BOOK REVIEWS

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How Did the First Stars and Galaxies Form? Abraham Loeb. 193 pp. Princeton U.P., Princeton, NJ, 2010. Price: $24.95 (paper) ISBN 978-0-691-14515-0. (Milan M. Ćirković, Reviewer.)

We inhabit a very, very small part of the universe which grew larger (epistemically speaking) in revolutionary shocks and convulsions: with Copernicus in 1543, Hubble in 1924, and probably also with Alan Guth, Andrei Linde and other cosmologists in the 1980s. Somewhat ironically, we exist owing to minuscule deviations of our universe from its original almost-perfect uniformity (the latter is, already somewhat quaintly, referred to as the Cosmological Principle)—deviations that grew into the *structure* we perceive: most prominently, galaxies, and stars. If one wanted to describe in one phrase the single most important process that has happened in the entire 13.7 billion years of cosmic history, the correct answer would undoubtedly be "the formation of structure." Most of the actual research in astrophysics and cosmology is concentrated on the elaboration of this process, which made gigantic strides in the last quarter of a century. Anyone interested in an introduction to this dramatic story, be they academic or educated nonprofessional, would do well to start with Loeb's book. It contains only the most important equations in the field, and its general level of mathematical sophistication is comparable to that of a calculus-based introductory physics course.

This small book is a gem belonging to an almost extinct genre: Intermediate-level monographs that are both *accessible* to educated non-specialists in the field and *tightly focused* on a problem. Apart from its intrinsic pedagogical value, this "middle kingdom" of scientific books is precious for an additional reason: it enables quick entry to people who are working in interdisciplinary fields or wish to switch to a related field. This is certainly not a luxury, as has for too long been assumed—on the contrary, early 3rd millennium science shows more and more that true interdisciplinary work is a necessity, be it in astrobiology, climate science, evolutionary computing, or countless other fields. There is a distinct and important advantage in being able to discuss, as Loeb does, the power spectrum of primordial density perturbations without either explaining Fourier transforms on the one hand, or tacitly assuming (say) that inflation suppresses higher-order tensor perturbations on the other. Instead, the author is free to zoom in upon presentation of the key issues which elude both highbrow monographs and wide-ranging massive textbooks. An example of that is a true educational pearl of wisdom to be found in Chapter 3: A brilliantly accessible presentation of the Press–Schechter formalism for predicting the number of dark matter haloes in a given mass interval at a particular cosmological epoch. This, one of the hardest topics in astrophysical cosmology for explaining to an entering audience, is dealt with elegantly and clearly in a couple of pages—a true *tour de force*.

Covered topics include the gravitational growth of perturbations in an expanding universe, the abundance and properties of dark matter halos and galaxies, early stars and early black holes, re-ionization, the observational methods used to detect the earliest galaxies and probe the diffuse gas between them, and much more. In addition, the book shows how tightly connected seemingly distinct fields, such as cosmology and the physics of star-formation, actually are. As Loeb points out, the actual process of star-formation taking place in the Milky Way at this very moment still involves many uncertainties; the analogous process at early cosmological epochs is much less well established. He describes the results from numerical simulations that have followed the collapse of protostellar clouds to near stellar densities. However, this computational effort is still a long way from predicting phenomena such as the initial mass distribution of both present-day and first stars, which is so critical to their detectability and their feedback influence on subsequent galaxy evolution.

A particular strength of the book is following a tight interplay between theoretical and observational work. A particularly good example is the exposition of the process of reionization of the intergalactic matter (chapters 5–7) where, interwoven with theoretical foundations of the problem, we find clear descriptions of the observational methods used to detect both the earliest galaxies and the tenuous web of ionized/neutral gas between them, accompanied by some nice pictures (sadly, in monochrome) of the new and future instruments such as the *James Webb Space Telescope* and new huge ground-based instruments, like the envisioned *Thirty-Meter Telescope*, currently under development. This gives a fine context for future discoveries in this exciting field.

The thoroughness of Loeb's instructional approach is demonstrated by, among other things, the presence of both a primary-source bibliography *and* a list of references suggested for further reading and study. There are also a table of useful numbers, a glossary of major astrophysical and cosmological terms, and a comprehensive index.

Probably the worst one can say about this book is to list items which could be, subjectively speaking of course, classified as omissions. Section 7.2 discusses the Gunn–Peterson effect, but does so rather briefly and only for neutral hydrogen HI; it lacks the discussion of the analogous effect for helium (HeII). In addition, the discrete absorption in the "Lyα forest" lines is somewhat neglected, although it arguably still presents the most important tool for understanding both inter- and intragalactic matter at high redshift. Also missing is a discussion of the integrated starlight emission from early stellar populations, a modern-day rendering of what puzzled Olbers and other early cosmologists, which could tell us much about the early generations of stars and the elusive Population III (metal-free "first stars" of the book title). On the other hand, very much detail—perhaps disproportionally so in comparison to the results thus far—is devoted to a rather limited 21 cm technique of searching for neutral hydrogen at early epochs which came in vogue in recent years. All these, I re-emphasize, are subjective and limited qualms, which disregard the obvious fact that in such an appealingly compact format important choices of discussion and omission are necessary.

