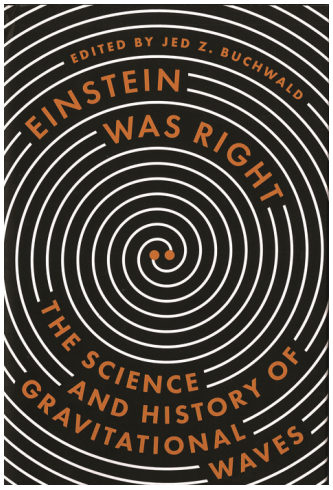


Einstein was Right: The Science and History of Gravitational Waves. Jed Z. Buchwald (ed.). Princeton University Press, 41 William Street, Princeton, New Jersey 08540, USA. 2020. xi + 235 pages. Price: US$ 35/£28.

This book contains nine articles by distinguished authors based on talks given by them in a conference at the California Institute of Technology (Caltech), USA. The articles by Barry C. Barish, Kip S. Thorne, Alessandra Buonanno, Daniel Kennefick and Harry Collins cover between them various aspects of the theory and detection of gravitational waves; the implications to physics and astrophysics of being able to observe gravitational waves emitted in extreme situations like the coalescence of black-hole binaries; the long scientific and technical efforts which went into making possible their eventual detection in 2015 and the history of the LIGO project and the sociology behind the massive effort. The articles by Jurgen Renn, Diana Kormos Buchwald and Don Howard deal with the genesis of general relativity, Einstein at Caltech and the influence of general relativity on 20th century philosophy of science. A preface by Buchwald traces how the conference came to be organized, and an introduction by Tilman Sauer provides brief introductions to the contributors and summaries of their articles.

The announcement of the first gravitational wave detection by LIGO was made on 11 February 2016, just a month before the Calctech conference covered by the book. In fact, Barish changed the title of his talk from 'The quest for gravitational waves' to 'The quest for (and discovery of) gravitational waves', following the first detection by advanced LIGO on 14 September 2015 and the announcement in February 2016, after detailed verification of the reality of the detection. At that time, while the public at large had become aware of the detection, not much was known, outside the world of gravitational-wave physicists, about details of the detection and the heroic efforts which preceded it. Over the five years since this announcement, much has been said about the first detection, its significance, detections which were made during the subsequent science runs, including the coalescence of a neutron star binary. So, it may seem that the articles in this book would now be rather dated, but that is most certainly not true. There is much that remains interesting and novel in the accounts, some of which are by people who have been directly involved with the LIGO project from the very beginning.

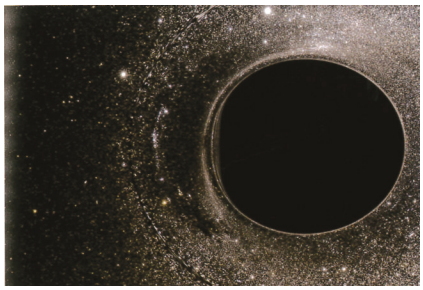
The first two articles are by Barish and Thorne, whose contributions have been seminal and who, along with Ray Weiss, were awarded the Nobel Prize after the first detection. Barish briefly recounts how doubts about the existence of gravitational waves in general relativity existed for decades after Einstein's first work on the subject in 1916, but how in the late 1950s, the 'problem of gravitational waves became an experimental rather than a theoretical question'. He mentions the importance of the pioneering efforts by Joseph Weber to detect gravitational waves using resonant bar detectors, briefly describes the development of LIGO and ends with a recounting of the first detection of gravitational waves.

I am always amazed by the writings of Thorne, who for decades has continued to find fascinating new ways to describe general relativity and its consequences. In his article Thorne covers a broad sweep of topics, including Einstein's quest for a relativistic theory of gravity, black holes, accretion discs around black holes, the geometry inside a black hole, gravitational waves and the new detections. Much of the matter he describes in his article is familiar, but as always with Thorne, there are new insights, marvellous diagrams and crisp explanations. There are several references to scenes and events in the movie 'Interstellar' by Christopher Nolan, for which Thorne was the scientific consultant and executive producer. These help to take the abstract concepts of general relativity to the 'real world'. In the section on gravitational waves, Thorne provides a brief and interesting account of how LIGO was conceptualized, put on a firm technical footing, presented as a project to the National Science Foundation and the US Congress, and finally approved. He also mentions the parallel experimental and theoretical efforts which eventually made the detection possible.

Buonanno in her article describes the astrophysical processes behind the formation and merger of black-hole binaries, the implications to astrophysics and fundamental physics which follow from the first two detections, viz. GW150914 and GW151226, likely future observations, including the tantalizing possibility of detecting a binary neutron star merger, and the bright future of gravitational wave astronomy.

The remaining six articles deal with various dimensions of general relativity and the discovery of gravitational waves, including the social and philosophical. The article 'The Wagers of science' by Kennefick, who was Thorne's research student at Caltech, begins with a bet which Thorne had made, that the first signal to be detected from LIGO would be from a coalescing binary, and that the detection would be made before numerical relativists would have successfully predicted the waveform. As we know now, the first part was correct while the second was not. Kennefick discusses the important contributions that theorists and numerical relativists made to the discovery by providing the model waveforms which were used in searching for the very weak signals.

