws." However, such an origin of matter and motion, mechanically unexplainable and different from any known process, contradicted his sense of both causality and uniformitarianism. "Although we can conceive of such a state of all matter," he wrote, "yet we have no indications whatever of natural instances of it, and in the present state of science we may look for mechanical antecedents to every natural state of matter which we either know or can conceive at any past epoch however remote."<sup>66</sup> Here we have the second law used, not to predict the far future but a singularity in the distant past. Apparently Thomson came to this idea as early as 1842, in his study of Fourier's theory of heat conduction when he pointed out that the heat equation would have no meaningful solutions for negative values of the time parameter. His biographer Silvanus P. Thompson recollected that Thomson once told him, "It was this argument from Fourier that made me think there must have been a beginning . . . Trace back the past, and one comes to a beginning—to a time zero, beyond which the values are impossible."<sup>67</sup>

Thomson did not propose a universal "heat death" in 1852, but Helmholtz seems to have understood him as doing so. In a popular lecture on the interaction of natural forces, delivered in Königsberg in February 1854, the German physicist and medical doctor offered the first full enunciation of the dire prospect:

If the universe be delivered over to the undisturbed action of its physical processes, all force [energy] will finally pass into the form of heat, and all heat come into a state of equilibrium. Then all possibility of a further change would be at an end, and the complete cessation of all natural processes must set

<sup>65</sup> Thomson 1882, p. 511.

<sup>66</sup> Thomson 1884, pp. 37–38.

<sup>67</sup> Thompson 1910, vol. 1, pp. 111–112.

in .... In short, the universe from that time onward would be condemned to a state of eternal rest.

Helmholtz realized the parallel of the scenario to that of the Bible, and ended his talk by stating that the second law "threatens [the human race] with a day of judgment, the dawn of which is still happily obscured."<sup>68</sup>

William Thomson's version of the cosmic consequences of the law of energy dissipation came in 1862. "The result," he wrote, "would inevitably be a state of universal rest and death." This would however only be the case "if the universe were finite and left to obey existing laws," and Thomson did not accept the first of the premises: "But it is impossible to conceive a limit to the extent of matter in the universe; and therefore science points rather to an endless progress, through an endless space, of action involving the transformation of potential energy into palpable motion and thence into heat, than to a single finite mechanism, running down like a clock, and stopping forever."<sup>69</sup> For Thomson the optimistic Victorian progressivist, the universal heat death was not real.

Without including Thomson's provisos, in 1864 Clausius offered his formulation of the heat death scenario. There is, he wrote, a general tendency in nature towards unidirectional change. "If one applies this to the universe in total, one reaches a remarkable conclusion .... Namely, if, in the universe, heat always shows the endeavour to change its distribution in such a way that existing temperature differences are thereby smoothened, then the universe must continually get closer and closer to the state, where the forces cannot produce any new motions, and no further differences exist."<sup>70</sup> Four years later, now employing the new entropy concept, Clausius reformulated the statement as follows: "*The entropy of the universe tends toward a maximum.* The more the universe approaches this limiting condition in which the entropy is a maximum, the more do the occasions of further change diminish; and supposing this condition to be at last completely attained, no further change could evermore take place, and

<sup>68</sup> Helmholtz 1995, p. 30 and p. 43.

<sup>69</sup> "On the age of the sun's heat," pp. 356–375 in Thomson 1891. Quotation on pp. 356–357. Thomson concluded that physics did not "give dispiriting views as to the destiny of the race of intelligent beings by which it [the earth] is at present inhabited." A somewhat similar position was reached by the Spanish engineer Francisco Rojas, according to whom the first law of thermodynamics demonstrated the existence of God (Rojas 1874).

<sup>70</sup> Clausius 1864, pp. 1–2.



the universe would be in a state of unchanging death."<sup>71</sup> Clausius further emphasized that the second law contradicted any idea of a cyclic universe, the popular view that "the same conditions constantly recur, and in the long run the state of the world remains unchanged." Not only for Clausius, but even more so for Thomson and his circle of Christian scientists, was it an appealing feature of the second law that it countered what they considered the materialistic and un-Christian notion of a cyclic world.

Of course, the claim of the heat death or similar pessimistic consequences of the second law did not go uncontested. Many scientists as well as non-scientists felt it unbearable that life in the universe shall one day cease to exist, and they came up with various suggestions to avoid the heat death. As early as 1852, before the heat death had been clearly formulated, the Scottish engineer and physicist William Rankine suggested that radiant heat might under certain circumstances allow a reconcentration of energy (and hence physical activity) to go on endlessly. He admitted that for other energy forms, "there will be an end of all physical phenomena," but believed radiant heat was an exception. Rankine conjectured that radiant heat was conducted by a bounded interstellar medium, and that outside this medium there was nothing but empty space. In that case, when the radiant heat reached the boundary it would be reflected and would eventually reconcentrate in one or more focal points. If one further imagines one of the extinct celestial bodies to pass such a focal point, "it will be vaporised and resolved into its elements," and part of the radiant heat would be converted into chemical energy and wake the body alive. It was thus conceivable, Rankine wrote, that "the world, as now created, may possibly be provided within itself with the means of reconcentrating its physical energies, and renewing its activity and life." Dissipative and constructive processes might eternally go on together, "and some of the luminous objects which we see in distant regions of space may be, not stars, but foci in the interstellar ether."<sup>72</sup>

During the following decades many speculations within the same spirit—attempts to devise counter-entropic processes—were suggested, but few of them attracted much attention, and none were

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<sup>71</sup> Clausius 1868, p. 405.

<sup>72</sup> Rankine 1881, pp. 200–202.

generally accepted. In later chapters we shall look at a couple of examples from the 20th century. Clausius did not accept Rankine's conjecture, which he found was in contradiction of the second law. In 1864 he answered it in a long and detailed paper in which he made use of Kirchhoff's recent work on heat or blackbody radiation. Clausius' conclusion was unambiguous: radiant heat was no exception to the second law and it could not provide a means for escaping the heat death.<sup>73</sup>

Around the mid-19th century, there grew up in Germany an opposition against idealism, clericalism and what was left of the *Naturphilosophie* of the romantic era.<sup>74</sup> The medical doctor and science popularizer Ludwig Büchner was among the most influential of the new cast of materialists and freethinkers. In his widely read book, *Kraft und Stoff* from 1855, Büchner offered a materialistic world view which included discussions of astronomy, spectral physics and thermodynamics. Inspired by Helmholtz and the French-German physicist and engineer Gustave Hirn, he dealt with the consequences of the second law of thermodynamics, but without adopting the heat death. Büchner could not believe that the *Wärmetod* meant the end of the universe, only that it was locally valid, that it applied to individual star systems. In his book, *Licht und Leben* from 1856 he argued for an eternal and cyclic universe which would "celebrate its resurrection some day."<sup>75</sup> In the end, the materialist Büchner had an almost religious faith in the eternity of life.

Another of the German scientific materialists, Heinrich Czolbe, defended his own philosophical system of materialism, what he called "sensualism." Like Büchner, he denied that the universe would ever end in an irreversible state of heat death. Moreover, not only did Czolbe conclude that there was no origin of the world; he consistently rejected all creative processes as superstition. Consequently he claimed that the earth, and even life on earth, had always existed.

Hermann Sonnenschmidt, another German, published in 1877 a book titled *Kosmologie* in which he developed a home-made system of the world on an astronomical basis. His work consisted of three parts: cosmogony, eschatology (!), and cosmography. In Sonnenschmidt's universe, time had no beginning and no end, and space was infinite,

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<sup>73</sup> Clausius 1864.

<sup>74</sup> Gregory 1977.

<sup>75</sup> *Ibid.*, p. 163.

continuously filled with matter. Although he accepted that the entropy law led to the decay of individual parts of the universe, such as stars and nebulae, he denied the cosmic heat death and argued for a cyclical universe. According to Sonnenschmidt, whose system allegedly rested on "a purely naturalistic basis," matter and time were eternal, subject to neither creation nor destruction. As to the ideas of "the Christian philosophers," he found them to be unreasonable as well as ridiculous. Since God is supposedly eternal and omniscient, he "must have known for quintillions of years, and even longer, when and how he would create the world."<sup>76</sup> Who, in an age of positive science, could seriously believe in such nonsense?

Related to, but still different from German scientific materialism, so-called scientific naturalism was much discussed in British intellectual life in the years around 1870. Some scientists, including Clifford, John Tyndall, Thomas Huxley, and Francis Galton, argued that explanation in terms of matter and motion being the ultimate goal of science, whereas spiritual values were irrelevant. Nature, they claimed, was just a complex system of atoms and energy. Although few of the naturalists were atheists, their position was widely seen as a provocative challenge to Christian faith and the established social order; a challenge that appeared even graver as it coincided with the publication of Darwin's *Descent of Man* in 1871. Among the much discussed provocations was Tyndall's presidential address to the 1874 meeting of the British Association in Belfast, where he, in conclusion of a long account of the triumphant march of science through history, said: "The impregnable position of science may be described in a few words. We claim, and we shall wrest, from theology the entire domain of cosmological theory."<sup>77</sup> In the polarized debate of the 1870s Tyndall's rejection of Christian theism made headlines and gave him a reputation as a materialist. A materialist of a kind he was, but his particular form of materialism was qualified, and included a strong dose of romantic idealism.

For Thomson, Tait, Maxwell and other British physicists who were opposed to materialism or scientific naturalism, reversibility was associated with mechanicism and materialism (and, implicitly, atheism) while such views were contradicted by the irreversibility as

<sup>76</sup> Sonnenschmidt 1880, p. 9.

<sup>77</sup> Tyndall 1874, p. xciv. On scientific naturalism and the reaction to it, see Turner 1974. See also Barton 1987 for a close analysis of the Belfast address.



expressed by the second law of thermodynamics. In 1868, Maxwell wrote to a correspondent that according to the materialists, "if every motion great and small were accurately reversed, and the world left to itself again, everything would happen backwards . . . . Of course all living things would regrede from the grave to the cradle and we should have a memory of the future but not of the past." But given the fundamental nature of the second law this was a grave mistake. On the contrary, the law "leads to the doctrine of a beginning and an end instead of cyclical progression for ever."<sup>78</sup> Not only was the heat death an integral part of the anti-materialistic, thermodynamic worldview; so was the beginning of the world. Thomson had indicated as much in 1854, and in an address of 1870 Maxwell noted with satisfaction that, "This idea of a beginning is one which the physical researches of recent times have brought home to us."<sup>79</sup>

## ENTROPY AND CREATION

On a cosmic scale, a beginning implies a universe of finite age, which most people would not hesitate to identify with a created universe. The claim that thermodynamics leads to a finite-age, created universe has been called the entropological or *entropic argument* for creation (whether or not formulated in terms of entropy). It was commonly employed during the Victorian era, and not only in Britain. Thus, in a review of a French anti-positivist book in *Saturday Review*, the reviewer reported the author's view that the second law did not only lead to a heat death, but also made it "infinitely probable that the laws which now regulate the world had been arranged by an intelligent Cause."<sup>80</sup> The entropic argument was primarily discussed during the period 1860–1920, after which it no longer attracted much interest. But as an additional argument for a universe of finite age it can still be met in modern literature, though usually without the inference to a creator. In *God & the New Physics*, the physicist Paul

<sup>78</sup> Maxwell 1990–2002, vol. 2, pp. 360–361. The correspondent was Mark Pattison, rector of Lincoln College in Oxford.

<sup>79</sup> Harmann 1998, p. 205. Also Maxwell 1871, p. 245: "A consideration of the dissipation of energy leads to the determination of a superior limit to the antiquity of the observed order of things."

<sup>80</sup> Maxwell 1990–2002, vol. 2, p. 359. The book was Elme Marie Caro, *Le Matérialisme et la Science* (Paris, 1867). Landsberg 1991, a valuable survey of the *argumentum entropologicum*, includes references to the literature.

Davies infers "that the universe cannot have existed for ever, otherwise it would have reached its equilibrium end state an infinite time ago. Conclusion: the universe did not always exist."<sup>81</sup>

Before proceeding with the historical account, a brief introduction to the entropic "proof" of God's existence may be at place.<sup>82</sup> The proof or argument can be formulated as follows. According to the entropy law, an isolated system will eventually reach internal thermal equilibrium, after which time only fluctuations about the state of equilibrium can take place. Now the universe is far from equilibrium and so it cannot be of infinite age; it must have had a beginning, and been born in a state of minimum entropy. This initial state can only have been brought about by something outside the universe, namely God. The argument can be considered a variant of the classical cosmological proof for the existence of God, a proof which dates back to thinkers such as Avicenna, Maimonides and Thomas Aquinas. The cosmological proof depends on the fact that everything in the world is contingent and therefore must have a cause, a reason for its existence; to avoid an infinite regress, an ultimate cause must exist in the form of a necessary being, God. A slightly different formulation of the entropic proof is this:

1. The entropy of the world increases continually.
2. Our present world is not in a state of high entropy.
3. Hence the world must be of finite age.
4. The world once had a beginning, was created.
5. If created, there must be a creator, God.

Even if one accepts the premises (1) and (2), and therefore is led to (3), the conclusion (5) does not follow. It was perfectly possible to use the entropy law to infer a finite-age universe, without any reference to either creation or a creator. Moreover, the entropic argument shares with other forms of the cosmological argument a common factor—that the best it can do is to provide evidence for a creative God (or, for that matter, several gods); it cannot be an argument for the Christian God. The entropic proof was an attempt to demonstrate the existence of God from positive scientific knowledge. In this respect it differs from

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<sup>81</sup> Davies 1983, p. 11.

<sup>82</sup> See the interesting discussion in Landsberg 1991.

arguments of the God-of-the-gaps type where divine action is inferred from the impotence of science to account for certain phenomena.

Although the cosmological consequences of the second law were often stated in terms such as "beginning" and "end," obviously this shall not be understood literally, in the meaning of creation and annihilation. The most the entropic argument can do is to lead to a beginning of changes and processes in the universe, just as the heat death is an end of changes and processes, not of the universe itself. The argument is not, and was never used as, a proof of God's creation of the world out of nothing. But if it is accepted that processes cannot arise spontaneously out of inert matter, a transcendent agent must have breathed life into the matter, and must have wound up the cosmic clock.

Physicists, philosophers and theologians who discussed the entropic argument in the late 19th century were aware of the problems of applying the second law to the cosmos in its entirety. Is the universe a thermodynamically closed system in the sense that there is no energy transfer between it and its "surroundings"? It was generally taken for granted that the law would apply cosmologically only if the universe was spatially bounded, that is, limited in size and number of objects. There were even thinkers who were so impressed by the majestic second law that they inferred from its absolute validity that the universe must be limited in space. This was the reasoning of Eduard von Hartmann, a prominent German philosopher, and his argument was accepted by several writers of an apologetic inclination.<sup>83</sup>

In German-speaking Europe, the entropic argument seems to have first been discussed in public by the Würzburg physiologist and physicist Adolph Fick in his book, *Die Naturkräfte in ihrer Wechselbeziehung* from 1869. However, Fick endorsed neither the heat death nor the entropic argument as a proof of a created world.<sup>84</sup> Dozens of authors subsequently joined the discussion, physicists as well as philosophers and theologians. Jesuit scholars, such as the physics teacher Ludwig Dressel, were particularly active. It was also a Jesuit, Johannes Hontheim, who coined the name *argumentum entropologicum*, which appeared in a latin dissertation of 1893. In Germany the entropic proof was discussed mostly by Catholic

<sup>83</sup> Schnippenkötter 1920, p. 53. The dissertation of Schnippenkötter, a German physics teacher, is a valuable source of information on the entropic argument as discussed in Germany in particular.

<sup>84</sup> Fick 1903, pp. 296–361. Fick, who did important work on the borderline between medicine and physics, is known for the two laws of diffusion named after him.

theologians, whereas it did not figure in evangelical theology, and caught the interest of few Protestant physicists. Caspar Isenkrahe, a Catholic and physics professor at the gymnasium in Trier, Germany, wrote several books and papers in which he argued that the existence of God could be proved scientifically.<sup>85</sup> His chief apologetic weapon was the law of entropy increase.

After this digression, we go back to Britain, where Thomson and Maxwell were among those who made use of the entropic argument. So did Tait in 1871, when he concluded that "the present order of things has *not* been evolved through infinite past time by the agency of laws now at work, but must have had a distinctive beginning, a state beyond which we are totally unable to penetrate, a state, in fact, which must have been produced by other than the now acting causes."<sup>86</sup> Few if any readers would fail to identify Tait's other agency with God. Also, Tait's colleague Stewart accepted the entropic creation argument, which he turned into a pedagogical example in an elementary textbook in energy physics. Imagine the universe as a cosmic candle, he wrote. If the candle is not lit, then perhaps it makes sense to regard it as having existed forever. But if we regard the universe-candle to be lit, as of course we should, "we become absolutely certain that it cannot have been burning from eternity, and that a time will come when it will cease to burn."<sup>87</sup>

The more explicit apologetic use of the new energy physics was left to others—theologians, philosophers, or Christian authors. One of the earliest commentators was Joseph John Murphy, an Irish author and close associate of James Thomson, William's brother. In books from 1869 and 1873 Murphy dealt with the principles of energy conservation and dissipation, including their theological implications. In *The Scientific Bases of Faith* he argued that the best argument for a universe of finite age came from energy dissipation. This process, he wrote, "has been constantly going on from the first beginning of things; but it cannot have been going on through actually infinite time, because if it were so, an infinite quantity of motive power must have been expended and destroyed in every part of the

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<sup>85</sup> E.g., Isenkrahe 1920. As a physicist, Isenkrahe was principally known for a corpuscular theory of gravitation which he proposed in 1879. On Isenkrahe as an apologetic, see Schnlppenkötter 1920.

<sup>86</sup> Tait 1871, p. 6. The same message occurred in Tait 1876, pp. 25–26.

<sup>87</sup> Stewart 1873, p. 153.



universe; and the laws of force [energy] exclude the possibility of any such supply of motive power."<sup>88</sup>

An illuminating perspective on the British debate can be obtained through William Stanley Jevons' celebrated book, *Principles of Science*. Jevons, who did important work in logic and economics, was also a philosopher of science, and in the final part of his book he discussed topics of a cosmological nature. Although he wanted to keep theology out of the book, he did not hide his dissatisfaction with materialists and positivists of the Comtean school. "My purpose," he wrote near the end, is "showing that atheism and materialism are no necessary results of scientific method . . . . [And that] we cannot disprove the possibility of Divine interference in the course of nature."<sup>89</sup> Jevons clearly stated the entropic creation argument (he did not refer to entropy) to the effect that the universe must be finite in time, but he, like many others, saw it as a problem rather than a solution. Either the universe was created in the past, or it must be assumed that some inexplicable change in natural laws occurred in the past. We are on the horns of a trilemma, he stated: "We must either deny that anything exists, or we must allow that it was created out of nothing at some moment of past time, or that it existed from eternity." Jevons was not happy about either horns of the dilemma. The first he dismissed as absurd, and the other two seemed equally inconceivable to him. He even considered that the present order of things might be but "a part of one single pulsation in the existence of the universe." Yet he did not endorse the cyclical universe any more than creation in a finite past. It was only after having been criticized by Clifford that he felt forced to admit that "the known laws of nature do not enable us to assign a 'beginning'."<sup>90</sup>

In Clifford's lecture of 1874 on "The First and Last Catastrophe," the mathematician launched an attack on all attempts to find out of beginnings and ends from the present state of nature. Such endeavours, which he found in Maxwell, Tait, Jevons, Murphy and others, were unwarranted extrapolations from thermodynamics to cosmic history. It is a fallacy, he said, to conclude

that if we consider the case of the whole universe we should be able, supposing we had paper and ink enough, to write down

<sup>88</sup> Murphy 1873, p. 51. See also Murphy 1869, and Smith 1998, pp. 312–313. According to Seeger 1967, a similar argument was made in Gibson 1875.

<sup>89</sup> Jevons 1877, p. 766.

<sup>90</sup> *Ibid.*, preface, p. xxxii.

an equation which would enable us to make out the history of the world forward, as far forward as we liked to go; but if we attempted to calculate the history of the world backward, we should come to a point where the equation would begin to talk nonsense—we should come to a state of things which could not have been produced from any previous state of things by any known natural laws.<sup>91</sup>

According to Clifford, such reasoning was based on illegitimate extrapolation. Thermodynamics could be used to find the time that the earth passed from a liquid to a solid state, as Thomson had done, but not to find “the time of the commencement of the universe.” He denied that there was any evidence of a catastrophe implying the beginning of the laws of nature, and concluded that we know nothing, and cannot know anything, of either the beginning or end of the universe. The creation scenario was as unjustified as the heat death scenario. Clifford’s position was seemingly agnostic, but in reality he argued that the world is infinitely old.

Clifford’s was just one out of many responses to the hard-to-swallow conclusion of a created universe which would die in the far future. I shall briefly mention some other responses, all of them from non-astronomers, which illustrate the variety in scientists’ attempts to circumvent or refute the doctrine of the heat death. The Austrian positivist physicist and philosopher Ernst Mach was nominally a Catholic, but in reality he was an atheist and strongly opposed to Christian doctrines. In his influential *The Science of Mechanics* he wrote that “the physical philosophy of theology is a fruitless achievement, a reversion to a lower state of scientific culture.”<sup>92</sup> Yet he had enough historical sense to warn his readers against considering science and religion to be constantly involved in a warfare. In a lecture on the history of the principle of energy conservation of 1871, he criticized the concept of the heat death and its corollary, the creation of the world, by arguing that they were scientifically meaningless.<sup>93</sup> It is “completely illusory” to apply the second law to the entire universe, not because of any problem with the law in particular but because of the subject, the universe, to which no meaningful statements could be attached. Scientific theorems about the universe “appear to me worse

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<sup>91</sup> Clifford 1879, vol. 1, p. 221. The lecture was originally published in 1875.

<sup>92</sup> Mach 1960, p. 557.

<sup>93</sup> Mach 1909, pp. 36–37. The lecture was first published in 1872.

than the worst philosophical theorems," he stated. The same message was brought home in a later reworking of the essay:

Expressions such as "the energy of the world" and "the entropy of the world" are somewhat scholastic in nature. Energy and entropy are concepts of measure. What meaning can it have to apply these concepts to a case where they are *not even applicable*, in which their values are indeterminate? If the entropy of the world could be determined, it would be an absolute measure of time and then the second law in Clausius' formulation would be merely a tautology.<sup>94</sup>

Mach's point that the universe is not a thing, but the collection of all things, and that the whole cannot be treated in the same way as the parts of which it consists, was later to be repeated and elaborated by both scientists and philosophers in order to argue that there can be no scientific cosmology.

Stallo, who shared much of Mach's positivistic thinking, fully agreed. He argued that the universe must be infinite in space, time and matter, and that it is "wholly inadmissible" to apply the second law of thermodynamics to it. The universe is not a distinct body and therefore physical laws do not apply to it, only to its constituent parts. "It follows," Stallo wrote, "that all cosmogonies which purport to be theories of the universe as an absolute whole, in the light of physical and dynamical laws, are fundamentally absurd."<sup>95</sup> Georg Helm, the German physicist and leader of the school of energeticism, agreed with his kindred spirits Mach and Stallo. According to him, the cosmological formulations of the laws of thermodynamics were "nothing more than a metaphysical aberration."<sup>96</sup>

The Russian physicist Orest Chwolson, professor at the University of St. Petersburg and a well known author of textbooks, dealt with the question in papers of 1908 and 1910. Possibly inspired by Boltzmann, he distinguished strictly between what he called the observable "world" and the presumably much larger "universe," the totality of everything that exist. The world is known to be essentially homogeneous, to consist of the same forms of matter and to be

<sup>94</sup> Mach 1923, p. 209. See also Jaki 1974, pp. 297–298, who observes that Mach's insistence on localism seems to be inconsistent with the famous "Mach's principle," that the inertia of matter is the result of interactions from *all* matter in the universe.

<sup>95</sup> Stallo 1882, p. 276.

<sup>96</sup> Helm 2000, p. 176. German original 1898.

governed by the same laws of physics. But what about the universe at large? Chwolson found a finite, bounded universe to be an impossibility, but did not therefore conclude that it was infinite. On the contrary, an infinite universe was nothing but “a meaningless combination of empty words,” about which nothing scientifically could be said. He also denied that the laws of physics, including the entropy law, were valid throughout the entire universe or could have any meaning in an infinite universe. Chwolson insisted that the scientist’s domain was strictly the world, or what were parts of the world: “Physics has nothing to do with the universe; it is not an object of scientific research as it is not accessible to any observation . . . . When the physicist speaks of the ‘world’, he means his limited [and observable] world . . . . To identify this world with the universe is a proof of either *thoughtlessness or madness*, and in any case *lack of scientific understanding*.”<sup>97</sup> It followed that the entropic proof for a created universe must be rejected.

In the ideological debate of the late 19th century, finitism—the view that the world is finite in time and space—was usually associated with conservatism and Christian belief, whereas socialists and materialists adhered to the doctrine of an infinite and eternal universe. But there were exceptions to the rule. Thus, the devout Christian William Thomson had no doubt that the universe is spatially infinite. “I say *finitude* is incomprehensible, the infinite in the universe *is* comprehensible,” he said in a popular lecture of 1884. “What would you think of a universe in which you could travel one, ten or a thousand miles, or even to California, and then find it come to an end? Can you suppose an end of matter or an end of space? The idea is incomprehensible.”<sup>98</sup>

Another exception, of a very different kind, is provided by the German physicist, economist and positivist philosopher Eugen Karl Dühring, who subscribed to mechanical materialism and a socialist world view. Although an uncompromising atheist, he argued that the universe might well have had an origin, a beginning in time. The universe is limited in space, he wrote, and “For the same reason, not only must the number of the earth’s revolutions round the sun up to the present time be a finite number, even though it cannot be stated, but

<sup>97</sup> Quoted in Schnittenköpper 1920, p. 52. See also Chwolson 1910.

<sup>98</sup> “The wave theory of light,” pp. 307–355 in Thomson 1891. Quotation on p. 322.



all periodical processes of nature must have had some beginning, and all differentiation, all the multifariousness of nature which appears in succession must have its roots in one self-equal state."<sup>99</sup> This was a most unusual view for a materialist. As to the original or self-equal state of the world, Dühring explained that it was "an unchanging existence of matter which comprised no accumulation of changes in time."

Eugen Dühring would probably have remained an unwritten chapter in the history of ideas had Friedrich Engels not devoted an entire book to refute his views of science, history and society. Together with the posthumously published book, *Dialektik der Natur*, Engels' book, *Anti-Dühring* became the foundation of the dialectical natural philosophy which served as part of the communist world view. Engels was early on acquainted with Clausius' formulation of the laws of thermodynamics. In letters to Marx he expressed his dislike of the idea of an ever-increasing entropy and its consequence, the heat death. As the socialist Engels saw it, irreversibility was incompatible with dialectical materialism, a philosophy that required eternal recurrence as a fundamental pattern of nature. "The eternally repeated succession of worlds in infinite time is only the logical complement to the co-existence of innumerable worlds in infinite space," he wrote.<sup>100</sup> The law of entropy increase was ideologically dangerous because of its association with creation and theism: "Clausius—if correct—proves that the world is created, hence that matter can be created, hence that it is destructible."<sup>101</sup> In *Anti-Dühring*, Engels took up the question of a cosmic beginning:

If the world had ever been in a state in which no change whatever was taking place, how could it pass from this state to alteration? The absolutely unchanging, especially when it has been in this state from eternity, cannot possibly get out of such a state by itself and pass over into a state of motion and change. An initial impulse must therefore have come from outside the universe, an impulse which set it in motion. But as everyone knows, the "initial impulse" is only another expression for God.<sup>102</sup>

<sup>99</sup> Dühring 1875, as quoted in Engels 1975, p. 62.

<sup>100</sup> Engels 1973, p. 27. The fragments of which the book was collected were written in the period 1872–1882. They were edited and appeared in print only in 1927, published in the Soviet Union in both German and Russian. The first English edition dates from 1940.

<sup>101</sup> *Ibid.*, p. 277.

<sup>102</sup> Engels 1975, p. 68.

As examples of entropic-theological reasoning I shall consider the arguments of F. Brentano and, in less details, A. E. Haas. The German philosopher Franz von Brentano was ordained, a Catholic priest in 1864, but nine years later he left the church, in part because of dissatisfaction with the new doctrine of papal infallibility but also because he found some of the basic teachings of the church to be contradictory. However, he remained a theist of Christian inclination, and was convinced that the existence of God followed from scientific and philosophical principles. Brentano first discussed the theological implications of the laws of thermodynamics in a lecture on "The Law of Entropy and its Significance for Metaphysics" which he gave in Würzburg in the winter semester of 1868–69. He subsequently dealt with the theme in several lectures at the universities of Würzburg and Vienna, and he also discussed it with his friend Boltzmann. However, his apologetic arguments were not well known at the time as they were only published posthumously.<sup>103</sup> Brentano developed systematically four proofs of God: the teleological proof, the proof from motion, the proof from contingency, and what he called the psychological proof. Of these, the last one was the most original, but in the present context it is his proof from motion which merits attention.

The proof from motion was basically the classical argument of a first mover, revised and extended by recent discoveries of physics. With these discoveries "it is possible to show," Brentano wrote, "that in contrast to the Aristotelian doctrine of the eternity of motion, all the alteration that we observe in the world must have had a beginning." He was referring, of course, to the laws of energy conservation and entropy increase. First he discussed the heat death and some of the attempts to escape it, concluding that no such route of escape existed. Then he turned around the arrow of time: "If our inference to the final state was necessary, then ... the development of the world, in as much as it leads to an end, must also once have had a beginning."<sup>104</sup> In his advocacy of the entropic proof of God, Brentano argued against the German psychologist Wilhelm Wundt, who had claimed that the second law would not apply to a universe which was

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<sup>103</sup> Brentano 1987, a translation of *Vom Dasein Gottes* (Leipzig, 1929), compiled and edited by Alfred Kastil. According to Brentano, Fick presented his arguments at the same time in a series of lectures on the interaction of natural forces. "And shortly thereafter when I went to England, it appeared that there the famous physicist, Tait, had drawn the same conclusion, a sure sign of how obvious it is and how perfectly inevitably it forces itself upon us." (p. 279).

<sup>104</sup> Brentano 1987, p. 270 and p. 279.

infinite in space but finite in mass. This Brentano found to be a paradoxical notion, indeed "utterly impossible."<sup>105</sup> After having carefully considered various possible loopholes in the entropic argument, he found it to be compulsive. Scientific reason clearly told that the energy of the universe had come into existence a finite period of time ago, supplied by "an ultramundane principle." Brentano further argued that the principle had to have the properties of a creator or an intelligence.

The creative principle whose existence we have proved is creator of everything that belongs to the universe, or has or could have an influence on it. For only in this case ... can it have knowledge of the universe ... And the creative intelligence is to be regarded, not only as the creator of everything that belongs to the universe, but also as its sole, first cause.<sup>106</sup>

Finally he concluded that the creative principle must also be an omnipotent and infinite being. "Therefore it is God."

In an article of 1907, the 23-year-old Austrian physicist Arthur Haas, (about whom more in Chapter 5) reasoned in accordance with the entropic argument that the universe can have existed only for a finite period of time. Like Brentano, he criticized the many attempts which had been made by thinkers of a materialistic or positivistic inclination, to avoid the consequences of the second law in order to retain the eternity of the universe. Ostwald, Haeckel, Loschmidt, Felix Auerbach and Karl Reuschle were among those who were criticized for pseudo-scientific reasoning, for mixing "artificial hypotheses" with "dogma of philosophical faith." Haas concluded that an eternal world was inconsistent with the laws of physics, but also that a world with a beginning in time cannot be accounted for purely in terms of physics. His argument was essentially of the God-of-the-gaps type:

The monistic-materialistic conception of the world is therefore unable to explain the world picture, ... With the recognition of its inability it follows that physics has reached the limit of its capacity with respect to philosophy. But the importance of this apparently negative result is that it demands the *assumption of a being whose actions are not subjugated to the general laws of nature; [a being] who is independent of nature, transcends it and rules over it.*<sup>107</sup>

<sup>105</sup> *Ibid.*, p. 278. On Wundt's article of 1877 on the cosmological problem, see Jaki 1969, pp. 162-164.

<sup>106</sup> Brentano 1987, p. 305.

<sup>107</sup> Haas 1907, p. 524.

Physics has no power to suggest how this being—which Haas readily identified with God—acts on nature. It may be through an initial act of cosmic creation or by continual creative intervention throughout eternity. The physicist just cannot tell and must leave the question to the theologian. “Physics itself leaves the choice open between theism, deism and cosmic pantheism,” Haas wrote. “Only with atheism is it absolutely inconsistent, in so far the meaning of physics is not restricted to the so often misunderstood laws of conservation of ‘force and matter’ and leaves out all other laws.”<sup>108</sup>

Pierre Duhem’s response to the heat death scenario was, like that of Mach, methodologically grounded. Although his philosophical views were influenced by Mach, Duhem was a devout Catholic who freely confessed that his science was “the physics of a believer.” However, with this phrase he did not refer to apologetics. Duhem defended the autonomy of science and believed it should be independent of any metaphysical or religious opinion. His insistence on a sharp separation between science and faith made him a target of criticism from some Catholics, who suspected him of “fideism,” the heretical belief that faith rests on faith and nothing else. In order to illustrate the relationship between physics and theology, he mentioned as an example the entropic argument of creation and decay. One might believe that the believer Duhem happily accepted it as support of Christian doctrines, but this was not the case. The argument “implicitly assumes the assimilation of the universe to a finite collection of bodies isolated in a space absolutely void of matter,” and this assumption he found doubtful. Moreover, he argued that the entropy law merely says that the entropy of the world increases endlessly, not that it has any lower or upper limit. “Nothing then would stop this magnitude from varying from  $-\infty$  to  $+\infty$  while the time itself varied from  $-\infty$  to  $+\infty$ .”<sup>109</sup>

Duhem’s aim was of course not to argue against a universe of finite age, but to warn that physical theory does not justify long-term predictions of such a kind. In this respect he was, like Clifford before

<sup>108</sup> *Ibid.*, p. 525.

<sup>109</sup> The essay “Physics of a believer” was first published in French in 1905. Here quoted from Duhem 1974, pp. 273–311. See also Hiebert 1966, pp. 1070–1073. The argument that the entropy may increase asymptotically for an infinite time was made many years before Duhem discussed it. Duhem’s contention that in a cosmological context there is no upper limit to the entropy happens to be true for an expanding universe. In 1982 Steven Frautschi confirmed that there will be no heat death in the traditional sense, as the universe will never achieve equilibrium. Frautschi 1982.



him, an agnostic. In agreement with his general philosophy of science Duhem pointed out that it would be perfectly possible to construct a new thermodynamics which "might tell us that the entropy of the universe after increasing for a period of 100 million years will decrease over a new period of 100 million year in order to increase again in an eternal cycle." Duhem certainly did not subscribe to such a world view, but he wanted to bring home the point that science is incapable of making trustworthy predictions about either the beginning or the end of the world, or its perpetual activity. This was also the opinion of Bernhard Bavink (on whom more in Chapter 5), who in a book of 1914 criticized apologetic interpretations of the second law of thermodynamics.<sup>110</sup> According to Bavink, there was no reason to accept the law unconditionally, such as Hartmann had done. He concluded that the entropy law could not serve as a sure guide to cosmological questions concerned with the extension of the universe in space and time.

Contrary to Mach and Duhem, the Swedish chemist and physicist Svante Arrhenius followed the tradition initiated by Rankine, that is, he looked for mechanisms that would compensate the continual increase in entropy. For Arrhenius it was an intellectual and emotional necessity to establish a cosmology that secured eternal cosmic evolution in an infinite, self-perpetuating universe. Only such a universe would be scientifically comprehensible and make supernatural causes unnecessary, he claimed. In a paper of 1909 he argued for a kind of cosmological principle—that the universe is not only spatially infinite but also populated throughout with stars and nebulae: "It is an axiom that when we cannot prove something to be true, we must assume that qualitatively it is of the same kind as what is accessible to our senses . . . . So, there is in essence no weighty reason why the universe should not be uniformly populated with stars."<sup>111</sup> Although Chwolson did not mention Arrhenius by name, his paper of 1910, published in the same journal, may well have been a response to the Swedish Nobel laureate. Chwolson flatly rejected Arrhenius's views, which he branded as pseudo-scientific and antropomorphic.

Arrhenius's dismissal of a created world and its end in a heat death was a premise, not a conclusion, which may explain the less

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<sup>110</sup> Bavink 1914, p. 125–135.

<sup>111</sup> Arrhenius 1909, p. 218 and p. 226.

than impressive logic of his argument:

If Clausius were correct, this heat death ought to have been realized in the infinite time of the existence of the world, which has definitely not happened. Or else the world has not existed for an infinite time but has had a beginning; but this contradicts the first part of Clausius' statement, that the energy of the world is constant, for in that case the entire energy would have come into existence in the moment of creation. This is *totally* incomprehensible and we therefore have to look for a case to which Clausius' entropy does not apply.<sup>112</sup>

A similar argument against a beginning and end of the universe had earlier been employed by the eminent zoologist and evolutionist Ernst Haeckel. An advocate of materialism and monism, Haeckel rejected the immortality of the soul and the existence of a personal God who had created the world. He wanted science to replace traditional religion. "If this theory of entropy were true, we should have a 'beginning' corresponding to this assumed 'end' of the world," he wrote in his book, *Die Welträthsel* from 1899.<sup>113</sup> Appalled by these consequences the atheist Haeckel concluded that Clausius' law had to be rejected. Not only did he claim that the law did not apply to the world at large, he also believed that it contradicted the first law of thermodynamics. Haeckel argued in favour of an infinite and eternal universe filled with an all-pervading "substance" (which might be matter, ether or energy). His cosmos was in constant and cyclic evolution, with matter-building processes endlessly changing with destructive processes.

Unlike Haeckel, Arrhenius was unwilling to dismiss the entropy law, and therefore had to look for entropy-decreasing cosmic processes. The solution he came up with, in works between 1903 and 1913, was radiation pressure as a mechanism that would allow that "the cosmic development can take place in a continuing cycle, where there is no trace of any beginning or end, and by means of which an ever-undiminished prospect can be maintained even for life."<sup>114</sup> Arrhenius' suggestion did not win approval, but it did attract the

<sup>112</sup> Arrhenius 1921, pp. 189–190, first published in 1907.

<sup>113</sup> Haeckel 1900, p. 247. The misconception that a created universe is grossly inconsistent with energy conservation continued to be advanced in later cosmology and appeared, for instance, in Fred Hoyle's attack on the big-bang model.

<sup>114</sup> Arrhenius 1921, p. 206.

attention of Henri Poincaré, who showed that "Arrhenius' demon" was unable to counter the second law of thermodynamics. After Poincaré's detailed and damaging criticism, little more was heard of Arrhenius' cosmology.<sup>115</sup> Yet, as late as 1927, another Frenchman, the distinguished philosopher of science Abel Rey, brought new attention to Arrhenius' proposal and general idea of an eternal universe. Rey's programmatic *Le Retour Éternel et la Philosophie de la Physique* pictured eternal recurrence as the supreme embodiment of scientific objectivity and rationality, whereas he associated irreversibility with subjectivism. The rationalist Rey shared the Laplacian view of the universe as a perfect machine, and called the idea of eternal recurrence "one of the most profound, the least discussed, and the most fertile" of scientific hypotheses.<sup>116</sup>

Recurring or cyclic conceptions of the universe were popular in the early part of the 20th century. At the same time that Arrhenius proposed his idea, another physicist and chemist (and future Nobel laureate) made a somewhat similar suggestion, although in the context of radioactivity rather than astronomy. In 1908 Frederick Soddy, a pioneer in radiochemical research and Rutherford's former collaborator, gave a series of public lectures at the University of Glasgow which were published as *The Interpretation of Radium*. In the final chapter Soddy speculated that subatomic (or what would soon become nuclear) energy played a role not only in radioactive processes, but also cosmologically. As "the most attractive and consistent explanation of the universe in light of present knowledge," he proposed "that matter is breaking down and its energy being evolved and degraded in one part of a cycle of evolution, and in another part still unknown to us, the matter is being built up with the utilisation of waste energy." The consequences would be that, "in spite of the incessant changes, an equilibrium condition would result, and continue indefinitely."<sup>117</sup>

Four years earlier, Soddy had suggested a different picture of the universe and its enormous amount of hidden energy contained in the form of radioactivity. He wrote of "a sudden beginning of the universe" and found it necessary to suppose that "the universe as a thing in being had its origin in some initial creative act, in which a certain

<sup>115</sup> Poincaré 1911, pp. 240–265.

<sup>116</sup> Rey 1927, p. 267. See also Jaki 1974, pp. 343–345.

<sup>117</sup> Soddy 1909, pp. 241–242.

amount of energy was conferred upon it, sufficient to keep it in being for some period of years."<sup>118</sup> This could be read as a scientific version of the biblical creation story, except that Soddy was not religious, and his taste was for a cyclic world view. He was raised in a Calvinist home, but as a young man he renounced his parents' religion and turned away from any kind of religious doctrine. The universe that he imagined to keep going by means of atom-destructive and complementary atom-constructive processes, was "a conservative system, limited with reference neither to the future nor the past, and demanding neither an initial creative act to start it nor a final state of exhaustion as its necessary termination."<sup>119</sup> Soddy was from an early date captivated by Ourobos, the tail-devouring serpent which for the alchemists served as a symbol for eternity and immortality, and in his book of 1909 he used it to symbolize cyclic and regenerative cosmological processes.

That the Victorian physicists' discussion of the thermodynamic argument for a universe of finite age was not well known in the early part of the 20th century may be illustrated by the geophysicist Arthur Holmes, who in 1913 published *The Age of the Earth*. His formulation of the problem was almost exactly the same as that of Jevons and his contemporaries: "If the development of the universe be everywhere towards equalization of temperature implied by the laws of thermodynamics, the question arises—why in the abundance of time past, has this melancholy state not already overtaken us? Either we must believe in a definite beginning ... or else we must assume that the phenomena which we have studied simply reflect our limited experience."<sup>120</sup> Holmes, like most others, tended toward the latter alternative. Like Arrhenius, he suggested that there must exist some external force that replenish the sun and the stars, for "in the universe nothing is lost ... in its cyclic development [is] the secret of its eternity."

Among the few astronomers who commented on the thermal future of the world, or the solar system, Camille Flammarion is probably the best known. In his best-selling book, *La Fin du Monde* from 1894, a science-fiction novel mixed with popular science, he wrote of how humankind would eventually disappear from earth because of changed thermal conditions. Although his vision has often been used

<sup>118</sup> Soddy 1904, p. 188. Kragh 1996, p. 41.

<sup>119</sup> Soddy 1909, p. 189. On Soddy and his lifelong interest in cyclic processes, see Sclove 1989.

<sup>120</sup> Holmes 1913, pp. 120–121.



to illustrate the heat death, in fact the mechanisms he invoked for the deterioration of the earth's habitability had nothing to do with Clausius' prediction.<sup>121</sup> Flammarion subscribed to a mystical, cosmic religion with little connection to traditional Christianity, and he was convinced that the universe was full of intelligent life. As a progressivist and social optimist, he believed that life would go on endlessly, if not on earth then elsewhere. Consequently he explicitly denied that the heat death would ever occur. His elementary objection, a standard argument both then and later, was that the second law was only valid for a finite system, not for the supposedly infinite universe.

Starting in 1872 with what came to be known as the *H*-theorem, Ludwig Boltzmann and others developed a molecular-dynamical understanding of thermodynamics which culminated in 1877 with Boltzmann's celebrated statistical theory, in which entropy was defined in terms of a probability measure (the famous expression  $S = k_B \log W$ ). This and the following developments constitute a complex history, most of which is irrelevant for the present purpose, and I shall suffice to mention some of the results that were of cosmological relevance.<sup>122</sup> The *H*-function, which according to Boltzmann was proportional to the negative of the entropy, was derived from the kinetic theory of gases, and claimed to provide a mechanical reduction of the second law. But how can this law, the very expression of nature's irreversibility, be derived from a theory which is manifestly reversible? Boltzmann's colleague, Joseph Loschmidt, believed that the irreversibility problem or paradox proved that the second law cannot be absolutely valid. He seems to have been motivated by a desire to avoid the heat death, to "destroy the terroristic nimbus of the second law, which has made it appear to be an annihilating principle for all living beings of the universe," as he wrote in his brief objection of 1876. Loschmidt's paradox inspired Boltzmann to further develop his theory into a genuinely probabilistic theory of molecular disorder, which in the 1890s became the subject of intense scrutiny and much debate.

Another problem, the recurrence paradox, was raised by the mathematician Ernst Zermelo, who in 1896 claimed that the second law disagreed with Newtonian mechanics because of the theorem, proved by Poincaré, that an isolated mechanical system will at some stage in its

<sup>121</sup> Kleinert 1992.

<sup>122</sup> Brush 1986 is a good introduction. For Boltzmann's theories, see also Curd 1982.

development return to its initial state (or arbitrarily close to it). This could be seen as a problem for the second law, but Zermelo instead concluded that it was a problem for the mechanical theory or world view.

Unknown to Zermelo and Boltzmann, Poincaré had noted the same paradox three years earlier. When the world has reached the equilibrium state corresponding to the heat death, it follows from the recurrence theorem that it will *not* remain there forever. "It merely stays there for an enormously long time, a time which is longer the more numerous are the molecules. This state will not be the final death of the universe, but a sort of slumber, from which it will awake after millions of millions of centuries." Poincaré expressed the hope that "some day the telescope will show us a world in the process of waking up, where the laws of thermodynamics are reversed."<sup>123</sup> As far as Poincaré was concerned, this was little more than an academic exercise. His proof of the mechanical recurrence theorem required physical space, and the number of particles in it, to be finite, and there was no reason why the real universe should match these conditions. Poincaré's confidence in the absolute validity of the second law remained unshaken, and he regarded the prediction of a cyclic, recurring universe to have no relevance for the real world.<sup>124</sup>

Boltzmann shared, at least for a period, Poincaré's conviction that the heat death was an unavoidable consequence of the second law. In a popular lecture of 1886 he made it clear that all attempts to save the universe from the heat death had been unsuccessful and would remain futile.<sup>125</sup> Boltzmann continued to think about the problem, and in the 1890s he addressed some of the metaphysical and cosmological problems of his statistical theory of entropy. This theory enabled him to come up with a new answer to the old problem of why we have not already suffered the heat death. In 1895 he developed a remarkable scenario of anti-entropic pockets in a universe which as a whole is in thermal equilibrium:

If we assume the universe great enough we can make the probability of one relatively small part being in any given state

<sup>123</sup> Brush 1966, vol. 2, p. 206. See also Brush 1980.

<sup>124</sup> The idea of eternal recurrence was also suggested by Friedrich Nietzsche, but only published posthumously in *Der Wille zur Macht*. See Brush 1978, pp. 72–75, and Rey 1927, pp. 309–313. Nietzsche dismissed the concept of a finite-age universe created in the past, which he regarded to be nothing but a religious myth.

<sup>125</sup> Boltzmann 1905, p. 33.

(however far from the state of thermal equilibrium) as great as we please. We can also make the probability great that, though the whole universe is in thermal equilibrium, our world is in its present state. But can we imagine, on the other side, how small a part of the whole universe this world is? Assuming the universe great enough, the probability that such a small part of it as our present world be in its presents state, is no longer small. If this assumption were correct, our world would return more and more to thermal equilibrium; but because the whole universe is so great, it might be probable that at some future time some other world might deviate as far from thermal equilibrium as our world does at present.<sup>126</sup>

It is to be noted that Boltzmann assumed the universe to be in thermal equilibrium, and thus implicitly that it has existed forever or for an exceedingly long time; he did not consider the possibility of a finite-age solution. Also noteworthy is that he operated with two meanings of the term universe, as when he distinguished between "the whole universe" and "our world;" in general he suggested a many-worlds picture, although these worlds were apparently taken to be just different parts of the universe and not (as in later theories) causally separated regions.

In one of his replies of 1897 to Zermelo, Boltzmann stated that his mechanical explanation of the second law depended on the ("of course unprovable") assumption that the universe started from a very improbable, low-entropic state and is still in a relatively improbable state far from the heat death—after all, life exists. He offered two ways to understand the assumption. According to the first scenario, our world is a representative sample of the entire, low-entropy universe. The other was a scenario of entropy fluctuations in an otherwise high-entropic universe. "There must then be in the universe, which is in thermal equilibrium as a whole and therefore dead, here and there relatively small regions of the size of our galaxy (which we call worlds), which during the relatively short time of eons deviate significantly from thermal equilibrium." Boltzmann preferred the second viewpoint because it promised an understanding of "the second law and the heat death of each individual world without invoking a unidirectional change of the entire universe from a definite

<sup>126</sup> Boltzmann 1895, p. 415. For more than a century, Boltzmann's argument has attracted the interest of physicists and philosophers. For a recent review, see Ćirković 2003.

initial state to a final state.”<sup>127</sup> In the second volume of his great textbook on gas theory, he included a section on “Applications to the Universe” in which he repeated and amplified his ideas of many worlds, entropy fluctuations, and time reversal. He was of course fully aware that these “cosmological considerations” were highly speculative, but found them to be consistent and also useful because they opened up for new perspectives.<sup>128</sup>

Boltzmann’s view of isolated low-entropic regions in the universe was shared by his younger colleague, the Polish physicist Marian von Smoluchowski, a specialist in statistical mechanics and fluctuation phenomena. They both argued that in a literal sense Clausius’ statement of 1865 was wrong—or “vacuous” as Smoluchowski wrote—and that there is no overall development in the universe as a whole.<sup>129</sup> According to Smoluchowski, all molecular processes were in principle reversible. The apparent irreversibility is a subjective feature which merely reflects when an observation is made and how long it takes. If a physical system was observed for an immeasurable period of time, all processes in it would appear as reversible.

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<sup>127</sup> Brush 1966, vol. 2, p. 242. Boltzmann distinguished between the entire universe (*Universum*) and individual worlds (*Einzelwelten*).

<sup>128</sup> Boltzmann 1898, pp. 256–259.

<sup>129</sup> Smoluchowski 1914. See also Bernhardt 1969.



# 3

## Expanding Horizons

# 3

## Expanding Horizons

### FROM REDSHIFTS TO AN EXPANDING UNIVERSE<sup>1</sup>

A few years before the outbreak of World War I, the Dutch astronomer Jacobus Kapteyn argued that the major radius of the ellipsoid-shaped Milky Way was about 50,000 light years, and that, outside this distance there was an infinite space unpopulated by stars. At about the same time Vesto Slipher at the Lowell Observatory, Arizona, found the first Doppler shift for a spiral nebula, soon to be followed by more data that indicated that most nebulae were receding from the earth at great velocities.

Slipher did not interpret the redshifts cosmologically, but others did, and they suggested that there was a relationship, perhaps linear, between redshift and distance. Although such a relationship was not established until 1929, Slipher's observations contributed to a revival of the island-universe theory, according to which the Milky Way was just one of a multitude of "worlds" spread around in the huge ocean of space. The whole issue was a matter of controversy, and in the "Great Debate" in 1920 between Heber Curtis and Harlow Shapley (arguing for and against the island-universe theory, respectively) no consensus was achieved. It was only with Edwin Hubble's discovery

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<sup>1</sup> This brief section, based on Kragh 2003a, is only meant to give a condensed survey of the most important developments. For more detailed treatments, including references to the literature, see North 1965, Smith 1982, Kerzberg 1992 and Ellis 1988.



in 1923 of a Cepheid in the Andromeda nebula that it became possible to determine the distance to Andromeda, and then settle the debate in favor of the island-universe theory. Now the universe came to be seen as a vast congregation of galaxies, somewhat analogous to a gas made up of molecules.

Until Hubble's determination of a linear relationship between velocities and distances, the recession of the galaxies was not seen as indicating a changing universe. A book on astrophysics from 1924 included one of the very few speculations that the observed redshifts might have something to do with the past of the universe. The author of *Modern Astrophysics*, Herbert Dingle (on whom more later), suggested that the recession might be "the legacy of a huge disruption, in the childhood of matter, of a single parent mass." The suggestion was not unlike the one on which Lemaître would base his big-bang picture seven years later, but Dingle did not seriously believe in an exploding universe of a finite age. He considered the possibility that "we exist at a special point of time in a Universe which had a beginning in time" only to turn it down as "an assumption which we are as loth to make as the corresponding one, that we are at a particular place in a finite space."<sup>2</sup> The Copernican principle was assumed to apply not only spatially, but also temporally.

Meanwhile, important developments had occurred in theoretical cosmology. The great breakthrough—effectively the foundation of modern cosmology—was Einstein's application of his new theory of general relativity to the universe at large. Einstein's universe of 1917 was static and spatially finite in spite of having no boundary—a result due to space being conceived as positively curved. In order to secure its static character, he modified his gravitational field equations by adding a term proportional to the metrical tensor, the famous cosmological term characterized by the constant  $\Lambda$ . The model universe was homogeneously filled with dilute matter, and could be ascribed a definite radius ( $R$ ), volume, and mass. In Einstein's model, the mass of the static universe was  $\mu = 2\pi^2 R^3$  and the cosmological constant given by  $\Lambda = 1/2\kappa\rho = R^{-2}$ . That is,

$$\mu = \frac{4\pi^2}{\kappa\sqrt{\Lambda}} = \frac{\pi c^2}{2G\sqrt{\Lambda}}$$

<sup>2</sup> Dingle 1924, p. 399 and p. 401.



Einstein at first believed that this was the only solution compatible with general relativity, but later in 1917 the Dutch astronomer Willem de Sitter found a solution which included no matter, but was nonetheless spatially closed. If just a single particle (or galaxy) was introduced in De Sitter's universe, light from it would appear redshifted to the receiver. In De Sitter's world, as interpreted after 1930, space would expand according to  $R = \exp(\sqrt{\Lambda}/3ct)$ .

Einstein found De Sitter's model objectionable, primarily because he believed that the curved space-time in the absence of matter disagreed with the spirit of general relativity and also with Mach's principle. But he had to admit that it was a solution of the field equations, and De Sitter's alternative soon attracted interest from astronomers and physicists who found it attractive because of its connection to the galactic redshifts that Slipher had reported. During the 1920s a small group of theoretical physicists and mathematically inclined astronomers—De Sitter, Hermann Weyl, Georges Lemaître, Alexander Friedmann, Howard Robertson, Richard Tolman, and a few others—investigated which of the two relativistic alternatives was the more satisfactory. During the course of this work they gradually recognized that it was not a question of either Einstein's or De Sitter's model, for none of these seemed to represent the real universe. By the late 1920s a few theoreticians argued for hybrid theories in which the space-time metric depended on the time coordinate in a matter-filled universe, but even these models were not considered to be evolutionary in a physical sense.

The collapse of the static universe paradigm took place by the interaction of two separate approaches, the one observational and the other theoretical. In 1929 Hubble published data on redshifts and distances ( $r$ ) of galaxies that indicated a linear relationship between the two quantities. If the redshifts were interpreted as due to Doppler effects, it meant that the galaxies had a recessional velocity  $v$  away from the earth, following what later became known as the Hubble law,  $v = Hr$  (where  $H$  is Hubble's constant).<sup>3</sup> The Swiss astronomer Fritz Zwicky immediately proposed an alternative explanation that explained the empirical relationship by a "tired light" mechanism, but within a few years the majority of researchers had concluded that

<sup>3</sup> The association of Hubble's name with the now famous law occurred only from about 1950. Until then, it was referred to under other names and described as a "relation" rather than a "law." See Kragh and Smith 2003.

what Hubble had discovered was a universe expanding in agreement with relativistic cosmology. The possibility of an expanding universe, and in general dynamic solutions to the field equations, had been pointed out as early as 1922 by Friedmann, and five years later Lemaître would find similar expanding solutions from which he concluded that the universe is in fact in a state of expansion. Neither Friedmann's nor Lemaître's pioneering works made any impact at all, and it was only after Hubble's 1929 paper that the situation changed. It then happened drastically and, so it seems, irreversibly.

As a result of Hubble's data, and also of theoretical work done by Robertson and Tolman, the climate now became receptive to the idea of an evolving universe. Eddington studied Lemaître's old paper and realized that it provided the solution to the cosmologists' dilemma. With the enthusiastic support of Eddington and De Sitter, the expanding universe became the basis of a new world view, and cosmology experienced a sudden paradigm shift, almost in the strong sense of Thomas Kuhn. The favored model in the years after 1930, named after Lemaître and Eddington, was a universe expanding asymptotically from a static Einstein world and was therefore without a definite origin in time. The suggestion that the world had a beginning, that it originated in an explosive act from a small and compact nucleus, was first made by Lemaître in 1931, and soon afterwards developed into a mathematical model. However, it was only after World War II that this kind of finite-age universe became generally accepted, eventually under the undignified name "big bang." The equations that described the Lemaître-Eddington model as well as Lemaître's primeval-atom model included as an important ingredient, the cosmological constant, originally introduced to keep the universe static. Einstein, who had long wanted to get rid of the constant, realized that the expanding universe made it expendable, and in a model he constructed in 1931, it no longer figured.

Apart from the Lemaître-Eddington model, a cosmological model proposed jointly in 1932 by Einstein and De Sitter attracted considerable attention. The Einstein-De Sitter model was a kind of discount universe, a solution to the Friedmann-Lemaître equations that did without a cosmological constant, without pressure, and without space curvature (i.e. it assumed a Euclidean space and was thus infinite). The two cosmologists found that such a model did not disagree with observational facts such as the mean density of matter in the

universe. The matter density  $\rho = 3H^2/8\pi G$  was critical, with gravitational attraction just balancing the expansion, and led to an ever-increasing universe where the scale factor expands according to  $R(t) \sim t^{2/3}$ . However, Einstein and De Sitter did not write down the variation of  $R(t)$ , and neither did they note that it implies a big-bang universe—an abrupt beginning of the world. The age of the Einstein-De Sitter universe is two thirds the Hubble time, which at the time implied that the universe would have been in existence for a mere 1.2 billion years.

Whereas many physicists and astronomers considered Einstein's general theory of relativity the only acceptable basis for cosmological models, during the 1930s this kind of standard cosmology faced serious competition from other theories. Among the alternatives were qualitative theories of a recurrent universe with a continual supply of energy, to be considered below; but these were widely ignored by the cosmologists who worked within the relativistic tradition. On the other hand, they could not and did not ignore the alternative, sometimes known as kinematic relativity, which E. A. Milne developed from 1932 onwards. Milne's theory and its philosophical and religious connotations will be taken up in Chapter 6.

