DETECTION OF SOLAR p MODES IN THE GUIDING SIGNALS OF THE LUMINOSITY OSCILLATIONS IMAGER

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ABSTRACT

The Luminosity Oscillations Imager (LOI) is a sub-unit of the VIRGO instrument on-board the SOHO spacecraft. The scientific goal of the LOI is to detect the oscillations modes of the Sun in intensity using a low resolution detector. The instrument has an active guiding for keeping the Sun centered on the detector. This latter has built-in 4 limb detectors that are 4 quadrants of an annulus with an inner and outer apparent solar radius of 0.95 and 1.05 $R_\odot$. These limb pixels are used for providing an error signal that commands the high voltages applied on 2 orthogonally placed piezoelectric actuators. Here we report on the detection of the p modes both in intensity, (East-West and North-South pixels), and in the high voltages. Due to the servo loop, modes detected in the guiding pixels are not detected in the high voltages, and vice versa. The amplitudes of the p modes detected is about a factor 3 larger than for the regular scientific pixels. The implications for the flux perturbation induced by p modes will be discussed.

Keywords: solar oscillations - p modes - flux perturbation

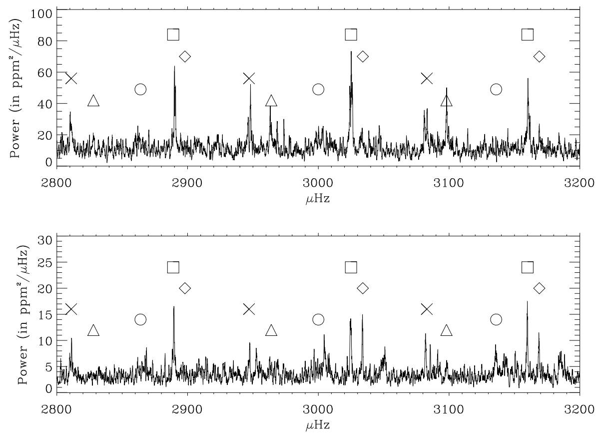

Figure 1: Power spectrum for the East-West (top) and North-South (bottom) guiding pixels; ◇ l=0, △ l=1, □ l=2, × l = 3, ○ l=4. The frequency resolution is 54 nHz. The spectra are smoothed to 10 points to enhance the p modes. The maximum p mode amplitude is 8 ppm.

1. Introduction

When detecting solar p modes in intensity, it is commonly assumed that the flux perturbation induced by the modes is proportional to spherical harmonics and to the limb darkening function. This approximation takes only into account the temperature perturbation. This is not valid because we know that in the visible continuum the opacity perturbation is comparable to the temperature perturbation; therefore it should be taken into account. A better understanding of the perturbation would improve our knowledge of the response of the atmosphere to the p modes. But it would also reduce the mode leakage caused by the use of an erroneous flux perturbation.

Here we report on the detection of solar p modes in the guiding signals of the Luminosity Oscillations Imager, which comprise the limb pixels and the guiding voltages.

In this article firstly we browse the LOI instrument. In the second part we describe the data reduction and the results. Then, we discuss our results by comparing them to theory, and conclude.

2. Description of the LOI instrument

The design of the LOI instrument is extensively described in Appourchaux et al, 1995. Briefly, it consists of a Ritchey-Chrétien telescope (f=1300 mm) imaging the Sun through a 5 nm bandpass interference filter at 500 nm. The image is projected on a photodiode array detector. The detector has 12 scientific pixels and 4 guiding pixels. The shape of the scientific pixels are trimmed to detect low degree modes for $l < 7$. The guiding pixels are 4 quadrants of an annulus with an equivalent inner and outer radius of 0.95 and 1.05 solar radius, respectively. The error signals for the guiding servo are the differences between two opposite pixels. The error signals are fed back to two piezoelectric actuators that move the secondary mirror around its vertex. The actuators provide both the coarse and fine pointing; the total range is $\pm 7.5'$ with a 0.2" resolution; the 3db bandwidth of the servo control loop is at 10 Hz. The current of each scientific pixel is amplified and digitised using Voltage-to-Frequency Converters. The current of each guiding pixel is amplified and digitised by the common data acquisition system. The 12 scientific pixels are read simultaneously while the 4 guiding pixels are read sequentially. The sampling time of the instrument is 60 s. The integration time of the scientific pixels is the same as the sampling time. The integration time of the guiding pixels is about 3 s distributed over the 1 minute period.

