The Birth of Modern Cosmology

CMS NOTES

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In the late 1990s I began to teach courses in the history of astronomy and cosmology as a complement to my existing courses in the history of mathematics. I was very impressed by John North's *Measure of the Universe* [14], a history of cosmology from the end of the 19th century to the 1960s. The book explores its subject from historical, scientific and philosophical viewpoints. In terms of historical sophistication and seriousness, it vastly betters popular works on astronomy that include historical surveys. It is one of the finest books of professional history of science over the past sixty years.

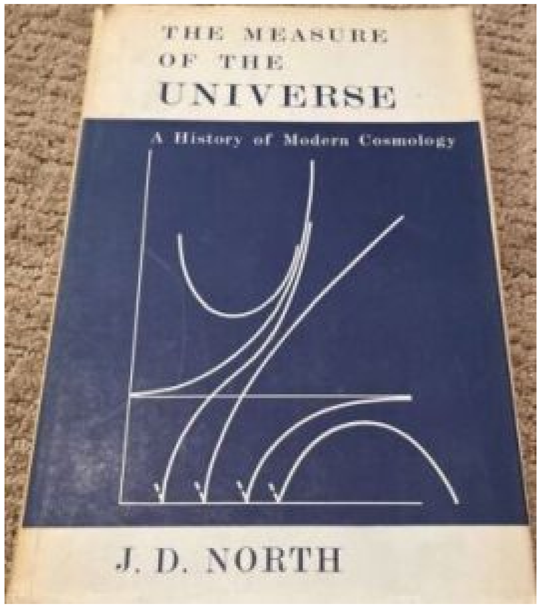

Figure 1. John North (1934–2008) and *The Measure of the Universe* (1965). *The Independent*; the author's copy of [14].

In 2006 I published *The Cosmos: A Historical Perspective*, a book based on my courses' lecture notes and aimed at a broad academic and student audience [5]. One subject discussed in this book that has engaged me more recently is the emergence of modern cosmology in the period from about 1912 to 1935 [6]. The first decades of the 20th century witnessed one of the most remarkable coincidences in the entire history of science. On the one hand there was the development of a new mathematical theory of gravity by Albert Einstein, followed by his publication in 1917 of a geometric model of the universe based on this theory [3]. In developing this model Einstein was not at all engaged with astronomy. Rather, he was concerned with certain questions in the foundations of physics related to something known as Mach's principle (see [19]). At the same time that Einstein was working on his new theory, the astronomer Vesto Slipher had established in Flagstaff, Arizona, a program of spectroscopic observation of spiral nebulae. Slipher's research program had no connection whatsoever with any of the developments underway in theoretical physics. To the astonishment and sometime disbelief of astronomers, Slipher found that the nebulae possess large redshifts, orders of magnitude larger than those of any celestial objects in our galaxy. It was also found in these observations and subsequent ones that there is at least a rough correlation between the faintness of the nebulae and the size of their spectral shifts [16; 17; 18]. Slipher's observations were perhaps the most unprecedented and significant discovery in the whole history of astronomy.

Figure 2. Vesto Slipher (1875–1969) and the Clark 24" Refractor at the Lowell Observatory in Flagstaff, Arizona. Wikimedia Commons and *Clio: Your Guide to History*.

As the 1920s unfolded there were exciting developments in both observational astronomy and relativistic cosmology [11, 12, 13, 20]. Astronomers recognized that the spiral nebulae are very distant objects external to the Milky Way galaxy. Further spectroscopic work by Edwin Hubble and Milton Humason at Mount Wilson established that there is a linear relationship between distance and redshift, a result presented in 1929 in a famous paper [8]. Meanwhile researchers in relativistic cosmology devised various geometric models, "invented universes" in the words of one historian [10]. In 1922 the Russian mathematical physicist Alexander Friedmann published a geometric model of an expanding universe. Although Friedmann did not refer to contemporary astronomical work, it is important to note that he cited writings by the Dutch mathematical astronomer Willem de Sitter and English astrophysicist Arthur Eddington in which Slipher's observations were discussed. Later in the decade Georges Lemaître developed mathematical models similar to Friedmann's, but he presented them as actual physical descriptions of the universe.

