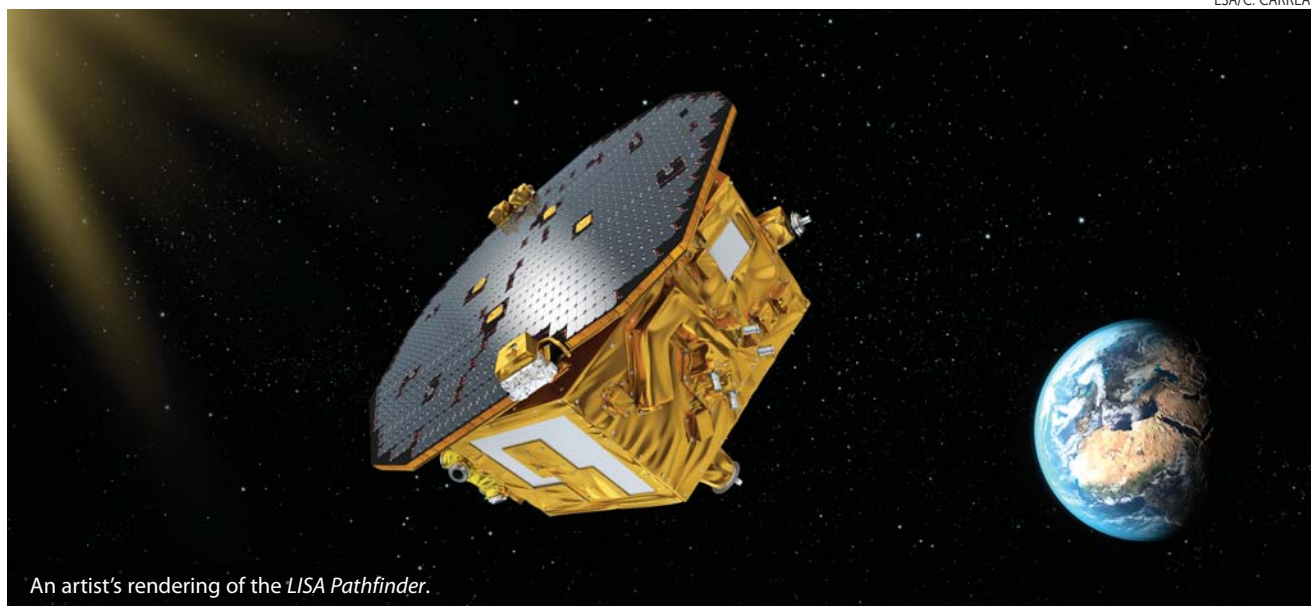




An artist's rendering of the *LISA Pathfinder*.

A bird's-eye overview of gravitational-wave astronomy

Gravitational-wave astronomy has undergone a revolution since 2008, when Michele Maggiore's *Gravitational Waves, Volume 1: Theory and Experiments* was published. In 2015 the Laser Interferometer Gravitational-Wave Observatory (LIGO) detected gravitational waves from a black hole binary merger, and *LISA Pathfinder* was launched, paving the way for future gravitational-wave observations in space. Since then the LIGO/Virgo collaboration has detected a total of 10 black hole binary mergers and a neutron star merger, an event that marked the birth of multimessenger astronomy. An international network of pulsar timing arrays is expected to lead to more detections within the next few years. In short, gravitational-wave astronomy is in full bloom.

When Maggiore's first volume went to press, the publisher could claim that it was the "only existing book on gravitational waves." That is no longer true. Jolien Creighton and Warren Anderson's *Gravitational-Wave Physics and Astronomy: An Introduction to Theory, Experiment and Data Analysis*, published in 2011, contains an excellent introduction to interferometric detectors and gravitational-wave data analysis. In 2014 Eric Poisson

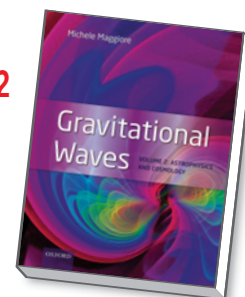
and Clifford Will published the superb *Gravity: Newtonian, Post-Newtonian, Relativistic*, which deals with the motion of self-gravitating bodies, the physics of gravitational waves, and experimental tests of general relativity. A revised edition of Peter Saulson's 1994 *Fundamentals of Interferometric Gravitational Wave Detectors* was released in 2017.

