

Cosmology

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Philosophical Concept

The term 'cosmology' has three main uses. At its most general, it designates a worldview, for example, the Mayan cosmology. In the early eighteenth century, shortly after the term made its first appearance, Christian Wolff used it to draw a distinction between physics, the empirical study of the material world, and cosmology, the branch of metaphysics dealing with material nature in its most general aspects. This usage remained popular into the twentieth century, especially among Kantian and neo-scholastic philosophers. But recent developments in science that allow the construction of plausible universe models have, effectively, pre-empted the use of the term in order to designate the science that deals with the origins and structure of the physical universe as a whole.

Cosmology may be said to have gone through three major phases, each associated with a single major figure – Aristotle, Newton and Einstein. The ancient Greeks were the first to attempt to give a reasoned account of the cosmos. Aristotle constructed a complex interlocking set of spheres centred on an immovable central earth to account for the motions of the heavenly bodies. Newton formulated a theory of gravitational force that required space and time to be both absolute and infinite. Though the laws of nature could, in principle, be specified, nothing could be said about the origins or overall structure of the cosmos. In 1915, Einstein proposed a general theory of relativity whose field-equations could be satisfied by numerous universe-models. Hubble's discovery of the galactic red shift in 1929 led Lemaître in 1931 to choose from among these alternatives an expanding-universe model, which, though challenged in the 1950s by a rival steady-state theory, became the 'standard' view after the cosmic microwave background radiation it had predicted was observed in 1964. The 'Big Bang' theory has since been modified in one important respect by the addition of an inflationary episode in the first fraction of a second of cosmic expansion. As a 'cosmic' theory, it continues to raise issues of special interest to philosophers.

1. Aristotle's cosmos

Cosmology and philosophy came into existence together in the Greek-speaking world of the sixth century bc when some daring minds sought a 'reasoned account' of the origins and nature of the universe. They assumed that the complex must originally have come from the simple, and thus sought clues in the world around them for the elements and processes responsible, resting their claims on argument rather than on the authority of a tradition. Plato was sharply critical of

his predecessors' lack of attention to the traces of mind he saw everywhere in the world around; his *Timaeus* took the universe to be the work of a demiurge (artificer) who imposed partial order on a pre-existent and recalcitrant receptacle (see Plato §16). He acknowledged that his account fell short of knowledge proper. But it could still claim the status of a likely story.

Aristotle went much further, and the cosmology he constructed would substantially endure for two millennia. Beginning from the sophisticated geometrical combinations of circles whereby his contemporaries Eudoxus and Callippus had sought to 'save' the motions of the seven 'wandering stars', he proposed a set of fifty-five rotating concentric spheres, the poles of each carried by the sphere next outside it, and each given its own motion of rotation by an immanent mover, akin to a soul. The complex motion of each planet is the resultant of the motions of its own cluster of spheres, the innermost of which carries the planet. The physics of earth does not apply to these spheres, whose eternal circular motions are quite unlike the rectilinear natural motions found on earth. Nothing much further can be said about the nature of the spheres and the celestial bodies they carry except that they are incorruptible (see Aristotle §16).

The aim of Aristotle's cosmology was to give a plausible causal explanation of the planetary motions, and in this it succeeded. It was not of much practical use for the needs of working astronomers, and its concentric spheres could not explain the known regular variations in planetary brightness. The epicycles and eccentrics first introduced by Apollonius and Hipparchus and later welded by Ptolemy into an accurately predictive geometrical scheme were of much more use for practical ends, but could not compete with Aristotle's ingenious model in explanatory appeal. The fact that the two approaches could not be reconciled was troublesome, but medieval philosophers grew accustomed to arguing that the truth of things would be found in 'physics', that is, in causal explanation, even though 'mathematics' would perhaps be more effective for saving the phenomena.

