

for life in the universe as an emotional magnet for popular support and federal patronage. Most intriguing is the inference, made more by Poundstone than Davidson but clearly present in both, that patronage issues created a bias toward finding positive indicators of life, leading some (but not Sagan) to overemphasize positive indicators and downplay negative ones.

Historians and scientists alike should find Davidson's treatment more nuanced and complex, and therefore more satisfying. Lay readers may find Poundstone's shotgun approach more digestible. Nevertheless, both books are worthy and welcome additions, and provide a firm basis for future inquiry into the place (and price) of popularization and political activism in science.

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Quintessence: The Mystery of Missing Mass in the Universe

Lawrence Krauss

Basic Books (Perseus Books Group), New York, 2000. 350 pp.
\$26.00 hc ISBN 0-465-03740-2

The *New York Times* review of Lawrence Krauss's very successful 1995 book, *The Physics of Star Trek* (Basic; Harper Collins) began by calling it "classic bait-and-switch—and to the benefit of the reader." It was more a book about physics than about *Star Trek*.

In *Quintessence*, an updated version of his 1989 popular account of dark matter, *The Fifth Essence* (out of print), Krauss is back at his old tricks. *Quintessence* is actually a first-hand and very readable account of one of the most remarkable periods in the history of cosmology—the past twenty years, which exposed the deep connections between cosmology and particle physics. Krauss's book chronicles this time and conveys both the science and the excitement from the point of view of an important participant. (Krauss heads the physics department at Case Western Reserve University.)

The burst of theoretical activity in the 1980s (called by one particle theorist the go-go junk-bond days of early universe cosmology) was powered by powerful ideas in particle physics. Before the advent of the Standard Model of particle physics in the late 1970s, early-universe cosmology was

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V I B R A T I O N S O L U T I O N S

unthinkable. At 10^{-5} sec, hadrons in the universe should have overlapped and the exponentially rising number of particle states (with mass) should have led to a limiting thermodynamic temperature. The Standard Model of particle physics opened the door: The early universe was a dilute gas of weakly interacting quarks, leptons, and other particles. Speculations about physics beyond the Standard Model (grand unification, supersymmetry, and superstrings) introduced intriguing new cosmological possibilities.

While *Quintessence* surveys the standard cosmology and many of the bold theoretical ideas that came from the 1980s, the centerpiece of the book is "The New Improved Standard Model" as Krauss aptly calls it: The hot Big-Bang model supplemented by inflation and cold dark matter, the most compelling ideas to emerge from connecting quarks to the cosmos. (Alan Guth's inflation theory holds that the universe went through a very early spurt of tremendous growth, whose consequences resolve almost all of the fundamental questions left unanswered by the standard cosmology.) The cold dark matter part of this paradigm asserts that the long-sought dark matter that holds the universe together consists of slowly moving (cold) elementary particles left over from the earliest, fiery moments.

By the early 1990s, the inflation-plus-cold-dark-matter paradigm had established itself as the most important set of ideas in cosmology since the Big Bang. If correct, it would extend the standard cosmological model back to a time when the largest structures were quantum fluctuations and the heat of the Big Bang existed in the form of false-vacuum energy. The philosophical implications of this paradigm rival those of Copernican theory: If correct, we are not made of the primary stuff of the cosmos, and what we call the Big Bang was in fact just a rapid burst of exponential expansion driven by false-vacuum energy. And it was not a singular event—there should have been an infinite number of such little big-bang events, creating an infinity of causally disconnected bubbles. According to inflation, the universe is actually a multiverse.

Because of inflation's attractiveness and boldness, observers and experimenters were eager to disprove it, producing the tension between theorists and experimenters that characterizes all healthy fields of science. That's where Krauss left off when *Fifth Essence* was published.

The soft spot that observers were aiming for was the hallmark prediction of inflation—a spatially flat universe whose total density of matter and energy summed to the critical density. The tremendous expansion during inflation makes the universe appear flat; Einstein's theory says a flat universe must have the critical density. While there was growing evidence that the bulk of the matter that holds the universe together is not made of baryons—consistent with the idea of cold dark matter—most measurements of the amount of dark matter fell far short of the critical density. Evidence for particle dark matter was compelling enough that large experimental efforts were launched to detect the most promising particle suspects: the axion and the neutralino.

Cold dark matter received a major boost in 1992. The Cosmic Background Explorer (COBE) detected small variations in the temperature of the cosmic microwave background that gave evidence for the primeval lumpiness that seeded all structure. The amplitude of the matter inhomogeneity (about 1 part in 10^5) is just what is needed to account for all the structure that exists today, provided the dark matter is nonbaryonic. In 1998 the Superkamionade neutrino observatory experiment showed at least one neutrino species to have sufficient mass to enable relic neutrinos to contribute as much to the mass budget of the universe as stars do. Particle dark matter is no longer a conjecture, although the bulk of it still remains to be identified.

While cold dark matter was looking good, flatness was not: matter could only account for about $1/3$ of the required critical density. A surprising (to some) turn of events came in 1998 with the discovery that the universe is accelerating, not slowing, and does indeed have the critical density predicted by inflation. The missing $2/3$ of the critical density is in the form of "the dark energy" that is causing the acceleration. That startling finding brings us to the present day and Krauss's revised book. While the simplest explanation for the accelerated expansion is a tiny, but nonzero, value of the cosmological constant (the zero-point energy of the vacuum), an idea Krauss and I and several others suggested independently more than a decade ago, there is a slight problem. The contributions of the known particles to the zero-point energy exceed the critical density by at least 55 orders of magnitude!

This suggests that some deep prin-

ciple might zero out the cosmological constant. If this is so, then something else must be causing the universe to accelerate. It must be dark, it must be smooth, and it must have large, negative pressure. Some have called it "Quintessence," the name also used by Krauss to refer to particle dark matter (the fifth essence); I prefer dark energy in analogy to Fritz Zwicky's naming of dark matter 70 years ago. The existence of dark energy received independent confirmation with the results of the Boomerang cosmic microwave background experiment, reported in April, which showed the universe to be flat. Krauss tries to take advantage of this double use, which is the only confusing part of the book.

In the epilogue, Krauss says that even more remarkable than the theoretical ideas that we have about the birth of the universe is the fact that we will be able to test them, and soon. With the explosion of precision cosmological measurements and observations, I fully agree. I would add: Equally remarkable is how prophetic his book was; after more than a decade, only a new preface and one new chapter were needed to bring it up to date.

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Introduction to Semiconductor Physics

▶ Holger T. Grahn
World Scientific, River Edge, N.J.,
1999. 183 pp. \$28.00 hc
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The first part of Holger Grahn's *Introduction to Semiconductor Physics* is based on a course of that name Grahn gave in the department of Physical Electronics at Tokyo Institute of Technology during the 1995–1996 academic year. The second part, in particular the extensive discussion of optical properties, including the effects of external fields, is based on his lecture, entitled Optical Properties of Semiconductors, given within the Institute of Solid State Physics at the Technical University of Berlin in 1997. There have been similar publications treating optical properties of semiconductors; perhaps one of the most popular, as defined by its presence on many office bookshelves, is Jacques Pankove's *Optical Processes in Semiconductors* (Dover, 1976.)

Introduction to Semiconductor Physics has fourteen chapters cover-