# search & discovery

Radio-wave deflection experiments confirm Einstein

Einstein yes, Brans–Dicke no, is the apparent verdict of some recent experiments at the National Radio Astronomy Observatory, Green Bank, West Virginia. Edward Fomalont and Richard Sramek measured the deflection of microwave radiation by the Sun's gravitational field and report results sufficiently precise that they are consistent with Einstein's general relativity but not with scalar–tensor formulations such as Brans–Dicke theory. The remaining uncertainty concerns possible systematic errors in these observations, not the formal statistical error, which appears to be sufficiently small. The experimenters used a 35-km baseline radio interferometer to study three nearly collinear radio sources at two frequencies and found the bending to be 1.015 ± 0.011 times that predicted by general relativity; the Brans–Dicke prediction differs by about seven percent.

Although studies of solar light bending have been going on since Arthur Eddington's solar-eclipse expedition of 1919, not until about eight years ago did radio-interferometric techniques allow reduction of experimental error down to a few percent, and the NRAO group is now the first to report a sufficiently small experimental error to rule out either one or the other formulation. They described their results in a special experimental session at the VII Texas Symposium on Relativistic Astrophysics, held in Dallas 16 to 20 December. Two other groups have recently reported experiments with errors quite small (about three percent) but not yet small enough to distinguish between the two theories. One group worked at the
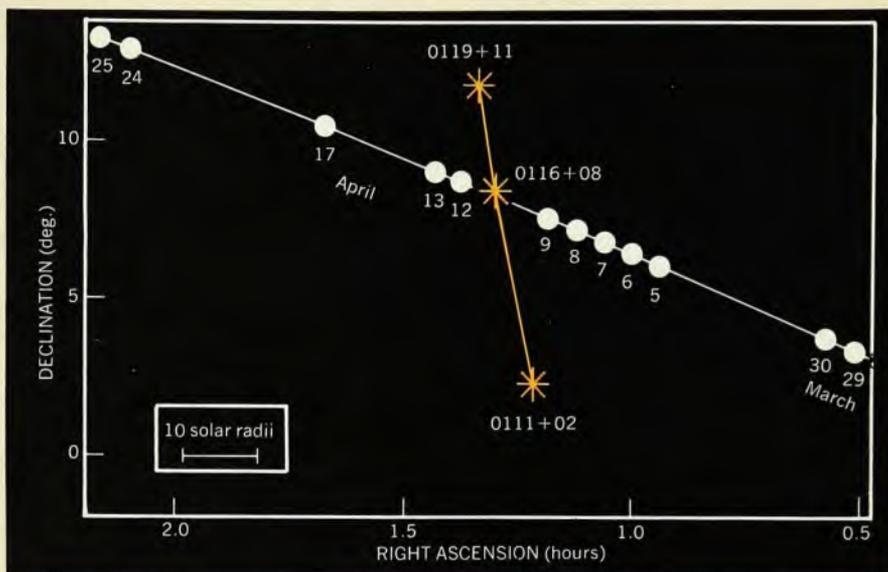
Positions of the radio sources and of the Sun at noon are shown here for the NRAO experiment. Because of the small angular separation between the occulted source (0116 + 08) and its calibrator (an average of the outer sources), the observers could correct for transient shifts.

Westerbork Observatory, The Netherlands (Kurt W. Weiler, Ron D. Ekers, Ernst Raimond, Kelvin J. Wellington) and described their results at the Dallas meeting; the other group (Charles Counselman, Thomas Clark, Hans Hinteregger, Stephan Kent, Curtis Knight, Alan Rogers, Irwin Shapiro and Alan Whitney) used antennas at NRAO and at the Haystack Observatory in Westford, Mass, and reported their results in a recent issue of *Physical Review Letters*.[1]

As radiation passes by the Sun on its way toward an earthbound detector, it is bent by the solar gravitational field; all relativistic theories agree here. The amount of bending, in seconds of arc, is predicted by metric theories of gravity to be

$$\delta\theta \approx (\tfrac{1}{2})(1 + \gamma)(1.75/d)$$

where d is the distance of closest approach of the ray path to the center of the Sun in solar radii and γ is one of the so-called "PPN" (Parametrized Post-Newtonian) parameters that are often used to distinguish among the various theories of gravitation. According to Einstein's theory, γ equals one. For

Ion–surface scattering reveals unexpected oscillations

A series of ion-surface scattering studies has revealed surprising oscillatory cross sections that some atomic physicists are hailing as macroscopic evidence of quantum-mechanical phase interference phenomena. Robert Erickson and David Smith (Central Research Laboratories, 3M Company, St. Paul) saw[1] the pronounced regularly spaced oscillations when they measured scattering cross sections as a function of primary energy for the elastic scattering of low-energy noble-gas ions from a number of

solid surfaces. Although similar oscillations are well known in ionic collisions in gases, this is the first report of such oscillations in scattering from surfaces. Erickson and Smith explain their results in terms of binary collisions (as in a gas) between an incident ion and a surface atom, and a resulting quasimolecular state with shared electrons. Although not everyone is satisfied that the experimental data are yet sufficient to rule out other likely explanations, most agree that the results are exciting

if this interpretation is borne out.

Low-energy ion scattering has been used for the past few years to study surfaces, because the elastically scattered ions have energies characteristic of the surface atoms. In such analyses, however, little attention is given to scattering cross sections. Erickson and Smith were spurred on to their studies, Erickson told us, by conversations with John Leys, an analytic chemist at the 3M Company, who had noticed some irregularities when he measured peak

tion they are particularly interested in increasing the pulse length to something like a microsecond, while maintaining high efficiency and high power output. Addition of SF_6 to a pure nitrogen electrical-discharge laser appears to have the desired effect, although the reason is not completely clear yet—perhaps the SF_6 quenches the lower laser state or possibly as an electronegative gas it controls the initiating discharge in such a way as to lengthen the pulse. Preliminary data obtained by Steve Suchard at Aerospace Corp., a subcontractor to Los Alamos on this project, show that in a "pin" laser (a transversely excited electron-beam laser in which a row of needle points controls the discharge) with nitrogen and SF_6, the pulse length can be extended to 400 nsec—ten times longer than the pulses without SF_6—at an efficiency said to be "high."

