

Can Two Luminaries Share One Standard Candle to Reveal Cosmic History?

The Extravagant Universe: Exploding Stars, Dark Energy, and the Accelerating Cosmos

Robert P. Kirshner
*Princeton U. Press, Princeton,
 N.J., 2002. \$29.95 (282 pp.).
 ISBN 0-691-05862-8*

Reviewed by David Branch

PHYSICS TODAY readers are likely aware of the startling discovery in the late 1990s that the expansion of the universe appears to be accelerating. The direct evidence is the observed relation between the brightnesses and redshifts of very distant (high-redshift or high- z) type Ia supernovae. The observed brightness of a "standard candle" such as a type Ia supernova tells its distance and therefore the time elapsed since it exploded. Furthermore, the supernova's redshift gives the factor by which the universe has expanded during that elapsed time. Thus is revealed the history of the cosmic expansion.

Normal type Ia supernovae are our best standard candles for determining distances on cosmological scales because they are luminous enough to be seen from afar and alike enough so their observed brightnesses can be used to infer distance. Such supernovae are nearly alike because, we think, they are produced by carbon-oxygen white dwarfs in nearly identical ways. The white dwarfs are thought to accrete matter from close binary companions until they approach the same limiting mass—the Chandrasekhar mass—at which point they undergo thermonuclear disruption.

The cause of the cosmic acceleration indicated by observations of type Ia supernovae may prove to be Albert

Einstein's cosmological constant—nowadays equated with the energy density of the vacuum—or it may be some other kind of "dark energy." The nature of dark energy is the deepest mystery in contemporary cosmology and astroparticle physics.

Two international teams found the cosmic acceleration. The Supernova Cosmology Project (SCP), headquartered at Lawrence Berkeley National Laboratory and led by Saul Perlmutter, began to search for distant standard candles in the late 1980s to determine the cosmic expansion rate at ever earlier times. They found their first high- z type Ia supernova in 1992. The High- Z Supernova Search (HZSS) team, organized in late 1994, is led by Brian Schmidt of the Australian National University and includes astronomers at such other institutions as Harvard University; the University of California, Berkeley; and the Cerro Tololo Inter-American Observatory.

The Extravagant Universe recounts the discovery of cosmic acceleration from the viewpoint of Harvard professor Robert Kirshner, a senior member of the HZSS. Kirshner's avowed aim is to help the reader share in the adventure. In the process of conveying his personal adventure, Kirshner endows *The Extravagant Universe* with a strong autobiographical component: He relates many ups and downs of his professional odyssey, from winning an essay prize as a Harvard undergraduate to suffering aching gums as a middle-aged astronomical observer on a Chilean mountaintop.

The first eight chapters provide an introduction to cosmology at the level of Astronomy 101, with some emphasis on the history of the subject. That tale is often told, but seldom so engagingly. The analogies are apt, the anecdotes are amusing, and the writing is brisk and witty—in places, downright funny. Kirshner's story of his encounters with Caltech astronomer Fritz Zwicky beginning in 1970, entirely reminiscent of my own experiences with that singular character, had me laughing out loud.

The final three chapters get to the search for high- z type Ia supernovae

and the discovery of the acceleration. The writing continues to sparkle and Kirshner succeeds in conveying the difficulty and excitement of the hunt for remote supernovae—made all the more stimulating for him, one senses, by his rocky relationships with senior members of the competing team. But caution: You are entering a spin zone. When it comes to acknowledging the SCP for its pioneering development of observation techniques and analysis approaches that were to be used by both teams, Kirshner turns out to be a stinker. The SCP personnel are treated with an air of condescension and inappropriately portrayed as a bit scientifically naive. Even credit for developing the breakthrough observational strategy that enabled both teams to guarantee the discovery of high- z type Ia supernovae in batches at predetermined times, so that photometric and spectroscopic follow-up with large telescopes could be scheduled in advance, is directed elsewhere rather than to the SCP, to whom it belongs.

The Extravagant Universe should be popular with science aficionados in the general public, and some PHYSICS TODAY readers will want to read it too. Enjoy it with a dram of salt. There is no other firsthand book-length account of the discovery of the cosmic acceleration, but if you have not already done so, be sure also to read Perlmutter's article in PHYSICS TODAY (April 2003, page 53).

Atmospheric Pollution: History, Science, and Regulation

Mark Z. Jacobson
*Cambridge U. Press, New York,
 2002. \$110.00, \$50.00 paper
 (399 pp.). ISBN 0-521-81171-6,
 ISBN 0-521-01044-6 paper*

Scientific and political interest in atmospheric pollution, as well as attempts to regulate it, have expanded from local to regional to global scales over the three decades since the passage of the US Clean Air Act of 1970. Acid deposition, ozone depletion, regional-scale smog, and global warming—

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unknown or little understood before 1970—are at the center of atmospheric research, domestic regulation, and international affairs. With regard to international affairs, witness the broad effect on US–European relations of the Bush administration’s rejection of the Kyoto Protocol on climate change.

