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Physical cosmology from Einstein to 1965

Several histories of physical cosmology have been written so far, some of them superb instances of history of science writing (e.g., North, 1994; Kragh, 1996, 2004, 2012; Kragh and Longair, 2019; Peebles, 2020), but to set the stage for what follows, we will recapitulate a few points salient for our study. The treatment will out of necessity be very brief; all interested readers are directed to the appropriate items in the literature. Many good textbooks give the physics side of the story; some contain selected historical analyses and reminiscences. A good example is Peebles (1993).

Modern physical cosmology "officially" started with Albert Einstein's 1917 paper, although a good case could be made for the Boltzmann–Zermelo debate about 20 years earlier, as it was the first debate to explicitly invoke the beginning of the universe within the discourse of physics, and it appeared in major peer-reviewed research journals.[5] The debate focused on the entropy of the universe and Ludwig Boltzmann's anthropic strategy for explaining the thermodynamical arrow of time and, as such, could be regarded as relevant for the cosmological *boundary conditions* (see the rehashing of the anthropic strategy for modern day in Ćirković, 2003). Any hope of understanding the *dynamical laws* had to wait for the development of Einstein's theory of gravitation.

General relativity, however, performed admirably in setting the groundwork for cosmological dynamics in the true sense, even if its first two applications were, somewhat ironically, *static*. In the 100+ years since Einstein's first cosmological model, physical cosmology has radically transformed our view of the world, perhaps the most radical such shift since Nicolaus Copernicus and Galileo Galilei. For present purposes, we can divide its rich history up to 1965 into four major eras.

The first era comprised a sort of prehistory of cosmology, stretching from antiquity to 1917. Among the important early elements, we might mention Olbers's paradox and the so-called gravitational paradox originating with Isaac Newton, both of which seemed to indicate the finite age of the physical world.[6] In the last

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part of this period, a very interesting cosmological debate was ignited by Ludwig Boltzmann in his controversy with Ernst Zermelo (1895–1896) on the origin of the thermodynamical disequilibrium of the universe – attested to, as Boltzmann presciently argued, by the existence of us as intelligent observers. The tremendous improvements in astronomical instrumentation in the course of the nineteenth century and throughout the first decades of the twentieth century culminated in the construction of the 100-inch (2.5 m) Hooker telescope at Mount Wilson Observatory, California, dedicated in 1917 – the year of the first cosmological models. Before long, the Mount Wilson telescope ushered in a kind of Copernican turn within the realm of physical cosmology.

The second era featured the pursuit of the static universe and lasted from 1917 to 1929. Two main early models, Einstein's static universe and de Sitter's empty universe, emerged in 1917 as a consequence of the great theoretical breakthrough in formulating the first and still the best metric theory of gravity. Both models were characterized by contemporaries as static, based on the mathematical fact that their metric coefficients are independent of time, although the label subsequently only applied to the Einstein model. The dearth of empirical knowledge continued in this phase, and cosmology was regarded as a mathematical game rather than a description of physical reality (and published in corresponding sections of scientific journals). The seminal work of Alexander Friedmann in the early 1920s was not widely known and was rediscovered only later.

The third era developed the expanding mathematical universe (1929–1948). Edwin Hubble and Milton L. Humason's discovery of the expanding universe created conditions for a "cosmological revolution" – cosmologists finally had something clearly dynamical to work with. Georges Lemaître (1931) and George Gamow (1946, 1948, 1949), together with the belatedly read and understood contribution of Alexander Friedmann (1922), laid the foundations for relativistic cosmological models of the expanding universe. What Lemaître called the "primeval atom" became better known as the (hot) Big Bang. The work of those three, together with the important input of Sir Arthur Eddington, Richard Tolman, and a few others who shyly started calling themselves cosmologists,[7] helped physical cosmology attain a modicum of seriousness and authority. Today, this era looks and is often described, especially in popular accounts, as heroic, but we should keep in mind that cosmology was still, in Fred Hoyle's pointed words, the science of "two and a half facts."[8]

The final era, the "great controversy," raged from 1948 to 1965 and merits its own chapter.