SPATIALLY RESOLVED OBSERVATIONS OF LOW-DEGREE SOLAR OSCILLATIONS

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ABSTRACT We have recently completed an instrument, called LOWL, which is optimized for the observation of solar oscillations of low degree. The instrument combines the stability of an atomic wavelength standard with the capability to image the solar disk with moderate spatial resolution. We present the initial observations from the instrument which confirm that the data is of sufficient quality to allow the determination of the rotation rate of the solar core in the near future.

INTRODUCTION

The low-degree acoustic oscillations derive their importance from their ability to probe the structure and rotation of the solar core. In the past, measurements of these low-degree modes have been primarily limited to observations of the sun in integrated light. This observing technique suffers from the inability to separate individual oscillation modes. This shortcoming is not important for the measurement of multiplet averaged eigenfrequencies, but it does severely compromise rotation measurements because the mode linewidths are comparable to the frequency splitting. This results in the blending of modes in a given multiplet in integrated light power spectra. Observations with spatial resolution, however, allow the isolation of individual modes as well as the separation of prograde and retrograde traveling waves. This gives spatially resolved observations a distinct advantage over integrated light observations for the purpose of measuring rotational frequency splittings, and therefore solar rotation, with minimal systematic error.

We have constructed an instrument specifically optimized to observe solar oscillations of low degree. The primary goal of the LOWL instrument is to measure the frequency splitting of the low-degree modes in order to determine the rotation rate of the solar core. Measurement of solar core rotation bears directly on several important questions including the distribution and evolution of solar and stellar angular momentum (MacGregor and Brenner, 1991; Charbonneau and MacGregor, 1993), the solar dynamo (Gilman et al., 1989), and the solar quadrupole moment with its implications for General Relativity.
INSTRUMENT

The main requirements for an instrument to observe low-degree frequency splittings are that the instrument spatially resolve the solar disk, and have a zero-point that is stable at the m/s level. Requirements for the observation of low-degree oscillations (Veitzer et al., 1992) and the characteristics of the LOWL instrument (Tomczyk et al., 1992, 1994) have been described in detail elsewhere.

The LOWL instrument is located at the Mauna Loa Solar Observatory at an elevation of 3400 m on Mauna Loa on the island of Hawaii. The LOWL is a doppler imager based on a Potassium Magneto-Optical Filter. It employs a two-beam technique to simultaneously observe solar images in opposite wings of the absorption line of Potassium at 769.9 nm. The instrument has spatial resolution of 25 arcseconds and a noise level of 15 m/s/pixel per 15 second observation. Thermally induced zero-point drift has been reduced to a level of 6 cm/s rms integrated over the 5-minute band. The LOWL instrument is compact, stable, is immune to intensity fluctuations of atmospheric or instrumental origin, and has a doppler analyzer with no moving parts.

OBSERVATIONS

The LOWL instrument was put into operation on Feb. 26, 1994. We are now in the process of analyzing the initial 3 months of data. Standard helioseismic reduction routines have been adapted from those used for Fourier Tachometer data analysis (Brown, 1985). Velocity images are averaged over one minute intervals and decomposed into spherical harmonics including all modes up to $l=80$, followed by temporal fourier transforms.

![Mean Velocity and Ephemeris Velocity, 6/5/94](image)

Fig. 1 Mean velocity (bottom), and ephemeris velocity throughout June 5, 1994. The small perturbations of the lower curve are due to low-degree oscillations.
Fig. 2 An $l$-$\nu$ diagram for the 3 month dataset, with an enlargement of a portion of the diagram shown to the right.

In Figure 1 we have plotted the mean velocity of solar images over the course of one day along with the theoretical observer-sun velocity variation. The observed velocities follow the theoretical curve except for an offset which is constant and instrumental in origin. This figure illustrates instrument stability which is comparable to integrated light instruments with a noise level approaching the solar noise limit.

- An $l$-$\nu$ diagram was computed by collapsing all of the modes of same degree after shifting the spectra to allow for solar rotation, and is shown in Figure 2. An enlargement of a portion of the diagram is shown to the right in Figure 2 where individual modes are clearly visible down to $l=0$. The LOWL instrument provides high quality observations of both low and intermediate degree oscillations.

The ability to measure low-degree frequency splittings is illustrated in Figure 3 where we have plotted a portion of the prograde, $m=0$, and retrograde spectra for $l=1$. Individual modes are observed with high signal-to-noise ratio.
Fig. 3 $m$-$\nu$ diagram for $l=1$ modes. The prograde spectrum ($m=-1$) is shown at the bottom, $m=0$ spectrum is shown at center, and retrograde spectrum ($m=1$) is shown at the top.

SUMMARY

We have shown that the LOWL instrument is capable measuring the frequency splittings of the low-degree solar oscillations. Estimation of the rotational frequency splittings for the 3 month dataset is currently underway. Preliminary results from a 17 day subset of this data has been presented (Schou and Tomczyk, these proceedings). We find that the uncertainty in the splitting coefficients is roughly consistent with the limits set by mode statistics (Veitzer et al., 1992). We expect that this 3 month dataset will provide a measurement of the solar rotation rate at $.2R_\odot$ accurate to $\sim 25\%$. Longer datasets will be accumulated in the near future which will allow increasingly tighter constraints to be placed on solar core rotation.

REFERENCES
