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ESSAY REVIEW

Two Theories of the Universe

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Helge Kragh, *Cosmology and Controversy: The Historical Development of Two Theories of the Universe* (Princeton: Princeton University Press, 1996), xiii + 500 pp. ISBN 0-691-02623-8. $35.00

1. Introduction

Cosmology as *Weltanschauung* is as old as the world. Cosmology as a physical discipline, however, is a child of this century, born in 1917, when Albert Einstein and Willem de Sitter first applied the theory of general relativity to the space-time of the entire universe. When did the child come of age and become a fully-fledged science? A popular myth shared by many practitioners holds that this did not happen until 1965, when the discovery of the 2.7K cosmic microwave background radiation validated the concept of the hot big bang. Earlier accomplishments lined up to culminate in the 1965 event include the derivation of evolving relativistic models by Alexander Friedmann and Georges Lemaître, Edwin Hubble's discovery of the redshift–magnitude relationship and George Gamow's theory of the primordial nucleosynthesis containing the prediction of the microwave background left from the hot and dense past of the universe. This linear development is thrown into sharper relief in textbooks by referring to an inarticulate background of unbridled speculation that cosmology in general is believed to have been before 1965.

Debunking myths of this sort is part of the job of philosophers and historians of science. Cosmology, however, has not been extremely lucky in this regard. Whereas the philosophy and history of quantum mechanics and of relativity

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theory have been flourishing industries for decades, the science of the universe, despite its obvious fundamental significance, has very seldom attracted the attention of philosophers and historians. A comprehensive account of the development of cosmology in this century, comparable in scope and depth to multivolume editions devoted to quantum mechanics and relativity, is yet to be produced. Helge Kragh's work is an important step in this direction.

Summarising several years of extensive study of published and unpublished sources (including interviews and correspondence with many principal participants in the story to be told), Kragh's book focuses on the period 1940–1965 which was marked by a major controversy between two rival conceptions of the universe: big-bang and steady-state theories. Technically competent, but, at the same time, generally accessible, this work is highly recommended not only to historians and philosophers, but also to practicing scientists (especially to those cosmologists who would like to know more about the history of their discipline), as well as to the general reader.

The book is indeed an example of history at its best. It gives a real sense of the dynamics of the unfolding conflict within a discipline (thus casting doubt on the view that 'normal science' excludes intertheoretic competition) and provides a detailed and well-documented answer to the question: how did cosmology get to where it did by early 1970s? The internal logic of cosmological theorising and the dramatic expansion of the empirical basis of cosmology in 1955–1965 were primarily responsible for the eventual resolution of the controversy. But its vicissitudes are impossible to understand without taking into account the peculiar relations among scientific communities, their diverging research styles, various cultural influences and the role of particular personalities involved in the debate. The complexity of the situation is reflected in Kragh's account and so is—although to a much lesser extent—the fact that the cosmological debate incorporated distinctively methodological and philosophical dimensions. These deserve special attention. But first things first.

2. From Mathematical to Physical Cosmology

The book begins by setting a necessary background to the big-bang vs steady-state rivalry. After briefly recapitulating the early work on relativistic cosmology (1917–1931), Kragh identifies the roots of the big-bang concept with Abbé Lemaître's hypothesis of the 'primeval superatom' at the beginning of the universe, the subsequent disintegration of which was supposed to have given rise to cosmic matter. Drawing in a qualitative and rather speculative way on such ideas as quantum indeterminacy and radioactivity, the hypothesis, nonetheless, anticipated and prepared the ground for the later transition from purely mathematical to physical cosmology in the works of Gamow and his collaborators (1940–1953). These 'provided cosmology with a new perspective linking the science of the universe intimately to nuclear physics' (p. 80). The decade separating these two contributions was marked by empirical and conceptual challenges that the young discipline immediately confronted. Thanks to the efforts of Howard Robertson, Arthur Walker, Richard Tolman and others, the formal structure of 'mathematical' cosmology was established in the early 1930s. This accomplishment, however, owes much to a vigorous attack on the foundations of general relativity and evolutionary models of the universe based thereon launched in 1932 by Edward Milne.

His own alternative (which later became known as 'kinematic relativity') was a grandiose attempt at deducing all of local physics from a small number of general cosmological assumptions and basic epistemic principles of a largely operationalist nature. In Milne's opinion, instead of being built 'from bottom up', cosmology had to arise from postulates about the overall structure of the universe and considerations concerning the experience of distance and temporal relations. Milne's chief reason for claiming such a unique status for cosmology was, roughly and broadly, that cosmology deals with a unique object of study. There is only one universe and its evolution is a singular cosmic event. The features of this unique object, including its large-scale structure and the local laws of nature operating in it, could not, according to Milne, be established by generalising from experience (for generalisation makes no sense when applied to a single individual). Rather, they must emerge, in a unique and self-consistent way, from general concepts.

