search & discovery

Sun appears to be oscillating at many frequencies

Last year Henry Hill and his collaborators reported seeing normal modes of oscillation in the Sun, with periods ranging from 6–70 minutes. By now the group says they have seen oscillations at a minimum of 20 different frequencies. Recently a group at the Crimean Astrophysical Observatory reported a period of 160 minutes, which was also observed by a group at the University of Birmingham, England (who also reported two shorter periods).

The ability to observe normal modes of the Sun would offer a new tool for probing the Sun's interior with seismic waves, just as is done for Earth.

Hill (University of Arizona) and his collaborators had been doing measurements of solar oblateness, which showed a null result (PHYSICS TODAY, September 1974, page 17), in disagreement with the earlier conclusions of Robert Dicke and Mark Goldenberg (Princeton University). As early as 1972 Hill and his collaborators had observed solar oscillations with their astrometric telescope. In the technique used, they define a point on the limb of the Sun with a Fourier transform of the outer 0.5% of the brightness curve to establish an edge. They examine the equatorial and polar diameters, rapidly sampling them for long periods of time. Then they look at the power spectrum to

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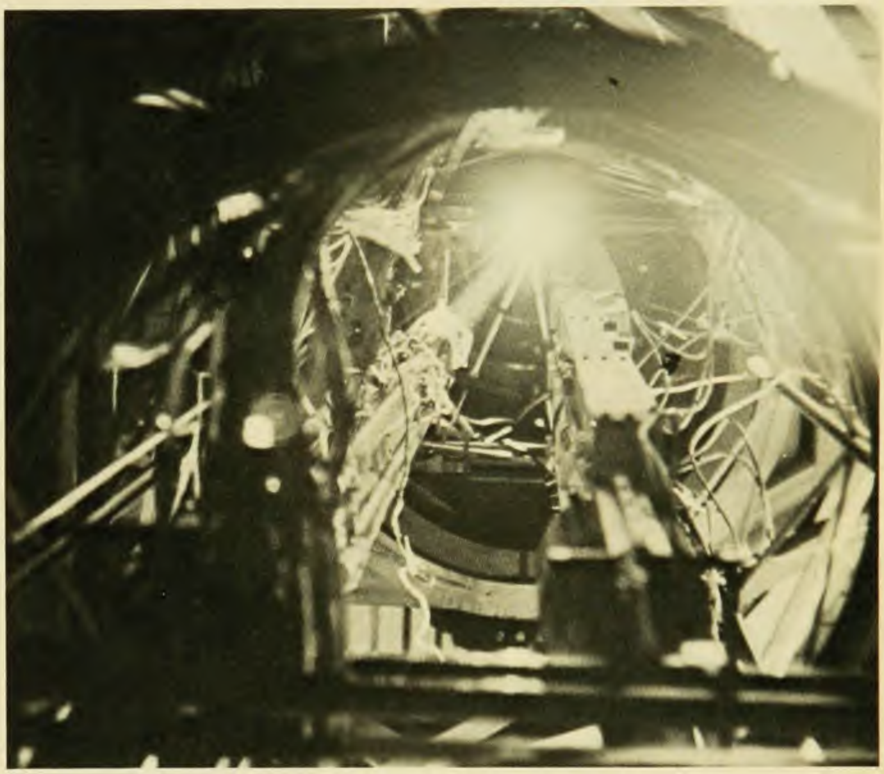


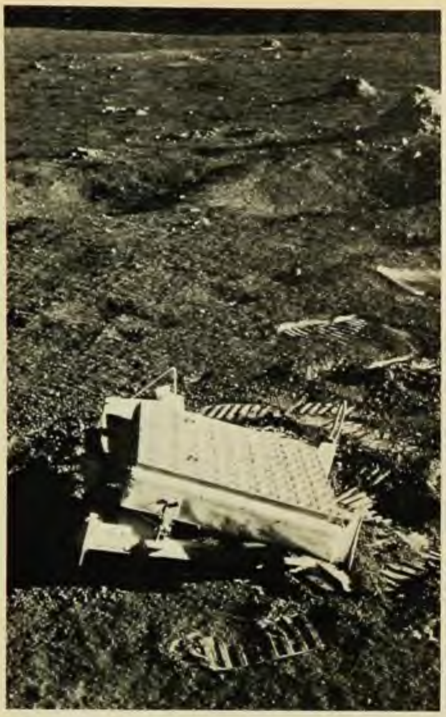
Solar telescope used by SCLERA group to study solar oscillations. Sunlight can be seen scattering off lens (center) and mirrors. The visible shaft of sunlight extends from lens down to illuminate sun detector (left); star detector is just right of center. The bright V with apex at the lens is made by light scattering off the tubes on which the detectors hang.

