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Is Einstein still right? Black holes, gravitational waves, and the quest to verify Einstein's greatest creation FREE

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David Derbes

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BOOK REVIEWS

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Is Einstein Still Right? Black Holes, Gravitational Waves, and the Quest to Verify Einstein's Greatest Creation. Clifford M. Will and Nicolás Yunes. 304 pp. Oxford U. P., New York, 2020. Price $23.99 (cloth) ISBN 0-198-88421-20. (David Derbes, Reviewer)

Physics is an experimental science. Advances in physics often come after a number of observations challenge the current understanding. Einstein's theory of gravity is an exception.

At its birth, general relativity's empirical support rested upon a single measurement: the advance of Mercury's perihelion by an additional 43 arc sec per century, unexplained by Newton's gravity but found in Einstein's. Two more effects were predicted: the bending of light grazing the Sun's limb (twice that given by Newtonian theory) and the gravitational red shift of spectral lines. Apart from these three classic tests, many physicists are not familiar with the evidence supporting Einstein's theory of gravity. Gravity's weakness at terrestrial scales prevented further tests until appropriate technology could be developed. A practical fourth test, Shapiro's radio echoes, had to wait more than 40 years.

What of theory? A brief period of activity followed the new theory, but then the field lay fallow for more than 30 years. Following the end of World War II, several established physicists turned to general relativity. This new focus led to two important conferences in 1955 and 1957. These marked the beginning of a golden age in theoretical general relativity, lasting about 20 years.

In 1981, Clifford Will produced a masterful survey of the then-current state of the art, *Theory and Experiment in Gravitational Physics*. A revised version was reviewed in this journal (*Am. J. Phys.* **62**, 1153 (1994). See also C. M. Will, "PTG-1, Resource Letter on Precision Tests of Gravity," *Am. J. Phys.* **78**, 1240 (2010)). A second edition followed in 2018. To have produced such a valuable resource for the community would have been enough for most physicists. However, Will did something more in offering a version of his book for general readers: *Was Einstein Right? Putting General Relativity to the Test*, in 1986 (revised in 1993). To paraphrase Rutherford, if you cannot explain your work to your dentist, you do not really understand it. Not many have translated their research into a form suitable for lay folk, as Will has done, but it is a distinguished group, including Einstein himself.

As the golden age of theory was drawing to a close, a golden age of experiment in general relativity was opening. The nearly 40 years since the first publication of *Was Einstein Right?* have witnessed a bounty of spectacular astrophysical observations, many bearing on general relativity's validity. A few have been front page news (images from the Webb space telescope, the first pictures of a black hole). Several have proved worthy of the Nobel Prize, most recently LIGO and black hole observations. These surely have inspired some young people to consider astrophysics as a career. It is clearly time for a sequel to Will's popular book. Does Einstein's theory prove equal to these observations? Can the narrative be made accessible? The answer to both questions is emphatically yes. Will is now joined by his friend and colleague Nicolás Yunes, and they have delivered splendidly.

The new book, though slim, is three books in one. First, it is a history of the discovery of some consequences of Einstein's theory that its creator either did not find or did not immediately believe. Next, it describes the heroic efforts and jaw-dropping technological feats to test these consequences. Finally, it discusses the results themselves. In a few cases, plans for yet more precise measurements of known results are sketched, e.g., the orbiting gravitational wave observatory LISA. Like a really good cheesecake, this book is surprisingly dense, and probably best digested in small bites.

Has not general relativity already proved itself? Why bother with more tests? In the first chapter, Will and Yunes review some recent results, and point to three clouds in general relativity: dark energy, dark matter, and the lack of a consistent quantum theory of gravity. Extending the difficult measurements of general relativity to a few more decimals may indicate if and how the theory breaks down. Perhaps new physics is needed to sweep away these clouds.

The remainder of the book deals, chapter by chapter, with six broad areas: relativistic effects on time measurements; gravitational influence on light's propagation; the subtle effects of gravity on spacetime (de Sitter's geodetic deviation and the Lense–Thirring frame dragging effect, measured by the exquisitely precise Gravity Probe-B); the new tests afforded by Hulse and Taylor's discovery of the binary pulsar; and the tests and observations from black holes. The next two chapters discuss LIGO and the direct observation of gravitational waves. The ninth chapter concerns the future of gravitational wave physics, looking forward to LISA and the development of better Earth-based instruments. A last chapter provides a dialogue between the authors, a look back at their personal involvement and speculation about the future development of their subject. Throughout, attention is given to the individuals, and frequently the politics, involved; why and how this or that experiment came to be; and the theoretical questions underpinning the tests, e.g., do gravitational waves exist? If so, can they transfer energy? None of these was answered quickly. The measurement of gravitational effects more often than not calls for big science and substantial government spending.

Reading this book taught me many things. Here are two I particularly enjoyed. The sets of general relativists and astrophysicists used to be, stealing a line from Wilde, "two nations separated by a common study." A 1963 conference in Dallas brought together many from each camp, perhaps for the first time. It seems (p. 153) some relativists had to be told the definition of a star's magnitude, and some astrophysicists the meaning of the Riemann tensor! The second is the relativistic resolution of Newton's bucket. A bucket of water set spinning causes the water's surface to curve. Newton took this as proof that space is absolute, for if the universe were rotating about a stationary bucket the water's surface would stay flat. Ernst Mach disagreed, guessing that the two situations would be indistinguishable. The matter was settled theoretically by calculations in the 1960s based on the Lense–Thirring frame dragging effect. Place a stationary bucket at the center of a spherical shell which is then spun around it. Frame dragging causes a slight dip in the water's surface, which approaches the original Newton result as the mass and radius of the shell approach those of the universe. The effect itself was confirmed by Gravity Probe-B to within twenty percent. The test spanned 50 years from conception to data analysis.

Who should read this book? Roughly equivalent to a math-free review article, it is perfect for physicists in other disciplines who want to catch up with recent results and work in development without having to read through a stack of papers. It seems to me also appropriate for juniors and seniors in high school considering a career in physics, or for college students majoring in physics but not sure of which direction to go. (I donated a copy to my former institution's library.) It would make a very good supplement to a modern physics course that covered general relativity. Curious lay readers should find the material accessible as there are no equations.

I hope that this wonderful book, genuinely full of wonders, finds a wide and varied audience. Physicists are producing awe-inspiring empirical results in general relativity at a fantastic rate. Most of our fellow citizens are getting only a taste of the details. If they have the appetite for these wonders, they should be able to get a proper meal. Will and Yunes have set the table admirably.

David Derbes taught high school physics for 40 years, mostly at the University of Chicago Laboratory Schools. He retired in 2019. His retirement hobby is manuscript salvage, getting significant never-published work into print, often as part of a team.

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