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PREFACE

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The general theory of relativity is at once the most profound and the least tested of all physical theories. It originated in Einstein's wrestling with an elemental discrepanc According to special relativity no signal can propagate faster than the speed of light. According to Newtonian theory gravitation acts at a distance instantaneously. Ten years of reflection, speculation and grinding hard work brought Einstein to an answer in which an experimental observation (the universality of free fall), a mathematical formalism (the tensor calculus), a metaphysical insight (the notion of curved space-time) and a nove physical concept (the use of a tensor rather than a scalar potential) were combined into a theoretical structure of compelling beauty: a theory that was far more than just a next approximation beyond Newton: that was exact, complete and radically new in its outlook on gravitation and the cosmos.

But this heroic creation has shortcomings. It resists quantization. It puts gravity on a peculiar special footing hard to reconcile with the hoped for grand unification among the different forces of nature. And even on its own terms it involves, as Einstein saw, a strange mixture of the inevitable and ad hoc in its manner of relating the mass-energy tensor to the curvature tensor. With good reason many theorists believe, in C. N. Yang's words, that "Einstein's general theory of relativity, though profoundly beautiful, is likely to be amended".

Above all it needs testing. When Einstein propounded general relativity in 1915 he conceived three (and only three) observational tests of the theory: the gravitational redshift, the deflection of starlight by the Sun, and a correction to the Newtonian value for the precession of the perihelion of the planet Mercury. The additional perihelion precession neatly accounted for a known discrepancy, though doubts now exist about the size of the Newtonian contribution from the Sun's quadrupole mass moment. The deflection of starlight became the subject of a celebrated albeit rather ill-done experiment by Dyson, Eddington and Davidson in 1919. The gravitational redshift, which is a test more of Einstein's equivalence principle than of relativity as a whole, was at first detectable only in stars, where it was hard to disentangle from other effects. For over forty years, these three results, all open to objection, were the only direct experimental support for Einstein's vast theoretical edifice.

From 1960 on new technologies opened the way to new tests, including improved version of the three classical tests. The gravitational redshift was verified first to 1% in laboratory experiment and then in 1976 to 2 parts in 10^4 through NASA's Gravity Probe A: the Vessot-Levine suborbital hydrogen maser clock experiment. For starlight deflection optical measurements continued to prove frustratingly difficult but application of very long baseline interferometry (VLBI) to radio stars near the plane of the ecliptic has finally verified the Einstein prediction to 1%. Even greater precision (0.1%) has been reached in a different but related test suggested by I. I. Shapiro in 1964: the relativisti delay in the measured round-trip travel time of radar signals reflected from planets or spacecraft passing behind the Sun. Refinement of the perihelion test is held up by continuing uncertainty over the Sun's quadrupole mass moment, but when that is settled the progress made in recent years on the grand solution for the dynamics of the solar system should make for a decided advance in this test also.

Another important development since the 1960s has been a class of negative experiments General relativity is in two respects a minimalist theory: its assumptions are restricted and austere, and in the weak field approximation at least its testable deviations from Newtonian theory are few. This austerity is less characteristic of the large number of alternative theories of gravitation that have surfaced in the seventy years since Einstein' work. Many seem conceptually clumsy, which is enough to make some critics discount them, but in addition there has been a recognition, largely through the work of Nordvedt and Will that the alternative theories often predict positive physical effects where general relativ gives none. One example, the Nordvedt effect, will suffice. Several theories predict an oscillation in the Earth-Moon distance, absent in Newtonian or Einsteinian gravitation, as the two bodies orbit each other in the field of the Sun. Lunar laser ranging shows that no such effect exists down to the measurement limit of 20 to 30 cm.

A third class of observations has come from astrophysical discoveries, ranging from the probable detection of a black hole in Cygnus X-1 to measurements of the periastron shift, and even perhaps of gravitational radiation losses, in the Taylor-Hulse binary pulsar. But these, exciting as they are, are marginal at best as quantitative checks of general relativity. The uncertainties are too many. More generally, concerns of three kinds remain. First, admiration for the new observational tests needs to be tempered with caution. All depend on computer fitting of elaborate theoretical models with many (usually hundreds) of adjustable parameters. Impressive as the achievements are, some residuum of doubt must exist whether everything in nature and the model has been accounted for. Next, to exclude alternative theories, most of them inelegant, is not to establish Einstein's theory. Finally, none of the quantitative tests extend beyond checking the weak-field spherically-symmetric limit of the Schwarzchild metric. As J. A. Wheeler has remarked: "It is hard to conceive a science so exposed for lack of evidence."

It was therefore a significant event when late in 1959 L. I. Schiff, and independently G. E. Pugh, conceived a new experiment based on observations of gyroscopes in Earth orbit, which, if it could be executed, would measure not one but two previously untested effects of general relativity. The smaller of these, a precession of 0.042 arc-s/yr caused by the dragging of the inertial frame by the rotating Earth, corresponds to measuring the gravitational analog of a magnetic field. The special importance of this gravitomagnetic effect, as it is often called, has been emphasized by many theoretical physicists, most cogently by C. N. Yang, who has remarked that any satisfactory amendment of Einstein's theory is "likely to entangle with spin and rotation", and that while it is easy to imagine that the amendment would not disturb the usual tests, it would not be at all surprising if this effect were to give results in disagreement with the theory.

The larger precession, usually known as the geodetic effect, is from the motion of the gyroscope through the curved space-time around the Earth. Its magnitude is 6.6 arc-s/yr. If measured to the accuracy we expect (1 part in 10^4), it will supply the most precise test yet made of any specific prediction from the general theory of relativity.

An endeavor to perform the Schiff experiment was started at Stanford University in the early 1960s by W. M. Fairbank and R. H. Cannon, and has been pursued since then by a joint team from the Stanford Physics and Aero-Astro Departments, mainly under NASA support. Since 1970 the experiment has been known as the Gravity Probe B experiment. The initial research phase was completed in 1980; it was followed by studies of a number of possible flight programs. In March 1984 the NASA Administrator gave his approval to commence work on a program known as STORE (Shuttle Test Of the Relativity Experiment). STORE consists of the development of a flight instrument, with cryogenic support system, and its test on Shuttle in 1991. It will be followed if all goes well by refurbishment, interfacing of the instrument with a spacecraft, and relaunch as a free-flying Science Mission in 1994. In 1984 Stanford selected Lockheed Missiles and Space Company, Inc. as its aerospace subcontractor for STORE. NASA Marshall Space Flight Center has overall responsibility for the program, and provides support in some areas of hardware development, notably in the fabrication of gyroscope rotors.

The six papers in this volume constitute a brief status report on Gravity Probe B by members of the Stanford/Lockheed team, with special emphasis on the progress of STORE.

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