Prediction of solar oscillation frequencies

SIR—Deviations from spherical symmetry in the Sun cause a splitting of otherwise degenerate oscillation frequencies ν_{nlm} of modes with the same order n and degree l. This splitting is usually represented by a truncated expansion in Legendre polynomials P_k of the form

$$\langle \nu_{nlm} - \nu_{nl0} \rangle = \sum_{k=1}^{5} a_k(L, t) P_k(m/L)$$

where t is time, $L^2 = l(l+1)$, m is the azimuthal order of the mode, and the angular brackets denote an average over n. The odd k terms result from advection by rotation; the even k terms arise from an axisymmetric aspherical component of the structure of the Sun.

Several measurements have been made of the even coefficients a_{2j} for acoustic oscillations (p modes), the first in December 1981–January 1982. They showed little systematic variation with L, indicating scarcely any radial variation of solar asphericity at distances from the centre greater than about 0.55 of the Sun's radius (the lower extent of the most deeply penetrating modes contributing to the 1981–82 data set, obtained at a time of high solar activity). These coefficients do, however, vary with time, and the figure shows that there is a correlation with the sunspots.

Let us suppose that a measure of the longitudinally integrated sunspot density

$$\sigma(\theta, t) = \sum_k \beta_k(t) P_k(\cos\theta)$$

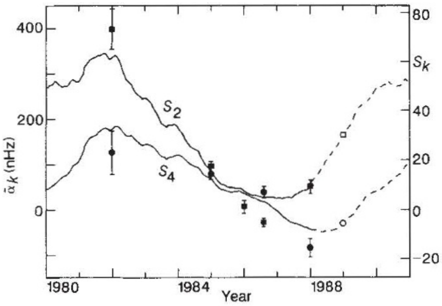
is a direct indication of the acoustic asphericity in the internal structure of the Sun, in the sense that σ is proportional to the variation with respect to t and colatitude θ of the propagation speed of acoustic waves. In this case, odd terms hardly contribute to the splitting and

$$a_{2j} \propto S_{2j} \equiv (-1)^j \frac{(2j)!}{2^{2j}(j!)^2} \beta_{2j}$$

is approximately satisfied by the even terms[1], provided by $l>j$ (which is the case for all the modes considered).

Averages $\bar{a}_2$ and $\bar{a}_4$ over L of the splitting coefficients a_2 and a_4 are compared with S_2 and S_4 in the figure. The direct contributions from the centrifugal distortion of the star, −22 nHz to $\bar{a}_2$ and +1 nHz to $\bar{a}_4$, have been subtracted; these were estimated from the internal angular velocity $\Omega(r, \theta)$ inferred by Brown *et al.*[2] using an asymptotic frequency-splitting analysis[3]. The rise of $\bar{a}_2$ following a sunspot minimum, announced recently[4] and discussed in my News and Views article last week[5], is mimicked (rather weakly) by S_2. But S_4 lags behind S_2, and at the time of the latest measurements it, like $\bar{a}_4$, had not increased.

New observations by a team from the National Solar Observatory, United States, are being undertaken at the South Pole. If the sunspots really are a superficial indicator of an underlying acoustic asphericity, one can predict the results of those observations from the figure. The mean coefficient $\bar{a}_2$ should rise further to about 140 nHz, and, following the upturn of S_4, $\bar{a}_4$ should also have started to rise,



Averaged even coefficients a_{2j} of acoustic solar oscillations. Squares, $\tilde{a}_2 = \bar{a}_2 + 22$ nHz; circles, $\tilde{a}_4 = \bar{a}_4 - 1$ nHz; data for the filled symbols before 1987–88 from ref. 6; 1987–88 data from ref. 4. Open symbols, predictions for the observations presently being carried out. Lines, S_2 and S_4, obtained by fitting equation (2) to the longitudinally integrated relative surface density $\sigma(\theta, t)$ of sunspot numbers. (The relative density is defined such that if σ were independent of θ it would take the value of the total sunspot number over the entire surface of the Sun). Sunspot numbers obtained by summing meridian passages over intervals of one Carrington rotation period P, and then smoothing with a running mean of interval $6P$. Data from Mt Wilson archives[7]. Prediction (dashed lines) carried out using data from the previous cycle, and should be improved when sunspot data are available for the period of the current observations.

although its value, about −30 nHz, will not be substantially greater than it was last austral summer.