Selfishly, the interested reader will find this book too short, especially since Loeb has found space and audacity at the very end for a beautiful and teasing vignette on the future of the universe. It touches upon some of the most interesting of his own research in physical eschatology, and begins with a wonderful sentence: "Every time an American president delivers the 'State of the Union' address, I imagine what it would be like to hear a supplementary comment about the 'State of the Universe' surrounding the Union." One may only hope that the author will find time and energy for more books like *How Did the First Stars and Galaxies Form?* And let's hope that, more generally, the very same style and spirit of bold, non-parochial, and non-compromising science writing will endure.

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The Shape of Inner Space: String Theory and the Geometry of the Universe's Dimensions Shing-Tung Yau and Steve Nadis. 393 pp. Basic Books, NY, 2010. Price: $30.00 (hardcover) ISBN 978-0-465-02023-2. (Joshua Erlich, Reviewer.)

The Shape of Inner Space is a portrait of a beautiful branch of geometric analysis as seen through the eyes of one of its pioneers, Fields medal winner Shing-Tung Yau. Astronomy magazine contributing editor Steve Nadis shares the credit with Yau for their clear presentation of both the technical mathematical concepts necessary to appreciate the significance of Calabi-Yau manifolds, and the recent developments in particle physics and cosmology that hold the (perhaps distant) possibility of lifting Yau's ideas from a realm of abstract theory to one of physical fact. The book's focus is twofold: the events leading up to and following Yau's proof of a conjecture by mathematician Eugenio Calabi regarding the existence of a class of complex geometries, and the Calabi-Yau manifolds themselves, especially in relation to string theory.

The first chapter hints at the *raison d'être* for a book about a special class of manifolds and their discovery more than thirty years ago, which is that the extra dimensions of string theory must be carefully hidden and to do so one is naturally led to the Calabi-Yau manifolds. This should be motivation enough for the reader interested in string theory and the possibility of extra dimensions to invest the mental energy required to understand the sophisticated mathematical ideas that follow, but the promise of glimpsing the world through the mind of such a remarkable thinker as Yau makes the effort all the more worthwhile. Yau and Nadis take a step back to appreciate the history of geometry from the ancient times of Pythagoras and Euclid to the present. Along the way, we learn of the difficult circumstances surrounding Yau's childhood, including poverty, the early death of his father, and his time spent leading a local gang of disorderly youths. Yau paints a picture of a young man who, given the promise of a mediocre life, gambled against the odds on a career in mathematics and succeeded, thanks to a level of focus derived from the natural instinct to survive.

After describing the sequence of events that led him to the United States and to his enamoration with geometry, Yau explains as only a master could the conjecture by Calabi and the subsequent discovery of Calabi-Yau manifolds that are the centerpiece of this book. The reader is thrown into a world of complex manifolds, geometric analysis, and differential equations, yet the book is written so that the persistent layperson could follow all of the main ideas. Equations are noticeably absent and the mathematical buzzwords, symbols, and acronyms are all explained, but their plentiful and repeated use requires that the book be read with attention, lest frequent reference to earlier sections be required. Flipping to a typical page, I find "Euler characteristic," "mirror symmetry," "moduli space," and "SYZ" (used as a noun to refer to a conjecture by Strominger, Yau, and Zaslow). The relation between the mathematical ideas and Einstein's general relativity is alluded to from early on, making contact with physics well before the focus on string theory later in the book. The more technical mathematical details required to master the subject are absent from the book, as well they should be, but the mathematically educated reader may be left wanting for a deeper understanding of some of the topics discussed. The second volume of Joseph Polchinski's textbook on string theory summarizes in more detail those aspects of the mathematics behind Calabi-Yau manifolds that are most relevant to the subject, and would be an appropriate reference for those with a suitable background.

The latter two-thirds of *The Shape of Inner Space* describes the interplay between the mathematical subject matter of Yau's expertise and the parallel developments in theoretical physics for which Calabi-Yau manifolds have proved so crucial. The relevant question from the physics perspective is how string theory might describe our world despite its requirement of extra spatial dimensions. One possibility is that the extra dimensions are compactified and of such tiny extent that they have so far been undetectable. But what should those extra dimensions look like? A sphere? A donut? The equations of string theory indicate that stable solutions have a property called supersymmetry, a property that requires the extra dimensions to be curled up in geometries of precisely the type discovered by Calabi and Yau. Following this realization by string theorists Candelas, Horowitz, Strominger, and Witten in 1985, the Calabi-Yau manifold became the center of attention for the string theory community.

The Shape of Inner Space goes on to describe some of the most intriguing conjectures to have come out of string theory, which are generally given the title of dualities. Yau and Nadis nicely explain the possibility that compactifications on different Calabi-Yau manifolds may lead to identical physics, a possibility known as mirror symmetry for reasons explained in the book. The authors describe how extra dimensions could be discovered in upcoming particle physics experiments, or by measuring the gravitational interaction at short distances by a modern-day Cavendish experiment, or by analyzing details in the cosmic microwave background. The reader is left hopeful that evidence for extra dimensions may be just around the corner—an exciting prospect, indeed.