## EINSTEIN'S COSMIC RELIGIOSITY

Albert Einstein, the founder of the theory of relativity (and the cosmologies based thereupon), was not a religious person in the ordinary sense of the word. He was raised by non-religious Jewish parents, and after a brief period of intense juvenile religiosity he changed abruptly to atheism at the age of 12 or 13. As he expressed it in his autobiographical notes written some 55 years later: "Through the reading of popular scientific books I soon reached the conviction that much in the stories of the Bible could not be true. The consequence was a positively fanatic orgy of freethinking [*eine durchaus fanatische Freigeisterei*] ..."<sup>4</sup> Throughout his life, Einstein was never a member of any church, or a supporter of any religious confession. He never attended religious services, and his last wish was not to be buried according to Jewish tradition, but to be cremated.

<sup>4</sup> Schilpp 1959, p. 5. The autobiographical notes were written in 1946–47 and the first edition of *Albert Einstein: Philosoph-Scientist* was published 1949.

During his scientifically most creative period, from 1905 to about 1924, Einstein did not explicitly address religious questions, which at that time were apparently of little importance to him. Only in 1930 did he address the topic, for instance in an article on "Religion and Science" written for *New York Times Magazine*. One should not expect to find in Einstein's writings, or in the recorded interviews and conversations, a consistent and fully worked out philosophy of religion or a theory of the interaction between science and theology. Rather, what we have is a series of statements scattered over many sources—some short and improvised, others more elaborate and thoughtful. When comparing Einstein's various comments it is not hard to find, in some cases, inconsistencies between them. Yet his comments on religion were considered interesting enough to attract the attention of leading theologians, including influential figures such as the German Protestant Paul Tillich and the Swiss Catholic Hans Küng.

Was Einstein religious? This seemingly innocent question is difficult to tackle, such as illustrated by the fact that it has been answered in the most different ways, from a clear *no* to an equally clear *yes*. To a large extent this is due to the ambiguity of terms such as "religious" and "religion." It does not help much to know that Einstein near the end of his life described himself as a "deeply religious nonbeliever."<sup>5</sup> One of the few things which is beyond discussion is that Einstein did not believe in the personal God of the Bible: a God who cares for human beings, who rewards and punishes his creations, who listens to their prayers. "I cannot conceive of a personal God," he wrote in a letter of 1927. And 27 years later he amplified in another letter: "It was, of course, a lie what you read about my religious convictions, a lie which is being systematically repeated. I do not believe in a personal God and I have never denied this but have expressed it clearly."<sup>6</sup> Einstein was not a theist, but he also explicitly denied that his rejection of a personal God made him an atheist. "I'm not an atheist, and I don't think I can call myself a pantheist," he said.<sup>7</sup>

When Einstein nonetheless is often described as a cosmic pantheist it is because of his often expressed admiration for Spinoza's thoughts. What he found appealing in Spinoza was not, however, pantheism in its general meaning of a divine nature, or that God and

<sup>5</sup> Letter of 30 March 1954, quoted in Seelig 1956, p. 28.

<sup>6</sup> For the two letters, see Dukas and Hoffman 1979, p. 66 and p. 44.

<sup>7</sup> Quoted in Jammer 1999, p. 48.



cosmos are one and the same, but rather the Jewish philosopher's insistence on a lawful and harmonious universe governed by strictly deterministic laws of such a kind that they can be comprehended by man. Einstein considered qualities such as lawfulness, harmony and determinism to be objective features of the world, and he valued them highly. Sometimes he spoke of them as if they reflected the existence of a supreme being, a kind of God, perhaps, but if so a most abstract and anti-anthropomorphic God. In 1936 he pointed out that the pursuit of fundamental science presupposes "a sort of faith," namely that the world is lawful and rationally comprehensible. Moreover, the serious scientist—meaning himself—"becomes convinced that a spirit is manifest in the laws of the Universe—a spirit vastly superior to that of man, and one in the face of which we with our modest powers must feel humble. In this way the pursuit of science leads to a religious feeling of a special sort, which is indeed quite different from the religiosity of someone more naive."<sup>8</sup>

In his afore-mentioned letter of 1927 he expressed himself in the same way: "My religiosity consists in a humble admiration of the infinitely superior spirit that reveals itself in the little that we, with our weak and transitory understanding, can comprehend of reality. Morality is of the highest importance—but for us, not for God."<sup>9</sup> What he called cosmic religiosity was a non-confessional and non-institutional form of religion among whose representatives he mentioned, thinkers as diverse as Buddha, Democritus, Francis of Assisi, and Spinoza. This form of religiosity, Einstein claimed, accepts no God and has no theology, but it arouses in humans a deep respect and desire for science and art. "Cosmic religious feeling is the strongest and noblest incitement to scientific research," he wrote.<sup>10</sup> Religion in this sense was a mystical feeling towards the laws of the universe, as well as a set of moral obligations; but the two aspects should not be linked. With regard to moral obligations, in an address of 1939 in the theological seminary at Princeton he said, "The highest principles for our aspirations and judgments are given to us in the Jewish-Christian religious tradition."<sup>11</sup>

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<sup>8</sup> Dukas and Hoffman 1979, p. 33.

<sup>9</sup> *Ibid.*, p. 66. Also, "I have found no better expression than 'religious' for confidence in the rational nature of reality as it is accessible to human reason." Jammer 1999, p. 48.

<sup>10</sup> Einstein 1935, p. 27.

<sup>11</sup> Einstein 1950, p. 23.

I guess it is, to a large extent, a matter of taste whether this makes Einstein religious or an atheist. Certainly, he has been claimed to harbor both views. The English freethinker Chapman Cohen was chairman of the Secular Society, an organization founded in 1898 with the purpose of combating religion. According to him, Einstein's impersonal, Spinozist God was no God at all, and hence what Einstein confessed was really a "practical atheism." As far as Cohen was concerned, Spinoza's God could just as well be called Abracadabra: "Spinoza's system is fundamentally Atheistic in character. Let anyone apply the simple test of using the term *nature* or *existence* where Spinoza uses the term God and he will find it work out equally well."<sup>12</sup> But Einstein disliked as much to be counted as an atheist as he resisted being used for religious purposes. It may have been with people like Cohen in mind that he, in a strongly worded letter of 1941, distanced himself from "the fanatical atheists whose intolerance is of the same kind as the intolerance of the religious fanatics."<sup>13</sup>

According to a widely accepted typology proposed by Ian Barbour, the various attitudes to how science and religion relate (or should relate) can be summarized in four positions.<sup>14</sup> According to the *integration thesis*, science and religion coexist as partners in close contact. They are basically concerned with the same things. One can use science to get religious insights or, conversely, use religion to obtain a truer and greater understanding of how nature works. The *dialogue thesis* admits the integrity and relative independence of science and religion, yet argues that there are important similarities; for example in methodologies and the use of models and analogies. Science will be richer by engaging in a dialogue with religion, and the relationship holds for religion as well. In the *independence view*, the differences are stressed, and the similarities denied or seen as insignificant. Science and religion are about different kinds of reality: they use different methods, and the languages they speak are so different that no meaningful translation is possible. According to the advocate of the independence view, there can be no conflict between science and religion if only these are properly understood and

<sup>12</sup> Chapman 1931, p. 132. His essay on "Einstein and God" (pp. 127–133) first appeared in the *Freethinker*, 26 May 1929.

<sup>13</sup> Jammer 1999, p. 97.

<sup>14</sup> Barbour 1990. Several other typologies have been proposed, some of them much more complex and fine-grained. For criticism of Barbour's fourfold typology, see, e.g., Cantor and Kenny 2001.

compartmentalized. But the lack of conflict is due only to science and religion being wholly different, hence allowing no possibility of constructive interaction.

Finally, the *conflict thesis* claims that science and religion are not only different, but incompatible, and therefore necessarily enemies. One can accept the scientific worldview, but if so, religious faith is not an option; or one can believe in God, and is then forced to deny science as the superior knowledge of the natural world.

Einstein discussed the relationship between science (or physics) and religion at several occasions, but never expressed his viewpoint very clearly; nor did his views fit well with Barbour's classification, except that he explicitly denied the conflict thesis. When Einstein believed that science could not possibly be in genuine opposition to religion—or vice versa—it was however, largely because he considered the two areas to have no common ground: that is, he tended to follow the independence thesis. Science is descriptive and analytic, and deals with what *is*, while religion is normative, and deals with what *ought to be*. For example, in an essay of 1941 he wrote that, "science can only ascertain what *is*, but not what *should be*, and outside of its domain value judgments of all kinds remain necessary. Religion, on the other hand, deals only with evaluations of human thought and action."<sup>15</sup>

He was of course aware that there have in fact been conflicts between science and religion, such as Galileo's condemnation by the Catholic church; but these "must all be ascribed to a misapprehension of the situation," namely that religion illegitimately intervened into the realm of science, or that science intervened into areas that belonged to religion. In this respect, Einstein was what the historian Loren Graham has called a "restrictionist," that is, an advocate of the view that science cannot inform us about human behavior, social values or religious questions (whereas the "expansionist" takes the opposite view).<sup>16</sup> Incidentally, it may seem puzzling that Einstein associated morality with religion, as his sense of religion had nothing to do with the way humans should act. "There is nothing divine about morality, it is a purely human affair," he wrote.

<sup>15</sup> The essay "Science and Religion" is reprinted many places, e.g., in Einstein 1950, pp. 21–30, where the quotation is on p. 25.

<sup>16</sup> Graham 1981. On Einstein, see pp. 36–46, 62–66.

Among Einstein's non-scientific articles, his contribution of 1941 on "Science and Religion" is particularly valuable, if also somewhat problematic. It is in this essay that Einstein wrote, "I cannot conceive of a genuine scientist without that profound faith [that the laws of nature are comprehensible to reason]," and then continued with the famous aphorism, "Science without religion is lame, religion without science is blind." This sounds like as good a definition of the dialogue thesis as any, except that Einstein also pointed out that religion and science are dealing with distinctly different realms. And he further qualified his statement by emphasizing that when science is lame without religion, it is religion in *his*, abstract and impersonal sense. In a brief essay of 1948, Einstein confirmed that whereas science deals with the order in nature, religion is concerned with man, either in an existentialist or a social sense. He nevertheless concluded that "The interpretation of religion, as here advanced, implies a dependence of science on the religious attitude."<sup>17</sup> The qualification "as here advanced" is important, and so is the use of "religious attitude" rather than "religion."

Whatever Einstein meant with his formula, or more precisely, when it came to specific scientific theories, he adamantly denied that they had any religious relevance. The theory of relativity was sometimes believed to have not only philosophical but also religious implications, to be either a threat against religion or to open up new vistas in religious thought. The Archbishop of Boston, Cardinal William O'Connell, belonged to the first group. In 1929 he advised his fellow-Catholics to shun the theory of relativity because it was "a befogged speculation producing universal doubt about God and his Creation... cloaking the ghastly apparition of atheism." Einstein of course denied that this was the case. The theory, he wrote, is neither theistic nor atheistic—it "is a purely scientific matter and has nothing to do with religion."<sup>18</sup>

Whereas O'Connell warned against Einstein's theory because it was materialistic, other Catholics suggested that it expressed a subjective idealism. For Catholics in the Thomist tradition, either interpretation was a sign of warning.

In the early 1920s, when relativity was hotly debated, many non-physicists (and also some physicists) declined to follow Einstein's

<sup>17</sup> Jammer 1999, p. 117.

<sup>18</sup> *Ibid.*, p. 48 and p. 155.



restrictionist attitude. The famous American-British poet T. S. Eliot complained that Anglican bishops claimed that relativity "provides a climate more favorable to God than has existed for generations."<sup>19</sup> As late as 1939 a theologian had suggested that time as a fourth dimension might serve to connect mortal life with eternal life. "While we are limited to three-dimensional understanding, it is mortal life," he wrote. "Where we perceive it in four dimensions, it is eternal life."<sup>20</sup> To mention one more example, in 1921 Herbert Wildon Carr, a British professor of philosophy, claimed that "Einstein's space-time is the death-knell of materialism, ... If space is not endless, but finite (and this is the essential principle of the Riemannian geometry), and if time is not in its existence independent of space, ... then the very foundation of the materialistic concept is undermined." Hugh Elliot, an anti-idealist and author of works defending materialism and secular values, did not agree. According to him, relativity was fully concordant with a materialist view, with which he meant that mind cannot exist apart from matter. In his rejoinder, Carr accused his opponent of having misunderstood the essence of Einstein's theory, and reaffirmed that "Materialism is a metaphysical theory which may be right, and relativity is an anti-metaphysical theory which may be wrong, but acceptance of the one is the rejection of the other."<sup>21</sup> No dialogue here.

One point to note is Einstein's view on religion, and its possible relevance for science, which may or may not be of interest; another point and definitely important factor is whether or not his religious or metaphysical sentiments affected his science. Einstein never claimed so, except in a most general sense, namely that his quasi-religious belief in a harmonious, lawful and rational universe was an important background for all his work. It is also only in this vague sense that one can accept Lewis Feuer's claim that Einstein's "Spinozist faith was more than a religious ethic; it became a regulative principle for discovery of the laws of nature."<sup>22</sup> When it comes to more specific cases—say the theory of relativity or the photon

<sup>19</sup> Quoted in Friedman and Donley 1985, p. 80.

<sup>20</sup> Article in *Hibbert Journal*, here quoted from Frank 1948, p. 317.

<sup>21</sup> Carr 1921. Elliot 1921. See also Carr's rejoinder in the same volume of *Nature*, p. 467. Carr referred to Hermann Weyl's *Raum, Zeit, Materie* as strong support of his view. Neither Carr nor Elliot referred directly to religion, although it would seem that Carr's version of anti-materialism—a metaphysics based on the independent existence of mind—embraced religion.

<sup>22</sup> Feuer 1971, p. 338. See also Feuer 1974, pp. 78–80.

hypothesis—the answer is undoubtedly a *no*. In the present context it is natural to ask if Einstein's cosmological model of 1917, or his view of cosmology in general, was in any way affected by his religious feelings. Perhaps disappointingly, the answer must again be in the negative. Not only was the pioneering theory of 1917 strictly scientific, in its origin it also seems to have been wholly independent of religious motivations.

When the theory of the new universe became generally known, neither it nor other relativistic models were much discussed in philosophical or religious contexts. Remarkably, relativistic cosmology played almost no role in the popular debate over relativity in the 1920s. Einstein at first dismissed the idea of an expanding universe, then by the early 1930s he had accepted it and also eventually come to adopt Lemaître's theory of a universe with a violent beginning. In a letter to Eddington from 1934, Lemaître wrote: "I have received with great pleasure your beautiful book on the expanding universe. ... I had the great pleasure to find professor Einstein very enthusiastic about it [the fireworks universe]." <sup>23</sup> However, none of Einstein's conversions came easily. The hypothesis of the universe originating in a primeval, compact state was sometimes associated with theism, and for this reason considered problematical. Lemaître recalled that when he tried to explain the hypothesis to Einstein in the early 1930s, Einstein invariably stopped him with the remark, "No, not that, it smells too much of creation." <sup>24</sup> But Einstein, like so many others, made the mistake of identifying "beginning" with creation, something that Lemaître, trained as he was in Thomistic philosophy, would never do. Einstein, in his last contribution to cosmology, dating from 1945, advocated a universe of the big-bang type. Nothing in Einstein's path from a closed, static universe to an expanding world of finite age can reasonably be ascribed to religious motivations; nor did he ever intimate any religious consequences of modern cosmology.

Although Max Jammer, in his major study of Einstein and religion, was careful to distinguish Einstein's science from his religious views, he did suggest one possible connection—namely that the introduction of the cosmological constant in 1917 was influenced by

<sup>23</sup> Undated draft. The reference is to Eddington 1934. Lemaître archive, Louvain-de-la-Neuve.

<sup>24</sup> Lemaître 1958b, p. 130.

Einstein's reading of Spinoza.<sup>25</sup> "Spinoza's influence on his thinking about cosmology could be recognized," Jammer writes, referring to the verse "the Heavens endure from everlasting to everlasting" and to certain passages in Spinoza's *Ethics* concerning God's immutability. I find Jammer's suggestion to be unconvincing.

## A REGENERATING UNIVERSE?

The relativistic models of the universe considered by Einstein, De Sitter and their followers were atemporal in the sense of being static. But as soon as their content of matter and radiation was taken into account, the universe would presumably be subject to the second law of thermodynamics, and therefore would eventually suffer the heat death. With the introduction of the expanding universe around 1930, the feature of unidirectionality was more clearly emphasized, as it was now exhibited not only by the physical state of the universe, but also by its space curvature. As mentioned in Chapter 2, many scientists (as well as non-scientists) were unwilling to accept a unidirectional universe whose fate would be the cessation of all physical processes. Rankine, Loschmidt, Crookes, Arrhenius, and Soddy all suggested ways to avoid the heat death, for example by postulating processes that might balance the steady dissipation of energy and then result in an eternal, if dynamical universe.

The tradition continued after World War I, when several scientists suggested cosmic pictures in the same spirit, modernizing the view by taking into account some of the then recent advances in physics.<sup>26</sup> Although these theories were ignored by most astronomers and physicists—with the result that they are rarely mentioned in historical works on cosmology—their advocates included respected scientists such as Emil Wiechert, William MacMillan, Robert Millikan and Walther Nernst, of which the latter two were Nobel laureates. Their works were entirely different not only from those of Hubble and

<sup>25</sup> Jammer 1999, p. 63 and p. 247.

<sup>26</sup> The section is based on Kragh 1995 and Kragh 1996, pp. 143–160, where further references can be found. See also Jaki 1974, pp. 336–357, who puts the idea of the regenerating universe in the same basket as conceptions of a cyclical universe. The two have something in common, such as being eternal, but are nonetheless different. The recycling universes of Nernst, MacMillan and their followers were not cyclical or oscillatory in the sense of exhibiting a temporal periodicity over long spans of time, returning after aeons to the same state. Moreover, in a cyclical universe there is typically no continual creation of matter, which is a distinctive feature of the regenerating models.

other observational astronomers, but also from those of relativists in the Einstein-De Sitter tradition. With the acceptance of the relativistic, expanding universe, theories centered on an eternal universe largely disappeared from scientific cosmology, but not completely so. The later steady-state theory had some similarity to the older tradition of a recycling universe, and in an even clearer way the similarity can be found in the plasma cosmology proposed by the Swedish physicist Hannes Alfvén in the 1960s.<sup>27</sup>

Walther Nernst, the great physical chemist and Nobel laureate of 1920, became interested in astrophysics shortly before World War I—most likely inspired by Arrhenius. Although an expert in chemical thermodynamics, he never used the concept of entropy, which he found unnecessary and regarded with suspicion, associated as it was with Clausius' cosmological formulation of the second law.<sup>28</sup> Ever since 1886, when he studied under Boltzmann and had first become acquainted with the gloomy prediction of the heat death, he had denied believing in this alleged consequence of the second law of thermodynamics. Nernst was strongly and emotionally opposed to any *Götterdämmerung des Weltalls*—a universal Armageddon—and his work in astrophysics was, as he admitted, wholly motivated by his desire to find an alternative.<sup>29</sup>

Nernst first thought of a mechanism for maintaining energy equilibrium in the universe during a lecture of 1912, namely by speculating that atoms were continually recreated from the ether. Nine years later, he developed the idea into a cosmic world picture, now justifying it by the new quantum theory. Nernst, who never abandoned the ether, considered the medium to be a huge energy reservoir, with its energy being stored in the form of the zero-point energy known from quantum theory. In his 1921 booklet, *Das Weltgebäude im Lichte der Neueren Forschung* he speculated that the hidden energy of the ether would occasionally, over long spans of time, form configurations out of which radioactive atoms would be created. Eternal recycling of radioactivity would prevent the heat death, and secure the stationary universe to which Nernst was so clearly committed metaphysically. As he wrote: "Our eyes need not, in the far future, have to look at the

<sup>27</sup> See Lerner 1991.

<sup>28</sup> For Nernst's and other chemists' problems with entropy, see Kragh and Weininger 1996.

<sup>29</sup> Nernst 1921, p. 2. Nernst 1935, p. 528. For a contemporary survey of Nernst's early thoughts on astrophysics and cosmology, see Günther 1924.



world as a horrible graveyard, but at a continual abundance of brightly shining stars which come into existence and disappear."<sup>30</sup>

Nernst based his cosmological view on what he called the "principle of the stationary condition of the cosmos," according to which the universe does not change its large-scale features. The transformation of stellar matter by radioactive processes, such as taking place in the interior of the stars, could therefore not be a one-way process, but had to be balanced by the formation of new matter. He regarded the principle an "intellectual necessity," an *a priori* hypothesis which could not be subjected to direct experimental tests and whose acceptance was, in the end, subjective or "a matter of taste." The energy irradiated by the formed radioactive nuclei would in part be absorbed by the ether, and out of the energy-enriched ether new radioactive nuclei would arise. Nernst realized that his scenario was speculative and out of tune with contemporary physics, but he saw no other way to maintain the eternal, stationary universe which for him had priority over the known laws of physics.

It is clear from Nernst's writings that he felt the stationary universe to be not only an intellectual but also an emotional necessity, and that he felt strongly about it. But he did not indicate any connections to either religious or spiritual contexts. Nernst seems to have been areligious, and he never alluded in his writings to religion or any metaphysical beliefs of a religious nature. In this respect he differed from his older contemporary Emil Wiechert, whose views on cosmology were in many ways similar to those of Nernst. Wiechert was a recognized German theoretical physicist, one of the fathers of the ether-based electromagnetic world view, and a pioneer in geophysics. He stuck throughout his life to the ether, which he claimed constituted a cure against the "materialism" of Einsteinian relativity. In works of 1921, he speculated, much like Nernst, that ether-matter transmutations might continually take place in the depths of space, and in this way provide a cosmic cycle that made the heat death avoidable.<sup>31</sup> Contrary to Nernst, Wiechert saw his ether-driven perpetual universe as part of a general fight against materialism, and he suggested that the ether was not merely a physical entity, but was also connected with the human spirit. "The cosmic background, the

<sup>30</sup> Nernst 1921, p. 37.

<sup>31</sup> Wiechert 1921a and Wiechert 1921b. The latter paper, together with other of Wiechert's works, is reproduced in Schröder 2001.

ether, provides the foundation also for our spiritual life. ... We must emancipate ourselves from any materialism which will only admit in the world that which is sensible. Behind the world that we see there is another world the action of which we feel but for whose recognition we are equipped only most incompletely."<sup>32</sup>

The ether of the 19th century had barely survived in the 1920s, but alive it was, if only outside mainstream physics. In England, Oliver Lodge continued to defend the world ether, much as he had done 40 years earlier, for he was convinced not only that ether was scientifically indispensable, but also that it was connected with his Christian faith in the immortality of the soul. The continuity in his thoughts is illustrated by his reference in 1925 to mind and psychical attributes as belonging to "the Unseen Universe."<sup>33</sup> Lodge's ether functioned as an intermediary between the spiritual and the material universe, and was a vehicle of the mind. The ether was omnipresent and permanent, and therefore more real than matter, and in principle it provided an explanation of the immortality of souls. "Matter is not part of our real being, not of our essential nature," he wrote; "it is but an instrument that we use for a time and then discard."<sup>34</sup> He saw the primacy of the ether confirmed in its energy density, which far exceeded that of matter. In 1920 he confirmed earlier estimates of the ether's energy density, that it was probably between  $10^{30}$  and  $10^{33}$  ergs per cubic centimeter.<sup>35</sup>

According to Lodge, the world once consisted of an undifferentiated ether out of whose dynamic fluctuations electrons and protons were created, and from these particles stars and galaxies were eventually formed through a long evolutionary process. He realized that if the stars continued to shine their energy into the confines of space, the heat death would follow, and this he could not tolerate. Around 1920 he suggested a kind of matter creation driven by radiation pressure, "that light-pressure may afford an escape from some popular eschatological conclusions based on the doctrine of the dissipation of energy."<sup>36</sup> In his book, *Evolution and Creation* from 1926 he elaborated

<sup>32</sup> Wiechert 1921a, pp. 68–69. The sentence should probably not be read as support of either spiritualism or religion. According to a personal communication from Wilfried Schröder, Wiechert had no interest in these areas.

<sup>33</sup> Lodge 1925, p. 163. For Lodge's Victorian background, see Wilson 1971.

<sup>34</sup> Lodge 1925, p. 176.

<sup>35</sup> Lodge 1920b. Wiechert's estimate was  $10^{31}$ , in agreement with Lodge's value.

<sup>36</sup> Lodge 1920a. According to Lodge, the idea was suggested to him by his assistant Edward E. Robinson.

the idea, now assuming building-up processes of fresh matter from radiation, a kind of pair production of electrons and protons. "I would urge that creation is a continuous process, not going on once and for all and then stopping, but continuing now, and always continuing: that what we are confronted with is not really a succession, a series, a beginning and an ending, a past and a future,—but in some sense an eternal Now."<sup>37</sup> As late as 1931, at the British Association discussion of the evolving universe, the 81-year-old physicist was claiming that too much attention had been paid to the second law of thermodynamics, and that "the final and inevitable increase of entropy to a maximum is a bug-bear, an idol, to which philosophers need not bow the knee."<sup>38</sup>

Contrary to Nernst and Wiechert, Lodge did not present his speculations as a scientific hypothesis, but admitted that they were part of a larger world view where religion and psychical evolution were the components of principal interest. Since the 1880s he had been an active spiritualist and researcher in psychical phenomena, areas he found to be in harmony with his Christian faith. Although he dismissed as myths a good deal of the content of the Bible, he accepted Christ as the son of God and believed that much of the essence of Christianity was confirmed by, and in fact given a fuller meaning through, spiritualism and ethereal physics. Not only was his kind of physics compatible with religion—the two were unified. One should not try to keep science and religion separate, but on the contrary "try to take a comprehensive view of the universe as a whole, including both the material and spiritual side."<sup>39</sup> And Lodge's view was comprehensive indeed. His ether was essential both to his physics and his religion; it was "the primary instrument of Mind, the vehicle of Soul, the habitation of Spirit. Truly it may be called the living garment of God."<sup>40</sup>

In the United States, ideas of a recreative universe broadly similar to those of Nernst and Wiechert were independently developed by William Duncan MacMillan, professor of astronomy at the University of Chicago. MacMillan was active in the American debate over the theory of relativity, which he rejected as materialistic and contrary to

<sup>37</sup> Lodge 1926, p. 96.

<sup>38</sup> *Nature* 128 (1931), 722.

<sup>39</sup> Lodge 1933, p. 38. See also Wilson 1996.

<sup>40</sup> Lodge 1925, p. 179.



common sense; but he was also one of the first to argue that cosmological theory could not build on mathematics and gravitation alone, but had to take into account atomic and subatomic physics.

MacMillan first expounded his hypothesis of a regenerating universe with an equilibrium between organization and dissipation processes in 1918, and in subsequent papers he developed the idea. Interestingly, at a time when the island-universe hypothesis was still questioned by many astronomers, he was adopting an infinite, Euclidean universe uniformly populated with stars and nebulae. His assumption that "the distribution of matter throughout space is uniform in the sense that the limiting density of any sphere, as the radius of the sphere increases indefinitely, is not zero; and that this portion of the physical universe which comes under our observation is not essentially peculiar" is in effect a formulation of the cosmological principle.<sup>41</sup> Since he also denied "that the universe as a whole has ever been or ever will be essentially different from what it is today,"<sup>42</sup> he effectively formulated what was called, in the later steady-state cosmology, the perfect cosmological principle. He realized the problem with Olbers' paradox, but believed it could be avoided by assuming a loss in radiation intensity over intergalactic distances.

Although MacMillan avoided referring to religious issues in his writings on cosmogony and astrophysics, it is quite clear that there was more at stake for him than simply coming up with a scientifically acceptable theory of the universe. He, like some of his kindred spirits, just did not *want* a running-down universe. His eternal, ever-creative universe was a fundamental postulate, not a picture deduced from either theory or observation. He found it legitimate to propose a cosmological model designed to lend support to a cosmic optimism that he felt was threatened by the world view of modern physics. "The haunting fear of a general stellar death is gone," he wrote in 1920, referring to his own theory. "The forbidding picture of the galaxy as a dismal, dreary graveyard of dead stars fades away from our sight; and in its stead we see an indefinite continuation of our present active, living universe with its never-ending ebb and flow of energy."<sup>43</sup> It is hardly an accident that both Nernst and MacMillan

<sup>41</sup> MacMillan 1923, p. 107.

<sup>42</sup> MacMillan 1925, p. 99. The similarity between MacMillan's ideas and those of the later steady-state theory was first pointed out in Schlegel 1958.

<sup>43</sup> MacMillan 1920, p. 73.

used the gloomy term "graveyard" in connection with the consequences of the heat death.

Although MacMillan's speculations made no impact on his astronomer colleagues, the theories did find a receptive ear in physicist Robert Millikan, who had known MacMillan from his years at the University of Chicago where he had become acquainted with his cosmological ideas. In the mid-1920s Millikan increasingly focused on cosmic-ray physics, and then began to extend his studies into a cosmological scheme consonant with, and in part inspired by, MacMillan's views. From his experimental data he concluded that the cosmic rays were energetically inhomogeneous and electrically neutral, consisting of distinct bands of high-energy photons. Since he found the energies to correspond to the binding energy of atomic nuclei, he suggested that the cosmic photons arose from nuclear building-up processes in the universe. Space, he believed, was filled with a tenuous gas of electrons and protons and these would occasionally recombine into heavier nuclei, thereby producing the cosmic-ray photons which he dramatically described as "the birth cries of the elements." But if this was all, it would in the end lead to a dead universe, not the preferred, perpetually creative and evolutionary cosmos; consequently Millikan postulated that "These building stones [electrons and protons] are continually being replenished throughout the heavens by the condensation with the aid of some as yet wholly unknown mechanism of radiant heat into positive and negative electrons."<sup>44</sup>

Millikan's updated version of MacMillan's theory made headlines in American newspapers, which praised the country's spirit of robust optimism, so much needed at a time marked by the economic recession. On the last day of 1930, the *New York Times* commented: "Neither drought nor flood nor financial depression nor any other terrestrial ill can stay the cosmic optimism of the science that not only has such practical applications, but that has faith in a continuing creation and that cooperates with 'a Creator continually on the job'."<sup>45</sup> Both MacMillan and Millikan resisted a universe without some kind of continual creation and associated it with a mechanistic, atheistic and materialistic world view which modern science had made obsolete.

<sup>44</sup> Millikan and Cameron 1928, p. 554.

<sup>45</sup> Quoted in De Maria and Russo 1990, p. 406. The phrase with the busy creator appeared in Millikan's retiring presidential address to the American Association for the Advancement of Science, see Millikan 1931, p. 170.

It was not mere rhetoric when Millikan and his research student G. Harvey Cameron ended a major scientific paper of 1928 by pointing out that the universal heat death rested on certain extravagant extrapolations, and that "modern philosophers and theologians have also objected on the ground that it overthrows the doctrine of Immanence and requires a return to the middle-age assumption of a Deus ex machina."<sup>46</sup>

Millikan was only happy if he could use his science to further the cause of religion and integrate the scientific and religious world views. The early 1920s witnessed a resurgence of protestant fundamentalism throughout the United States. In California, as elsewhere, this was followed by an anti-scientific crusade against evolution in particular, whether inorganic or organic. The situation disturbed Millikan, who had no more sympathy for Christian fundamentalism than he had for materialism and atheism.<sup>47</sup> To him, true Christianity was in perfect harmony not only with the established results of science, but also with the practice and attitude of the scientist. In response to a query from a reporter, in 1927 he said, "Science dominated by the spirit of religion is the key to progress and the hope of mankind."<sup>48</sup> Four years earlier he had formulated a draft statement concerning the role of science in relation to religion. The revised statement, published in *Science*, was signed by a distinguished group of church leaders, businessmen, and scientists, including the physicists Millikan and Michael Pupin, the astronomer William Wallace Campbell, the chemist Arthur Noyes, and the mathematician George Birkhoff. Its purpose was to correct two misconceptions, namely that religion implies fundamentalism (called "medieval theology") and that science is materialistic and irreligious. The main part of the message ran as follows:

We, the undersigned, deeply regret that in recent controversies there has been a tendency to present science and religion as irreconcilable and antagonistic domains of thought, for in fact they meet distinct human needs, and in the rounding out of human life they supplement rather than displace or oppose

<sup>46</sup> Millikan and Cameron 1928, p. 556. In another paper of 1928, Millikan stated that he was now able "to banish forever the nihilistic doctrine of its [the universe's] ultimate 'heat death.'" Millikan 1928, p. 283.

<sup>47</sup> Kargon 1982, pp. 145-147.

<sup>48</sup> *Ibid.*, p. 147. See further Millikan's autobiography (Millikan 1951), pp. 301-310.

each other. ... It is a sublime conception of God which is furnished by science, and one wholly consonant with the highest ideals of religion, when it represents Him as revealing Himself through countless ages in the development of the earth as an abode for man and in the age-long inbreathing of life into its constituent matter, culminating in man with his spiritual nature and all his Godlike powers.<sup>49</sup>

The wish to present a cosmological view in agreement with the doctrines of Christianity may have contributed to Millikan's interpretation of his cosmic-ray data and the conclusions he drew from them. However, both data and conclusions were criticized by other physicists, most notably by his fellow Nobel laureate Arthur Holly Compton, who in a series of worldwide experiments demonstrated that cosmic rays are not photons but consist mainly of charged particles. The controversy between America's two foremost physicists raged through a couple of years, but by 1934 it was clear that Compton was right and hence there was no basis for the cosmic building-up processes from which Millikan had concluded a God who was continually on the job.

Millikan grudgingly admitted his defeat, but did so without abandoning the idea of an evolving universe revealing the creator's continual activity. In the much publicized debate between Millikan and Compton, religion undoubtedly played some role, but it was never a question of a divine versus a materialistic universe. Compton, who was the son of a Presbyterian minister, and who as a young man had considered entering the ministry or becoming a missionary, was no less serious and outspoken in his Christian faith than Millikan was. He, too, believed that recent discoveries in physics pointed "to the existence of a supreme being guiding the affair of the universe," but he paid less attention to natural theology than his colleague from California.<sup>50</sup> The controversy between Millikan and Compton was settled strictly by scientific arguments.

It is difficult to judge how much support the idea of a regenerating universe enjoyed during the interwar period, except that it was largely ignored by the physics and astronomy communities. In England, Henry Piaggio, professor of mathematics at University

<sup>49</sup> Reproduced in Millikan 1951, p. 311.

<sup>50</sup> De Maria and Russo 1989, p. 228. On Compton as a devout Christian, see Johnston 1967.

College Nottingham, defended Millikan's position against the heat death and the mechanistic picture of the universe as a clock running down. "The process of creation may not yet be finished," he agreed.<sup>51</sup> Also, A. C. Gifford, a New Zealander, wanted an ever-living and purposive universe of the type suggested by MacMillan and Millikan. "So glorious a universe must have a higher destiny. If it was created, surely the creator will prevent it from passing into nothingness," was his argument. "The present appears no longer as a passing stage in a slow march towards death, but as a glorious cycle of the eternal heaven."<sup>52</sup>

Reginald Kapp, professor of electrical engineering at University College London, argued in his book, *Science versus Materialism* that the theories of continual creation of matter in equilibrium with matter annihilation ("at-any-time-theories") were philosophically preferable to theories of a finite-age universe ("once-upon-a-time-theories") which he associated with materialism. After the advent of the steady-state theory in 1948, Kapp argued in several works that his book anticipated the theory of Gold, Bondi and Hoyle.<sup>53</sup>

None of the advocates of the recycling universe accepted the theory of the expanding universe, although there was no need for any direct contradiction between the two. They either ignored it or came up with alternative, non-Doppler explanations of Hubble's linear relationship between the redshifts and distances of the galaxies. Thus, in 1932 MacMillan suggested a "tired-light" hypothesis according to which the photons lost energy on their travels through space. The energy might either disappear in space and reappear in the shape of material particles, or it might form a kind of low-frequency cosmic background radiation.<sup>54</sup> As to the latter possibility, he admitted that "there is at present no evidence of such radiation"—he was right, of course, but 33 years later the situation changed! Nernst's solution belonged to the same class, but was more specific. By assuming the photons' energy loss to follow the expression  $dE/dt = -HE$  (where  $H$  is Hubble's constant) he could derive the Hubble relation without making use of the Doppler principle. According to Nernst, the cause of the linear relation was not that the universe expands, but simply

<sup>51</sup> Piaggio 1931, a critical comment to Eddington's prediction of the heat death (see below).

<sup>52</sup> Gifford 1934, p. 253 and p. 257.

<sup>53</sup> Kapp 1940. See Kragh 1996, pp. 196–197.

<sup>54</sup> MacMillan 1932.



that it takes more time for the photons to reach the earth if the light-emitting galaxy is located further away.<sup>55</sup> The acceptance of the expanding universe during the 1930s probably contributed to a lack of interest in universe models of the Nernst-MacMillan type.

That Nernst's cosmological view reflected a deep, metaphysical (but probably not religious) opposition to the notion of the universe having a beginning is illustrated by a discussion he had with young Carl Friedrich von Weizsäcker in 1938. Weizsäcker was at the time engaged in studies of element formation in stars, which involved speculations about the origin of the universe. But this was a notion Nernst would have nothing of. According to Weizsäcker's recollections, Nernst flatly and passionately denied that a finite-age universe could be part of science. He insisted that whatever the experimental evidence, "the infinite duration of time was a basic element of all scientific thought, and to deny this would mean to betray the very foundation of science." Moreover, Weizsäcker identified Nernst's attitude with some blend of pantheism and scientism; he felt that, in Nernst's mind, "the everlasting universe had taken the place both of the eternal God and of the immortal soul ... and it was blasphemy to deny it God's attributes."<sup>56</sup>

Discussions of entropy and the world's final fate in a heat death can be found in many places outside the scientific literature. It played an important role in the German cultural pessimist Oswald Spengler's book, *Der Untergang des Abendlandes*, an enormously influential work which predicted the decline of Western civilization.<sup>57</sup> As an example of how the discussion penetrated even theological literature, consider the 1939 edition of a book entitled *Cosmology*, written by J. A. McWilliams, a Jesuit scholar at St. Louis University.<sup>58</sup> The book, essentially a philosophical-theological textbook in the neo-scholastic tradition, had very little in common with scientific cosmology, but it did include chapters on both entropy and relativity theory.

The author of *Cosmology* presented the heat death as was it consistent with Catholic faith, whereas he criticized the hypotheses of

<sup>55</sup> Nernst 1935b. Explanations similar to Nernst's were later suggested by Erwin Finlay-Freundlich and others, see Assis and Neves 1995.

<sup>56</sup> Weizsäcker 1964, pp. 152-153

<sup>57</sup> The first volume was published in 1918, and by 1926 it had gone through thirty printings. The English edition appeared in 1926 as *The Decline of the West*. Spengler described the heat death as an intrinsically necessary development, "The twilight of the Gods" (*Götterdämmerung*).

<sup>58</sup> McWilliams 1939 (first edition 1928), quotations from p. 41 and p. 45. According to the front of the book, McWilliams was "Professor of Cosmology."

Nernst, MacMillan and Millikan, not only because they lacked scientific support but also because he found them problematical from a theological perspective, since the theories were "altogether mechanical." Millikan and other advocates of a recurrent universe directly or indirectly identified it with an eternal universe, but as McWilliams pointed out, "even granted the world will never come to a *stop*, that does not mean that it never *started*. Hence it would not mean that the world was eternal, much less uncreated." Moreover, he reminded his readers about what had been known since the Middle Ages—that beginning cannot be identified with creation: "Creation does not directly refer to the duration of the world, but to the reason for its existence; and it means that the reason for the world's existence is not within itself but in Another." The universe might be finite in time or be eternal; in either case it was created and in accordance with Christian thought. Below we shall meet other examples of theological discussions of the second law, but from an Anglican perspective.

## JEANS' PLATONISM

In the early part of the 20th century, James Hopwood Jeans made important contributions to molecular physics and the new quantum theory, and from about 1914 he began a series of works in theoretical astrophysics that culminated in his influential book, *Problems of Cosmogony and Stellar Dynamics* published in 1919. Working as an independent scientist, he continued for a while his astrophysical research, but after 1928—the year of publication of his *Astronomy and Cosmogony*—he retired from active research and turned with great success to popularizing science.

From the mid-1920s, Jeans began to focus on astro- and cosmophysical problems, including cosmology, which he in part discussed in popular and semipopular contexts. He soon reached a position that differed drastically from that held by Nernst, MacMillan and Millikan. According to Jeans, young stars consisted mainly of transuranic elements which would spontaneously transform into radiation, partly through ordinary radioactive decay but mostly by annihilation—not only between protons and electrons, but also by the annihilation of entire atomic nuclei. Contrary to most other ideas of evolution, most notably those of biology, Jeans' world started with



complex, superheavy elements which gradually decomposed into radiation and lighter atoms. In this respect, if only in this, he agreed with Nernst.

What mattered was the strict unidirectionality of cosmic processes—from the complex to the simple, from organized forms to unorganized. Where would that leave life? In his Trueman Wood Lecture delivered before the Royal Society of Arts on 7 March 1928 he told the audience that life was just accidental, whereas “torrential deluges of life-destroying radiation” were essential. His pessimistic forecast was that all life and activity were bound to disappear, melt away: “So far as we can judge, our part of the universe has lived the more eventful part of its life already; what we are witnessing is less the rising of the curtain before the play than the burning out of the candle-ends on an empty stage on which the drama is already over.”<sup>59</sup> Half a year later he repeated the grim message in a lecture given at the University of Bristol, where he made it clear that there was no escape from the heat death:

The fabric of the universe weathers, crumbles, and dissolves with age, and no restoration or reconstruction is possible. The second law of thermodynamics compels the natural universe to move ever in the same direction along the same road, a road which ends only in death and annihilation.<sup>60</sup>

Jeans supplied his forecast with a table showing the destructive effects of high-energy radiation; for example, the electromagnetic radiation of a wavelength  $10^{-14}$  m would disintegrate atomic nuclei. It was not the first case of physical eschatology, but it was one of the first in which the future state of the universe was lent authority by what seemingly were exact scientific arguments.<sup>61</sup>

Naturally, Jeans’ pessimistic forecast did not go unanswered. An editorial in *Nature* piously pointed out that there might still be hope, because “a degradation of the physical universe is not necessarily a

<sup>59</sup> Jeans 1928a, p. 470.

<sup>60</sup> Jeans 1928b, p. 698.

<sup>61</sup> Although examples of “physical eschatology” can be found much earlier, it was only from the 1960s that the area attracted serious interest among physicists and astronomers. For a bibliographical survey, see Ćirković 2002. The first use of the term “astronomical eschatology” may have been in Milne 1952a, p. 164. As mentioned in Chapter 2, Sonnenschmidt referred in his book from 1877 to eschatology in an astronomical context.

degradation of the world of spirit. ... Might it not be that only in the dead smoke of radiation can life attain its fullest development?"<sup>62</sup>

On a more scientific note, the Indian physicist A. C. Banerji argued that the prediction might not happen, "as materialization of radiation is possible, and electrons, positrons, positive protons and negative protons can be created or re-created out of the photons."<sup>63</sup>

Although Jeans dismissed the notion of a cyclic or perpetual universe as scientifically unsound, he realized that it appealed to many people, and was probably more popular than the idea of a unidirectional birth-to-death universe. The reason, he thought, was man's habit of thinking in micro-macro analogies. "Most men find the final dissolution of the universe as distasteful a thought as the dissolution of their own personality," he philosophized.<sup>64</sup> Just as they wanted personal immortality, they wanted an imperishable universe. Jeans' conception collided head-on with the views of MacMillan, Millikan and others who favored a constructive and eternal universe—a view Jeans would have nothing of. Not only did it violate the second law of thermodynamics, it was also based on what he thought were fanciful building-up hypotheses with no justifications in physics. "With universes as with mortals, the only life is progress to the grave," he declared in his book, *The Universe Around Us* from 1929. "It is hard to see what advantage could accrue from an eternal reiteration of the same theme, or even from endless variations of it."<sup>65</sup> At the centenary meeting of the British Association in 1931, Millikan and Jeans defended their opposite cases. Jeans admitted that the universe *might* move to a state of lower entropy, but since he gave the odds for the unlikely process to be  $1:10^{79}$ , this could only be "a speculation or a pious hope."<sup>66</sup> Millikan did not directly address Jeans, but sought to convince the audience that his atom-building hypothesis was "natural enough" and should be tested experimentally, independent of the theoretical physicists' sweeping generalizations of laboratory-based knowledge.

<sup>62</sup> *Nature* 122 (1928), p. 703.

<sup>63</sup> Banerji 1934, who further suggested a mechanism based on pair production to explain the original expansion of the universe from an Einstein state.

<sup>64</sup> Jeans 1931, p. 182, quoted from the paperback edition of 1937.

<sup>65</sup> Jeans 1930, p. 330.

<sup>66</sup> *Nature* 128 (1931), p. 702. The denominator  $10^{79}$  is Eddington's cosmic number, the number of protons or electrons in the observable universe. See also De Maria and Russo 1990.

At the time of the 1931 meeting, the expanding universe had just made its appearance. Jeans accepted it at an early state, if initially not without qualifications. He was worried that the new theory might result in an age of the universe incompatible with what he believed was the age of the oldest stars, and for this reason he left a door open for a non-Doppler explanation of the type suggested by Zwicky. In spite of this reservation, Jeans' popular books were instrumental in disseminating the idea of the expanding universe to a broader public. But Lemaître's and Eddington's theory did not change his basic ideas of the universe, nor did it influence his general philosophy of physics, which was formed primarily under the impact of the new quantum mechanics rather than progress in astronomy and cosmology.

Jeans' view of the physical sciences, as he most fully expounded it in his book, *Physics and Philosophy* from 1942, can be briefly summarized as a particular mixture of positivism and idealism. Scientists, he repeatedly claimed, can never know the real or essential nature of anything, but are confined to study and correlate observation data in the form of numbers. They can draw pictures of nature, but these are mathematical pictures and will forever remain so. This holds for atoms as well as for galaxies:

The ultimate realities of the universe are at present quite beyond the reach of science, and may be—and probably are—for ever beyond the comprehension of the human mind. ... The observing astronomer watches and records the dots and dashes of the needle which delivers the message, the theoretical astronomer translates these into words ... but it is for others to try to understand and explain the ultimate decoded meaning of the words he writes down.<sup>67</sup>

Which these others were, he did not tell, but he was presumably thinking of philosophers and theologians. In his presidential address to the British Association meeting in Aberdeen in 1934 he explained that science has no access to an objective nature, should such exist: "The Nature we study does not consist so much of something we perceive as of our perceptions; it is not the object of the subject-object relation, but the relation itself."<sup>68</sup> This led him to emphasize mathematics,

<sup>67</sup> Jeans 1930, pp. 338–340.

<sup>68</sup> Jeans 1934, p. 360.

and numbers in particular, as the essence of the physical sciences. "All the concrete details of the picture, the apples, the pears and bananas, the ether and atoms and electrons, are mere clothing that we ourselves drape over our mathematical symbols—they do not belong to Nature, but to the parables by which we try to make Nature comprehensible."<sup>69</sup>

It followed that the mechanical models and materialism of the Victorian scientist were gone and out, for his objective universe had proved to be nothing but a construct of our own minds. Hence reality could not be recognized by objective, experimental interrogations of nature, for "reality is wholly mental." According to Jeans, this opened the door for an idealism where mind and matter coexisted in a single system. The world view of modern physics—Jeans' world view, that is—was moving in the direction of philosophical ideas advocated by the great idealistic tradition from Plato to Berkeley to Hegel. Yet the mental or spiritual feature in nature could not be a reflection of the individual minds, which had to somehow be coordinated, to be part of "a universal or Absolute mind," which some people would call God. Jeans' mathematical and Platonic God was, however, far from the one worshipped by Christians. For one thing, it was abstract and unconcerned with human beings, not unlike Einstein's God. On the other hand, it was not totally divorced from humankind, for Jeans thought there was "evidence of a designing or controlling power that has something in common with our own individual minds."<sup>70</sup>

Jeans' philosophical and quasi-religious views were severely criticized by the atheist Chapman Cohen, who charged that Jeans' reasoning was facile and inconsistent. The message of the book, *The Mysterious Universe* reminded him of "the out-of-date theology of the Bridgewater Treatise."<sup>71</sup> Also, another atheist author, the American Woolsey Teller, found Jeans' universal mind to be as unacceptable as the more traditional God of Christianity. Teller published in 1938 a book, *The Atheism of Astronomy* with the purpose of refuting any idea that the universe is governed by an intelligence. He dismissed as "fantastic nonsense" the belief in a plan behind the universe, and

<sup>69</sup> *Ibid.*, p. 356.

<sup>70</sup> Jeans 1931, p. 187. First edition 1930. Other scientists have been led to conclusions similar to Jeans'. The American physicist Henry Margenau felt "justified in introducing a Universal Mind, a mind that knows, and is perhaps a personal manifestation of, the World Formula." He identified the universal mind with God or as part of God. See Margenau 1984, p. 119.

<sup>71</sup> Cohen 1931, p. 120.

ridiculed Jeans' notion of God as a supreme mathematician, which was "as much a myth as the bewhiskered god of the Jews."<sup>72</sup>

While Jeans' treatment of the greater aspects of life and knowledge made a great impact on public debate, scientists and philosophers were less impressed. In the book, *Philosophy and the Physicists* from 1937, the philosopher Susan Stebbing subjected the works of Jeans, Eddington and others to critical scrutiny. While she dealt with Eddington over several chapters and in great detail, she obviously had much less respect for the philosophical ideas of Jeans, which she did within a single chapter.<sup>73</sup> Stebbing, a logician and professor at the University of London, pointed out many examples of Jeans' obscurity and "strangely perverted, ... confused, contradictory reasoning." Nor was she impressed by Jeans' construction of God. As she noticed, Jeans had fallen right into the trap of anthropomorphism that he justly warned against, for his whole discussion was permeated by the notion of a divine power "which selects and rejects, plans and designs, seeks and achieves, thinks as human beings think although much more effectively and on a grander scale." Also, Jeans' biographer and colleague in astrophysics, Arthur E. Milne, raised objections against Jeans' mathematical picture of the Great Architect. Jeans denounced anthropomorphism, but had he not formed a picture of God in his own image? Milne was as powerful a mathematician as Jeans, but he wanted a God to worship and praise and found none in Jeans' construction.<sup>74</sup>

Although Jeans' metaphysical ideas did not influence his own work in astronomy and cosmic physics, they did to some extent color the way in which he expressed his ideas of the beginning of the material universe. This subject, usually ignored by astronomers, he first addressed in his 1928 Bristol lecture, and he repeated it almost verbatim in his book, *The Universe Around Us* from the following year. Jeans argued from the second law that evolution could not be traced indefinitely back in time and that the atoms found today must thus have begun to exist, which "leads us to contemplate a definite event, or series of events, or continuous process, of creation of matter." He suggested as a naturalistic interpretation that matter was originally

<sup>72</sup> Teller 1938, which can be found on the internet as [www.infidels.org/library/historical/woolsey\\_teller/atheism\\_of\\_astronomy.html#1.2](http://www.infidels.org/library/historical/woolsey_teller/atheism_of_astronomy.html#1.2)

<sup>73</sup> Stebbing 1937, pp. 10-42.

<sup>74</sup> Milne 1952b, pp. 152-166. See further Chapter 6.

created as electrons and protons by high-energy photons “being poured into empty space”—he did not bother to tell by whom or from where. As what he admitted was a crude imagery he proposed a metaphor that would soon become famous, namely, “we may think of the finger of God agitating the ether.” He elaborated:

Travelling as far back in time as we can brings us not to the creation of the picture, but to its edge, and the origin of the picture lies as much outside the picture as the artist is outside his canvas. On this view, discussing the creation of the universe in terms of time and space is like trying to discover the artist and the action of painting by going to the edge of the picture. This brings us very near to those philosophical systems which regard *the universe as a thought in the mind of its Creator*, and so reduce all discussion of material creation to futility.<sup>75</sup>

It is to be noted, first, that Jeans did not anticipate a big-bang origin of the universe, as his creation could be “a definite event, or series of events, or [a] continuous process;” and, second, that he did not, after all, regard the creation itself to belong to science. Here his positivism took over, and he reminded his readers that the physicist should not try to explain phenomena but merely to decode messages from the outside world.

James Jeans flirted with God and religion, but his flirtation had more to do with Platonic or Keplerian natural theology than with Christianity. “The Great Architect of the Universe now begins to appear as a pure mathematician,” he famously wrote in the book, *The Mysterious Universe*, wherein he also stressed the mental nature of the world:

If the universe is a universe of thought, then its creation must have been an act of thought. Indeed the finiteness of time and space almost compel us, of themselves, to picture the creation as an act of thought; the determination of the constants such as the radius of the universe and the number of electrons it contained imply thought, whose richness is measured by the immensity of these quantities. Time and space, which form the setting for the thought, must have come into being as part of this act.<sup>76</sup>

<sup>75</sup> Jeans 1928b, p. 699. Emphasis added.

<sup>76</sup> Jeans 1931, p. 167 and p. 182.

Again, in an interview of about 1934 Jeans said that the material universe was derivative from consciousness, not the other way around. The universe, he suggested, was closer to a great thought than to a great machine.<sup>77</sup>

*The Mysterious Universe* was reviewed by Herbert Dingle, a 40-year-old astrophysicist at the Imperial College London with an interest in history and the philosophy of science.<sup>78</sup> Dingle found the volume to be admirably written but also criticized the signs it showed of "the triumphant Aristotelians" who excelled in hypotheses and speculations. Later in the decade he would crusade against such modern Aristotelianism, but not with Jeans as a main target. Although Dingle found it hard to swallow Jeans' idealism, he fully shared the latter's positivism, such as illustrated by an essay from 1928 on "Physics and God." Here Dingle went out of his way to argue that the aim of science is not to discover the nature or reality of things, but to find numerical relations between phenomena. "All that can come from the ultimate analysis of the material world is a set of numbers," he wrote. God was not a *Deus ex machina*, but a *Deus ex aequatione*. Yet Dingle concluded in favor of the independence thesis: "Whatever spiritual reality may underlie the events of nature is eternally inaccessible to science. There can thus be no direct collision between the idea of God and the demands of science. ... Whether God be immanent or transcendent is illusory, He must remain forever unilluminated by the scientific torch."<sup>79</sup>

A very different kind of cosmology, belonging to the spiritual rather than the astronomical tradition, was suggested by John Elov Boodin, a professor of philosophy of religion at the University of California, Los Angeles. In a book of 1934, Boodin argued for a vitalistic and idealistic universe, a Christian cosmos guided by life and mind. But he also discussed competently the most recent scientific cosmologies, including the theories of Einstein, Friedmann, Lemaître and Tolman. In spite of the idealistic features in Jeans' conception of the universe, Boodin found it to be mechanistic, purposeless and therefore unacceptable. The picture of God's finger agitating the primordial ether was dismissed as "romantic philosophy" and "mere obscurantism." As he pointed out: "If we require a creative genius to

<sup>77</sup> Sullivan 1934, p. 132.

<sup>78</sup> *Nature* 126 (1930), 799-800.

<sup>79</sup> Dingle 1928, p. 46.



start the universe, why not assume that this creative genius is eternally involved in the nature of the cosmos?"<sup>80</sup> Boodin was impressed by the recent progress of scientific knowledge but denied that the universe could be understood purely on the basis of what he called mechanistic physics: "A mechanistic hypothesis, molded upon inorganic matter, cannot be a sufficient explanation of the universe. ... The mechanistic hypothesis, if taken as a philosophy, lands us in intellectual bankruptcy. It requires a miracle in order to start the world and holds out no promise for the future except universal death."<sup>81</sup> Twenty years later, the message of the last line would be repeated by Fred Hoyle and other steady-state cosmologists.

## EDDINGTON'S WORLDS

Widely acclaimed as one of the greatest astrophysicists and theoretical astronomers of the 20th century, Arthur Stanley Eddington needs no introduction.<sup>82</sup> He obtained public fame as a leader of the 1919 solar eclipse expedition, and for his early contributions to and expositions of the theory of relativity, an area of physics in which he was recognized as a world authority. His scientific contributions in the 1920s focused mainly on the theory of stars, and it was only from about 1930 that he began to examine relativistic models of the universe. The years around 1930 also marked a major change in his research career because he started developing his ambitious unified theory, a line of theoretical research that would occupy him until his death in 1944. His concern with questions of cosmology predated his work on relativistic models, and first appeared in connection with the problem of cosmic rays and their possible interpretation as "birthcries of the elements."

Eddington did not actively intervene in the debate between Millikan and Jeans, perhaps because he did not agree with either of the parties. On the one hand, he found Jeans' claim of evolution from more to less complex matter to be artificial and unacceptable. "Personally, when I contemplate the uranium nucleus consisting of an agglomeration of 238 protons and 146 electrons, I want to know

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<sup>80</sup> Boodin 1934, p. 112.

<sup>81</sup> *Ibid.*, pp. 107-108.

<sup>82</sup> If such is needed, see Douglas 1956 and Evans 1998.

how all these have been gathered together."<sup>83</sup> As he argued in his classical book, *Internal Constitution of the Stars* of 1926, stellar energy would be provided by the fusion of hydrogen into helium, possibly with electron-proton annihilation playing a role as well. From helium, still heavier elements could be built up. On the other hand, he could not accept Millikan's cosmic-ray theory either, and had no sympathy at all for models of a recycling universe: "Sub-atomic energy extends the life of the universe from millions to billions of years; other possibilities of rejuvenation may extend it from billions to trillions. But unless we can circumvent the second law of thermodynamics—which is much the same as saying unless we can make time run backwards—the universe is steadily getting nearer to an ultimate state of uniform changelessness."<sup>84</sup>

Like Jeans, Eddington was convinced that there was no escape from the heat death associated with the second law, and wrote in 1928 that he had "no great desire" that Clausius' law should succeed in averting the final running down of the universe. Such a fate was often looked upon as pessimistic and contrary to religion, but Eddington disagreed—after all, "Since when has the teaching that 'heaven and earth shall pass away' become ecclesiastically un-orthodox?"<sup>85</sup> His lack of desire also included the cyclical universe. "I am no Phoenix worshipper," he admitted. "I would feel more content that the Universe should accomplish some great scheme of evolution and, having achieved whatever may be achieved, lapse back into chaotic changelessness, than that its purpose should be banalized by continual repetition. I am an Evolutionist, not a Multiplicationist. It seems rather stupid to keep doing the same thing over and over again."<sup>86</sup> However, contrary to Jeans and some other scientists (and theologians), Eddington did not make use of the entropic argument to infer a beginning of the universe, a concept he felt uneasy about.

