ASTRONOMY

Stars in the Beginning

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How Did the First Stars and Galaxies Form?

by Abraham Loeb

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Frontiers in Physics.

Abraham Loeb has a warning for those seeking a career in theoretical cosmology: If you devote yourself to trying to understand the global properties of the universe and its underlying physics, you risk becoming obsolete once data are so precise that further refinement is pointless. And if you study the complex processes by which stars, galaxies, and black holes form from cosmological initial conditions, you are likely to spend an entire career without ever reaching an elegant resolution of the problem. You may, however, decide to ignore these risks after being taken to the common frontiers of cosmology and astrophysics in the engaging, fast-paced *How Did the First Stars and Galaxies Form?* Loeb's infectious excitement stirs desire to join him in these endeavors.

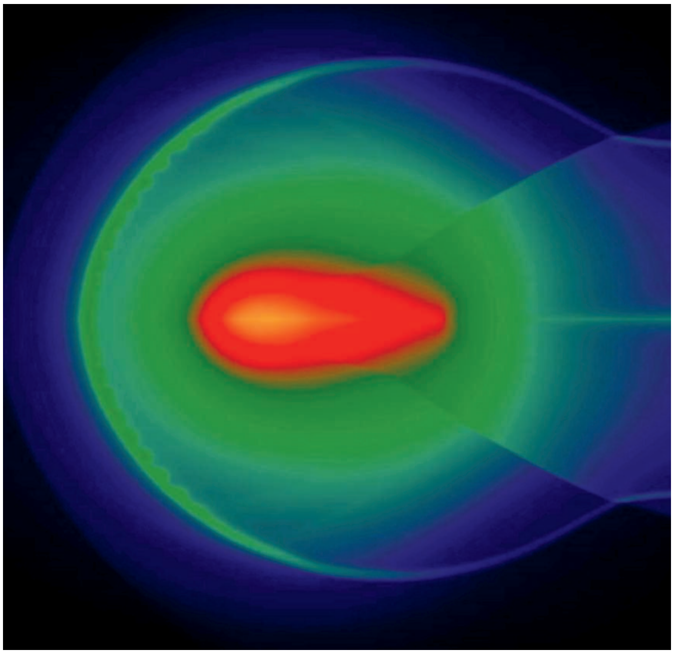
The first stars were the result of an unavoidable meeting between the simplicity of cosmology and the complexity of astrophysics. Their initial conditions are thought to be tiny overdensities of matter laid down in the inflationary epoch moments after the Big Bang. After a few hundred thousand years, the fluctuations were still miniscule (just one part in a hundred thousand), as revealed in the cosmic microwave background. That crucial observation sets a firm foundation for theoretical models of the subsequent growth of structure via gravitational instability. Growing clumps of cold dark matter collapsed, later trapping cooling baryonic matter (mostly hydrogen and helium) in their deepening potential wells. The baryons themselves became gravitationally unstable, concentrating to higher and higher densities, pressures, and temperatures that eventually (about 100 million years after the Big Bang) allowed nuclear fusion of hydrogen to provide energy and pressure to halt the collapse. These first stars then illuminated, reionized, and spread heavy elements through the universe. They may have evolved into—or at least set the conditions for the formation of—the first black holes. They were the opening act for the formation and evolution of all complex structures, a cosmic saga of galaxies, stars, planets, and (ultimately) life. Although attractive, this scenario, based on theoretical and numerical studies of structure formation, remains difficult to test observationally because the first stars are, literally, near the edge of the observable universe.

Loeb (Harvard University) tells this tale from the perspective of a theoretical cosmologist who has made important contributions to our understanding of all these stages. Writing at a level suitable for advanced undergraduates, he introduces the concepts required to understand our modern view of cosmology. He focuses on structure formation and predictions of the frequency and mass of collapsed dark matter halos, the nurseries of the earliest stars and galaxies. Loeb develops this formalism to predict observational signatures of cosmic reionization, given assumptions about how these halos are populated with ionizing sources, such as stars and accreting black holes.

As the author points out, the actual process of star formation and its outcome involve large degrees of uncertainty. He describes the results from numerical simulations that have followed collapse to near stellar densities. However, these are still a long way from, for example, predicting the mass of the first stars, which is so critical to their detectability and their influence on subsequent galaxy evolution.

Loeb presents a scenario to explain how supermassive black holes (millions to billions of times the mass of the Sun), which are seen in the centers of most nearby galaxies, could have formed in the environments of the first stars and galaxies. A few examples of these black holes have been seen as quasars in the early (less-than-one-billion-year-old) universe, which likely requires initial seed masses to be much greater than the circa 100 solar masses expected of the earliest stars. Loeb suggests that such massive seeds could have formed in halos that only experience cooling by atomic processes, which would likely require an intense surrounding ultraviolet radiation field to destroy H_2 molecules. However, some have argued that such strong radiation fields can, if they generate ionization fronts that compress gas to high densities, promote molecule formation (*1*). The astrophysical complexities associated with the interplay among radiation, hydrodynamics, astrochemistry, gravity, and potentially even dark matter annihilation (*2*) are such that the mechanism of supermassive black hole formation and its relation to the earliest stars remain quite uncertain. Perhaps these great uncertainties motivated Loeb's apt choice of cover illustration (a large question mark).

