Helioseismology from the South Pole: 1987 campaign

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Helioseismology is the study of the Sun's interior by means of observations of its global oscillations. The Sun constantly oscillates, at periods of about 5 minutes, in millions of different modes which probe different depth and latitude ranges. The observer's task is to measure the frequency, amplitude, and time behavior of as many of these oscillations as possible in order to build a detailed picture of the solar interior. This field has grown rapidly since its start in 1975 with the literature doubling every 2 years and now nearing 1,000 references.

Helioseismological observations have been made from the Amundsen-Scott South Pole Station nearly every year since 1980. This site offers the unique advantage of uninterrupted sunlight during the austral summer (except for clouds, of course) and otherwise generally good atmospheric conditions for astronomical observations. Thus, it is possible to measure oscillations without long nighttime gaps which confuse measurements made at low-latitude observatories.

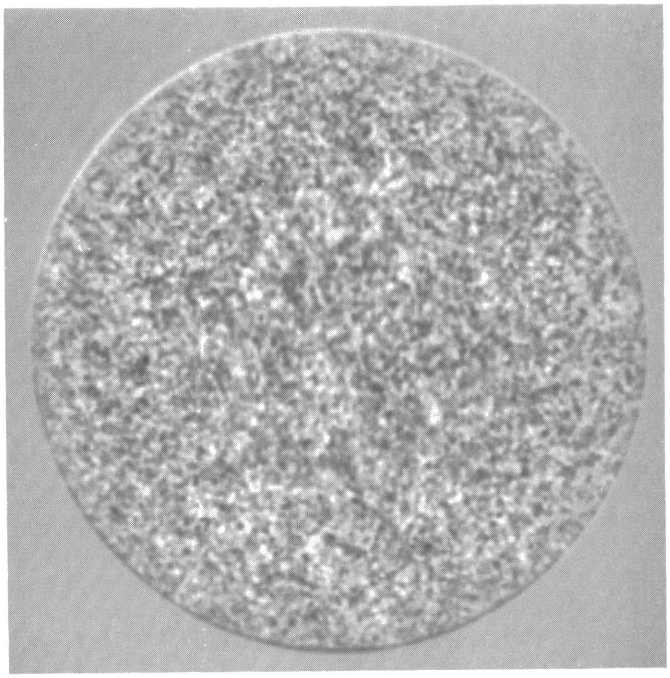
Measurements from the South Pole and elsewhere have shown that the solar interior is roughly similar to the predictions of the theory of stellar structure and evolution. This theory is one of the key foundations of our present picture of the universe. It is, therefore, disturbing that there are small, but highly significant, discrepancies between theory and observations and that these discrepancies have not been resolved by reasonable adjustments of theoretical parameters and physics. Currently, the source of these discrepancies is not at all clear. Helioseismology, however, not only revealed the problem but offers excellent prospects for solving it.

In December 1981, at a time of high solar activity, we made observations from the South Pole with the solar disk resolved into about 50,000 spatial elements (Pomerantz, Harvey, and Duvall 1982). This allowed unambiguous measurement of the frequencies of thousands of oscillations (Pomerantz et al. 1985; Duvall, Harvey, and Pomerantz 1988; Duvall et al. 1988). These measurements have been used to deduce the depth variation of sound speed and the interior rotation vs. depth and latitude (Duvall, Harvey, and Pomerantz 1986). An unexpected result was the first evidence that the internal structure is different along equatorial and polar radii. Comparison of our frequency measurements with those made at other observatories suggests that the frequencies of the oscillations and the structural asymmetry may vary with the level of solar activity, but comparisons are currently contradictory.

To help resolve this issue, we obtained additional observations in November 1987 at a time when the Sun was near the low point of its 11-year cycle of activity. The experimental setup was essentially the same as used in 1981, but with some improvements. A new optical system was constructed and mounted on the Bartol Solar Tracking Platform which replaced the original vertical telescope (Pomerantz 1983). A better camera system was available so the new measurements have a higher signal-to-noise ratio and also the weather was more favorable in 1987. About 16,000 images were recorded at a rate of one per 75 seconds over a period of 17 days. The figure shows the difference of two images obtained about half an oscillation period apart. The oscillations are visible as dark and light patches.

Processing the 2 gigabytes of recorded data is a formidable job which is not complete at the time of this writing. So far, indications are that the data are satisfactory for making a good comparison with our 1981 results to determine whether the oscillations change with the level of solar activity.