2. Newton's infinites

Aristotle's cosmology fell as the Copernican heliocentric model (see Copernicus) gradually proved itself in the hands of Kepler and Galileo. In his *Astronomia nova* (1609), Kepler argued that a proper cosmology, one that could claim to give a true account of the motions and distances of the planets, would have to elucidate the causes of those motions and not merely save the phenomena. His own attempts to explain the motions in terms of forces acting at a distance were not successful. It was left to Newton to carry this programme through, utilizing a gravitational attraction that varied inversely as the square of the distance. Leibniz and the Cartesian physicists of the day were willing to concede that the new mechanics of Newton's *Principia* (1687) could save the phenomena, but they insisted that action at a distance could not be accounted an explanation, and hence that the *Principia* did not support a genuine cosmology (see *Mechanics*, classical §3; Newton, I.).

In order to support the reality of the forces he postulated, Newton introduced the idea of ‘absolute’ motion (changes in which would be the indication of forces acting) and its corollaries, absolute space and absolute time. Absolute space is Euclidean and thus boundless; it exists independently of any material contents, unlike an Aristotelian place. Absolute time ‘flows equably without relation to anything external’; it is thus independent of actual physical change (unlike Aristotelian time) and it is without beginning or end. Not much purchase here for questions about the origin and extent of the material universe! A century later, indeed, Kant would argue that the proclivity of human reason to pose cosmological questions such as these, which necessarily (in his view) lead to antinomy, forces a radical critique of pure reason itself (see Kant, I. §8).

Newton made one significant cosmological claim. In Aristotle’s universe, terrestrial and celestial bodies were altogether different in nature, so that a simple science of the two was impossible. Newton showed, however, that a single mechanics governed earth and planets, and in the boldly inductivist third rule of reasoning of the *Principia* postulated that qualities characterizing bodies at the local level should be deemed to characterize the universe generally. The inverse square law of gravitation could, on this basis, be portrayed as a cosmological law governing the attraction between any two particles in the universe. Kant was the first to see just how this might explain the origin of such stable cosmic structures as planetary systems or even the Milky Way. Questions about origin or structure at the level of the universe, however, still seemed fruitless.

3. The expanding universe

In 1915, Einstein formulated a general theory of relativity, employing non-Euclidean geometry to describe a unified spacetime in which the curvature of spacetime replaces gravitational force as a cause of motion (see Spacetime §3; Relativity theory, philosophical significance of §§4–7). Universe models could now be constructed as solutions to the field equations of the new theory, though constraints were needed on the large number of possible solutions. A variety of ‘natural assumptions’ were introduced regarding large-scale cosmic structure, some of them given the status of ‘cosmological principles’. Notable amongst these was Einstein’s daring conjecture that matter should be distributed uniformly over space on the largest scale. When Einstein discovered that his equations tended to yield unstable models, he added a cosmological constant representing a repulsion that increased with distance, since he assumed that a plausible universe model ought to be static. Alexander Friedmann (1924) and Georges Lemaître (1927) proposed, instead, nonstatic solutions in which space itself could be expanding.

Hubble’s discovery of the galactic red shift in 1929 was the next significant development. It indicated that the galaxies are moving away from us, and from one another, at speeds proportional to their distances. Lemaître (1931) realized how neatly this fitted the nonstatic models of general relativity and formulated the theory of the expanding universe, later called the

‘Big Bang’ theory. From the rate of expansion, one could calculate an upper limit on the length of time since the expansion began from a single enormously condensed volume. An answer to the ancient cosmological query about origins suddenly seemed to be within reach. But a disappointment was in store. Using Hubble’s figure for the expansion constant, the limit-age came out as roughly two billion years, much shorter than the estimated age of the solar system or of the oldest stars.

This was one, though not the principal, motivation for the construction of an alternative ‘steady-state’ model by Bondi and Gold (1947). It rested on what they described as the ‘perfect’ cosmological principle, requiring a homogeneous distribution of matter in an infinite space and throughout an infinite time. To account for the Hubble expansion, they postulated the continuous creation of hydrogen throughout space at a rate too low to be detectable, sufficient to allow new galaxies to replace the old as the old move out of view. Baade (1952) showed that Hubble’s estimate for galactic distances was too low and that the ‘Big Bang’ age in consequence was a much safer ten to twenty billion years. And in the late 1950s, evidence began to mount that the relative abundance of galaxies of different types varied with distance (that is, with era in the past), contrary to the ‘perfect’ principle.

