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 managing to lose his job.

Most of the Arecibo effort on extraterrestrial intelligence has been devoted to looking for signals rather than sending them. Drake and Sagan are looking at four frequencies: 1420 MHz (21-cm line of hydrogen), 1667 MHz (spectral line of the OH radical), 1652 MHz (where no observations have yet been made; the frequency is associated with the center of gravity of the H_2O molecule and is in the middle of the so-called "waterhole"), and 2380 MHz (which happens to be one of the antenna's radar frequencies). At all but the last frequency, the system noise is 100 K; at 2380 MHz, it is 42 K. A 1008-channel receiver was used. All frequencies have a bandwidth of 1 kHz—much less than that used in other searches, but still too wide, Drake believes. They observed with a 32-second integration time, making two independent samples and inspected the results immediately on an oscilloscope. If something looks interesting, the observers can look again promptly.

The observers looked for signals from nearby stars, such as Barnard's star, which they would have been able to detect with an effective isotropic radiative power greater than 10^{10} watts (10^{-3} Arecibos).

They also searched in four nearby galaxies, testing 10^{12} stars. These were Messier 33, Messier 49, Leo I and Leo II; the nearest is 1.5 million light years away. They are able to detect a power equivalent to 200 million Arecibos—something far beyond our technology. In the course of their observations, Drake and Sagan saw what appeared to be an intelligent signal coming from six different directions in Leo I. To their dismay, the signal turned out to be a terrestrial source intercepted by the sidelobes of the antenna.

The final speaker was Philip Morrison (MIT), who is chairman of a NASA advisory committee that is examining observational strategies. He noted that we should not be looking for a signal, but a high gradient in the signal. Morrison feels that we are still in the pioneering stage of the search. The second stage requires dedicated instruments: he would like to see a small, dedicated enterprise built now. —GBL

Group meets in USSR on Very Big Accelerator

This month, beginning on 17 May, an international study group will meet in Serpukhov in the Soviet Union, to discuss the prospects and possibilities of constructing a "Very Big Accelerator" by a world collaboration among many different countries. It would be a machine with much higher energy than any accelerator being planned by an individual nation.

In March 1975 a meeting was held in New Orleans, attended by about 25 high-energy physicists from the US, Western Europe, the Soviet Union and Japan to discuss various forms of international collaboration. The future development of high-energy physics was discussed, and many participants emphasized the desirability of extending the energy frontier beyond the limits presently available or recently proposed. any Many fundamental problems seem to require this extension for their solution, such as the question of the existence of a quantum of the weak interaction, the relation between the weak and electromagnetic interaction, and problems related to the quark hypothesis.

Many believe that national and regional authorities may no longer be willing to support projects that are considerably larger than those presently in existence or in the planning stage. Thus the Very Big Accelerator is being discussed.

At the meeting this month in Serpukhov, the American participants are expected to be J. D. Bjorken (SLAC), Robert E. Diebold (Argonne National Laboratory), Leon Lederman (Columbia University), Wolfgang K. H. Panofsky (SLAC), Victor Weisskopf (MIT) and Robert R. Wilson (Fermi National Accelerator Laboratory).

The international group will consider the possibility of building a proton accelerator of the order of 10 TeV (10^{13} eV) or an electron–positron colliding-beam device with each beam of about 100 GeV. Weisskopf emphasized to us that much of the discussion will probably focus on the best choice for an instrument and an energy range. To that end, the group is expected to consider the physics problems requiring higher energy and the numerous technical problems of achieving it.

"A world collaboration on the Very Big Accelerator," Weisskopf said, "would have important significance besides the mere scientific advantages, as a symbol of common human values beyond competition and strife, and as an example of intensive international collaboration across ideological frontiers." The former director of CERN said that the history of that laboratory has shown that high-energy physics is very conducive to such efforts because of its distance from commercial and military applications. There are many obvious political and social difficulties and problems in the way of such a project, Weisskopf notes, with little hope for an early realization. But, he feels, it is advisable to begin with this international study group.

Weisskopf urges that the vision of the Very Big Accelerator should not interfere in any way with further development of national or regional high-energy facilities. "Indeed," he says, "any international effort can be successful only if it is based upon well-developed national and regional research activities."

ERDA and the National Science Foundation are sponsoring the American participation. —GBL

Solar oscillations

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see at what frequencies there is significant power. Hill says that the Fourier transform is unaffected by the smearing effect of the terrestrial atmosphere.