This program could never have been accomplished without the outstanding support provided by Antarctic Services, Inc., personnel at the South Pole and elsewhere as well as by cognizant members of the Division of Polar Programs at the National Science Foundation and VXE-6. Their efforts allowed us to start observing promptly after our arrival on the second flight of the season in spite of abnormally low temperatures. We are also indebted to personnel of Photometrics, Ltd., for making special modifications to their digital camera system.



Difference between two images of the Sun recorded about half an oscillation period apart with the equipment used in the 1987 campaign. Each image is recorded with a charge-coupled-device camera and a filter which transmits light only from cool parts of the solar atmosphere where oscillations are particularly strong. The difference image shows oscillations as light and dark patches. These patterns are the superposition of thousands of modes of oscillation which probe different depth and latitude ranges in the Sun.

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A search for ultra-high-energy gamma rays at the South Pole

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In the same year that Amundsen reached the South Pole, an Austrian physicist, Victor Hess, discovered that the outer layers of the Earth's atmosphere are continuously being bombarded by a rain of charged particles called cosmic rays. In yet another of many attempts which have been made in the ensuing years to pin down the origin of this important component of extraterrestrial radiation, a new instrument was set up at the South Pole during the 1987–1988 austral summer.

Recently it has been discovered that some X-ray binary systems (such as Cygnus X-3 and Vela X-1) emit gamma rays with energies greater than 100 terraelectronvolts. The gamma rays arise from the decay of neutral π-mesons which in turn are produced by the interaction of energetic protons with gas in the region around the X-ray binary. These protons—the grandparents of the gamma rays—are accelerated in the complex electric and magnetic fields associated with the neutron star and accretion disc of the binary system. Only a fraction of the protons interact, and those which escape are injected into the interstellar medium to become "cosmic rays." It is more fruitful to study the gamma rays as a clue to cosmic ray origin, rather than to look at the incoming proton beam itself: unlike the charged protons which "random walk" as they are scattered by magnetic fields in the galaxy, the gamma rays travel in straight lines. This makes it possible to identify point sources, provided the exceedingly small gamma-ray signal can be picked out from the more abundant and isotropic cosmic-ray background.

Detection of high-energy cosmic and gamma rays is rather complicated. Because of the very low flux above 100 terraelectronvolts (approximately 1 per square meter per year), a very large area detector is required, and one must make use of the fact that both the cosmic and gamma rays generate cascades containing many thousands of particles when they interact in the Earth's atmosphere. At the altitude of the South Pole, the particles are traveling at the velocity of light in a disk about 50–100 meters in radius and a few meters thick (figure 1). In the Bartol/Leeds telescope, sixteen 1-square-meter blocks of plastic scintillator are spread out over about 7,000 square meters (figure 2). The disk arrives at each detector at a different time (see figure 1) and, by measuring the relative arrival times, it is possible to deduce the arrival direction of the incoming cosmic ray or gamma ray to within about 1°. The precision of measurement necessary at each accurately known detector position is about one billionth of a second.

The South Pole provides a unique location for studying X-ray binary systems which are candidate sources of ultra-high-energy gamma rays: many more are visible than from northern latitudes and, most importantly, every source remains at constant elevation. This latter feature is particularly crucial because most of the sources detected so far appear to be sporadic emitters of radiations. Additionally, the height of Amundsen-Scott Station (equivalent to 3,200 at warmer latitudes) means that the cascades of particles are close to their maximum size. Thus, the energy threshold of the telescope is relatively low. An added bonus that was not anticipated when this project began

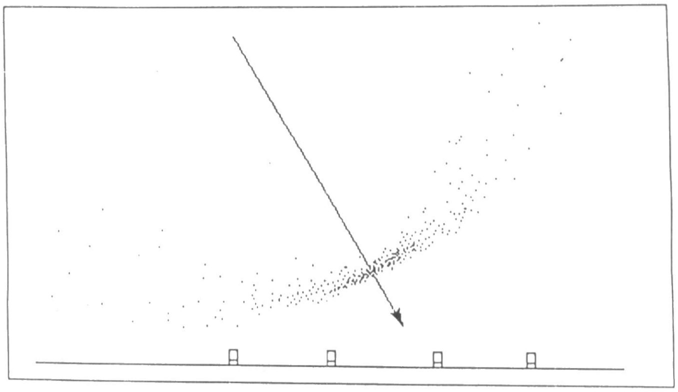

Figure 1. A schematic representation of the particle cascade (dots) about to hit four detectors. The arrow shows the direction of the incoming cosmic ray or gamma ray which has initiated the cascade.