On the contrary, in his Gifford Lectures of 1927, he explicitly distanced himself from the argument. While he had no problem in conceiving an infinite future time, he found the difficulty of an infinite past to be "appalling" and yet he did not accept the antithesis—a

<sup>83</sup> Eddington 1927–29, p. 111. Until 1932, when the neutron was discovered, it was generally accepted that the atomic nucleus consisted of protons and electrons.

<sup>84</sup> *Ibid.*, p. 117.

<sup>85</sup> Eddington 1935, p. 59.

<sup>86</sup> Eddington 1928, p. 86. In 1935, he phrased it somewhat differently, as he dismissed the cyclic universe "from a moral standpoint" (Eddington 1935, p. 59).

finite-age universe. He was fully aware that the entropic argument "has been quoted as scientific proof of the intervention of the Creator," but this he found to be "incredible" as well as a "naive theological doctrine." Eddington thought of it as a dilemma: "As a scientist I simply do not believe that the present order of things started off with a bang; unscientifically I feel equally unwilling to accept discontinuity in the divine nature."<sup>87</sup> The conception of God that the entropic argument could offer was deistic, and this was not Eddington's God: "Even those who would welcome a proof of the intervention of a Creator will probably consider that a single winding-up at some remote epoch is not really the kind of relation between God and his world that brings satisfaction to the mind."<sup>88</sup>

He returned to the theme in an address he gave to the Mathematical Society of London in January 1931, at a time when he had accepted the expanding universe but before Lemaître proposed his hypothesis of an explosive origin of the world. After having stressed entropy as the sole arrow of time, he repeated that "Philosophically, the notion of a beginning of the present order of Nature is repugnant to me."<sup>89</sup> This was strongly worded, but apparently Eddington felt strongly about the issue. When his former student Georges Lemaître shortly later suggested his primeval-atom hypothesis—the first case of a big-bang universe—Eddington was unable to follow. During the 1930s and 1940s Lemaître's theory slowly won acceptance, but Eddington never accepted it, and may have continued to find it "repugnant." In his last paper to the Royal Astronomical Society, presented shortly before his death in 1944, he argued for a model of the universe of the same type that he had advocated in 1930, that is, a universe which started its expansion in a pre-existing equilibrium state. With regard to the time elapsed since "the universe burst" he argued that the time scale was about 10 billion years. This was, however, not to be identified with the age of the world, which was infinite, but with the time since condensations began to form.<sup>90</sup>

Eddington seriously worked to build up a system of philosophy of science, and his efforts were much discussed in the 1930s, although

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<sup>87</sup> Eddington 1928, p. 85.

<sup>88</sup> Eddington 1935, p. 59.

<sup>89</sup> Eddington 1931, p. 450. The sentence also appeared in Eddington 1935, p. 59, now only with "abrupt beginning" instead of "beginning."

<sup>90</sup> Eddington 1944a.

they rarely met the approval of philosophers. On the contrary, reviewers and commentators usually criticized his philosophical works for being incoherent and lacking in clarity.<sup>91</sup> Here I only want to call attention to two important and persistent themes in his writings, namely, (1) his strict limitation of the domain of physics, and (2) his insistence on the predominating role played by the human mind.

Eddington's restrictionism ruled out anything that smelled even faintly of scientism. He often pointed out that physics deals only with a small part of what we experience, namely what can be expressed quantitatively or metrically. "The cleavage between the scientific and the extra-scientific domain of experience is, I believe, not a cleavage between the concrete and the transcendental but between the metrical and the non-metrical," he wrote; "within the whole domain of experience a selected portion is capable of that exact representation which is requisite for development by the scientific method."<sup>92</sup> Whereas in other scientists a restrictionist attitude has implied narrowness, this was not the case with Eddington, who considered the vast areas of non-metrical human experience to be far more important than those covered by the exact sciences. So did some other scientists with an inclination for the spiritual world, such as Lodge, but Eddington had no confidence in spiritualism, and his restrictionism prevented him from trying to extend physics to cover also the psychical and mystical realms. He found it "preposterous" to believe that the spiritual world could be ruled by laws like those known from physics and chemistry. "Physical science," he wrote,

is by its own implications led to recognise a domain of experience beyond its frontiers, but not to *annex* it. All varieties of mysticism represent an escape from the closed world of physics into the open world beyond it and to which it points. But just because mysticism concerns an experience beyond physics, we must not call in physical science to guarantee it or to confirm our interpretation of it. That would be to bow our necks again to the yoke from which we have escaped.<sup>93</sup>

<sup>91</sup> Analysis of Eddington's philosophy of science can be found in Witt-Hansen 1958, Yolton 1960 and Merleau-Ponty 1965. For contemporary criticism, see Russell 1931, Joad 1932, and Stebbing 1937. In 1941, Eddington and Jeans, who was sided by Dingle, became involved in a minor controversy concerning Eddington's philosophy of science. The controversy, which can be followed in *Nature* 148 (1941), did not relate to spiritual or religious issues.

<sup>92</sup> Eddington 1928, p. 275.

<sup>93</sup> Quoted in Douglas 1956, p. 131. See also Eddington 1939a, pp. 52-53.

On the other hand, Eddington's subjective idealism led him at times to a position close to objective idealism—the view that the entire world is spiritual and governed by a soul of some kind. Our scientific knowledge of the world is limited to metrical and structural knowledge, but “should occasion arise, the function of the external world can be enlarged so as to comprise more than our physical knowledge. If we find reason to be dissatisfied with a purely physical world external to ourselves, there is room for a spiritual interpretation of the ‘something’ of which the physical universe is only the abstract structure.”<sup>94</sup>

There were clear elements of positivism in Eddington's philosophy of science, for example, in his insistence that physics can never reveal the true nature of things but only deal with relations between observables, such as pointer-readings from instruments. These data or pointer-readings were however not to be taken as representing an objective nature, for they were subjectively selected by the human mind. Thus, the scientist does not simply discover phenomena in an external nature—he partly manufactures them in the sense of forcing them to fit into forms that depend on the observer's mind and his instruments. The indispensable and controlling role of the mind was part of Eddington's thinking from an early date, and probably predated his meeting with the theory of relativity. Already in his first philosophical essay, published in *Mind* in 1920, he emphasized that matter has no meaning without mind, as it is merely “a property of the world singled out by mind on account of its permanence.” And likewise with the laws of nature: “I am almost inclined to attribute the whole responsibility for the laws of mechanics and gravitation to the mind, and deny the external world any share in them.”<sup>95</sup>

During Eddington's development of his unified cosmo-physical theory in the 1930s, he increasingly gave his philosophy a more rationalistic turn. It was possible, he thought, to obtain knowledge of the fundamental laws of nature by pure deductions from the peculiarities of the human mind. Consequently these laws could not refer to an objective world and could not be objective in the ordinary sense of the term. “All the laws of nature that are usually classed as fundamental can be foreseen wholly from epistemological considerations.

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<sup>94</sup> Eddington 1939b, p. 209.

<sup>95</sup> Eddington 1920, p. 158 and p. 155.

They correspond to *a priori* knowledge, and are therefore *wholly subjective*."

It is to be noted that Eddington's claim to predict laws of physics concerned only fundamental laws. As to contingent or what he called special facts—"which distinguish the actual universe from all other possible universes obeying the same laws"—these were believed to be "born continually as the universe follows its unpredictable course."<sup>96</sup> If the laws of nature are not the contributions of an external world but essentially the subjective constructions of the physicists, little or no room for the empirical-inductive method is left in fundamental physics. Eddington believed he had proved the fallacy of empiricism. "The theory," he wrote in 1936 with reference to his new relativistic theory of electrons and protons, "does not rest on... observable tests. It is even more purely epistemological than macroscopic theory... It should be possible to judge whether the mathematical treatment and solutions are correct, without turning up the answer in the book of nature." He elaborated with a vision which calls in mind Laplace's famous demon:

[T]here is nothing in the whole system of laws of physics that cannot be deduced unambiguously from epistemological considerations. An intelligence, unacquainted with our universe, but acquainted with the system of thought by which the human mind interprets to itself the content of its sensory experience, should be able to attain all the knowledge of physics that we have attained by experiment. He would not deduce the particular events and objects of our experience but he would deduce the generalizations we have based on them.<sup>97</sup>

Eddington's idealism stood in provocative contrast to the standard view concerning physical science. He did not deny the existence of an objective world, but he identified it with the conscious and spiritual world, not with the shadowy phenomena studied by physicists.

As indicated even by this cursory review, in spite of Eddington's intention to restrict the domain of physics, the role of the mind could not avoid serving as a connection to spiritual and religious aspects. Eddington was deeply religious and his entire life and work was permeated by the religious values of the Society of Friends, better known

<sup>96</sup> Eddington 1939b, p. 57 and p. 64.

<sup>97</sup> Eddington 1936, p. 3 and p. 327.

as the Quakers. Although the Quakers are recognized to belong to the Christian community, they do not worship Christ as the son of God—the creator of the world—nor do they count the Bible as a holy book revealing the thoughts of God. They have no creeds, no theology and no church, and their society is only loosely organized. Believing that every human being have something of God—an “Inner Light”—in him or her, they base their religion on experience and inspiration. A disproportionate number of eminent scientists have been Quakers (including John Dalton), possibly because their religion begins with experience rather than dogma, and so is more easily brought into harmony with science. This, in any case, was what Eddington suggested in his Swarthmore Lecture of 1929, published as *Science and the Unseen World*. “I think it may be said that Quakerism in dispensing with creeds holds out a hand to the scientist,” he wrote. “The spirit of seeking which animates us refuses to regard any kind of creed as its goal.”<sup>98</sup>

Bertrand Russell, who was not a friend of religion, included in the book, *The Scientific Outlook* from 1931 a chapter on science and religion in which he singled out Eddington and Jeans as scientific apologetics: “Eddington deduces religion from the fact that atoms do not obey the laws of mathematics. Jeans deduces it from the fact that they do. Both these arguments have been accepted with equal enthusiasm by the theologians, who hold, apparently, that the demand for consistency belongs to the cold reason and must not interfere with our deeper religious feelings.”<sup>99</sup> It was wittily written, but the last sentence was wrong, or at least a gross exaggeration; and the first sentence was unfair. In fact, in both his books, *Nature of the Physical World* and *Science and the Unseen World* Eddington had stated quite clearly that science and religion belong to different realms, and that spiritual truth cannot be deduced from scientific theory. Besides, he was fully aware of the danger of such a linking:

The lack of finality of scientific theories would be a very serious limitation of our argument, if we had staked much on their permanence. The religious reader may well be content that I have not offered him a God revealed by the quantum theory,

<sup>98</sup> Eddington 1939a, p. 89. First edition 1929. The title was presumably an allusion to Stewart and Tait's old book.

<sup>99</sup> Russell 1931, p. 108.



the heat death in the far future, but which did not have any abrupt origin a finite time ago. Can any of these views or convictions be said to be religiously based? Eddington frankly stated his views—published as they were in popular works—in emotional, esthetic and moral terms; but this does not in itself indicate any *religious* connection. In his 1928 dismissal of the big bang, quoted above, he wrote that he could not (“unscientifically”) accept a discontinuity in the divine nature. This may be interpreted as a theological view transferred into a scientific context, but the brief passage is too obscure to allow any firm conclusion to be drawn from it. Perhaps the only indication that Eddington’s views were partly motivated by his religious sentiments comes from his book, *Science and the Unseen World*, where he quoted a passage from the Old Testament to the effect that God speaks in a small voice, just as a Quaker would expect.<sup>107</sup>

To the freethinker Bertrand Russell, the heat death was a sure sign of the absence of purpose in the universe. “I see no reason therefore to believe in any sort of God, however vague and attenuated,” he wrote in an essay of 1930.<sup>108</sup> With regard to the beginning of the universe it is of interest to note that while the deeply religious Eddington dismissed the notion of an origin, the atheist Russell found entropic reasoning to be quite a strong argument for a created world. “I think we ought provisionally to accept the hypothesis that the world had a beginning at some definite, though unknown, date,” he wrote. But of course, Russell did not infer that the world was therefore made by a Creator:

There is no reason whatever why the universe should not have begun spontaneously, except that it seems odd that it should do so. ... To infer a Creator is to infer a cause, and causal inferences are only admissible in science when they proceed from observed causal laws. Creation out of nothing is an occurrence which has not been observed. There is, therefore, no better reason to suppose that the world was caused by a Creator than to suppose that it was uncaused; either equally contradicts the causal laws that we can observe.<sup>109</sup>

<sup>107</sup> *Ibid.*, pp. 25–26. See also Batten 1994, p. 257, who suggests that the passage is consonant with Eddington’s rejection of an explosive origin of the universe.

<sup>108</sup> Russell 1967, p. 34. Essay from 1930 on “Has Religion Made Useful Contributions to Civilization?”

<sup>109</sup> Russell 1931, p. 118.

## THE THEOLOGIANS: BARNES AND INGE

In the British debate about science and religion in the interwar period, cosmology did not receive very much attention, possibly because it was a science that lacked a solid observational basis, and was considered speculative even by many astronomers. Darwinian evolution and the problem of free will, such as illuminated by the new biology and quantum-mechanical uncertainty, were considered more interesting subjects. Yet cosmological questions did enter the debate, in particular the classical problems of the world's beginning and end which were of so obvious theological relevance. I shall survey the views of two leading British men of the church, E. W. Barnes and W. R. Inge, whose analyses of the cosmology-theology interface appeared about the same time, in the early 1930s.<sup>110</sup> By coincidence, this was shortly after the expanding and also the explosive universe had been proposed, which gives their comments an additional perspective.

Ernest William Barnes was a leading and often controversial exponent of what was known as Anglican Modernism. He started his career as a mathematician at Trinity College, Cambridge, where Eddington, Ronald Fisher and Lancelot Hogben, among others, followed his courses in mathematical analysis. His research in pure and applied mathematics focused on gamma functions, hypergeometric functions, and asymptotic expansions of integral functions. In 1909 he was elected Fellow of the Royal Society, but six years later he left academic life to take up work in the Anglican Church (he had been ordained as early as 1902). After a period as Canon of Westminster, in 1924 he was appointed Bishop of Birmingham, a position he kept until 1953. Barnes was eager to present a version of Christianity which was in harmony with the modern world view, both socially or scientifically, and he saw the fight against superstition and obscurantism as a major task for modern Anglicanism. For example, in 1927 he caused much controversy by claiming in a sermon that the story of Adam and Eve should be considered as merely a myth, a piece of folklore. As a theologian, Barnes belonged to the liberal wing of the Church of England, his liberal evangelicalism including the view that Christians had nothing to fear from the new scientific world

<sup>110</sup> For Barnes and Inge, and the British debate in general, see Bowler 2001, especially pp. 260–277. On Barnes, see also Bowler 1998.

view. In a sermon on "God" from 1926, he argued against the notion of a fundamentally irrational, divinely created universe:

It is one of my postulates of faith that that which is rational to the Supreme Mind Who created us must also be rational to us. Abandon this faith and the only value of science is its practical utility. Abandon this faith and you open flood-gates through which every kind of superstition can pour to overwhelm the reasonable spiritual understanding which humanity has acquired slowly and preserves with difficulty.<sup>111</sup>

Barnes' most interesting work, from a scientific point of view, is his book, *Scientific Theory and Religion* from 1933, an expanded version of the Gifford Lectures he delivered at the University of Aberdeen 1927–29. In this most impressive and wide-ranging book he covered confidently and with much insight not only theology and philosophy, but also large portions of biology and theoretical physics. Rarely has a theologian's work included so many tensor equations! As to his theological position, Barnes' God was transcendent *and* immanent—He was the source of spiritual experience *and* the creator of the material world: "Man is the outcome of Nature's processes. ... Without exaggeration we can assert that Man's spiritual experience is as unreal as a dream unless the God to whom it leads him is also the God whose nature is shown in the universe as a whole."<sup>112</sup> From this view of two inseparable divine realms it followed that theology had to take into account, but not necessarily follow, the new scientific knowledge. Barnes rejected natural theology and also any dualism between the natural and the supernatural:

The only foundation for any belief in God worth preserving must be discovered, not in inanimate nature, but in that moral order, emergent through animate nature, from which man's spiritual longings have been derived. ... Whether we regard God as immanent or transcendent or as transcending the differences implied by these words, the whole realm of Nature derives its existence from Him. It is, therefore, subject to His

<sup>111</sup> Barnes 1927, p. 291.

<sup>112</sup> Barnes 1933, p. 5. Barnes' anti-idealism was opposed not only to the views of Jeans and Eddington, but also to the process philosophy of A. N. Whitehead and its development into process theology. For a contemporary review of Barnes' and Whitehead's cosmologies, see Liddgett 1933. The book was reviewed in *Nature* (vol. 132, p. 79) by "R.A.S.," possibly the astronomer R. A. Sampson, according to whom "Science and religion are in different regions. No bridge can be made between the two."

guidance, the domain of His activity. God has not withdrawn from Nature to revisit it at intervals when His presence is shown in supernatural interventions.<sup>113</sup>

Barnes realized of course that there were vast regions of the phenomenal world that could not, at least not so far, be understood by the methods of science; but he was reluctant to admit the existence of realms outside the reach of science, as then "we give to religious quacks and obscurantist domains where only too probably they will house superstition."<sup>114</sup> Throughout his book, Barnes avoided the new idealism of Jeans and Eddington, which conflicted with his own leaning toward realist philosophy.

At the time Barnes wrote his book, there was no scientific basis at all for deciding whether the universe was spatially finite or not. All that one could do was to point to the various possibilities, as given for example by the solutions to the cosmological field equations, and then evaluate these more or less emotionally. Barnes' feelings told him that the universe must be finite, though unbounded. "Infinite space is simply a scandal to human thought," he said in 1931. "In Riemannian spherical space we can have a finite and uniform distribution of universes [galaxies], inasmuch as such space is unbounded ... there is no fact of observation to set against the belief that space has a very small positive curvature."<sup>115</sup> His rejection of an infinite universe was subjective, or perhaps epistemic, but not explicitly rooted in religious arguments.

Barnes' discussion of the cosmological consequences of thermodynamics at first seemed to show that he accepted the heat death (unless God intervenes, that is) and also the entropic argument for a beginning. "We thus seem driven to the belief that God lies behind [the] phenomena," he wrote.<sup>116</sup> But later in the book he made it clear that he did not accept such a proof of God resting on the classical notion that "there was a time when God wound up the clock and a time will come when it will stop if He does not wind it up again." Not that he had any strong arguments against the picture—it just went against his "instinct" and "general outlook," which told him that God

<sup>113</sup> Barnes 1933, pieced together of quotations from p. 180 and p. 589.

<sup>114</sup> *Ibid.*, p. 11.

<sup>115</sup> Barnes 1931, p. 598. The address was reprinted in *Scientific American*, July 1932, pp. 30–32.

<sup>116</sup> Barnes 1933, p. 240, and following quotation from p. 595.

was no transcendent watchmaker. Barnes much preferred another kind of cosmological argument, namely that there must be a reason why nature is rationally intelligible to humans. This fact pointed toward God as nature's rational principle, although Barnes admitted that it was an indication only. For one thing, it assumed that the whole of nature can be described scientifically; for another, it merely pointed toward some God, not necessarily the God of the Christian religion.

With respect to the heat death, Barnes did not seem to have strong feelings. He knew that the prediction rested on certain assumptions, and that there were alternative cosmological schemes in which it would not occur. Among these was the McMillan-Millikan theory of a recurrent universe, which he mentioned as a possibility but without supporting it. In his 1931 address to the British Association he considered "a never-ending sequence of alternate periods of world-building and world-destruction, the rise and fall of universes without end," if only as a possibility that was "not very satisfying." Barnes admitted that he was "by no means happy" with the expanding universe, and mentioned that the redshifts might be due to other causes. Introducing a theme that would later be part of anthropic reasoning, he pointed out that if the galaxies really move away as fast as suggested by Hubble's measurements, we are lucky to live in an epoch when they can be seen at all.

Barnes pictured the earliest universe as filled with a tenuous, highly diluted gas, which at some time and for some reason began to aggregate into lumps of denser mass. He was well aware of the difficulties of such a scheme, and indeed of all schemes of the very early universe. How did the aggregation begin? Certainly not in the way that many Christians might believe, for "No man of science will postulate a supernatural intervention, a stirring of the uniformly distributed matter filling space." If the recurrent universe would not do either, perhaps, Barnes speculated, one would be forced to consider, "the opinion entertained by some philosophers that time is not real."<sup>117</sup> In his 1931 address he also took up another classical theme of cosmological speculation: the possible existence of conscious beings elsewhere in the universe. Not only did he not see this as a great

<sup>117</sup> Most likely a reference to the British philosopher John McTaggart, who in *The Nature of Existence* from 1927 concluded that time as a transitional concept has no meaning.

problem for Christian religion, personally he had "no doubt that there are many other inhabited worlds, and that on some of them beings exist who are immeasurably beyond our mental level."

The October 1931 British Association symposium on "The Question of the Relation of the Physical Universe to Life and Mind" was an important event in the history of cosmological thought. The centenary meeting was introduced by the association's new president, the South African general and statesman Jan Christiaan Smuts. Although not a scientist, Smuts had a reputation as a natural philosopher of a sort, primarily based on his book, *Holism and Evolution* from 1926 in which he developed a teleological-evolutionary world view that resonated well with the spirit of the time. In his presidential address he surveyed recent developments in physics, astronomy and biology, concluding that materialism had now been replaced with an organic and holistic universe where mind was as real as galaxies. "The world consists not only of electrons and radiations, but also of souls and aspirations. Beauty and holiness are as much aspects of nature as energy and entropy." How happily had not the relationship between science and religion developed since Tyndall gave his infamous presidential address nearly 60 years earlier! Smuts admitted the cosmic process of decline, as given by the entropy law, but thought it was insignificant compared to the emergence of life and mind, to the "embryonic infant world emerging, throbbing with passionate life, and striving towards rational and spiritual self-realization." Science had taken on metaphysical and spiritual aspects, and "is perhaps the clearest revelation of God to our age."<sup>118</sup> The astronomers and physicists participating in the 1931 symposium may not have taken Smuts very seriously, but his holistic philosophy of nature reflected a view which was popular at the time.

William Ralph Inge, Dean of St. Paul's from 1911 until his retirement in 1934, was in many ways different from Barnes, but he shared with him a distaste for the supernatural such as that found in Catholic theology. Theologically he favored a Christian Platonism, and politically he was a conservative with a reputation for being arch-reactionary. Sometimes known as "the gloomy dean," he wrote and preached widely and gladly against such modern myths as evolution and human

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<sup>118</sup> Smuts 1931, pp. 18, 17 and 13. See also Smuts' contribution to the symposium on cosmology, *Nature* 128 (1931), 718-719.

progress. This is not to say that he was an anti-evolutionist when it came to biology, for example, but he denied any general evolutionary scheme that progressively led from the lower to the higher.

Unlike Barnes, Inge had had no scientific training, but he kept up with developments in the sciences, and stressed the relevance of science for theological doctrines. As he nicely formulated it in an essay from 1925: "A religion which does not touch science, and a science which does not touch religion, are mutilated and barren. Not that religion can ever be a science, or science a religion; but we may hope for a time when the science of a religious man will be scientific, and when the religion of a scientific man religious."<sup>119</sup> In the same essay he expressed his neo-Platonic view that the reality of things, including the reality of humans, was not to be found in the natural or sensible world:

The true nature of things lies behind their visible appearances, and beyond time and space. The mere question of survival in time, and for time, is almost frivolous to the religious mind. ... I honestly believe, ... that the destruction of the supra-mundane physics of the Middle Ages by the discoveries of astronomy will be found to have done a good service to religion, by forbidding it to seek its treasure and its everlasting home in space and in time.<sup>120</sup>

Inge's most important work, from our perspective, was his book, *God and the Astronomers* from 1934, based on his Warburton Lectures 1931–33. His analysis in this book of the spiritual significance of modern cosmology was of course rooted in his theological views and preference of *philosophia perennis*. Reality was for him ultimately a heavenly kingdom unconnected with the material universe, and it was only in this kingdom of absolute values that humans would find their immortality. His Christian God was creative, but not necessarily ever-creative or bound to creation. Thus Inge argued consistently against pantheism with its false notion of God being bound up with his creation, as if the world was as necessary to God as He was to the world. Such heresy he found in the philosophies of Henri Bergson and Samuel Alexander, where God was essentially connected with the cosmic processes and therefore could perish with them. Similar

<sup>119</sup> Untitled essay in Needham 1925, pp. 343–389, on p. 348.

<sup>120</sup> *Ibid.*, pp. 381–382.



heretical views were to be found in the process philosophy of Alfred Whitehead, to be considered in Chapter 5.

Inge was not overly concerned with the heat death, which he did not see as necessarily in conflict with Christian belief and ideals. Just like William Thomson had done back in 1851, and several other authors since then, Inge referred to the 102nd Psalm. "The idea of the end of the world is intolerable only to modernist philosophy, which finds in the idea of unending temporal progress a pitiful substitute for the blessed hope of everlasting life," whereas "the philosophy of the Great Tradition may view the prospect of 'the new *Götterdämmerung*' without deep concern, just because the fate of its own God is not involved."<sup>121</sup> Nevertheless, Inge admitted that he preferred a universe that will be there forever, not for theological reasons, but because "we cannot even imagine a condition in which there are no events."<sup>122</sup>

Just as Barnes, Inge did not subscribe to the entropic argument for a beginning of the universe, or relate it to divine creation. True, the argument seemed to agree nicely with the traditional Christian belief of the universe being created *ex nihilo*, but Inge objected to this "naive deistic doctrine" which did not even have unambiguous support in Genesis. Commenting on Eddington, Inge wrote that although the hypothesis that the order of things "started off with a bang" was not really incredible, "it is so unlike what we observe of the divine working that most of us would be unwilling to accept it."<sup>123</sup> At any rate, he could see no obligation why Christians should trace back in time the cosmic movie until they found a discontinuity to be explained in terms of a first mover. "What we assert is the absolute *dependence* of the creation on the Creator,"<sup>124</sup> he wrote, a notion for which a bang, big or small, was irrelevant.

The emphasis on atemporal creation in the form of continual dependence may explain Inge's (at first sight surprising) sympathy for models of the recurrent or recycling universe. This idea "has long attracted me," he wrote, for "in that case the universe may be perpetual as its Creator is eternal; and there must be some hitherto unknown agency which counterbalances entropy."<sup>125</sup> He noted with

<sup>121</sup> Inge 1934, p. 27 and p. 69. The "Great Tradition" refers of course to Christian thinking.

<sup>122</sup> *Ibid.*, p. 101.

<sup>123</sup> *Ibid.*, p. 244.

<sup>124</sup> *Ibid.*, p. 234.

<sup>125</sup> *Ibid.*, p. 50.

satisfaction that Einstein had recently abandoned the theory of an ever-expanding universe and replaced it with a cyclical model—apparently he was not aware that it was but a brief flirtation. As to possible entropy-reducing processes he mentioned Arrhenius and also Millikan's more recent and "very attractive" theory, although he was aware that it had little support among scientists. "Are we sure that there is no creation (say) of hydrogen atoms out of radiation?" he asked.

A discovery of such a balance between creation and destruction would be extremely welcome to most of us. It would end the necessity for believing in the creation of the universe in Time. It would satisfy our very natural feeling that a perpetual continuance of the universe would be more in accordance with what we may imagine to be the will of God than its temporary existence and final annihilation.<sup>126</sup>

The point to note is that we have here a church leader and distinguished theologian endorsing a recurrent, eternal universe in order to *avoid* a creation of the world at a definite time in the past. Inge was well informed about contemporary developments in the sciences, but he was a layman, and his knowledge was somewhat sporadic (which he willingly admitted). His comments on the expanding universe indicate that he did not fully understand what it was about. Although he referred to Einstein's cyclical model of 1931, and in a footnote mentioned Milne's very recent ideas of 1932, he seemed to have been unaware of the big-bang, ever-expanding model that Einstein and De Sitter had proposed that same year. Contrary to Barnes, he was silent about Lemaître's primeval-atom hypothesis first stated in 1931.<sup>127</sup>

To many religious people, whether laypersons or theologians, the new scientific world view of relativity, quantum mechanics and evolutionary biology seemed confusing and hostile to higher values. W. R. Matthews, Inge's successor as Dean of St. Paul, was among the many who gave voice to the worries. He assumed the expanding universe was merely a speculation, but nonetheless he complained in a book of 1935 that it "add[s] to our bewilderment and our sense of

<sup>126</sup> *Ibid.*, pp. 64–65.

<sup>127</sup> Of course, from the fact that an author does not refer to a theory, one cannot infer that he or she was unaware of it. Barnes mentioned both Lemaître's theory and the Einstein-De Sitter theory, but his book came too late to influence the content of *God and the Astronomers* (preface, p. ix).

homelessness." The heat death, such as predicted by Jeans and Eddington, might be taken to agree with the apocalyptic passages in the Bible, and the increase of entropy might even indicate a created universe. But Matthews found it of little comfort to the theologian. "The impression grows upon us that we are in a world which is alien to our values, indifferent to our hopes, and, if purposive at all, is directed towards ends for which we are irrelevant."<sup>128</sup>

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<sup>128</sup> Matthews 1935, pp. 98–99.



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# The Primeval-atom Universe

# The Primeval-atom Universe

FROM FRIEDMANN TO LEMAÎTRE

The important papers that Alexander Friedmann published in *Zeitschrift für Physik* in 1922 and 1924 were thoroughly mathematical and abstract, following in this respect the tradition initiated by Einstein and De Sitter. The emphasis of the Russian theoretician was clearly on the mathematical aspects, whereas he showed little interest in the physics of the one and only universe we live in. Thus, it is noteworthy that physical terms such as "galaxies," "radiation" or "energy" did not appear in his papers, which were also devoid of observational data and did not even refer to the galactic redshifts studied by Slipher. Yet, in spite of his mathematical approach Friedmann was the first to introduce in relativistic cosmology two concepts of momentous importance, the age of the world and the creation of the world. This he did in connection with what he called a monotonic world model of the first kind: "Since the radius of curvature cannot be smaller than zero, it must decrease with decreasing time,  $t$ , from  $R_0$  to the value zero at time  $t'$ . We shall call the growth time of  $R$  from 0 to  $R_0$  the time since the creation of the world."<sup>1</sup> He further gave an expression for "the time since the

<sup>1</sup> Friedmann 1922, as translated in Lang and Gingerich 1979, p. 842. In a footnote, Friedmann added: "The time since the creation of the universe is the time that has elapsed from the moment when space was a point ( $R = 0$ ) to the present state ( $R = R_0$ ); this term may also be infinite."

creation of the (monotonic) world," but seems to have considered the age of the universe as merely a mathematical curiosity, not a possible physical reality. Although he did use the term "creation" (the German *Erschaffung*) rather than more neutral terms such as "beginning" or "origin," there is no reason to assume that he associated it with any metaphysical or religious meaning.

Friedmann's interest in cosmology was not, however, narrowly limited to mathematical models. In the preface his semi-popular book from 1923, *The World as Space and Time*, he emphasized that his approach to the general theory of relativity was not philosophical, but conceptual and mathematical. It was, however, originally written for publication in a philosophical review journal; and with its emphasis on the conceptual structure of the theory of relativity it may have appealed in particular to readers with a philosophical interest. At the end of the book, Friedmann discussed the dynamic models of the universe he had found the previous year. *The World as Space and Time* is thus the first book ever that presents expanding, contracting and oscillating model universes, but unfortunately it was published in Russian only, and that at a time when cultural and scientific contacts with the West had almost ceased to exist. Friedmann realized, of course, the hypothetical nature of the models, but could not resist the temptation "to calculate, out of curiosity, the time which has passed since the moment when the universe was created out of a point to its present stage." Without revealing the basis for his result, he stated it as "tens of billions of ordinary years."<sup>2</sup> Among the different types of non-stationary models he had listed in 1922, he seems to have been particularly fascinated by the possibility of a cyclical universe:

Cases are also possible when the radius of curvature changes periodically: The universe contracts into a point (into nothing) and then increases its radius from the point up to a certain value, then again diminishes its radius of curvature, transforms itself into a point, etc. This brings to mind what Hindu mythology has to say about cycles of existence, and it also becomes possible to speak about "the creation of the world from nothing," but all this should at present be considered as

<sup>2</sup> See the German translation (Friedmann 2000), p. 110, and on pp. 37–38 Georg Singer's attempt to reconstruct Friedmann's value. According to Singer, Friedmann used the term "creation" as an expressive metaphor and not with any religious motive. For Friedmann's life and career, see Frenkel 1988 and Tropp, Frenkel and Chernin 1993.



curious facts which cannot be reliably supported by the inadequate astronomical observational material.<sup>3</sup>

Friedmann introduced his book with a quotation from the Book of Wisdom, apochryphically associated with Solomon. His version was "Thou has created all things in measure and number," a slightly abbreviated version of "Thou hast ordered all things in measure and number and weight" (Wisdom 11:20). He ended with a verse from the ode *God*, written in 1784 by the Russian poet Gavrilla Romanovich Derjavine:

To measure the deep ocean,  
to count the [grains of] sand, the shining stars,  
how sharp shouldn't be your mind,  
if you had neither measure nor number.<sup>4</sup>

The message of the verse, reflecting the natural theology that flourished in the 18th century, was that God had created the universe rationally and provided man with a mind that enabled him to understand God's creation. This may indicate a religious aspect in Friedmann's thoughts, but it may also have been just a way to end the book in an elegant and appealing manner.<sup>5</sup>

In his book from 1923, as well in his second paper to the *Zeitschrift für Physik*, Friedmann dealt with the notorious question of whether the universe is finite or not. Contrary to most other scientists, both then and later, he emphasized that the question cannot be decided by the metrical properties of space alone. It was commonly believed that it follows from a constant positive space curvature that the universe must be finite, but Friedmann pointed out that this was not the case. The inference presupposes certain additional hypotheses which do not follow from the metric of the universe: "Thus, the world's metric alone does not enable us to solve the problem of the finiteness of the universe. To solve it, we need additional theoretical and experimental investigations. ... From a constant and positive curvature of the universe it follows by no means that our world is finite."<sup>6</sup> In his article of 1924

<sup>3</sup> Friedmann 2000, p. 109.

<sup>4</sup> My translation from German. See Singer's comment in Friedmann 2000, p. 140.

<sup>5</sup> Luminet 1997, p. 213, suggests that Friedmann had religious motives and states that he was an orthodox Christian. This is not confirmed by other literature on Friedmann that I know of.

<sup>6</sup> Friedmann 2000, pp. 110–111.

Friedmann likewise pointed out that a universe with a constant negative curvature might well be finite in size. This important insight was usually ignored in the philosophical and theological discussion concerning the finiteness of the universe. Friedmann did not himself indicate any preference for either a finite or an infinite universe.

In the 1920s, the magical word "creation" rarely appeared in a cosmological context, and if it did it was only casually, as one of Friedmann's "curious facts." For example, in 1928 the Japanese physicist Seitaro Suzuki calculated from thermodynamical theory the equilibrium ratio between the cosmic abundance of hydrogen and helium. He argued that the observed ratio might be explained "if the cosmos had, at the creation, the temperature higher than  $10^9$  degrees."<sup>7</sup> He did not explain what he meant with this somewhat enigmatic remark. It can be safely concluded that in a physical-realistic sense, the notion of a universe with a sudden origin—a creation, perhaps—had not entered scientific cosmology in the 1920s.

Georges Édouard Lemaître came from a deeply religious family. Born in 1894, he attended the Jesuit high school of Charlerois, Belgium, from where he proceeded to the College Saint Michel, a preparatory school in Brussels. However, although he was undoubtedly influenced by his Jesuit teaching, and was in later life sometimes assumed to be a Jesuit scholar, he was never a member of the Society of Jesus. After having served in the Belgian army during the entire World War I, Lemaître pursued a remarkable double career, as a theoretical physicist and simultaneously as a priest within the Catholic church.<sup>8</sup> In 1920 he completed a Belgian doctoral thesis in mathematics, and that same year he entered the Maison Saint Rombaut, a part of the seminary of the Archdiocese of Malines. On 23 September 1923 he was ordained a Catholic priest and immediately thereafter went to Cambridge to spend a year as a postgraduate student under Eddington. There his priority was mathematical physics, not theology.

The British authority in relativity was impressed by the young Belgian scholar. "I found M. Lemaître a very brilliant student, wonderfully quick and clear-sighted, and of great mathematical ability," he wrote to Théophile de Donder, a Belgian theoretical physicist and

<sup>7</sup> Suzuki 1928, p. 169.

<sup>8</sup> The literature on Lemaître in English language is limited. Biographies in French include De Rath 1994 and Lambert 2000. For an introduction in English, see Berger 1984.

specialist in general relativity. "He did some excellent work whilst here, which I hope he will publish soon. ... In case his name is considered for any post in Belgium I would be able to give him my strongest recommendations."<sup>9</sup> In 1925, after having returned from a study tour to the United States, Lemaître could write to Eddington: "I am glad to tell you that I have been appointed lecturer at the University of Louvain. The rector alluded to your kind intervention through M. De Donder in his inaugural address and I know that it has been very much appreciated."<sup>10</sup> Lemaître and Eddington continued to have close connections, and they often met during the 1930s. Although Lemaître did not agree with his former professor's attempt to construct a theory that unified microphysics and cosmology (see Chapter 5), he was much interested in it, and studied Eddington's works carefully. Thus, on Eddington's request he read carefully the proofs of his friend's difficult book, *Relativity Theory of Protons and Electrons*. "I am really immensely indebted to you for your suggestions and criticisms," Eddington told him. "I can see from the corrections noted on the sheets how carefully you have gone through it all."<sup>11</sup> Lemaître's interest in Eddington's theory was limited to its mathematical aspects, whereas he did not feel attracted by its physical and philosophical perspectives.

After Lemaître had received his Ph.D. degree from the Massachusetts Institute of Technology in 1927, he was appointed to a professorship at the Catholic University of Louvain. That same year he made his breakthrough in cosmology, although it was only recognized as such some years later. When he wrote his later so famous paper on the expanding universe, he was unaware that Friedmann had anticipated him by five years. As he wrote to De Sitter in 1930, "I did not know this memoir when I wrote my paper; it was, in the end, made known to me by Einstein. I mentioned it at a popular conference on 'la grandeur de l'espace.'"<sup>12</sup> The fundamental equations

<sup>9</sup> Douglas 1956, p. 111.

<sup>10</sup> Letter of 29 November 1925. Carbon copy in the Lemaître archive, Catholic University of Louvain.

<sup>11</sup> Letter of 4 June 1936. Eddington asked Lemaître to read the proofs in a letter of 27 February 1936 (Lemaître archive). For Lemaître's critical interest in Eddington's theory, see Lemaître 1937 and the account in Lambert 2000, pp. 173–185.

<sup>12</sup> Letter of 5 April 1930, reproduced in Luminet 1997, pp. 304–305. The conference took place in Brussels on 31 January 1929 and the lecture was published as Lemaître 1929, where the reference to Friedmann is on p. 216. Einstein mentioned Friedmann's work to Lemaître during the 1927 Solvay conference (see Lemaître 1958b).

which Lemaître arrived at, often known as the Friedmann-Lemaître equations, were

$$3\left(\frac{R'}{R}\right)^2 + \frac{3}{R^2} = \Lambda + \kappa\rho$$

and

$$2\frac{R''}{R} + \left(\frac{R'}{R}\right)^2 + \frac{1}{R^2} = \Lambda - \rho p$$

Here,  $R$  is the scale factor (a measure of the distance between two galaxies),  $\Lambda$  the cosmological constant,  $\kappa$  the Einstein gravitational constant ( $= 8\pi G/c^2$ ), and  $p$  the pressure.  $R'$  denotes  $dR/dt$ . The velocity of light is taken to be unity. Apart from the pressure term, Lemaître's equations were identical to Friedmann's.

Although from a formal and mathematical point of view Lemaître did little more than unknowingly repeat what Friedmann had done in 1922, from a physical point of view his paper was markedly different. His work was not an instrumentalist description or a mathematical exercise in general relativity, but, on the contrary, was aimed at presenting a picture of the one and only real universe. In this respect one may be tempted to compare Lemaître's world model of 1927 with another, much older and much more famous masterpiece of cosmology, Copernicus' *De Revolutionibus Orbium Coelestium* presented nearly 400 years earlier. Lemaître's realist intentions are seen most clearly in his thorough and competent discussion of observational data on galactic redshifts, from which he concluded that the universe is expanding.<sup>13</sup> Moreover, he derived a linear velocity-distance relation, what came to be known as the Hubble relation, and found for the proportionality constant a numerical value that did not differ much from the one that Hubble obtained two years later. In a book review of 1950, he commented on what were his own contributions:

If my mathematical bibliography [of 1927] was seriously incomplete because I did not know the works of Friedmann, it is completely up to date from an astronomical point of view; I calculate the expansion coefficient (575 km sec per megaparsec, 625 with a doubtful statistical correlation). Naturally,

<sup>13</sup> Most of this discussion was left out in the English translation, Lemaître 1931a, which therefore gives a somewhat distorted picture of Lemaître's work. The original French version is reproduced in, e.g., Stoffel 1996.

before the discovery and study of galactic clusters, there could be no question of establishing Hubble's law, but only to determine the coefficient. The title of my note left no one in doubt of my intentions: "Un univers [homogène] de masse constante et de rayon croissant rendant compte de la vitesse radiale des nébuleuses extra-galactiques" [i.e.: A homogeneous universe of constant mass and increasing radius accounting for the radial velocity of extra-galactic nebulae].<sup>14</sup>

Note that Lemaître classified Friedmann's work as mathematical, and that he emphasized the astronomical nature of his own work. The recession constant that Hubble derived in 1929, purely observationally, was about 500 km per second per megaparsec, a value that he corrected to 558 in 1931. With regard to the title of Lemaître's paper it is worthy to note that in its initial manuscript version the expression "rayon croissant" (increasing radius) was "rayon variable" (varying radius), which indicates that in his mind he was focusing on a particular model of the universe, with a continually increasing radius of curvature.<sup>15</sup> Although Lemaître's work of 1927 differed in a number of ways from Friedmann's earlier paper, it was, like Friedmann's, strictly a scientific work within the young tradition of relativistic cosmology. It included no considerations of a broader, philosophical nature, and there was not as much as a trace of religious attitude in it.

The model universe that Lemaître suggested in 1927 included the cosmological constant, and started its slow expansion in a pre-existing Einstein state. The mass of Lemaître's universe was the same as Einstein's, but as  $t \rightarrow \infty$  its density would gradually vanish and approach that of the De Sitter state, as  $\rho \sim R^{-3} \sim \exp(-\sqrt{3}\Lambda ct)$ . Although it was thus not of the big-bang type—a notion and a name that still belonged to the future—Lemaître argued that the expanding universe needed a cause for its increasing departure from the static Einstein world. At the time he could not say what this cause was, except that it might have been "set up by the radiation itself," as he somewhat cryptically expressed it. Yet the mere willingness to look for a cause for the expansion is remarkable, as it underlines the physical nature of his model. Although Lemaître did what he could to

<sup>14</sup> In a review of Paul Couderc, *L'Expansion de l'Univers* (Paris: Presses Universitaires de France, 1950), in *Annales d'Astrophysique* 13 (1950), 344–345. For Lemaître's crucial role in the discovery of the expanding universe, see Kragh and Smith 2003.

<sup>15</sup> The original manuscript of Lemaître's paper, including the author's handwritten revisions, is reproduced in Stoffel 1996, pp. 41–55.

make his work known to his peers—except the obvious thing of publishing it in a widely read scientific journal—his efforts were unsuccessful. He sent copies of his paper to Eddington and De Sitter, among others, but apparently none of the two eminent astronomers read it at the time. Einstein did know about the theory, but refused to take it seriously as a description of the real universe.<sup>16</sup>

It was only in the early spring of 1930 that the expanding universe was discovered in the social sense, that is, to become generally known, widely discussed, and largely accepted. At a meeting of the Royal Astronomical Society of 10 January, Eddington and De Sitter agreed that none of the static models would do, and that some kind of non-static universe would probably be the only solution to the dilemma. Lemaître now reminded Eddington of his theory of 1927, and the British astronomer immediately realized how the theory of the expanding universe fitted perfectly with Hubble's measurements. In Leiden, De Sitter was no less enthusiastic about the new revelation. As he told Shapley in a letter of 17 April: "I have been very busy lately on spiral nebulae and on the relativistic explanation of the big velocities. ... Only very lately I have found the true solution, or at least a possible solution, which must be somewhere near the truth, in a paper ... by Lemaître ... which had escaped my notice at the time."<sup>17</sup> To make a long story short, by 1931 cosmology had experienced something like a paradigm shift. Although the relativistic, expanding, universe met some resistance, most specialists agreed with Eddington and De Sitter that the universe is expanding, and that future work in cosmology had to be based on the equations found first by Friedmann and later by Lemaître.

In addition to the scientific contributions to the new cosmology, the expanding universe received wide public notice through newspaper coverage and a number of popular works. The new picture of the world entered the pages of *Times* in May 1932, when Jeans explained it to the readers. In America, the expanding universe made headlines in connection with visits by De Sitter, Lemaître and Einstein in the early 1930s. *Science News Letter* wrote on 10 January 1931 about the "Belgian priest, Abbé Le Maitre, who teaches astronomy and meditates fruitfully in his monastery cell ... [and] who pointed out that the

<sup>16</sup> Lemaître 1958b.

<sup>17</sup> Quoted in Smith 1982, p. 187.

universe, as postulated mathematically by Einstein, would collapse if anyone in it did so much as wave his arm."

On 24 October 1931, *The Brooklyn Tablet* could inform its readers that "The Einstein universe is quite out of date. So is the De Sitter universe. These were the two very best and latest universes we had. Now we must get acquainted with the Le Maitre universe." Other newspapers could not resist the temptation to connect the declining economy with the expanding universe. Thus *Press*, a Cleveland newspaper, on 2 January 1932 commented: "The depression, outstanding economic event of 1930, continued to hold the terrestrial limelight during 1931. The heavens fared better in both years. ... It was definitely established thru the co-operative efforts of a large number of astronomers, mathematical physicists and relativity experts that the entire universe is expanding. ... The matter was clinched by the discovery of Lemaître that the idea of an expanding universe was inherent in the Einstein equations altho Einstein himself had failed to notice it." Among the books that explained to laypersons the mysteries of the expanding universe, the earliest was Jeans' *The Mysterious Universe*, followed in 1931 by James Crowther's *An Outline of the Universe*; in 1932 by De Sitter's *Kosmos*; and in 1933 by Eddington's *The Expanding Universe*. Lemaître was approached by The Macmillan Company and also by Princeton University Press, both of which companies wanted him to write a book on the expanding universe, but nothing came of the plans.<sup>18</sup>

Among the many scientists who in the early 1930s explored the new world picture, a few focused on the expansion of the universe as a possible alternative to entropy as an arrow of time. As shown by the galactic redshifts, the universe is expanding, not contracting. But why? After all, the Friedmann-Lemaître equations are, like Einstein's more general cosmological field equations, symmetric with respect to the direction of time. In England, the problem was studied by William McCrea and George McVittie, and in Russia it was addressed in a different way by the young Leningrad physicist Matvei Bronstein. Contrary to McVittie, Bronstein believed that the problem could not be solved by referring to a time-asymmetric situation in the

<sup>18</sup> Lemaître archive. Lemaître actually signed in 1933 a contract with Macmillan to write *The Expansion of Space*, but apparently the contract was cancelled. His *L'Hypothèse de l'Atome Primitif*, published in 1946 and translated into English in 1950 as *The Primeval Atom*, was a collection of articles. On Jeans' and Eddington's popularizations, see Whitworth 1996.



initial state of the world, but that it required a modification of the Friedmann-Lemaître equations. "A physical theory upon which the solution of the cosmological problem can be based cannot be symmetrical with respect to the interchange of the past and the future," he wrote. He discarded Boltzmann's entropic theory of symmetric time, and concluded that "the real universe, be it stationary or not, must be highly asymmetrical in  $\pm t$ , and indeed it can hardly be expected that any rational human being would earnestly believe that any such things as stars absorbing, instead of emitting, energy or as killed soldiers rising up and marching away from the field in perfect order (but backwards) are really possible in nature."<sup>19</sup>

As Bronstein pointed out, a collapsing universe would satisfy the equations of Lemaître's theory as well as the expanding one. He suggested that the asymmetry of cosmic history was due to a time-dependent cosmological constant acting as an arrow of time in the cosmological equations. In Bronstein's theory  $-\Lambda(t)$  was postulated to be a function that could only increase, never decrease, and thus have properties similar to the entropy. The price to pay was a violation of energy conservation on a cosmic scale, which Bronstein found was justified. He also speculated that the cosmological constant might represent some form of energy, and that there might exist an energy transfer between ordinary matter and the energy or matter associated with the lambda-constant. This amounts to the suggestion that the lambda-energy may decay as a result of the emission of matter or radiation, an idea which was ignored at the time but recently has attracted considerable interest in connection with the problem of dark energy.<sup>20</sup>

After the works of Friedmann and Lemaître had become known, and the expanding universe had become generally accepted, it was obvious that some of the solutions to the Friedmann-Lemaître equations were monotonically expanding from a singular state,  $R = 0$ . However, for a while such solutions or world models were ignored or assumed not to correspond to physical reality. For example, as early as June 1930, shortly after having converted to Lemaître's theory, De Sitter investigated the possible world models, and included among them models that started in a singularity.<sup>21</sup> However, he

<sup>19</sup> Bronstein 1933, p. 74. See also Bronstein and Landau 1933.

<sup>20</sup> For a recent review, see Peebles and Ratra 2003. The physical meaning of the cosmological constant as representing the energy density of the vacuum was first proposed in Lemaître 1934.

<sup>21</sup> De Sitter 1930.

seems to have considered them to be merely mathematical solutions to which no physical significance could be ascribed. Or, as he wrote in another paper, it does not "sound very probable ... that the evolution started from an infinitely small radius."<sup>22</sup> Lemaître may have agreed, but in the spring of 1931 he decided that these solutions might well approximate the way that the real universe developed.

### A QUANTUM ORIGIN OF THE WORLD

In a paper that appeared in the March 1931 issue of *Monthly Notices*, Lemaître elaborated on various aspects of the expanding universe, which he had introduced four years earlier. His model still presupposed an original equilibrium universe of the Einstein type; only did he now seriously address the question of what caused the initial instability. His best answer was that the expansion was due to what he called "stagnation," a process in which condensations would result in a diminished pressure. In that case, the radius of curvature would increase: that is, the universe would expand. (A pressure-increasing process would have resulted in a contraction.) What is of interest here is that Lemaître's cosmological model was still the Lemaître-Eddington universe, with an asymptotic expansion from an equilibrium state, but with no sudden beginning in time.

It is unknown exactly when he first seriously considered an abrupt beginning from a point-like state, but he may well have had the idea for some time. Eddington's previously mentioned address of January 1931, in which he discussed the entropic end of the world and took exception to the notion of a cosmic beginning, spurred Lemaître to go public with his new view, but it scarcely caused it. His brief note to *Nature* of 9 May is one of the most remarkable pieces of literature in modern physical science, and one of the most far-reaching.<sup>23</sup> Contrary to Eddington, his former student was "inclined to think that the present state of quantum theory suggests a beginning of the world very different from the present order of Nature." Quantum mechanics was essential to Lemaître's new vision, as also reflected in the title of his note, which continued: "Thermodynamical principles

<sup>22</sup> De Sitter 1931, p. 7.

<sup>23</sup> Lemaître 1931. On Lemaître's primeval-atom hypothesis, see Godart and Heller 1985, pp. 67-77, and Kragh 1996, pp. 44-55.

from the point of view of quantum theory may be stated as follows: (1) Energy of constant total amount is distributed in discrete quanta. (2) The number of distinct quanta is ever increasing. If we go back in the course of time we must find fewer and fewer quanta, until we find all the energy of the universe packed in a few or even in a unique quantum."

Around 1930, there was much discussion among physicists that it might be necessary to abandon the traditional space-time continuum in certain areas of quantum physics. For example, Niels Bohr argued just a few months before Lemaître's note that the concepts of space and time have only statistical validity. The wording of the note on the beginning of the universe suggests that the Belgian cosmologist was thoroughly familiar with the views of Bohr and other quantum physicists:

Now, in atomic processes, the notions of space and time are no more than statistical notions: they fade out when applied to individual phenomena involving but a small number of quanta. If the world has begun with a single quantum, the notions of space and time would altogether fail to have any meaning at the beginning; they would only begin to have a sensible meaning when the original quantum had been divided into a sufficient number of quanta. If this suggestion is correct, the beginning of the world happened a little before the beginning of space and time. I think such a beginning of the world is far enough from the present order of Nature to be not at all repugnant.

Lemaître, aware of the incomplete state of quantum and nuclear physics, realized that it was premature to specify the original quantum, but nonetheless suggested that it might be likened to a huge atomic nucleus, with an atomic number acting as a kind of quantum number. In that case, he wrote, "we could conceive the beginning of the universe in the form of a unique atom [atomic nucleus], the atomic weight of which is the total mass of the universe. This highly unstable atom would divide in smaller and smaller atoms by a kind of super-radioactive process."

Writing before the discovery of the neutron and the breakthrough of nuclear physics in 1932, Lemaître had to express himself vaguely and metaphorically. The suggestion of a super-super-transuranic atom may seem wild (and probably did seem wild to many contemporary

physicists), but this was merely his attempt to visualize the unvisualizable initial state of the universe. Whereas in 1931 and at other occasions he used the image of a radioactive nucleus, in 1946 he suggested an "isotope of the neutron" as a more appropriate image.<sup>24</sup>

Whatever the image, it might seem unbelievable that the present world in all its magnificent and colorful diversity could really have evolved from a single, undifferentiated quantum. But here, in the final paragraph of his note, he resorted to another result of quantum physics, the fundamental indeterminism as expressed by Heisenberg's uncertainty principle. The quantum character of the beginning might in principle account for the contingency of the future evolution. Lemaître put it elegantly:

Clearly the initial quantum could not conceal in itself the whole cause of evolution; but, according to the principle of indeterminacy, that is not necessary. Our world is now understood to be a world where something really happens; the whole story of the world need not have been written down in the first quantum like a song on the disc of a phonograph. The whole matter of the world must have been present at the beginning, but the story it has to tell may be written step by step.

The note in *Nature*, here given almost in full, was an imaginative hypothesis, not a scientific theory. Yet it was written by the celebrated founder of the expanded universe, a leading specialist in relativistic cosmology, and for this reason alone it attracted attention. For example, the *New York Times* found it important enough to reproduce it on 19 May 1931 in almost its entirety.

The first time that Lemaître got a chance to elaborate his hypothesis was in October 1931, when he was invited to participate in the centenary conference of the British Association. At this occasion he outlined a more complete, if still purely qualitative scenario of cosmic evolution, including the formation of stars and clusters of stars. He emphasized the rapidity of the initial explosion, which since then had slowed down but of which there were still traces to be found. "The last two thousand million years are slow evolution," he declared; "they are ashes and smoke of bright but very rapid fireworks." The new element in his thinking was that a part of the

<sup>24</sup> Lemaître 1946, p. 155. Hypothetical "polyneutrons" of planetary or stellar masses formed the basis of a cosmological theory developed by Maria Goeppert and Edward Teller in 1948-49. See Kragh 1996, pp. 123-126.

primeval smoke, originating from the original disintegration of the super-radioactive atom, was to be identified with the presently observed cosmic radiation. His picture of the early universe was this: "At the origin, all the mass of the universe would exist in the form of a unique atom; the radius of the universe, although not strictly zero, being relatively small. The whole universe would be produced by the disintegration of this primeval atom. It can be shown that the radius of space must increase. Some fragments retain their products of disintegration and form clusters of stars or individual stars of any mass."

In his original hypothesis of the cosmological origin of the cosmic radiation, Lemaître did not associate the rays with the initial explosion of the primeval atom, but with the formation and subsequent disintegration of super-radioactive stars shortly thereafter. "Cosmic rays would be glimpses of the primeval fireworks of the formation of a star from an atom, coming to us after their long journey through space," he said.<sup>25</sup>

In another work from 1931 Lemaître described poetically the cosmic radiation as "one of the most curious of the hieroglyphes of our astronomical library."<sup>26</sup> It followed that the radiation had to consist mostly of charged particles, contrary to what Millikan believed but in agreement with Compton's view. Whereas to Millikan the cosmic rays were "birth cries of the elements"—results of creative processes still going on and indirectly indications of God's continual creativity—to Lemaître they were "the birth cries of the universe."<sup>27</sup>

Lemaître's fireworks theory of 1931 was a scientific hypothesis of the origin of the world. It was partly inspired by his insight that the half-lives of long-living isotopes of thorium and uranium are of the same order of magnitude as the Hubble time. This suggested to him that all elements had once been radioactive and that our present world was the nearly burnt-out result of a previous radioactive universe.

Whether the world started in a radioactive flash or not, the very notion of a beginning of the universe was in any case problematic. Lemaître, who was familiar with the classics of philosophy, knew that Kant's *Kritik der Reinen Vernunft* had concluded that the universe cannot be understood scientifically. It is not an object that refers to

<sup>25</sup> Lemaître, contribution to symposium on "The Question of the Relation of the Physical Universe to Life and Mind," *Nature* 128 (1931), 700-722, on p. 705.

<sup>26</sup> Lemaître 1931c. Reprinted in Lemaître 1946, pp. 67-92, on p. 87.

<sup>27</sup> Vechhierello 1934, p. 23.

something objectively existing, but a so-called regulative principle of merely heuristic value. In his "first antimony" Kant proved by means of a *reductio ad absurdum* argument the thesis that "The world has a beginning in time, and is limited also with regard to space." He then went on to prove (to his own satisfaction) the anti-thesis, that "The world has no beginning and no limits in space, but is infinite, in respect both to time and space."<sup>28</sup> Since the concept of the world is thus contradictory, it cannot cover a physical reality.

