by Maxwell's textbook *Matter and Motion*,[3] written in 1876 for beginning students in mechanics. The organizational structure of that textbook is nearly identical to texts used in colleges and high schools today, some 130 years later. They have the same introduction of vector algebra in the beginning course, the same sequence of material, and the same end-of-book review of the important points.

Maxwell was thus, both in terms of what he said and what he wrote, far ahead of his contemporaries in the teaching of physics.

I am indebted to Yitzhak Sharon, of the Richard Stockton College of New Jersey, for his input.

References

1. H. Lamb, in *James Clerk Maxwell: A Commemorative Volume, 1831–1931*, Cambridge U. Press, New York (1931), p. 142.
2. J. C. Maxwell, *Five of Maxwell's Papers*, Project Gutenberg eBook (2004), http://www.gutenberg.org/catalog/world/readfile?fk_files=1457501.
3. J. C. Maxwell, *Matter and Motion*, Society for Promoting Christian Knowledge, London (1877).

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Big Bang paternity in question

In his informative but somewhat hagiographic article on Alexander Friedmann's contributions to modern cosmology (PHYSICS TODAY, October 2012, page 38), Ari Belenkiy suggests that the Russian physicist should be recognized as the father of Big Bang cosmology. I believe the suggestion is unsupported by historical documentation and that Belenkiy misrepresents to some extent the work of the other pioneer of modern cosmology, Georges Lemaître. It seems to me that Belenkiy, when discussing priority, does not make a sufficiently clear distinction between expanding models and finite-age models of the Big Bang type. Of course, Lemaître's 1927 paper proposing a universe expanding from a static Einstein state does not earn him credit for fathering Big Bang cosmology—but has anyone said that it does?

Friedmann's 1922 paper was not an argument for the expanding universe, which appeared as a mathematical possibility only and not as the solution that corresponds to the actual universe. Although Friedmann wrote in his 1922 paper of a "beginning of the world" in connection with solutions that correspond to expanding world models, he did it in an uncommitted way and without referring to astronomical or physical data. Neither in the 1922 work nor in his companion paper of 1924 did he mention physical terms such as "energy" or "radiation," not to mention "nebula" or "redshift."

If later commentators have presented Friedmann's cosmological papers as basically mathematical and unconcerned with physics and astronomy, it is because that is how the papers were. Belenkiy objects by referring to "Friedmann's considerable achievements in meteorology and aerodynamics"—hardly a relevant argument with regard to his two cosmological papers. It was precisely in that respect that Lemaître went beyond Friedmann. The Belgian physicist did not "fail" to consider all the solutions that Friedmann had discussed. He focused on the expanding solution that seemed to correspond to the redshift data and thus to the real universe as studied by the astronomers.

At any rate, Lemaître's candidacy for paternity of the Big Bang universe rests on his "primeval atom" hypothesis of 1931 in which he offered for the first time a *physical* picture of the nonsingular beginning of the universe.[1] While one can perhaps call Friedmann the father of the Big Bang in an abstract, uncommitted, and mathematical sense—although that would stretch the notion of paternity—it was only with Lemaître that the physical Big Bang entered the history of science.

Finally, when Belenkiy deplores the lack of recognition of Friedmann and refers to Yakov Zeldovich and other Russian scientists as exceptions, one should keep in mind the context of the cold war in the 1960s and later: In the Soviet Union, there was a political need to credit Friedmann as the true and only founder of relativistic evolution cosmology.

This brief letter is in no way an attempt to belittle the great work of Friedmann, only to offer a more balanced view. Friedmann's seminal contributions to cosmology are beyond question, but there is no need to exaggerate them or to read later advances into them.

Reference

1. H. Kragh, D. Lambert, *Ann. Sci.* **64**, 445 (2007).

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■ **I very much appreciated** the article by Ari Belenkiy on Alexander Friedmann. However, I noticed a typographical error just under Belenkiy's equation 1 on page 39: The constant k should be divided by c^4, rather than by c^2 as in the text.

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■ **Belenkiy replies:** As an applied scientist, Alexander Friedmann was keenly interested in testing his theories with available data. An interpretation of the right side of Einstein's field equations as the "flow of matter" was particularly appealing to him as a meteorologist. Several of his recently discovered letters to Paul Ehrenfest in June 1922 (PHYSICS TODAY, March 2013, page 9) clearly show Friedmann knew he had made an important discovery.

While Friedmann had some *a priori* estimates of Λ and Λ *critical*, he was wise enough not to include them in the final draft of his 1922 paper; he remained uncommitted to a particular scenario until the empirical data provided information.[1] He was unaware of Vesto Slipher's data on the nebulae's high radial velocities, publicized by Arthur Eddington in 1923. As the letters to Ehrenfest testify, Russia was so devastated at the time Friedmann was writing his 1922 paper that he was still unable to obtain a copy of Willem de Sitter's original 1917 paper, which first highlighted Slipher's data. (Most likely, Friedmann learned of de Sitter's solution of general relativity equations indirectly from a secondary source.)

Furthermore, in his 1923 book, Friedmann discussed the possibility of the universe's birth from a "singularity." Thus all components of the Big Bang cosmology were present in Friedmann's writings long before Georges Lemaître entered the field.

As for Peter Hammerling's comment, Friedmann's metric, in contrast to the modern one, had the additional factor c^{-2}, thus forcing renormalization of the relevant constants k and λ by the inverse factor c^2.

Reference

1. A. Belenkiy, in *Origins of the Expanding Universe: 1912–1932*, M. J. Way, D. Hunter, eds., ASP conf. ser. 471, Astronomical Society of the Pacific, San Francisco (2013), p. 71; http://arxiv.org/abs/1302.1498.

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