Lunar ranging confirms equivalence principle

Accumulated ranging data from reflector packages placed on the Moon by the Apollo astronauts have verified a previously untestable aspect of the equivalence principle. According to two simultaneously reported but essentially independent analyses of the same laser ranging data, Earth's gravitational self energy contributes equally to its inertial and passive gravitational mass. This equivalence would rule out Brans–Dicke–Jordan theory for small values of the coupling constant. Both analyses were published in the 15 March issue of *Physical Review Letters*. One,[1] covering six years of data, was reported by the "LURE" group (for Lunar Ranging Experiment): This group was established before the first Apollo mission to carry out the laser ranging experiment. Among its members are James Williams (Jet Propulsion Laboratory), Robert Dicke (Princeton University) and Peter Bender (Joint Institute for Laboratory Astrophysics), Carroll Alley (University of Maryland), Douglas Currie and James Faller (JILA), Derral Mulholland and Eric Silverberg (McDonald Observatory, University of Texas). The second report,[2] covering essentially the same data, is by Irwin Shapiro and Charles Counselman (Massachusetts Institute of Technology) and Robert King (Air Force Cambridge Research Laboratories).

The equivalence of inertial and gravitational masses has been measured by increasingly precise experiments to test the composition independence of free fall (the Eötvos–Dicke–Braginsky experiment). But these experiments did not rule out the possibility, suggested in 1961 by Dicke, that the gravitational self energy of a body could vary with its position in the gravitational potential of another body. Consequently the gravitational self energy of a large body (for example, Jupiter) could contribute anomalously to the weight of the body. For the relatively small objects involved in the Eötvos–Dicke–Braginsky experiments, the gravitational self-energy contribution to mass is immeasurably small. As the Massachusetts group points out, the gravitational binding energy for a meter-sized object is only one part in 10^{23} of the total energy, about 11 orders of magnitude too small to be presently detectable.

In 1968, however, Kenneth Nordtvedt (Montana State University) reexamined the equivalence principle in metric



Lunar laser-ranging reflector package. This device, shown at Fra Mauro landing site, was installed by Apollo-14 astronauts. It contains 100 solid fused-silica corner reflectors mounted in a 46-cm square aluminum panel. Each reflector is 3.8 cm in diameter.

theories of gravity. Among his conclusions was that any violation of the equivalence principle should be detectable in the Earth–Moon–Sun system. More specifically, there should be a variation δr in the Earth–Moon distance, with a synodic period of 29.53 days, such that

$$\delta r = C_0 \cdot \eta \cos D$$

Here C_0 is a constant equal to about ten meters, and D is the difference in the mean longitudes of the Moon and the Sun. The so-called "Nordtvedt parameter" η, which is zero for general relativity, was evaluated for those metric theories with energy–momentum conservation and spatial isotropy as

$$\eta = 4\beta - \gamma - 3$$

Here β and γ are two of the PPN (Parametrized Post Newtonian) parameters often used to distinguish among the various metric theories of gravity. For general relativity, γ is one; for Brans–Dicke–Jordan theory, which adds a scalar field with coupling constant ω to Einstein's tensor theory, γ is $(1 + \omega)/(2 + \omega)$.

The LURE group and the Massachusetts group both estimated η by analyzing the roundtrip travel times of 3-nanosec duration ruby-laser pulses from the McDonald Observatory towards one or another retroreflector package on the Moon and back again. Both groups used a lunar librational model developed by members of the LURE group. The analyses were in all other ways believed to be independent, with the Massachusetts group being the first one to obtain reliable results, according to both teams.