Milne's project of inextricably mixing physics and philosophy failed in the end. Its impact on the subsequent development of cosmology, however, was manifold. Milne's kinematic considerations played a role in the derivation of the generic metric of relativistic evolutionary models (i.e. the famous Robertson–Walker metric). His cosmological principle was the first explicit statement of the postulate of large-scale uniformity and isotropy of the universe adopted in almost all later cosmological models. Milne's cosmological philosophy, along with the rather different proposals of Paul Dirac and of Arthur Eddington, provoked a heated debate in 1937. In the long run, Milne's ideas concerning the consequences of the uniqueness of the universe proved important for clarifying the conceptual foundations of cosmology and its special status among other physical sciences. These ideas directly influenced the philosophy of the steady-state project. Furthermore, despite the failure of particular research programmes based on such ideas, the latter contain a valuable grain of truth: cosmology does bring with it not only a host of theories and models but also a unique and new perspective on 'local physics'. (More on this below.)

Kragh's exposition of Milne's programme is very brief and cannot do full justice to it. This was probably not part of the author's plan in a book concentrating on a later period and apparently not concerned with foundational and philosophical issues in cosmology. The reader interested in such issues, as they arose in the debate surrounding Milne's theory, is advised to consult recent works by George Gale and co-authors (Gale, 1992, 1997; Gale and Urani, 1993; Urani and Gale, 1994; Gale and Shanks, 1996), as well as the classical study by John North (1965).

Turning now to more empirical questions, the newly created evolutionary cosmology met its first major observational challenge almost right away, in the early 1930s. This has become known as the time-scale problem: the Hubble age of the universe in most popular relativistic models turned out to be less than the age of the Earth as estimated from radioisotope probing, and still lesser than the age of oldest stars in the galaxy calculated in astrophysics. This situation—repugnant, as they say, to intellect—caused much stir among many astrophysicists and cosmologists at the time. Others, however, remained relatively cool. They appealed to other evolutionary models incorporating longer time scales (such as the Eddington–Lemaître model) or simply continued to adhere to the short-lived universe in the hope that difficulties would somehow resolve themselves. This is precisely what happened. The whole problem proved to be a consequence of the wrong scale of extragalactic distances employed by Hubble. After this had been recalibrated in mid-1950s, the time-scale 'problem' dissolved. While still in existence, however, it managed to catalyse the creation of steady-state theory in 1948.

Before this happened, another development took place in the new world, to which Russian-born Gamow brought his profound knowledge of nuclear physics, as well as his peculiar sense of humour (which one of his contemporaries later characterised as 'irresistible and irrelevant'). Kragh traces Gamow's reflections on the cosmological origin of elements to the pre-war years, and examines the genesis of the big-bang nucleosynthesis theory against the background of earlier developments in nuclear astrophysics in the 1920s and 1930s that culminated in Hans Bethe's 1938–1939 work on the CN cycle. The key idea of cosmological nucleosynthesis was to utilise non-equilibrium conditions obtaining in the huge expanding laboratory, the early universe, in order to produce the actual distribution of chemical elements by means of simple nuclear reactions starting from a hot and dense gas of neutrons. This scenario formed the basis of the first elaborate version of what a rival steady-state theorist, Fred Hoyle, later dubbed 'big-bang' theory. The theory presented in 1946 in Ralph Alpher's and Gamow's so-called $\alpha\beta\gamma$ paper (Bethe being added by Gamow as the third co-author for primarily alphabetical reasons) was the beginning of a series of works published in 1946–1953 by Gamow and his disciples, Alpher, Robert Herman and James Follin. These detailed the conditions and mechanisms of the consecutive synthesis of elements by neutron capture and subsequent β-decay during the famous 'first three minutes' of the cosmological expansion. The programme eventually ran into the mass-gap problem—the absence of stable nuclei of atomic weights 5 and 8—and came to a temporary halt about 1953.

3. The Steady-State Alternative

At that time the steady-state theory was already under way, having been introduced in 1948 by the 'Cambridge trio' of Hermann Bondi, Thomas Gold and Hoyle. The theory depicted a universe whose average physical characteristics were constant, not only throughout space, but also in time. The dilution of the mean density of matter due to cosmological expansion was compensated for by the continual creation of new matter postulated to take place at such a slow rate that no local observations could register it. The eternal self-perpetuating universe of steady-state theorists was obviously immune to the time-scale problem, avoided a difficult question of the 'cosmic beginning' and had other appealing features. By strictly excluding global evolutionary effects, the theory led to more definite predictions than its big-bang rival whose freedom to adjust various parameters was almost unlimited. The cost of these advantages, however, was severe. The continuous creation of matter implied by the model infringed upon conservation laws and also raised questions (which were never properly answered) about the physical mechanisms of matter creation. But the empirical adequacy of the theory in the 1950s and the intellectual courage of its main defenders kept the steady-state alternative as the mainspring of cosmology for more than a decade.