How does Maggiore's two-volume opus, now completed by *Gravitational Waves, Volume 2: Astrophysics and Cosmology*, compare with those more specialized references? Volume 1 was not reviewed in *PHYSICS TODAY*, but Poisson reviewed it for *Classical and Quantum Gravity*. Despite some minor criticisms, he called it a "truly remarkable achievement," an assessment with which I agree. Maggiore's first book covers the basics of gravitational-wave physics, including the theory of gravitational-wave generation and propagation and data-analysis techniques. A few chapters, such as the ones on resonant mass detectors and interferometric detectors, are now of mostly historical interest, as the technology has advanced significantly since 2008.

Volume 2, which builds on and draws from the material in volume 1, is a ped-

Gravitational Waves, Volume 2
Astrophysics and Cosmology

Michele Maggiore
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agogical introduction to astrophysical and cosmological sources of gravitational waves. The chapter numbering picks up where volume 1 left off. The opening chapter 10, on stellar collapse, contains topics that are not often covered in textbooks, such as gravitational waves from neutrino emission. However, its coverage of numerical relativity simulations is already slightly outdated. Chapter 11 focuses on neutron stars and reviews current observations and various mechanisms for gravitational-wave emission, including stellar oscillations, instabilities, and postmerger radiation. Chapter 12 is an excellent introduction to black hole perturbation theory. Maggiore covers the basics of linearized perturbations of nonrotating black holes. He also presents some advanced topics, such as gauge transformations, the radiation from infalling point particles, and a rigorous definition in terms of Laplace transforms of both black hole quasinormal modes and late-time power-law tails.

The book moves into more mathematical territory in chapter 13, which

discusses the $3+1$ formulation of Einstein's equations, conserved quantities in general relativity, and the Newman–Penrose formalism. Chapter 14 covers the modeling of binary mergers of compact objects, including the effective-one-body formalism developed by Alessandra Buonanno, Thibault Damour, and their collaborators; chapter 15 offers a summary of the LIGO/Virgo discoveries. Chapter 16 discusses massive black hole binaries, including estimates of the stochastic background that they produce and of their detectability by space-based detectors and pulsar timing arrays.

The final seven chapters focus on cosmology. After a compact and clear introduction to the basics of Friedmann–Robertson–Walker cosmology in chapter 17, Maggiore turns to the helicity decomposition of metric perturbations in flat and curved spacetime in chapter 18. Chapter 19 describes the evolution of cosmological scalar and tensor perturbations; it also introduces binary mergers as “standard sirens” to probe dark energy and modified gravity. Subsequent chapters describe the imprint of primordial gravitational waves on the cosmic

microwave background, inflationary cosmology, and stochastic backgrounds of cosmological origin. Finally, chapter 23 revisits Steven Detweiler's original calculation of the effect of gravitational waves on the timing of a single pulsar, describes the response of pulsar timing arrays to continuous and stochastic signals, and concludes with a description of modern data-analysis techniques and the status of current gravitational-wave searches.

Maggiore is a high-energy theorist and cosmologist by training, and his approach to his subject reflects that expertise. I admire his effort to cover all aspects of gravitational-wave research, although the result is, perhaps inevitably, uneven in depth and scope. Important omissions include comprehensive treatments of modified theories of gravity and the timing of binary pulsars. In my opinion—which, of course, reflects my own bias and expertise—the book shines in its treatment of cosmological gravitational waves. Some of the material on astrophysical sources, however, is more descriptive than didactic. Readers interested in perturbations of rotating black

holes, core collapse, compact binary formation, or astrophysical stochastic backgrounds are still best served by research articles and specialized reviews. I also have a minor quibble with the excessive use of margin notes, which can be distracting.

In summary, the book covers a staggering breadth of material and is extremely useful as a bird's-eye overview of the field. When I was a student, the bible for newcomers to gravitational-wave astronomy was Kip Thorne's outstanding 1987 review in Stephen Hawking and Werner Israel's *Three Hundred Years of Gravitation*, which has been steadily updated by Thorne's students and collaborators over the years. More recently I have referred students to a handful of newer review articles. Maggiore's book is more comprehensive and pedagogical than those articles, and from now on I will recommend it as the best entry point for students who want to join this blooming research field.

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