outer solar envelope. Our formulation does not remove angular momentum from the outer parts of the radiative zone with the required efficiency and an important physical process is either missing or inadequately described in our models.

An important consequence of helioseismology is our increased confidence in the validity of the SSM. Further improvements in the nuclear energy generation processes in the Sun and in diffusion coefficients in the solar interior (Bahcall & Loeb, 1990) have further refined on the SSM (Bahcall & Pinsonneault, 1992a,b). Helioseismology also provides an excellent opportunity to test non-standard solar models (NSSM). By narrowing down on the range of plausible solar models, helioseismology will enhance our ability to use observations of solar neutrinos to study low energy particle physics.

There has recently been a resurgence of interest in the context of cosmological inflation in the possibility of varying G cosmology and that Newton's constant of gravitation may be a function of time in a Brans-Dicke like manner (Accetta *et al.*, 1990; Krauss & White, 1992). We have been able to set limits on varying-G during the evolution of the Sun using the observed solar p-mode spectrum (Demarque *et al.*, 1994). This is basically because the depth of the solar convection zone is affected by varying G. This work has been extended to solar g-modes (Guenther *et al.*, 1995), which were found to have even greater sensitivity to varying G. This result is consistent with the greater sensitivity of g-modes to the density distribution near the center of the Sun.

Helioseismology will continue to offer a great opportunity to test the evolution of rotating stars. The physics of the outer layer of the Sun, where current models fail (Guenther, 1994), in particular the superadiabatic layer just below the photosphere, will become amenable to more realistic modeling with the advent of the GONG network and the launching of the SOHO space mission in the near future.

10. The solar interior and BISON observations (Y. Elsworth)

The data taken by the Birmingham Solar Oscillation Network (BISON) forms an interesting link between the twin themes of this session: solar and stellar seismology. Like stellar astronomers, we view the Sun as a star without spatial resolution. There are clearly disadvantages in this, in that we lose information about oscillations which vary rapidly across the Sun. But we are not limited to just the simple radial mode which has l=0; because of Doppler imaging we see modes with a range of l from 0 to 4. Unlike stellar astronomers, our star is near to us and the photon flux is high enough that we need not be limited by photon shot noise. We detect the modes by measuring the integrated surface velocity of the Sun. With long inte-

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gration times, and for the coherent modes, the smallest amplitudes that we can measure are between 1 and 0.1 cm s^{-1}. The instrument that we use is reported in the literature. It can be described in outline as follows: with rapid switching between each side of the line, we measure the intensity on the sides of the 770nm solar Fraunhofer line. From those intensities we form a ratio which is the difference in the intensity on the two sides of the line divided by the total intensity measured. This ratio is nearly linearly proportional to the relative velocity of the observer and the Sun. The measurement is thus differential and relies on atomic physics for its stability. Hence we have measurements of high stability dating from our first observations in the late 1970s. The data we obtain from each single station are therefore very clean. However that is not enough. Our goal is to derive spectra that are free from the contaminating effects of sidebands that necessarily occur in interrupted data sets. To this end we have a world-wide network that currently has six stations. In recent years we have achieved fills of between 70 and 80% over several months. The good fill and high quality have allowed us to produce a 32 month spectrum with 66% fill. There is a huge range of science that can be addressed by that data set. Here I wish to concentrate on just two aspects - the mode separation as the probe of the solar core and rotational splitting of the modes. The small splitting (or fine structure) between nearly degenerate modes l=0 and l=2 and l=1 and l=3 is a measure of the physics of the energy generating core of the Sun. We have previously shown that the standard solar model is a good description of the Sun and its evolution; now we have improved the statistical accuracy of our measurement and are able to comment on refinements to the models. In particular, we reported at the GONG 94 meeting that models which incorporate helium and other heavy element settling are more consistent with our data than is the standard model (Elsworth *et al.*, 1995a,b). The rotational splitting data, also first shown at the GONG 94 conference, is entirely new. For the first time we have been able to detect low-l, low-n modes whose line-width is much less than the splitting induced by the rotation of the Sun. The modes in question are those between 1400 and 1800mHz. For frequencies above this range one must either use an instrument which resolves the surface of the Sun or one must deconvolute that splitting from overlapping groups of lines. Given the signal to noise ratio in the data this process is risky.

In the same way as discussed for the fine structure, the rotational splitting measured gives us information about the core of the Sun. Current high-l measurement have provided information on the rotation rate of the Sun as a function of depth but they cannot probe close to the very core. The modes which we study penetrate into core to within 6% of a solar radius from the center. For those modes we find a mode-splitting which is just below the rate predicted by the surface rotation. This is consistent with the core of the Sun rotating relatively slowly. The results from other workers in the field have implied a rather faster rotation for the solar core. However, it should be emphasized that the other results do not come from cleanly split lines and we would therefore consider them to be less reliable than our current result.

11. Frequencies and splittings of low-degree solar p modes: Results of the Luminosity Oscillations Imager (T. Appourchaux)

The design of the LOI instrument was an original idea of Andersen *et al.* (1988). It consists of a Ritchey-Chrétien telescope (f=1300 mm) imaging the Sun through an 5-nm passband interference filter at 500 nm. The image is projected on a photodiode array detector built to our specifications (Appourchaux *et al.*, 1992). The detector is made out of 12 scientific pixels and of 4 guiding pixels. The shape of the scientific pixels are trimmed to detect low degree modes for $l < 7$ (Appourchaux and Andersen, 1990). The guiding pixels are 4 quadrants of an annulus with an inner and outer radius of 0.95 and 1.05 solar radius, respectively.

The LOI instrument was installed on an equatorial mount on May 2, 1994 in Tenerife. The time series analyzed here starts from May 2 and ends on October 11. The duty cycle is about 33%. Most observations were performed when the Sahara desert blows sand in the sky of Tenerife, and therefore lowers the transparency and increases the scattered light. The clock of the PC was drifting from day to day. This drift was daily measured and if necessary the PC clock was readjusted. The observed stability of the guiding was about 0.2-0.4″.

Table 1 summarizes the frequencies of the detected modes. For $l = 2$, we are in agreement with Elsworth *et al.* (1994), and Toutain and Kosovichev (1994) (average over $l = 1, 2$: 440 $\pm$ 10 nHz, 452 $\pm$ 20 nHz respectively), and in disagreement with Fossat *et al.* (1994) (low order modes: 499 $\pm$ 15 nHz); these 3 values represent an average of the splitting of sectoral modes, and should therefore be slightly higher than our a_1 by a few nHz (Gough, *private communication*). For $l = 3$, we are in disagreement with Fossat *et al.* (1994) (low order modes: 463 $\pm$ 15 nHz). On the other hand, we are in good agreement with the values of a_1 found by Rhodes *et al.* (1990) for $l = 3, 4$ and 5 (426 $\pm$ 28 nHz, 412 $\pm$ 10 nHz, 406 $\pm$ 8 nHz, respectively). It must be pointed out that the agreement with Rhodes *et al.* (1990) may be even better as the autocorrelation method, that they used, systematically overestimates the splittings below $l = 10$ (Brown and Morrow, 1987).

The splitting we found for $l = 2$ confirm the findings of Elsworth *et al.* (1994), Fossat *et al.* (1994), Jiménez *et al.* (1994), and of Toutain and