The group, which consists of Hill, Robin Stebbins (National Center for Atmospheric Research) and Timothy Brown (High Altitude Observatory, NCAR), work at the Santa Catalina Laboratory for Experimental Relativity by Astrometry in Tucson. They made their initial announcement last June at the Fifth International Conference on Atomic Masses and Fundamental Constants, held in Paris. By now the group believes they have seen 20 modes in the 6–70-minute range. There is a broad peak at a period of 68.3 minutes, which the group feels may contain the fundamental acoustic mode. The longest period, Stebbins told us, that looks like it is clearly there is 109 minutes.

Hill says that the amplitudes of each period are all of the order of 5–10 arcmillisec out of a total solar diameter of 2000 arcsec. A naive interpretation of these results would mean that the sun was changing in size by 4–8 km during an oscillation. The Birmingham results for comparable oscillations imply size changes of the order of 0.4 km, Hill said; he explains the discrepancy by saying that the SCLERA group, unlike the Crimean and Birmingham observers, is not only seeing a deformation of the Sun itself, but also a change in the light-distribution curve. The whole sun is oscillating, he goes on, with waves reflecting in and out of the core. All one can see, however, is the outer 0.1%, and this outside portion acts like the end of a whip, moving with larger (but still relatively small) amplitude. Hill and his collaborators claim that the large amplitudes they see are primarily from brightness fluctuations caused by temperature variations. A small fraction of the amplitude, however, may be caused by an actual physical displacement, Stebbins says.

Most of the data were collected last October and November, when a typical run lasted 6–8 hours. The length of the data set determines the feasibility of observing longer periods. However, the SCLERA workers hope that they can string data sets from one day to the next by matching phases. If so, resolution of the period will be vastly improved. For example, the 68-minute period, which has an 8-minute uncertainty would, by linking three days, be defined to 0.75 minutes.

Stebbins outlined the group's arguments for believing that the pulsations observed are normal modes of the sun. He points out that other observers over the last 15 years have seen solar oscillations with periods of about five minutes, but Stebbins says that they were localized and lasted only a few cycles. More recently Franz-Ludwig Deubner (Fraunhofer Institute, Freiburg, Germany) has seen large-scale oscillations with periods of about five minutes and reported a 40–50-minute periodicity earlier. Normal modes are an organized motion of the entire body. Stebbins says that the group observed simultaneous coherent oscillations at the equator and at the poles—suggesting that the oscillations really show motion of the entire sun. Furthermore, the oscillations have been observed at widely separated times—one to two years.

Another argument is that, although the 5-minute oscillations damp out in a few cycles, Stebbins says, the SCLERA oscillations persist for days; that is, they last for hundreds of cycles in some cases.

In the Crimean experiment, done by A. B. Severny, V. A. Kotov and T. T. Tsap,[1] the experimenters compared the line-of-sight velocity at the solar surface near the equator with the velocity around the poles. They did this by feeding integrated sunlight into a magnetograph, at the end of which was a pair of exit slits located in the wing of a spectral line. The line shift can be measured by the intensity difference. To measure velocity instead of a magnetic signal, they place a circular polarizer in the central part of the beam, which acts to distinguish the center of the Sun from the limb. By chopping, the Crimean experimenters see light alternately from the entire disk and from around the limb.

The experimenters report an oscillation period of 2 hours 40 minutes with some hint of small-amplitude oscillations with a shorter period. Their initial observations were done August–October 1974 and March 1975, a total of 122 hours. The group now has observed for over a hundred days.

The Birmingham experimenters, J. R. Brookes, G. R. Isaak and H. B. van der Raay,[2] used a resonant optical scattering method. A polarized absorption line impinges on sodium or potassium vapor, which is placed in a longitudinal magnetic field; this causes Zeeman splitting. So one effectively absorbs light into the two wings of the line. The experimenters observed mainly the diurnal motion of the earth, but after removal of that signal, the residuals were examined for solar effects. Although the experimenters observed for 12 days, only two days were suitable.

The Birmingham group reports a period of 2.65 hours, which they identify with the fundamental radial oscillation mode of the Sun. In addition, they report a 58-minute period that they attribute to the fundamental nonradial mode and a 40-minute period, which they say is the second harmonic of the radial mode.

The phase of the Birmingham and Crimean 2.65-hour periods are in good agreement, according to both groups.

