

Further Tests to Decide Between Gravity Theories

Several experiments, either in preparation or in operation, may provide further evidence for deciding between general relativity and the scalar-tensor theories of gravitation.

The three classical tests of general relativity—the red shift, deflection of light and the advance in the perihelion of Mercury—have been the only consequences of the theory accessible to experimental measurement. Of the three tests, the perihelion motion is the most sensitive to differences between general relativity and other gravitational theories. As a result, the solar-oblateness measurements of Robert H. Dicke and H. Mark Goldenberg (Princeton)¹ were able to lend support to one of the alternative theories, the scalar-tensor theory of Dicke and Carl Brans.²

Experiments. C. W. F. Everitt and William M. Fairbank (Stanford) have designed an experimental test of general relativity that is based on observation of gyroscopes in a satellite. According to calculations of Leonard I. Schiff,³ a gyroscope in orbit around the earth undergoes two relativistic precession effects. One is due solely to the satellite's orbital motion and yields a predicted precession of 7 arc-sec/year in an 800-km orbit. The other is due to rotation of the earth and is approximately 0.05 arc-sec/year. For a satellite moving in a polar orbit the two effects are perpendicular, as indicated in the illustration. A telescope in the satellite will compare the gyroscope orientation with the line of sight to a fixed star.

To permit direct measurement of the spin axis, the design calls for a spherical quartz gyro rotor that is coated with superconductor. A system of gas jets will spin the rotor, and the direction of the resulting magnetic moment will be determined by a magnetometer device (designed by M. Bol, Bascom S. Deaver Jr and Fairbank). Superconducting shielding will reduce the effects of external fields essentially to zero.

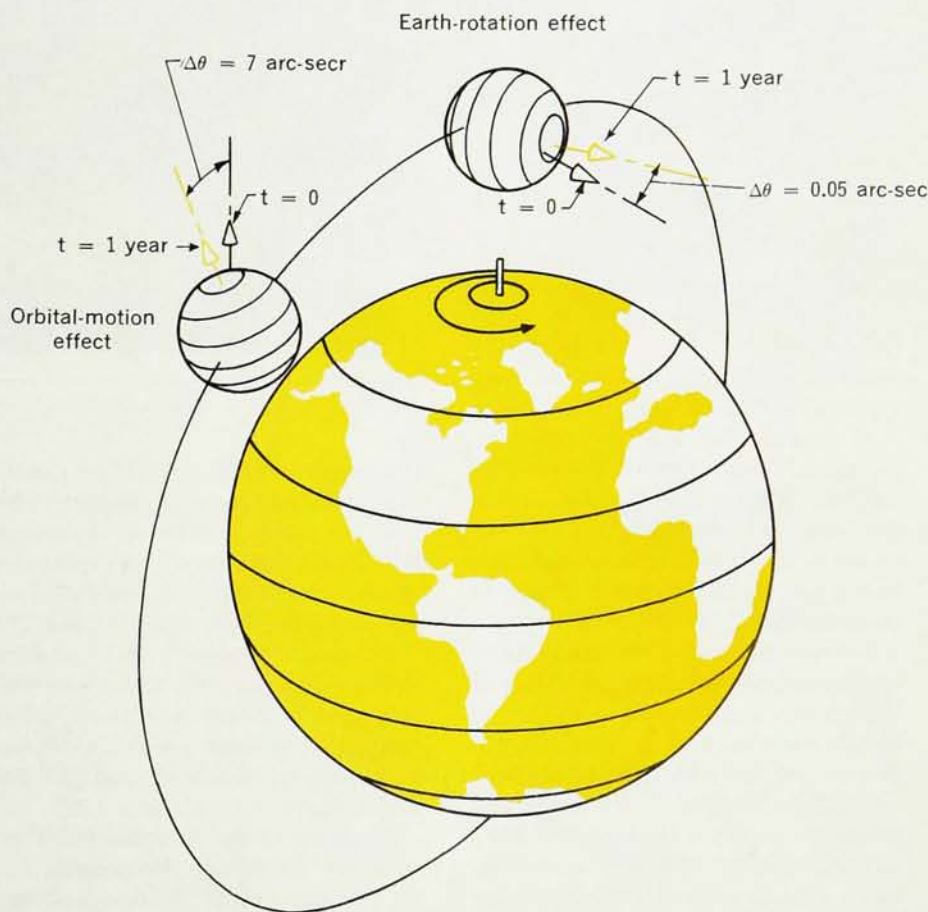
Irwin I. Shapiro (MIT) and Gordon H. Pettengill, Melvin L. Stone, Michael E. Ash and William B. Smith, all of