Eddington was an admirer of the general theory of relativity and its formulation in terms of differential geometry. In his 1920 book, *Space, Time and Gravitation: An Outline of the General Theory of Relativity,* he wrote, "a geometer like Riemann might almost have foreseen the more important features of the actual world" [1, p. 167]. It is then not surprising that Eddington believed that the distance-redshift law, although discovered by astronomers, was foreshadowed in the work of theorists. In his 1933 book *The Expanding Universe* he wrote, "These observational results are in some ways so disturbing that there is a natural hesitation in accepting them at their face value. But they have not come upon us like a bolt from the blue, since theorists for the last fifteen years have been half expecting that a study of the most remote objects of the universe might yield a rather sensational development" [2, p. 2].

One of the leading pioneers of relativistic cosmology was the American mathematical physicist Howard P. Robertson. In 1949 the volume of essays *Albert Einstein: Philosopher-Scientist* was published to honor Einstein on the occasion of his 70th birthday. Robertson contributed the essay "Geometry as a branch of physics." Although Robertson was primarily concerned here with questions in the foundations of geometry, he did refer to the general theory of relativity. He called attention to the empirical success of this theory, presumably referring to eclipse observations and predictions of the motion of the perihelion of Mercury. However, he put forward the following remarkable assessment: "Einstein's achievements would be substantially as great even though it were not for these minute observational tests" [15, p. 329]. It is difficult to imagine a more complete statement of the theoretical viewpoint than this one.

Historian of science Paul Forman maintains that an historic shift occurred at the end of the 20th century, from a conception of science and theory as primary relative to technology, to a conception of technology as primary relative to science [4]. Forman sees the shift from the primacy of science before about 1980 (a primacy which he repeatedly describes as "preposterous") to the primacy of technology after 1980 as the defining feature of a wider shift in the cultural zeitgeist from modernity to postmodernity. In the writings of scientists such as Eddington and Robertson one finds an unequivocal commitment to the primacy of theory relative to technology, of science relative to practice. Both the emphasis on theory among cosmologists from the 1920s through to the 1970s, and the exponential growth of technology and observational work since then are consistent with the cultural and historical schema identified by Forman. By the early years of the new millennium the noted philosopher Don Ihde could assert that "Science is embodied in its technologies, and technologies determine what is science" [9, p. 431].

General relativity and theoretical physics have continued to play a major role in cosmology, a fact that is evident in current inflationary theories of the early universe. The discovery of cosmic acceleration in the 1990s—the most significant event in cosmology since the discovery of the cosmic background radiation in 1964—required theoretical mathematical calculations of the rate of universal expansion. Nonetheless, technological innovation and an embrace of practice is a pervasive characteristic of modern cosmology. Nobel prizes are awarded to observational cosmologists such as Arnold Penzias, James Peebles or George Smoot and not to theoreticians such as Robert Dicke, Alan Guth or Edward Witten. The place of theory has been usurped by technology. Indeed, the eminent astronomer Martin Harwit sees the technological character of modern astronomy as its defining and redemptive feature [7].

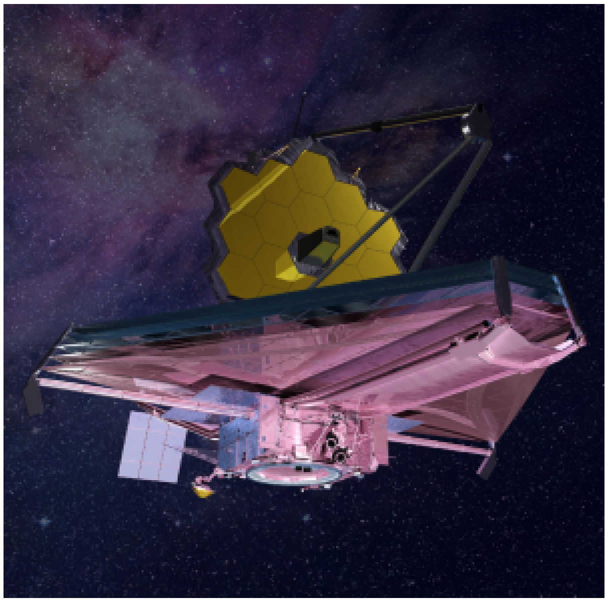

Figure 3. Artist concept of the James Webb Space Telescope (2022), an infrared orbiting telescope. NASA**.**

Cosmology advances today through a myriad of technological tools—radio, optical, infrared, x-ray and gamma-ray telescopes; satellite probes and orbiting observatories; computer modeling and simulation; adaptive optics, LED devices, neutrino detectors and gravitational wave interferometers. The Webb Space Telescope is providing an array of dazzling images and is also probing the structure of the early universe. But for all the prominence of technology, we should in the final analysis remember the role theory also plays in interpreting these findings and revealing the nature of the cosmos.

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