The LURE group found $C_0 \cdot \eta$ to be 0 ± 30 cm. This uncertainty, roughly eight times the statistical error, is estimated from possible systematic errors and limitations in the model. Taking C_0 as 9.26 meters, they find η to be 0.00 ± 0.03, equivalent to a ratio of $1 \pm 1.5 \times 10^{-11}$ for gravitational to inertial mass. They note that this is consistent with Brans–Dicke–Jordan theory only for $\omega > 29$, whereas Dicke's most recent prediction is 7.5. They expect that improvement in the distance measurement and in data analysis will lead to an order-of-magnitude improvement in the estimation of η within the next few years. Shapiro, Counselman and King find that η is -0.001 ± 0.015, with the uncertainty roughly four times the statistical error. The Mars–Sun–Jupiter system, they point out, is a promising independent one for verifying the equivalence principle for massive bodies, with the larger magnitude of the effects roughly cancelling the larger uncertainty in the measurement of interplanetary distances by radar. —MSR

References

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Searches for intelligence beyond Earth continue

The first timid searches for life in space began in 1959 with Project Ozma. Since then quite a number of groups have expanded the search for extraterrestrial intelligence, although the amount of effort is still small in comparison to the difficulty of the problem. At the February meeting of the American Association for the Advancement of Science in Boston, several groups discussed their pioneering attemps, which, as the reader may suppose, have so far proved unsuccessful.

There are still no definitely known planets outside our solar system, according to George Gatewood, who described the observing program at Allegheny Observatory of the University of Pittsburgh, in which 33 stars (within 15 light years of Earth) are being studied; all could have planetary-like systems around them. The most likely candidate to have a genuine planet is Barnard's star, which is being vigorously observed. Gatewood feels nothing definitive will be known for 5–10 years. Other suspected planetary systems include Epsilon Eridani and BD+43°4305. Gatewood noted that a space-borne telescope would revolutionize astrometry, making measurements two orders of magnitude more precise.

L. Frank Baum's Ozma was a land very exotic and very far away. Frank Drake's Ozma, initiated in 1959, was a search for exotic lands in two stars, studied for several hundred hours, at a frequency of 1420 MHz, the 21-cm line of hydrogen. It employed an 85-foot dish, a one-channel filter system and a receiver at 350 K.

Ozma II, a search conducted from November 1972 to August 1975 by Patrick Palmer (University of Chicago) and Ben Zuckerman (University of Maryland), used the 300-foot dish and the 140-foot dish at Green Bank, West Virginia, at a frequency of 1420 MHz. They had a receiving system equivalent to 384 channels, and the receiver operated at 50 K.

Palmer and Zuckerman observed 659 stars all told, tracking each source for four minutes at a time. In no sense did they monitor one star continuously. Typically each star was observed six or seven times. The stars studied were 6–76 light years away and similar to our Sun. They searched for a narrow signal with time variability. After scanning 90% of the data (without automation), no convincing evidence of extraterrestrial intelligence was found. Palmer feels that improvements in sensitivity are not the most important factor. Instead, he feels we must develop techniques that will analyze all radio frequencies simultaneously.

N. S. Kardashev of the Institute for Cosmic Research in Moscow was on the program but did not appear. In his place Carl Sagan (Cornell University) mentioned that the Moscow institute and one at Gorky University are each operating a network to search for extraterrestrial intelligence. To Sagan's knowledge, the Soviet observers have no convincing positive results.

Arecibo. Frank Drake, who is director of the National Astronomy and Ionosphere Observatory in Arecibo, Puerto Rico, discussed work done by him and Sagan at Arecibo, which has a 1000-foot-diameter dish with a total collecting area of 20 acres. In connection with the resurfacing of the dish, the transmitter, which operates at 2380 MHz, was used to send a 3-minute message to outer space, in the direction of the globular cluster Messier 13. When the beam was focused, it had an effective isotropic radiative power of 1.5×10^{13} watts. In tests preparatory to sending the message to Messier 13, the message was transmitted with the radio beam sweeping the sky, due to the Earth's rotation. Thus many stars received 12-second pieces of the message—not enough time to interpret it. Drake remarked that if an intelligent being picked up the signal, he would start watching our position in the sky for more messages, but none would be forthcoming. Thus the greatest discovery of the century would only result in another scientist