

traveled. The experiment has become a favorite anecdote in physics textbooks, but the comparison between those idealized accounts and the actual issues confronting experimentalists is eye-opening. For example, differences in temperature of merely 1/500 of a degree between the arms of the experimental apparatus might produce misleading results, but attempts to shield the arms from such variations might theoretically also interfere with the ether wind that the experiment was meant to measure.

In the first two sections, the experiments discussed are null in the sense that they show no difference between the behaviors of two systems or of the same system in different situations. The last section discusses searches for new particles or novel decays in high-energy experiments at the Large Hadron Collider. Its experiments are of critical importance

for physicists investigating the possible limitations or omissions of the standard model. Null results are outcomes that agree with the null hypothesis; they can be accounted for by the standard model and mean that the experiment does not point to novel physics.

Physicists and physics students will likely be familiar with many of those experiments, but not with the detailed history behind them or the technical and conceptual challenges that confronted the experimenters. *Measuring Nothing, Repeatedly* is written as a textbook and would be ideal for a course that offers a broad survey of the challenges and limits of experimentation and data analysis.

Apart from its potential as a textbook, *Measuring Nothing, Repeatedly* will be valuable to anyone interested in either the history of physics or the general problems of conducting experiments and evaluat-

ing their outcomes. There is a wide and variegated gap between idealized visions of scientific experiments that can be easily analyzed and the messy real-world experiments that scientists actually perform. Experimentalists must try to account for random errors, known sources of systematic error, and, most challenging of all, unknown sources of systematic error. Experimental designs that mitigate one sort of problem may amplify another. Even theorists who have neither the inclination nor the expertise to do experimental work can benefit from a finer appreciation of the problems that experimentalists confront and the sources of doubt that must accompany all empirical tests of physical theories.

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A social history of eclipse expeditions

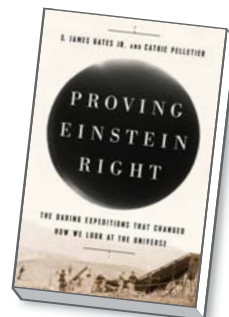
Written by a theoretical physicist and a novelist, *Proving Einstein Right: The Daring Expeditions that Changed How We Look at the Universe* is a wonderful social history of attempts to test the

general theory of relativity by photographing stars during eclipses. The best-known efforts were the British expeditions to Africa and South America during the eclipse of 1919, which generated pop-

Proving Einstein Right
The Daring Expeditions that Changed How We Look at the Universe

S. James Gates Jr and Cathie Pelletier

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ular acclaim for Albert Einstein and his theory. But several expeditions had tried to obtain such images during previous eclipses; only one, from Lick Observatory in 1918, succeeded, and its results were never published. The book's account of those earlier expeditions is especially valuable because there is no comparable history of those unsuccessful attempts.

In *Proving Einstein Right*, S. James Gates Jr and Cathie Pelletier give extensive details on each venture, including brief biographies of the scientists involved. They also provide accounts of the travels, entertainments, and lodgings of the expeditioners, down to who ate lunch with whom and the origins of the steamship company that carried British astronomers to Brazil in 1919. The authors describe the social conditions in the host countries, including the condi-

tions of workers on rubber plantations in Brazil and the lives of the enslaved workers forced to farm cocoa in Príncipe, the island off the west coast of Africa where Arthur Eddington's 1919 expedition landed. They even digress to a British report of murders by slavers in Angola.

It's a good read. All that's missing is one failed expedition and almost all the science.

Einstein's theories of gravitation, which he developed from 1911 to 1915, predicted a shift in the spectrum of sunlight compared with the absorption spectra from terrestrial sources. That shift, which had not been found by astronomers in the US or in Europe, is described in the book as a "Doppler effect," which it is not. The authors also do not touch on how the failures of the redshift measurements were eventually reconciled with the general theory of relativity.

Einstein's 1911 theory predicted a difference in angle of 0.83 arcseconds between light from a star passing at the limb of the Sun and light from the same star when the Sun was further away, a value essentially the same as the Newtonian prediction. The 1915 theory doubled it. *Proving Einstein Right* treats that change as simply a corrected calculation. It was not; the theory of 1911 and the generally covariant theory of 1915 were quite different. The 1915 theory also implied an explanation of the advance of the perihelion of Mercury—described here as a "wobble"—one of the key pieces of data that Newtonian theory could not account for.

Equally absent is a narrative of the difficulties that astronomers faced in analyzing the data for both the redshift and the light deflection. Estimating the gravitational deflection required clamping together two glass photographic plates, one depicting an eclipse and the other depicting the same field of stars during another season when the Sun was not in the field, and then using a micrometer to measure the distance between the two images of each star. The displacements were assumed to be a linear combination of several factors—for example, the slight misalignments of the clamped plates and the gravitational displacement. The coefficient estimates can be obtained by least squares if there are enough star images.

Unfortunately, the Eddington photo-

graphs that showed the best agreement with Einstein's 1915 prediction did not contain enough stars. Eddington had to do some finagling. Meanwhile, in Brazil, one telescope gave a result matching the Newtonian prediction, and the other gave a value more than a standard deviation higher than Einstein's prediction. Readers of *Proving Einstein Right* will not learn about those results, or how they were reconciled with Einstein's theory, or the controversies over the claim by Astronomer Royal Frank Dyson and Eddington that the results of the British expeditions confirmed Einstein's theory.

Nor will they find the fascinating reason why the Lick Observatory results from 1918 were never published. Lick director William Wallace Campbell presented the results to the Royal Astronomical Society as a preliminary refutation of Einstein's 1915 prediction; his colleague Heber Curtis made a similar presentation to the Astronomical Society of the Pacific. But Adelaide Hobe, a Carnegie assistant at Lick, remeasured the eclipse images against a new image of the comparison star field and obtained different numbers. Campbell decided the results were too uncertain to publish and that Curtis, who made the original calculations, was incompetent. Somewhat unjustly, Curtis soon was appointed the director of the Allegheny Observatory in Pittsburgh, Pennsylvania, while Hobe remained an assistant at Lick.

Other scientific questions are treated dismissively. Before his general theory was published, Einstein went to Göttingen, Germany, to visit David Hilbert, who was also working on a relativistic field theory of gravitation and gave a public report on it. Hilbert published his theory shortly after Einstein's appeared. Who owed what to whom is a subject of some historical debate, especially since the critical field equation had been cut out of Hilbert's manuscript. But *Proving Einstein Right* dismisses the matter in a couple of sentences.

Despite the dearth of scientific detail, this is a marvelous book that should be read by anyone interested in eclipse expeditions. For the history of the science, however, readers will have to look elsewhere.

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