Bigio told PHYSICS TODAY that there is "a good chance of high power, long pulses and scalability" with this design— a sentiment echoing that of all the other physicists we talked to. It remains to be seen which, if any, of these lasers will fulfill its expectations, and during the next year or so we should know.

—JTS

References

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Energy levels in ionic states of helium and molecular nitrogen. In the lasers being developed at the University of Texas at Dallas, energy is stored in dimerized helium ions, He_2^+, and transferred to nitrogen by a charge-transfer process. The lasing transition is shown here by a colored line: wavelength is 4278 Å.

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Radio-wave deflection

Brans–Dicke theory, which adds a scalar field with coupling constant ω to Einstein's tensor theory,

$$\gamma = (1 + \omega)/(2 + \omega)$$

Fomalont and Sramek believe that their results rule out any theory in which ω is less than about 23; they then note that for such a high value of the coupling constant, the scalar–tensor and Einstein theories are not very different, even in what they say about the early stages of the Universe or near massive objects. (Robert Dicke has most recently proposed[2] that ω has a value of 7.5.)

The Green Bank interferometer consisted of three steerable 85-foot antennas and one steerable 45-foot antenna. The larger antennas are fairly close to each other (maximum separation 2.7 km); the smaller is about 35 km distant and is connected to a control building by a phase-stable radio link. By correlating the signals of the 45-foot element to each of the 85-foot elements, three baselines of about 35 km are formed. The observations were made simultaneously at 2695 MHz and 8085 MHz on twelve days between 29 March and 25 April 1974. Each observing day was $9\frac{1}{2}$ hours long and followed an identical schedule—0119, 0116, 0111, 0116, 0119 . . . .—with each observation lasting about six minutes and $1\frac{1}{2}$ minutes needed to switch. Source 0116+08, then, which undergoes the largest deflection, was observed every 15 minutes, 38 times each day, and each comparison source was observed every 30 minutes. The experimenters report a relative positional accuracy of .04 arc sec among the sources. They are scheduled to repeat their experiment this month.

Dual frequency. Two features distinguish the latest NRAO experiment from most other radio-interferometric studies: the treatment of coronal bending and the use of three collinear radio sources. The solar corona bends radio waves more strongly than it bends visible light, so coronal bending has presented problems. Because Fomalont and Sramek observed at two frequencies, they were able to separate the bending caused by the solar corona, a frequency-dependent effect, from the relativistic bending, which is independent of frequency. At the same Dallas

meeting, the group working at Westerbork described their own dual-frequency studies (with a much shorter baseline), which had an error of about 3.3%.

As have most others who have studied solar deflection, the Netherlands group observed two quasistellar radio sources, 3C 273 and 3C 279, one of which (3C 279) passes close to the Sun each year on 8 October. In this method of calibration, the difference in the interference-fringe phase between the two sources is assumed to be a measure of their angular separation. According to Fomalont and Sramek, their own use of three nearly collinear sources allowed them to correct for that part of the interference-fringe phase that is caused not by coronal or relativistic bending but by arbitrary, time-related (such as changes in cable path length or in receiver electronics) or time-and-direction related (water-vapor clouds, antenna movement, earth tides) shifts. The closest source to the Sun was 0116+08, and the two outer sources (0119+11 and 0111+02) were the calibrator sources. They averaged the interference-fringe phase of the outer sources and compared this phase with the phase of the occulted source so that the effective angular separation between 0116+08 and its calibrator is very small.
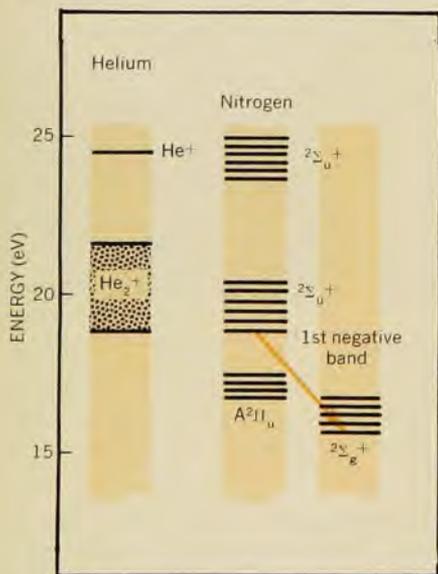
The Haystack–NRAO observations[1] were the first accurate application of very-long-baseline interferometry (VLBI) to test general relativity. This was a collaborative effort of scientists from three institutions: the Massachusetts Institute of Technology (Counselman, Kent, Knight and Shapiro), the Goddard Space Flight Center in Greenbelt, Md (Clark) and the Haystack Observatory (Hinteregger, Rogers and Whitney). They used two antennas at Haystack and two at Green Bank, about 845 km distant, to form two long-base-line interferometers, one directed at 3C 273 and the other simultaneously at 3C 279. They report a gravitational deflection of 0.99 ± 0.03 times the Einstein prediction.

The advantage of VLBI, Shapiro points out to us, is that because each signal is recorded independently, the baseline can be longer than in conventional or "short" baseline interferommetry, which uses a direct electrical connection between the receivers. Since accuracy is roughly proportional to baseline length (up to several thousand kilometers), he continues, VLBI will eventually win out, although at present the short-baseline technique is competitive.

—MSR

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