The collaboration between Yau and Nadis, with their different backgrounds, makes for a somewhat unusual mode of presentation. Much of the book is written in the first person, and the pronoun "I" is always meant to refer to Yau. However, the preface explains that certain discussions in the book about nonmathematical topics such as experimental physics and cosmology are the result of Nadis' interviews with other experts on those subjects. At times, there is some disconnect between the narrative presentation of Yau and the documentary style of Nadis, though on the whole the authors pull it off. Plentiful figures throughout the book provide helpful visualizations of the concepts described in the text, and photographs of relevant mathematicians and physicists are a nice addition.

The personal aspects of the book are inspirational, and provide proof that it is possible from humble means to become a leading figure in a career of one's own choosing. At times, Yau's pride shows through, though I did not find it particularly off-putting. Despite the vast background in mathematics and physics that would be required for a thorough understanding of all of the notions described in the book, Yau and Nadis leave the reader feeling that the details are within reach. I expect that some more advanced readers will be stimulated to continue with technical books and articles on the subject matter, as if having discovered a newfound desire to climb, once having been taken to the base of an impressive mountain and shown the possibility of reaching the summit.

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BOOKS RECEIVED

Advanced Particle Physics Volume I: Particles, Fields, and Quantum Electrodynamics. O. M. Boykin. 655 pp. CRC Press, Taylor and Francis Group, Boca Raton, FL, 2011. Price: $99.95 (hardcover) ISBN 978-1-4398-0414-8.

Advanced Particle Physics Volume II: The Standard Model and Beyond. O. M. Boykin. 564 pp. CRC Press, Taylor and Francis Group, Boca Raton, FL, 2011. Price: $99.95 (hardcover) ISBN 978-1-4398-0416-2.

Atomic Astrophysics and Spectroscopy. Anil K. Pradhan and Sultana N. Nahar. 371 pp. Cambridge U. P., New York, 2011. Price: $75.00 (hardcover) ISBN 978-0-521-82536-8.

Complex Webs: Anticipating the Improbable. Bruce J. West and Paolo Grigolini. 385 pp. Cambridge U. P., New York, 2011. Price: $75.00 (hardcover) ISBN 978-0-521-11366-3.

Developing a Talent for Science. Ritsert C. Jansen. 181 pp. Cambridge U. P., New York, 2011. Price: $27.99 (paper) ISBN 978-0-521-14961-7.

Fundamentals of Attosecond Optics. Zenghu Chang. 546 pp. CRC Press, Taylor and Francis Group, Boca Raton, FL, 2011. Price: $89.95 (hardcover) ISBN 978-1-4200-8937-0.

Mathematical Methods for Optical Physics and Engineering. Gregory J. Gbur. 817 pp. Cambridge U. P., New York, 2011. Price: $90.00 (hardcover) ISBN 978-0-521-51610-5.

The Pinch Technique and its Applications to Non-Abelian Gauge Theories. John M. Cornwall, Joannis Papavassiliou, and Danielle Binosi. 303 pp. Cambridge U. P., New York, 2011. Price: $115.00 (hardcover) ISBN 978-0-521-43752-3.

Principles of Plasma Physics for Scientists and Engineers. Umran S. Inan and Marek Golkowski. 284 pp. Cambridge U. P., New York, 2011. Price: $99.00 (hardcover) ISBN 978-0-521-19372-6.

Quantum Man: Richard Feynman's Life in Science. Lawrence M. Krauss. 367 pp. W. W. Norton & Co., New York, 2011. Price: $24.95 (hardcover) ISBN 978-0-393-06471-1.

The Shaping of Life: The Generation of Biological Pattern. Lionel G. Harrison. 271 pp. Cambridge U. P., New York, 2011. Price: $99.00 (hardcover) ISBN 978-0-521-55350-6.

Strange New Worlds: The Search for Alien Planets and Life Beyond our Solar System. Ray Jayawardhana. 255 pp. Princeton U. P., NJ, 2011. Price: $24.95 (hardcover) ISBN 978-0-691-14254-8.

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Though astrophysicists have developed a theoretical framework for understanding how the first stars and galaxies formed, only now is it possible to begin testing those theories with actual observations of the very distant, early universe. This book covers all the basic concepts in cosmology, drawing on insights from an astronomer who has pioneered much of this research over the past two decades.Â Me neither. Harvard University astrophysicist and cosmologist Abraham Loeb can, and he does in this latest installment of the Princeton Frontiers in Physics series. While the book targets potential cosmologists and scientists, general readers will enjoy the non-technical chapters. The first stars were 30â€“300 times the mass of our sun and burned faster due to the abundance of hydrogen around them, and therefore died much youngerâ€”perhaps after only a few million years. As far as I know, nobody is sure yet whether the stars formed first and then gathered into galaxies or the galactic clouds formed first, wherein the first stars were born. Or even if the outlines of the galactic clusters formed first. Top-down or bottom up? Probably a bit of both. It depends on the exact properties of dark matter and the Big Bang, both of which are incompletely understood. In any case, the galaxies