MIT's Lincoln Laboratory, are bouncing radar pulses off Venus and Mercury as the planets pass behind the sun (achieving nearly grazing incidence of the pulses). The time delay between pulse transmission and detection will be increased, according to general relativity, as a result of the sun's gravitational effect on the speed of propagation. Measurement of the delay is being performed in conjunction with the Haystack radar installation in Tyngsboro, Mass. In this test, proposed by Shapiro,⁴ data analysis is complicated by the necessity of considering simultaneously the orbital perturbations of the moon and all the planets.

Shapiro is also involved in planning a deflection experiment with another

group at MIT and Lincoln Lab: Bernard F. Burke, Hans Hinteregger and Alan E. E. Rogers. In this group's experiment a radio interferometer will monitor the separation between two or more quasars as one of them passes near the sun.

Another experiment that measures the gravitational deflection of light is being constructed by Henry A. Hill and Carl A. Zanon (Wesleyan U. and U. of Arizona). These measurements evolved from Hill's experience with Dicke in the solar-oblateness experiment. A star-tracking photoelectric telescope will use the sun to define a direction in space and the sun diameter as a unit of length in attempts to overcome several sources of systematic errors present in previous measurements of starlight deflection. The experiment will measure the distance be-



RELATIVISTIC PRECESSION EFFECTS are expected for gyroscopes in earth satellites in one of the new tests of gravitational theories.

tween two stars while the sun apparently moves past them on the celestial sphere. The deflection of starlight, as it passes near the sun, will cause a small apparent change in the distance between the stars as their positions change with respect to the sun. Hill and Zannoni will use an atomic time standard, so that additional valuable astronomical data will be provided by the experiment.

In an attempt to test the relativistic dependence of time on gravitational potential, Norman F. Ramsey (Harvard), Daniel Kleppner (MIT) and Robert F. Vessot (Hewlett-Packard) are planning to compare the rate of a clock on the earth to one in a satellite placed in synchronous orbit about the earth. Hydrogen masers will serve as time standards. In addition to providing a nearly maximal effect a synchronous orbit permits continuous observation of the satellite clock.

Implications. Gyroscopic-precession predictions by a number of alternative theories of gravitation are different from those predicted by general relativity. So the Everitt-Fairbank experiment appears capable of deciding unambiguously between the theories.

If Shapiro's radar experiment yields a delay larger than that predicted by general relativity, then both general relativity and the Brans-Dicke theory would be disproved. On the other hand, if the delay is smaller than that predicted by general relativity, the measurement could be consistent with the Brans-Dicke theory.

If the deflection in Hill's optical experiment and in the MIT-Lincoln Lab radio experiment is different than that predicted by general relativity, the consequences are the same as those implied by the radar data in Shapiro's experiment.

Ramsey, on the other hand, views his experiment primarily as a test of the equivalence principle as applied to time measurement. It is similar in purpose to the experiments of Robert V. Pound, Glen A. Rebka Jr and Joseph L. Snider (Harvard).⁵ They showed that the effects of a gravitational field in a local experiment are indistinguishable from those due to uniform acceleration. By measuring the source velocity required to match

the energy of Mössbauer-effect gamma rays with the resonant energy of an absorber placed well below the source, they found that theory and experiment agreed within 1%. Ramsey's efforts are to improve upon that accuracy.

Progress. Models of the gyroscope and telescope are now under construction and will be laboratory tested sometime this year. A flyable Dewar flask is being designed, and the first flights should take place in 1969.

Meanwhile, the Shapiro radar experiment is already in progress, although not yet at its designed sensitivity. Preliminary radio-interferometer measurements will start soon with the Haystack and Westford antennas,

which are separated by about 1 km. If neither the earth's atmosphere nor the solar corona causes insuperable difficulties, the group envisions using two pairs of antennas. The pairs would be separated by a much longer baseline and would be coordinated by atomic clocks.

Hill's star-tracking experiment, after a preliminary measurement of the sun diameter, should be under way in a year.