However, Kant's argument rested on a number of assumptions that were taken for granted in the late 18th century, but some of which have lost their validity within the world picture of 20th-century physics.<sup>29</sup> For one thing, it presupposed space to be Euclidean. For another, and this is more important, the dilemma was based on the assumption of determinism, that future states of a physical system can necessarily be traced back to some initial conditions. A deterministic explanation of a beginning must refer to a more remote state, which must refer to its antecedent state, *etc.*, so that the problem ends in an infinite regress. Lemaître realized that with quantum mechanical indeterminacy the dilemma would not occur. The evolution of the universe is not coded in the primeval atom, for according to quantum theory, "From the same beginning, widely different universes could have evolved," as he later remarked.<sup>30</sup> On the basis of the new quantum theory, Lemaître thus opposed the "indifference principle" which Descartes had enunciated nearly 300 years earlier. Only when the initial atom has split into a large number of quanta will the indeterminacy become inefficient and be replaced by the determinism that Kant assumed a necessity.

It was probably the stagnation process, which he had originally applied to the static Einstein universe, that induced Lemaître to publish his idea and elaborate it into a quantitative model of the universe governed by the Friedmann-Lemaître equations. Without this process it would not be possible to reconcile the age of the universe with the age of the stars, as accepted at the time. With stagnation and a positive cosmological constant he could construct a model that not only implied an age of the universe considerably longer than the Hubble

<sup>28</sup> See any edition of *Critique of Pure Reason*, Chapter II, Section II.

<sup>29</sup> See the detailed examinations in Mittelstaedt and Strohmeyer 1990, and, for Lemaître's position, Ladrière 1996.

<sup>30</sup> Lemaître 1958a, p. 6.

time, but also with a relatively quiet cosmic epoch (the "stagnation phase") favorable to the formation of galaxies. He described the model in a paper of November 1931, which should be rated as the first scientific contribution ever to big-bang cosmology. The evolution of what came to be known as the Lemaître universe occurred in three phases: "A first period of rapid expansion in which the atom-universe was broken into atomic stars; a period of slowing-down; followed by a third period of accelerated expansion. It is doubtless in this third period that we find ourselves today, and the acceleration of space which followed the period of slow expansion could well be responsible for the separation of the stars into extra-galactic nebulae."<sup>31</sup>

William Barnes, as we have seen, considered infinite space "a scandal to human thought." In his book, *Scientific Theory and Religion* the bishop even went as far as to claim that "If God's Universe is finite, we can begin to understand the range of His activity: if it is infinite, any such hope must be abandoned."<sup>32</sup> Lemaître very much agreed. Both his model of 1927 and his big-bang universe of 1931 were spatially closed, a choice which was not observationally, but epistemically based. His commitment to spatial finitude was evident as early as 1925, in his first contribution to relativistic cosmology. In a reformulation of De Sitter's world model Lemaître derived a geometrically flat, non-static model. Whereas he found the non-static feature to be promising, he abandoned the model because of "the impossibility of filling up an infinite space with matter which cannot but be finite. De Sitter's solution has to be abandoned ... because it does not give a finite space without introducing an impossible boundary."<sup>33</sup>

Lemaître's commitment to finitude reflected an epistemic attitude rooted in theology. He strongly believed that the universe, as all its component parts, was comprehensible to the human mind, a belief he could not reconcile with an infinite space populated with an infinity of objects. In a talk from around 1950, he spoke of "the nightmare of infinite space," and declared as his credo that the universe "is like Eden, the garden which had been placed at the disposal of man so

<sup>31</sup> Lemaître 1931c. Lemaître 1946, pp. 91-92.

<sup>32</sup> Barnes 1933, p. 49.

<sup>33</sup> Lemaître 1925, p. 192. Strictly speaking, a flat universe is not necessarily infinite. Depending on the topology, it might be finite, if very large. As mentioned in Chapter 3, Friedmann realized that there is no one-to-one correspondence between finiteness and metrical properties.



that he could cultivate it and explore it."<sup>34</sup> At the same occasion he briefly considered the possibility that the expanding universe we live in is the result of an earlier universe that had contracted into what, from our perspective, would be the primeval atom. He resumed his speculation of such a "Phenix universe" in his address to the 1958 Solvay congress, where he found it to be "quite conceivable" but nonetheless concluded that "a useful cosmology can [not] be built up starting from a Phenix nucleon gas."<sup>35</sup>

Just like his belief in spatial finitude, Lemaître's attitude to cosmic singularities was influenced by his epistemic presuppositions. Although his primeval-atom universe was a big-bang model, it was not a universe starting in a singularity, that is, from the "state" of  $R = 0$  at  $t = 0$ . Such a singularity is beyond physical comprehension, whereas his hypothetical super-atom would be subject to the laws of physics. On the other hand, Lemaître insisted that it was physically meaningless to speak of time (and hence existence) in the primeval atom "before" the initial explosion. He found it impossible to define a physical state for a system when there was no conceivable method of time measurement.<sup>36</sup> Although he resisted the initial singularity, as a specialist in general relativity he realized that the "annihilation of space" could not easily be avoided. When in 1933, at the request of Einstein, he investigated anisotropic models in the hope of making the singularity disappear, the result was disappointing. Yet neither he nor Einstein considered the calculations as proof that the singularity was therefore physically inevitable. As Lemaître declared, "Matter has to find a way to avoid the annihilation of its volume."<sup>37</sup>

Finally, attention should be called to Lemaître's persistent belief in a non-zero cosmological constant, in spite of the view of most other cosmologists. Contrary to Einstein, who since 1931 would have nothing to do with the constant, Lemaître referred to it as "a happy accident" that was a "logical convenience" as well as a "theoretical necessity."<sup>38</sup> He tried several times to convince Einstein of the necessity of a non-zero cosmological constant, but in vain. In a letter

<sup>34</sup> Godart and Heller 1978, p. 359. See also Tolman 1934, p. 484, who referred to conversations with Lemaître. His preference for a closed model, Tolman said, reflected his epistemic optimism, since "an infinite universe could not be regarded in its totality as an object susceptible to scientific treatment."

<sup>35</sup> Lemaître 1958a, p. 9.

<sup>36</sup> See Berenda 1951.

<sup>37</sup> Lemaître 1933. The singularity investigations in the 1930s and later work leading to the Penrose-Hawking singularity theorems are examined in Earman 1999.

<sup>38</sup> Lemaître 1959.

of 1947, Einstein made it clear that his objections were aesthetically based: "Since I have introduced this term I had always a bad conscience. But at that time [1917] I could see no other possibility. ... I found it very ugly indeed ... About the justification of such feelings concerning logical simplicity it is difficult to argue. I cannot help to feel it strongly and I am unable to believe that such an ugly thing should be realised in nature."<sup>39</sup> Needless to say, in this respect Lemaître's sense of scientific aesthetics differed from Einstein's. He did not find the constant to be ugly at all. In an unpublished address from about 1950, Lemaître referred to Einstein's and others' rejection of the  $\Lambda$ -constant as "prejudices of a psychological and aesthetic origin,"<sup>40</sup> but then his own preference for a non-zero constant was scarcely less of a "prejudice."

## TWO ROADS TO THE TRUTH

Given Lemaître's deep insights in physical science as well as theology it was only natural that he was concerned with the science-religion relationship since an early date. Thus, in a manuscript of 1921 on "God's First Three Declarations" he sought to obtain an improved understanding of certain passages in Genesis by means of concepts from modern physics.<sup>41</sup> His manuscript was, he wrote, "an attempt to interpret scientifically the first verses of Genesis," in particular, God's creation of light and the subsequent creation of the material world. This was a classical theological problem that had occupied the minds of theologians for centuries, for how could light exist in a universe that did not yet exist? On the second day of creation, God commanded the waters to be divided, and then, on the third day, that earth should appear. This was the problem that bothered young Lemaître, and that, he thought in his youthful optimism, could be illuminated by the help of physics. For example, he used the idea of blackbody radiation to argue that the *Fiat lux* ("Let there be light") was just another way of expressing the divine creation *ex nihilo*: "It is

<sup>39</sup> Einstein to Lemaître, 26 September 1947, quoted in Kragh 1996, p. 54. For a full discussion, see Earman 2001.

<sup>40</sup> Godart and Heller 1978, p. 352.

<sup>41</sup> "Les trois premières paroles de Dieu." The manuscript is reproduced in Stoffel 1996, pp. 107–111. Lemaître's religious views are discussed in Lambert 1997. See also Lambert 1996a and Lambert 1996b.

impossible for any body to subsist without emanating light, as all bodies at a certain temperature emit radiation of all wavelengths (theory of black bodies). In a physical sense, absolute darkness is nothingness. ... Before the *Fiat lux*, there was absolutely no light and therefore absolutely nothing existed." In this early phase of his life he found it reasonable to apply physics to the study of the Bible, as he believed there was a general agreement between Scripture and modern science. However, he soon came to the conclusion that concordance was not the right approach, and that the Bible should not be read as a scientific text.

During his stays in the United States 1932–1933, the news media were greatly interested in his view on the relationship between science and religion. How remarkable with this mathematician and universe-builder who was also a pious Catholic priest! As Duncan Aikman from *New York Times Magazine* reported, "Here is a man who believes firmly in the Bible as a revelation from on high, but who develops a theory of the universe without the slightest regard for the teachings of revealed religion on genesis. And there is no conflict!" In an interview with Aikman, Lemaître explained his view by telling a story in which he figured:

An old father was expounding at the desk. Before him sat the lad who was to discover the expanding universe and who, even then, was brimful of science. In his eagerness the lad read into a passage of Genesis an anticipation of modern science. "I pointed it out," says Lemaître, "but the old father was skeptical. 'If there is a coincidence,' he decided, 'it is of no importance. Also if you should prove to me that it exists I would consider it unfortunate. It will merely encourage more thoughtless people to imagine that the Bible teaches infallible science, whereas the most we can say is that occasionally one of the prophets made a correct scientific guess.'"<sup>42</sup>

The view of the old father was of course that held by the mature Lemaître, which was the Thomist theory of "two roads" to the truth, one religious and the other scientific. The two roads were entirely separate, but although they were expressed in different languages and concerned with different domains they ran parallel and would in

<sup>42</sup> *New York Times Magazine*, 19 February 1933. A part of the interview was reproduced in *The Literary Digest* 115 (11 March 1933), p. 23 and also in Vecchierello 1934, pp. 21–23.

the end lead to the same truth. The insights from the two roads could supplement each other, but because of their different natures they were independent. "There were two ways of arriving at the truth," he told Aikman,

I decided to follow them both. Nothing in my working life, nothing I have ever learned in my studies of either science or religion has ever caused me to change that opinion. I have no conflict to reconcile. Science has not shaken my faith in religion and religion has never caused me to question the conclusions I reached by scientific methods.

Although documentary evidence is missing, it is likely that Lemaître's attitude was influenced by Eddington's restrictionist view of science. At any rate, by the early 1930s Lemaître had adopted a position that in many ways was similar to Eddington's. According to this position there could not be any real or justified conflicts between faith and science. The Bible gave information about the ways of salvation, but had almost nothing to say about the world of nature. Scientists are "a literal-minded lot," Lemaître said to Aikman. "Hundreds of professional and amateur scientists actually believe the Bible pretends to teach science. This is a good deal like assuming that there must be authentic religious dogma in the binomial theorem. ... Should a priest reject relativity because it contains no authoritative exposition of the doctrine of the Trinity?" Likewise, although the astronomer knows that the world is a couple of billion years old, and Genesis tells us in clear words that creation was accomplished in six days, there is no reason to abandon the Bible. "Genesis is simply trying to teach us that one day in seven should be devoted to rest, worship and reverence—all necessary for salvation."

Moreover, if scientific knowledge were necessary to salvation, it would have been revealed to the writers of the Scriptures. The doctrine of the Trinity—"much more abstruse than anything in relativity or quantum mechanics"—is stated in the Bible because it is necessary to salvation, which is not the case with the theory of relativity, of which "neither St. Paul nor Moses had the slightest idea." Lemaître elaborated his position as follows:

The writers of the Bible were illuminated more or less—some more than others—on the question of salvation. On other questions they were as wise or as ignorant as their generation.

Hence it is utterly unimportant that errors of historic or scientific fact should be found in the Bible, especially if errors relate to events that were not directly observed by those who wrote about them. The idea that because they were right in their doctrine of immortality and salvation they must also be right on all other subjects is simply the fallacy of people who have incomplete understanding of why the Bible was given to us at all.

This liberal attitude was not particularly controversial in the 1930s, when the separate autonomies of science and religion were widely admitted within the Catholic church, but of course it was unwelcome among American and other fundamentalist groups.

The general idea that the Scripture is not a textbook where answers to cosmological questions can be looked up, has a very long history in Catholic thought. Lemaître was undoubtedly aware that the view had been held by Augustine more than 1,500 years earlier. "What is it to me whether the heavens like a sphere surround the earth which is balanced as a mass at the centre of the universe, or whether they cover the earth as would a disc placed over it?" the Church father asked. "As far as the form of the heavens is concerned, it can be said in brief that the Biblical authors knew where the truth lay. But the Spirit of God, who spoke through them, did not wish to teach men things of no relevance to their salvation."<sup>43</sup> In his letter of 1615 to grand duchess Christina, Galileo quoted Augustine in support of his view that the Copernican universe did not contradict the true meaning of the Bible. The positions of the sun, the earth and the stars "in no way concern the primary purpose of the sacred writings, which is the service of God and the salvation of souls." Galileo famously added that "The intention of the Holy Ghost is to teach us how one goes to heaven, not how the heaven goes."<sup>44</sup>

By the 1930s, the relevant cosmological questions had changed since the days of Augustine and Galileo, but Lemaître's position was essentially the same as that of his two great predecessors. Essentially, but not totally. Whereas Augustine affirmed that Moses "knew where the truth lay," to Lemaître he did not have "the slightest idea."

Lemaître had been a member of the Pontifical Academy of Sciences since its establishment in 1936, when it replaced the *Accademia dei Novizi*

<sup>43</sup> As quoted in McMullin 1981, p. 21.

<sup>44</sup> Galileo 1957, p. 182 and p. 186.

Lincei, and from 1960 to his death in 1966 he served as the academy's president. The first international symposium sponsored by the renewed academy was to be held in late 1939, on the topic of the age of the universe, but was cancelled because of the war. Lemaître's activities within the academy were interrupted during the years of war, and only resumed in 1948, when he delivered a lecture on the primeval-atom hypothesis before the assembled academicians. It was on Lemaître's instigation that Paul Dirac in 1961 was invited to become a member, which he accepted. Dirac had at that time some interest in religion, and discussed the subject with Lemaître, whom he had known since the early 1930s. In 1968 he wrote for the Pontifical Academy a survey of Lemaître's scientific contributions, in which he recalled a conversation they once had about cosmic evolution. "Feeling stimulated by the grandeur of the picture he has given us, I told him that I thought cosmology was the branch of science that lies closest to religion." This is undoubtedly a view shared by many people—scientists or not—but to Dirac's surprise Lemaître disagreed. "After thinking it over he suggested psychology as lying closest to religion."<sup>45</sup> Lemaître's insistence on the great conceptual distance between the "two roads" made him conclude that the sciences, including cosmology, were of no direct relevance for religion, a subject whose domain was souls, not galaxies.

He often expressed the difference between faith and science, or between God and the physical world, by referring to *Deus absconditus*, the hidden God of Isaias ("The God of Israel, who saves his people, is a God who conceals himself." Is 45:15). In 1936 Lemaître gave a talk to a Catholic congress in Malines, where he emphasized that "The activity of divine omnipresence is everywhere essentially hidden. It can never be a question of reducing the supreme Being to the rank of a scientific hypothesis."<sup>46</sup>

At the 1958 Solvay Congress he gave a survey of his theory of the explosive universe and the problem of clusters of galaxies. Most unusually, for a speaker at a high-level scientific conference, he used the occasion to make clear his position concerning cosmology and religion:

As far as I can see, such a theory [of the primeval atom] remains entirely outside any metaphysical or religious question. It leaves

<sup>45</sup> Dirac 1968, p. 14. During his most creative years as a physicist, in the 1920s and 1930s, Dirac had atheistic sympathies. See Kragh 1990, p. 256.

<sup>46</sup> Quoted in Lambert 1997, p. 50.

the materialist free to deny any transcendental Being. He may keep, for the bottom of space-time, the same attitude of mind he has been able to adopt for events occurring in non-singular places in space-time. For the believer, it removes any attempt to familiarity with God, as were Laplace's chiquenaude or Jeans' finger. It is consonant with the wording of Isaias speaking of the "Hidden God" hidden even in the beginning of creature.... Science has not to surrender in face of the Universe and when Pascal tries to infer the existence of God from the supposed infinity of Nature, we may think that he is looking in the wrong direction. There is no natural limitation to the power of mind. The Universe does not make an exception, it is not outside of its grip.<sup>47</sup>

In the discussion following Lemaître's address, questions and comments—from Wolfgang Pauli, Oskar Klein, Hermann Bondi, John Wheeler, and others—were restricted to scientific problems. His statements about religion were politely ignored.

Although Lemaître often stressed the separation between science and religion, he also admitted that Christian faith might sometimes affect the way in which scientists think about and represent the physical world. Faith might be an advantage to the scientist, as he believed it was, in his own case. It was an intellectual resource of central importance to his epistemic optimism, that is, his belief that God has given man mental faculties so as to be able to discover every aspect of the universe. In a popular lecture delivered in Brussels in 1929, he surveyed the state of cosmology and ended on a religious note by expressing his gratitude to "He who has said 'I am the truth' and has given us the intelligence to recognize it and to read and reflect upon His glory in our universe, which He has adapted so wonderfully to the cognitive faculties that He has endowed us with."<sup>48</sup>

Lemaître's emphasis on two different levels of understanding—the scientific and the religious—did not imply that cosmology, or the other sciences, was totally irrelevant for religion. He believed that religious and metaphysical values were important, indeed essential, to the scientist on a broader ethical level, but that they should not interfere in his methods or conclusions. "To search thoroughly for the

<sup>47</sup> Lemaître 1958a, p. 7.

<sup>48</sup> Lemaître 1929, p. 216.



truth involves a searching of souls as well as of spectra," he said in his 1933 interview. The Christian researcher does not differ in his methods and attitudes from the non-believer, but he is inspired by his knowledge that all creation is due to God, that divine activity is everywhere, if essentially hidden. "Does the church need science?" he asked. His surprising answer: "Certainly not. The Cross and the Gospel are enough."<sup>49</sup> Yet the Church has an interest in everything human, and for this reason it must also participate actively in that most noble endeavour, the quest for scientific truth.

Although it may be tempting to see Lemaître's primeval-atom universe as a projection of his religious view of creation into a scientific context, there is no basis for the often stated allegation of apologetic features in his cosmology. As we have seen, he emphatically denied that the Christian view of creation could be scientifically justified, or that God could enter as an argument in scientific theory. Nor is there any evidence that his faith motivated him in any direct way to propose his cosmological theories of 1927 and 1931. True, in his note to *Nature* of 9 May 1931 he was originally inclined to include a reference to God, such as shown by a manuscript version, where the note ended with the paragraph: "I think that everyone who believes in a supreme being supporting every being and every acting, believe also that God is essentially hidden and may be glad to see how present physics provides a veil hiding the creation."<sup>50</sup> The paragraph was crossed out by Lemaître, undoubtedly because he feared it would mislead readers and make them think that his hypothesis gave support to the Christian notion of God. On the contrary, his reference to the hidden God reflected his belief that the Creator was *not* to be found in the beginning of the universe.

Lemaître carefully distinguished between the "beginning" and the "creation" of the world, and he never spoke himself of the primeval atom in terms of the latter concept. What he called "natural beginning" belonged to the domain of science and was entirely different from the "supernatural creation" of theology. He even went so far as to claim that "the hypothesis of the primeval atom is the antithesis of the supernatural creation of the world."<sup>51</sup> In an unpublished

<sup>49</sup> Godart and Heller 1985a, p. 174.

<sup>50</sup> Lemaître archive.

<sup>51</sup> Unpublished manuscript of 1960, quoted in Lambert 1997, p. 41. The formulation is unfortunate, as it implies an either-or relationship between natural beginning and supernatural creation.

manuscript intended for a Japanese Catholic encyclopedia, he wrote about the explosion of the primordial atom:

We may speak of this event as of a beginning. I do not say a creation. Physically it is a beginning in the sense that if something has happened before, it has no observable influence on the behaviour of our universe. ... Any pre-existence of our universe has a metaphysical character. Physically everything happens as if the theoretical zero was really a beginning. The question if it was really a beginning or rather a creation, something starting from nothing, is a philosophical question which cannot be settled by physical or astronomical considerations.<sup>52</sup>

In spite of his clear statements, it was and still is common to suggest that the theory of the explosive universe was a result of Lemaître's need to reconcile his cosmology with the doctrines of the Catholic church. For example, in a book published in 1965 the philosopher Stephen Toulmin claimed that "Both the Abbé Lemaître and Sir Edmund Whittaker frankly preferred the Big-Bang picture because it could be reconciled with religious teachings about the Creation more satisfactorily than its rivals."<sup>53</sup> Some years later, the Swedish astrophysicist and Nobel laureate Hannes Alfvén repeated the myth that to Lemaître the big-bang theory "was very attractive, because it gave a justification to the creation *ex nihilo*, which St Thomas had helped establish as a credo."<sup>54</sup>

In 1951, Lemaître became involved in one of the more remarkable episodes in the modern history of science and religion.<sup>55</sup> Pope Pius XII was fascinated by the theory of the expanding universe and acquainted with the writings of Jeans, Lemaître, Milne, Whittaker and others. On 22 November 1951, he delivered an address to the Pontifical Academy in the presence of, among others, several cardinals and the Italian minister for education. It is unknown who actually wrote the address, but the principal author may have been Agostino Genelli, a Franciscan priest and psychologist.<sup>56</sup> In this address, *Un Ora*, the pope dealt in considerable detail with the support to the notion of a creator which he thought had recently come

<sup>52</sup> The article is reproduced in Godart and Heller 1985b.

<sup>53</sup> Toulmin and Goodfield 1965, p. 260.

<sup>54</sup> Alfvén 1977, p. 7.

<sup>55</sup> The section builds in part on Kragh 1996, pp. 256–259.

<sup>56</sup> McMullin 1981, p. 54.

from cosmology in the shape of the big-bang theory of George Gamow, a much improved version of Lemaître's old primeval-atom theory.

The basic argument of the pope was not only that there is no disagreement between the astronomers and the church, but that the results of modern physical science give solid evidence for the existence of a transcendent creator.<sup>57</sup> In the start of his address, he endorsed unreservedly the big-bang picture: "Everything seems to indicate that the material content of the universe had a mighty beginning in time, being endowed at birth with vast reserves of energy, in virtue of which, at first rapidly, and then ever more slowly, it evolved into its present state." The pope argued that the size and age of the universe, as estimated from astronomical data, were in full agreement with Christian faith. Modern astronomers "introduce nothing different from the opening words of Genesis, *'In the beginning God created heaven and earth...'*—that is to say, at the beginnings of things in time." He claimed that although different theories did not entirely agree with respect to the nature and conditions of the first matter of the universe, "there is a certain amount of agreement. It is agreed that the density, pressure and temperature of primitive matter must each have touched prodigious values." Pius XII continued:

Clearly and critically, as when it [the enlightened mind] examines facts and passes judgment on them, it perceives the work of creative omnipotence and recognizes that its power, set in motion by the mighty *Fiat* of the Creating Spirit billions of years ago, called into existence with a gesture of generous love and spread over the universe matter bursting with energy. Indeed, it would seem that present-day science, with one sweep back across the centuries, have succeeded in bearing witness to the august instant of the primordial *Fiat Lux*, when, along with matter, there burst forth from nothing a sea of light and radiation, and the elements split and churned and formed into millions of galaxies. ...

What, then, is the importance of modern science in the argument for the existence of God based on change in the universe? By means of exact and detailed research into the large-scale

<sup>57</sup> Italian original in *Acta Apostolicae Sedis—Commentarium Officiale* 44 (1952), 31–43. Quotations are from the English translation in McLaughlin 1957, pp. 137–147 (see also [www.papalencyclicals.net](http://www.papalencyclicals.net)). Excerpts of the address were reprinted in *Bulletin of the Atomic Scientists* 8 (1952), pp. 142–146. The pope's speech received much attention also outside clerical and scientific circles. See, for instance, "Behind every door: God," *Time* 58 (3 December 1951), 75–77.

and small-scale worlds it has considerably broadened and deepened the empirical foundation on which the argument rests, and from which it concludes to the existence of an *Ens a se*, immutable by His very nature. ... Thus, with that concreteness which is characteristic of physical proofs, it has confirmed the contingency of the universe and also the well-founded deduction as to the epoch when the world came forth from the hands of the Creator. Hence, creation took place. We say: therefore, there is a Creator. Therefore, God exists!

At the time during which the pope gave his presentation of cosmology, the field was not characterized by harmonious agreement, but, on the contrary, by a fierce controversy caused by the challenge of the steady-state theory of Hoyle, Bondi, Gold and others. But the pope chose to ignore this and other alternatives and claimed that "modern scholars in these fields [astronomy and physics] regard the idea of creation as quite compatible with scientific conceptions, and ... they are even led naturally to such a conclusion by their researches." The only place in his address where the pope alluded to rival cosmological theories was while discussing the second law of thermodynamics. He accepted the consequence of the law, the heat death, as in agreement with Christian belief, whereas he briefly dismissed the hypothesis of "continued supplementary creation." This may have been an allusion to the steady-state theory, but it may also have been a reference to the older cyclical conceptions of Nernst, MacMillan and Millikan.

So, the pope argued in no uncertain terms that there was a significant concordance between science and religion. His main message was apologetic, that big-bang cosmology's notion of a beginning of the universe justified, supported or even proved the religious concept of a divinely created world. Understandably, the message was not only unacceptable to atheists but also hard to swallow for many theologians, both within and without the Catholic church. On the other hand, there is no doubt that the pope's intervention left among many laypersons the impression that the biblical Genesis had literally been proved by big-bang cosmology. The impression was certainly not shared by Lemaître, the father or grandfather of the big-bang theory.

Lemaître knew that the theory of the universe with an abrupt beginning in the past was still a hypothesis plagued by difficulties, and in lack of convincing experimental evidence. It might be wrong,

although he thought it was not, and the pope had presented it in a much too authoritative way. For this reason, and because he strongly believed that science and religion were separate realms, he was not happy at all with the address of the sovereign of the Catholic church. He was apparently not consulted in advance, and only knew about the address at the time it was read. Worried about its consequences, he intervened together with Daniel O'Connell, the newly appointed Jesuit director of the Vatican Observatory and science advisor to the pope.<sup>58</sup> O'Connell, who since the 1930s had pursued a career in astronomy, was sympathetic to Lemaître's version of big-bang theory. However, his view on its relevance for religion may have been closer to the pope's than it was to Lemaître's. Shortly after the papal address, O'Connell wrote a highly critical review essay of Fred Hoyle's *The Nature of the Universe* in which he contrasted the steady-state theory with Lemaître's cosmology, "which so clearly implies a Creator."<sup>59</sup>

Whatever the differences between Lemaître and O'Connell, the two scientists and priests may have succeeded in modifying the pope's views and persuaded him that the close association between science and theology he had argued was helpful neither to science nor to the church. In 1952, Pius XII delivered an address in Rome to the Eighth General Assembly of the International Astronomical Union, and this time his speech was much more moderate and avoided specific references to the metaphysical and religious implications of the big-bang theory.<sup>60</sup> On the other hand, the pope's view did not change materially, and he maintained in a general way that modern astronomy and cosmology indicated "the existence of an infinitely superior Spirit, a Spirit which creates, conserves and governs."<sup>61</sup> And in another discourse of 1952 he argued that all great scientists—including Darwin—were, at least at the end of their lives, profoundly religious.<sup>62</sup> It thus seems that Lemaître was at best only moderately successful in convincing the pope that his approach to

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<sup>58</sup> Turek 1986.

<sup>59</sup> O'Connell 1952–53. See also Kragh 1996, p. 195.

<sup>60</sup> McLaughlin 1957, pp. 185–194.

<sup>61</sup> The address was widely seen as one more attempt to argue the existence of God from the results of science. See, e.g., "Pope says science proves God exists," *New York Times*, 8 September 1952, p. 23.

<sup>62</sup> Lambert 1996a, p. 98. The pope was wrong. Historians agree that Darwin was never profoundly Christian and increasingly turned toward an agnostic attitude. Although he did not want his evolutionary theory of natural selection to be used for either theistic or atheistic purposes, at the end of his life he was close to atheism.

the relationship between science and religion was unfruitful and basically wrong.

## MATTERS OF TASTE

Due to his much publicized travels in the United States, Lemaître's theory of an expanding universe originating in a primeval atom became well known in the early 1930s. It even featured in the July 1932 issue of *Popular Mechanics*. According to *The Tower* of 7 December 1933, "The noted Belgian priest-scientist who is a guest professor at the Catholic University [of America, Washington D.C.] for the winter season has made a profound impression on the scientists in this country at his every appearance." Lemaître's appearances included participation in a conference of Catholic scientists in Boston, under the presidency of the city's archbishop, William O'Connell, the very same who a few years earlier had warned against the atheistic theory of relativity. One may surmise that Lemaître used the occasion to enlighten the archbishop.

If Lemaître's theory made headlines in the newspapers, it was received much more reservedly by his colleagues in cosmology, physics and astronomy. Caution with regard to the very possibility of a scientific study of the universe at large was a predominant theme in the discourse over cosmology, not only in the 1930s but also during the following two decades. The uncertainty was particularly strong when it came to the primordial state of the universe, but it also covered other aspects of cosmology. According to Hubble, writing in 1936, theoretical cosmology consisted to a large extent of "unverified speculations" which scientists rightly regarded as "topics of conversations until tests can be devised."<sup>63</sup> It was generally admitted that the main problem of turning cosmology into a proper science was the lack of observational tests to discriminate between the many competing models. In the language of the philosophy of science, cosmology was empirically underdetermined. Facts were lacking, and in the absence of facts it seemed to many scientists that cosmology would remain a topic of speculation that did not deserve to be taken seriously, and in which it would be unwise to invest much work.

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<sup>63</sup> Hubble 1936, p. 6.

Hubble had considered a big-bang model of Lemaître's type, but found the model in no way attractive. On the contrary, although he admitted that it could not be ruled out by data, he judged Lemaître's universe with a sudden beginning to be "rather dubious."<sup>64</sup> Hubble had of course no serious doubts about cosmology as an area of scientific research, but he did warn that "Not until the empirical results are exhausted, need we pass to the dreamy realms of speculations." Indeed, he sometimes emphasized that there were no observational reasons to prefer an expanding over a static universe. In a public lecture of 1940, he went as far as stating: "No effects of expansion—no recession factor—can be detected. The available data still favor the model of a static universe rather than that of a rapidly expanding universe."<sup>65</sup>

One will look in vain for any religious element in Hubble's attitude to the universe. His view on science was distinctly within the narrow, positivistic tradition that characterized much of American science in the interwar period. Arguing that the realm of science was "the public domain of positive knowledge," Hubble emphasized that values have no place whatsoever in the scientific project.<sup>66</sup> Not that he was unconcerned with human values; he just thought that these were of a purely private nature and therefore had to be kept separate from science. As to religious values, he remained silent and also avoided discussing religion in his correspondence with friends and colleagues. It would probably be true to say that Hubble was areligious.

John Stanley Plaskett, a Canadian observational astronomer, agreed with Hubble in his view on cosmology. In the spring of 1933 he delivered a lecture in which he reviewed the recent developments of cosmology, emphasizing its reliance on mathematical models with only slender empirical support. Plaskett was willing to seriously consider the expansion of the universe, perhaps even admitting it as a fact, but when it came to its beginning in an explosive event he had no more patience. Lemaître's hypothesis was "the wildest speculation of all," even "an example of speculation run mad without a shred of evidence to support it."<sup>67</sup> If Lemaître's fireworks theory was

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<sup>64</sup> Hubble 1937, p. 62.

<sup>65</sup> Hubble 1940, p. 407.

<sup>66</sup> For Hubble's opinion of the nature and aim of science, see Hubble 1954:

<sup>67</sup> Plaskett 1933, p. 252.



what cosmologists could come up with, no wonder if cosmology was not highly regarded as a science.

Whether keeping to the solutions of general relativistic cosmology or including also the non-relativistic alternatives, almost all cosmologists admitted that in most cases the choice between theories could not be decided by the established methods of science. There was room, and wide room, for appeal to aesthetical and metaphysical preferences. Indeed, for more than three decades the cosmological literature included frequent references to "personal taste," "emotional satisfaction," "philosophical views" and similar subjective expressions. They clearly sent the signal that cosmology was not yet a science on a par with the other sciences, where subjective evaluations had long ago been replaced by objective knowledge based on rational and experimental methods. Two decades after the appearance of the first big-bang model, the situation had not changed materially. Commenting on the choice between various cosmological models, in 1951 the Manchester physicist Martin Johnson wrote that this was "an aesthetic or imaginative choice" rather than a rational one. In his opinion, cosmology had "more in common with the poetic or artistic attitude towards experience than with the solely logical."<sup>68</sup> Two years later, the Swedish physicist Oskar Klein referred to cosmology as a field where "personal taste will greatly influence the choice of basic hypotheses" and where subjective factors were unavoidable.<sup>69</sup>

As we have seen, such evaluations were common with regard to questions of the cosmological constant, the initial state of the world, and the finitude of space. To quote just one more example, the Polish-Canadian theoretician and former collaborator of Einstein's, Leopold Infeld, agreed with Lemaître that a finite, closed space was to be preferred. He "would rather see our universe closed than open," for in such a universe "there is mathematical beauty" and no philosophical problems with infinities in space and time. By contrast, Infeld found the open Einstein-De Sitter universe to be "dull and uninspired."<sup>70</sup>

Most physicists not engaged in cosmological or astrophysical research ignored the field. If they did not, their evaluations of it were often highly critical, as was the case with Percy W. Bridgman, the

<sup>68</sup> Johnson 1951.

<sup>69</sup> Klein 1954, p. 43.

<sup>70</sup> Infeld 1959, p. 496.

1946 Nobel-winning American physicist. A specialist in thermodynamics and high-pressure physics, Bridgman was also a noted philosopher of science in the positivist tradition. In his book, *The Logic of Modern Physics* from 1927 he developed an operationalist philosophy, the key message of which was that the meaning of a concept is given by the operations (physical or mental) that can be applied to specify and understand the concept. Not surprisingly, cosmology did not fit well within an operationalist framework. In two papers of 1932, Bridgman addressed cosmological questions, including the cosmic heat death.<sup>71</sup> He expressed doubt that the dire scenario was really a consequence of the second law, and also questioned if the law could be applied to the universe at all. Bridgman had no confidence that astrophysics and, in particular, cosmology would ever become decent sciences based on empirical evidence:

To the untutored critic it must appear a trifle rash to peer  $10^{16}$  years back into the past or even greater distances into the future on the basis of laws verified by not more than 300 years' observation. The only justification for such hair-raising extrapolations is to be found in the tacit assumption of some system of metaphysics; we are convinced that nature obeys mathematically exact rules, and that we have found some of them.<sup>72</sup>

The belief in scientific cosmology, he went on, is nothing but a "metaphysical conviction," and one that is particularly strong among researchers in relativistic cosmology. It is pure metaphysics to believe that "the universe is run on exact mathematical principles, and ... that it is possible for human beings by a fortunate tour de force to formulate these principles." According to Bridgmann, cosmologists were over-ambitious, arrogant and doctrinaire: "I ask an eminent cosmologist in conversation why he does not give up the Einstein equations if they make him so much trouble, and he replies that such a thing is unthinkable, that these are the only things we are really sure of."<sup>73</sup>

Bridgman stressed that in cosmological thinking, subjective elements of an emotional, aesthetic and metaphysical kind must necessarily play an important role. "The artistic element in the cosmologist

<sup>71</sup> "Statistical mechanics and the second law of thermodynamics," and "The time scale," reproduced in Bridgman 1955, pp. 236 and 269–277, from where the quotations are taken.

<sup>72</sup> On p. 275.

<sup>73</sup> Paper of 1933, "On the nature and the limitations of cosmical inquiries," reprinted in *ibid.*, pp. 278–308, on p. 308.

finds expressing in selecting those formulations or solutions, out of the many possible ones, which are most elegant or simple." Likewise, the emotional element determined to a large degree the cosmologist's attitude to the extreme past and the extreme future. Bridgman's point was of course that this would make it impossible to evaluate objectively, hence scientifically, the claims made by cosmologists. He did not specifically link cosmology and religion, but was generally suspicious of religious motives and sympathies. Having rejected religion as a young man, he continually contrasted religion and science. As he wrote in *Harper's Magazine* in 1933, "acceptance of any of the traditional or conventional religions ... [is] incompatible with plain decent intellectual honesty."<sup>74</sup>

Insofar as cosmologists considered Lemaître's new claim at all, it was mostly as a mathematical model—a particular solution to the Friedmann-Lemaître equations—not as a theory of how the real universe had evolved. The crucial feature of a physical origin in time was generally avoided or sought explained away. Bishop Barnes opined, probably correctly: "I do not think that many cosmogonists have yet been persuaded by the theory of Lemaître. It is usually regarded as a brilliantly clever *jeu d'esprit* rather than a sober reconstruction of the beginning of the world."<sup>75</sup> He was unwilling to "bring in God ... to let off the cosmic firework of Lemaître's imagination," but then, so was the Belgian cosmologist. Barnes' God was not to be found in the origin of our universe:

The circumstances which thus seem to demand His presence are too remote and obscure to afford me any true satisfaction. Men have thought to find God at the special creation of their own species, or active when mind or life first appeared on the earth. They have made him God of the gaps in human knowledge. To me the God of the trigger is as little satisfying as the God of the gaps. It is because throughout the physical Universe I find thought and plan and power that behind it I see God as creator.<sup>76</sup>

In this respect, there was little difference between Barnes, the Anglican, and Lemaître, the Catholic. Theologians had long recognized the

<sup>74</sup> Bridgman 1955, p. 363. On his rejection of religion, see Walter 1990, pp. 13–14, 136, 256.

<sup>75</sup> Barnes 1933, p. 408. This also seems to have been the attitude of Bridgman, who in 1933 briefly referred to Lemaître's theory as odd and "highly improbable." Bridgman 1955, p. 285.

<sup>76</sup> Barnes 1933, p. 409.

problems with "God of the gaps," to invoke God as an explanatory principle where scientific knowledge is lacking or incomplete, and they would often reconfirm that it was an unhealthy position. For example, it was clearly expressed by the German evangelical theologian Dietrich Bonhoeffer in a letter of 1944, written from his prison cell in Nazi Germany. Inspired by his reading of Weizsäcker's *Zum Weltbild der Physik*, Bonhoeffer wrote: "If in fact the frontiers of knowledge are being pushed further and further back (and that is bound to be the case), then God is being pushed back with them, and is therefore continually in retreat. We are to find God in what we know, not in what we don't know."<sup>77</sup>

Richard Tolman, one of the leading cosmologists of the period, was a pioneer in the study of thermodynamics from the point of view of the general theory of relativity. In 1931 he re-examined the cosmic entropy problems in the case of a non-static universe filled with blackbody radiation.<sup>78</sup> The first of the classical problems was, why has the entropy of the universe not already reached its maximum value? As we have seen, one common answer to this problem was to assume that the universe had been created at a finite time in the past; but Tolman considered it an ad hoc solution and therefore to be scientifically uninteresting. The other problem concerned the heat death as the ultimate fate of the universe, or "to allow an emotionally satisfactory feeling" towards the state of the world in the far future. Tolman's calculations showed that for his particular model, universe entropy would not reach a maximum state, but he was uncertain if the result would apply also to the real, matter-filled and expanding universe. Yet he knew that with relativistic cosmology the problems of entropy had to be reconsidered. "It would seem wisest," he wrote, "if we no longer dogmatically assert that the principles of thermodynamics necessarily require a universe which was created at a finite time in the past and which fated for stagnation and death in the future."<sup>79</sup> Milne agreed, although by an entirely different line of argument (see Chapter 6).

<sup>77</sup> Bonhoeffer 1971, p. 311. Saunders 2002, p. 96, claims that the notion of God of the gaps appears here for the first time, which is obviously wrong. Bonhoeffer, who actively resisted the National Socialists, was imprisoned in 1943 and in April 1945 he was hanged in a concentration camp.

<sup>78</sup> Tolman 1931.

<sup>79</sup> Tolman 1934, p. 444. Whittaker admitted Tolman's point, but considered the loophole of escape from the heat death so narrow that it was scarcely worth considering (Whittaker 1949, p. 46).

Tolman's major work was the authoritative book, *Relativity, Thermodynamics and Cosmology*, which included a comprehensive and detailed account of relativistic cosmology. He found it necessary to warn against philosophical preferences and "the evils of autistic and wishfulfilling thinking" in cosmology. Among such prejudices he included the belief that the universe was created in the past. "We must be specially careful to keep our judgements uninfected by the demands of theology and unswerved by human hopes and fears. The discovery of models, which start expansion from a singular state of zero volume, must not be confused with a proof that the actual universe was created at a finite time in the past." The beginning of the world was a radical concept, which was difficult to accept, and to which scientists had to accustom themselves. Tolman, worried about the time-scale problem, suggested that no definite meaning could be associated with the beginning of the physical universe: "Indeed, it is difficult to escape the feeling that the time span for the phenomena of the universe might be most appropriately taken as extending from minus infinity in the past to plus infinity in the future."<sup>80</sup>

Neither did Tolman's East Coast colleague Howard Robertson welcome Lemaître's model. In an address of 1932, he mentioned the theoretical possibility of an initial singularity; but he found it unappealing, and preferred "emotionally more satisfactory" solutions such as the non-singular, ever-expanding Lemaître-Eddington model. The following year, in a much cited survey in *Reviews of Modern Physics*, he concluded in favor of this model, whereas he specifically excluded from his plausible universes those which have "arisen in finite time from the singular state  $R = 0$ ."<sup>81</sup> Also the German astronomer Otto Heckmann found the Lemaître-Eddington model attractive, "because it allows the possibility of a world without catastrophic behavior either in the past or in the future."<sup>82</sup>

The opinion of veteran cosmologist De Sitter is particularly noteworthy. In 1930, at a time when the big-bang solution had not yet been suggested, he pointed out the disturbing lack of observational data to narrow down the class of cosmological models. "The selection

<sup>80</sup> Tolman 1934, p. 486.

<sup>81</sup> Robertson 1932, Robertson 1933, p. 80.

<sup>82</sup> Heckmann 1932, p. 106.

must remain a matter of taste or of philosophical preference," he wrote.<sup>83</sup> Like many of his colleagues, De Sitter was worried that the age of the universe, as roughly given by the Hubble time, seemed to be much smaller than the ages of stars and galaxies. He even suggested that there might be no connection between the expansion of the universe and the evolutionary changes of its astronomical objects. "After all," he cryptically said in his Lowell Lectures of November 1931, "the 'universe' is an hypothesis, like the atom, and must be allowed the freedom to have properties and to do things which would be contradictory for a finite material structure."<sup>84</sup> He was not the only cosmologist of the time who preferred to put the "beginning of the world" in inverted commas. Thus, "There appears to be a definite 'beginning of time,' a few thousand million years back in history, as there is a definite 'absolute zero' of temperature."<sup>85</sup> This may have been the first time that the analogy was proposed, although De Sitter did not mention that thermodynamics forbids that  $T=0$  can be attained (just as little as  $t=0$  can be reached in cosmology). He also mentioned the possibility "to relegate the epoch of the starting of the expansion to minus infinity, e.g., by using instead of the ordinary time the logarithm of the time elapsed since the beginning." It was precisely this possibility that Milne would exploit in his new cosmology, but De Sitter dismissed it as merely a mathematical trick.

Uncertainties with regard to cosmology's scientific status continued to be voiced during the following decades, and were reinforced by the controversy between evolution theories and the steady-state alternative in the 1950s. For example, in 1954 the question was discussed at length in a debate between Hermann Bondi and Gerald Whitrow.<sup>86</sup> It was also only in this decade that the big-bang universe entered the cosmological scene, and when the initial state of the world was gradually admitted to be a scientifically meaningful concept. The uneasiness about the scientific status of cosmology in the 1930s, and the recourse to an emotionally and subjectively colored

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<sup>83</sup> De Sitter 1930, p. 218.

<sup>84</sup> De Sitter 1932, p. 133.

<sup>85</sup> *Ibid.*, p. 131.

<sup>86</sup> Kragh 1996, pp. 233–236. Nor was it the last time that scientists questioned the scientific legitimacy of cosmology. For a recent example, see Disney 2000. According to Disney, an astrophysicist, much of modern cosmology is pseudoscientific and quasi-religious: "The most unhealthy aspect of cosmology is its outspoken parallel with religion. Both deal with big but probably unanswerable questions" (p. 1132).

language, indicates that metaphysical considerations were often of importance to the cosmologists. These considerations may in some cases have been associated with religious views, but only on rare occasions did they explicitly refer to religion. Their frequency cannot be taken as an indication that cosmology was particularly influenced by religious ideas.

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**Cosmo-physics**



# Cosmo-physics

## IDEALISM AND NUMEROLOGY

**E**mpiricism is traditionally considered the hallmark of the British spirit in philosophy and science, distinguishing it from the more rationalistic *Geist* of Continental thinking.

The empirical attitude of British science never reigned supreme, however. In British physics, astronomy and cosmology there existed in the 1930s a strong rationalistic trend radically opposed to what was usually associated with the national spirit. Since integration of cosmology and physics was an important part of the trend, it may be referred to as cosmo-physics.<sup>1</sup> The leading cosmo-physicists of the period were Milne and Eddington, whose methods and styles for a time attracted a heterogeneous group of younger theoreticians, including P. Dirac; A. G. Walker; G. J. Whitrow; G. C. McVittie; G. J. Temple; and W. H. McCrea. Jeans, too, may reasonably be counted among them. The cosmo-physicists were under constant attack from empirically-minded scientists and philosophers, but in England their position was strong enough to form a viable scientific subculture, if not a proper school of physics.

The scientific systems raised by Milne and Eddington might appear very different in results and methods, and indeed they

<sup>1</sup> Kragh 1982, on which parts of the section relies. See also Durham 2003.

were: Eddington's universe was finite, obeying the theory of general relativity and intimately linked to atomic theory; Milne's was flat and infinite, in conflict with general relativity and free from atomic physics. Eddington, convinced of the truth of general relativity, rejected Milne's operationalism and his entire approach to cosmology.<sup>2</sup> Nonetheless, when it came to the fundamental issues of legitimate scientific reasoning, the two astronomers had more in common than they would admit. Both systems were grand and ambitious projects of reconstruction, more like *Weltanschauungen* than like ordinary physical theories. Methodologically, both Eddington and Milne argued for deductivism, a sort of synoptic thinking based upon *a priori* principles from which the laws of nature were deducible by rational reasoning. As for the experiential input, it should be reduced to those elements of which human beings are directly aware—the basic contents of our consciousness. Eddington and Milne agreed upon the importance of common sense experience, which they thought strong enough to fix the fundamental principles of physics. Milne furthermore agreed with Eddington that in discussing interactions between elementary particles, the relation of any given particle to the rest of the universe cannot be ignored.

Despite the alleged appeal to empiristic doctrines, cosmo-physics was characterized by full-blown rationalism. The philosopher Charlie D. Broad likened Eddington to Descartes, and the comparison might cover Milne as well: "For Descartes the laws of motion were deducible from the perfection of God, whilst for Eddington they are deducible from the peculiarities of the human mind. ... For both philosophers the experiments are rather a concession to our muddle-headedness and lack of insight."<sup>3</sup> In the synoptic-rationalistic-idealistic systems of Eddington and Milne, experimental tests were of no more significance than in mathematics. Of course, neither of them ignored the value of observational evidence when it supported their views.

To some extent cosmo-physics can be seen as a continuation of the anti-empirical tradition in British intellectual life represented by philosophers of an idealist inclination, like Samuel Alexander; John McTaggart; Robin G. Collingwood and, more relevant in the present context, Alfred North Whitehead. Best known for his collaboration

<sup>2</sup> See Eddington 1939c and also his scathing review of Milne 1935 in *Nature* 135 (1935), 635–636.

<sup>3</sup> Broad 1940, p. 312.

with Bertrand Russell on the monumental book, *Principia Mathematica* from 1910, Whitehead's early works were in mathematics and mathematical logic, but after World War I he left mathematics for philosophy. In the 1920s and 1930s, Whitehead attempted to give a unified picture of reality in which no gulf existed between nature and man, knowledge and value. He presented in 1922 an alternative, non-Einsteinian theory of gravitation with cosmological implications that were, so he claimed, directly deducible from his natural philosophy.<sup>4</sup> He believed, as did Milne and Eddington, that general epistemological considerations were crucial to physical theory, and he shared with Milne the belief that Einstein's theory of gravitation was unnecessarily complex, a mathematical machinery obscuring the rational understanding of physical phenomena. His non-covariant, action-at-a-distance theory differed conceptually and mathematically from Einstein's, yet, as Eddington showed, it led to the same predictions.<sup>5</sup> Whitehead's theory of relativity was taken up by George Temple and a few others, but soon fell into oblivion. Only after World War II was it further developed and applied to cosmological problems, primarily by John L. Synge and C. B. Rayner.<sup>6</sup>

The kind of cosmology that Whitehead proposed from the mid 1920s onwards was of an entirely different kind, as it was a metaphysical world system rather than a scientific theory of the universe. His principal work, *Process and Reality*, carried the subtitle *An Essay in Cosmology*, but here "cosmology" should be understood as a philosophical attempt to understand the world in its totality. Whitehead's philosophy of nature was organistic, evolutionary, teleological and holistic.<sup>7</sup> Everything is in flux, even the laws of nature, and the universe develops with a purpose. Since the laws of physics depend on the individual characters of the objects constituting nature, "Thus the conception of the Universe as evolving, and subject to fixed eternal laws regulating all behaviour should be abandoned."<sup>8</sup> Whitehead's claim was metaphysical rather than physical, and was not immediately translatable into the claim that the laws of nature vary with time in some regular way (such as Dirac's  $G \sim t^{-1}$ ).

<sup>4</sup> Whitehead 1922.

<sup>5</sup> Eddington 1924.

<sup>6</sup> North 1965, pp. 190–196. On later gravitation theories of the Whitehead type, see Schild 1962.

<sup>7</sup> Whitehead 1929. For analysis, see Christian 1959.

<sup>8</sup> Whitehead 1933, p. 143. See also Whitehead 1929, pp. 139–140.

In *Process and Reality* Whitehead pointed out that certain basic features of physics are arbitrary, in the sense of being contingent: they are what they are, and have to be accepted as they are, but there is no reason why they could not have been different (as examples he mentioned Planck's constant and the four-dimensional space-time continuum). Why are they as they are? Are there other possible worlds where they are different? His reply to this old question was not only that such worlds may exist, but that they *must* exist, namely in other parts of space-time or, in his phraseology, cosmic epochs. He also suggested that entropy-generating processes might be taken as a measure of the intensity of what he called "God's satisfaction." The law of entropy increase, he seems to have thought, indicated that God continually became less satisfied with the world.

Because of its very nature, Whitehead's system was irrelevant to the physicists' and astronomers' attempts to understand the universe, but it was not irrelevant to the science-religion discussion. In his widely read book, *Science and the Modern World*, Whitehead presented science and religion as separate but complementary realms, neither of which gave a full understanding of reality: "Science is concerned with the general conditions which are observed to regulate physical phenomena; whereas religion is wholly wrapped up in the contemplation of moral and aesthetic values. On the one side there is the law of gravitation, and on the other the contemplation of the beauty of holiness. What one side sees, the other misses; and vice versa."<sup>9</sup> In a series of lectures delivered in Boston in 1926, Whitehead similarly drew an analogy between science and religion. They were concerned with very different domains of reality, but were still aspects of the same world, and had in common the fact that they were both truth-seeking activities. As Whitehead expressed it: "The dogmas of religion are the attempts to formulate in precise terms the truths disclosed to the religious experience of mankind. In exactly the same way the dogmas of physical science are the attempts to formulate in precise terms the truths discovered by the sense perceptions of mankind."<sup>10</sup>

In the last part of *Process and Reality*, Whitehead suggested a new picture of God and his relation to the physical world—a picture that

<sup>9</sup> Whitehead 1956, p. 184 (first published in 1925).

<sup>10</sup> Whitehead 1974, p. 57 (first published in 1926).

Charles Hartshorne, John Cobb and others would later develop into what is known as process theology. According to process thinkers inspired by Whitehead, God is the source of novelty and order, but he is not the transcendent majesty of classical Christianity. On the contrary, Whitehead argued that God is partly immanent and interacts reciprocally with the world. He is influenced by events in the physical world and shares with it a measure of temporality. This implies a new picture of the creator, as God "is not *before* all creation, but *with* all creation." Whitehead summarized his radically unorthodox concept of God as follows:

It is as true to say that God is permanent and the World fluent, as that the World is permanent and God is fluent. It is as true to say that God is one and the World many, as that the World is one and God many. It is as true to say that, in comparison with the World, God is actual eminently, as that, in comparison with God, the World is actual eminently. It is as true to say that the World is immanent in God, as that God is immanent in the World. It is as true to say that God transcends the World, as that the World transcends God. It is as true to say that God creates the World, as that the World creates God.<sup>11</sup>

Since Whitehead's God did not have temporal priority over nature, he did not create the world out of nothing. With its emphasis on eternal processes and a God whose creativity occurs continually, process philosophy is not easily compatible with the big-bang picture of the universe.

The grand project that Arthur Eddington pursued from 1929 until his death in 1944 was no less ambitious than Whitehead's, but it was restricted to physics. Although the former's vision of a new philosophy of nature differed very much from Whitehead's ideas, he did recognize an affinity and described Whitehead as "an ally who from the opposite side of the mountain is tunnelling to meet his less philosophically minded colleagues."<sup>12</sup>

Eddington's project, which culminated in his posthumously published book, *Fundamental Theory* from 1946, had its origin in Dirac's relativistic theory of the electron from 1928.<sup>13</sup> In his attempt to

<sup>11</sup> Whitehead 1929, p. 521 and p. 528.

<sup>12</sup> Eddington 1928, p. 250.

<sup>13</sup> On Eddington's theory, see Kilmister 1994.

generalize and extend Dirac's wave equation, Eddington argued that the inverse fine-structure constant ( $\alpha^{-1} = hc/2\pi e^2 = \hbar c/e^2$ ) expressed a certain number of algebraic degrees of freedom and therefore had to be an integer. In a paper of 1929, he found  $\alpha^{-1} = 16 + 1/2 \times 16(16 - 1) = 136$ , a value which did not, however, agree with the best experimental data. He consequently added an extra number, which he justified by means of the exclusion principle, namely as arising from the indistinguishability of two electrons. For the rest of his life, he stuck to  $\alpha^{-1} = 137$ , claiming to have "obtained [it] by pure deduction, employing only hypotheses already accepted as fundamental in quantum mechanics."<sup>14</sup> As late as 1944, in his very last publication, he quoted the experimental value  $\alpha^{-1} = 137.009$  and concluded, somewhat arrogantly, that the small discrepancy was an experimental problem rather than a problem for his theory.<sup>15</sup>

Eddington's much discussed theory of the fine-structure constant was only one part of a much larger research project, the aim of which was to connect the microphysical and cosmical constants of nature. As he wrote in 1935, "We may ... look on the universe as a symphony played on seven primitive constants as music played on the seven notes of a scale."<sup>16</sup> The seven constants he considered to be fundamental were  $e$  (the elementary charge),  $m, M$  (the mass of the electron and the proton),  $h$  (Planck's constant),  $c$  (the velocity of light),  $G$  (Newton's constant of gravitation), and  $\Lambda$  (the cosmological constant). Apart from the fine-structure constant, the other small dimensionless number in his theory was the mass ratio between the proton and the electron,  $M/m$ . This number Eddington suggested could be found in the roots of the quadratic equation

$$10x^2 - 136x\omega + \omega^2 = 0$$

Here,  $\omega$  is what Eddington called a "standard mass," the mass of an unspecified neutral particle. The mass ratio comes out as the ratio between the two roots,  $M/m = 1847.6$ , a value he believed was intimately related to the inverse fine-structure constant.

<sup>14</sup> Eddington 1932, p. 41. On Eddington and the fine-structure constant, see Kragh 2003b. Readers of Eddington's works should keep in mind that he used the term *fine-structure constant* (and the symbol  $\alpha$ ) for the quantity  $\hbar c/e^2$ .

<sup>15</sup> Eddington 1944b.

<sup>16</sup> Eddington 1935, p. 227.

Whereas Einstein in 1931 abandoned the cosmological constant as unnecessary in an expanding universe, to Eddington it was of fundamental importance, as he conceived it a measure of the repulsing force causing the expansion. Moreover, in Eddington's view the cosmic yardstick fixing a radius for spherical space was  $\Lambda^{-1/2}$ , not the Hubble distance  $c/H$ . Only with a non-zero  $\Lambda$  would the wanted connection between atomic theory and cosmology make sense.

According to Eddington's philosophy, Dirac's wave equation could not be applied to a single electron. "An electron has no individuality," he wrote in 1931; it "is not separable from all other electrons in the universe in the way the classical picture supposed. I take the view that the mass of an electron is an interchange energy with all the other charges in the universe suitably averaged."<sup>17</sup> He found from the Dirac equation, interpreted cosmologically, that the mass constant  $\gamma = mc/\alpha\hbar$  was related to the radius  $R$  of the static Einstein universe by

$$\gamma = \frac{mc}{\alpha\hbar} = \frac{\sqrt{N}}{R}$$

where  $N$ , the so-called cosmical number, denotes the number of electrons in the universe, about  $10^{79}$ . In later works, Eddington claimed to be able to deduce the number rigorously from theory, as  $2 \times 136 \times 2^{256} \cong 3.15 \times 10^{79}$ . Assuming that the total number of protons equals the number of electrons, he further argued that, in the case of an Einstein universe, this number can be written as

$$N = \frac{\pi R c^2}{2MG}$$

Combining the two equations yields the relation

$$\frac{e^2}{GmM} = \frac{2}{\pi} \sqrt{N}$$

Moreover, by means of Einstein's relation  $\Lambda = R^{-2}$  he found an expression of the cosmological constant in terms of known constants of nature. From this he derived a value of the Hubble constant ( $528 \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$ ) in fair agreement with the one known from observations.

<sup>17</sup> Eddington 1931b.