Kragh's exposition of the rise, development and fall of steady-state cosmology is superb. He unravels the convoluted history of the relations between this theory and observations with great precision. A good portion of the story is devoted, not surprisingly, to radio astronomy which eventually killed the steady-state model. The 1964–1965 detection of the 2.7K background drove the last nail into the coffin of a theory already overthrown by careful counts of radio sources and by improved data on the abundance of light elements. Before this happened, however, the theory had its golden moments. Thus Hoyle's brilliant contributions to the theory of stellar nucleosynthesis, including his famous 'anthropic' prediction of the resonance level in C^{12}, were inspired by the steady-state programme and certainly helped to support it: if elements can be cooked up in stars, the hot big-bang state of the whole universe is unnecessary to produce them. By an irony of fate, Hoyle's later work (with Roger Tayler) revealed that the amount of helium that could be produced in stars is insufficient to explain its actual abundance and, hence, that a non-stellar hot site was needed, after all.

Not a single important detail concerning the fate of the steady-state theory is missing from Kragh's account. He abstracts, however, from certain important conceptual developments stimulated by the steady-state project. Dennis Sciama's (1953) work on Mach's principle should be mentioned in this connection. On one hand, this work was conducted in the framework of steady-state theory and was certainly prompted not only by its physics but also by its philosophy. Thus, Bondi and Gold's idea of the influence of the global features of the universe on the local properties of matter (including those that figure in the laws of nature) found an interesting manifestation in Sciama's interpretation of Mach's principle. On the other hand, the same idea is involved in the Brans–Dicke (1961) scalar-tensor theory of gravity which was influenced by Sciama's work, but presumed a different—not stationary but time-dependent—picture of the interaction between structural and nomic properties of the universe. The concept of such an interaction, which is clearly present in some versions of the steady-state theory, has its origin in the global perspective that cosmology as a whole presupposes. Steady-state theorists were not the first to draw attention to the importance of the cosmological point of view—Milne, as mentioned, did it in the 1930s. But their elaboration of its consequences constitutes a metatheoretical result that outlived the theory itself. Being primarily historical, Kragh's work relegates these more philosophical issues (inasmuch as it touches on them at all) to the category of 'extrascientific' considerations on par with theological, ideological and even moral ones that came up in discussions of the 'creation cosmology' in the 1950s. I believe, on the contrary (Balashov, 1994), that, unlike these clearly external influences, philosophical considerations were part and parcel of the steady-state project and that it would be wrong to sort them away as 'extrascientific noise'.

I shall return to philosophy later. To complete my brief survey of Kragh's story, one cannot help but agree with his conclusion that 'the outcome of the [big-bang vs steady-state] controversy was decided by observations and experiments' (p. 269). But as he shows, the character of this controversy was affected by many outside factors. In his autobiography Gamow mentions Edward Teller's remark that the idea of the stationary universe gained such popularity in England because it had 'ever been the policy of Great Britain to maintain the *status quo* in Europe' (Gamow, 1970, pp. 127–128). (What a wonderful opportunity for the social constructivist to capitalise upon!)

Jokes aside, social circumstances did play a role in the story. First of all, the debate was essentially confined to the British astronomical community: it was really not between Gamow's big-bang theory and the steady-state theory, but rather between evolutionary and steady-state models of the universe. Gamow's theory was known in England, but virtually nobody outside America contributed to it at that time. Big-bang theorists across the Atlantic, on their part, paid little attention to the Bondi–Gold–Hoyle theory, despite close personal relations between Gamow and Hoyle. The two communities pursued their own agendas. Big-bang theorists were primarily interested in the nuclear physics which unfolded in the laboratory of the early universe and reported their results in such journals as *Physical Review* and *Reviews of Modern Physics*. Steady-state advocates and their British opponents were mainly concerned with global properties of the 'laboratory' itself and conducted their dispute in *Monthly Notices*, *Proceedings* and other journals of the Royal Societies. The 'profane cosmology-as-engineering view [espoused by Gamow's team] was as foreign to the British school of cosmology as the steady-state theory was to the Americans' (p. 137).