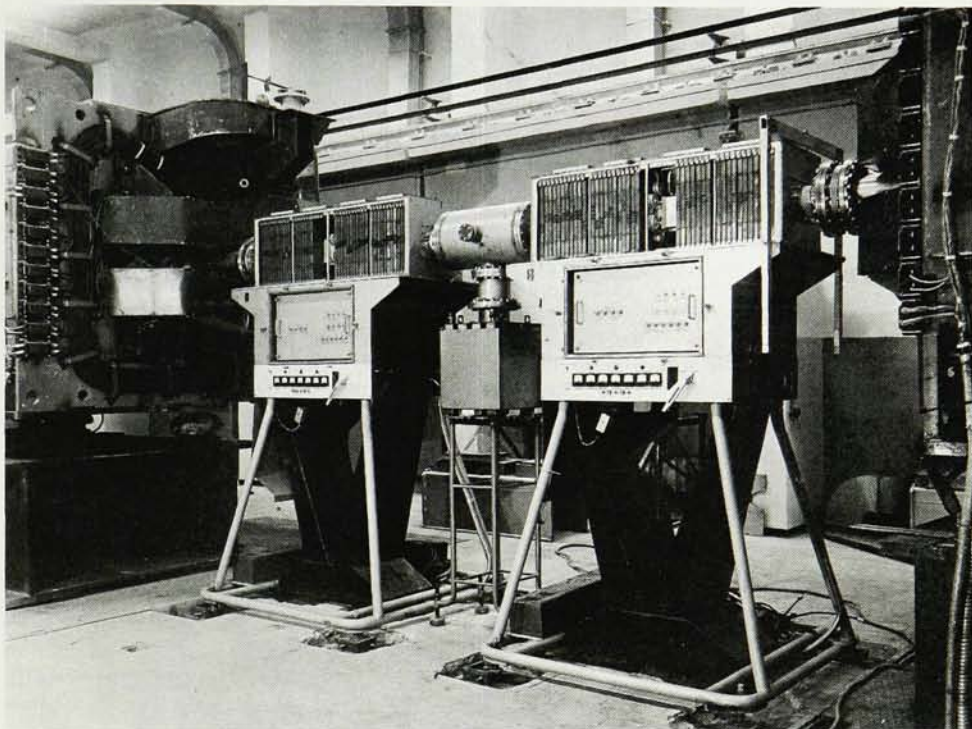
The dominant limitation in the Ramsey maser experiment is the accuracy of the satellite clock. So the main research and development at present is in making a better clock. Hewlett-Packard is developing one suitable for





SERPUKHOV SYNCHROTRON

The world's largest accelerator (photo above), turned on in mid September, has produced 76-GeV protons. The 470-meter-diameter ring is covered with 9 meters of earth. Control room and 100-MeV linac injector (below the ground) are in foreground. Curved roof covers experimental hall (behind). Each magnet unit (left photo) is 10 meters long and separated into five subassemblies by the square tabs. Magnet coils are wound with 70 tons of aluminum bus bar. At right is beam transport from linac to synchrotron. The rf accelerating cavities (right photo), which are ferrite-tuned, are fed rf power from the V-shaped base.



satellite use, but assignment of a specific space vehicle has not yet been made.

—GP

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Electron Affinity of Helium Measured by Photodetachment

The first direct measurement of the electron affinity of helium has been reported by a team of physicists at the Joint Institute for Laboratory Astrophysics at Boulder, Colorado. This parameter represents the binding energy of an extra electron that may attach to an atom to form a negative ion.

Although helium has no stable negative ion, since 1939 it has been known that the $^4P_{5/2}$ excited state of the ion is metastable against autoionization to the neutral atom, with a calculated lifetime of about one milli-

second. B. Brehm, M. A. Gusinow and J. L. Hall report their measurement of the electron affinity in *Phys. Rev. Letters* **19**, 737 (1967). They used a laser beam to photodetach the negative ions and an electron energy analyzer to obtain the kinetic energy spectrum of the resultant free electrons.

The negative ions are formed by double charge exchange (two electrons transferred) between a 2.5-keV beam of positive helium ions and a target of neutral potassium. The beam is then decelerated to 700 eV; the negative component is separated from positive ions and neutral atoms, mass analyzed and focused. The light beam is