Atmospheric pollution emerges from almost every form of human activity, so it is clear that attempts to limit pollution must be comprehensive. Efforts to extract an understanding of the causes and consequences of pollution, particularly global warming, reach backward into the earliest epochs of Earth’s history and project forward a century or more.

Mark Jacobson’s new undergraduate textbook *Atmospheric Pollution: History, Science, and Regulation* captures important parts of the vast panorama of science and human experience related to the atmosphere. Jacobson is an associate professor of civil and environmental engineering at Stanford University. His recent work on the role of soot in global warming is groundbreaking. His book covers a field so large that no previous text has satisfactorily reflected the full array of problems and issues, particularly as an introduction for science majors. Jacobson’s book also falls short of that objective, but may be the best available.

Starting with a basic introduction to Earth’s geologic history, atmospheric structure, composition, and chemistry, Jacobson discusses the origins of smog, its effects, and global efforts to regulate it. Some details of smog chemistry are discussed at too great a length, but the narrative is clear, the figures have strong pedagogic value, and the photographs are thoroughly engaging. Too little is said about regional smog and its long-range transport, a problem that now assumes transcontinental scale, and too much is said about aerosol-related air pollution. The latter is understandable because aerosols are at the center of Jacobson’s recent research.

The text is highlighted with interesting stories that dig deeper than most anecdotes. For example, similar books often note that Thomas Midgley Jr invented both tetraethyl lead and chlorofluorocarbons. The use of tetraethyl lead as a gasoline additive was responsible for widespread lead poisoning in children and chlorofluorocarbons cause ozone depletion. Some books note the irony that this prolific inventor, who suffered from polio later in life, died by entanglement in a hoist he had designed to lift

his body upright in bed. But few, if any, have delved into the interesting, relevant, and unfortunate details of the decision, by Midgley and others, to pursue tetraethyl lead over other, possibly safer, alternatives. Such historical notes richly complement the scientific details.

After a discussion of meteorology that is advanced enough that it may confuse some beginners, Jacobson moves on to comprehensive chapters on indoor air pollution, acid deposition, ozone depletion, and acid rain. The strongest of these chapters treats ozone depletion. The weakest, on global warming, contains only a skimpy discussion about the impacts of temperature increase and other climate changes. More problematically, the scientific details in that chapter are sometimes outdated.

Overall, the book carefully builds a framework for understanding atmospheric issues, and that framework provides a solid basis for examining what might be done to address those issues. The problems at the end of each chapter are simple, yet instructive. The text doesn’t condescend with oversimplification and is only occasionally too difficult for a beginning science major.

My one disappointment is that regulation too often receives cursory treatment. The subtitle of the book suggests a balance in the content that is not really achieved. In particular, only one sentence addresses the landmark emissions trading provision of the 1990 Clean Air Act amendments. Furthermore, little in the sections on ozone depletion and global warming reflects the potential impacts of proposed or implemented policies. *Atmospheric Pollution* is not a resource for understanding air-pollution policy, but it is a well-rounded introduction to problems of the atmosphere and offers rich material for students contemplating their solutions.

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An Introduction to Seismology, Earthquakes, and Earth Structure

Seth Stein and
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Blackwell, Malden, Mass., 2003.
\$34.95 paper (498 pp.).
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Seismology is the study of earthquakes and Earth structure using the

waves that accompany quakes and other Earth vibrations. Analysis of those seismic waves is the basis of most current knowledge about our planet’s interior. Seth Stein and Michael Wyession, two highly regarded seismologists, have written a massive book that is a welcome addition to the handful of seismology texts appropriate for graduate or advanced undergraduate study. But with its enormous quantity of material, often presented in detailed figures, and its emphasis on deep-Earth examples, *An Introduction to Seismology, Earthquakes, and Earth Structure* is a valuable reference for specialists as well.

The text covers the meat and potatoes of seismology—seismic-wave propagation, Earth structure, and earthquake sources. Much more is presented, though, including plate tectonics, signal processing, seismometry, and inverse theory. An extensive appendix outlines matrix algebra, vector calculus, and even principles of computer programming. Each chapter ends with a brief discussion of classic and current references, followed by homework problems. Some of those problems are designed to be solved with computers. Answers to odd-numbered problems are in the back of the book, and solutions to all of them are available to instructors over the Internet.

Stein and Wyession begin their book with an introduction on the societal implications of earthquakes, which, worldwide, cause significant economic disruption and an average of more than 10 000 deaths per year. The authors then present the basic seismological theory, beginning with a rather long section that discusses waves on a string. That treatment is followed by a more traditional development of waves in elastic solids, moving from stress and strain to wave equations. The book fully treats reflection and transmission of waves, including conversions between compressional and shear waves.

Theory, starting with reflection and refraction techniques, is then applied to determine Earth structure. Stein and Wyession pay particular attention to waves that travel through, bounce off, or refract around Earth’s core. That’s perhaps not surprising, because Wyession’s research is in deep-Earth structure. The development of wave propagation is followed by a welcome section on the implications of seismological results—particularly Earth’s radial velocity structure—for the composition of the crust, mantle, and core.

Stein and Wyession thoroughly describe earthquake sources and include