

struggled to maintain their individuality in the face of the demands of their field. What Pais's accounts make clear is that individual creativity requires continued interactions with colleagues (whether by extensive correspondence as in the case of Pauli and Heisenberg, or by intensive association with the brightest young people in the field, as in the case of Bohr), and that cutting one's self off from the mainstream of inquiries and inquirers is at one's peril. This was so for Einstein, when he embarked on his quest for a unified theory, and for Dirac, when he became dissatisfied with the conventional quantum electrodynamics. The book is thus also a portrait of a community—the elite community of the world's best theorists.

The Genius of Physics is a fascinating book, a tribute to the field, to its outstanding practitioners, and to its author. Pais captured better than any one else the vitality and the accomplishments of elementary-particle and high-energy physics, and he was able to convey better than anyone else what it meant to be part of that exhilarating enterprise during the 20th century. His wide erudition, his perspicacious insights, and the clarity of his exposition will be missed.

Rare Earth: Why Complex Life Is Uncommon in the Universe

▶ Peter D. Ward and Donald Brownlee
Copernicus (Springer-Verlag), New York, 2000. 336 pp. \$27.50 hc ISBN 0-387-98701-0

The origin of animal life on earth was a remarkable evolutionary achievement, the apparent result of an endless array of environmental accidents. The key question, however, is whether this array represents a unique path, or even a rare one. Put another way, How many lucky accidents must occur before complex life can form?

Peter D. Ward, a geologist, and Douglas Brownlee, an astronomer, both at the University of Washington, have attempted to address this question in *Rare Earth*. In the process, they have written a thought-provoking and authoritative introduction to the issues and accidents that have affected the evolution of life on Earth and on other worlds. I believe they fall short, however, of their ultimate goal:

to demonstrate that complex life is extremely rare in the Universe.

Carl Sagan argued almost 30 years ago that there may be many millions of intelligent species in the galaxy, and this claim provides a straw man for Ward and Brownlee's argument. But it has been some time since Sagan's early, wildly optimistic estimates have been adopted by most scientists, even those still actively pursuing extraterrestrial life. Nevertheless, this book may force a very useful and sober popular reconsideration of the all-too-prevalent notion that intelligent aliens are all around us.

Ward and Brownlee summarize clearly the developments over the past few decades that reveal the complexity of the evolution of advanced life forms on earth. However, demonstrating the complexity of a process is different from demonstrating that the end result is rare. If anything, Ward and Brownlee show clearly how much remains to be learned in the area that NASA has named astrobiology—a combination of geology, paleontology, astronomy, and biology that pertains to understanding the evolution of life and its signatures.

I was particularly interested in seeing this book after I heard about it, having just written a book that required me to explore several issues associated with the evolution and demise of terrestrial and extraterrestrial life forms. What I had found striking about the progress of life from single-celled prokaryotes (cells without nuclei) to multicelled, complex animals, is the important role of environmental catastrophes in the process. It is not at all clear that such catastrophes inhibit progress. Indeed, I expect that catastrophes may have been necessary, a notion that Ward and Brownlee also address. If catastrophes are indeed necessary, it is difficult to argue that such events might not similarly have driven evolution on other planets.

Overall, I enjoyed the book. It provides a great collection of diverse information brought together in one place and is very up-to-date. It includes such new ideas as "snowball earth"—the idea that the entire surface of the earth froze over and thawed several times during the past several billion years.

Nevertheless, I think the weakest aspect of the book is its description and defense of the rare-Earth hypothesis itself. The authors have not made completely clear, for example, precisely what the rare-Earth hypothesis is, beyond some qualitative notion that complex animal life is rare and vul-

nerable. If "rare" means far rarer than in Sagan's view, it is not particularly surprising. Or does "rare" really mean we are unique? What tests can establish or refute rareness? Several other poorly defined concepts, such as "Astrobiology Revolution" and "Principle of Mediocrity," are also introduced and capitalized, as if to imply some special scientific significance—which remained unclear to me.

In the end, the question of assigning a probability to the appearance of complex life with a sample of one (Earth) is fraught with difficulties. Frank Drake's famous equation (relating the occurrence of intelligent civilizations to a product of independent probabilities, such as the probability of finding a stable Sun-like star, times the probability of having a planet in a zone around it that could accommodate liquid water, and so on) was undeniably useful in opening the debate. Ward and Brownlee's book provides important new fodder. Nonetheless, the statistics of rare events are notoriously difficult to analyze.

It is undeniable that the specific route that led to modern terrestrial life-forms is remarkably complex and probably has a small absolute probability. But the same can be said for the series of events that led me to my computer this evening. We are probably not yet well equipped, in our knowledge of the relevant variables, to perform a proper maximum-likelihood analysis of the occurrence of life in the universe.

