# news and views

## New data from solar oscillations

*from Douglas Gough*

NEW analyses of the observations of solar oscillations have posed more problems about the internal structure of the Sun. At a meeting on Highlights of Solar Physics held recently in Toulouse, Henry Hill (SCLERA, Arizona) presented evidence that of the oscillations he had reported previously at least those with periods of 45 min and 1 h contain components that are internal gravity waves. He compared signals obtained from integrating light from different extents of the solar limb and was able to deduce that there is significant power in modes with horizontal wavelengths between 1/40 and 1/20 the radius of the Sun. If these modes were standing acoustic waves their frequencies would be at least twice those observed, whereas gravity modes, or $g$ modes, could have the observed frequencies.

The problem this observation raises is that if the structure of the Sun were as most solar physicists believe, with a convective envelope penetrating some 20% of the solar radius beneath the photosphere, one would not expect to see the modes Hill reports. Wojtek Dziembowski emphasised at the Toulouse meeting that typical gravity waves with so short a horizontal wavelength are severely confined within the radative interior of the Sun, being attenuated through so deep a convection zone by a factor of a million or more. Therefore they could not possibly be seen at the photosphere. How can this difficulty be resolved?

One potential explanation, as Jurgen Christensen-Dalsgaard has pointed out, is simply that the modes are not so confined beneath the convection zone. There is a class of solar oscillations; formally classified as $g$ modes, whose amplitude is greatest at the surface. They are those overtones which, irrespective of the detailed structure of the Sun, have frequencies close to $\sqrt{gk}$, where $g$ is the acceleration due to gravity and $k$ is the horizontal wavenumber of the mode. The modes have the same frequency as surface waves on deep water, and are dynamically similar. Unfortunately such modes with wavenumbers corresponding to those reported by Hill would have periods between about 25 min and 35 min, which are too short to account for the observations.

A second possibility is that the solar structure is actually rather different from the so-called standard models. Some years ago Paul Joss (*Astrophys. J.* **191**, 771; 1974) argued that the Sun was formed with a low heavy element abundance and subsequently suffered contamination of its surface by infalling interstellar material. If that were the case the Sun would have a very shallow convection zone. It would support a class of $g$ modes trapped just beneath this zone which have substantial amplitudes in the photosphere, and have periods and wavelengths compatible with Hill's observations.

At first sight this idea sounds attractive, especially since it also leads to a low neutron flux consistent with Davis's measurements. But there are difficulties in explaining how the Sun could have formed with so low a heavy element abundance that would be required to explain the present luminosity. Potentially more serious an objection, however, comes from Franz Deubner's measurements of the diagnostic diagram for the 5-min oscillations, recently confirmed by Rhodes Jr, Simon and Ulrich (*Astrophys. J.* **218**, 521, 901; 1977) which seems to be reproducible theoretically only with solar models having convection zones even deeper than those of the 'standard' models. The theory of the 5-min oscillations, however, is not yet sufficiently developed for us to know how serious an obstacle this raises for advocates of the shallow convection zone.

A result we have been waiting for since Deubner's first publication of the diagnostic diagram is the rotational splitting of the 5-min modes, which measures the mean Coriolis force experienced by the oscillating fluid. This has now been provided by Deubner, Rhodes Jr. and Ulrich and will be published soon in *Astronomy and Astrophysics*. Unfortunately there is much scatter in the data, but it has at least been possible to deduce that the solar angular velocity at the equator increases with depth. This result is consistent with our previous deductions from comparisons of the photospheric rotation deduced from Doppler shifts and the more rapid rotation of magnetic features, which presumably reflects the motion near or below the base of the supergranules.

Rotational splitting may also have been detected in the 2 h 40 min oscillations reported by Severny, Kotor and Tsap (*Nature* **259**, 87; 1976). This is of particular interest because the long period oscillations penetrate deep into the solar interior, unlike the 5-min modes which are confined to within about 10,000 km of the photosphere.

At the Toulouse meeting the Crimean astronomers reported a modulation in the amplitude of the 80 min Fourier component of these oscillations with a period of about 27 d, or possibly half that value. If this results from rotational splitting of nonaxisymmetrical $g$ modes it could have important implications concerning the mean rotation of the entire Sun, although whether it implies slow or rapid rotation depends on the degree of the surface harmonic characterising the mode. This has not yet been measured. The result would have a bearing on the solar oblateness, and in this context it is interesting to note that the rotationally induced precession of the $g$ modes deduced from the Russian observations could be comparable with the precession of the apparent oblateness of the Sun reported by Dicke (*Solar Phys.* **37**, 271; 1976).

These new results have not changed our ideas about the solar structure, but they have added to the data that must constrain our theoretical models. □

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* The proceedings of the meeting in Toulouse on Highlights of Solar Physics have been edited by J. Rösch and will be published by the CNRS in October.

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