The precise relationships between the natural constants changed as Eddington's programme developed, but not substantially. Around 1936, the year when he collected and elaborated his results in his book, *Relativity Theory of Electrons and Protons*, he paid particular attention to the formulae

$$\frac{e^2}{GmM} = \frac{1}{\pi} \sqrt{3N}, \quad \frac{2c\pi}{h} \sqrt{\frac{mM}{\Lambda}} = \sqrt{\frac{N}{30}} \quad \text{and} \quad \frac{hc}{2\pi e^2} = \frac{Nh\Lambda}{2\pi mc}$$

The large value of the dimensionless combination  $e^2/GmM \cong 10^{39}$  had earlier been pointed out, first by Hermann Weyl in 1919.<sup>18</sup> With Eddington's use of the relationship, it became of crucial importance to the cosmo-physicists. Weyl shared Eddington's belief in some deep-lying connection between the atom and the universe, but he was unable to accept Eddington's theory, which he considered to be premature.<sup>19</sup>

Eddington's fundamental theory of the constants of nature, and his general attempt to link atomic theory with cosmology, aroused great interest in the 1930s. Although it was rejected by most leading quantum physicists, others found it fascinating and followed in his footsteps. The Eddington-inspired physicists worked independently, without forming a group and with no direct connection to the British astronomer. Eddington followed his unorthodox research programme in splendid isolation, apparently uninterested in the work done by other physicists in the tradition he had initiated. The isolated or closed nature of Eddington's research is illustrated by bibliometric studies. Among the references in his 14 research papers on cosmo-physics published between 1929 and 1939, no less than 70 percent are to his own works, which strongly indicates how independent his work was.<sup>20</sup> (The average self-reference ratio in physics papers in the period was much smaller, typically 10 percent.)

In a letter to the Swedish physicist Oskar Klein, Pauli dismissed Eddington's approach as "complete nonsense" and "romantic poetry."<sup>21</sup> Max Born criticized it for resting on arbitrary assumptions and later, after having left Germany for Great Britain, attacked it as

<sup>18</sup> Weyl 1919.

<sup>19</sup> Weyl 1934.

<sup>20</sup> Kragh and Reeves 1991.

<sup>21</sup> Hermann *et al.* 1979, p. 491.



being pseudo-scientific.<sup>22</sup> But opposition or lack of interest was not the only response. For example, Arnold Sommerfeld found Eddington's programme to be attractive because it promised "amazing perspectives in the unification of the physical world picture." In a letter of 1937 to Einstein, Sommerfeld confirmed his interest in Eddington's work, although adding that "nobody understands this approach."<sup>23</sup> Another of the leading physicists of the period, Erwin Schrödinger, was for a period "convinced that, for a long time to come, the most important research in physical theory will follow closely the lines of thought inaugurated by Sir Arthur Eddington."<sup>24</sup>

Eddington's numerological approach attracted attention, if not always respect, among both British, Continental and American physicists. Thus, several physicists in German-speaking Europe not only accepted the approach, but also developed it and contributed to the scientific literature with works in the numerological tradition. Foremost in the group was perhaps the Austrian A. E. Haas, of whom more below. The German Hans Ertel, another industrious Eddington epigone, introduced the expanding universe in the numerological approach to cosmology.<sup>25</sup> He argued that Eddington's value for the cosmical number should be revised to  $N = 2^{136} \times 2^{137} \times 2^{-10}$  and that it was related to other constants of nature by

$$G = \left(\frac{e}{m}\right)^2 \frac{\alpha}{8\sqrt{N}}$$

Samuel Sambursky, a physicist at the Hebrew University in Jerusalem, used Eddingtonian arguments to arrive at the non-Eddingtonian notion of a static universe.<sup>26</sup> By assuming Planck's constant to decrease in time, he could reconcile the observed redshifts with the static universe he preferred. Sambursky's assumption that  $dh/dt = -Hh$  was equivalent to Nernst's earlier tired-light hypothesis. Dozens of other physicists engaged in the same kind of reasoning as Haas, Ertel and Sambursky, but there is no need to go into further details with the subject.

<sup>22</sup> Born 1931. Born 1956, p. 44.

<sup>23</sup> Sommerfeld 1929. Hermann 1968, p. 118.

<sup>24</sup> Schrödinger 1937. Rieger 1988.

<sup>25</sup> Schröder and Treder 1996. Ertel was also one of the first to consider Lemaître's big-bang model, and the only academic to view it in the perspective of cosmo-numerology.

<sup>26</sup> Sambursky 1937.

## LARGE NUMBERS

Physicists who read the 20 February 1937 issue of *Nature* can scarcely have avoided being surprised. The journal's letter section included a note by Paul Dirac, the Nobel laureate and celebrated pioneer of quantum mechanics. Until then, Dirac had in his research focused exclusively on problems of quantum theory and not shown any interest at all in cosmology. Yet the subject of his *Nature* note, admittedly inspired by recent works by Eddington and Milne, was a new cosmological hypothesis. Unlike Eddington, Dirac had no problem with adopting the idea of Lemaître, that "the universe had a beginning about  $2 \times 10^9$  years ago, when all the spiral nebulae were shot out from a small region of space, or perhaps from a point."<sup>27</sup> Expressing the age of the universe (the Hubble time) in atomic time units of  $e^2/mc^3$  yields a dimensionless number close to  $10^{39}$  and thus of the same magnitude as Weyl's ratio between the electrical and gravitational forces. Dirac believed that the nearness of the numbers could not be a coincidence but was an instance of a general principle of nature—what he later called the large number hypothesis (LNH). This principle postulates that whenever two very large numbers  $A$  and  $B$  turn up in nature (or can be constructed from natural constants), they must be related in the simple way  $A = kB$ , where  $k$  is a numerical constant not very different from one. It then follows that  $e^2/GmM$  must be of the same order of magnitude as  $T_0$ , the age of the universe expressed in atomic units, and therefore that the quantity must vary with the epoch. Assuming that  $e$ ,  $m$  and  $M$  were true constants, Dirac thus suggested that  $G(t) \sim t^{-1}$ . In words, Newton's gravitational constant decreases slowly with the epoch. As we shall see, a different kind of variation of  $G$  had been proposed by Milne two years earlier.

The idea that laws and constants of nature may not be true constants over time, had in a general way been discussed at a few earlier occasions, but did not gain support. In a lecture of 1911, Poincaré considered the possibility, if only to reject it as unfounded. Not only did it lack any empirical support, Poincaré also concluded that

<sup>27</sup> Dirac 1937, p. 323. On Dirac and his cosmological theory, see Kragh 1982 and Kragh 1990, pp. 223–246.

permanent laws of nature were a precondition for the very possibility of studying nature scientifically.<sup>28</sup>

Dirac further noted that if  $\rho$  denotes the mean density of luminating matter in the universe, observationally estimated to be about  $5 \times 10^{-31} \text{ g} \cdot \text{cm}^{-3}$ , then

$$\mu = \frac{\rho(cH^{-1})^3}{M} \cong 10^{79}$$

This is just another way of expressing Eddington's cosmical number, the number of protons in the universe, or its visible part. From the empirical fact that  $\mu \cong T_0^2$  combined with the LNH, Dirac found it justified to conclude that  $N$  varies as  $t^2$ —"the number of protons and neutrons in the universe must be increasing proportionally to  $t^2$ ." The matter creation thus introduced was a spontaneous process, unexplainable according to contemporary microphysics. However, in his more elaborate cosmological theory of 1938, Dirac decided to keep to the safer ground of energy conservation, arguing that  $N = \text{constant}$  was consistent with the LNH.<sup>29</sup> On the other hand, he kept to the  $G(t) \sim t^{-1}$  hypothesis and deduced from the LNH the rate of expansion of the universe (namely  $R \sim t^{1/3}$ ). Moreover, he argued that a universe agreeing with the LNH had to be infinite, spatially flat, and with a zero cosmological constant.

The above gives the essence of Dirac's cosmology, a theory he would return to only in the 1970s. It was evidently a theory faced with severe problems, one of them being that the age of the Dirac universe would be one-third of the Hubble time, or a mere 700 million years (this result follows from the  $R \sim t^{1/3}$  variation, which implies that  $t_0 = H_0^{-1}/3$ ). The predicted age was thus less than the fairly reliably known age of the earth. But this and other difficulties did not really shatter Dirac's confidence in the theory. He strongly believed in the LNH, which he considered a meta-scientific principle of great aesthetical value, a prime example of what he called mathematical beauty in physics.<sup>30</sup> Dirac first expounded his principle of mathematical beauty in his James Scott Lecture of 1939, when he argued that there is a perfect harmony between the objective laws of nature and

<sup>28</sup> Poincaré 1913, pp. 48–67. See also Balashov 1992.

<sup>29</sup> Dirac 1938.

<sup>30</sup> On Dirac and beautiful mathematics, see Kragh 1990, pp. 275–292 and McAllister 1990.

the rules that physicists find internally interesting and mathematically beautiful.

One example of nature's beauty was to be found in big-bang cosmology governed by the LNH. From the  $G(t)$  hypothesis, Dirac generalized: "At the beginning of time the laws of Nature were probably very different from what they are now. Thus we should consider the laws of Nature as continually changing with the epoch, instead of as holding uniformly throughout space-time."<sup>31</sup> He even went as far as to suggest that the laws of nature at a given cosmic time were not the same at all places in the universe. His argument was straightforward, but not, perhaps, very convincing: "We should expect them also to depend on position in space, in order to preserve the beautiful idea of the theory of relativity that there is fundamental similarity between space and time."<sup>32</sup>

Dirac was a rationalist, although very much in his own way. His deep belief in beautiful equations and mathematical structures was strikingly metaphysical. Although he never referred to the mathematical beauty in nature as something reflecting the mind of a creator (as Jeans did), at least on one occasion he indicated that his belief could be likened to a religious belief.<sup>33</sup> He sometimes spoke of mathematical beauty in emotional terms, and it is possible that his commitment to it acted as a kind of quasi-religion, a substitute for those emotions and spiritual longings he, as a rationalist, would not admit into either his life or his science.

There is nothing that indicates a religious element in Dirac's work on cosmology or other parts of physics.<sup>34</sup> On the contrary, during his most creative scientific phase in the 1920s and 1930s Paul Dirac was not a religious person and he had no sympathy at all with the cause of religion. To the extent that he considered religion a worthy subject to think of at all, he seemed to have been either an atheist or an agnostic. According to Heisenberg's recollections of informal discussions during the 1927 Solvay congress, Dirac flatly rejected religion and showed himself to be a "fanatic of rationalism."<sup>35</sup> As far as he, Dirac, was concerned, religion was based on irrationalism and

<sup>31</sup> Dirac 1939, p. 913.

<sup>32</sup> *Ibid.*

<sup>33</sup> Dirac, "Basic Beliefs and Fundamental Research," unpublished talk, University of Miami, 1972. Part of the talk is quoted in Dyson 1986.

<sup>34</sup> The following section is based on Kragh 1990, pp. 256-257.

<sup>35</sup> Heisenberg 1971, p. 87.

arbitrary postulates, and hence was without the slightest appeal to the man of science; religion, Dirac maintained (again according to Heisenberg), was merely a system of myths, an opium for the people. Pauli is to have sarcastically commented, "But yes, our friend Dirac has a religion, and the basic postulate of this religion is: 'There is no God, and Dirac is his prophet.'"<sup>36</sup>

Much later in life, Dirac did express some interest in religion, if only in his own rationalistic way. Thus, in an address of 1971 he discussed as a fundamental problem of physics (!) if God exists.<sup>37</sup> According to Dirac, the determinism of classical mechanics left no place for God, but the indeterminism associated with modern quantum physics at least made it possible to entertain scientifically the notion of a higher being. In his opinion, God would be a justified hypothesis if the emergence of life required a highly improbable event to have taken place in the past. If so,

I feel that under those conditions ... it would be necessary to assume the existence of a god to start off life. I would like, therefore, to set up this connexion between the existence of a god and the physical laws: if physical laws are such that to start off life involves an excessively small chance, so that it will not be reasonable to suppose that life would have started just by blind chance, then there must be a god, and such a god would probably be showing his influence in the quantum jumps which are taking place later on. On the other hand, if life can start very easily and does not need any divine influence, then I will say that there is no god.

Quite characteristically, Dirac addressed the question in an objective, scientific way. It did not occur to him that there might be other reasons, say, associated with the soul and its salvation, to believe in God. I find it also noteworthy that Dirac focused on the existence of life as a possible justification of God's existence, whereas he did not mention God as the possible creator of the physical universe.

Dirac's cosmology served as inspiration for Robert Dicke's introduction of what eventually became known as the anthropic principle. In an article of 1957, Dicke connected the large number of coincidences with the possibilities of life in the universe. He argued that the present value of the Hubble constant, as well as other large numbers,

<sup>36</sup> *Ibid.*

<sup>37</sup> Unpublished lecture given at the 21st Lindau Meeting for Nobel laureates. Kragh 1990, p. 257.

should be understood not as a result of the LNH but as a consequence of there being at least one habitable planet with human life. In a letter to *Nature* of 1961, he discussed several of the large dimensionless numbers. As he saw it, these did not indicate any variation in time of the constants but could be explained by "the existence of physicists now and the assumption of the validity of Mach's principle." More specifically Dicke argued that "with the assumption of an evolutionary universe,  $T$  is not permitted to take one of an enormous range of values, but is somewhat limited by the biological requirements to be met during the epoch of man."<sup>38</sup> It took another 13 years before Brandon Carter coined the term anthropic principle in the sense of "what we can expect to observe must be restricted by the conditions necessary for our presence as observers."<sup>39</sup> Dirac never adopted the anthropic principle, in whatever of its several forms. He preferred his own hypothesis because it allowed the possibility of endless life.

## JORDAN'S COSMOLOGY

Dirac's cosmological theory of 1937–38 was not well received. Most of his colleagues in physics preferred to ignore it, and to the limited extent that it was discussed in a broader framework, it was severely criticized on methodological grounds (see below). Eddington only mentioned Dirac's theory once, and then to dismiss it as "unnecessarily complicated and fantastic."<sup>40</sup> As mentioned, Dirac himself abandoned it for more than two decades. Nonetheless, the theory was well known and made some impact in the late 1930s, primarily through the works of Pascual Jordan, the German quantum physicist. In an important book published in 1952, Jordan could look back on the past 15 years and conclude, largely rightly: "I am the only one who has been ready to take Dirac's world model seriously, which even its originator has partly abandoned, and to reconsider its more precise formulation." He added, "I must admit that in this idea of Dirac's I recognize one of the great insights of our time and consider it an important task to develop it further."<sup>41</sup> Although not a Nobel

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<sup>38</sup> Dicke 1961. See also Barrow and Tipler 1986.

<sup>39</sup> Carter 1974.

<sup>40</sup> Eddington 1939c, p. 234.

<sup>41</sup> Jordan 1952, p. 137.

laureate, Jordan was a theorist almost as brilliant as Dirac, and he was one of the undisputed pioneers of quantum mechanics and quantum field theory. Contrary to Dirac, Jordan embraced from the beginning the Copenhagen view of quantum physics and Niels Bohr's complementarity principle, which he in the 1930s sought to extend to the realm of biology. Jordan was a declared positivist and also a prime example of an "expansionist." Nor is it pointless to mention that he became a member of the National Socialist party, although he would have nothing to do with the notorious *Deutsche Physik* movement which branded quantum and relativity theory as non-Aryan and as expressions of Jewish thought.<sup>42</sup>

Young Jordan found in quantum physics philosophical perspectives that made possible a return to religious belief. Writing under the pseudonym "Ernst Domeier," in the early 1930s he published several articles in which he expressed a longing for religion. For him, the overthrow of materialism and determinism, such as promised by quantum theory in general, and quantum biology in particular, became a religious question. He never suggested that the existence of God could be proved by science, but he did argue that modern science had made it more legitimate to believe in God. A de-legitimization of religious belief could no longer be defended on scientific grounds. As he wrote in 1954, the changes that had occurred in modern science did not mean "that the atomic physicists can lead [us] to a positive proof of religious truth or, say, of human free will; but it does mean that those contradictions ... of natural-scientific thought and religious world view, out of which the tragic errors of the last centuries arose, are cleared away."<sup>43</sup>

Jordan's turn to cosmology was directly motivated by Dirac's papers of 1937-38, which he enthusiastically welcomed and strove to elaborate. However, his interest in cosmology predated Dirac's first announcement of the large number hypothesis, such as is revealed by his book, *Die Physik des 20. Jahrhunderts* from 1936. This important book, appearing in many German editions, and translated into several languages, was in a general sense inspired by Bernhard Bavink, a German philosopher and teacher of physics.<sup>44</sup> A prolific author both in physics and philosophy of science, Bavink was best known for his

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<sup>42</sup> Wise 1994.

<sup>43</sup> Beyler 1994, p. 532.

<sup>44</sup> On Bavink, see Hentschel 1993.

*Ergebnisse und Probleme der Naturwissenschaften*, which first appeared in 1914 and which, by 1948 had been published in 10 editions and also translated into English and French.

Bavink, who was of Protestant faith, had a profound interest in the relationship between physics and religion. In a paper of 1910 he examined the entropic argument for the existence of God, only to conclude that it was invalid and that no theological consequences followed from thermodynamics. The same message was included in his book of 1914. The essence of theism, as he saw it, was that there would be no world without God; whether or not the world had a beginning in time was of no great importance. In general he criticized the tendency to look for God only in cosmic processes. If God had created the world, atoms were his creations no less than galaxies. To think differently would be "half, theism, half atheism."<sup>45</sup> Bavink was for a time sympathetic to German nationalism and the national-socialist movement of Hitler; but from about 1934 he became increasingly antagonistic to anti-Semitism, racist ideology, and the attempts within the Third Reich to base science on a purportedly "Aryan" foundation. In his book, *Die Naturwissenschaft auf dem Wege zur Religion* from 1932, he endeavoured to present science and religion as partners in a dialogue rather than natural enemies. Although he denied that the new relativity and quantum physics could lead to a proof of God's existence, he believed it was in far better congruence with Christian belief than the physics of the classical era. Quantum theory, he argued, indicated a continually creative agent, and offered a grander view of God's greatness and omnipresence. The book attracted international attention and was quickly translated into English and Swedish. Bavink was aware that big-bang cosmology was sometimes taken as scientific proof of a created universe—and hence of God's existence—but this was an argument he rejected. As he pointed out in a later work, the question of the creation of the world has nothing to do with its temporal development; it is precisely the same whether the universe has a finite age or has existed since eternity.<sup>46</sup>

In his work of 1936, Jordan offered a semi-historical and semi-philosophical account of physics and the other natural sciences, as

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<sup>45</sup> Bavink 1914, p. 144.

<sup>46</sup> Bavink 1952, p. 101.



seen through the glasses of a convinced positivist. As he repeatedly emphasized, the new physics was anti-materialistic and had "conclusively liquidated" the materialism of former science. This was also one of Bavink's messages, except that Bavink had gone further, namely to try to find a road to a positive evaluation of God through the understanding of modern physics and the other sciences. Jordan admitted that in an examination of the new relationship between science and philosophy, "Certainly the religious question cannot be avoided," and he also believed that with the defeat of materialism followed "a positive gain in freedom of motion for religious thinking." But that was as far as he was willing to go. As a positivist, Jordan wanted to limit his analysis to what are "scientifically proven and independent of personal opinion," and he denied that knowledge of God could be obtained scientifically, that is, be grounded in empirical data.

Still, although positivist science—strictly empirical and value-free as it is—cannot lead to God, Jordan maintained that "the positivist conception offers new possibilities of granting living space to religion without contradiction from scientific thought." There was no direct route from scientific knowledge to religious insight, yet Jordan was eager to stress the legitimacy of religion and other forms of spiritual quest. To Jordan, religion was clearly more than opium for the people. On the other hand, even though positivism opened up for a reconsideration of religion, he fully recognized that religious experience did not match at all with the positivist criterion of meaningfulness. "Positivist criticism," he wrote, "will only admit to the theses of theological theories a meaningful contact when they are shown on closer analysis to be expressions of concrete experiences." This cautious attitude also remained with Jordan in his works published after the war. Thus, in a book titled *Der Naturwissenschaftler vor der Religiösen Frage*, he repeated that modern science had destroyed materialism and thereby broken down the walls separating science and religion.<sup>47</sup> But he also emphasized that his personal belief was irrelevant, that the matter had to be illuminated purely in terms of scientific and historical facts. Jordan was a Christian, but he preferred to hide his belief behind the cover of positivism.

<sup>47</sup> Jordan 1963, pp. 11–23. Jordan closed his book with two lines from Psalm 121, "I look to the mountains, where will my help come from?" The verse continues: "My help will come from the Lord, who made heaven and earth."

In the final chapter of his 1936 book, Jordan discussed the recent progress in cosmology and the vexed problem of the age of the world. Already at that time, he had accepted the big-bang picture of Lemaître, to whom he explicitly referred:

If we mentally pursue the development of the universe farther and farther back, we come to a point where everything is at an end, or rather, everything is at the beginning. About 10 billion years ago the world diameter, today grown to 10 million [billion] light years, must have been vanishingly small. ... [T]he initially small universe arose from an original explosion. Not only atoms, stars and milky way systems but also space and time were born at that time. Since then the universe has been growing, growing with the furious velocity which we detect in the flight of the spiral nebulae.<sup>48</sup>

Jordan was aware that the scenario—and that is all it was—had similarities to Genesis, but he refrained from making any direct connection between the two pictures. Rather, he pointed out that the scenario was scientifically based and motivated, that “our scientific research on the future and past of the universe need not be influenced by human desires and hopes or by theological theories of creation.” And yet, scientific as the picture of the exploding universe allegedly was, Jordan found it appropriate to end his book with a reference to speculations that the universe might be nothing but the dream of God, asking “Whether prayer or ritual perhaps be nothing but attempts to make HIM more drowsy, so that HE does not awaken and stop our dreaming.”

Jordan had studied Eddington’s *Relativity Theory of Protons and Electrons* with great interest—“Eddington’s new approach will be a source of important and fertile ideas in physical research,” he predicted—and when he became acquainted with Dirac’s theory he eagerly adopted it. However, Jordan the positivist strove to represent cosmo-physics as complying with the norms of his favored philosophy of science. Numerological reasonings based on the constants of nature were not speculative or *a priori* at all; on the contrary, they supplied purely observational facts and thus confirmed him in the belief that it was possible “to distinguish quite clearly between what are *observational facts*—which are as such *independent of any theory*—and

<sup>48</sup> Jordan 1944, p. 183.

what are the results of theoretical considerations." Jordan discussed various relations between the constants of nature, largely the same relationships that Eddington, Haas and Dirac had discussed. There was little new material in Jordan's discussion, but there was new thinking in his interpretation. The German positivist physicist considered the Eddington-Haas-Dirac relations as "mere reformulations of experience, freed from hypotheses," and Dirac's version to be nothing but "empirical cosmology."<sup>49</sup>

The main content of Jordan's early cosmology, such as that which he developed in the late 1930s and through the years of war, was as follows.<sup>50</sup> He took over from Dirac the proportionality  $G(t) \sim t^{-1}$  and also the spontaneous creation of matter in the universe, but in a far more dramatic version than the gentle creation of individual hydrogen atoms homogeneously throughout the depths of the universe. He proposed that stars and nebulae might be formed spontaneously as whole bodies, at first as nuclear "droplets" with a maximum density corresponding to that of an atomic nucleus (given by  $M/a^3$ , where  $a$  is a smallest length, the classical electron radius). He considered a closed world model expanding uniformly with the speed of light, so that the radius grows proportionally with the epoch ( $R = cT$ ). A uniformly expanding model had been considered by E. A. Milne within his so-called kinematic-relativistic cosmology, and is allowed also by general relativity, but only in the case of an empty universe. Since Jordan wanted his cosmology to comply with Einstein's theory of general relativity, and since he never expressed any interest in Milne's alternative, this was a problematic feature. Jordan did not explicitly address the problem, but of course he realized that a cosmology with matter creation implied some modification of the field equations of general relativity.

Another problem for Jordan's cosmology, a problem shared with Dirac's and most other cosmological models of the time, was the so-called age paradox, namely, that it led to an age of the universe which was smaller than that of the earth. In his theory of 1938, Dirac had vaguely suggested that the problem might be solved by assuming radioactive decay to vary with the epoch, an idea which Jordan developed together with Fritz Houtermans. They assumed that

<sup>49</sup> Jordan 1938.

<sup>50</sup> Jordan 1939, Jordan 1944.

$\beta$ -emitters did not follow the ordinary decay law  $N = N_0 \exp(-kt)$ , but instead the expression

$$N(t) = N_0 \exp(-2k\sqrt{t})$$

If this was the case, radiometric dating by means of the rubidium-strontium method would have to be reinterpreted, and might lead to a value of the age of the earth in agreement with cosmological theory.<sup>51</sup> Still, in 1964 Jordan found it possible that  $\beta$ -radioactivity might vary with time, whereas he maintained the temporal constancy of the other constants of nature (with the exception of  $G$ , of course).<sup>52</sup>

The spontaneous creation of high-density bodies may seem to imply a gross violation of the law of energy conservation, but according to Jordan this was not the case, as he argued that matter creation was energetically compensated for, by the expansion of the universe. For dimensional and numerical reasons he assumed that

$$\rho = (\kappa c^2 T^2)^{-1}$$

where  $\kappa$  is the Einstein gravitational constant  $8\pi G/c^2$ , and  $T = H^{-1}$ . With  $\mu = \rho R^3$  and  $R = cT$ , the expression can be written as  $\kappa\mu = R$  or, apart from a factor  $8\pi$ ,

$$\mu c^2 = \frac{G\mu^2}{R}$$

As we shall see, the same expression had been suggested by Haas in 1936. Jordan followed Haas in interpreting the left side as the mass-energy of all the particles in the universe, and the right side as the contributions of the particles to the negative gravitational energy of the universe. The mass increase is thus compensated for by an increase in negative potential energy, leaving the total energy of the universe unchanged, namely, equal to zero.

Many years later, at the 1958 Solvay Congress, Fred Hoyle used the same argument in support of the very different kind of matter creation that occurs in the steady-state theory.<sup>53</sup> And again, after the

<sup>51</sup> Houtermans and Jordan 1946. Another hypothesis of varying radioactive decay was proposed a few years earlier by Haldane (see Chapter 6).

<sup>52</sup> Jordan, Ehlers and Kundt 1964.

<sup>53</sup> Hoyle 1958.

standard big-bang model had been firmly established in the 1970s, the Haas-Jordan idea of a universe with zero net energy came to play an important role in the first generation of quantum creation cosmologies that eventually led to the modern view of the inflationary universe. Physicists in this modern tradition have consistently ignored, or rather, have been unaware of, the early contributions of Haas and Jordan. Today the idea is usually credited to Edward Tryon, who in a paper of 1973 essentially repeated the Haas-Jordan argument, without knowing that it had been proposed more than 35 years earlier.<sup>54</sup>

Neither Haas nor Jordan placed their idea of a universe with zero net energy in a theological context, but others have used it to justify God's creation of the universe out of nothing. In 1958, in a discussion of Thomas of Aquinas' relevance to modern cosmology, the distinguished American physicist Henry Margenau considered a finite spherical universe homogeneously filled with matter. Like his predecessors, he argued that  $G\mu/Rc^2 \cong 1$ , from which he concluded that divine *creatio ex nihilo* is possible.<sup>55</sup> But, one may ask, does this really explain the creation of the universe out of nothing? Does "nothing" have zero energy? Moreover, it cannot be an argument for *divine* creation, but, at most, an argument for matter creation in accordance with the law of energy conservation.

Jordan was one of the very first scientists before World War II to subscribe to a version of the big-bang universe, an idea which in the 1930s was generally considered highly speculative, if not a flight of fancy—a *jeu d'esprit* (to use Barnes' expression of 1933). Jordan's world model was clearly inspired by Lemaître's fireworks model of 1931, and like his Belgian source it was finite in space as well as in time. However, contrary to Lemaître (but following Dirac), Jordan preferred to put the cosmological constant equal to zero. Although Jordan was strongly influenced by Dirac, he ended up with a world model that differed in important respects from that of his British colleague: whereas Dirac argued in 1938 from the large number hypothesis that space was flat and infinite, according to Jordan it was finite and with a positive space curvature.

In 1944 Jordan elaborated his ideas in a paper in *Physikalische Zeitschrift*. However, because of the war it made no impact at the

<sup>54</sup> Tryon 1973. For the continuing appeal of the idea, see, e.g., Overduin and Fahr 2003.

<sup>55</sup> As discussed in Jammer 1999, pp. 201–203.

time, and was scarcely known to people outside of Germany. Jordan believed that the universe had come into existence some 10 billion years ago, but not in an explosive event, such as in Lemaître's scenario, for initially there was no matter in the universe—no fireworks to explode. Matter, he explained, was formed along with the expansion. According to Jordan, the history of the universe could be traced back to a time when its radius was only one atomic length (about  $10^{-15}$  m), and when it consisted of only one pair of newly created neutrons. As space expanded and the neutrons separated, the change in gravitational energy would be balanced by the creation of new matter. Ten seconds after the big bang, the universe would have grown to the size of the sun, though with a mass less than that of the moon. At this early time, so Jordan explained, the universe would consist of about  $10^{12}$  stars of an average mass of  $10^9$  kilograms, and a supernova formed at that time would initially have a radius of only 1 mm.

One might think that Jordan's daring scenario of the very early universe was highly speculative, but somehow he convinced himself that it was in "satisfactory agreement with the epistemological requirements of positivism." He contrasted his own, methodologically satisfactory picture with Lemaître's alternative of a pre-existing primordial atom which, Jordan thought, necessarily led to the meaningless question of a causal mechanism for the initial explosion. Of course, Jordan's picture of the creation of the material universe also differed from the theory that George Gamow and his collaborators began to develop at the same time—a theory which in a qualitative sense relied on Lemaître's and which eventually would become accepted as the basis of the correct theory of the early universe.

As he developed his ideas in the 1940s, Jordan extended his cosmological theory into the realm of astrophysics.<sup>56</sup> For example, he noticed that the heaviest stars have a mass of about  $10^{60}$  nucleon masses, which he interpreted as the  $3/2$  power of the cosmic epoch in Dirac's atomic units. From this he suggested that the stellar mass would increase in time as  $M_{\odot} \sim t^{3/2}$ , not in the sense that a star continuously became heavier, but in the sense that the later a star was formed the heavier it would be. He consequently suggested that the upper limit of stellar masses was a consequence of cosmology and not, as generally accepted, the result of astrophysical laws. Naturally,

<sup>56</sup> Jordan 1944 and elaborated in Jordan 1947.

this claim did not help in making his theory acceptable to the majority of astrophysicists.

In order to incorporate increasing stellar masses in a consistent way into his theory, Jordan was led to postulate the spontaneous creation of entire stars *ex nihilo* in such a way that the concentrated droplets of nuclear matter would first appear as supernovae, and subsequently turn into ordinary stars. Moreover, he found that the rate of stellar creation per galaxy would proceed as  $t^{1/4}$ , and from this he deduced a rate of supernova formation of about 1 supernova per galaxy per year. But, as Hermann Bondi pointed out in 1952, this figure is more than 100 times as large as the observed rate and hence, Bondi concluded, "the theory must be false."<sup>57</sup> Jordan was aware of the flagrant discrepancy and sought to explain it within the framework of his theory; but most astronomers and physicists considered his explanation to be grossly *ad hoc*, as explaining away an anomaly rather than explaining it. The criticism of Bondi and others was one more reason why Jordan's theory was not highly regarded by mainstream astrophysicists.

Jordan's theory included matter creation, and assumed a spatially finite universe with an origin in time. These were features which strongly contradicted the official ideological world view of communism in the 1950s. Soviet ideologues saw in all kinds of big-bang theories the stamp of clericalism and bourgeois idealism, and a big-bang theory with the creation of stars out of nothing was even more abominable to orthodox defenders of dialectical materialism. It cannot have made things better that the theory came from a former Nazi with strong anti-communist views—a spokesman of Western German re-armament and a member of the Christian Democratic party (Jordan was a member of the parliament, the *Bundestag*, from 1957–61). No wonder that Jordan's theory was renounced by Soviet scientists, with criticism that was not only scientifically based. At the Eighth Congress of the International Astronomical Union, held in Rome in 1952, two of the Soviet delegates, B. V. Kukarkin and A. G. Masevich, attacked Jordan's cosmology because it was open to the kind of religious exploitation that they knew from the pope's address the previous year. Kukarkin, a former vice president of the International Astronomical Union, claimed that many Western

<sup>57</sup> Bondi 1952, p. 164.

cosmologists knowingly or unknowingly formulated their hypotheses in agreement with religious dogmas.<sup>58</sup> But Jordan was in good company, for the targets of the Soviet criticism included also Gamow, Milne and Lemaître, and even the “thoroughly idealistic and absurd” steady-state theory.

## HERBERT DINGLE AND MODERN ARISTOTELIANISM

The cosmo-physical theories of Milne, Eddington, Dirac and their followers were bound to meet resistance from physicists committed to the more traditional ideal of inductive science based on experiment and observation. The favourite method of the cosmo-physicists was to rely on desiderata such as simplicity and inner harmony in the suggestion of hypotheses, and only subsequently to test these, via their deductive consequences, against the observable world.

In 1937 the two conceptions of theoretical physics were dramatically confronted in the pages of *Nature*, motivated by an unusually sharp attack from Herbert Dingle, the astrophysicist and philosopher of science.<sup>59</sup> According to Dingle—an inductivist and empiricist—science was organized common sense, and philosophy an attempt to extract critically and systematically the results of the special sciences.<sup>60</sup> This view—the time-honoured view of Galileo, Newton and Maxwell, he claimed—he now felt was threatened by the rationalistic excesses of the British cosmo-physicists, the “modern Aristotelians” and their unbalanced apriorist methods.

Dingle’s philosophy of science also included religion and the relationship between religion and science, a topic he first dealt with in 1928 (see Chapter 3). In a book from 1931 he elaborated on the theme, arguing that religious experience is always an individual matter, whereas science is a method of dealing rationally with what are common to all normal people; for this reason alone, there can be no direct antagonism between science and religious experience. “Science has nothing to say about holiness, sacredness, morality, or any other part

<sup>58</sup> Graham 1972, p. 170. Struve and Zebergs 1962, p. 32.

<sup>59</sup> The debate is analysed in Kragh 1982, Gale and Shanks 1996, and Gale and Urani 1999. After the war, Dingle became head of the newly founded Department of History and Philosophy of Science at University College, London, and he was among the founders of the *British Journal for the Philosophy of Science*. On Dingle’s later career, see Chang 1993.

<sup>60</sup> Dingle 1937a.



of experience of like character. ... Science and Religion are essentially independent."<sup>61</sup> Like Einstein, he explained historical disputes such as that between Galileo and the Roman Church, as a controversy between religious dogmas and science, not between religion and science. When it came to subjects such as miracles and the infallibility of the Bible, Dingle concluded that the scientist *qua* scientist must remain agnostic. The same held for the existence of God: when it is stated that from the scientific point of view that God does not exist, what it all means is that God is not a common experience. Dingle phrased it as follows: "The idea of a personal God is irrelevant in physics, not because it is unsuccessful but because it is too successful, not because it cannot correlate our common experiences—it correlates them all at one fell swoop—but because it cannot correlate them rationally."<sup>62</sup>

The 1937 debate did not concern religion, but rather, methodology and the standards of science. In his initial attack, Dingle accused the cosmo-physicists of perverting the proper method of science, that is, to start with sense observation and only allow general principles afterwards and insofar these can be derived by induction from the observational data. His primary target was Milne's theory, which to him was nothing but pseudo-science; but it was Dirac's new cosmology which called him into action. "This [Milne's] combination of paralysis of the reason with intoxication of the fancy is shown, if possible, even more strongly in Prof. P. A. M. Dirac's letter in *Nature* of February 20 last, in which he, too, appears as a victim of the great 'Universe' mania."<sup>63</sup> He questioned the scientific status of cosmology, especially if it was based on mathematical models and general principles. Cosmology might then become just another idolatry, degenerate into what Dingle called "cosmythology" and "cosmolatry." If the methods of Milne and Dirac were generally accepted, the proud tradition of experimental philosophy would come to an end. "The question presented to us now is whether the *foundation* of science shall be observation or invention. ... Instead of the induction of principles from phenomena we are given a pseudo-science of invertebrate cosmythology, and invited to commit suicide to avoid the need of dying."

<sup>61</sup> Dingle 1931, p. 121.

<sup>62</sup> *Ibid.*, p. 130.

<sup>63</sup> Dingle 1937a, p. 784.

The debate in *Nature* caused by Dingle's strongly worded objections engaged many of Britain's most eminent scientists and scholars, including the physicist and cosmologist W. H. McCrea; the biologist J. B. S. Haldane; the statistician and geophysicist H. Jeffreys; the astronomers R. A. Sampson and J. G. Whitrow; the physicist C. G. Darwin; the mathematician L. N. G. Filon; and the philosopher G. D. Hicks.<sup>64</sup> In his reply, Milne maintained that his theory rested on the positivistic doctrine of introducing only elements that can in principle be observed, but this was about the only concession he gave to Dingle's empiricism. (On Milne's philosophy of physics, see Chapter 6.) Also, Eddington refused to bow before Dingle's objections. He repeated his view that the general laws of physics do not state objective knowledge, but are expressions of the human mind. "I have found," he said, "that a great part of the current scheme of physics is deducible by *a priori* argument and therefore does not constitute knowledge of an objective universe." Dirac's response was brief and much more conciliatory. He sought to avoid philosophical discussion, and acknowledged that a proper balance must be maintained between empirical-inductive methods and speculative-deductive methods. He believed that he had kept such a balance, as his cosmological hypothesis lent itself to experimental tests, and built upon the constants of nature as provided by observation.

It is noteworthy that both camps claimed support of their arguments by reference to positivistic methodology, although of somewhat different kinds. Dingle and his allied Jeffreys accused their opponents of sinning against positivistic virtues as taught by Mach and Pearson, an accusation that Milne and Eddington denied. As mentioned, Jordan explicitly justified his version of cosmo-physics by reference to standards of logical positivism. If the debate showed nothing else, it did show that positivism was varied and flexible as a doctrine. The root cause of the problematic hypothetico-deductivism was not the method itself, but its excessive reliance on mathematics. At least, this was how Jeffreys diagnosed the problem: "I think the source of the trouble is the belief that there is some special virtue in mathematics. Instead of being regarded as what it is, a tool for dealing with arguments too complicated to be presented without it, it has

<sup>64</sup> "Physical science and philosophy," *Nature* 139 (1937), 1000-1010.

become emotionalized to such an extent that many people think that nothing but mathematics has any meaning."

Highly interesting as the debate is from a methodological point of view, it was more than just an academic dispute concerning the proper methods of science. It also related, if only indirectly, to matters of ideology, science policy, and cultural standards. This, Dingle made clear in a final round of the controversy, where he intimated that Milne and his allies sought intellectual dictatorship over British theoretical astronomy. Dirac's paper was "an example of the bacteria which can flourish in the poisoned atmosphere; in a pure environment it would not have come to birth." Dingle's real concern was with "the general intellectual miasma that threatens to envelop the world of science." The debate of the late 1930s reflected the dire political situation at the time—the dangers of dictatorships and authoritarian regimes. Associating "Aristotelianism" with authoritarianism, it was probably to such dangers Dingle referred in his defense of empiricism:

The times are not so auspicious that we can rest comfortably in a mental atmosphere in which the ideas fittest to survive are not those which stand in the most rational relation to experience, but those which can don the most impressive garb of pseudo-profundity. There is evidence enough on the Continent of the effects of doctrines derived "rationally without recourse to experience." To purify the air seems to me an urgent necessity.<sup>65</sup>

Certainly, not only did fascist and communist ideologies question accepted views of science; also there was at the time a revival of anti-science feelings, anti-intellectualism and mysticism. When John Bernal in 1939 scornfully wrote of "those metaphysical and mystical theories which touch on the universe at large" he may have alluded to the cosmo-physicists.<sup>66</sup> Now the theories of Milne and Dirac were definitely not "mystical" (whereas Eddington's might qualify), but there is little doubt that the ideas of cosmo-physics, either in their rationalistic or more spiritual version, harmonized better with the spirit of time than did the dominant analytic-empirical approach favored by Dingle. At any rate, in the period around the outbreak of World War II, British scientists were clearly occupied with methodological issues,

<sup>65</sup> Dingle 1937b, p. 1012.

<sup>66</sup> Bernal 1939, p. 3. See also Chapter 6.

which they tended to associate with the contemporary political and ideological situation.<sup>67</sup>

Occasionally the scientists involved in the discussion included in their analyses also religious issues. To mention but one example, at the end of 1938 Viscount Samuel discussed in the Royal Institution the relationship between science and philosophy. Europe was preparing for war, Samuel observed, and behind the armies were the political creeds, such as communism, national-socialism, fascism, and democracy. "And behind the creeds are the philosophers: Marx and Engels; Hegel, Nietzsche, Spengler, Sorel and Croce; Mill and the other protagonists of liberty. Some of the creeds, it is true, are anti-intellectual; but irrationalism also is a philosophy of a kind."<sup>68</sup> Viscount Samuel suggested an unholy alliance between the forces of darkness and idealist philosophies of science, and urged a return to an empiricist and realist view of nature. Fortunately, there were signs that philosophy and science were coming closer together. He expressed as his hope that if this union becomes complete, the isolation of religion could also be overcome, and it might be possible at last to possess a unified and harmonious basis for thought and action.

## TWO CATHOLIC COSMOLOGISTS

Although considered important enough to have his entry in the *Dictionary of Scientific Biography*, the Austrian Arthur Erich Haas is a rather obscure figure in the history of physics, and rarely appears in the histories of cosmology. Yet he was an important author of physics textbooks, and a pioneer of cosmo-physics whose works on the subject were well known to his contemporaries.<sup>69</sup> He studied physics at Vienna and Göttingen and then, after having received his doctorate, turned to the history and philosophy of physical ideas, which in 1909 resulted in a monograph on the history of the principle of energy conservation. Long before the history of science had become an academic

<sup>67</sup> The 1937 dispute was re-opened in 1941, this time with Eddington being accused of apriorism by Dingle, Jeans and Jeffreys. See *Nature* 148 (1941), 140-141, 256-257, 341-342, 503-505.

Dingle continued his crusade after the war, when he attacked the steady-state cosmological theory in particular. See Chapter 6 and, in greater details, Kragh 1996, pp. 224-229.

<sup>68</sup> As excerpted in *Nature* 143 (1939), 210. For another example of linking philosophy of science with political ideology, see Allen 1940.

<sup>69</sup> On Haas, see Armin Hermann's biographical introduction pp. 7-26 in Haas 1966.

field, he had written articles on the subject, and also given lecture courses on it at the universities of Vienna and Leipzig. Haas is best known for a work of 1910, in which he, for the first time, introduced Planck's quantum theory in the architecture of atoms. Haas's atomic model attracted considerable attention among leading physicists such as Sommerfeld and Lorentz, but after the appearance of Niels Bohr's model of 1913 it quickly fell into oblivion. During the 1920s, Haas taught theoretical physics at the University of Vienna, and from 1927 to 1930 he spent much of his time on lecture tours in the United States. Although he did not contribute to the new quantum mechanics, he followed it closely and wrote in 1928 one of the first textbooks ever on the subject, *Materiewellen und Quantenmechanik*. In 1935, he emigrated to the United States, where the following year he was appointed professor of physics at the (Catholic) University of Notre Dame.

Haas had become interested in numerological physics many years before Eddington made the field popular. Indeed, much of his 1910 atomic theory relied on reasoning of a numerological nature. As early as 1918 he had pointed out the significance of dimensionless constants, and suggested on this basis a relationship between atomic constants and Newton's constant of gravitation.<sup>70</sup> His suggestion was

$$G = \left(\frac{e}{m}\right)^2 \pi^{-2} \sqrt{M/m}$$

After Hubble announced his discovery of the receding nebulae, Haas eagerly took up cosmological questions, which he investigated within his favored cosmo-numerological approach. His book, *Kosmologische Probleme der Physik* from 1934, based on lectures given at the University of Vienna, provided an excellent introduction to relativistic cosmology, and was one of the earliest books of its kind. One year before Eddington, he had observed that Weyl's number  $e^2/GmM$  was very close to the square root of the number of protons in the universe.

Among Haas's many results was nothing less than "a purely theoretical derivation of the mass of the universe" based on the assumption that, numerically, the gravitational energy of the universe equals the proper energy of all particles in it.<sup>71</sup> Haas had always insisted that

<sup>70</sup> Haas 1918.

<sup>71</sup> Haas 1936.

the universe must be spatially closed, hence be finite in volume and containing only a finite number of objects. With  $\mu$  denoting the mass of the universe, the assumption of zero total energy means that  $G\mu^2/R = \mu c^2$  or  $\mu = Rc^2/G$ . He further related the natural constants to Eddington's cosmical number by the formula

$$\sqrt{N} = \frac{10}{3} \frac{hc}{GM^2}$$

In another paper, Haas argued that at the largest distance possible in a spherically closed universe (which is  $\pi R$ ), the recessional velocity of galaxies becomes equal to the velocity of light.<sup>72</sup> From this he deduced that

$$G = \pi H_0 a^2 c / M$$

where  $H_0$  is the present value of Hubble's parameter, and  $a = e^2/mc^2$  is the classical electron radius. He concluded that the relationship agreed nicely with experimental data. Among Haas's contributions to early physical cosmology must also be counted a symposium he arranged at the University of Notre Dame in the spring of 1938.<sup>73</sup> The theme of the symposium was "The Physics of the Universe and the Nature of Primordial Particles," and among the participants were leading physicists and astronomers, including A. H. Compton; C. D. Anderson; H. Shapley; Gregory Breit; and Lemaître. Haas gave a talk on his favorite topic, "Cosmic Constants."

Haas was a Catholic, and as a young man he argued explicitly that the second law of thermodynamics led to a beginning and end of the world, and that this constituted proof of a divine creator.<sup>74</sup> However, he seemed to have soon abandoned this kind of entropic reasoning, and been content to point out the general congruence between Christianity and the world view of modern physics. In a popular lecture of 1911 he dealt with the problem of the infinite universe, both in a spatial and a temporal sense. As to infinite space he admitted it as a possibility, but it was conceptually problematic, and he doubted that an infinite number of objects could be consistent with the laws of physics. Haas was much more attracted by the idea of a finite,

<sup>72</sup> Haas 1938a. For other of Haas's cosmo-physical relations, see Haas 1934.

<sup>73</sup> *Science* 87 (1938), 487-490.

<sup>74</sup> Haas 1907. See Chapter 2.

unbounded universe, such as allowed by Riemannian geometry. By adopting this idea he could avoid Olbers' paradox, and also the gravitational paradox, without accepting Seeliger's modification of Newton's law of gravitation.

As to the time scale, Haas launched two arguments in favor of a finite-age universe. One was the familiar entropic argument, although at this occasion he did not refer to either creation or a creator. His other argument, based on the young science of radioactivity, was more original. Uranium and the other elements were slowly decaying, from higher to lower atomic weights, and of course with finite half-lives. How could there still be radioactive elements in the earth's crust, and probably all over in the universe, if the world had existed in an eternity? "The phenomenon of atomic decay, which probably governs not only radium and uranium but all matter, constitutes an important new objection against the assumption of an eternal world."<sup>75</sup> Haas' suggestion to link together radioactivity and cosmology in this way may have been the first of its kind. When, many years later, Lemaître suggested his hypothesis of a universe of finite age, he referred to radioactive minerals as important evidence.

In none of his many works on cosmo-physics in the 1930s did Haas refer to religious or spiritual aspects, but rather he presented them in the positivistic style of Jordan. The only time he publicly addressed the question was in a paper of 1938 published in *The New Scholasticism*, the journal of The American Catholic Philosophical Association.<sup>76</sup>

Haas argued that modern quantum theory and cosmology had shown that the physical universe can be understood scientifically only to a limited degree. Even in principle, it defies an exhaustive scientific explanation. For example, the origin of the universe is a unique process, and "It seems to be utterly meaningless to consider such process from the standpoint of physical law." Rather than deploring the limitations of nomological science, he welcomed the view that there was much which cannot be the object of scientific research but only of "humble veneration." Haas believed that the new physics and cosmology had strengthened religious sentiments and made science-based or scientific atheism a much less plausible

<sup>75</sup> Haas 1912, p. 184. At the time it was often assumed that all chemical elements are radioactive, only that most of them had exceedingly long half-lives.

<sup>76</sup> Haas 1938b.

position than in the earlier, materialistic physics. He grounded his conclusion on two arguments: the heat death and the finite extension of the universe.

The first phenomenon, and in general the temporal asymmetry implied by the second law of thermodynamics, stood in "complete opposition to the atheistic theory," he maintained. Like several other Christian writers, he claimed that according to the atheistic world view it was a fundamental dogma that the universe is infinite in space and time. But, fortunately for the believer, the dogma was undermined by modern cosmological knowledge. "Theoretical physicists believe in the finite extension of the universe," Haas wrote, conveniently neglecting the infinite world models proposed by Milne, Dirac and Einstein and De Sitter. Not only did modern science allegedly lead to a spatially finite universe—thus making it impossible to see in the universe a substitute for the infinite deity—it also pointed to a universe of finite duration. As Haas noted, "this scientific conclusion is in very interesting agreement with the religious idea of creation." He refrained from elaborating.

Edmund Taylor Whittaker had in common with Haas that he was a Catholic, and interested in the relationship between Christianity and relativistic cosmology; also, he shared with Haas a deep interest in the history of physics.<sup>77</sup> After studies at Trinity College, Cambridge, in 1906 Whittaker was appointed professor of astronomy in the University of Dublin. Six years later he was elected to the chair of mathematics in the University of Edinburgh, where he taught until his retirement 34 years later. In 1930 he was received into the Roman Catholic church, and until his death in 1956 he remained active within British Catholic life. His scientific eminence is illustrated by his election in 1905 to become a Fellow of the Royal Society (at the age of 32) and also his appointment in 1936 as a member of the new Pontifical Academy of Sciences.

Although starting as an astronomer, Whittaker worked primarily in pure and applied mathematics. He also contributed to aspects of mathematical physics, such as generalized dynamics and potential theory, much of which work he summarized in his book, *A Treatise on the Analytical Dynamics of Particles and Rigid Bodies*, first published in 1904. The book became the standard work from which an entire

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<sup>77</sup> On Whittaker's life and work, see Temple 1956.



generation of British physicists learned mathematical theory and methods. Whittaker also published on the general theory of relativity, in particular on electromagnetic phenomena. In an important paper of 1935 he formulated a new version of Gauss's theorem within the framework of general relativity, by introducing what he called "potential mass" in addition to the gravitational mass.<sup>78</sup> The result would later be employed by William McCrea to formulate a version of steady-state cosmology in agreement with the general theory of relativity.

To historians of the physical sciences, Whittaker is best known for his monumental and erudite treatise *A History of Aether and Electricity*, first published in 1910 and subsequently in greatly enlarged editions. When Eddington began his research program to integrate quantum mechanics and cosmology, Whittaker immediately became interested, and he closely followed Eddington's work, which he saw to its completion as editor of the posthumous *Fundamental Theory*. Although fascinated by Eddington's philosophy, he was by no means an Eddingtonian in either physics or philosophy; and he never took much interest in the numerical relationships between natural constants.<sup>79</sup>

In a review of *The Nature of the Physical World*, Whittaker expressed his satisfaction with Eddington's refusal to use modern science apologetically.<sup>80</sup> Ironically, Whittaker himself developed to become a chief apologetic, one of the few scientists who openly used the state of cosmology as a nearly scientific proof of God. No wonder that pope Pius XII found in him a model to use in his argument for Christian religion being strongly supported by contemporary cosmology. Whittaker first took on this role in his book, *The Beginning and End of the World*, based on his Riddell Memorial Lectures. Unsurprisingly, he supported the old entropic argument which he thought was a valid proof of the existence of God. For him, as for the earlier generations of Victorian scientists, creation and entropy were inseparably connected. The second law of thermodynamics did not

<sup>78</sup> Whittaker 1935.

<sup>79</sup> See the critical remarks in Whittaker 1942. In an extensive review of the book, *Relativity Theory of Protons and Electrons*, Whittaker admitted that it was written by a man of genius, but he added that "whether it produces conviction is another matter." *The Observatory* 60 (1937), 14-23. Although he found the book to be very interesting from a mathematical and philosophical point of view, Whittaker thought that Eddington's theory was so remote from ordinary physics that it would scarcely have much significance to the physical sciences.

<sup>80</sup> *Nature* 123 (1929), 4-5.

merely indicate a beginning of the universe—it led to the conclusion that there had been “a *creation*, when the total entropy of the universe was less than it has ever been subsequently.” Whittaker went on along the theological trajectory:

The knowledge that the world has been created in time, and will ultimately die, is of primary importance for metaphysics and theology; for it implies that God is not Nature, and Nature is not God ... For if God were bound up with the world, it would be necessary for God to be born and to perish.<sup>81</sup>

According to the world model favored by Eddington—the Lemaître-Eddington model—the universe had always existed, the expansion set in asymptotically only at some time in the past. Even Lemaître’s big-bang model presupposed a kind of physical beginning: an original, highly compressed state of the world in which time had no meaning. But Whittaker denied that the initial state of the world was a pre-existing, inert universe. He seems to have rejected not only Jeans’ finger but also Lemaître’s acausal mechanism of the origin of the universe:

There is no ground for supposing that matter ... existed before this in an inert condition, and was in some sense galvanized into activity at a certain instant: for what could have determined this instant rather than all of the other instants of past eternity? It is simpler to postulate a creation *ex nihilo*, an operation of Divine Will to constitute Nature from nothingness.<sup>82</sup>

In his works between 1942 and 1946, Whittaker emphasized with great religious feeling the significance of modern cosmology to the philosopher and theologian. Although he was careful not to claim that a universe of finite age constituted a proof of God’s existence in any direct sense, he did his best to demonstrate the consonance of modern cosmological theory with the doctrines of Christian natural theology. In the 27th Guthrie Lecture, delivered 18 May 1943, he stated as a matter of fact that modern cosmology had shown that “there must have been a Creation.”<sup>83</sup> Like Lemaître in his 1931 paper, he appealed to quantum indeterminacy to emphasize that the present

<sup>81</sup> Whittaker 1942, p. 40.

<sup>82</sup> *Ibid.*, p. 63.

<sup>83</sup> Whittaker 1943, p. 460.

universe is not a mathematical consequence of the state of matter and energy at its origin a couple of billion years ago. There was room for freedom and the intrusion of genuinely new elements that could not be derived from the laws of physics. On the other hand, the quantum mechanical indeterminacy that made pure determinism impossible, could be regarded from the theistic point of view as acts of the divine will, and therefore as part of God's deterministic plan.

Whittaker's most sustained attempt at cosmo-theology appeared in the Donnelan Lectures that he delivered in Trinity College, Dublin, in 1946 and which appeared as a book the same year. The message of *Space and Spirit* was that the world view of modern physics and astronomy offered strong arguments in favor of a universe created by an almighty and omniscient God: "The deeper understanding of the nature of the material universe, which has been achieved by scientific discovery, has opened up new prospects and possibilities to the advocate of belief in God."<sup>84</sup> Whereas Lemaître refrained from speaking of the origin of the universe as a creation, Whittaker had no such reservations (and his was a Creation with capital C). Not only did he find God confirmed in the finite age of the universe, he also found the divine creator in the lawfulness of the universe, the fact that the universe is a cosmos, not a chaos:

Mathematical law is a concept of the mind; and from the existence of mathematical law it is not unreasonable to infer that there is a mind, analogous to our minds, in or behind material Nature: the order which exists is meant to exist; ... When we reflect on the unity of the cosmos—its coherence and interconnectedness, the adaption and co-ordination of its parts—we are led to consider that it exists for some intelligible end. In a world that was not the expression of intelligence, science could never have come into being.<sup>85</sup>

Moreover, since the mathematical laws are universally valid, the same throughout the universe, they must reflect the will of a single mind, and hence be an argument for monotheism such as Christianity. Having thus argued for monotheism (or perhaps mono-deism), Whittaker was faced with the age-old problem of identifying the universal mind with the transcendent God of the Bible. So far the

<sup>84</sup> Whittaker 1946, p. 135.

<sup>85</sup> *Ibid.*, pp. 129–130.

argument might as well point to an immanent mind, to a form of pantheism. But according to Whittaker, modern cosmology and thermodynamics came to the rescue:

If we have the knowledge that the universe cannot have existed for an infinite time in the past under the operation of our present laws of nature—in other words, that there must have been a Creation—and moreover that there must come a time when for physical reasons life will be impossible, then these are facts which make it incredible to suppose that God is bound and conditioned by a world which has its appointed times of birth and death. If we have in any way arrived at the conviction that God exists, modern cosmology points to the further conclusion that He must be, in one aspect of least, extramundane.<sup>86</sup>

Although Whittaker's views differed in important respects from those of his fellow-Catholic Lemaître, the two agreed that although the history of the universe can be traced far backwards in time, its origin will forever be beyond the possibility of scientific explanation. In Whittaker's words, "The Creation itself being a unique event is of course outside science altogether."

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<sup>86</sup> *Ibid.*, p. 131.



# 6

## **Cosmology between Theism and Atheism**

# 6

## Cosmology between Theism and Atheism

### FROM ASTROPHYSICS TO COSMOLOGY

Edward Arthur Milne has been described as “one of the greatest figures in the greatest period of development of modern astrophysics and cosmology.”<sup>1</sup> Yet today he is not well known, and rarely appears in the historical literature on astronomy. His wildly ambitious attempt to provide a new and more rational foundation for physics—to create a “world structure” or cosmophysics—aroused great interest from 1932 to about 1945; but only a few years after his premature death in 1950 it was generally realized to be a failure, if definitely a grand one. It was relegated to the churchyard of wrong theories of everything, grouped together with Eddington’s equally ambitious fundamental theory. Whereas his cosmological theory had long ago ceased to interest astronomers and physicists, Milne’s methodology and research program has attracted considerable interest among historians and philosophers of science.<sup>2</sup>

Milne was born in Hull in 1896. Having received a stipend for Trinity College, he began to study mathematics shortly before the outbreak of World War I. In Cambridge, he followed the lectures of, among others, the physicist Sydney Chapman and the mathematician

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<sup>1</sup> McCrea 1951, p. 428.

<sup>2</sup> See the list of references in Kragh and Rebsdorf 2002. North 1965, pp. 149–185 gives a precise account of Milne’s cosmo-physical theory.

Godfrey H. Hardy. Barnes, the later bishop, acted as his director of studies, but nothing indicates that Barnes' instruction went beyond mathematics. Because of poor eyesight Milne was exempt from active military service, but in 1916 he joined the anti-aircraft experimental station of the Munitions Invention Department. During this period, which included a stay in France, he did important work on ballistics, sound ranging methods and atmospheric theory. He worked under a distinguished group of researchers which included the physicist Ralph Fowler and the physiologist Archibald Hill, later a Nobel laureate.