Renn in 'The genesis and transformation of relativity' provides an account of the long struggle that Einstein went through in formulating the field equations of general relativity. Renn describes Einstein's use of the equivalence principle and Mach's principle; his identification of the metric tensor of space-time as the descriptor of gravity and geodesic lines as trajectories; the prediction of light bending and gravitational redshift even before the completion of the



A field of many stars gravitationally lensed by fast-spinning black hole.

theory; the Entwurf (draft) theory that he worked on with Marcel Grossman and Michele Besso, and the emergence of the correct field equations. The story, while generally known, has many twists and turns and matters of detail, and involves several distinguished players who worked with Einstein and some others who competed with him. Renn ends with a description of how understanding of general relativity developed after 1915, the early history of gravitational waves, the renaissance in their understanding which began in the 1950s and the search for gravitational waves.

Collins in the 'Detection of gravitational waves – a reflection', provides a sociologist's view of the experimental search for gravitational waves, the development of ideas by many talented experimentalists, their conflicting approaches and the social dimensions of the whole long and expensive process. He describes in detail the influence of Weber's attempts to detect gravitational waves with resonant bar detectors on the development of LIGO. Collins argues that Weber's work led to the understanding that short-duration burst events which produce short-wavelength gravitational waves could be detected from the Earth, and but for Weber, all efforts could have concentrated on spaced-based detections which are still in the future. Weber's experiments and influence are also mentioned in several other locations in the book.

In 'Einstein at Caltech', Buchwald describes the many attempts made by Robert Millikan to bring Einstein to Caltech; how Einstein arrived in Caltech for his first visit in 1930; his later visits and eventual acceptance of a position at the Institute for Advanced Study in Princeton, USA.

The concluding article by Howard is on 'How general relativity shaped twentieth-century philosophy of science'. The author discusses the profound influence that the theory had on shaping the philosophy of science in the first decades of the 20th century. Special relativity had already caused a stir by introducing the concepts of four-dimensional space-time, the equivalence of all inertial frames and the consequent constancy of the speed of light. The influence of the general theory on the philosophy of science was much greater, because of the dynamical nature of space-time introduced by the theory, and the requirement of general covariance. The latter had caused difficulties to Einstein and Grossman in the development of the Entwurf theory, who came to believe that general covariance should not be a requirement for a theory of gravitation, since it prevented the theory from leading to reasonable physical results. Howard (as well Renn in his article) discusses this point in some detail. Howard describes how Einstein, even during the early years of his first investigations in physics, was knowledgeable about the philosophy of science (he was presented Immanuel Kant's *Critiques* when he was 13 years old), and interacted constructively with philosophers, who in turn had deep knowledge of physics.

The book is in general well written and the articles are all interesting and informative. In spite of my decades-long acquaintance with the subject, I found much material that I was not familiar with and which was enlightening. I strongly recommend the book to libraries as well as individuals with interest in the history of general relativity and gravitational waves.

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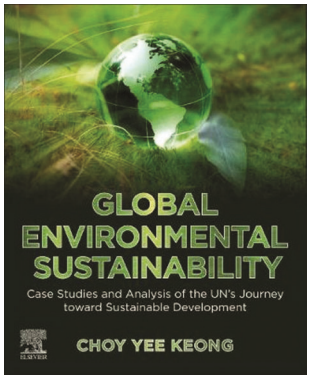

Global Environmental Sustainability: Case Studies and Analysis of the UN's Journey toward Sustainable Development. Choy Yee Keong. Elsevier, Radarweg 29, P.O. Box 211, 1000 AE Amsterdam, The Netherlands. 2021. xxviii + 435 pages. Price: US$ 140.00. ISBN-13: 978-0128-224199; ISBN-10: 0128224193.

Conservation and sustainable management of the natural environment, including its biodiversity, is critical for sustaining long-term human existence[1]. Indian scriptures emphasize harmony and the human connection with nature, ecological balance, and the need for ethical treatment of nature by humans to sustain natural resources for posterity. The concept of sustainable development has evolved, focusing on key concepts of environmental, social and economic sustainability. However, this environmentally sustainable and morally justifiable development ideology gradually eroded with the advent of the Industrial Revolution in the 1800s in western Europe, characterized by massive capitalist modes of production and consumption. The dominant Western industrial culture and the neoliberal capitalist expansion came at the cost of depletion of natural resources and environmental impoverishment globally. In the wake of the severe global environmental deterioration caused by uncontrolled human economic activities, and acknowledging the increasing threat of environmental degradation, in 1949, a United Nations (UN) Scientific Conference examined the conservation and sustainable management of natural resources[2].

The UN, committed to addressing this challenge, has made continuous and unrelenting efforts by convening a host of international environmental meetings and conferences to advance its core mandate of bringing about wiser use of our natural environment. The UN convened a paradigm-breaking global environmental conference[3], the Stockholm Conference in 1972, intending to call upon the international community to reverse the environmental decline by implementing environmental protection measures and launch a new liberation movement to free humans from the threat of their own thraldom to environmental perils of their own making. Declarations, agreements, regulations and action plans were adopted at such conferences[4] to facilitate and guide the global community to effectively address the challenges of balancing its three core values of sustainable development, namely environmental protection, economic growth and social equity.

This book conceptually and theoretically analyses the ethical constraints for sustainable development by considering human responsibility towards the natural world, and provides a philosophical framework for rethinking our relationships with nature. The publication takes a multidisciplinary and interdisciplinary approach, considering science, environment, ecology, economics, politics, philosophy, anthropology and