But it was the discovery by Penzias and Wilson of the uniform cosmic microwave background radiation, reflecting a 3°K black-body temperature distribution, that proved decisive (1965). Alpher and Herman had predicted long before (1948) that just such a relic of radiation should be expected from the original Big Bang. The effect of the discovery was not only to bring over most cosmologists to the Big Bang theory but also, to a significant extent, it validated cosmology itself as a respectable branch of science. Fresh data concerning the observed cosmic helium abundance (25 per cent by mass) also fitted the Big Bang account of helium formation in the first minutes of the cosmic expansion.

Still, some serious challenges remained. In the Big Bang model, the universe might be (geometrically) ‘open’, in which case it would be infinite and galaxies would continue to expand indefinitely, or it could be ‘closed’, finite, with the galaxies ultimately collapsing again inwards, or ‘flat’, poised between. The decisive factor is the average cosmic mass-density. Collins and Hawking (1973) showed that for a long-lived universe like ours to develop, one in which the background radiation is isotropic, the early universe would have had to be ‘flat’ to an almost unbelievably exact degree. Cosmologists had always assumed that no particular initial cosmic parameter setting would be needed, so this discovery was both unexpected and unwelcome. Collins and Hawking responded with what Carter (1974) dubbed the ‘anthropic principle’: the fact that we have observed the universe to be long-lived and isotropic is merely a consequence of our own existence. Were it not to be of that sort, we would not be here! To convert this ‘principle’ into an explanation, a further premise was necessary. Their choice was a many-universe hypothesis: if our universe is one among a large number of actual universes, we would

naturally find ourselves in one that is suited for human existence. Other writers, most of them philosophers of religion, pointed out on the other hand that such 'fine tuning' would be what one would expect were the universe to be the work of a provident Creator (see God, arguments for the existence of §5). Here, then, were two unconventional sorts of anthropic *explanation*, each requiring a much broader context than usual to make it acceptable. (It seems doubtful that there is a nontrivial anthropic *principle*, strictly speaking.) The same two alternatives were also proposed in response to a rather different sort of fine tuning. Were the physical constants, notably the relative strengths of the four fundamental forces, to be even very slightly different, a long-lived galactic universe containing the heavy elements needed for complex life would not have developed.

Alan Guth (1981) took a more conventional approach to the 'flatness' problem. He proposed a modification of the Big Bang model that would automatically bring about the critical mass-density needed: a gigantic inflation within the first fraction of a second of the cosmic expansion. This would also eliminate several other troublesome anomalies in the original Big Bang theory; it would, for example, achieve the needed causal coordination across different spatial regions of the early universe. The inflationary hypothesis illustrates the extent to which quantum theory has entered into the cosmological debate. On the one hand, standard quantum ideas have permitted physicists to reconstruct the probable sequence of the early expansion, allowing the derivation of testable predictions concerning, for example, the relative cosmic abundance of the lighter elements. On the other, the enormous energies and densities of the very first moments of the (hypothetical) expansion have become a conceptual testing-ground for quantum field theory of a sort that the particle accelerators of earth could never provide.

Cosmology is, as it has always been, a testing-ground for philosophical ideas, lying at the limits of our notions of space, time and causality. Inductivist doubts as to whether a unique object such as the universe could ever become a legitimate object of knowledge have been to some extent quieted. A theory of the universe can be tested as theory normally is, by such criteria as coherence, predictive novelty and consilience. The vast expansion in our conceptual horizons that Big Bang theory and its inflationary addendum have brought about have led philosophers to be more wary than they were of the sort of appeal to intuition on which philosophies of nature in the past were often based. For the same reason, reliance on 'cosmological principles' as anything more than idealizations of a regulative sort has become increasingly suspect. Discussions of anthropic forms of explanation have forced scientists and philosophers alike to clarify what counts as 'explaining' and what resources can legitimately be drawn on in the process. The many-universe models, particularly those prompted by the inflationary hypothesis, have raised new questions about what should count as a distinct universe. It is less than a century since Einstein opened the new era in cosmology. No doubt surprises as great as those already encountered still lie ahead.

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