When he returned to Cambridge in 1919, he was elected a Fellow of Trinity College and from 1920–24 was appointed assistant director of the Solar Physics Observatory in Cambridge. Concurrently with his work in the observatory, he started giving lectures on astrophysics. Among his students was Paul Dirac, whom he supervised for a brief period in 1925, substituting for Fowler. At the young age of 28, he was appointed professor of applied mathematics at the University of Manchester, only to move on after three years to become the first Rouse Ball professor of mathematics at the University of Oxford, a position he retained until his death when 54 years old. Milne was elected a member of the Royal Society in 1926, and he received a number of other professional honors. His controversial and generally ill-regarded cosmo-physical theory did not seriously taint his reputation as an outstanding astrophysicist. The most prestigious prizes an astronomer could receive were the gold medal of the Royal Astronomical Society and the Bruce gold medal of the Astronomical Society of the Pacific. Milne was awarded both medals, in 1925 and 1945, respectively.

Milne's research career fell into three, largely consecutive stages. During the 1920s he focused on the theory of stellar atmospheres and the radiation equilibria of stars.<sup>3</sup> The most important of a series of works in this area was a paper he published in 1923 together with Fowler. Following upon the Indian physicist Meghnad Saha's pioneering work of 1920 on stellar spectra, they obtained a greatly improved theory that allowed them to determine the temperature and pressure of stellar atmospheres. In 1930 Milne gave a full exposition of this and his other works in a book-length article on

<sup>3</sup> Tayler 1996. Chandrasekhar 1987, pp. 74–92.



"Thermodynamics of the Stars" in *Handbuch der Astrophysik* (vol. III/1). By that time he had become interested in stellar structure, and had suggested a theory that strongly disagreed with the view of Eddington. The disagreement evolved into a controversy which strained the relationship between the two astrophysicists. Although some of Milne's arguments were of lasting significance, most were not, and by the mid-1930s it was generally admitted that Eddington had come victoriously out of the controversy.<sup>4</sup>

Scientifically important as Milne's work in astrophysics was, in the present context his theory of cosmology or cosmo-physics is of far greater interest. He first developed his own view on the structure and development of the universe in May 1932, after a brief and intense period of thinking, a revelation of a sort. "I was definitely visited by 10 days of inspiration, it was like the flinging aside of a curtain," he wrote to his brother a few months later. The result of the revelation, he went on, "destroys at one swoop much of the recent much-advertised work of Einstein, Jeans and Eddington, gives the only satisfactory (philosophically satisfactory) picture of the universe and of the content of reality which I am acquainted with, destroys time and space as legitimate objective conceptions and brings the light of cold reasoning into the fantastic medleys of thought created by Jeans and Eddington."<sup>5</sup> The following year Milne offered a much extended account of his theory in a 95-page article in *Zeitschrift für Astrophysik*. Milne completed this work while staying in Potsdam during the fall of 1932. While there, he gave lectures on astrophysics in various places in Germany and also in Copenhagen, and had discussions with Einstein. He was particularly stimulated by the German astronomer Erwin Freundlich, with whom he discussed cosmology and the latest progress in the theory of relativity. Freundlich published in 1933 a sympathetic account of Milne's theory, the first work on it outside of Britain.<sup>6</sup>

Although Milne had no cosmology of his own before 1932, he did have an interest in the subject. For example, in an anonymous review in *Nature* (vol. 126, pp. 742-743) under the title "World Physics and its Time Relations" he provided in late 1930 a competent and critical discussion of the recent cosmological ideas of Richard Tolman. Another

<sup>4</sup> Douglas 1956, pp. 63-64.

<sup>5</sup> Letter of 10 August 1932. Quoted in Gale and Shanks 1996, p. 286.

<sup>6</sup> Freundlich 1933.

route to cosmology came by way of thermodynamics, via a critical view of the heat death. About 1930, Milne communicated a paper to the Royal Society in which he argued that the notion of entropy increase is not applicable to the universe at large. The paper was declined, one of the reasons being that Jeans, who was serving as secretary of the society, thoroughly disagreed with its conclusions. When the British Association held its centenary meeting in London in 1931, Milne wanted to take up the subject in his address, but was dissuaded from doing so by Jeans; instead he spoke on a less controversial, astrophysical subject. Yet, he seems to have put forward his argument in an informal discussion, such as recalled by Whitrow, and Milne later incorporated it in his Cadbury Lecture of 1950.<sup>7</sup>

Milne's argument was not merely that the second law was not applicable to an infinite universe, but also that it required the possibility of dividing the universe into two portions, such that all processes in one portion leave the state of the second portion unaffected. This requirement would automatically exclude world-wide processes such as cosmic entropy increase. Milne concluded that there was no way in which changes of entropy in the whole universe could possibly be assessed. He kept to this view: "I am now convinced that an unconditional prediction of a heat-death for the universe is an over-statement," he wrote shortly before his death.<sup>8</sup> He was willing to accept the possibility that the Milky Way system would suffer from the heat death, but according to his cosmological theory (developed only after 1932) the overwhelming majority of galaxies were of much more recent origin and for them the drama of evolution had only just begun.

In his Cadbury Lectures, Milne developed his argument in greater detail, if only qualitatively. He cautiously concluded, not that the entropy of the universe was not increasing, but that the verdict could only be stated as "not proven." If we cannot infer that the universe ends in a heat death, what can we infer with regard to the final state of the whole universe? According to Milne, the answer was that

<sup>7</sup> Whitrow 1980, pp. 6-7. Milne 1952b, p. 146. Since Milne's address included no reference to entropy, he must have made his thermodynamic argument during a discussion of which there is no printed record. According to Whitrow, Milne "was careful to point out that we cannot say that the entropy of the universe is *not* increasing, ... [only that] we have no means for assessing change of entropy for the whole universe, since we can calculate such a change for 'closed systems' with something outside them but the universe *ex hypothesi* has nothing (physical) outside it."

<sup>8</sup> Milne 1952a, p. 166.

there is no final state. He did not need to appeal to special mechanisms for rejuvenation, such as had Arrhenius, Nernst and Millikan, for it followed from his theory that "the universe as a whole has no age and no size, only an age and a size when a particular observer is singled out, at a particular stage of his experience."<sup>9</sup> A few years earlier he had developed the same theme; only at this occasion, he introduced God into his argument. As a non-believer in cosmic entropy-increase, naturally he could not subscribe to the entropic proof of God, but there were other ways in which God could enter the picture. Milne said, "There has always seemed to me something derogating from the omnipotence of the Creator, if the totality of things created had to be subject to the humiliation of a 'heat death'."<sup>10</sup> Fortunately, according to his cosmological theory the heat death was not a consequence of thermodynamics.

## A KINEMATIC UNIVERSE

Milne saw no reason to accept Einstein's general theory of relativity as the basis for cosmology. Space was for him not an object of observation, not something physical, but just a system of reference; as such it could have no structure, curved or not, and nor could space itself expand or contract. The question of space curvature is "illegitimate," he said in a lucid presentation of his ideas he gave in 1943. The reason, he explained, is that the observer maps

his events in any type of space he chooses; and having chosen a type of space for measures in one scale of time, he may find it convenient, when he changes his scale of time, to adopt a space conformal to the first as his new map. ... [The curvature of space] is not a real fact about the system, but only something appertaining to the particular mode of description of the system.<sup>11</sup>

As to time, it was a primitive experience coupled to observers, not the fourth component of a space-time continuum. Milne's own model supposed a flat, infinite space and simple kinematic considerations.

<sup>9</sup> Milne 1952b, p. 151.

<sup>10</sup> Milne 1948, p. 12.

<sup>11</sup> Milne 1943-44, as reprinted in Munitz 1957, pp. 354-376, quotation on p. 362.

In his systematic 1935 presentation of his theory in the book, *Relativity, Gravitation and World-Structure*, he argued in great detail that all the basic laws of cosmical physics can be deduced from a very few principles. These he essentially obtained from analyzing the concepts used to order temporal experiences, and to communicate them by means of light signals. The physics arising from such considerations would naturally be restricted to distance and temporal relations; they could involve no initial appeal to dynamical or gravitational assumptions. In later works Milne did extend his theory to dynamics, including the theory of gravitation, which he fully presented in the book, *Kinematic Relativity* from 1948. He also sought to deduce electromagnetism without special assumptions, but never succeeded to make his equations fully agree with the Maxwell equations. He even made a half-hearted attempt to understand atomic theory in terms of kinematic relativity, as he called his theory, but this part of his work was a complete failure. Contrary to Eddington, he did not try to unify cosmology and atomic physics. His theory was essentially cosmological, and he paid little attention to atomic physics and almost none to quantum mechanics.

Milne considered a spherical part of infinite space where, shortly after  $t = 0$ , all the particles would move with uniform velocities, that is, he neglected collisions and gravitational attraction. He sometimes referred to "observer-particles," as he found it necessary to provide the particles with observers in order to determine the distribution of matter and motion in the universe. His observers were abstract entities, but they had human-like properties insofar they had to be able to reckon the flow of time. They possessed an "ego" to have something to perceive (and Milne consistently referred to his fundamental observer as "he," never "she".) Without such a perceiving ego, "space does not exist. It is a map I invent for the location in it of objects I perceive. If there are no objects to perceive, there is no space."<sup>12</sup>

In his idealized model, the observer-particles were taken to represent the galaxies of the real universe. By simple kinematic considerations Milne could show that the system would evolve in a Hubble-like way, with the fastest moving particles creating a densely populated spherical front near distance  $ct$  from the point of origin.

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<sup>12</sup> Munitz 1957, p. 369.

The spatial density of the system, as mapped by each observer, was given by

$$\rho = \frac{Bt}{c^3(t^2 - r^2/c^2)^2}$$

where  $B$  is a constant. This means that at time  $t$  the system is bounded at distance  $ct$  by an impenetrable barrier or singularity of infinite particle density. In spite of the infinite number of galaxies, Milne could show that the total brightness would be finite.

Milne found an outward velocity in agreement with Hubble's law and thus explained the expansion of his model universe without Einstein's gravitation theory—indeed without any gravitation at all. This simple explanation he found to be preferable to that of relativistic cosmology, as expressed in his article of 1933: "A fundamental difference between explanations of the current 'expanding space' type and the kinematic explanation, is that the former attribute the observed expansion to gravitational influences. The preference for the kinematical explanation is immediate on grounds of simplicity."<sup>13</sup> In Milne's expanding universe the distance between any two galaxies, moving with relative velocity  $v$ , would increase in time as  $r = vt$ . If the Hubble parameter is identified with the inverse of  $t$ , this corresponds to the Hubble law  $v = Hr$ . In Milne's model the age of the universe should thus be the same as the Hubble time, which at the time was estimated to be about 1.8 billion years. He presented his new world system to the British Association meeting in September 1933, and at this occasion he stressed that "The expansion is an inevitable phenomenon, . . . It is a primitive phenomenon, as foreshadowed by the author of Genesis."<sup>14</sup>

Milne's world system built on two fundamental principles or postulates. The one was the principle of the constancy of the velocity of light, which it shared with the special theory of relativity. Milne originally called the other postulate "the extended principle of relativity," but it soon came to be known under its presently known name, the cosmological principle. According to Milne, the world would, as a

<sup>13</sup> Milne 1933, p. 10.

<sup>14</sup> Discussion session on the expanding universe, British Association Report p. 437. As Milne explained, "The earliest reference I have found to the expansion of the universe is Genesis 1.6, when the Authorized Version gives in a marginal note the information that in Hebrew, the word 'firmament' also means 'expansion.'"

matter of principle, appear to be centered around each observer, and would look the same to each of them. All observers would see the same events occurring, and agree upon the laws of nature. This cosmological principle corresponded to the commonly held assumption of large-scale homogeneity and isotropy, as formulated by Einstein and others within a relativistic framework, but Milne believed that his version differed from Einstein's. In any case, it was only with Milne's theory that the cosmological principle became a basic postulate of cosmology and was widely discussed.

Among the results communicated by Milne in 1935 was that the value of Newton's constant of gravitation increases with the epoch, namely according to

$$G = \frac{c^3}{M_0} t$$

Here  $M_0$  denotes what Milne called the fictitious or apparent mass of the universe, the extrapolated mass around an observer from  $r \approx 0$  to  $r = ct$ . With  $t$  equal to the Hubble time, he found  $M_0 = 2.55 \times 10^{52}$  kg, which corresponds to a number of nucleons in the (apparent) universe of the same order of magnitude as Eddington's number,  $10^{79}$ . However, in the real universe there was an infinite number of galaxies and other material objects. The result of  $G \sim t$  had the advantage that shortly after  $t = 0$ , when the particle-galaxies were closely packed, there would be no gravitation to brake the rapid expansion; with increasing epoch  $G$  would grow, but now the galaxies would be so far apart that gravitation could be neglected. As Milne pointed out, in Dirac's theory the situation was just the opposite, which he considered a problem. In a later work, where he extended kinematic relativity to also cover electromagnetic phenomena, he considered Dirac's large-number relationships.<sup>15</sup> Milne concluded that, within his own system, it was not justified to conclude either that  $G$  decreases with time, or that matter is continually created.

The relative change in  $G$  would be extremely small, about  $\Delta G/G = 5 \times 10^{-10}$  per year, but the rate was of no great significance to Milne, who placed all of his results, including  $G \sim t$ , in a conventionalist perspective. He emphasized that the equation does not imply that local gravitation, as in the solar system, increases in strength. In

<sup>15</sup> Milne 1938.

fact, he did not consider the time dependence of  $G$  to be subject to experimental test. As another illustration of the conventionalist character that Milne assigned to his equations, consider the time parameter  $t$ —what Milne called the kinematic time. His analysis of time, lying at the heart of his project to reconstruct physics, was based on the wish to establish a rational scheme of time-keeping without which, he felt, the universe would not be intelligible. Milne therefore investigated the conditions necessary for two observers to communicate with each other. Communication depends on the possibility of “regradation” of the clock of one of the observers in accordance with that of the other so that their arbitrarily graduated clocks keep the same time. Milne was able to show that in an ideal expanding universe, satisfying the cosmological principle, any two observers located at any two of the uniformly receding particles can graduate their clocks in congruence. The common time of these observers is the kinematic time  $t$ .

On the other hand, a set of observers, any two members of which are at relative rest, can also regraduate their clocks and thus communicate rationally with each other. The time scale used in the latter case is the dynamic time  $\tau$ . This measure of time is public—a kind of absolute time. Milne found that the two time scales were connected by

$$\tau = t_0 \log\left(\frac{t}{t_0}\right) + t_0$$

where the constant  $t_0$  can be interpreted as the present epoch. The relation can also be written as

$$\frac{d\tau}{t_0} = \frac{dt}{t}$$

That is, to any instant  $t = t_0$  we have  $\tau = t$  and  $d\tau = dt$ , which means that the two scales are indistinguishable. Because the principle of inertia holds for observers using  $\tau$ -time, Milne concluded that this time can be identified with the time of Newtonian physics. Optical time-keepers, on the other hand, would run according to  $t$ -time. The proportionality between  $G$  and  $t$  does not hold for observers using  $\tau$ -time, where  $G$  reduces to a constant. Whereas, on the  $t$ -scale, the universe is expanding from a point-origin; on the  $\tau$ -scale the world system is static, its history extending backwards to  $\tau = -\infty$ ; and its geometry is not Euclidean, but hyperbolic. In 1938, Milne wrote: “It is

not a fanciful speculation to see in the interplay of radiation keeping  $t$ -time with matter obeying the classical laws of physics on the  $\tau$ -scale a phenomenon giving rise to the possibility of change in the universe *in time*, and so an origin for the action of evolution in both the inorganic and organic universes."<sup>16</sup> Milne's idea of a logarithmic time scale reappeared in some later cosmological theories, where it was found convenient for the purpose of avoiding the troublesome cosmic beginning.<sup>17</sup>

According to Milne, it was not meaningful to ask if the universe was *really* expanding or not. As he liked to emphasize, the two descriptions are merely two different descriptions of the same physical entity. "It is simply a matter of convenience whether we employ the  $t$ -scale or the  $\tau$ -scale on any given occasion," he wrote in 1950. In principle many other time scales could be used: "We could choose any number of different scales of time, but the dynamics corresponding to each would be different. We speak of just *two* such scales because there are two species of dynamics which it is important for us to consider."<sup>18</sup> It followed from Milne's understanding of the time scales that he was unconcerned with the age paradox, which for him was a pseudo-problem. He believed that the methods of dating the ages of the stars and the earth were based on the  $\tau$ -scale, which left time for objects of an arbitrarily high age.

The methodological and epistemological views that informed Milne's theory attracted as much interest as his cosmology, and were responsible for a good deal of the controversy which surrounded his project. These views had roots back in the 1920s, many years before he took up cosmology. For example, in his inaugural address of 1929 on "The Aims of Mathematical Physics" he praised the constructive role of pure mathematical thought and proposed the positivistic criterion that "the physical content of the assertion which results from a piece of mathematico-physical reasoning must be a relation between observables only."<sup>19</sup> His philosophical position was strongly anti-inductivistic, and he often claimed that the only role which experimental facts should play in theory development was to test already

<sup>16</sup> *Ibid.*, p. 354.

<sup>17</sup> First in Misner 1969, who did refer to Milne, what most later authors did not. Characteristically, Misner was unaware of Milne's idea until he was referred to it by Chandrasekhar.

<sup>18</sup> Milne 1952b, p. 89 and p. 94.

<sup>19</sup> Quoted in Urani and Gale 1994, p. 395.



established theories. They should not and could not be used to generate theories inductively. "What are large collections of facts for?" he asked in 1935. "To make theories *from*, says Bacon; to try ready-made theories *by*, says the history of discovery."<sup>20</sup> Milne adopted from positivism the verifiability criterion of meaning-content, when he stated that "non-verifiable propositions about the world of nature have no significant content." But he also realized that many of his own propositions were far from verifiable, and argued that many questions of cosmology must be answered by pure reason instead of observation.

I have already given general considerations which lead us to conclude that the universe must include an infinite number of particles, but bearing in mind the historic vulnerability of general considerations I only point out here that whilst observation could conceivably verify the existence of a finite number of objects in the universe it could never conceivably verify the existence of an infinite number. The philosopher may take comfort from the fact that, in spite of the much vaunted sway and dominance of pure observation and experiment in ordinary physics, world-physics propounds questions of an objective, non-metaphysical character which cannot be answered by observation but must be answered, if at all, by pure reason; natural philosophy is something bigger than the totality of conceivable observations.<sup>21</sup>

Whatever his intentions, Milne's way of doing physics resulted in an extreme deductivism and rationalism which had rarely been seen since the days of Descartes. Even before his cosmological adventure his ideal of theoretical physics was geometry, and on many occasions he compared physical laws with geometric theorems.

Milne's kinematic-relativistic cosmology aroused great interest in the 1930s, when it was much more discussed than, say, Lemaître's theory of the exploding universe. *Relativity, Gravitation and World-Structure* was reviewed by authorities such as Whittaker, Eddington and Robertson. Many of the responses were critical, but other scientists, mostly in England, considered the theory to be promising, and they started to develop aspects of it. From 1932 to 1940 there appeared about 70 papers related in one way or another to Milne's theory, which means that it had a predominant position in that period. Among those

<sup>20</sup> Milne 1935, p. 125.

<sup>21</sup> Milne 1935, p. 83 and p. 266.

who worked within the problem area defined by kinematic relativity were William McCrea; Arthur G. Walker; Martin Johnson; and Gerald Whitrow (who was a student of Milne).

Most of the interest in Milne's theory came from British physicists and astronomers, but initially American astronomers also found it worthwhile to study it. "Your paper is very widely discussed and we are holding seminars on the subject," Hubble wrote to him in the spring of 1933. "[Alfred?] Fowler, down from Berkeley, was particularly enthusiastic. I will not venture comments until the implications are comfortably straightened out in my head."<sup>22</sup> During the 1930s Hubble vacillated between a static and an expanding universe, which may explain his interest in Milne's theory, which offered both possibilities. He found the kinematic model to "possess unusually significant features," as he expressed it in his book, *The Realm of the Universe*.<sup>23</sup> In a letter to Shapley of 1938, Milne described the advantages of the two time scales, ending with "Hubble's two views of the universe are not exclusive or incompatible—they are two different ways of saying or describing the same thing."<sup>24</sup> He believed that Hubble's recent observations provided empirical support of his theory. What he privately reported to Shapley, he publicly expressed as follows: "Hubble's observations disclosed a density-distribution of nebulae increasing outwards if recession is adopted, and a homogeneous distribution if recession is denied. This is just what is predicted on the present treatment."<sup>25</sup>

Milne was fully aware that his theory was unorthodox in its scope, style and peculiar philosophical flavor. In fact, he considered this unorthodoxy to be part of its strength. In the fall of 1934 he wrote to his friend Chandrasekhar about his forthcoming monograph: "Unless the book is wholly ignored as the work of a 'crank', it is bound to arouse hostile criticism. I shall be told that I do not understand the theory of relativity and that my work fails because it has no experimental basis."<sup>26</sup> And indeed, this is what many of Milne's critics told him. Although he was no foreigner to polemics, and took a certain pleasure

<sup>22</sup> Letter of 3 May 1933. Western Manuscripts, Bodleian Library, Oxford.

<sup>23</sup> Hubble 1936, p. 199.

<sup>24</sup> Milne to Shapley, 28 April 1938. Carbon copy in Lemaître archive.

<sup>25</sup> Milne 1938, p. 344.

<sup>26</sup> Letter of 27 September 1934, as excerpted in a communication of 1950 from Chandrasekhar to McCrea. Western Manuscripts, Bodleian Library, Oxford.

in provoking colleagues who had views different from his own, he came to believe that he was the victim of a repressive community of conservative physicists and astronomers. On one occasion he compared himself with another arch-heretic, Giordano Bruno.<sup>27</sup> In 1943 the misunderstood genius confided to Chandrasekhar: "I do not know whether I have ever opened my heart to you on that theory. I only know that the texture of the argumentation in it is something utterly and surprisingly different from usual mathematical physics, and that when it comes to be recognized, it will be regarded as revolutionary. It is not usual to crack up one's work in this way; but it is all very near my heart, and though I know it is rather despised by many people like H. P. Robertson, I feel certain that some day it will be understood."<sup>28</sup> But Milne's theory of the universe never won general recognition. At the time of his death, he was alone in defending it and soon it was forgotten.

## COSMOS AND GOD

Milne was brought up as a member of the Church of England. Although, as he recalled, there were periods, especially in the early 1920s, when he tended towards agnosticism, for most of his life he remained a devout Christian who was convinced that the universe was created by an almighty God. This is by no means remarkable, but it is remarkable that he explicitly connected his religious belief and his views on scientific cosmology. Whereas he admitted that science has usually nothing to gain from incorporating a religious perspective, or vice versa, when it came to cosmology he thought the matter was different. This is not to say, though, that he developed his system of world physics for apologetic reasons. His reasons were strictly scientific (and to some extent also epistemological) and the religious element only entered post hoc. Apart from casual references, such as in his 1933 British Association address, arguments of a theological

<sup>27</sup> Milne 1952b, p. 72.

<sup>28</sup> Letter of 6 July 1943, as excerpted in a communication of 1950 from Chandrasekhar to McCrea. Western Manuscripts, Bodleian Library, Oxford. Partly reproduced in Chandrasekhar 1987, p. 85. Milne's frustrations of not being "understood" were strikingly repeated by Eddington, who in a letter of 1944 wrote: "In the case of Einstein and Dirac people have thought it worthwhile to penetrate the obscurity. I believe they will understand me right when they realise they have got to do so." Douglas 1956, p. 178.

nature first appeared in his great monograph of 1935, where he included among his many pages densely packed with mathematical equations a brief section on "Creation and Deity."<sup>29</sup>

He was of course aware that reference to God "may appear somewhat out of place" in a work devoted to mathematical cosmology, but believed that, in this case, it was defensible, indeed necessary. His universe was rational, apart from "the one supreme irrationality of creation," and it was this supreme irrationality which made it necessary to add God to the scheme. His argument was quite traditional, namely that cosmic creation demands a first cause, something which transcends space and time. God was not *in* the universe, nor should he be identified *with* the universe, but Milne nonetheless believed that, figuratively, "we have found God in the universe." He was not satisfied with asking "how," "where" and "when" questions, he also wanted to address the ultimative "why the universe," and for this purpose he needed God. The next time that God appeared in Milne's writings was in 1937, in connection with the debate in *Nature* caused by Dingle's attack on the deductivist trend in physical science. In his response, Milne stated that when his research program had been completed and a truly rational physics had been established, there would be no need to appeal to empirical laws. "Laws of Nature would then be no more arbitrary than geometrical theorems. God's creation would be subject to laws not at God's further disposal. The laws would be consequences of the world-shape."<sup>30</sup>

In his follow-up volume to *Relativity, Gravitation and World-Structure*, the *Kinematic Relativity* from 1948, he mentioned God only in the very last paragraph, stating that without Him the picture of the cosmos would be incomplete. Moreover: "It requires a more powerful God to create an infinite universe than a finite universe; it requires a greater God to leave room for an infinity of opportunities for the play of evolution than to wind up a mechanism, once and for all. We rescue the idea of God from the littlenesses that a pessimistic science has in the past placed upon him."<sup>31</sup>

At about the same time as Milne completed his manuscript for *Kinematic Relativity* he was invited to participate in a conference in

<sup>29</sup> Milne 1935, pp. 138-140.

<sup>30</sup> Milne 1937, p. 999.

<sup>31</sup> Milne 1948, p. 233.

Brussels on relativity theory. He chose to speak on his own, kinematic version of relativity and its associated cosmological theory. As we have seen, it was essential to Milne's project that the universe originated from a point-singularity, not an extended body such as Lemaître's primeval atom. His argument was unusual: "To put it baldly, creation of a system of finite extent at one time is a logical impossibility; something beyond the power of God himself. Thus, however unnatural may seem the idea of creation at a point, it is the only form of creation which is free from logical contradiction."<sup>32</sup> The attribution of the act of creation to a divine first cause was, he thought, justified by biological as well as physical considerations. Because,

If evolution consists in the occurrence of mutations, there would be something little and, as it were, pettifogging in the application of the evolutionary process to a finite universe, in which only a finite number of evolutionary experiments could be practised. It would be to put Deity in a strait-jacket. On the other hand, in creating an infinite universe, we can say that God has provided himself with the means of exhibiting and practising his own omnipotence.

After having accounted in a qualitative way for his cosmological theory, Milne concluded: "The system cries out that it was made by a God outside time and space, who yet has the opportunity of freeing himself from the shackles of inevitable, inorganic physical law in the infinitely many modes of organic evolution latent in the system."<sup>33</sup>

During the discussion session of the Brussels conference, Lemaître was among those who raised critical questions to Milne's controversial address. He severely criticized the scientific basis of Milne's world model, but conspicuously and no doubt deliberately avoided any comments to his references to God. Yet there can be little doubt that Lemaître, the theologically trained cosmologist, found these to be primitive and fundamentally misplaced. Hermann Weyl, the mathematician and pioneer cosmologist, did feel obliged to protest. After all, Milne's theory operated with two time parameters, and it was only with one of them that a created universe came out. "It seems to me highly objectionable to infer *creation by a divine power* from the

<sup>32</sup> Milne 1949, p. 10.

<sup>33</sup> *Ibid.*, p. 25.

fact that in terms of one of these [time] parameters,  $t$ , there is an absolute beginning of time  $t = 0$ —unless one shows on physical grounds that this parameter  $t$  is the natural measure of time in such a strong sense as, e.g., the Kelvin thermodynamical scale (with its absolute zero) is the natural scale of temperature.”<sup>34</sup> Milne did not respond to Weyl’s charge of having illegitimately introduced a theological argument, and none of the other participants at the conference followed up the theme.

Milne gave the fullest exposition of his cosmo-apologetics in his manuscript for the Cadbury Lectures, posthumously published in 1952 under the editorship of Whitrow as the book, *Modern Cosmology and the Christian Idea of God*. It was, as Whitrow wrote in his preface, “the scientific testament of one of the most original natural philosophers of our time.” Milne was convinced that metaphysical and even theological arguments had a role to play in science, especially when trying to understand the creation of the universe. It was a regrettable prejudice among men of science to deny such a role. “Investigators who leave out God, the *raison d’être* of the universe, find themselves lamentably handicapped in dealing with cosmological questions,” he wrote.<sup>35</sup>

Much of Milne’s cosmo-theological discussion concerned God as a perfectly rational being, and whether or not his creative power was limited by his very rationality. Are omnipotence and divine rationality fully compatible? Is God limited by his own rationality and the nature of the laws he has created? These were classical theological questions, and Milne felt there was a need to consider them anew. He believed that God the Almighty was almighty only in a restricted sense: “God Himself is limited by reason in the divine act of creation. God cannot do the impossible.” For example, he could not have created a universe in which one direction was preferred to any other, or any one state of motion preferred to any other—“even Omnipotence could not fix such a frame,” Milne claimed.<sup>36</sup> Nor could God have created laws of nature in whatever way he pleased and still remain perfectly rational. Thus, the force of gravity *must* vary as  $r^{-2}$  precisely and not, say, as  $r^{-2 \pm \epsilon}$  with  $\epsilon$  being an arbitrarily small number. The

<sup>34</sup> In the conference report (see Milne 1949), p. 65. Weyl was religious, but did not believe in a personal God. He described God as “the completed infinite,” a being responsible for the harmoniously ordered universe but incomprehensible by mind. See Weyl 1932, pp. 1–30.

<sup>35</sup> Milne 1952b, p. 62.

<sup>36</sup> *Ibid.*, p. 33 and p. 57.

form of the law could not possibly be otherwise, at least not in Milne's cosmology. "God is not free to design the law of gravitation as He pleases, any more than He is free to let the sum of the angles of a plane triangle add up to something different from  $180^\circ$ . With God all things are not possible."<sup>37</sup>

Likewise, as he had mentioned also at the Brussels conference, at the beginning the divinely created universe must necessarily have been a point-singularity, whereas an extended universe was deemed an impossibility, and hence, beyond God's power. Milne used his rational God scientifically, in the sense that he argued that certain cosmological theories were incompatible with God's rationality. The impossibility of an extended initial universe ruled out Lemaître's hypothesis of the universe originating in the explosion of a super-radioactive atom. Nor could Milne find any divine rationality in the new steady-state theory which he had disliked ever since it was introduced in 1948. An irrational element could not be allowed in cosmological theory, and Milne believed that the hypothesis of continual creation of matter was such an element because it required a definite rate of matter creation. According to the steady-state theory, the rate was about  $10^{-43} \text{ g} \cdot \text{s}^{-1} \cdot \text{m}^{-3}$ , and, Milne claimed, "no reason can be given for the choice by God of any particular value for this quantity."<sup>38</sup> Elsewhere in his book Milne spoke more emotionally against the "latest fashion of continuous creation," the steady-state theory:

According to that, creation is limited to the routine production, with penny-in-the-slot regularity and monotony, of hydrogen atoms. And this has been going on from eternity, and will continue to eternity. All the wonder, all the marvel, of the created universe is a consequence of the sporadic formation of hydrogen atoms out of nothing in just the local frames of rest. ... By concentrating on the creation of *matter* alone, and leaving out the mode of creation of *frames of motion*, the Providence of Bondi, Gold, and Hoyle does only half its job; and to do the authors of this theory justice, they do not believe or assert that any transcendental omnipotence is behind the simple acts of creation at all.<sup>39</sup>

<sup>37</sup> *Ibid.*, p. 85.

<sup>38</sup> *Ibid.*, p. 23. The quantity is given by  $3\rho H$ , where  $\rho$  is the mean density of matter in the universe, and  $H$  the Hubble parameter. It is not clear why God could have no reason to single out this value.

<sup>39</sup> *Ibid.*, p. 77. As we shall see shortly, Hoyle used the steady-state theory to argue against a transcendent creator and Christianity in general.

It is ironic that in 1947 Milne had warned to put God in a straight-jacket, for, so it must have seemed to many of his readers, was this not precisely what he was doing when dictating what God could do and not do? More fundamentally, how could he know God's sense of rationality? Was he not projecting his own view of what is rational and possible on God? Such problems were not peculiar to Milne's system, but are of a general theological nature. As we shall see in Chapter 7, they still appear in the modern discussion of science and theology.

In spite of Milne's emphasis on the original, divine creation, his world system was not a deistic clockwork universe. In agreement with what he had stated in 1935, he described God as "fully employed in the subsequent history of his universe," not busy with creating new laws of nature but with causing opportunities of organic evolution. Divinely based life processes would forever occur throughout the infinite universe, for it "is the essence of Christianity, that God actually intervenes in History."<sup>40</sup> Milne somewhat arbitrarily restricted this intervention to the realm of biology, and he was not very clear about the connection between determinate physical laws and indeterminate biological evolution.

Organic evolution throughout the universe? Yes, Milne entered the age-old debate about extraterrestrial intelligent life, and he did it as a pluralist. He was aware of the theological problems of pluralism, such as the incarnation being a unique event. If the incarnation occurred only once, on our earth, what about the inhabitants who possibly lived on countless other planets? How could their souls be saved? To the deist Thomas Paine, the problem was a strong argument against Christian belief, as put forward in his seminal book, *The Age of Reason* from 1794. "Are we to suppose that every world in the boundless creation had an Eve, an apple, a serpent, and a redeemer?" Paine found the idea to be ridiculous: "In this case, the person who is irreverently called the Son of God, and sometimes God himself, would have nothing else to do than to travel from world to world, in an endless succession of death, with scarcely a momentary interval of life."<sup>41</sup>

Milne did not share Paine's conclusion, and came up with a science-fiction like solution which was as original as it was theologically

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<sup>40</sup> *Ibid.*, p. 153.

<sup>41</sup> Quoted in Crowe 1986, pp. 163-164.



doubtful. He believed that in principle the new science of radio astronomy might solve the problem by securing interplanetary communication and with it, interplanetary salvation. "In that case there would be no difficulty in the uniqueness of the historical event of the Incarnation. For knowledge of it would be capable of being transmitted by signals to other planets and the re-enactment of the tragedy of the crucifixion in other planets would be unnecessary."<sup>42</sup>

The term "re-enactment" may reflect an influence from Robin G. Collingwood, the distinguished historian and philosopher in whose idealistic philosophy re-enactment was a key term, referring to the historian's re-experience of the thoughts of earlier individuals. From 1934 to 1941 Collingwood was Waynflete Professor of Metaphysical Philosophy at Oxford, and hence a colleague of Milne. Although as academic disciplines, metaphysical philosophy and applied mathematics are worlds apart, apparently the two professors shared some common intellectual ground. Thus, in the preface to his book of 1935 Milne expressed his indebtedness to Collingwood "for certain suggestions." It is uncertain what these suggestions were, but Collingwood had a deep interest in the connection between history, metaphysics and science, and he benefitted from Milne's insight in the exact sciences. In the preface to the book, *The Idea of Nature*—Collingwood's ambitious attempt to integrate history and natural philosophy—he thanked Milne for being responsible for an extensive footnote on the theory of relativity.<sup>43</sup>

Collingwood's philosophy of nature was influenced by Whitehead, Jeans and Eddington, rather than Milne, and it is evident that he did not have a solid understanding of contemporary physical science. Indeed, much of what he said in *The Idea of Nature* borders on nonsense. In a reference to the observed galactic redshifts he mentioned "the theory that the physical universe originated at a date not infinitely remote in the past, in something resembling an explosion of energy which at once began time and began, in time, to generate space." He revealed his lack of knowledge of recent developments when he claimed that "modern science is now committed to a view of the physical universe as finite, certainly in space and probably in time."<sup>44</sup> The spatial finiteness of the universe was the original view of

<sup>42</sup> Milne 1952b, p. 154. See also Dick 1999, pp. 517–519.

<sup>43</sup> Collingwood 1960, p. 153. First edition 1945.

<sup>44</sup> *Ibid.*, pp. 154–155.

Einstein and was entertained also by Eddington, but around 1940 cosmologists were in no way "committed" to it (Milne, for one, denied it).

Collingwood questioned the general validity of the second law of thermodynamics and its consequence, the heat death. He suggested, somewhat naively, that the prediction of a heat death was based on "habitual observation of relatively short-phase processes" and that it might turn out to be wrong if much longer periods were considered. Although Collingwood was not very clear on the matter, apparently he suggested that anti-entropic processes must exist to explain organic evolution. As far as religion is concerned, he misrepresented to some extent the views of Jeans and Eddington by presenting them as theists. They were, he wrote, advocates of the view that "the material world depends on God."<sup>45</sup>

## RESPONSES

Because Milne never wrote works intended for the general public, outside the circle of astronomers his views were much less known than those of Jeans and Eddington. It is noteworthy that Susan Stebbing, in her critical 1937 analysis *Philosophy and the Physicist*, avoided mention of Milne and his system of kinematic relativity. British philosophers were not unfamiliar with it, though, if for no other reason than because Milne had himself published in the philosophical literature.<sup>46</sup> In 1949 the epistemological aspects of his cosmophysics were competently and sympathetically reviewed by the American philosopher Robert Cohen.<sup>47</sup> In spite of critical remarks, Cohen concluded that Milne's theory was of such scope and originality that it deserved to be carefully studied and tested. Another prominent philosopher, Karl Popper, adopted Milne's conventionalism and his two time scales, in an attempt to clarify the consequences of the nebular redshifts; he concluded with Milne that the question of whether the universe expanded or not could not be answered independently of the chosen time scale.<sup>48</sup> In addition to Cohen, Milne's

<sup>45</sup> *Ibid.*, p. 27.

<sup>46</sup> E.g., Milne 1934, based on an address delivered to the British Institute of Philosophy on 17 October 1933.

<sup>47</sup> Cohen 1949–50.

<sup>48</sup> Popper 1940. On Popper and cosmology, see Kragh 1996, pp. 244–246.

kinematic relativity received comments also from Adolf Grünbaum, the later so distinguished American philosopher of science. Grünbaum focused on the two time scales and the "far-reaching theological claim" that Milne drew from them, to his mind illegitimately. Grünbaum denied on philosophical grounds that Milne's time scales implied the existence in the past of some singular event, something like an absolute creation.<sup>49</sup>

Milne's lack of visibility in the public debate is further illustrated by John Desmond Bernal's book, *The Social Function of Science* which included a criticism of what he saw as a worrying tendency toward anti-intellectualism, a revolt against science. Even more worryingly, "This mysticism and abandonment of rational thought is not only a sign of popular or political disquiet; it penetrates far into the structure of science itself." As an example, Bernal mentioned that "those metaphysical and mystical theories which touch on the universe at large or the nature of life, which had been laughed out of court in the 18th and 19th centuries, are attempting to win their way back into scientific acceptance."<sup>50</sup> The Marxist and self-appointed social reformer charged that

modern science is being made an ally of ancient religion, and even to a large extent a substitute for it. Through the work of Jeans, Eddington, Whitehead and J. S. Haldane, assisted by the Bishop of Birmingham [W. Barnes] and Dean Inge, a new scientific mythical religion is being built up, based on the idea of a continuous creation of absolute values in an evolutionary process culminating in man.

Bernal did not include Milne among his targets, nor did he mention him at all. He may not have been aware that Milne had found a place for God in his cosmo-physics, a place that would appear prominently only after the war. At any rate, Milne could not possibly be accused of endorsing mysticism, such as could Jeans and Eddington. On the contrary, Milne was an extreme rationalist whose God was the highest reason; he certainly did not try to import religious mysticism to the realm of science. But then, as Bernal noted, the use of science in modernist religion was an implicit admission of its importance: "No religious views could expect to hold their own in cultured circles

<sup>49</sup> Grünbaum 1952.

<sup>50</sup> Bernal 1939, pp. 3-5.

unless they were at least phrased in scientific terminology, and did not contradict the positive results of the scientific theory of the day." Bishop Barnes, for one, would not disagree.

The Haldane mentioned by Bernal was John Scott Haldane, an eminent Scottish physiologist who was strongly influenced by idealist philosophy of a Hegelian tinge. In his Gifford Lectures, published in 1928 as the book, *Sciences and Philosophy*, J. S. Haldane argued that life was a primary reality and the universe a great mind. Although his views had elements in common with those of Jeans and Eddington, he did not believe that the universe could ever be explained in terms of physics. On the contrary, he insisted that life was closer to ultimate reality than the ideas of matter and energy used by the physicists. Thus, in an address to the British Association in 1908, he concluded that biological phenomena "differ in kind from physical and chemical phenomena." There might be areas where biology and the physical sciences met, "and [if] one of the two sciences is swallowed up, that one will not be Biology."<sup>51</sup> Max Born happened to know Viscount Haldane, former Minister of War and the brother of J. S. Haldane. He recalled how he once "got a letter from him [Viscount Haldane] with a manuscript by his brother, the famous physiologist in Oxford, in which the physicists were attacked, and a proof was given that the second law of thermodynamics was wrong." Born was asked whether the proof was right or wrong, and "I sat at my desk till late night and of course found a mistake."<sup>52</sup>

J. S. Haldane's son, the no less eminent evolutionary biologist John Burdon Sanderson Haldane, was not only greatly fascinated by "the nature of life" but also followed with keen interest the debate on "the universe at large." He found Milne's theory interesting because of its thorough "historical" nature, and because it pictured the universe as evolving from a singularity. A Marxist and card-carrying member of the British Communist Party (like Bernal), he referred approvingly to the theory as an expression of the fundamental dialectics of nature suggested by Friedrich Engels! In a book of 1938, he reviewed Milne's world physics, which he found was "beautifully dialectical" and in harmony with Marxist thought.<sup>53</sup> It is unknown

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<sup>51</sup> Haldane 1908, p. 871.

<sup>52</sup> Born 1975, p. 244.

<sup>53</sup> Haldane 1938, pp. 62-73.

how Milne responded to appear in company with Engels, Marx and Lenin, but I guess he would rather have been without the honor. In early 1945 Haldane published a grand and speculative hypothesis of his own, based on Milne's theory, this "landmark of human thought" which "accords with my own philosophical views." He did not hide that his preference for Milne's system was ideologically rooted, and that he saw it as a way of avoiding the choice between the traditional cosmologies, either with a beginning in the past or describing an eternal universe:

On the first hypothesis, why was it not created better; on the second, why has it not got better in the course of eternity? On neither theory have we very strong grounds for hoping that the world will be a better place a million, let alone a thousand years hence, than it is today. But on Milne's theory the laws of nature change with time. The universe has a real history, not a series of cycles of evolution. Although, from one point of view, the past is infinite, life could not have started much before it did, or have got much further than it has at the present date. If this is so, human effort is worth while, and human life has a meaning.<sup>54</sup>

Haldane suggested that, since in Milne's model galactic distances in kinematic time varied as  $r = ct$ , there would at any time exist a maximum size of photons given by  $\lambda = ct$  and thus a minimum frequency of the order  $1/t$ . Going far back in time, say to  $t = 10^{-72}$ s, photons would therefore have had enormous frequencies and energies; at the time  $10^{-92}$ s, the smallest photons would have had an energy corresponding to the mass of a galaxy (that is, in  $t$ -time; in  $\tau$ -time, nothing would change). Haldane thus pictured the universe as originating from one or a few such superphotons of almost infinite energy, and sketched from this assumption (which he realized was "wildly speculative") the entire evolutionary history of matter and life. Where did the original superphotons come from? Haldane could not tell, except that they might have been "primordial constituents of the universe." Interestingly, in the course of his wild speculations he was led to suggest that "at a sufficiently early date most of the mass of the universe, or all of it, may have been radiation rather than matter." This may have been the first time a radiation-dominated early universe was suggested.

<sup>54</sup> Haldane 1945b, p. 132. See also Haldane 1945a.

Among other things, Haldane's use of the two time scales suggested a new picture of the history of the earth. He argued that the decay of radioactive nuclei would follow  $t$ -time, which would therefore be the proper time scale for geology. From  $d\tau/t_0 = dt/t$  it follows that the decay law, in dynamic time, reads

$$\frac{dN}{d\tau} = -\lambda N(t) \frac{t}{t_0}$$

It follows that the rate of decay will first increase and only subsequently, after having passed a maximum at  $t = 1/\lambda$ , decrease. Developing this idea he arrived at the "surprising conclusion" that the heat production caused by radioactivity in the earth's crust did not gradually diminish, as in the standard view; it would increase and continue to do so for another couple of billion years. He also applied Milne's two time scales to biological processes and speculated that life on earth might possibly continue to  $t = 10^{15}$  years, long after the sun had been extinguished. J. B. S. Haldane surely has a place in the annals of physical eschatology.

Haldane was no foreigner to eschatology, although previously he had largely limited his speculations to the possibility of life in the far future, first in the best-selling book, *Daedalus* from 1924. In his essay "The Last Judgment," of 1927, he speculated about the end of the world. "The star on which we live had a beginning and will doubtless have an end," he wrote.<sup>55</sup> But although life on earth would be destroyed, on other planets biological evolution would go on, possibly in the form of descendants of humans. The following year, in a response to Jeans' view of the heat death, he considered the end of the universe in the more absolute, cosmological sense. In agreement with Boltzmann, he suggested that we may live in a huge low-entropic fluctuation. In that case, he thought, "there is no need to assume a break in the order of Nature to account for the beginning of the present universe."<sup>56</sup> Haldane's early occupation with futurological speculations may help explain his later interest in Milne's cosmology, unusual at a first glance.

<sup>55</sup> Haldane 1927, p. 287. Adams 2000 provides a detailed analysis of Haldane's biological eschatology, but fails to mention his connection to Milne's cosmology.

<sup>56</sup> Haldane 1928, p. 809.

Milne supported Haldane's cosmic evolution scenario wholeheartedly.<sup>57</sup> One would think that the whole picture collapsed because of the arbitrary use of  $t$ -time, but in 1945 Milne seems to have reached the conclusion that kinematic and dynamic time were not, after all, equally valid. He now found the  $\tau$ -scale "a concession to our Newtonian predilections," whereas "phenomena themselves" were best studied through the more fundamental  $t$ -scale. Milne's picture of what a few years later would be called the big bang was as follows: "Just as the epoch  $t = 0$  is a singularity in the mechanical  $t$ -history of the universe—an epoch at which the density was infinite—so the epoch  $t = 0$  is a singularity in the optical history of the universe, namely, an epoch at which the frequency of radiation was infinite, because the wave-length had to be zero." With an allusion to Genesis he stated that, at the creation of the universe, "light must be present." He further suggested, as he did on some other occasions, that the presently observed cosmic rays were the fossils of the primitive high-frequency radiation. In this respect, his big-bang hypothesis had some similarity to Lemaître's.

As Cohen (who was a Marxist and described himself as a Jewish atheist) pointed out in his review, Milne's use of  $t = 0$  as evidence for a divine creator was but a simplified form of the old argument to a first cause, and therefore shared its defects. But the postulated first event did not follow logically from Milne's cosmology, which in itself was theologically neutral. Haldane, too, was eager to dissociate the theologically interpreted creation from Milne's theory. In a comment in the Marxist periodical *Modern Quarterly* he emphasized that to use the kinematic time only involved a distortion of the theory. When properly understood, Milne's kinematic cosmology was, he repeated, "beautifully dialectical," indeed "the kind of theory which a Marxist would expect to be true."<sup>58</sup>

The Milne-Haldane hypothesis did not live for long, but long enough to be included in a popular review article that the American astronomer Thornton Page wrote on the origin of the earth. Page seems to have considered Milne's idea of two time scales to be of some interest, but he had no confidence in Haldane's scenario, "the

<sup>57</sup> In an untitled companion paper to Haldane 1945b (pp. 135–136).

<sup>58</sup> *The Modern Quarterly* 2 (1946–47), 93–94. Although not a Christian, Haldane was deeply religious. His faith has been described as reason, his church as science (Adams 2000, p. 483).

most bizarre suggestion of all in this field [cosmogony] already rich in speculation."<sup>59</sup> Few would have contradicted him. Georges Lemaître was well acquainted with Milne's theory, but as a convinced relativist it did not appeal to him. In 1933 Milne had sent him a dedicated copy of his article in *Zeitschrift für Astrophysik*; Lemaître studied it carefully and continued to follow the development of Milne's ideas.<sup>60</sup> Only in 1945 did he publicly comment on the theory of kinematic relativity and what he called the Milne-Haldane hypothesis.<sup>61</sup> Although Lemaître granted that one could formally operate with two time scales, he pointed out that all physical phenomena are so intimately interrelated that it is impossible to separate them in a non-arbitrary way in two different time categories. As to Haldane's super-photons, he argued that they could not be ascribed any physical meaning, not even in principle. Lemaître considered the Milne-Haldane hypothesis to be science fiction, not science.

As Lemaître dismissed the ideas of Milne and Haldane, so he was not happy at all with Milne's attempt to use cosmology in the service of theology. He preferred not to enter a discussion of the issue, but his brief review of the book, *Modern Cosmology and the Christian Idea of God* left little doubt that the Belgian priest and cosmologist did not share Milne's unusual version of natural theology. The review appeared in *Revue des Questions Scientifiques*, a Catholic journal founded in 1877, originally with the purpose of countering scientific materialism and positivistic tendencies in science.<sup>62</sup> Among the many distinguished contributors to the journal was Pierre Duhem and, later, Lemaître.

I do not think Milne's adventure into apologetic cosmology made much of a splash in theological circles, but remarked it was. Eric Mascall, a priest and philosopher of religion in Oxford, gave in 1956 the Bampton Lectures in which he reviewed the relations between science and traditional Christian theology. Before he turned to theology, he had studied mathematics and physics, and thus was in a good position to evaluate the theological implications of modern physics. In general, Mascall believed that there was no conflict

<sup>59</sup> Page 1948, p. 23.

<sup>60</sup> Lambert 1999, p. 223.

<sup>61</sup> Lemaître 1945. In the same issue of *Ciel et Terre* (pp. 208–213), the Belgian astronomer Raymond Coutrez offered his view on the Milne-Haldane hypothesis. Contrary to Lemaître, Coutrez found it to be highly interesting and the result of two "constructive and ingenious spirits."

<sup>62</sup> *Revue des Questions Scientifiques* 16 (1955), 585. On the early history of the journal, see Nye 1976.



difficult to follow the paroles from Moscow, but for a while they did. In the anti-theistic and anti-clerical campaign which was an important part of the Stalinist ideology, Lemaître was a main target, and sometimes Milne was included in his wake. An odd couple, perhaps, but then both were Christians and advocates of a universe of finite age. The notorious Andrei Zhdanov, chief ideologue and father of "Zhdanovism", attacked in 1947 the Western bourgeois astronomers whom he accused of idealism, fideism and apologeticism. Zhdanov's attack marked the beginning of a new and harder intellectual climate in the Soviet Union. He lashed out in particular against those who

assert that the world is finite, that it is limited in time and space, and the astronomer Milne even "calculated" that the world had been created two billion years ago. ... The reactionary scientists Lemaître, Milne and others made use of the "red shift" in order to strengthen religious views on the structure of the universe ... [and] want to revive the fairy tale of the origin of the world from nothing. ... Another failure of the "theory" in question consists of the fact that it brings us to the idealistic attitude of assuming the world to be finite.<sup>68</sup>

Of course, contrary to Lemaître, Milne did not subscribe to a finite universe. And, contrary to Milne, Lemaître was careful not to draw religious consequences from cosmology. But these were details of no relevance to Zhdanov and his fellow ideologues. The consequence of Stalinist Zhdanovism was that for a period of about 10 years cosmological research was practically non-existent in the Soviet Union.

Milne's successor as the holder of the Rouse Ball chair in applied mathematics was the theoretical chemist Charles Alfred Coulson, a pioneer of quantum chemistry and, like Milne, a former Fellow of Trinity College.<sup>69</sup> Coulson was no less a devout Christian than his predecessor, but in a different and much more active way. A member of the Methodist church, since 1930 he had served as a lay preacher and after becoming professor in Oxford he used his position to disseminate in addresses and books his views about religion and its relation to science. His arguments in favor of religion were not

<sup>68</sup> Quoted in Tropp, Frenkel and Chernin 1993, pp. 223–224. On Soviet cosmology in the period, and its relation to religion, see also Kragh 1996, pp. 259–268.

<sup>69</sup> For Coulson and his view on applied mathematics and quantum chemistry, see Simões and Gavroglu 1998–99. A fuller exposition of Coulson's views on science and religion is presented in Simões 2004.

theologically sophisticated, but largely followed the older tradition of natural theology.

Not surprisingly, Coulson argued that there can be no conflict between science and religion. "Either they go together or are in conflict," he wrote.<sup>70</sup> Of course, he believed they go together. In his John Calvin McNair lectures of 1954, delivered at the University of North Carolina, USA, he referred critically to the view of God that Milne had argued in the book, *Modern Cosmology and the Christian Idea of God*. This view "seems to me like using some preconceived view of Nature to limit or restrict His operation." God—"whose center is everywhere and His circumference nowhere"—did not merely intervene in nature, either continually or at the creation of the world, such as Milne had believed. According to Coulson, "Either God is the whole of Nature, with no gaps, or He's not there at all."<sup>71</sup> Although the laws and matter of nature reflected a divine power—he described nature as "sacramental"—God did not act indirectly through them:

... a God who is obliged to conceal His actions of providence so that we cannot see Him, a God who hides His presence in Nature behind the law of large numbers, is a God for whom I have no use; He is a God who leaves Nature still unexplained, while He sneaks in through the loopholes, cheating both us and nature with His disguised 'room for manouvre.'<sup>72</sup>

For Coulson, the Methodist quantum chemist, science and religion could not be separated, for science was one way to God, "an essentially religious activity."<sup>73</sup> Whether the scientist admitted it or not, he was God's mouthpiece.

## THE STEADY-STATE MODEL

1948 was a great year in the annals of cosmology.<sup>74</sup> In Washington D.C., Russian-born George Gamow and his collaborator Ralph Alpher published an important paper on the physics of the early universe,

<sup>70</sup> Coulson 1955, p. 4.

<sup>71</sup> *Ibid.*, p. 19, p. 102 and p. 22.

<sup>72</sup> *Ibid.*, p. 21. Coulson's view not only differed from Milne's, but also from that of Lemaitre, who stressed the hidden God.

<sup>73</sup> *Ibid.*, p. 31.

<sup>74</sup> For a full historical account, including references to primary and secondary sources, see Kragh 1996.

effectively the beginning of modern big-bang cosmology. In a qualitative sense their cosmic scenario was similar to Lemaître's, but it was developed independently and, contrary to the primeval-atom model, it relied on advanced nuclear-physical calculations. Gamow and Alpher, soon to be joined by Robert Herman, assumed the very early universe to consist of a hot, highly compressed neutron gas which somehow "exploded" by beginning to decay into protons and electrons. They carefully avoided the question of what caused the neutron soup to decay, and neither did they address the problem of the state of the universe before the explosion. (However, Gamow did on a few occasions speculate that the expanding universe was preceded by an earlier phase of contraction.) The magical moment  $t = 0$ , after which they claimed validity for their calculations, was not really the creation of the universe but the beginning of the expansion. What Gamow and Alpher did try to explain was the build-up of chemical elements during the first minutes of the rapidly expanding inferno of nuclear particles.

The original Gamow-Alpher model was matter-dominated, but they soon realized that the temperature had to be exceedingly high for element formation to occur, and at such a high temperature electromagnetic radiation would be abundant. The earliest state of the universe was not dominated by matter, but by a fireball of hot radiation. With the rapid expansion and corresponding decrease in temperature, matter would gradually replace radiation as the main stuff of the universe. The Gamow-Alpher-Herman theory as of late 1948 was essentially a nuclear-physical model of the early phase of a universe expanding in accordance with the Friedmann-Lemaître equations. Although the big-bang model of Gamow and his collaborators was little noticed at the time, and almost completely ignored by astronomers, in its broad features it agreed with what was probably the view of a majority of physicists and astronomers. Most experts tended to believe that the universe was of finite age and that it evolved in agreement with the laws of general relativity. For example, this was a leading theme in the articles by Lemaître, Tolman and Gamow which appeared in the special issue of *Reviews of Modern Physics* celebrating Einstein's 70-year's birthday. And it was Einstein's view, too.

But not all agreed. In Cambridge, England, Fred Hoyle, Thomas Gold and Hermann Bondi concluded in private discussions that relativistic finite-age theories were unsatisfactory. Not only did the theories, in most cases, disagree with the ages of stars and the earth,

they also postulated a singular creation event which in principle defied scientific understanding. What the Cambridge trio wanted was an eternal universe which expanded in time and in which there was no systematic change over long periods of time. Contrary to the older speculations of Nernst, MacMillan and others, they had no problems with the expanding universe and the standard interpretation of galactic redshifts as caused by a Doppler effect. But how can an expanding universe remain unchanged? The solution, originally proposed by Gold, was to introduce the hypothesis of continual creation of matter throughout the universe. The discussions of the three British physicists were quickly developed into what became known as the steady-state theory, published in two separate versions in 1948. Although Hoyle's version differed in important respects from that of Bondi and Gold, the two papers had more in common than what separated them, and together they formed the foundation of the steady-state theory of the universe, a radical alternative to evolution theories based on the theory of general relativity.

The steady-state theory of the universe was conceptually founded on the "perfect cosmological principle," the postulate that the universe in its large-scale features is not only spatially but also temporally homogeneous. The principle implied a universe of infinite age and hence the theory eliminated the time scale difficulty. Hoyle, Bondi and Gold could show that the metric of their cosmological model must be of the De Sitter type, that is, a Euclidean space expanding as  $\exp(Ht)$ , where  $H$  is the Hubble constant, which is here a true constant and not a parameter depending on cosmic time. According to the perfect cosmological principle, the average density of matter must forever remain the same, which in an expanding universe can only be the case if new matter is produced continually. This feature of the steady-state cosmology was most controversial and was often seen as the main characteristic of the theory, which was consequently sometimes referred to as "continuous creation cosmology." The constant average density of matter was given by  $\rho = 3H^2/8\pi G$ , which happened to be precisely the same as the "critical" value in the Einstein-De Sitter theory (where  $\rho$  decreases with time). The creation of matter in steady-state theory had to take place at the exceedingly slow rate of  $3\rho H \cong 10^{-43} \text{ g} \cdot \text{s} \cdot \text{cm}^{-3}$ , which made the process impossible to observe directly. (Tiny as the number is, in absolute terms it is tantalizingly large, corresponding to the formation of billions of suns each second within the visible universe.)

