Complexity: A Guided Tour

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Complexity: A Guided Tour

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books

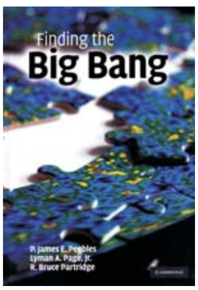
The cosmic microwave background in living color

Finding the Big Bang

P. James E. Peebles, Lyman A. Page Jr, and R. Bruce Partridge
Cambridge U. Press, New York, 2009. $80.00 (571 pp.). ISBN 978-0-521-51982-3

Reviewed by John C. Mather

A thrilling page-turner, *Finding the Big Bang* is the adventure story of one of modern science's great discoveries, the cosmic microwave background radiation from the early universe. The book is edited by three insiders: James Peebles, Lyman Page Jr, and Bruce Partridge. Peebles, the lead editor, has been at the center of the story for 45 years and is the author of some of the standard textbooks in cosmology, including *Principles of Physical Cosmology* (Princeton University Press, 1993). Lyman Page Jr is a major participant in NASA's mission to measure the CMBR with the *Wilkinson Microwave Anisotropy Probe*. Bruce Partridge has also participated in efforts to measure the CMBR and wrote *3K: The Cosmic Microwave Background Radiation* (Cambridge University Press, 1995). Peebles, Page, and Partridge were there, and they tell a good story.



The book starts with a coherent historical introduction that parses the matrix of original papers and reveals the key steps for predicting and measuring the CMBR. Following is the heart of the book—44 essays of more than 300 pages recalling CMBR work in the 1960s. The volume concludes with a look at CMBR physics from the 1970s to the present day. The introductory material could be used to teach basic cosmology to undergraduates. In addition to Peebles's *Principles of Physical Cosmology* I also like Steven Weinberg's *The First Three Minutes* (Basic Books, 1993), still a brilliant popular summary, and his self-contained *Cosmology* (Oxford University Press, 2008), which was reviewed in PHYSICS TODAY (June 2009, page 50).

The essays, which have a wonderful variety of biographical detail, reveal in living color the personalities, motivations, feelings, and scientific steps and missteps along the way.

One chapter by Paul Henry begins, "The last thing I remember from that day is Dusty Rhoads and Gene DeFreece depositing me at my motel room. . . . And at that point I passed out." How can one not keep on reading? And the chapter by Rainer Weiss includes, "Much as the free-fall was a rude introduction to the hazards of ballooning, it was also a gift to keep us from confirming an erroneous result."

Real revelations to me were the essays by Andrei Doroshkevich, Malcolm Longair, Igor Novikov, Yuri Smirnov, and Rashid Sunyaev. They all cite Yakov Zel'dovich as an incredible force whose constant personal attention and brilliant insights pushed his colleagues to greatness during those tough times in the Soviet Union of the 1960s. The final chapter summarizes progress since the 1960s. It is a deep and densely packed story of intense efforts to reach the now-standard ΛCDM (cold dark matter model with a cosmological constant) with well-measured parameters. The section could be used to introduce graduate students to modern cosmology.

Why didn't anybody measure the CMBR sooner? It looks easy now—Timo Stein, a bright German high-school student, has done it (*Sterne und Weltraum*, 13 June 2008). Joseph Weber told me that he wanted to do it in the late 1940s, but people told him it was impossible. Arno Penzias, in this book, explains what kept observers from trying to detect the CMBR before he and Robert Wilson discovered it in 1964. The work would have been difficult, and the time to payoff would have been long. Moreover, there were plenty of obviously important and much easier experiments for a scientist to do. Says Penzias, "First of all, there were no idle radio astronomers. The first few radio observatories were just being set up, and almost anything they did would break new ground—at least as long as the rudimentary equipment they used worked well enough to produce useful data." So, people didn't try to measure the CMBR in 1948, when George Gamow and Ralph Alpher predicted its existence and began their vain efforts to get others to detect it. It was tough to do even in the 1960s. In fact, some scientists, for various reasons, did not realize it was time to make a measurement. But at least some people were like me and followed Peebles's advice, quoted by Yu Jer-tsang: "Stop reading, start thinking."

Finding the Big Bang will be of interest to anyone who wants to know how scientific discoveries are really made. For me, reading the essays was like studying my family tree, and it was endlessly fascinating. For all of us, the answers to key questions in this area of cosmology—for example, How did we get here? Where are we going?—can now be discovered in this fine book.

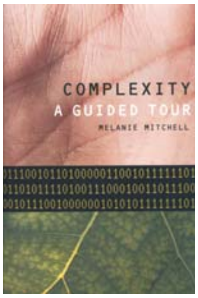
John Mather is senior project scientist for the *James Webb Space Telescope* at NASA's Goddard Space Flight Center in Greenbelt, Maryland. He and George Smoot shared the 2006 Nobel Prize in Physics for their measurements of the cosmic microwave background radiation. Mather is coauthor with John Boslough of *The Very First Light: The True Inside Story of the Scientific Journey Back to the Dawn of the Universe* (Basic Books, 2008).