Finally, I consider the influence on the solar irradiance, I. If the internal acoustic asphericity is visible as a surface temperature perturbation[6] of such magnitude that the variation of solar irradiance may be explained simply by a latitudinal redistribution of radiant flux at constant solar luminosity, then the changing shape of the asphericity during the rising phase of the cycle[1,5] would lead to a rise of I, at the very beginning of a new cycle, which is slow compared with what one would expect if I were proportional simply to total sunspot number. The prediction from the figure would then suggest that the Solar Maximum Mission ACRIM[7] is measuring a mean irradiance of 1,367.5 W m^{-2} at present, rather than the value of 1,367.7 W m^{-2} deduced on the basis of sunspot number. The irradiance variation would be roughly proportional to sunspot number during the declining phase of the cycle, however, because then the sunspots are at low latitudes and the detailed shape of their distribution has little influence on I.

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1. Gough, D.O. in *Seismology of the Sun and Sun-like Stars* (ed. Rolfe, E. 663–667 ESA SP-286, Noordwijk, 1988).
2. Brown, T.M. *et al. Astrophys. J.* (in the press).
3. Gough, D.O. & Taylor, P.P. *Mem. Soc. astr. Italiana*, **55**, 215–226 (1984).
4. Jefferies, S.M. *et. al. Seismology of the Sun and Sun-like Stars* (ed. Rolfe, E. 277–282 ESA SP-286, Noordwijk, 1988).
5. Gough, D.O. *Nature* **336**, 618–619 (1988).
6. Kuhn, J.R. *Astrophys. J.* **331**, L131–L134 (1988).
7. Willson, R.C. & Hudson, H.S. *Nature* **332**, 810–812 (1988).

Stephan's Quintet

SIR—In his review[1] of Halton Arp's book *Quasars, Redshifts and Controversies* Michael Rowan-Robinson's only reference to a specific scientific problem is misleading.

This issue is the nature of the five closely associated galaxies called Stephan's Quintet. We showed[2] in 1961, well before Arp set out on his controversial career, that one of the galaxies has a much smaller redshift, by a factor of 7–8, than the other four. The question then is whether this is an accidental configuration with each component at its redshift distance, whether the difference is due to the fact that the lower redshift system NGC 7320 is being ejected from the group at a velocity of about 5,000 kilometres per second which we speculated might be the case, or whether the difference is due to some 'intrinsic' redshift property. Arp believes the last, and supposes that the four galaxies with higher redshifts have intrinsic components which dominate. Many people have studied this problem, and Arp gives an account of what he and others have done.

At the end of his account, on page 100 of the book, Arp lists the arguments for and against a large distance for the higher redshift system. Although he does editorialize, he gives a fair account. The statement by Rowan-Robinson that Arp is guilty of sophistry by giving arguments against the large distance is quite unfair. The uninitiated may well have concluded from the review that it is NGC7319 which is the single anomalous galaxy rather than NGC7320. To most of us, Stephan's Quintet remains a puzzle.

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1. Rowan-Robinson, M. *Nature* **336**, 287 (1988).
2. Burbidge, E.M. & Burbidge, G.R. *Astrophys. J.* **134**, 244 (1961).

Seal correction

In the letter *Characterization of a seal morbillivirus* (Cosby, S.L. *et al. Nature* **336**, 115; 1988) some of the figures in the table were printed incorrectly. The results for reactivity of monoclonal antibodies against canine distemper virus (CDV) with phocine distemper virus (PDV) should read

Anti-CDV monoclonal	PDV
H1 (3.734)	−
H2 (3.755)	−
H3 (4.043)	+
H4 (2.267)	−