A group at the University of Nice, which in 1973 reported a 40-minute oscillation (now believed to be due to terrestrial atmospheric effects), has done further experiments, which are now in total disagreement with the observations of Hill and his colleagues, they say. The 1973 measurements were done by Eric Fossat and Gilbert Ricort. In the new work, Fossat and Gerard Grec used a sodium-cell optical resonance detector, similar to that used by the Birmingham group to measure velocity of the Sun's surface. They observed for four days for a total data length of 25 hours. Searching for periods between 5 and 90 minutes, the Nice pair found no evidence of oscillations.

Fossat told us that their sensitivity is about 1 meter/sec, which corresponds, if one assumes that limb displacements are only due to matter motions, to limb motion amplitudes that are 20–45 times smaller than those of the two major peaks in the SCLERA spectrum. Fossat says that such a ratio between brightness fluctuations and velocity of matter does not appear to be allowed by hydrodynamics. So he feels that the SCLERA spectrum can be interpreted as pure noise.

Theory. In the same issue of *Nature* where the Birmingham and Crimean groups reported their results, J. Christensen-Dalsgaard and Douglas O. Gough[3] (University of Cambridge) discussed the theoretical implications of those experiments and more particularly, those of Hill and his coworkers. Using a linear adiabatic model of the Sun, the two Cantabrigians calculated the periods of normal modes of vibration, both acoustic and gravity, and compared them with the observed periods.

In the model used by Christensen-Dalsgaard and Gough, one assumes the Sun is in equilibrium, calculates how convection transports heat and then solves the hydrostatic equations. Then one obtains linear perturbation equations and solves the eigenvalue problem. In this way you find out what happens when you kick the sun; you learn at what frequencies it rings. Edward Spiegel (Columbia University) feels that the model ought to include turbulence, which can both drive and damp the modes. Yoshi Osaki (Tokyo University) recently found that by including nonadiabatic effects, the modes become unstable. Another difficulty Spiegel identifies in the linear adiabatic model is that the modes one calculates can be drastically altered by changing the boundary conditions somewhat at the upper surface. Gough argues that although the boundary conditions influence the theoretical stability of the oscillations, they have very little influence on the periods. And, it is the periods that are being compared with observation.

The model of Christensen-Dalsgaard and Gough appears to be in reasonably good agreement with the SCLERA results. Christensen-Dalsgaard and Gough say that the 160-minute period reported could correspond to their g_{10} or g_{11} mode, an opinion that disagrees with that given by the Birmingham group. Gough told us that their model cannot be altered to yield a fundamental radial oscillation with a period of 160 minutes.

Recent work by Peter Goldreich (Cal Tech) and Douglas Keeley (University of California, Santa Cruz) may bear on the belief of Hill and his collaborators that their signal is mainly due to a brightness fluctuation on the limb. Goldreich told us that he calculated the amplitude for excitation of normal modes for a stable sun with modes driven by stresses in the convective zone. He obtains an amplitude of 1/100 cm/sec, far smaller than that reported by Hill and his collaborators. The Goldreich and Keeley calculations indicate that Hill's diameter oscillations must imply a velocity oscillation more than ten times what the Crimean and Birmingham teams reported. Thus Goldreich feels that the SCLERA group cannot be seeing a diameter oscillation due to thermal variations.

New attempts. Fossat told us that the University of Nice group plans now to improve their sensitivity by observing moonlight instead of sunlight. They feel that because the moon does not rotate, the atmospheric effects caused by rotation will be removed. In addition observations of the Sun will be repeated with a different telescope to lengthen the observable period.

At Stanford, John Wilcox and his collaborators (Leif Svalgaard, Philip Scherrer, Phil Dittmer, Thomas Duvall and Eric Gustafson) are beginning observations using an apparatus similar to the Crimean one. The possibility of joint observations with the Crimean group is now being explored.

Robert Howard will be using the Hale Observatories magnetograph, and William Livingston will be doing measurements with the Kitt Peak magnetograph.

The Birmingham group plans to construct a two-dimensional spectrometer to determine the type of solar oscillation actually occurring.

Prospects. The Birmingham group believes that the rotational splitting of nonradial modes, which should show as a low-frequency beat, can determine the angular velocity of the Sun's interior.

Christensen-Dalsgaard and Gough point out that spectral information on the Sun opens the possibility of a limited inverse problem, much like that posed by geophysicists to probe the internal structure of the Earth with seismic waves—an exciting prospect indeed.

—GBL□

References

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2. J. R. Brookes, G. R. Isaak, H. B. van der Raay, Nature 259, 92 (1976).
3. J. Christensen-Dalsgaard, D. O. Gough, Nature 259, 89 (1976).