Should American pragmatism be blamed for the neglect of foundational questions that occupied British cosmologists at the time? Kragh suggests that, to some extent, it should. The fast post-war development of high-energy and solid state physics and, in general, the making of 'big science' in America diverted interest from other, less advanced areas. In sharp contrast with England, general relativity was rarely taught in physics departments of American universities. (This changed rather dramatically several years later.) This practical orientation influenced the fate of the big-bang programme itself. It never attracted wide attention in the 1950s and was developed by a handful of devoted researchers. The programme faded away by the mid-1950s, not only because of the mass-gap problem (see above), but for other reasons having nothing to do with cosmological theory. Its main proponents left the field: Gamow became interested in DNA, Alpher and Herman went into industry.

4. Philosophical Lessons: Laws of Nature and the Universe

Was the steady-state theory anything more than just an interesting historical example of scientific failure? I want to suggest that it was. The lasting value of steady-state cosmology is to be found in its development of the *concept* of the universe.

The universe as a whole is a peculiar object in that it comprises all that exists and yet is self-contained and singular. The question of how such a unique object can be adequately described in the language of physics is an important problem in the foundations of cosmology, to which steady-state proponents (and earlier Milne) drew particular attention long before this problem began to be debated by philosophers of science (see e.g. Munitz, 1962). A further question is how this description, if valid, could affect the understanding of more general issues. One such issue concerns the relationship between the laws of nature and the universe. If the laws of nature are real, they must characterise entire universe. In a sense, besides having a particular curvature, density and distribution of matter and other mundane characteristics of this sort, the universe as a whole possesses a property of a rather different kind—the property of being such that certain laws of nature hold in it. Both sorts of properties being features of the same individual object, there arises a question about possible connection between them. Laws of nature have their locus in the universe and hence are in some sense consequent upon the way it is. But the universe is the way it is partly as a matter of laws.

The authors of both versions of the steady-state model were equally impressed by this global perspective on local physical laws and incorporated the notion of interdependence of the material and nomic properties of the universe into their theories. Bondi and Gold referred in this regard to Mach's principle (their idea, as noted, was developed by Sciama). Hoyle's more mathematical version operated with Einstein's field equations modified in such a way as to include the features of a particular cosmological model (namely, the steady-state one) in its general formulation. What legitimised creating such a 'centaur', in which general (nomic) and particular (non-nomic) parameters were blended together in a single relation, was the idea that for the universe as a whole, the distinction between the general and the particular fades away. One of the motives of steady-state theorists for introducing a stationary state of the universe was to guarantee the constancy and uniformity of the laws of nature in view of a possible interdependence of laws and the material structure of the universe. No lawlike description of reality and, hence, no science of cosmology, they claimed, could be possible in a universe whose past was radically different from its present.

They proved to be wrong. But the notion of the relationship between the material and the nomic properties of the universe, which the steady-state advocates employed for their specific purposes, clearly does not stand or fall together with a particular cosmological theory. Being suggested by the cosmological point of view as such, the idea has a more general significance. It may have interesting implications in the context of the contemporary interplay between big-bang cosmology and high-energy physics in the effort to understand the processes at work during the first moments of cosmic evolution. Because of its global character, the cosmological perspective may impart an unprecedented kind of historicity to physics. In a sense, the evolution of the physical state of the universe as a whole may have 'carried' with it the evolution of certain nomic properties of matter. Specifically, the masses of certain particles (e.g. of the W boson) may have, according to current theories, changed as a result of a symmetry-breaking phase transition in the early universe. Does it mean that the laws of nature involving such changing nomic parameters have a history? Or, rather, does it suggest that what we formerly regarded as laws do not really deserve this honorific title? In any event, it appears that at least some physical laws may carry an 'imprint' of the universe as a whole and thus be bound up with its evolution—a possibility discussed by a growing number of physicists and cosmologists (Schweber, 1997).

Much depends here, of course, on what kind of being the laws of nature are. This is a matter of intense debate in contemporary analytic metaphysics. Perhaps it is now time to test the metaphysics of laws against a cosmologically-informed physics. Maybe cosmology has a good chance of becoming (borrowing an expression from Howard Stein (1970), p. 285) a 'contemporary locus of metaphysical research' and an ample source of fresh philosophical ideas? It may be appropriate to end by quoting from Hoyle:

> I take the view that the laws of physics are not what people think they are. What we count as the laws are a combination of the true laws together with a cosmological influence. There are long-range interactions. When you look at a book on particle physics and look at the masses of the fundamental particles, if you believe in the canonical view of physics, then all that is a part of basic physics. I don't believe it. There *is* a basic physics. But in my way of looking at things, I don't have to assume that the various peculiar aspects of physics—particular masses, etc.—depend wholly on the basic laws. They are also a product of the way the universe actually is. What we actually see in the laboratory is a product of two things: long-range cosmological influence and the laws, which are very very much more elegant and symmetrical than particle physicists believe (From Lightman and Brawer, 1990, p. 65).

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