The theory could not tell in which form the new matter was created, but it was usually assumed to be in the form of hydrogen atoms. It is important to notice that the steady-state matter creation was not a transformation of radiation energy into matter, but creation of new matter out of nothing. This of course violates the law of energy conservation, but to such a small degree that it cannot be ruled out experimentally. The new matter had the advantage that it prevented the heat death, and thus made possible a universe in which life could be sustained forever. Hoyle argued that although the entropy increases locally, the creation of matter prevents a global increase of entropy towards a maximum value. Some astronomers saw in the absence of a heat death an appealing feature of the steady-state theory. For example, it was a major reason why Harold Spencer-Jones, the royal astronomer of England, was sympathetic to the theory.

The new steady-state theory was in a finished form by 1950, and attracted a small number of British researchers, of whom William McCrea and Dennis Sciama were the most important. In papers between 1951 and 1953, McCrea argued that continuous creation of matter did not necessarily imply *ex nihilo* creation but that it could be incorporated into standard general relativity.<sup>75</sup> The most successful result of steady-state cosmology was indirect and led in 1957 Hoyle, in cooperation with American astrophysicists, to an important nuclear theory of the origin of elements. The theory did not presuppose a hot, superdense universe in the past, such as assumed by Gamow, but that element formation occurred in novae and the interior of stars. Although the theory did not rely on steady-state assumptions explicitly, it was generally regarded as a triumph of steady-state cosmology because it contradicted the big-bang assumption.

In England, the steady-state theory with its continuous creation of matter became controversial shortly after 1948. According to *Time* magazine, it "ranked as a leading conversation piece in British intellectual circles...[and was] debated in learned societies, it was bidding for a place among Britain's most striking contributions to modern scientific philosophy. It was, of course, also being attacked."<sup>76</sup> In the protracted controversy that followed, arguments of a methodological and epistemic nature played a significant role.

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<sup>75</sup> This aspect is examined in Kragh 1999.

<sup>76</sup> "According to Hoyle," *Time* 56 (20 November 1950), 84-91.

Foremost among the critics was Herbert Dingle, who resumed with a new target the crusade he had fought before the war against the rationalistic cosmologies of Milne, Eddington and Dirac. He now used similarly strongly worded rhetoric to warn against steady-state cosmology, which he accused of being dogmatic and plainly non-scientific. Other philosophically based criticism came from the philosopher Milton Munitz and the astronomers Gerald Whitrow and George McVittie. Characteristic of the debate was its foundational nature, sometimes concerning the meaning of science as such. Is steady-state theory more or less scientific than the big-bang theory? Is cosmology a science at all? Such broad questions were part and parcel of the British debate, but rarely turned up elsewhere.

Of course, this kind of discussion could not lead to an end of the controversy. Despite fundamental disagreements, both parties in the debate agreed that, ultimately, the question would have to be settled by observations. Bondi, who was inspired by Karl Popper's falsificationist philosophy of science, declared that the steady-state theory would have to be abandoned if observations contradicted just one of its predictions. But he and other steady-state theorists also emphasized that in any conflict between observation and theory, observation was as likely to be at fault as was theory. The theory was eventually falsified, but not easily. A relatively straightforward test seemed to derive from the variation of the speed of recession of the galaxies with their distances. Whereas evolution cosmologies predicted that the rate of recessional velocity was disproportionately larger for distant (and older) galaxies, according to the steady-state model the velocity increase should be directly proportional to the distance. Data due to Milton Humason and Allan Sandage at the Mount Wilson Observatory indicated a slowed-down expansion in agreement with the evolutionary view, but the data were not certain enough to constitute a crucial test.

Such a test, or something close to it, came from the new science of radio astronomy. The leading radio astronomer, Martin Ryle of Cambridge University, soon became an active opponent of steady-state cosmology. In 1955 his group completed a survey of radio sources, and from an analysis of the data he concluded that they could not be explained in terms of the steady-state theory. Yet, this conclusion was premature and not supported by data obtained by radio astronomers in Australia. The discussion over the interpretation of

radio source count measurements continued for another couple of years until in 1960 consensus was obtained among radio astronomers that the data were certain enough to constitute a serious problem for the steady-state theory. From about that time, a majority of astronomers agreed that the theory of Hoyle and his colleagues was no longer a viable alternative to relativistic evolution cosmology. The final blow to what was left of the steady-state theory came in 1965 with the unexpected discovery of the cosmic microwave background radiation. With the discovery from Arno Penzias and Robert Wilson, and its interpretation by Robert Dicke and James Peeble, the big-bang theory received impressive support; at the same time, it was a decisive blow against the steady-state cosmology which now became even more marginalized. As if it was not enough, in 1966 there appeared new data on the redshifts of quasars that could only be explained by the steady-state theory via the addition of artificial hypotheses. From then on it became generally accepted that the universe originated some 10 billion years ago in a superdense and superhot state.

### ANY PLACE FOR GOD?

None of the original trio of steady-state theorists was religious or brought up with any kind of religious education. On the contrary, they were either agnostics, atheists, or just plainly uninterested in matters of religion. When Hoyle was in his early teens he concluded that religious ideas were just fairy tales with no foundation in reality. Bondi developed from an early age a decidedly anti-religious view and tended to associate religion with intolerance and dogmatism. He never seemed to have changed his view, which was not far from that of Hoyle and Gold.<sup>77</sup>

Although there were no direct references to religion in the original papers of 1948, Hoyle, Bondi and Gold included references of a philosophical nature that clearly revealed their emotional dissatisfaction with a universe of a finite age. This dissatisfaction was an important motivation for the steady-state theory. Hoyle mentioned in the introduction to his paper, "esthetic objections to the creation of the universe in the remote past" because such an origin had to rely on

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<sup>77</sup> See, e.g., Bondi 1993.

"causes unknown to science."<sup>78</sup> Bondi and Gold similarly stated that only in an eternal universe developing in accordance with the perfect cosmological principle could cosmology ever hope to become scientific. In several of his later works, Hoyle could not or would not resist the temptation to refer to the big-bang event in religious or quasi-religious terms. In a textbook of 1980, written with his colleague and former student Jayant Narlikar, he wrote: "The abrupt beginning is deliberately regarded as *metaphysical*—that is, *outside physics*. ... To many people, this thought process seems highly satisfactory because a 'something' outside physics can then be introduced at  $\tau=0$ . By a semantic maneuver, the word 'something' is replaced by 'god,' except that the first letter became a capital, God, in order to warn us that we must not carry the enquiry any further."<sup>79</sup> Two years later, Hoyle, reflecting on his career in cosmology, had this to say about science and religion:

I have always thought it curious that, while most scientists claim to eschew religion, it actually dominates their thoughts more than it does the clergy. The passionate frenzy with which the big-bang cosmology is clutched to the corporate scientific bosom evidently arises from a deep-rooted attachment to the first page of Genesis, religious fundamentalism at its strongest.<sup>80</sup>

As late as 1992, he repeated the message of the big bang being "a metaphysical assumption" and that the standard big-bang theory was founded on "a religious miracle."<sup>81</sup> And in his autobiography, published in 1994, he stated that "Big-bang cosmology is a form of religious fundamentalism."<sup>82</sup>

It was Hoyle's popular and best-selling book, *The Nature of the Universe* from 1950 which really attracted public attention to the steady-state theory and its possible wider implications. Hoyle did not hide his distaste for the big-bang idea, a term which he invented in his BBC broadcast on which the book was based. In the final chapter he broadened the discussion from astronomy and cosmology to also cover a variety of non-scientific perspectives. After having attacked

<sup>78</sup> Hoyle 1948, p. 372.

<sup>79</sup> Hoyle and Narlikar 1980, p. 428.

<sup>80</sup> Hoyle 1982, p. 23.

<sup>81</sup> Hoyle 1992, p. 199.

<sup>82</sup> Hoyle 1994, p. 413.



Marxism and materialism, he proceeded to offer his view on religion in general, and Christianity in particular. Hoyle asked, rhetorically, if there was any reason to assume that the Hebrew cosmology, as presented in the Old Testament, was scientifically plausible. The answer was no, of course, from which he went on to state as his view "that religion is but a desperate attempt to find an escape from the truly dreadful situation in which we find ourselves."<sup>83</sup> Do minds—he did not speak of souls—have any continued existence after death? This question, he claimed, was only meaningful if the mind is "capable of physical detection," that is, has a connection to the physical body of man. As no such connection had ever been detected, he dismissed scornfully the Christian belief in an immortal soul. The Christians were anxious to avoid the notion of a final death, but all what they offered was "an equally horrible alternative... an eternity of frustration."

No, Hoyle saw nothing of value in the Christian message, and preferred a scientific cosmology such as that offered by the steady-state theory. "I think such a dynamic evolution would be more in keeping with the grandeur of the physical Universe than the static picture offered by formal religion." It should be noted that in *The Nature of the Universe* Hoyle did not make any specific association between big-bang cosmology and theism, nor between steady-state theory and atheism. His discussion was superficial and kept on a very general level. Although in later writings he did claim the connection between big-bang theory and Christian theism, he did never explicitly argue that his own steady-state theory disproved God or was consonant with atheism.

Nonetheless, Hoyle's attack on Christianity in the BBC broadcast and the book aroused antagonistic feelings in many people, and helped to make him a controversial figure. The BBC received many letters from indignant listeners who protested Hoyle's remarks against religion.<sup>84</sup> Among those who complained were Frederick Copleston, a Jesuit historian of philosophy; Geoffrey Fisher, Archbishop of Canterbury; and Dorothy L. Sayers, famous as a novelist but also a devout Christian and an active supporter of the Anglican Church. At the Modern Churchmen's Conference in Cambridge in 1950, a number of its members were disturbed by

<sup>83</sup> Hoyle 1950, p. 115.

<sup>84</sup> Many of the letters were published in *The Listener*, vols. 43 and 44 (1950).

Hoyle's recently published book and its effect on people's attitude to Christianity. It did not help much that theologians assured that the steady-state theory held no authority in science, and that faith in God had anyway nothing to do with what cosmological view happened to be accepted at the time being. As one theologian pointed out, Christians "should be beware of accepting the latest pronouncements of cosmologists as final and of accepting them for destructive or constructive purposes, and equally they should avoid all manifestations of undue alarm at such pronouncements."<sup>85</sup>

Hoyle's atheism and scientific attitude to nature and mind was to some extent shared by Harlow Shapley, the outstanding American astronomer and statesman of science. Intellectually, they were both descendants of the Victorian scientific naturalists. Shapley was not committed to any particular model of the expanding universe, but he did have strong opinions about the relationship between astronomy and religion. A confirmed agnostic, in the postwar period he often participated in science-religion discussions, and in 1960 he edited a major work on the subject—*Science Ponders Religion*.

In Shapley's view, the universe began with a collection of hydrogen atoms, and neither it nor life was in need of any divine intercession. "In the beginning was the Word, ... and I might venture that the word was hydrogen gas," he said in a lecture of 1959.<sup>86</sup> As to the question of where the hydrogen atoms came from, he dismissed it as metaphysics. Insofar as religion deserved to survive, in Shapley's view it could only be in a modernized, secular version based on the insights of science. For this reason, he welcomed the pope's 1951 address as "an indication that church teaching can also evolve."<sup>87</sup> But he considered traditional Christianity to be hopelessly fossilized and rather, looked "for religious beliefs that are founded on science, and that grow with science."<sup>88</sup> In a popular book of 1958, he asked: "May not science, broadly taken, be the fundamental cultural soil in which we plant and vitalize our religions? Need so many of them remain dated and non-rational?"<sup>89</sup> Such a belief—one would scarcely call it religion—he found in a kind of pantheism, although one in which

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<sup>85</sup> Davidson 1955, p. 169.

<sup>86</sup> Shapley 1960, p. 3.

<sup>87</sup> Shapley 1967, p. 100. In Shapley 1958, pp. 84–87, he quoted an extended excerpt of the papal address.

<sup>88</sup> Shapley 1967, p. 105.

<sup>89</sup> Shapley 1958, p. 84.

God had disappeared, and nature alone remained. His view on religion was less aggressive than Hoyle's, but he agreed that religion was magical and had become important only because of social habits and the power of the clergy.

The sharpest reply to Hoyle's rather offhand remarks against religion was included in an essay review appearing in the new *Irish Astronomical Journal*, the journal of the Irish Astronomical Society which in its early volumes included several papers of a religious orientation. For example, one such paper suggested the usefulness of lessons in astronomy in connection with religious instruction. Following the age-old tradition of natural theology, the author suggested that astronomy would illustrate to the school children "the power of God who created the Universe, put it working under fixed laws, and sustain it in operation."<sup>90</sup>

As mentioned in Chapter 4, Daniel O'Connell was an Irish astronomer and Jesuit priest who from 1938 to 1952 had served as director of the Riverview College Observatory in Sydney, Australia. He was then appointed science advisor to the pope, and director of the Vatican Observatory. He held this position for 18 years, and in 1968 he succeeded Lemaître as president of the Pontifical Academy of Sciences. O'Connell followed the long-established Catholic tradition of denying that there could be any legitimate conflict between science and religion. Both were seeking truth, and how could truth possibly contradict truth? Sure, there were differences, for whereas scientists were concerned with nature, theologians studied God, "the Author of nature," and these were quite different domains. In agreement with Lemaître and other Catholic scientists, O'Connell warned against a literal understanding of the kind of cosmology to be found in the Bible. Religion was revealed, science was not. "God might have chosen to reveal to us the secrets of nature too, but He did not do so."<sup>91</sup> Instead God had endowed man with faculties to observe nature, and with an intellect to probe its secrets.

In a lengthy essay review of Hoyle's book, O'Connell expressed his sympathy for his fellow-Catholic Lemaître's idea of an exploding universe, "which so clearly implies a Creator."<sup>92</sup> Hoyle's alternative

<sup>90</sup> Lynn 1950-51, p. 239.

<sup>91</sup> O'Connell 1954-55, p. 71.

<sup>92</sup> O'Connell 1952-53, p. 135. This was an implication that Lemaître never admitted.

theory, on the other hand, had very little to recommend it either from an observational or a philosophical point of view. If Hoyle imagined his theory had done away with the need for a creator, he was utterly wrong, for creation was not limited to the origin of time. "To an omnipotent Creator continuous creation is no more difficult than instantaneous creation of the whole universe at once." As a man of the church, O'Connell used much of his review to criticize Hoyle's "naive," "unscientific" and "remarkably foolish" views on philosophy and religion. Hoyle, he complained, was simply ignorant about these matters and had made no effort to study Christian thought; yet he was impudent enough "expressly to teach philosophers and theologians their business."<sup>93</sup> O'Connell of course believed in the immaterial and immortal soul, and did not accept Hoyle's claim that the belief was unscientific. The soul had not been proven scientifically, but neither had it been—or could be—disproven. Moreover, he claimed that "we can, by pure reason, deduce from the existence of matter that there must be at least one pure spirit, the Creator and Sustainer of the material universe." Needless to say, Hoyle disagreed, but he did not bother to respond to O'Connell's sharply worded review.

In the cosmological controversy between the two rival world pictures, considerations of a philosophical nature were much more common than references to religion. But sometimes the two could be difficult to distinguish, as allusions to religious contexts were sometimes hidden in philosophical terms. Stephen Toulmin was sceptical with respect to any kind of theoretical cosmology—whether big bang or steady state—but only alluded to religion in the first case where it might appear to be more relevant: "The primeval-atom theory of the Abbé Lemaître has a direct intellectual ancestry which links it to the Creation stories of early mythology, by way of Christian theology and Plato's *Timaeus*."<sup>94</sup> In an essay of 1957 on "Scientific Mythology" Toulmin reconsidered in some detail the question of the cosmic heat death. Like so many earlier critics, he concluded that thermodynamics cannot possibly apply to the universe as a whole. Or, as he wrote, "The running-down universe is a myth, and we shall discover about the Apocalypse from physics only what we read into the subject."<sup>95</sup>

<sup>93</sup> *Ibid.*, p. 136. Similarly in Davidson 1955, p. 170.

<sup>94</sup> Toulmin and Goodfield 1965, p. 258.

<sup>95</sup> Toulmin 1982, p. 49.

According to Toulmin, writing at a time when the scientific status of cosmology was a matter of debate, any statement about the universe at large was scientifically illegitimate. Not only could there be no scientifically valid statement about the end of the universe; also, the question of its beginning necessarily had to be mythological.

Other critics, of the steady-state theory in particular, were upset by the introduction of continual creation of matter, a notion which caused heated discussion. In his aggressive attacks on the theory of Hoyle, Bondi and Gold, Dingle repeatedly accused it of relying on "a continuous series of miracles."<sup>96</sup> The Argentine physicist, atheist and philosopher Mario Bunge agreed and expressed his criticism of "the creation fantasy" in a no less aggressive way. "The concept of emergence out of nothing is characteristically theological or magical," he thundered.<sup>97</sup> A Marxist and positivist, Bunge endorsed a world view with clear affiliations to that of the more radical scientific naturalists of the 19th century. He had no sympathy at all for the big-bang theory, which together with the steady-state theory belonged to the class of "science-fiction cosmologies [which] will tend to use ideas of archaic supernaturalistic cosmogonies (notably the creation concept), and will either tend to elude test or conflict with evidence." He found the steady-state theory's postulate of an infinitely old universe to be "basically sound," as the hypothesis was "required by any this-worldly *Weltanschauung* and any scientific cosmology." Yet the soundness was all destroyed by the hypothesis of continual creation of matter. This, he charged, "is no less scandalous a fiction than the conjecture that the universe was created with a stroke a few billion years ago. Either creation hypothesis smuggles magic into cosmology, thus turning it into science-fiction."

According to Bunge, any advocacy of creation out of nothing amounted to endorsement of magic; hence steady-theory cosmology was not a scientific but a magical theory. In his attack on the state of contemporary cosmology Bunge was on line with Dingle, although he expressed himself differently. He ended his essay with words that had a striking similarity to those that Dingle had used in the late 1930s, and that he now re-used in his fight against the steady-state heresy:

It [modern cosmology] poses the historian of culture the thorny problem of explaining the gullibility of certain academic

<sup>96</sup> Dingle 1953. For more on the philosophical contexts of the controversy, see Kragh 1996, pp. 219–236.

<sup>97</sup> Bunge 1962.

circles: why is it that science-fiction cosmology—or, for that matter, Eddingtonian neo-Pythagoreanism, ESP, psychoanalysis, and philosophical psychology—is often accepted as academically respectable, and sometimes even made, by otherwise competent scientists and critical philosophers?<sup>98</sup>

The American philosopher Milton Munitz offered a much more sober, detailed and analytical criticism of modern cosmology than Dingle and Bunge, but he, too, associated continual creation of matter with mysticism and supernaturalism. Munitz's objections were partly semantically based, centering on the term "creation" which to him implied a creator—that is, it was necessarily a theological term. With address to the steady-state theory, he asked: "But if the Maker, the process of making, and the purpose is gone, *what is left of the concept of creation?*"<sup>99</sup>

The response of William Bonnor, a British specialist in cosmology and general relativity, is of particular interest because it specifically included the religious aspect. In a paper of 1957, he sided with Hoyle in criticizing the big-bang theory insofar as it relied on an unexplained (as well as unexplainable) singular event that would necessarily have to be miraculous. Two years later, in a BBC symposium on theories of the universe, he complained that some scientists had identified the initial singularity with God, and went on:

It seems to me highly improper to introduce God to solve our scientific problems. There is no place in science for miraculous interventions of this sort; and there is a danger, for those who believe in God, in identifying him with singularities in differential equations, lest the need for him disappear with improved mathematics.<sup>100</sup>

Much the same argument appeared in Bonnor's book, *The Mystery of the Expanding Universe*, a popular work published in 1964. Bonnor was an atheist, and he sensed that big-bang cosmology was apologetic in its very nature: "The underlying motive is, of course, to bring in God as creator. It seems like the opportunity Christian theology has been waiting for ever since science began to depose religion from

<sup>98</sup> *Ibid.*, p. 141. ESP = Extra Sensory Perception.

<sup>99</sup> Munitz 1952, p. 40.

<sup>100</sup> Bonnor 1960, p. 7.

the minds of rational men in the 17th century."<sup>101</sup> One might now believe that Bonnor embraced the steady-state alternative, but this was not the case. On the contrary, on scientific and methodological grounds he could not accept a theory which contradicted Einstein's general theory of relativity, and operated with continual creation of matter out of nothing. Strongly committed to relativity, what he wanted was a singularity-free universe with an unlimited past and future—but one consistent with the general theory of relativity. His favored candidate was an oscillating or cyclical model in which the universe oscillated smoothly, that is, with no big bangs and no big crunches. This model had some of the conceptual advantages of steady-state theory, such as avoiding the question of the origin of the universe, while at the same time keeping on the firm ground of general relativity. Appealing as it was, unfortunately it did not agree with observations.

## CONCEPTS OF CREATION

As already indicated, there is no particular connection between theism and big-bang cosmology, just as steady-state cosmology hardly needs to be associated with atheism. Indeed, one of the leading steady-state theorists, McCrea, was a Christian. This important point may be further illustrated by the attitude of Bernard Lovell, a leading radio astronomer and director of the Jodrell Bank Observatory. In a series of lectures broadcast on the BBC in 1958, Lovell reflected on the two rival theories of the universe without clearly preferring either of them.<sup>102</sup> A devoted Christian, in his religious view he was influenced by Whitehead's process philosophy, and from this perspective there was no reason to regard the steady-state theory as a threat against the belief in a divine being. To Lovell, the important thing was that creation of matter was a sure sign of God's activity; whether it occurred abruptly or continuously was of less significance. Contrary to most other scientists, he freely admitted that where science was impotent, as in explaining matter creation, metaphysics and religion had to enter. This God-of-the-gaps attitude was precisely of the kind which

<sup>101</sup> Bonnor 1964, p. 117.

<sup>102</sup> Lovell 1959.

Hoyle and Bonnor denounced as a betrayal of the spirit of science. Lovell would of course accept the verdict of observation, but in 1958 it was not possible to discriminate clearly between the two models on observational grounds. The situation was open and invited to meta-scientific (including religious) considerations. From his Christian perspective, Lovell found the rival models equally acceptable.

Lovell realized that the so-called creation of the world is not identical to the beginning of the world, a point which is of crucial importance when it comes to the relationship between cosmology and religion. Many Christians undoubtedly believe that God created the world out of nothing and then—apart from a few miracles—left it to evolve according to the divinely created laws of nature. However, most scholars agree that there is only slender support in the biblical narrative for the notion of a *creatio originans*, an initial creation of the world *ex nihilo*. After all, Genesis starts with "In the beginning, when God created the universe, the earth was formless and desolate.... Then God commanded, 'Let there be light'—and light appeared." Cosmic creation out of nothing was only introduced in the second half of the second century, developed in the early church to emphasize God's absolute sovereignty and the goodness of his creation, the world.<sup>103</sup>

There is, on the other hand, solid support in the Bible for the view of *creatio continua*, that God is continuously creative and still at work.<sup>104</sup> In Christian theology, the notion of creation is not primarily concerned with God's initial creation of the world at some moment in the past, but with the incessant act by which he preserves the world in existence so long as he will. The world is contingent, at any time. If God stops creating or preserving, the world and its creatures will cease to exist. This view, although not beyond discussion, is far from new or heterodox. It was principally introduced by Thomas Aquinas, according to whom there was no serious disagreement between Christian belief and the notion of a world which had always existed. In his book on the eternity of the world, *De Aeternitate Mundi*, he made it clear that being does not necessarily presuppose temporal priority of non-being. "There is no contradiction in saying that something made by God has always existed," he wrote (see also Chapter 1).

<sup>103</sup> See May 1994 for historical evidence.

<sup>104</sup> E.g., Psalms 104:14–30; 147:8–19. Job 34:14–15.



Accordingly, in his book from 1956 Mascall saw no reason why the steady-state theory should be particularly problematic from a theological point of view. The question of an infinitely old universe was of great scientific interest, but nothing that the Christian needed to worry about: "The whole question whether the world had a beginning or not is, in the last resort, profoundly unimportant for theology."<sup>105</sup> Mascall dealt in some detail with the steady-state theory, and pointed out the irony that Hoyle's position was in fact close to the Christian view: "An uninstructed person, when told that Hoyle is a fervent advocate of the view of continuous creation, might not unreasonably suppose that Hoyle was a convinced theist who saw the hand of God in every being and event in the world's history ... The uninstructed person would, however, be totally mistaken in his supposition."<sup>106</sup> In the view of Mascall (and of O'Connell, and many others), Hoyle had shown a "remarkable ignorance" of what Christian belief really is. He found it "almost amusing" that Hoyle believed continuous creation of matter had finally eliminated God from the universe, for in the 19th century the notion would have been conceived as most embarrassing to an atheistic or agnostic scientist.

Mascall realized that his view might seem to be disappointingly negative, as it denied any particular relation between theology and scientific cosmology. Yet he was adamant that there was no such particular relation, and that the connection could at most be of an indirect, non-committing nature: "The Christian may well rejoice in the fact that the heavens declare the glory of God and the firmament sheweth his handiwork, while adopting an attitude of extreme detachment towards arguments that attempt to prove the existence of God from the Second Law of Thermodynamics or the recession of the extra-galactic nebulae."<sup>107</sup> After all, the creation of the world was not the most important part of the Christian message. God was the creator as well as the redeemer, and Mascall considered the latter function to be far more important than the first one. His detached view with respect to cosmology's theological significance was by no means original or particularly controversial. It was supported by many other theologians, both then and later.

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<sup>105</sup> Mascall 1956, p. 155.

<sup>106</sup> *Ibid.*, pp. 158-159.

<sup>107</sup> *Ibid.*, p. 166.

For example, Ian Barbour, an influential figure in the later debate about science and religion, agreed with Mascall that both of the two rival cosmologies could be interpreted either naturalistically or theistically. Because he found *creatio continua* to be much better supported by the Bible than *creation originans*, he wanted to do only with the first concept of creation. In a book of 1966, he formulated his position as follows:

We will suggest that the Christian need not favor either theory, for the doctrine of creation is not really about temporal beginnings but about the basic relationship between the world and God. The religious content of the idea of creation is compatible with either theory, and the debate about them can be settled only on scientific grounds, when further data are available.<sup>108</sup>

When Barbour wrote these lines, the further data were in fact available, primarily in the form of the recently discovered microwave background radiation, if at the time observed only at one or two wavelengths. In spite of voices such as Mascall's and Barbour's, it is still commonly believed that an eternal universe is incompatible with Christian belief. To mention but one example, in 1997 the American astronomer and science popularizer Carl Sagan asked what the consequences would be if science demonstrated an infinitely old universe. His answer was this: "Indeed, this is the one conceivable finding of science that could disprove a Creator—because an infinitely old universe would never have been created."<sup>109</sup> As we have seen, this is not an acceptable answer from a theological point of view. Even an infinitely old universe would have to be maintained, to be continually created.

Due to the multifariousness and flexibility of the concept of religion, it is exceedingly hard to imagine how astronomy and physics should be able to disprove religious views. As an illustration, consider an article titled "Is Religion Refuted by Physics and Astronomy?" which appeared in 1967 in the prestigious yearbook *Vistas in Astronomy*. The author, Herman Zanstra, was a distinguished Dutch emeritus professor of astronomy who in his youth,

<sup>108</sup> Barbour 1966, quotation from Torchbook edition of 1971, p. 368. In his later works, Barbour has modified his position and been more willing to consider an initial beginning. On the theological discussion of creation and its relevance to cosmology, see Peters 1988.

<sup>109</sup> Sagan 1997, p. 265.

while staying at the University of Washington, had done pioneering work in astrophysics. He now argued that modern cosmology is fully congruent with religion—indeed, that it supports the notion of an omnipresent spiritual and creative being. But as Zanstra's God differed from that of Whittaker and Milne, so did his arguments, which included references to telepathy and paranormal experiences. Indeed, Lodge might have felt more at home with Zanstra's arguments than with Milne's. Zanstra believed that the soul is tied to bodily existence and, as a consequence, in the far future the heat death will wipe out any trace of consciousness. Taking body-soul dualism to be a central dogma of any true religion, he naturally wanted to avoid the heat death, and for this purpose he introduced non-physical, spiritual or occult forces as sustainers of the universe. "Astronomy has thus paved the way for occultism and so religion," he concluded. Zanstra did not believe that the physical world had been created out of nothing, but rather from an eternal spiritual reality, which "would be the Creator." This position left him with an answer to the heat death: "If our universe fails by not supplying organisms or by being impossible altogether, no matter, another home *can* be provided by God, either in the form of an entirely different Universe or in an occult hereafter."<sup>110</sup> Perhaps the most remarkable aspect of Zanstra's strange defence of cosmic religiosity is that it appeared in a respected yearbook devoted to astronomy.

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<sup>110</sup> Zanstra 1967, p. 19.

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**Epilogue:  
From Standard Model  
to Quantum Cosmology**

## Epilogue: From Standard Model to Quantum Cosmology

DEVELOPMENTS AFTER 1965

Following the discovery of the cosmic microwave background radiation, the hot big-bang theory quickly became established as the paradigmatic theory of cosmology.<sup>1</sup> Progress was rapid, both in theory and observation. Whereas nucleosynthesis of most chemical elements could be accounted for without the assumption of a big bang, Gamow and his collaborators showed around 1950 that helium was primarily the result of nuclear reactions in the early universe. From the late 1960s, new work on the primordial nucleosynthesis of deuterium, lithium and helium isotopes turned out to be a powerful test of big-bang cosmology. The abundance of the light isotopes predicted by theory was consistent with improved measurements and, in addition, provided a more accurate value of the average density of matter in the universe.

Elementary particle physics became increasingly integrated with early-universe cosmology, a field which was seen as a laboratory for the physics of extremely high energies—the ultimate if somewhat virtual laboratory. For example, detailed calculations made in 1977 by Gary Steigman, David Schramm and James Gunn showed that the number of neutrino species could not be larger than three if the hot big-bang theory was correct. The prediction was later confirmed by

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<sup>1</sup> There is no good history of post-1965 cosmology. A review is provided in Coles 2001.

high-energy accelerator experiments, which served to increase confidence in the basic correctness of the big-bang model. Particle physicists also applied grand unified theories (which unify the strong, weak and electromagnetic forces) to understand processes taking place a fraction of a second after the big bang. In this way, they were able to explain the observed ratio of photons to baryons—about one billion to one—rather than accepting the ratio as just a contingent fact of nature.

The big-bang theory received further support from progress within the general theory of relativity. It was of particular importance when, in the mid 1960s, Roger Penrose, Stephen Hawking and others reinvestigated the old question of a cosmic singularity at  $t=0$ . Singularities in space-time and the ultra-dense state of the earliest universe had traditionally been considered somewhat fictitious, but Penrose and Hawking proved that under very general conditions the universe *must* have started in a singularity.<sup>2</sup> In other words, not only is the big-bang scenario compatible with general relativity, it seems to follow from it. On the other hand, it is commonly accepted that the mathematical proof of the singularity theorem cannot be directly translated to a physical proof that the universe started in a singularity, in “nothing.” Immediately after  $t=0$  and before the Planck time  $t=10^{-43}$  s the universe cannot be described by quantum mechanics and general relativity, but only by some as yet unknown theory of quantum gravity. In spite of what is often said, the big-bang theory does not account for the creation of the universe out of nothing.

The most important contribution of particle physics to recent cosmology has been the inflationary theory, introduced in 1981 by Alan Guth (there were, as usual, predecessors). According to this theory or class of theories, the very early universe underwent a kind of extreme supercooling and expanded suddenly by a gigantic factor. In the course of only  $10^{-34}$  s the universe expanded by a factor of maybe  $10^{44}$ . Because the energy density is constant during the brief inflation era, an enormous amount of energy will be generated. After the initial explosion, the expansion slowed down in agreement with the standard big-bang theory. Following Guth’s article of 1981, the inflationary universe model was quickly improved and developed into a variety of versions. The theory explained, among other things,

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<sup>2</sup> Earman 1999.

the large-scale homogeneity of the universe, the absence of magnetic monopoles, and the near flatness of space: phenomena which could not be explained by the standard theory. In spite of the rapid dissemination of the inflationary theory, it is far from free of difficulties. One of the problems is that it has mutated in a large number of forms, some of which diverge radically from the ordinary big-bang model.<sup>3</sup>

Observations have contributed as much or more to progress in recent cosmology as theory has. Improvements in optical and radio astronomy led to such new discoveries as quasars (1963), pulsars (1967) and gamma bursts (1973), all being celestial objects which in various ways nourished the further development of the standard model.

Probably the most important event in modern observational cosmology was the launching in 1989 of the Cosmic Background Explorer (COBE) satellite, which measured the background microwaves much more precisely than did earlier experiments. Analysis of its data in the early 1990s showed a perfect fit with the Planck blackbody spectrum of temperature 2.736 K (in 1996 improved to  $2.7277 \pm 0.002$  K). Even more interestingly, the results showed small departures from isotropy which, in good agreement with inflation theory, were interpreted as inhomogeneities in the very early universe. The COBE observations turned out to be a great triumph for big-bang theory, and made it even harder to believe that this theory is not essentially correct. George Smoot presented the first COBE data on the anisotropy of the cosmic background radiation in a TV-transmitted press conference of April 1992. He interpreted the data as "direct evidence of the birth of the universe and its evolution." As if this was not enough, he added that looking at the data was "like seeing God."<sup>4</sup>

The 1990s witnessed a major transformation of what until then had been the standard model of the universe. The change was observation-driven, primarily caused by new data on distant supernovae from the Hubble Space Telescope and also from balloon-borne detectors and land-based observatories. According to cosmologists' interpretations of the data, they showed that the critical Einstein-De Sitter model dominated by matter cannot be correct. The universe anno 2000 was

<sup>3</sup> Earman and Mosterin 1999. Among the non-standard inflationary models is the class of "chaotic inflation" theories developed by Andrei Linde and others. According to these theories, the universe as a whole consists of an infinite number of causally unconnected space-time domains. Whereas these are born and die, the universe as a whole is eternal.

<sup>4</sup> Lemonick 1993, pp. 285-286. According to Smoot, he meant the much-quoted phrase merely as a metaphor, not in an apologetic sense.

still of the big-bang type, but now with a positive cosmological constant and (therefore) in a state of accelerated expansion. The value of Hubble's constant was pinned down to  $73 \pm 10 \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$ , corresponding to an age of the universe close to 14 billion years.

Although there is not enough ordinary matter in the universe to account for the critical density, it is presently believed that we do live in a critical, though accelerating universe. To the extent there is a new standard theory, it accounts for the missing mass-energy by invoking two hypothetical but theoretically justified forms of energy. The one is dark matter, an exotic form of matter which so far is not known from experiments but must exist abundantly. The other, which is even more exotic, is the so-called dark energy, which is assumed to be associated with the cosmological constant and therefore often referred to as  $\Lambda$ -energy. As early as 1934, Lemaître had pointed out that the cosmological constant corresponds to a vacuum with energy density  $\rho_{\Lambda} = \Lambda c^2 / 8\pi G$ , and a negative pressure  $p_{\Lambda} = -\rho_{\Lambda} c^2$ . About one third of the total matter-energy density of the universe is assumed to be due to matter, most of which is dark. The greater part of the universe is made up of the vacuum energy associated with the cosmological constant, which thus has made a most remarkable come-back. Lemaître, if he were still alive today, would probably rejoice.

Recently even more precise data have been supplied by the Wilkinson Microwave Anisotropy Probe, named after the American astronomer David Wilkinson, a pioneer in the study of the background radiation. The new measurements, made public in early 2003, have narrowed down the Hubble constant to  $71 \text{ km} \cdot \text{s}^{-1} \cdot \text{Mpc}^{-1}$  and the age of the universe to the unprecedentedly accurate value 13.7 billion years (with an uncertainty of only 1%). It is now believed that the universe consists of 73% dark energy, probably in the form of  $\Lambda$ -energy, 23% dark matter, and 4% baryonic or ordinary matter. Its geometry is flat or very nearly so. Cosmology has definitely become an exact science. But it is more than that.

## MODERN COSMO-THEOLOGY

From about 1980 theologians began to take a stronger interest in cosmology, and to cultivate connections to physicists and astronomers. Specialist journals such as *Zygon* and *Science & Christian Belief*



included an increasing number of papers related to cosmology, and conferences on the theology-cosmology interface began to appear. One of the first was an international colloquium held at the University of Denver, Colorado, in November 1974 with the participation of 20 cosmologists, theologians, and historians and philosophers of science. Among the scientists were Hannes Alfvén; Arno Penzias; Peter Bergmann; Jürgen Ehlers; and Gerald Whitrow (of whom Alfvén was a Nobel laureate and Penzias would receive the prize four years later).

Alfvén dismissed in his address religion as a "myth," and passionately criticized the big-bang theory for being dogmatic and violating basic standards of science, to be no less mythical than religion. "The prevailing attitude is that all the objections to big-bang cosmology are swept under the rug," he complained. "And this is the fate also of the Creator, who is indispensable for manufacturing the big-banging atomic bomb."<sup>5</sup> William McCrea, too, suggested that cosmology was inseparably connected to religion, but his attitude and sympathies were different. The former advocate of the steady-state theory argued that cosmology, in whatever form, must necessarily include the postulation of a creator. "Cosmology requires, I venture to assert, the concept of Creator and of personality, and together these mean God." He further believed that the universe is purposeful, and "purpose is inseparable from person, and the Person of the Creator is revealed in the person of Christ."<sup>6</sup>

The physicist Charles Misner was a Catholic and a specialist in the general theory of relativity, and the coauthor (with John Wheeler and Kip Thorne) of the authoritative textbook, *Gravitation*. Misner distinguished between God as a model-maker, and God as a "pyrotechnic engineer lighting the fuse": the latter metaphor obviously a reference to big-bang cosmology. As he pointed out, the model-making God is not limited to producing big-bang universes, but may equally well produce a steady-state universe or any other kind of universe. From modern cosmology Misner found "reinforcement for the traditional teaching that God created the universe." After all, he contended, physics is unable to explain the existence of the universe; it has to accept this as a contingent fact. "Saying that God created the Universe

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<sup>5</sup> Alfvén 1977, p. 12.

<sup>6</sup> McCrea 1977, p. 72.

does not explain either God or the Universe, but it keeps our consciousness alive to mysteries of awesome majesty that we might otherwise ignore, and that deserve our respect."<sup>7</sup>

Another conference on the dialogue between science and theology was held at Christ Church, Oxford, in September 1979. In the volume that came out of the meeting, several of the authors related to cosmological questions and their relevance to theology. For example, the German theologian Wolfhart Pannenberg reflected on possible relations between the concept of creation and the spatio-temporal structure of the physical universe, including the question of eschatology. Although physics predicts the death of the universe, this final state will occur only in the very far future; the Christian notion of the end of the world, on the other hand, speaks of an imminent end, a final chapter in cosmic as well as human history. Noting the difference, Pannenberg thought it was "one of the most obvious conflicts between a worldview based on modern science and the Christian faith."<sup>8</sup> Other theologians have argued that what matters is the immortality of the soul, not the fate of the body or the world of material structures.<sup>9</sup>

In an influential review at the Oxford conference, Ernan McMullin discussed the historical and contemporary relationship between cosmology and theology. Does the big-bang theory lend support to the claim that a creator is needed? Whereas this was affirmed by Pius XII in his speech of 1951, the Catholic McMullin would only concede that if the universe had a divinely caused beginning in time, it would look something like the big-bang universe of modern cosmology. But he emphatically denied that "the Christian doctrine of creation 'supports' the big bang model ... [and also] that the big bang model 'supports' the Christian doctrine of creation." As we have seen, some theologians, such as Mascall, Barbour and Peacocke, considered cosmology to be wholly irrelevant to theology. According to McMullin, this is an unbalanced view which ignores that the Bible speaks of a creator who is responsible for the existence of the world. Christian doctrines are more than metaphysics and codes for moral conduct; they are also cosmic claims, and for this reason theologians need to pay attention to cosmology. "For better or worse, faith in a

<sup>7</sup> Misner 1977, p. 96.

<sup>8</sup> Pannenberg 1981, p. 14.

<sup>9</sup> E.g., Davis 1999.

transcendent Creator commits one to a larger story than even the already-large story of man's Fall, Redemption and ultimate destiny."<sup>10</sup>

The aim of a conference on "Cosmos and Creation" held at the University of Surrey in 1982 was to explore whether the universe of contemporary astronomy was compatible with the religious concept of creation. Stanley Jaki, a Benedictine priest and distinguished historian of science, presented a historical review in which he argued that the universe, thanks to science, now appears as "an irrefragable pointer to God, the mysterious origin of all." But he also emphasized that although scientific evidence is compatible with a creative event in the past, science has nothing to say about creation as such: "Physical science or scientific cosmology is absolutely powerless to show that any stage of material interactions is not reducible to a previous state, however hypothetical. If science is impotent in this purely scientific respect, it is even more impotent with respect to a far deeper problem, a problem of very different nature, namely, that a given physical state must owe its existence to a direct creative act, which brought that physical state into being out of nothing."<sup>11</sup> With regard to cosmology's relevance for theology he fully agreed with McMullin that Christianity is not only about persons but also about the universe and what it contains of things.

McMullin's review in the 1979 conference included an early discussion of the anthropic principle in relation to theology. The essence of this principle, first fully articulated by Brandon Carter in 1974 but with roots back to the numerological physics of the 1930s, is, to put it briefly, that the universe is fine-tuned in the sense that there are a number of numerical coincidences of just the kind that is required for life to appear. According to McMullin, the delicate fine-tuning of laws and constants of nature cannot be used as an argument for the Christian doctrine of a creative God. The anthropic principle also featured in the 1982 "Cosmos and Creation" conference, where the British astrophysicist B. R. Carr gave an extensive review of it, but without explicitly addressing its theological implications.

In the very extensive later literature on the theological significance of the anthropic principle, opinions are divided. Some find the principle to be eminently suited to theistic interpretation, while others tend

<sup>10</sup> McMullin 1981, p. 39 and p. 49.

<sup>11</sup> Jaki 1982, p. 260. The issue of the *Irish Astronomical Journal* (pp. 223–262) was devoted to the conference theme, and included papers also by Michael Shallis, B. J. Carr, and John Polkinghorne.

to conceive it as a substitute for theistic arguments. To give but two examples, the philosopher of religion Richard Swinburne considers the anthropic principle as a rival to theistic explanation; an attempt to avoid the conclusion that God exists. He does admit that the fine-tuning of the universe needs explanation, but not that the anthropic principle is a valid answer. Instead, the values of the natural constants and initial conditions are "substantial evidence for the existence of God, which alone can give a plausible explanation of why they are as they are."<sup>12</sup>

On the other hand, the Anglican priest and former particle physicist John Polkinghorne argues that anthropic considerations are an important part of the case for theism and a purposeful universe. If only in an indirect way, it proves the existence of God. What has been called the theistic anthropological principle, a cosmological variant of the argument from design, has been formulated as an alternative to the many-worlds theories of chaotic inflation cosmology. In Polkinghorne's words: "By construction these other worlds are unknowable to us. A possible explanation of equal intellectual respectability—and to my mind of greater economy and elegance—would be that this one world is the way it is because it is the creation of the will of a Creator who purposes that it should be so."<sup>13</sup>

It will be no surprise that there is no consensus in the modern debate about the relationship between theology and big-bang cosmology. The literature on the subject is considerable and diverse, but the main positions may be characterized by two popular books published around 1980. In 1978 the astrophysicist Robert Jastrow published his book *God and the Astronomers*, probably unaware that the very same title had been used by William Inge in 1934. Although presenting himself as "an agnostic in religious matters," Jastrow concluded from his brief and questionable review of the history of modern cosmology, a theistic morale. Scientists have succeeded to understand even the very early universe, but they "will never be able to raise the curtain on the mystery of creation," that is, to make sense of the ultimate event at  $t = 0$ . From this claim he argued that modern big-bang cosmology leads to "a biblical view of the origin of the

<sup>12</sup> Swinburne 1990, p. 164. The literature on the anthropic principle (in its several versions) is overwhelmingly large. Barrow and Tipler 1986 is still the basic source on the subject. For a bibliographical guide as of 1991, see Balashov 1991.

<sup>13</sup> Polkinghorne 1986, p. 80. See also Polkinghorne 1998, p. 92.

world." Jastrow ended his book with a nicely crafted parable, the message of which can hardly be called agnostic:

For the scientist who has lived by his faith in the power of reason, the story ends like a bad dream. He has scaled the mountains of ignorance; he is about to conquer the highest peaks; as he pulls himself over the final rock, he is greeted by a band of theologians who have been sitting there for centuries.<sup>14</sup>

John O'Keefe, a Catholic and a NASA astronomer, followed the line by suggesting an intimate correspondence between theological views and modern cosmology. What the theologians of the past saw dimly, "we see more clearly, with the advantage of better physics and astronomy. But we are looking at the same God, the Creator."<sup>15</sup> The message of pope Pius XII was not forgotten.

Peter Atkins, a physical chemist, begged to disagree with Jastrow and O'Keefe. An advocate of scientism and atheism, his views on science and religion can be seen as developments of those argued by Hoyle. To Atkins, religion is mere "sentimental wishful thinking" and he believes that the big-bang theory has made God redundant as cosmic creation can be accounted for naturalistically.<sup>16</sup> The universe arose from a quantum vacuum fluctuation in a way which physicists are on their way to understand. Whereas theists claim that God is omniscient, according to Atkins this attribute really belongs to science. The history of science proves that science has always surmounted the barriers it encounters, and there is no reason why it will not continue to do so and present a satisfactory theory of the creation itself. Religion, on the other hand, has an embarrassingly long record of failures.

## QUANTUM COSMOLOGIES

Ideas of applying quantum mechanics directly to the entire universe, without having a quantum theory of gravity, date back to the 1930s, to Eddington and Schrödinger in particular. Only much later were ideas of this kind developed into quantum theories of the very early universe.

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<sup>14</sup> Jastrow 1992 (second edition), p. 107.

<sup>15</sup> *Ibid.*, p. 118.

<sup>16</sup> Atkins 1981.

In 1973 Edward Tryon suggested a model in which the universe arose from "nowhere," as a fluctuation in a background quantum-field vacuum in its ground state; and nine years later Alexander Vilenkin argued in a paper titled "Creation of Universes from Nothing" that the universe might be understood as a quantum tunneling effect from a "nothingness" of vacuum fluctuations.<sup>17</sup> Many other physicists have taken up the idea of explaining what they call the creation of the universe along similar lines. It is obvious, however, that such models do not really explain the origin of the universe *ex nihilo*. They assume a background quantum space-time out of which matter is sought to be explained; but the quantum vacuum is a far cry from nothingness, and for this reason such models have attracted relatively little theological interest.

In a paper of 1983 James Hartle and Stephen Hawking developed a very different kind of quantum cosmology which did not assume a pre-existing background space-time, and in which time did not enter as an external parameter but arose phenomenologically *with* the universe. The Hartle-Hawking model is highly speculative and probably not a candidate for the real universe, but because of its conceptual and mathematical innovations it has been much discussed also by philosophers and theologians. It received popular attention through Hawking's book, *A Brief History of Time*, a book which has sold extremely well. The interesting feature in the Hartle-Hawking model is that it is temporally unbounded, and thus eliminates the initial singularity. The past of the universe is finite, but there is no beginning at  $t = 0$  and hence no creation in the ordinary sense. In Hawking's model universe, "There would be no singularities at which the laws of science break down and no edge of space-time at which one would have to appeal to God or some new law to set the boundary conditions for space-time." He famously concluded: "So long as the universe had a beginning, we could suppose it had a creator. But if the universe is really completely self-contained, having no boundary or edge, it would have neither beginning nor end; it would simply be. What place, then, for a creator?"<sup>18</sup>

Theologians have eagerly discussed Hawking's challenge, but of course without accepting that he has found a way to make God

<sup>17</sup> Tryon 1973. Vilenkin 1982, where it is claimed that in the proposed cosmological scenario "the universe is spontaneously created from literally *nothing*" (p. 26).

<sup>18</sup> Hawking 1990, p. 144 and p. 149.

redundant as creator. His claim rests on the premises that God does not intervene in nature, and that his only possible cosmic role is to create the universe and then leave it to run according to scientific laws. These premises need not be accepted. Robert John Russell, a leading scholar in theology and science, actually finds Hawking's work "enormously helpful to the task of Christian theology" because it has shown a way in which a universe without a beginning can nonetheless be God's creation.<sup>19</sup>

The discussion of modern big-bang cosmology in relation to religious issues has been cultivated on a popular level as well as on a highly specialized academic level. In spite of the many learned publications with advanced theological, philosophical and scientific arguments in favour of either theism or atheism, the debate is, in my view, curiously sterile. I am not aware of a single person who has changed his commitment because of arguments advanced by the other party. If a scholar starts out defending the view that cosmology speaks in favor of the existence of God, one can be certain that he will keep to that view; and the same goes for those who argue that cosmology is incompatible with theism. To illustrate this kind of academic debate, I can do no better than briefly sketch the opposite positions of William Lane Craig and Quentin Smith as they appear in the book *Theism, Atheism and Big Bang Cosmology*.<sup>20</sup>

Craig and Smith are both philosophers, and well versed also in the technical aspects of modern cosmology. Craig, who defends the case of theism, starts out with the classical cosmological argument known as the *kalām* argument:

1. Everything that begins to exist has a cause of its existence.
2. The universe began to exist.
3. Therefore the universe has a cause of its existence.

If combined with the postulate that God is the first cause of the universe, this implies that God exists. The formulation avoids the objections that David Hume and later critics raised against other versions

<sup>19</sup> Russell 1993, p. 321. This was one of several contributions to a conference at the Vatican Observatory in October 1991. The purpose of the conference, which included specialists in physics, cosmology, theology and philosophy, was to explore the implications of quantum cosmologies for theology and philosophy.

<sup>20</sup> For a complementary discussion, see Grünbaum 1996 and Grünbaum 2000, according to whom big bang cosmology is consistent with atheism.

of the cosmological argument, namely that the first cause must itself be caused. Given the premise (1) the objection is not valid, for it is among God's attributes that he did not begin to exist. Craig and Smith agree to accept the premise (2), which they take to be strongly supported by the big-bang theory. The conclusion (3) follows logically from (1) and (2), and the point of discussion therefore is the validity of the premise (1).

Does everything that begins to exist have a cause? Craig believes that this is indeed the case, and asserts that creation out of nothing cannot possibly have any physical meaning. "For the universe to spring into being uncaused out of nothing seems intuitively to be really, if not logically, absurd."<sup>21</sup> He considers the ancient postulate that nothing can come from nothing (*ex nihilo nihil fit*) to be a basic metaphysical principle of such strength that it has priority over any theory physicists can come up with. It is, he claims, a statement concerning empirical reality which must be true by necessity. Craig is thus of the opinion that the universe is caused by something which must be bigger than itself and outside it, a transcendent being which he identifies with God. Of course, even if one accepts the argument it does not follow that the creator proved in this way is the Christian God.

Smith agrees that the universe has a beginning, but not that it is caused. His counterargument is essentially to deny the premise (1) by referring to the initial singularity at  $t = 0$  as uncaused in the sense that it is beyond prediction, even in principle. He argues for this claim in a number of ways, employing both empirical and logical arguments, and believes himself to have negated Craig's proof of God. "I believe the principle that everything that begins to exist has a cause is not true *a priori* and is not supported by the empirical evidence, ... The fact of the matter is that the most reasonable belief is that we came from nothing, by nothing and for nothing."<sup>22</sup> Smith is not content with having showed, to his own satisfaction, that atheism is consistent with big-bang cosmology; he also argues the stronger claim that theism and the big-bang theory are inconsistent. That is, he argues from big-bang theory that God does *not* exist. His argument is

<sup>21</sup> Craig and Smith 1995, p. 60. The book includes full bibliographical references to earlier literature on the subject.

<sup>22</sup> *Ibid.*, p. 135.



strange, or so it seems to me, as it relates to God's rationality and the way he is supposed to act in the most efficient way:

If God intends to create a universe that contains living beings at some stage in its history, then there is no reason for him to begin the universe with an inherently unpredictable singularity. Indeed, it is positively irrational. It is a sign of incompetent planning to create as the first natural state something that requires immediate supernatural intervention to ensure that it leads to the desired result.<sup>23</sup>

The argument is of the same kind as those Milne used many years earlier to show that God must have created an infinite universe starting in a singularity. God, being perfectly rational, ought to have acted in certain ways which happen to be the ways we humans find to be most rational. He should have started with an initial state that naturally led to life, and not with an unpredictable singularity. Or, in Smith's words, "Since there is no natural law governing the singularity, God has no basis on which to compute what will emerge from the singularity."

If Smith's arguments are questionable, so are Craig's counterarguments, one of which concerns God's reasons to act as he supposedly did. He points out, to my mind reasonably, that God may not conform to our standards of rationality and efficiency; and Craig then goes on to suggest that God might have had reasons for being causally engaged in the creation. "Perhaps God delights in the creative activity of fashioning a world.... Perhaps He has reasons of which we have no idea." Yes, perhaps.

Craig and Smith also discuss quantum cosmology in the form of the Hartle-Hawking model and its implications. Again there are no surprises. Craig denies the force of Hawking's argument that there is no place for God, among other reasons because Hawking fails to distinguish between God as the original creator of the universe, and God as its continual preserver. Smith, too, criticizes Hawking's argument—"probably the worst atheistic argument in the history of Western thought"—but nonetheless concludes that the Hartle-Hawking universe is godless and inconsistent with theism. But I shall stop my sketch of the Craig-Smith debate at this point. Needless to say, neither it nor other discussions of a similar kind has led to any real clarification of the old question of the relationship between God and the universe.

<sup>23</sup> *Ibid.*, pp. 202–203.



# ■ Bibliography

## ■ A

- Adams, Mark B.** (2000). "Last Judgment: The visionary biology of J. B. S. Haldane," *Journal of the History of Biology* **33**, 457–491.
- Alfvén, Hannes** (1977). "Cosmology: Myth or science?" 1–14 in Yourgrau and Breck, eds. 1977.
- Allen, H. Stanley** (1940). "The search for truth," *Nature* **146**, 637–639.
- Arrhenius, Svante** (1909). "Die Unendlichkeit der Welt," *Scientia* **5**, 217–229.
- (1921). *Das Werden der Welten*. 7th edn. Leipzig: Akademische Verlagsgesellschaft.
- Assis, A. K. T., and M. C. D. Neves** (1995). "The redshift revisited," *Astrophysics and Space Science* **227**, 13–24.
- Atkins, Peter W.** (1981). *The Creation*. Oxford: W. H. Freeman.

## ■ B

- Balashov, Yuri** (1991). "Resource letter AP-1: The anthropic principle," *American Journal of Physics* **59**, 1069–1076.
- (1992). "On the evolution of natural laws," *British Journal for the Philosophy of Science* **43**, 343–370.
- Banerji, A. C.** (1934). "Nuclear structure,  $\gamma$ -ray fission, and the expanding universe," *Nature* **133**, 984.
- Barbour, Ian** (1966). *Issues in Science and Religion*. New York: Prentice Hall.
- (1990). *Religion in an Age of Science*. San Francisco: HarperSanFrancisco.

- Barnes, Ernest W.** (1927). *Should such a Faith Offend? Sermons and Addresses*. London: Hodder and Stoughton.
- (1931). [Contribution to] "Discussion on the evolution of the universe," *Nature* **128**, 598–602.
- (1933). *Scientific Theory and Religion: The World Described by Science and its Spiritual Interpretation*. Cambridge: Cambridge University Press.
- Barrow, John D., and Frank J. Tipler** (1986). *The Anthropic Cosmological Principle*. Oxford: Clarendon Press.
- Barton, Ruth** (1987). "John Tyndall, pantheist: A rereading of the Belfast address," *Osiris* **3**, 111–134.
- Batten, Alan H.** (1994). "A most rare vision: Eddington's thinking on the relation between science and religion," *Quarterly Journal of the Royal Astronomical Society* **35**, 249–270.
- Bavink, Bernhard** (1914). *Allgemeine Ergebnisse und Probleme der Naturwissenschaft*. Leipzig: Hirzel.
- (1952). *Das Weltbild der heutigen Naturwissenschaften und seine Beziehungen zu Philosophie und Religion*. Iserlohn: Silva-Verlag.
- Beichler, James E.** (1988). "Ether/or: Hyperspace models of the ether in America," 206–233 in Stanley Goldberg and Roger H. Stuewer, eds., *The Michelson Era in American Science 1870–1930*. New York: AIP Conference Proceedings No. 179.
- Berenda, Carlton W.** (1951). "Notes on Lemaître's cosmology," *The Journal of Philosophy* **48**, 338–341.
- Berendzen, Richard, Richard Hart, and Daniel Seeley** (1976). *Man Discovers the Galaxies*. New York: Science History Publications.
- Berger, André**, ed. (1984). *The Big Bang and Georges Lemaître*. Dordrecht: Reidel.
- Bernal, John D.** (1939). *The Social Function of Science*. London: Routledge & Sons.
- Bernhardt, Hannelore** (1969). "Der Wiederkehrinwand gegen Boltzmanns H-Theorem und der Begriff der Irreversibilität," *NTM: Schriftenreihe für Geschichte der Naturwissenschaften, Technik und Medizin* **6**, 27–36.
- Beyley, Richard H.** (1994). *From Positivism to Organicism: Pascual Jordan's Interpretations of Modern Physics in Cultural Context*. Ph.D. Thesis, Harvard University.
- Boi, Luciano** (1994). "Die Beziehungen zwischen Raum, Kontinuum und Materie im Denken Riemanns: Die Äthervorstellung und die Einheit der Physik," *Philosophia Naturalis* **31**, 171–216.