The very first stars and galaxies are impossible to observe directly with current astronomical telescopes. Indeed, their detection is one of the main drivers of the next generation of facilities, including the James Webb Space Telescope, large (about 30-m-diameter) ground-based telescopes, the Atacama Large Millimeter Array, and low-frequency radio telescopes that hope to trace the cosmic web of atomic hydrogen before and after reionization. Loeb gives an excellent summary of the prospects of the last of these: although challenging,



Shock start. Density of primordial hydrogen and helium gas in a dark matter halo being impacted by ionizing radiation from the left, which drives shocks, generates instabilities, and may trigger star formation [from simulations of (*1*)].

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this technique has the potential to give us the most detailed view of the initial conditions of our universe. It will also tell us when and how early galaxies reionized the universe.

Perhaps inevitably, some current topics in this fast-moving research field receive only limited coverage. Whereas Loeb describes the detectability of the direct radiation from early sources, he omits mention of the integrated background light from these sources and the statistics of its fluctuations. There have been a number of claims of detections of these effects, including a recent study with the AKARI satellite (*3*). Some astronomers hope to find nucleosynthetic fingerprints of the first supernovae from the abundance patterns of elements dusted in the atmospheres of old, very metal poor galactic stars (*4*), and this complementary approach of cosmic archaeology deserves more discussion. Despite such omissions, readers will find *How Did the First Stars and Galaxies Form*? a lucid introduction to an exciting research field that is set to flourish in the next decades.

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SCIENCE AND THE LAW

Power and Pitfalls of DNA Profiling

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The Double Helix and the Law of Evidence

by David H. Kaye

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348 pp. $45, £33.95, €40.50.
ISBN 9780674035881.

Despite the first use of DNA profiling in a criminal investigation back in 1985, until very recently a search of any respectable library catalog for books on forensic DNA would have returned the unsatisfactory "no matching results." Fast-forward to 2010, and there are now, *inter alia*, scientific texts on forensic genetic testing, historical treatments, sociological and sociolegal examinations, and guides for scientifically illiterate lawyers. In *The Double Helix and the Law of Evidence*, David Kaye considers all of these angles. He describes the book as "part history, part legal analysis, part popular science, and part applied statistics."

The author intends the book to be the first of a pair on forensic DNA profiling. Nevertheless, this first text is itself quite comprehensive. Kaye (a law professor at Pennsylvania State University) begins his account in "pre-DNA" times, with a detailed discussion of the use of genetic markers (popularly known as blood grouping). After exploring early forensic uses of DNA data, he takes the reader diligently through the "DNA wars" to arrive at current developments and scientific advances. Along the way, Kaye chronicles the "scientific egos, journalistic hype, lawyerly maneuvering, and judicial doctrine and disposition," ensuring that the reader is never left for long in the depths of scientific or statistical exposition. The scope of Kaye's analysis, his insightful and meticulous eye for detail, the coverage of both law and science (not forgetting the math), and the spicing with human tales of crimes and academic rivalries combine to ensure the book will interest a medley of readers.

As Kaye points out in his introduction, the power of DNA technology is now beyond dispute. However, media portrayals of this power are often inaccurate, while those professionals tasked with employing the technology may not possess a competent understanding of its actual strengths and limitations. The book could go a long way toward correcting these failures, were it to become essential reading for reporters, criminal investigators, legal professionals, and, ultimately, the public—who are most often characterized as demanding the increased use of DNA evidence by law enforcement. Further, Kaye's account may help forensic scientists who do not work with DNA to better understand the trials and tribulations that were weathered by forensic DNA profiling on the "far from smooth" road to legal acceptance. With DNA hailed as the gold standard of forensic science, Kaye presents a lesson that bears learning by those disciplines or techniques currently struggling to sustain their integrity as a science and gain, or maintain, legal acceptance. DNA profiling did not become the gold standard overnight, and even gold can be tarnished if mistreated or mishandled.

Forensic DNA profiling offers a perhaps perfect example of a scientific technology that has captured the public imagination. Its value in criminal investigations can scarcely be overplayed, and its use in exonerating the innocent will continue to have far wider consequences than the (albeit vital) freeing of the innocent—leading to improvements across the criminal justice process. Its enthusiastic embracement by filmmakers and television producers needs no rehearsal here or by Kaye, who steers clear of indulging in the hype that has surrounded DNA profiling. He does, however, defend it as a profoundly valuable tool for investigators, if used with diligence: "industrial-strength quality control is not too much to demand." Yet in order to benefit from the power of DNA, the criminal justice system must be able to harness it.

Throughout the book, Kaye highlights idiosyncrasies of DNA that mean that the potential for misunderstanding and misuse are always present. For example, juries can give DNA undue weight, an issue that needs to be better understood before it can be overcome—and overcome it must be if flawed analyses of DNA data are not to lead to wrongful convictions. This is a systemic issue: "the system might have failed, as it too often does, because of the inadequacies of its participants." One of the root causes of such inadequacies lies in the lack of dialogue among legal, science, and criminal-justice professionals. Language receives much of the blame for this failure to exchange ideas, as scientists, lawyers, and law enforcement officials each have their own vernacular. The work of Kaye goes some way to demonstrate that the barriers to communication can be breached. Doing so may require some initially discomfiting forays into other disciplines, departures from comfort zones, and patience, but it is essential.

If we are to realize the full forensic potential of DNA to improve detection rates, convict the guilty, and exculpate the innocent, then everyone involved in the use of DNA profiling needs a proper appreciation of the technology's history, strengths, and weaknesses. This is what *The Double Helix and the Law of Evidence* provides. I look forward to the next installment and hope that Kaye turns his attention to a global consideration of the forensic use of DNA (taking in more than just the United States). For the present, may the book get the wide readership it deserves.

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