



Einstein rings, such as the one pictured here taken by the *Hubble Space Telescope*, are a result of the gravitational lensing of a light source.

A relativistic dialog

Physicists commonly have only cursory knowledge of general relativity (GR); for a long time, the subject simply wasn't needed for many careers in physics. That has been changing over the past two or so decades. Especially for those working in astrophysics or field theory, GR has become an essential piece of the foundation of what we do. There are now many good textbooks at a range of levels that introduce students to the field and take them as deeply into its details as they need or want to go.

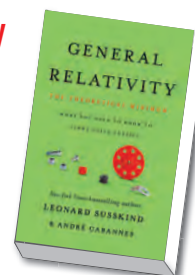
Leonard Susskind and André Cabannes's *General Relativity: The Theoretical Minimum* is an intriguing addition to the landscape of GR resources. As the subtitle indicates, the book is part of the Theoretical Minimum series written by Susskind and collaborators, which grew out of coursework Susskind teaches at Stanford University in the institution's Continuing Studies program for adult learners. In the preface, Cabannes describes himself as an example of the book's

audience: "individuals who studied physics . . . when they were students, then did other things in life, but kept an interest in sciences and would like to have some exposure to where physics stands today at a level above plain vulgarization." As someone who regularly teaches relativity, I dove into this text eager to see how a master presents it.

Most of *General Relativity* does not disappoint. The book is presented as a lecture by Susskind and is mostly written as though he were speaking, with occasional interjections and questions from Cabannes. Its discussion of general relativity's foundations is clear and deftly uses the principle of equivalence to describe the connection between gravity and geometry. It goes through the mathematics of curved spacetime in easy-to-follow language, laying out how to compute important quantities such as the motion of a body that freely falls in some spacetime. A student using this text should have no problems doing real GR calculations—in other words,

General Relativity The Theoretical Minimum

Leonard Susskind and
André Cabannes
Basic Books, 2023.
\$32.00



General Relativity is indeed well above vulgarization.

A good portion of the book focuses on the Schwarzschild metric, which describes nonrotating black holes and is an excellent tool for explaining how bodies and light move under the influence of gravity. The authors' discussion shines in its use of simple, clear language and mathematics to map the global structure of spacetime and show which regions are in causal contact with others. It also brilliantly clarifies the nature of a black hole's event horizon and singularity, the latter of which appears to be in the center of the black hole but in reality is in the future of anything crossing the horizon. Their description of Penrose diagrams, and how infalling matter forms black holes, is particularly lucid and beautiful.

Although I quite liked the overall approach and the topics presented in *General Relativity*, I found myself frustrated by what felt like a lack of attention to small but important details. At times the authors introduce terms, such as geodesic and parallel transport, that they do not define until many pages later. A brief description, perhaps with a parenthetical note indicating that the term will soon be carefully defined, would help in such cases.

Certain other things Susskind and Cabannes examine are simply wrong. For example, their discussion of black holes includes a description of the photon sphere—namely, light rays whose trajectories are bent by gravity so strongly that they orbit the black hole. They call that configuration an Einstein ring. But an Einstein ring is in fact a weak-gravity phenomenon that has nothing to do with black holes: It is a ring-shaped image caused by the serendipitous alignment of a light source, a gravitational lens, and an observer. Another example is in the discussion of gravitational waves, in which they write, “I think we could detect, in theory, one black holes collision per year. It is a lot.” But binary black hole collisions were first detected in September 2015, and the collaborative efforts of the Laser Interferometer Gravitational-Wave Observatory, the Virgo interferometer, and the Kamioka Gravitational-Wave Detector have now uncovered nearly 90 of them. That is a lot.

Although there are a moderate number of nits to pick, like those errors, they could easily be corrected in a future printing. Doing so would alleviate the unfortunately slapdash impression that they leave. Despite those flaws, Susskind and Cabannes’s *General Relativity* is an excellent volume for readers who know physics but aren’t familiar with GR and want a thorough introduction to the topic. I recommend it both to colleagues who want to learn the subject without sitting in on a whole course and to students who would like to learn the key concepts and techniques before studying the subject in detail. And I will happily incorporate many of the ways things are explained in this book into my own lectures.

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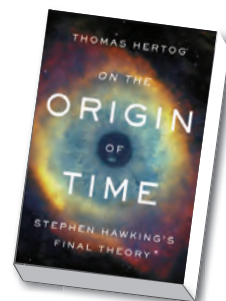
A timely retrospective

In his new book, Thomas Hertog delves into quantum physics and cosmology while simultaneously giving readers an insider’s view into the cosmological theory he developed in collaboration with Stephen Hawking. In *On the Origin of Time: Stephen Hawking’s Final Theory*, he interlaces personal stories, historical anecdotes, and other elements to craft a compelling and thought-provoking story.

Hertog eagerly tackles complex physical and cosmological ideas, presenting them in an accessible yet intellectually substantial manner. For example, he employs an endearing analogy involving eggs, chickens, and farms: “How come we have unbroken low-entropy eggs available to make an omelet? Eggs come from chickens, which are low-entropy systems on farms that are themselves

On the Origin of Time
Stephen Hawking’s Final Theory

Thomas Hertog
Bantam Books, 2023.
\$28.99



part of a low-entropy biosphere.” Similarly, he presents an explanation of cosmic inflation, tailored to a wide readership, that highlights the importance of scalar fields by cleverly describing them as drivers of repulsive “antigravity.”

Throughout the book, Hertog crafts beautiful sentences that captivate the reader’s imagination. One sentence that particularly struck a chord with me describes the Feynman path integral formulation of



The Belgian astronomer-cum-priest Georges Lemaître was the first to theorize that the universe was expanding.