- Boltzmann, Ludwig** (1895). "On certain questions of the theory of gases," *Nature* **51**, 483–485.
- (1898). *Vorlesungen über Gastheorie*. Part 2. Leipzig: Barth.
- (1905). *Populäre Schriften*. Leipzig: Barth.
- Bondi, Hermann** (1952). *Cosmology*. Cambridge: Cambridge University Press.
- (1993). "Religious divisions," *Nature* **365**, 484.
- Bonhoeffer, Dietrich** (1971). *Letters and Papers from Prison*. London: SCM Press.
- Bonnor, William** (1960). "Relativistic theories of the universe," 1–11 in Hermann Bondi *et al.*, eds., *Rival Theories of Cosmology*. London: Oxford University Press.
- (1964). *The Mystery of the Expanding Universe*. New York: Macmillan.
- Bonting, Sjoerd L.** (2003). "Theological implications of possible extraterrestrial life," *Zygon* **38**, 587–602.
- Boodin, John E.** (1934). *God. A Cosmic Philosophy of Religion*. New York: Macmillan.
- Bork, Alfred M.** (1964). "The fourth dimension in nineteenth-century physics," *Isis* **55**, 326–338.
- Born, Max** (1931). "Ansätze zur Quantenelektrodynamik," *Zeitschrift für Physik* **69**, 141–152.
- (1956). *Experiment and Theory in Physics*. New York: Dover Publications.
- Bowler, Peter J.** (1998). "Evolution and the Eucharist: Bishop E. W. Barnes on science and religion in the 1920s and 1930s," *British Journal for the History of Science* **31**, 453–467.
- (2001). *Reconciling Science and Religion: The debate in Early-Twentieth-Century Britain*. Chicago: University of Chicago Press.
- Brentano, Franz** (1987). *On the Existence of God*. Dordrecht: Martinus Nijhoff.
- Bridgman, Percy W.** (1955). *Reflections of a Physicist*. New York: Philosophical Library.
- Brill, D. R.** (1962). "Review of Jordan's extended theory of gravitation," 50–68 in Christian Møller, ed., *Evidence for Gravitational Theories*. New York: Academic Press.
- Broad, Charlie D.** (1940). "Discussion of Sir Arthur Eddington's 'The philosophy of physical science'," *Philosophy* **15**, 301–312.
- Brock, William H.** (1969). "Lockyer and the chemists: The first dissociation hypothesis," *Ambix* **16**, 81–99.

- Bronstein, Matvei** (1933). "On the expanding universe," *Physikalische Zeitschrift der Sowjetunion* **3**, 73–82.
- Bronstein, Matvei, and Lev Landau** (1933). "Über den zweiten Wärmesatz und die Zusammenhangsverhältnisse der Welt im grossen," *Physikalische Zeitschrift der Sowjetunion* **4**, 114–118.
- Brush, Stephen G.** (1966). *Kinetic Theory*. 2 vols. Oxford: Pergamon Press.
- (1978). *The Temperature of History: Phases of Science and Culture in the Nineteenth Century*. New York: Burt Franklin & Co.
- (1980). "Poincaré and cosmic evolution," *Physics Today* **33**: 3, 42–49.
- (1986). *The Kind of Motion We Call Heat: A History of the Kinetic Theory of Gases in the 19th Century*. 2 vols. Amsterdam: North-Holland.
- (1987). "The nebular hypothesis and the evolutionary worldview," *History of Science* **25**, 245–278.
- Brück, Mary T.** (2002). *Agnes Mary Clerke & the Rise of Astrophysics*. Cambridge: Cambridge University Press.
- Bunge, Mario** (1962). "Cosmology and magic," *The Monist* **47**, 116–141.

## ■ C

- Calinon, Auguste** (1889). "Les espaces géométriques," *Revue Philosophiques de la France et de l'Étranger* **27**, 588–595.
- Caneva, Kenneth L.** (1993). *Robert Mayer and the Conservation of Energy*. Princeton: Princeton University Press.
- (1997). "Colding, Ørsted, and the meaning of force," *Historical Studies in the Physical and Biological Sciences* **28**, 1–138.
- Cantor, Geoffrey, and Chris Kenny** (2001). "Barbour's fourfold way: Problems with his taxonomy of science-religion relationships," *Zygon* **36**, 765–781.
- Capek, Milic** (1971). *Bergson and Modern Physics*. Dordrecht: Kluwer.
- Cappi, Alberto** (1994). "Edgar Allan Poe's physical cosmology," *Quarterly Journal of the Royal Astronomical Society* **35**, 177–192.
- Cardwell, Donald S. L.** (1971). *From Watt to Clausius: The Rise of Thermodynamics in the Early Industrial Age*. London: Heinemann.
- Carr, H. Wildon** (1921). "Metaphysics and materialism," *Nature* **108**, 247–248.
- Carroll, William** (1998). "Thomas Aquinas and big bang cosmology," *Sapientia* **53**, 73–95.
- Carter, Brandon** (1974). "Large number coincidences and the anthropic principle in cosmology," 291–298 in Malcolm Longair, ed., *Confrontation of Cosmological Theories with Observation Data*. Dordrecht: Reidel.

- Chandrasekhar, Subrahmanyan** (1987). *Truth and Beauty: Aesthetics and Motivations in Science*. Chicago: University of Chicago Press.
- Chang, Hasok** (1993). "A misunderstood rebellion: The twin-paradox and Herbert Dingle's vision of science," *Studies in the History and Philosophy of Science* **24**, 741–790.
- Chapman, Cohen** (1931). *God and the Universe: Eddington, Jeans, Huxley & Einstein*. London: Pioneer Press.
- Christian, William A.** (1959). *An Interpretation of Whitehead's Metaphysics*. New Haven: Yale University Press.
- Chwolson, Orest** (1910). "Duerfen wir die physikalischen Gesetze auf das Universum anwenden?" *Scientia* **8**, 41–53.
- Čirković, Milan M.** (2003a). "Resource letter: PEs-1: Physical eschatology," *American Journal of Physics* **71**, 122–133.
- (2003b). "The thermodynamical arrow of time: Reinterpreting the Boltzmann-Schuetz argument," *Foundations of Physics* **33**, 467–490.
- Clarke, Bruce** (2001). *Energy Forms: Allegory and Science in the Era of Classical Thermodynamics*. Ann Arbor: University of Michigan Press.
- Clausius, Rudolf** (1864). "Ueber die Concentration von Wärme- und Lichtstrahlen und die Grenzen ihrer Wirkung," *Annalen der Physik und Chemie* **121**, 1–44.
- (1868). "On the second fundamental theorem of the mechanical theory of heat," *Philosophical Magazine* **35**, 405–419.
- Clerke, Agnes M.** (1886). *A Popular History of Astronomy during the Nineteenth Century*. Edinburgh: Adam & Charles Black.
- (1890). *The System of the Stars*. London: Longmans, Green & Co.
- (1901). "Low-temperature research at the Royal Institution, 1893–1900," *Proceedings of the Royal Institution* **16**, 699–719.
- (1903). *Problems in Astrophysics*. London: Adam & Charles Black.
- Clifford, William K.** (1879). *Lectures and Essays*. 2 vols. London: Macmillan.
- Cohen, I. Bernard**, ed. (1978). *Isaac Newton's Papers & Letters on Natural Philosophy*. Cambridge, Mass.: Harvard University Press.
- Cohen, Robert S.** (1949–50). "Epistemology and cosmology: E. A. Milne's theory of relativity," *The Review of Metaphysics* **3**, 385–405.
- Colding, Ludvig A.** (1972). *Ludvig Colding and the Conservation of Energy Principle*. Translated by Per Dahl. New York: Johnson Reprint Corporation.
- Coles, Peter**, ed. (2001). *The Routledge Companion to the New Cosmology*. London: Routledge.
- Collingwood, Robin** (1960). *The Idea of Nature*. London: Oxford University Press.

- Coulson, Charles A.** (1955). *Science and Christian Belief*. London: Oxford University Press.
- Craig, William L., and Quentin Smith** (1995). *Theism, Atheism and Big Bang Cosmology*. Oxford: Clarendon Press.
- Crookes, William** (1886). "On the nature and origin of the so-called elements," Report, *British Association for the Advancement of Science 1886*, 558–576.
- Crowe, Michael J.** (1986). *The Extraterrestrial Life Debate 1750–1900*. Cambridge: Cambridge University Press.
- (1994). *Modern Theories of the Universe: From Herschel to Hubble*. New York: Dover Publications.
- (2001). "Astronomy and religion (1780–1915): Four case studies involving ideas of extraterrestrial life," *Osiris* **16**, 209–226.
- Curd, Martin** (1982). "Popper on Boltzmann's theory of the direction of time," 263–303 in Roman Sexl and Joseph Blackmore, eds., *Ludwig Boltzmann. Ausgewählte Abhandlungen*. Braunschweig: Vieweg & Sohn.

## D

- Davidson, M.** (1955). "Modern cosmology and the theologians," *Vistas in Astronomy* **1**, 166–172.
- Davies, Paul** (1983). *God & the New Physics*. Harmondsworth: Penguin.
- Davis, John J.** (1999). "Cosmic endgame: Theological reflections on recent scientific speculations on the ultimate fate of the universe," *Science & Christian Belief* **11**, 15–27.
- DeKosky, Robert K.** (1973). "Spectroscopy and the elements in the late nineteenth century: The work of Sir William Crookes," *British Journal for the History of Science* **6**, 400–423.
- Descartes, René** (1996). *Discourse on Method and Meditations on First Philosophy*. Edited by David Weissman. New Haven: Yale University Press.
- De Maria, Michelangelo, and Arturo Russo** (1989). "Cosmic ray romancing: The discovery of the latitude effect and the Compton-Millikan controversy," *Historical Studies in the Physical and Biological Sciences* **19**, 211–266.
- (1990). "Cosmic rays and cosmological speculations in the 1920s: The debate between Jeans and Millikan," 401–409 in Bruno Bertotti *et al.*, eds., *Modern Cosmology in Retrospect*. Cambridge: Cambridge University Press.



- De Rath, Valérie** (1994). *Georges Lemaître, le Père du Big Bang*. Charleroi: Labor.
- De Sitter, Willem** (1930). "The expanding universe. Discussion of Lemaître's solution of the equations of the inertial field," *Bulletin of the Astronomical Institutes of the Netherlands* **5**, 211–218.
- (1931). "The expanding universe," *Scientia* **49**, 1–10.
- (1932). *Kosmos*. Cambridge, Mass.: Harvard University Press.
- Dick, Steven J.** (1999). *The Biological Universe. The Twentieth-Century Extraterrestrial Life Debate and the Limits of Science*. Cambridge: Cambridge University Press.
- Dicke, Robert H.** (1961). "Dirac's cosmology and Mach's principle," *Nature* **192**, 440–441.
- Dingle, Herbert** (1924). *Modern Astrophysics*. London: Collins Sons.
- (1928). "Physics and God," *The Hibbert Journal* **27**, 35–46.
- (1931). *Science and Human Experience*. London: Williams & Norgate.
- (1937a). "Modern Aristotelianism," *Nature* **139**, 784–786.
- (1937b). "Deductive and inductive methods in science. A reply," *Nature* **139**, 1011–1012.
- (1953). "Science and modern cosmology," *Monthly Notices of the Royal Astronomical Society* **113**, 393–407.
- Dirac, Paul A. M.** (1937). "The cosmological constants," *Nature* **139**, 323.
- (1938). "A new basis for cosmology," *Proceedings of the Royal Society A* **165**, 199–208.
- (1939). "The relation between mathematics and physics," *Proceedings of the Royal Society (Edinburgh)* **59**, 122–129.
- (1968). "The scientific work of Georges Lemaître," *Pontificia Academia Scientia, Commentarii* **2** (11), 1–20.
- Disney, M. J.** (2000). "The case against cosmology," *General Relativity and Gravitation* **32**, 1125–1134.
- Douglas, A. Vibert** (1956). *The Life of Arthur Stanley Eddington*. London: Thomas Nelson and Sons.
- Duhem, Pierre** (1974). *The Aim and Structure of Physical Theory*. New York: Atheneum.
- Dukas, Helen, and Banesh Hoffman**, eds. (1979). *Albert Einstein — The Human Side*. Princeton: Princeton University Press.
- Durham, Ian T.** (2003). "Numerology and the cosmos: Alternative cosmologies in 1930s Britain," *Cubo Matemática Educacional* **5**, 1–14.
- Dühring, Eugen K.** (1875). *Cursus der Philosophie als streng Wissenschaftlicher Weltanschauung und Lebensgestaltung*. Leipzig: Erich Koschny.

**Dyson, Freeman J.** (1986). "Paul A. M. Dirac," *Yearbook of the American Philosophical Society*, 100–104.

## ■ E

- Earman, John** (1999). "The Penrose-Hawking singularity theorems: History and implications," 235–270 in Hubert Goenner *et al.*, eds., *The Expanding Worlds of General Relativity*. Boston: Birkhäuser.
- (2001). "Lambda: The constant that refuses to die," *Archive for History of Exact Sciences* 55, 189–220.
- Earman, John, and Jesus Mosterin** (1999). "A critical look at inflationary cosmology," *Philosophy of Science* 66, 1–49.
- Eddington, Arthur S.** (1920). "The meaning of matter and the laws of nature according to the theory of relativity," *Mind* 120, 145–158.
- (1924). "A comparison of Whitehead's and Einstein's formulae," *Nature* 113, 192.
- (1925). "The domain of physical science," 187–218 in Joseph Needham, ed., *Science, Religion and Reality*. London: The Sheldon Press.
- (1927–29). "Sub-atomic energy," *Memoirs and Proceedings of the Manchester Literary and Philosophical Society* 72–73, 101–107.
- (1928). *The Nature of the Physical World*. Cambridge: Cambridge University Press.
- (1931a). "The end of the world: From the standpoint of mathematical physics," *Nature* 127, 447–453.
- (1931b). "On the value of the cosmical constant," *Proceedings of the Royal Society A* 133, 605–615.
- (1932). "The theory of electric charge," *Proceedings of the Royal Society A* 138, 17–41.
- (1935). *New Pathways in Science*. Cambridge: Cambridge University Press.
- (1936). *Relativity Theory of Protons and Electrons*. Cambridge: Cambridge University Press.
- (1939a). *Science and the Unseen World*. New York: Macmillan.
- (1939b). *The Philosophy of Physical Science*. Cambridge: Cambridge University Press.
- (1939c). "The cosmological controversy," *Science Progress* 34, 225–236.
- (1944a). "The recession-constant of the galaxies," *Monthly Notices of the Royal Astronomical Society* 104, 200–204.

- (1944b). "The evolution of the cosmical number," *Proceedings of the Cambridge Philosophical Society* **40**, 37–56.
- Einstein, Albert** (1935). *The World as I See It*. London: John Lane.
- (1950). *Out of My Later Years*. London: Thames and Hudson.
- Elliot, Hugh** (1921). "Relativity and materialism," *Nature* **108**, 432.
- Ellis, George F. R.** (1988). "The expanding universe: A history of cosmology from 1917 to 1960," 367–431 in Don Howard and John Stachel, eds., *Einstein and the History of General Relativity*. Boston: Birkhäuser.
- (1993). "The theology of the anthropic principle," 363–400 in Robert J. Russell, Nancy Murphy, and C. J. Isham, eds., *Quantum Cosmology and the Laws of Nature: Scientific Perspectives on Divine Action*. Vatican Observatory: Vatican City State.
- Engels, Friedrich** (1973). *Dialektik der Natur*. Berlin: Dietz Verlag.
- (1975). *Anti-Dühring: Herr Eugen Dühring's Revolution in Science*. London: Lawrence & Wishart.
- Evans, David S.** (1998). *The Eddington Enigma*. Princeton: Xlibris.

## ■ F

- Farwell, Ruth, and Christopher Knee** (1990). "The end of the absolute: A nineteenth-century contribution to general relativity," *Studies in the History and Philosophy of Science* **21**, 91–121.
- Felber, Hans-Joachim**, ed. (1994). *Briefwechsel zwischen Alexander von Humboldt und Friedrich Wilhelm Bessel*. Berlin: Akademie Verlag.
- Ferguson, James** (1778). *Astronomy Explained upon Sir Isaac Newton's Principles*. 6th edn. London: W. Strathan.
- Feuer, Lewis S.** (1971). "The social roots of Einstein's theory of relativity," *Annals of Science* **27**, 277–298, 313–344.
- (1974). *Einstein and the Generations of Science*. New York: Basic Books.
- Fick, Adolf** (1903). *Gesammelte Schriften*. Vol. 1. Würzburg: Stahels Verlag.
- Frank, Philipp** (1948). *Einstein. His Life and Times*. London: Jonathan Cape.
- Frautschi, Steven** (1982). "Entropy in an expanding universe," *Science* **217**, 593–599.
- Frenkel, Viktor Ya.** (1988). "Aleksandr Aleksandrovich Fridman (Friedmann): A biographical essay," *Soviet Physics — Uspekhi* **31**, 645–665.
- Freundlich, Erwin** (1933). "Ein neuartiger Versuch von E. A. Milne, das kosmologische Problem zu lösen und die Expansion der Spiralnebel zu deuten," *Die Naturwissenschaften* **21**, 54–59.

- Friedman, Alan J., and Carol C. Donley** (1985). *Einstein as Myth and Muse*. Cambridge: Cambridge University Press.
- Friedmann, Alexander** (1922). "Über die Krümmung des Raumes," *Zeitschrift für Physik* **10**, 377–386.
- (2000). *Die Welt als Raum und Zeit*. Frankfurt am Main: Harri Deutsch.

## ■ G

- Gale, George, and Niall Shanks** (1996). "Methodology and the birth of modern cosmological inquiry," *Studies in the History and Philosophy of Modern Physics* **27**, 279–296.
- Gale, George, and John Urani** (1999). "Milne, Bondi, and the 'second way' to cosmology," 343–376 in Hubert Goenner *et al.*, eds., *The Expanding Worlds of General Relativity*. Boston: Birkhäuser.
- Galileo** (1957). *Discoveries and Opinions of Galileo*. New York: Anchor Books.
- Gaukroger, Stephen** (1995). *Descartes. An Intellectual Biography*. Oxford: Clarendon Press.
- Gibson, Stanley T.** (1875). *Religion and Science*. London: Longmans, Green.
- Gifford, A. C.** (1934). "The immortality of the universe," *Scientia* **56**, 192–204.
- Godart, Odon, and Michael Heller** (1978). "Un travail inconnu de Georges Lemaître," *Pontifica Academia delle Scienze, Commentarii* **3**, 1–12.
- (1985a). *Cosmology of Lemaître*. Tucson: Pachart Publishing House.
- eds. (1985b). *The Expanding Universe: Lemaître's Unknown Manuscript*. Tucson: Pachart Publishing House.
- Grant, Edward**, ed. (1974). *A Source Book in Medieval Science*. Cambridge, Mass.: Harvard University Press.
- Gregory, Frederick** (1977). *Scientific Materialism in Nineteenth Century Germany*. Dordrecht: Reidel.
- Graham, Loren R.** (1972). *Science and Philosophy in the Soviet Union*. New York: Knopf.
- (1981). *Between Science and Values*. New York: Columbia University Press.
- Grünbaum, Adolph** (1952). "Some highlights of modern cosmology and cosmogony," *The Review of Metaphysics* **5**, 481–498.
- (1996). "Theological misinterpretations of current physical cosmology," *Foundations of Physics* **26**, 523–543.
- (2000). "A new critique of theological interpretations of physical cosmology," *British Journal for Philosophy of Science* **51**, 1–43.

**Günther, P.** (1924). "Die kosmologische Betrachtungen von Nernst," *Zeitschrift für Allgemeine Chemie* **37**, 454–457.

## H

- Haas, Arthur E.** (1907). "Die Physik und das kosmologische Problem," *Archiv für Systematische Philosophie* **13**, 511–525.
- (1912). "Ist die Welt in Raum und Zeit unendlich?" *Archiv für Systematische Philosophie* **18**, 167–184.
- (1918). "Über eine Beziehung der Gravitationskonstante zu den Grundgrößen der Elektrizitätstheorie," *Physikalische Zeitschrift* **19**, 30.
- (1934). *Kosmologische Probleme der Physik*. Leipzig: Akademische Verlagsgesellschaft.
- (1936). "An attempt to a purely theoretical derivation of the mass of the universe," *Physical Review* **49**, 411–412.
- (1938a). "The relation between the gravitational constant and Hubble's factor," *Physical Review* **53**, 207.
- (1938b). "Modern physics and religion," *The New Scholasticism* **12**, 1–8.
- (1966). *Der Erste Quantenansatz für das Atom*. Stuttgart: Ernst Battenberg Verlag.
- Haeckel, Ernst** (1900). *The Riddle of the Universe*. New York: Watts.
- Haldane, John B. S.** (1927). *Possible Worlds and other Essays*. London: Chatto & Windus.
- (1928). "The universe and irreversibility," *Nature* **122**, 808–809.
- (1938). *The Marxist Philosophy and the Sciences*. London: Allen & Unwin.
- (1945a). "A new theory of the past," *American Scientist* **33**, 129–145.
- (1945b). "A quantum theory of the origin of the solar system," *Nature* **155**, 133–135.
- Haldane, John S.** (1908). "The relation of physiology to physics and chemistry," Report, *British Association for the Advancement of Science*, 864–871.
- Harman, Peter M.** (1982). *Energy, Force, and Matter: The Conceptual Development of Nineteenth-Century Physics*. Cambridge: Cambridge University Press.
- (1998). *The Natural Philosophy of James Clerk Maxwell*. Cambridge: Cambridge University Press.
- Harrison, Edward** (1986). "Newton and the infinite universe," *Physics Today* **39**: 2, 24–32.

- Harrison, J. A.**, ed. (1965). *The Complete Works of Edgar Allan Poe*. New York: AMS Press.
- Hawking, Stephen W.** (1990). *A Brief History of Time*. Toronto: Bantam Books.
- Heckmann, Otto** (1932). "Die Ausdehnung der Welt in ihrer Abhängigkeit von der Zeit," *Nachrichten von der Gesellschaft der Wissenschaft zu Göttingen, Math.-Phys. Klasse*, 97–106.
- Heffernan, William C.** (1978). "The singularity of our inhabited world: William Whewell and A. R. Wallace in dissent," *Journal of the History of Ideas* 39, 81–100.
- Heimann, Peter M.** (1972). "The Unseen Universe: Physics and the philosophy of nature in Victorian Britain," *British Journal for the History of Science* 6, 73–79.
- Heisenberg, Werner** (1971). *Physics and Beyond*. New York: Harper & Row.
- Helm, Georg** (2000). *The Historical Development of Energetics*. Dordrecht: Kluwer Academic.
- Helmholtz, Hermann von** (1995). *Science and Culture. Popular and Philosophical Essays*. Edited by David Cahan. Chicago: Chicago University Press.
- Hentschel, Klaus** (1993). "Bernhard Bavink (1879–1947): Der Weg eines Naturphilosophen vom deutschnationalen Sympathisanten der NS-Bewegung bis zum unbequemen Non-Konformisten," *Sudhoffs Archiv* 77, 1–32.
- Hermann, Armin**, ed. (1968). *Albert Einstein — Arnold Sommerfeld. Briefwechsel*. Basel: Schwabe & Co.
- Hermann, Armin et al.**, eds. (1979). *Wolfgang Pauli. Wissenschaftlicher Briefwechsel*. Vol. 1. New York: Springer-Verlag.
- Herschel, John** (1849). *Outlines of Astronomy*. London: Longman, Brown, Green, and Longmans.
- Hiebert, Erwin N.** (1966). "The uses and abuses of thermodynamics in religion," *Dædalus* 95, 1046–1080.
- Hirsh, Richard E** (1979). "The riddle of the gaseous nebulae," *Isis* 70, 197–212.
- Holmes, Arthur** (1913). *The Age of the Earth*. New York: Harper.
- Hoskin, Michael** (1963). *William Herschel and the Construction of the Heavens*. London: Oldbourne.
- (1982). *Stellar Astronomy. Historical Studies*. New York: Science History Publications.
- (1987). "John Herschel's cosmology," *Journal for the History of Astronomy* 18, 1–34.

**Houtermans, Fritz G., and Pascual Jordan** (1946). "Über die Annahme der zeitlichen Veränderlichkeit des  $\beta$ -Zerfalls und die Möglichkeiten ihrer experimentellen Prüfung," *Zeitschrift für Naturforschung* **1**, 125–130.

**Hoyle, Fred** (1948). "A new model for the expanding universe," *Monthly Notices of the Royal Astronomical Society* **108**, 372–382.

— (1950). *The Nature of the Universe*. Oxford: Blackwell.

— (1958). "The steady state theory," 53–80 in R. Stoops, ed., *La Structure et l'Évolution de l'Univers*. Brussels: Coudenberg.

— (1982). "The universe: Past and present reflections," *Annual Review of Astronomy and Astrophysics* **20**, 1–35.

— (1992). "Mathematical theory of creation of matter," *Astrophysics and Space Science* **198**, 195–230.

— (1994). *Home is where the Wind Blows: Chapters from a Cosmologist's Life*. Mill Valley, Calif.: University Science Books.

**Hoyle, Fred, and Jayant Narlikar** (1980). *The Physics-Astronomy Frontier*. San Francisco: W. H. Freeman.

**Hubble, Edwin P.** (1936). *The Realm of the Nebulae*. New Haven: Yale University Press.

— (1937). *The Observational Approach to Cosmology*. Oxford: Clarendon Press.

— (1940). "Problems of nebular research," *Scientific Monthly* **51**, 391–408.

— (1954). *The Nature of Science and Other Lectures*. San Marino, Calif.: The Huntington Library.

## I

**Inge, William R.** (1934). *God and the Astronomers*. London: Longmans, Green and Co.

**Isenkrahe, Caspar** (1920). *Untersuchungen über das Endliche und Unendliche*. Bonn: Marcus & Weber.

## J

**Jaki, Stanley L.** (1966). *The Relevance of Physics*. Chicago: University of Chicago Press.

— (1969). *The Paradox of Olbers' Paradox*. New York: Herder and Herder.

— (1974). *Science and Creation. From Eternal Cycles to an Oscillating Universe*. Edinburgh: Scottish Academic Press.

- (1979). "Das Gravitations-Paradoxon des unendlichen Universums," *Sudhoffs Archiv* **63**, 105–122.
- (1982). "From scientific cosmology to a created universe," *The Irish Astronomical Journal* **15**, 253–262.
- Jammer, Max** (1999). *Einstein and Religion*. Princeton: Princeton University Press.
- Jastrow, Robert** (1992). *God and the Astronomers*. New York: Norton & Company.
- Jeans, James H.** (1928a). "The wider aspects of cosmogony," *Nature* **121**, 463–470.
- (1928b). "The physics of the universe," *Nature* **122**, 689–700.
- (1930). *The Universe Around Us*. Cambridge: Cambridge University Press.
- (1931). *The Mysterious Universe*. Cambridge: Cambridge University Press.
- (1934). "The new world-picture of modern physics," *Nature* **134**, 355–365.
- Jevons, William S.** (1877). *The Principles of Science*. 2nd. edn. New York: Dover Reprint, 1958.
- Joad, C. E. M.** (1932). *Philosophical Aspects of Modern Science*. London: Allen and Unwin.
- Johnson, Martin** (1951). "The meanings of time and space in philosophies of science," *American Scientist* **39**, 412–421.
- Johnston, Marjorie** (1967). *The Cosmos of Arthur Holly Compton*. New York: Alfred A. Knopf.
- Jones, R. V.** (1973). "James Clerk Maxwell at Aberdeen 1856–1860," *Notes and Records of the Royal Society* **28**, 57–81.
- Jordan, Pascual** (1938). "Zur empirischen Kosmologie," *Die Naturwissenschaften* **26**, 417–421.
- (1939). "Bemerkungen zur Kosmologie," *Annalen der Physik* **32**, 64–70.
- (1944a). "Über die Entstehung der Sterne," *Die Naturwissenschaften* **45**, 183–190, 233–244.
- (1944b). *Physics of the 20th Century*. New York: Philosophical Library.
- (1947). *Der Herkunft die Sterne*. Stuttgart: Hirzel.
- (1952). *Schwerkraft und Weltall*. Braunschweig: Vieweg.
- (1963). *Der Naturwissenschaftler vor der Religiösen Frage*. Oldenburg: Gerhard Stalling Verlag.
- Jordan, Pascual, Jürgen Ehlers, and Wolfgang Kundt** (1964). "Quantitatives zur Dirachschen Schwerkraft-Hypothese," *Zeitschrift für Physik* **178**, 501–518.



# K

- Kant, Immanuel** (1969). *Universal Natural History and Theory of the Heavens*. Ann Arbor: University of Michigan Press.
- Kapp, Reginald O.** (1940). *Science versus Materialism*. London: Methuen.
- Kargon, Robert** (1982). *The Rise of Robert Millikan: Portrait of a Life in American Science*. Ithaca: Cornell University Press.
- Kerzberg, Pierre** (1992). *The Invented Universe: The Einstein-De Sitter Controversy (1916–17) and the Rise of Relativistic Cosmology*. Oxford: Clarendon Press.
- Kilmister, Clive W.** (1994). *Eddington's Search for a Fundamental Theory. A Key to the Universe*. Cambridge: Cambridge University Press.
- Klein, Oskar** (1954). "Some cosmological considerations in connection with the problem of the origin of the elements," *Mémoires de la Société Royale des Sciences de Liège* **14**, 42–51.
- Kleinert, Andreas** (1992). "Camille Flammarion und der zweite Hauptsatz der Thermodynamik," *Berichte zur Wissenschaftsgeschichte* **15**, 243–250.
- Koerber, Felix** (1899). *Karl Friedrich Zöllner. Ein Deutsches Gelehrtenleben*. Berlin: Hermann Paetel.
- Kottler, Malcolm J.** (1974). "Alfred Russell Wallace, the origin of man, and spiritualism," *Isis* **65**, 144–192.
- Kragh, Helge** (1982). "Cosmo-physics in the thirties: Towards a history of Dirac cosmology," *Historical Studies in the Physical Sciences* **13**, 69–108.
- (1990). *Dirac: A Scientific Biography*. Cambridge: Cambridge University Press.
- (1995). "Cosmology between the wars: The Nernst-MacMillan alternative," *Journal for the History of Astronomy* **26**, 93–115.
- (1996). *Cosmology and Controversy: The Historical Development of Two Theories of the Universe*. Princeton: Princeton University Press.
- (1999). "Steady state cosmology and general relativity: Reconciliation or conflict?" 377–404 in Hubert Goenner *et al.*, eds., *The Expanding Worlds of General Relativity*. Basel: Birkhäuser Verlag.
- (2002). "The vortex atom: A Victorian theory of everything," *Centaurus* **44**, 32–114.
- (2003a). "Cosmologies and cosmogonies of space and time," 522–537 in Mary Jo Nye, ed., *Cambridge History of Science*, vol. 5: *The Modern Physical and Mathematical Sciences*. Cambridge: Cambridge University Press.

— (2003b). "Magic number: A partial history of the fine-structure constant," *Archive for History of the Exact Sciences* **57**, 395–431.

**Kragh, Helge, and Simon Rebsdorf** (2002). "Before cosmophysics: E. A. Milne on mathematics and physics," *Studies in History and Philosophy of Modern Physics* **33**, 35–50.

**Kragh, Helge, and Shawn Reeves** (1991). "The quantum pioneers: A bibliometric study," *Physica* **28**, 905–921.

**Kragh, Helge, and Robert W. Smith** (2003). "Who discovered the expanding universe?" *History of Science* **41**, 141–162.

**Kragh, Helge, and Stephen J. Weininger** (1996). "Sooner silence than confusion: The tortuous entry of entropy into chemistry," *Historical Studies in the Physical and Biological Sciences* **27**, 91–130.

**Kubrin, David** (1967). "Newton and the cyclical cosmos: Providence and the mechanical philosophy," *Journal of the History of Ideas* **28**, 325–346.

## L

**Ladrière, Jean** (1996). "La portée philosophique de l'hypothèse de l'atome primitif," 57–80 in Stoffel 1996.

**Lambert, Dominique** (1996a). "Pie XII et Georges Lemaître: Deux visions distinctes des rapports sciences-foi," 81–106 in Stoffel 1996.

— (1996b). "Mgr Georges Lemaître et les 'Amis de Jésus'," *Revue Théologique de Louvain* **27**, 309–343.

— (1997). "Monseigneur Georges Lemaître et le débat entre la cosmologie et la foi," *Revue Théologique de Louvain* **28**, 28–53.

— (2000). *Un Atome d'Univers: La Vie et l'Œuvre de Georges Lemaître*. Brussels: Éditions Racine.

**Landsberg, Peter T.** (1991). "From entropy to God?" 379–403 in K. Martínás, L. Ropolyi, and P. Szegedi, eds., *Thermodynamics: History and Philosophy*. Singapore: World Scientific.

**Lang, Kenneth R., and Owen Gingerich**, eds. (1979). *A Source Book in Astronomy and Astrophysics 1900–1975*. Cambridge, Mass.: Harvard University Press.

**Leibniz, Gottfried W.** (1934). *Leibniz: Philosophical Writings*. London: J. M. Dent and Sons.

**Lemaître, Georges** (1925). "Note on de Sitter's universe," *Journal of Mathematics and Physics* **4**, 188–192.

— (1929). "La grandeur de l'espace," *Revue des Questions Scientifiques* **15**, 189–216.

- (1931a). "A homogeneous universe of constant mass and increasing radius," *Monthly Notices of the Royal Astronomical Society* **91**, 483–490.
- (1931b). "The beginning of the world from the point of view of quantum theory," *Nature* **127**, 706.
- (1931c). "L'expansion de l'espace," *Revue des Questions Scientifiques* **17**, 391–340.
- (1933). "L'univers en expansion," *Annales de Société Scientifique de Bruxelles* **53**, 51–85.
- (1934). "Evolution of the expanding universe," *Proceedings of the National Academy of Sciences* **20**, 12–17.
- (1937). "Sur l'interprétation d'Eddington de l'équation de Dirac," *Annales de Société Scientifique de Bruxelles* **57**, 165–172.
- (1945). "A propos de la théorie de Milne-Haldane," *Ciel et Terre* **61**, 213–218.
- (1946). *L'Hypothèse de l'Atome Primitif: Essai de Cosmogonie*. Neuchatel: Éditions du Griffon.
- (1958a). "The primeval atom hypothesis and the problem of the clusters of galaxies," 1–32 in R. Stoops, ed., *La Structure et l'Évolution de l'Univers*. Brussels: Coudenberg.
- (1958b). "Rencontres avec A. Einstein," *Revue des Questions Scientifiques* **129**, 129–133.
- (1959). "The cosmological constant," 437–456 in Schilpp 1959.
- Lemonick, Michael D.** (1993). *The Light at the Edge of the Universe*. Princeton: Princeton University Press.
- Lerner, Eric J.** (1991). *The Big Bang Never Happened*. New York: Times Books.
- Lidgett, J. Scott** (1933). "Contrasted cosmologies," *Contemporary Review*, November, 550–558.
- Lodge, Oliver** (1920a). "Restauration of energy," *Nature* **106**, 341.
- (1920b). "Note on a possible structure for the ether," *Philosophical Magazine* **39**, 170–174.
- (1925). *Ether & Reality*. New York: George H. Doran Co.
- (1926). *Evolution and Creation*. London: Hodder and Stoughton.
- (1933). *My Philosophy: Representing My Views on the Many Functions of the Ether of Space*. London: Ernest Benn.
- Lovell, A. C. Bernard** (1959). *The Individual and the Universe*. Oxford: Oxford University Press.
- Luminet, Jean-Pierre**, ed. (1997). *Alexandre Friedmann, Georges Lemaître: Essais de Cosmologie*. Paris: Éditions du Seuil.
- Lynn, W.** (1950–51). "From astronomy to religion," *Irish Astronomical Journal* **1**, 238–239.

# M

- Mach, Ernst** (1909). *Die Geschichte und die Wurzel des Satzes von der Erhaltung der Arbeit*. 2nd edn. Leipzig: Barth.
- (1923). *Populärwissenschaftliche Vorlesungen*. 5th edn. Leipzig: Barth.
- (1960). *The Science of Mechanics*. La Salle, Ill.: Open Court.
- MacMillan, William D.** (1920). "The structure of the universe," *Science* **52**, 67–74.
- (1923). "Cosmic evolution," *Scientia* **33**, 3–12.
- (1925). "Some mathematical aspects of cosmology," *Science* **62**, 63–72, 96–99, 121–127.
- (1932). "Velocities of the spiral nebulae," *Nature* **129**, 93.
- Margenau, Henry** (1984). *The Miracle of Existence*. Woodbridge, Conn.: Ox Bow Press.
- Mascall, Erich L.** (1956). *Christian Theology and Natural Science. Some Questions and their Relations*. London: Longmans, Green and Co.
- Matthews, W. R.** (1935). *The Purpose of God*. London: Nisbet and Co.
- Maxwell, James Clerk** (1871). *Theory of Heat*. London: Longmans, Green, & Co.
- (1965). *The Scientific Papers of James Clerk Maxwell*. Edited by W. D. Niven. New York: Dover Publications.
- (1990–2002). *The Scientific Letters and Papers of James Clerk Maxwell*. 3 vols. Edited by P. M. Harman. Cambridge: Cambridge University Press.
- May, Gerhard** (1994). *Creatio ex Nihilo: The Doctrine of 'Creation out of Nothing' in Early Christian Thought*. Edinburgh: T&T Clark.
- McAllister, James W.** (1990). "Dirac and the aesthetic evaluation of theories," *Methodology and Science* **23**, 87–102.
- McCrea, William H.** (1951). "E. A. Milne," *Obituary Notices of Fellows of the Royal Society* **7**, 420–443.
- (1977). "Models, laws, and the universe," 59–74 in Yourgrau and Breck, eds. 1977.
- McLaughlin, P. J.** (1957). *The Church and Modern Science*. New York: Philosophical Library.
- McMullin, Ernan** (1981). "How should cosmology relate to theology?" 17–57 in Arthur R. Peacocke, ed., *The Sciences and Theology in the Twentieth Century*. London: Oriel Press.
- (1993). "Indifference principle and anthropic principle in cosmology," *Studies in the History and Philosophy of Science* **24**, 359–389.

- McWilliams, J. A.** (1939). *Cosmology. A Text for Colleges*. New York: Macmillan.
- Merleau-Ponty, Jacques** (1965). *Philosophie et Theorie Physique chez Eddington*. Paris: Besancon.
- (1983). *La Science de l'Univers à l'Âge du Positivism*. Paris: Vrin.
- Meyerson, Emile** (1930). *Identity and Reality*. London: Allen & Unwin.
- Millikan, Robert A.** (1928). "Available energy," *Science* **68**, 279–284.
- (1931). "Present status of theory and experiment as to atomic disintegration and atomic synthesis," *Nature* **127**, 167–170.
- (1951). *The Autobiography of Robert A. Millikan*. London: MacDonald.
- Millikan, Robert A., and G. Harvey Cameron** (1928). "The origin of the cosmic rays," *Physical Review* **32**, 533–557.
- Milne, Edward A.** (1933). "World structure and the expansion of the universe," *Zeitschrift für Astrophysik* **6**, 1–95.
- (1934). "Some points in the philosophy of physics: Time, evolution and creation," *Philosophy* **9**, 19–38.
- (1935). *Relativity, Gravitation and World-Structure*. Oxford: Clarendon Press.
- (1937). "On the origin of the laws of nature," *Nature* **139**, 997–999.
- (1938). "On the equations of electromagnetism," *Proceedings of the Royal Society A* **165**, 313–357.
- (1943–44). "The fundamental concepts of natural philosophy," *Proceedings of the Royal Society (Edinburgh) A* **62**, 10–24.
- (1948). *Kinematic Relativity. A Sequel to Relativity, Gravitation and World-Structure*. Oxford: Clarendon Press.
- (1949). "Kinematic relativity," 7–32 in *Théories Nouvelles de Relativité*. Paris: Hermann et Cie.
- (1952a). *Sir James Jeans. A Biography*. Cambridge: Cambridge University Press.
- (1952b). *Modern Cosmology and the Christian Idea of God*. Oxford: Clarendon Press.
- Misner, Charles W.** (1969). "Absolute zero of time," *Physical Review* **186**, 1328–1333.
- (1977). "Cosmology and theology," 75–100 in Yourgrau and Breck, eds. 1977.
- Mittelstaedt, Peter, and Ingeborg Strohmeier** (1990). "Die kosmologischen Antimonien in der Kritik der reinen Vernunft und die moderne physikalische Kosmologie," *Kant-Studien* **81**, 145–169.
- Munitz, Milton K.** (1954). "Creation and the 'new' cosmology," *British Journal for the Philosophy of Science* **5**, 32–46.

- ed. (1957). *Theories of the Universe: From Babylonian Myth to Modern Science*. Glencoe, Ill.: Free Press.
- Murphy, Joseph John** (1869). *Habit and Intelligence, in their Connexion with the Laws of Matter and Force*. 2 vols. London: Macmillan.
- (1873). *The Scientific Bases of Faith*. London: Macmillan.
- Myers, Greg** (1986). "Nineteenth-century popularizations of thermodynamics and the rhetoric of social prophecy," *Victorian Studies* 29, 35–66.

## ■ N

- Needham, Joseph**, ed. (1925), *Science, Religion and Reality*. London: The Sheldon Press.
- Nernst, Walther** (1921). *Das Weltgebäude im Lichte der neueren Forschung*. Berlin: Springer.
- (1935a). "Physikalische Betrachtungen zur Entwicklungstheorie der Sterne," *Zeitschrift für Physik* 97, 511–534.
- (1935b). "Einige weitere Anwendungen der Physik auf die Sternentwicklung," *Sitzungsberichte der Preussischen Akademie der Wissenschaften* 28, 473–479.
- Newcomb, Simon** (1894). "Modern mathematical thought," *Nature* 49, 325–329.
- (1906). *Side-Lights on Astronomy. Essays and Addresses*. New York: Harper and Brothers.
- Newton, Isaac** (1952). *Opticks*. New York: Dover Publications.
- (1999). *The Principia: Mathematical Principles of Natural Philosophy*. Berkeley: University of California Press.
- Nichol, John P.** (1851). *The Architecture of the Heavens*. London: Hippolyte Bailliere.
- North, John D.** (1965). *The Measure of the Universe: A History of Modern Cosmology*. London: Oxford University Press.
- Norton, John D.** (1999). "The cosmological woes of Newtonian gravitation theory," 271–324 in Hubert Goenner *et al.*, eds., *The Expanding Worlds of General Relativity*. Boston: Birkhäuser.
- Numbers, Ronald L.** (1977). *Creation by Natural Law: Laplace's Nebular Hypothesis in American Thought*. Seattle: University of Washington Press.
- Nye, Mary Jo** (1976). "The moral freedom of man and the determinism of nature: The Catholic synthesis of science and history in the *Revue des Questions Scientifiques*," *British Journal for the History of Science* 9, 274–292.

# ■ O

- O'Connell, Daniel** (1952–53). "According to Hoyle," *Irish Astronomical Journal* **2**, 127–138.
- (1954–55). "Religion and science," *Irish Astronomical Journal* **3**, 70–73.
- Oppenheim, Janet** (1985). *The Other World: Spiritualism and Psychical Research in England, 1850–1914*. Cambridge: Cambridge University Press.
- Overduin, James, and Hans-Jürgen Fahr** (2003). "Vacuum energy and the economical universe," *Foundations of Physics Letters* **16**, 119–125.

# ■ P

- Page, Thornton** (1948). "The origin of the earth," *Physics Today* **1**: 6, 12–24.
- Pannenberg, Wolfhart** (1981). "Theological questions to scientists," 3–16 in Arthur R. Peacocke, ed., *The Sciences and Theology in the Twentieth Century*. London: Oriel Press.
- Peebles, Phillip J. E., and Bharat Ratra** (2003). "The cosmological constant and dark energy," *Reviews of Modern Physics* **75**, 559–606.
- Peters, Ted**, ed. (1988). *Cosmos as Creation*. Nashville: Abingdon Press.
- Piaggio, Henry T. H.** (1931). "Science and prediction," *Nature* **127**, 454.
- Plaskett, John S.** (1933). "The expansion of the universe," *Journal of the Royal Astronomical Society of Canada* **27**, 235–252.
- Poincaré, Henri** (1911). *Leçons sur les Hypothèses Cosmogoniques*. Paris: Libraire Scientifique A. Hermann et Fils.
- (1913). *Dernière Pensées*. Paris: Flammarion.
- Polkinghorne, John** (1986). *One World: The Interaction of Science and Theology*. Princeton: Princeton University Press.
- (1998). *Beyond Science. The Wider Human Context*. Cambridge: Cambridge University Press.
- Popper, Karl** (1940). "Interpretations of nebular red-shifts," *Nature* **145**, 69–70.

# ■ R

- Rankine, William J. M.** (1881). *Miscellaneous Scientific Papers*. London: Charles Griffin and Company.
- Rey, Abel** (1927). *Le Retour Éternel et la Philosophie de la Physique*. Paris: Ernest Flammarion.

- Riemann, G. F. Bernhard** (1873). "On the hypotheses which lie at the bases of geometry," *Nature* **8**, 14–17, 36–37.
- Robertson, Howard P.** (1932). "The expanding universe," *Science* **76**, 221–226.
- (1933). "Relativistic cosmology," *Reviews of Modern Physics* **5**, 62–90.
- Rojas, Francisco** (1876). *Termodinámica*. Barcelona: Luis Tasso.
- Russell, Bertrand** (1931). *The Scientific Outlook*. New York: Norton.
- (1967). *Why I am not a Christian*. London: Unwin Books.
- Russell, Robert J.** (1993). "Finite creation without a beginning: The doctrine of creation in relation to big bang and quantum cosmologies," 291–326 in Robert J. Russell, Nancy Murphy, and C. J. Isham, eds., *Quantum Cosmology and the Laws of Nature: Scientific Perspectives on Divine Action*. Vatican Observatory: Vatican City State.
- Rüger, Alexander** (1988). "Atomism from cosmology: Erwin Schrödinger's work on wave mechanics and space-time structure," *Historical Studies in the Physical Sciences* **18**, 377–401.

## S

- Sagan, Carl** (1997). *The Demon-Haunted World: Science as a Candidate in the Dark*. London: Headline.
- Sambursky, Samuel** (1937). "Static universe and nebular red shift," *Physical Review* **52**, 335–338.
- Saunders, Nicholas** (2002). *Divine Action & Modern Science*. Cambridge: Cambridge University Press.
- Scheuer, Hans Günter** (1997). *Der Glaube der Astronomen und die Gestalt des Universums: Kosmologie und Theologie im 18. und 19. Jahrhundert*. Aachen: Shaker-Verlag.
- Schilpp, Paul A.**, ed. (1959). *Albert Einstein: Philosopher-Scientist*. New York: Harper.
- Schild, A.** (1962). "Gravitational theories of the Whitehead type and the principle of equivalence," 69–115 in C. Møller, ed., *Evidence for Gravitational Theories*. New York: Academic Press.
- Schlegel, Richard** (1958). "Steady-state theory at Chicago," *American Journal of Physics* **26**, 601–604.
- Schnippenkötter, Josef** (1920). *Das Entropiegesetz. Seine Physikalische Entwicklung und seine Philosophische und Apologetische Bedeutung*. Essen: Fredebeul & Koenen.
- Schröder, Wilfried**, ed. (2001). *Über den Äther in der Physik*. Bremen-Rönnebeck: Science Edition.



- Schröder, Wilfried, and H.-J. Treder** (1996). "Hans Ertel and cosmology," *Foundations of Physics* **26**, 1081–1088.
- Schrödinger, Erwin** (1937). "World structure," *Nature* **140**, 742–744.
- Schwarzschild, Karl** (1900). "Über das zulässige Krümmungsmaass des Raumes," *Vierteljahrsschrift der Astronomischen Gesellschaft* **35**, 337–347.
- (1998). "On the permissible curvature of space," *Classical and Quantum Gravity* **15**, 2539–2544.
- Sclove, Richard E.** (1989). "From alchemy to atomic war: Frederick Soddy's 'technology assessment' of atomic energy, 1900–1915," *Science, Technology, & Human Values* **14**, 163–194.
- Secchi, P. Angelo** (1878). *Die Sterne. Grundzüge der Astronomie der Fixsterne*. Leipzig: Brockhaus.
- Seeger, R. J.** (1967). "On humanistic aspects of entropy," *Physis* **9**, 215–234.
- Seelig, Carl** (1956). *Helle Zeit, Dunkle Zeit. In Memoriam Albert Einstein*. Zurich: Europa Verlag.
- Shapley, Harlow** (1958). *Of Stars and Men: The Human Response to an Expanding Universe*. London: Elek Books.
- ed. (1960). *Science Ponders Religion*. New York: Appleton-Century-Crofts.
- (1967). *Beyond the Observatory*. New York: Charles Scribner's Sons.
- Simões, Ana** (2004). "From learning to teaching and writing: The quantum chemist Charles Alfred Coulson and the crafting of science," *British Journal for the History of Science* (forthcoming).
- Simões, Ana, and Kostas Gavroglu** (1998–99). "Quantum chemistry qua applied mathematics: The contributions of Charles Alfred Coulson (1910–1974)," *Historical Studies in the Physical and Biological Sciences* **29**, 363–406.
- Smith, Crosbie W.** (1976). "William Thomson and the creation of thermodynamics, 1840–1855," *Archive for History of Exact Sciences* **16**, 231–288.
- (1998). *The Science of Energy: A Cultural History of Energy Physics in Victorian Britain*. London: Athlone.
- Smith, Robert W.** (1982). *The Expanding Universe: Astronomy's 'Great Debate' 1900–1931*. Cambridge: Cambridge University Press.
- Smoluchowski, Marian von** (1914). "Gültigkeitsgrenzen des zweiten Hauptsatzes der Wärmetheorie," 87–121 in Max Planck et al., *Vorträge über die Kinetische Theorie der Materie und der Elektrizität*. Leipzig: Teubner.

- Smuts, Jan C.** (1931). "The scientific world-view of today," Report, *British Association for the Advancement of Science*, 1–18.
- Soddy, Frederick** (1904). *Radio-Activity. An Elementary Treatise from the Standpoint of the Disintegration Theory*. London: The Electrician.
- (1909). *The Interpretation of Radium*. London: John Murray.
- Sommerfeld, Arnold** (1929). "Über die Anfänge der Quantentheorie von mehreren Freiheitsgraden," *Die Naturwissenschaften* **17**, 481–483.
- Sonnenschmidt, Hermann** (1880). *Kosmologie. Geschichte und Entwicklung des Weltbaues*. Cologne: E. H. Mayer.
- Stallo, John B.** (1882). *The Concepts and Theories of Modern Physics*. London: Kegan Paul, Trench & Co.
- Stebbing, L. Susan** (1937). *Philosophy and the Physicists*. London: Methuen.
- Stewart, Balfour** (1873). *The Conservation of Energy*. London: Henry S. King & Co.
- Stewart, Balfour, and Peter G. Tait** (1881). *The Unseen Universe. Or, Physical Speculations on a Future State*. London: Macmillan.
- Stoffel, Jean-François**, ed. (1996). *Mgr. Georges Lemaître, Savant et Croyant*. Louvain-la-Neuve: Centre Interfacultaire d'Étude en Histoire des Sciences.
- Struve, Otto, and Velta Zebergs** (1962). *Astronomy of the 20th Century*. New York: Macmillan.
- Sullivan, J. W. N.** (1934). *Contemporary Mind: Some Modern Answers*. London: Humphrey Toulmin.
- Suzuki, Seitaro** (1928). "On the thermal equilibrium of dissociation of atom-nuclei," *Proceedings of the Physico-Mathematical Society of Japan* **10**, 166–169.
- Swinburne, Richard** (1990). "Arguments from the fine-tuning of the universe," 154–173 in John Leslie, ed., *Physical Cosmology and Philosophy*. New York: Macmillan.

## T

- Tait, Peter G.** (1871). [Address by President of the Mathematics and Physics Section], Report, *British Association for the Advancement of Science*, 1–8.
- (1876). *Lectures on some Recent Advances in Physical Science*. London: Macmillan.

- Taylor, Roger J.** (1996). "E. A. Milne (1896–1950) and the structure of stellar atmospheres and stellar interiors," *Quarterly Journal of the Royal Astronomical Society* **37**, 355–363.
- Teller, Woolsey** (1938). *The Atheism of Astronomy*. New York: The Truth Seeker Company.
- Temple, George** (1956). "Edmund Taylor Whittaker, 1873–1956," *Biographical Memoirs of Fellows of the Royal Society* **2**, 299–325.
- Theerman, Paul** (1986). "James Clerk Maxwell and religion," *American Journal of Physics* **54**, 312–317.
- Thompson, Silvanus P.** (1910). *The Life of William Thomson, Baron Kelvin of Largs*. 2 vols. London: Macmillan.
- Thomson, J. J.** (1904). *Electricity and Matter*. London: Constable.
- (1905). "The structure of the atom," *Proceedings of the Royal Institution* **18**, 1–15.
- Thomson, William** (1882). *Mathematical and Physical Papers*. Vol. 1. Cambridge: Cambridge University Press.
- (1884). *Mathematical and Physical Papers*. Vol. 2. Cambridge: Cambridge University Press.
- (1891). *Popular Lectures and Addresses*. Vol. 1. London: Macmillan.
- Tipler, Frank J.** (1988a). "Olbers's paradox, the beginning of creation, and Johann Mädler," *Journal for the History of Astronomy* **19**, 45–48.
- (1988b). "Johann Mädler's resolution of Olbers' paradox," *Quarterly Journal of the Royal Astronomical Society* **29**, 313–325.
- Tolman, Richard C.** (1931). "On the problem of the entropy of the universe as a whole," *Physical Review* **37**, 1639–1660.
- (1934). *Relativity, Thermodynamics, and Cosmology*. Oxford: Oxford University Press.
- Toulmin, Stephen** (1982). *The Return to Cosmology: Postmodern Science and the Theology of Nature*. Berkeley: University of California Press.
- Toulmin, Stephen, and June Goodfield** (1965). *The Discovery of Time*. Chicago: University of Chicago Press.
- Tropp, Eduard A., Viktor Ya. Frenkel, and Arthur D. Chernin** (1993). *Alexander A. Friedmann: The Man who Made the Universe Expand*. Cambridge: Cambridge University Press.
- Tryon, Edward** (1973). "Is the universe a vacuum fluctuation?" *Nature* **246**, 396–397.
- Turek, Józeph** (1986). "Georges Lemaître and the Pontifical Academy of Sciences," *Vatican Observatory Publications* **2**, 166–175.

- Turner, Frank M.** (1974). *Between Science and Religion. The Reaction to Scientific Naturalism in Late Victorian England*. New Haven: Yale University Press.
- Tyndall, John** (1874). [Address by President of the Mathematics and Physics Section], Report, *British Association for the Advancement of Science*, lxvi–xcvii.

## ■ U

- Urani, John, and George Gale** (1994). "E. A. Milne and the origins of modern cosmology," 390–419 in J. Earman, M. Janssen, and J. D. Norton, eds., *The Attraction of Gravitation: New Studies in the History of General Relativity*. Boston: Birkhäuser.

## ■ V

- Vecchierello, H.** (1934). *Einstein and Relativity: Le Maitre and the Expanding Universe*. Paterson, N.J.: St. Anthony Guild Press.
- Vilenkin, Alexander** (1982). "Creation of universes from nothing," *Physics Letters* 117 B, 25–28.

## ■ W

- Wallace, Alfred R.** (1903a). "Man's place in the universe," *Fortnightly Review* 73 (March 1), 395–411.
- (1903b). *Man's Place in the Universe*. New York: McClure, Philips.
- Walter, Maila L.** (1990). *Science and Cultural Crisis: An Intellectual Biography of Percy Williams Bridgman (1882–1961)*. Stanford: Stanford University Press.
- Weizsäcker, Carl Friedrich von** (1964). *The Relevance of Science: Creation and Cosmogony*. New York: Harper and Row.
- Weyl, Herman** (1919). "Eine neue Erweiterung der Relativitätstheorie," *Annalen der Physik* 59, 101–133.
- (1932). *The Open World*. New Haven: Yale University Press.
- (1934). "Universum und Atom," *Die Naturwissenschaften* 22, 145–149.
- Whewell, William** (1996). *Philosophy of the Inductive Sciences, Founded upon their History*. 2 vols. London: Routledge.
- Whitrow, Gerald J.** (1980). *The Natural Philosophy of Time*. Oxford: Clarendon Press.

- Whitehead, Alfred N.** (1922). *The Principle of Relativity*. Cambridge: Cambridge University Press.
- (1929). *Process and Reality: An Essay in Cosmology*. New York: Macmillan.
- (1933). *Adventures of Ideas*. New York: Macmillan.
- (1956). *Science and the Modern World*. New York: Mentor Books.
- (1974). *Religion in the Making*. New York: New American Library.
- Whittaker, Edmund** (1935). "On Gauss' theorem and the concept of mass in general relativity," *Proceedings of the Royal Society A* **149**, 384–395.
- (1942). *The Beginning and End of the World*. Oxford: Oxford University Press.
- (1943). "Chance, freewill and necessity in the scientific conception of the universe," *Proceedings of the Physical Society* **55**, 459–471.
- (1946). *Space and Spirit: Theories of the Universe and the Arguments for the Existence of God*. London: Thomas Nelson and Sons.
- (1949). *From Euclid to Eddington*. Cambridge: Cambridge University Press.
- Whitworth, Michael** (1996). "The clothbound universe: Popular physics books 1919–1939," *Publishing History* **40**, 53–82.
- Wiechert, Emil** (1921a). "Der Äther im Weltbild der Physik," *Nachrichten von der Königlichen Gesellschaft der Wissenschaften zur Göttingen, Math.-Phys. Klasse*, No. 1, 29–70.
- (1921b). "Anmerkungen zur Theorie der Gravitation und über das Schicksal der Gestirne," *Vierteljahrsschrift der Astronomische Gesellschaft* **56**, 171–191.
- Wilson, David B.** (1971). "The thought of late Victorian physicists: Oliver Lodge's ethereal body," *Victorian Studies* **25**, 29–48.
- (1996). "On the importance of eliminating Science and Religion from the history of science and religion: The cases of Oliver Lodge, J. H. Jeans and A. S. Eddington," 27–47 in Jitse M. van der Meer, ed., *Facets of Faith and Science*, vol. 1: *Historiography and Modes of Interaction*. Lanham: University Press of America.
- Wise, M. Norton** (1994). "Pascual Jordan: Quantum mechanics, psychology, national socialism," 224–254 in Monika Renneberg and Mark Walker, eds., *Science, Technology and National Socialism*. Cambridge: Cambridge University Press.
- Witt-Hansen, Johannes** (1958). *Exposition and Critique of the Conceptions of Eddington Concerning the Philosophy of Physical Science*. Copenhagen: Gad.

■ **Y**

**Yolton, John W.** (1960). *The Philosophy of Science of A. S. Eddington*. The Hague: Martinus Nijhoff.

**Yourgrau, Wolfgang, and Allen D. Breck,** eds. (1977). *Cosmology, History, and Theology*. New York: Plenum Press.

■ **Z**

**Zanstra, Herman** (1967). "Is religion refuted by physics and astronomy?" *Vistas in Astronomy* **10**, 1–21.

**Zöllner, Johann K. F.** (1872). *Über die Natur der Cometen. Beiträge zur Geschichte und Theorie der Erkenntnis*. Leipzig: Engelmann.

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