Complexity

A Guided Tour

Melanie Mitchell
Oxford U. Press, New York, 2009. $29.95 (349 pp.). ISBN 978-0-19-512441-5

The notion of complexity is one of the most controversial and debated issues of scientific inquiry, and the chances are slim that the debate will be resolved anytime soon. Essentially, complexity is a collective noun for those uneasy feelings people have when faced with a system whose components and interactions are known but whose behavior adds up to more than the sum of its parts. But just what is it that makes us uncomfortable? Is it solely the system, or is it also our physical inability to make sense of the spectrum of behaviors produced by an interacting multicomponent system? Even the human brain, with its vast number of representational degrees of freedom, is limited by biophysical constraints.



Writing a book on complexity is a brave undertaking—anyone who chooses to do so becomes a target for criticism from both experts and journalists who feed on controversies. In *Complexity: A Guided Tour*, accomplished computer scientist Melanie Mitchell courageously takes the reader on an entertaining and illuminating journey through the jagged world of complex-systems research. Mitchell's writing on each topic she addresses is lucid and factual, based on research by her and others in the field and reported on in peer-reviewed journals. When discussing a controversial idea, she gives a balanced presentation of the views of both its proponents and opponents.

Mitchell suggests—in my opinion, rightfully so—that researchers should focus on "common principles" and pull back from talking about things that must hold "generally" in complex systems. Her philosophy echoes Nigel Goldenfeld and Leo Kadanoff's conclusion, expressed 10 years ago at the end of their article "Simple Lessons from Complexity": "But each complex system is different; apparently there are no general laws for complexity. Instead, one must reach for 'lessons' that might, with insight and understanding, be learned in one system and applied to another" (*Science*, volume 284, page 89, 1999). Complex behavior could then be interpreted as emerging from a network interaction of those principles, as implicitly suggested in the book's penultimate section and explicitly discussed in its concluding chapter.

Complexity: A Guided Tour occasionally reads as a list of seemingly unrelated topics, including universal computation, emergence, chaos, self-representation, species and genetic-level evolution, and complex networks. However, in some cases, Mitchell carefully chooses examples to illustrate the connection between complex behaviors in different systems; for instance, her computer model for making analogies (which only humans do well) is based on genetic algorithms and has much in common with models of how ants forage for food. She then considers a number of common principles that could be used as building blocks for a complexity science. That approach will inspire the reader to search for additional commonalities and principles.

Naturally, given the author's background, the book provides a computer-science-like view of complex systems and emphasizes information processing (that is, computing) in various systems. That, I would argue, is the main strength of the book. As Mitchell asserts throughout the text, our brains are themselves complex systems, where we store, access, represent (or simulate), and generate information. And in part, learning and understanding occur through pattern matching between internal neuronal activity and external input. So it may not be surprising that representation and information theory will have a large role in foundations of complexity science, as suggested by Mitchell's focus on the works of mathematicians and computer scientists such as Alan Turing, John von Neumann, Claude Shannon, and Norbert Wiener.

Although the emphasis on information and computation is, in my opinion, one strength of the book, I feel that the author could have explored its basic aspects in greater detail. In particular, two key issues deserve further discussion: the hierarchical (or terraced) encoding of information that occurs, for example, in the primate cerebral cortex, as shown by neuroscientists David Van Essen and Daniel Felleman; and the separation of scales in complex systems. Regarding the latter, I again quote Goldenfeld and Kadanoff: "Don't model bulldozers with quarks" (page 88). In general, there's no need to, because many complex systems exhibit a separation of scales—length, time, energy—that allows one to replace complex dynamics at a certain scale with effective models that statistically mimic the system's behavior at that scale. Those models are then hierarchically put together (the brain processes information that way) to produce a multiscale description of the system. A section on how such models are generated could have included current research by practitioners and further strengthened an already solid book.

Complexity: A Guided Tour is well written and engaging, laced with candid humor and occasional blunt remarks about some of the major characters in the field. It is a fine introduction to complexity science and could serve as a first-rate text for an advanced course for undergraduates and an excellent guide for courses at the graduate level. Experts and nonspecialists alike will have a hard time putting it down.

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Cracking the Einstein Code

Relativity and the Birth of Black Hole Physics

Fulvio Melia
U. Chicago Press, Chicago, 2009. $25.00 (137 pp.).
ISBN 978-0-226-51951-7

Black holes have resonated strongly with the general public since the term was coined in the 1960s. In part, that fascination is because the defining characteristic of a black hole—it is so compact that nothing, not even light, can escape from its surface—is a powerful catalyst for the imagination (particularly of science fiction authors and Hollywood screenwriters). Not surprisingly, some think of black holes as super vacuum cleaners in the sky that suck in everything around them. That common misconception is at the root of the widely publicized but completely unfounded concern that the Large Hadron Collider would create miniature black holes that would destroy Earth in a fraction of a second.

Interest in black holes has proved a great opportunity for physicists to educate the general public about the nature of gravity and, in particular, Einstein's theory of relativity. A recent addition to a long line of books that attempts to do just that is Fulvio Melia's *Cracking the Einstein Code: Relativity and the Birth of Black Hole Physics*. What makes Melia's book unique is that it focuses on the events and characters in the mid- to late 1960s when many of the fundamental properties of astrophysical black holes were elucidated. The hero of Melia's tale is New Zealander Roy Kerr, then a young postdoc at the University of Texas at Austin's new center for relativity. There, he single-handedly solved Einstein's field equations for the general case of a spinning collapsed object, thus cracking a problem that had stumped relativists for more than four