3. Data reduction and results

After the unpacketizing the data, the level-0 data are built from the 3 delayed transmissions of the VIRGO data; this is done at the VIRGO data center. The data are then converted from counts to engineering values using the calibration performed on ground. The 16 pixels are then converted to flux measured at 1 AU using the SOHO-Sun distance derived from the orbital data. The correction takes into account the real shape of the pixels, the limb darkening at 500 nm, and the in-flight size of the solar image at 1 AU. The pixels are also converted to zero radial velocity using the orbital data. Additional corrections are also taken into account such as the variations of pixel intensity with the sun offset angle, and a

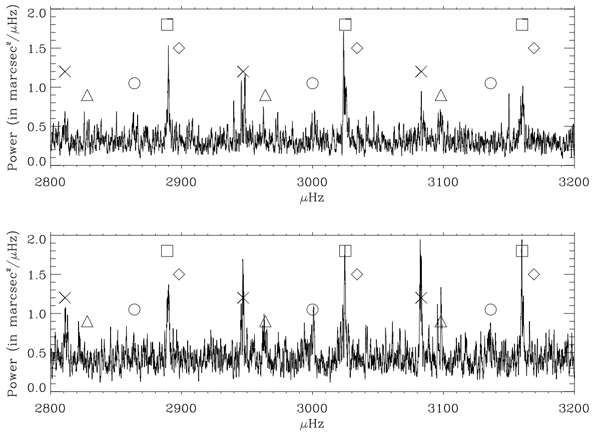

Figure 2: Power spectrum for the East-West (top) and North-South (bottom) high voltages; ◇ l=0, △ l=1, □ l=2, × $l = 3$, ○ l=4. The frequency resolution is 54 nHz. The spectra are smoothed to 10 points to enhance the p modes. A displacement of 10^{-3} arcsec corresponds to 23 ppm. The maximum p mode effect is equivalent to 28 ppm.

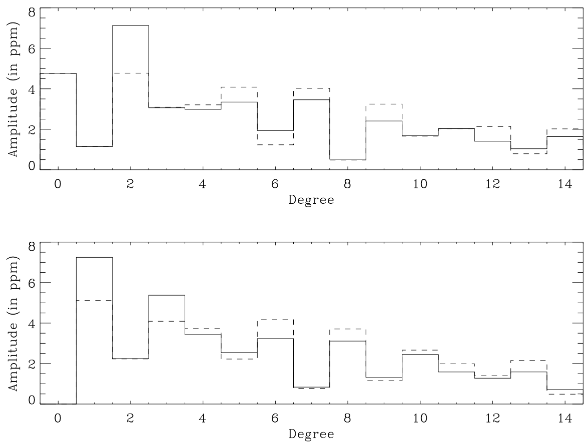

Figure 3: P mode visibilities as a function of l for the guiding pixels (top) and the high voltages (bottom), for the East-West signals (solid line), for the North-South signals (dashed lines). The visibilities have been normalized to that of an $l = 0$ with a full disk flux fluctuation of 1 ppm.

distortion effect function of temperature (Appourchaux et al, 1997).

The timeseries of the guiding pixels and of the high voltages are detrended using a binomial smoothing with a cut on at 0.5 mHz. Fig.1 and fig.2 show the power spectra for the guiding pixels and the high voltages, respectively.

4. Discussion

In order to understand these spectra, we computed the visibility of the modes for each guiding signal. Fig.3 shows the visibility of the largest m mode in a multiplet. The East-West signals are sensitive to $m = \pm l$ modes, and the North-South signals to $m \leq 1$. The visibility is normalized to that of an $l = 0$ with a full disk flux fluctuation of 1 ppm. The flux perturbation assumed here is the one computed by Toutain and Gouttebroze, 1993, neglecting surface distortion. If the flux perturbation were produced by the temperature alone, the visibility would be closer to 1. In fig.3, the visibility is about 3 to 5 times higher, this is due to the flux perturbation which acts like a limb brightening.

There are clear discrepancies with the computed visibility. The modes in the East-West pixels have a power about five times higher than in the North-South pixels. This difference cannot be attributed to a scaling error because the $l = 0$ modes have in both panels of fig.1 the same power above the noise level. For the guiding pixels the power of the mode is about the same as for the full disk imagery (about 2–3 ppm for full disk photometers or LOI data). Therefore, the computed sensitivity is about a factor 2–5 higher than the one measured for these pixels; while it agrees quite well for the high voltages. In addition, one can notice that some l are (not) detected even with a weak (high) visibility; for example $l = 1$ in fig.1, and in fig.2. It is not yet understood why our visibilities do not agree with the measurements. One solution would be to include the distortion of the surface in the computation. Another solution would be to study the effects of active latitude, or of convection on the flux perturbation (Toutain and Gouttebroze, 1993). In addition, the flux perturbation could also be studied by using the 12 scientific pixels of the LOI that span various μ, yet to be done.

On the more positive side, one can clearly see the rotational splitting of the modes in the East-West signals; this is less easily seen in the North-South signals. As expected the $l = 0$ mode is not detected in the high voltages.

5. Conclusion

We showed that p modes can be detected in the guiding signals of the LOI. Our preliminary analysis shows there are some disagreements between the theoretical and observed visibilities and the amplitudes of the observed modes. The theory of the flux perturbation induced by the p modes needs to be improved. This would help the modeling of the atmospheric response, and could reduce the mode leakage observed by the LOI. A detailed analysis of the flux perturbation with all the pixels of the LOI remains to be done.

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