The book could have benefited from tighter editing. Certain ideas are repeated almost verbatim in different chapters, and various biological notions are discussed several times before they are finally defined. There are numerous graphs that physicists will appreciate but that are not likely to clarify the discussions for lay readers. Finally, a few embarrassing typos survived, most notably the statement in the penultimate chapter that the stars in our galaxy number in the hundreds of millions, rather than hundreds of billions.

These quibbles aside, Ward and Brownlee carry the reader through an otherwise well laid-out and comprehensive progression that rises through the specific rungs on the evolutionary ladder and discusses the environmental cofactors that governed this progression. I also like their exploration of the current controversy associated with various key ideas in these fields.

The next generation of research is likely to bring us far closer to quantitative analysis of the probability that

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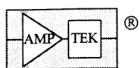


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complex life exists elsewhere in the Universe. Even if they have not yet convincingly resolved the issue for the reader, Ward and Brownlee have done an admirable job of demonstrating how forefront research in the fields of biology, paleontology, geology, and astronomy is leading us closer to knowing whether we truly are alone in the Universe.

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Carl Sagan: A Life in the Cosmos

William Poundstone
Henry Holt, New York, 1999.
473 pp. \$30.00 hc
ISBN 0-8050-5766-8

Carl Sagan: A Life

Keay Davidson
Wiley, New York, 1999. 540 pp.
\$30.00 hc ISBN 0-471-25286-7

Among celebrity scientists of the late 20th century, Carl Sagan was probably the best known and certainly was among the more controversial. He was the most visibly opinionated, not only about scientific issues but about pressing political issues that included the survival of the human race and the preservation of nature. He enjoyed a platform so vast that it transcended science itself.

His private life was also unusually visible; urban legends abound. Thankfully, neither of the biographers reviewed here tries to repeat every rumor, dig up every corpse, expose every alleged liaison, follow every pointed finger. What they both do is paint a vivid portrait of the toll that becoming and being Carl Sagan took of the man and of those who were directly involved with him.

From the perspective of science writer William Poundstone's *Carl Sagan: A Life in the Cosmos*, Carl Sagan set out consciously to become Carl Sagan and succeeded in spectacular fashion. From the point of view of Keay Davidson's *Carl Sagan: A Life*, Sagan was a complex and tortured man who filled his life with paradoxes that astounded, enraged, and fascinated contemporaries and mentors alike. Davidson is also a science writer and journalist, but is more sensitive than Poundstone to recent scholarship in science studies and the history of science.

From both authors we get the details of life and the impact on the

young Sagan of a passive father and of a mother who must have been a terror in even the most competitive warrens of Jewish Brooklyn. Both biographers make it quite clear that Sagan's mother was a contentious force who focused her life energies on her son. Both also make much of the mentors Sagan sought out as a student at the University of Chicago and elsewhere—including the geneticist H. J. Muller and the chemist Harold Urey—and how he parlayed these contacts into a career laced from the beginning with conflict and controversy. The authors make it possible to understand why Sagan was both attractive and repulsive to contemporary scientists, and they do a good job of rationalizing Sagan's ability to create and retain mass appeal. They both appreciate the fact that Sagan's pervasive public presence was made possible by new capabilities of visual mass communication, and that he used these more effectively than anyone in science did.

Poundstone is dead-on when he describes how touchy Sagan could be about image. Poundstone also is at his best when describing Sagan's writing method and the demands upon those who seek popular acclaim. He is on somewhat softer ground in technical areas. He neglects very telling episodes, such as Sagan's failures with the Mariner and Stratoscope projects at a time when, as Davidson poignantly describes, Sagan had seriously overextended himself in his mad dash to grab every brass ring.

Poundstone's is a less intimate portrait than Davidson's, and seems more celebratory. Poundstone is also prone to errors, which Davidson avoids by relying upon recent historical scholarship. Poundstone appears awestruck by Sagan's accomplishments; Davidson provides many cogent and insightful critiques.

Davidson does a particularly nice job of exploring the microstructure of Sagan's fame, how he enthralled audiences by describing the planets "vividly, as if he had just returned from them." He sets out a coherent intellectual framework and then rationalizes Sagan's world view centered on the search for life in the universe. One of his more interesting speculative insights comes when he attempts to psychoanalyze Sagan's efforts to design the Pioneer plaque. The only distraction I found in Davidson's otherwise exemplary treatment is that he introduces and repeatedly reintroduces Sagan's wives by name and number.

Both authors identify the search