WHAT HAVE WE LEARNT WITH THE LUMINOSITY OSCILLATIONS IMAGER OVER THE PAST 6 YEARS?

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ABSTRACT

We summarize what we achieved with 6 years of LOI data. We present old as well as new results regarding the p-mode parameters dependence upon solar activity. We have also derived the dependence of the solar background noise upon solar activity and solar disk position. Inversions done using LOI frequencies and higher-degree mode frequencies from GONG confirm previous velocity inversions.

Key words: intensity - p modes - SOHO - Sun.

1. INTRODUCTION

The Luminosity Oscillations Imager is one of a kind, that is the only instrument that measured in intensity the low-degree p modes from the ground (Appourchaux et al. 1995), and that is measuring the low degree p modes from space aboard the SOHO spacecraft. As such, there are no other imaging instruments with such a capability. While this asset is not to be diminished, the question arises as to whether it can constructively contribute to the field of helioseismology. Instruments that detects p modes in velocity benefit from a better signal-to-noise ratio allowing them to detect modes as low as 1000 μHz. In addition, instruments such as GONG[1] and MDI[2] make high-resolution images of the Sun permitting them to derive by inversion the internal structure from the surface nearly down to the core. Nevertheless, it must be emphasized that scientific progress should not always be ranked on the ability of making interesting discoveries, but more likely on the ability of confirming these discoveries[3].

The LOI is not just merely another helioseismic instrument, it has contributed to the understanding of several source of systematic errors. For instance, it was demonstrated by Toutain et al. (1997) that observations of solar p modes in intensity looks indeed different from those performed in velocity. This resulted in the discovery of low-degree p-mode profile asymmetries (Toutain et al. 1998, and references therein). Last but not least, the LOI has different mode sensitivities as it observes in intensity; the mode leakage is therefore significantly different from that of velocity instruments, as are the systematic errors associated this leakage (Appourchaux et al. 1998).

The goal of this paper is to make a short summary of what has been achieved by the LOI since the opening of the cover. It will show that an instrument detecting solar p modes in intensity confirms most of the discoveries performed in velocity.

2. THE LOI AND GONG DATA SETS

The LOI time series analysed here starts on 27 March 1996 0:00 TAI and ends on 26 March 2001 23:59 TAI. The level 1 data reduction has been described by Appourchaux (2001) and references therein. For studying the effect of activity, we have extracted five 1-year time series from the initial 5-year data set, and one 5-year time series. The mode are extracted using simple spherical harmonics as described by Appourchaux (2001).

The p-mode data are fitted using Maximum Likelihood Estimators. The use of the technique has been described in detail in Appourchaux (1998); the systematic errors are also therein described. The model of the p-mode profile was assumed to be an asymmetrical profile (Nigam et al. 1998) for $l \leq 3$. The splittings were decomposed using Clebsh-Gordan coefficients. The measured "noise" level from three pixels were used to model the solar noise (Appourchaux et al. 1998). The leakage and noise covariance matrix were derived from Appourchaux et al. (1998).

As a complementary (if not complimentary) data set,

[1]Global Oscillation Network Group
[2]Michelson Doppler Imager
[3]The failure to confirm g-mode detection can serve as an example (Appourchaux et al. 2000)

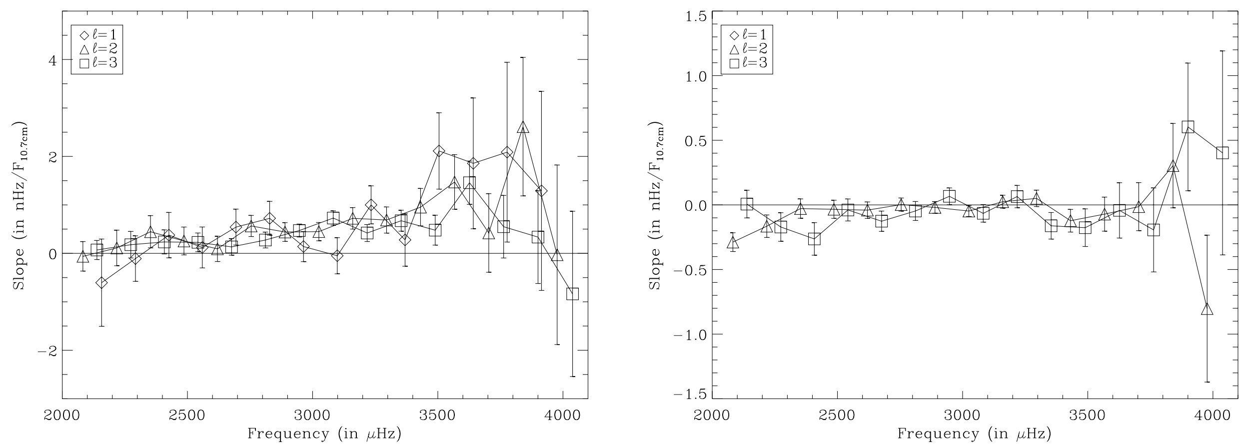

Figure 1. Slope of the solar-activity dependence of the a_2 (left) and a_4 (right) splitting coefficients upon the 10.7-cm radio flux as a function of frequency for the LOI. These coefficients can be translated into differential mode frequency shift of the order of +150 μHz at 3000 μHz between the $m = 0$ mode and the $|m| = l$ modes.

we have also analysed a coeval data sets from the GONG network. This additional work is needed because of the lack of resolution of the LOI; higher degree modes are necessary for proper structure and rotation inversion. Low degree modes ($l \leq 10$) were fitted using the same method as the LOI with the Fourier spectra. For $l > 10$ the yearly frequencies were obtained from the GONG network.

3. P MODES AND SOLAR ACTIVITY

It has already been shown that the solar activity affects significantly p-mode parameters such as frequencies, amplitudes and linewidths (Appourchaux 2001, and references therein) and even a_i splitting coefficients (Antia et al. 2001). In the course of the meeting, we even learnt that amplitudes, linewidths and mode energy were m dependent, and also affected by solar activity (Barban et al, Toutain and Kosovichev; these proceedings). Latitude-dependent amplitude variations were marginally detected with the LOI (Fröhlich et al. 2001). More interesting and more difficult parameters to measure are the even a_i coefficient. They represent the asphericity of the solar structure such as due to an internal magnetic field or the oblateness of the Sun. Unfortunately, Antia et al. (2001) showed that these coefficients depend strongly upon the surface magnetic field depending itself upon solar activity. We obtained similar results with the LOI as shown in Figure 1 for the slope of the dependence of the a_i upon the 10.7-cm solar radio flux. It has not been yet possible to find a dependence upon solar activity for the odd a_i, (Appourchaux 2001).

4. NON-PERIODIC SOLAR BACKGROUND

For each of the twelve disc pixels of the LOI, a parametric fit was made to the non-periodic solar background signal. The fit to the power spectrum of the five yearly time series were made with a sum of three functions all having the form $P(\nu) = A/(1 + (2\pi\nu\tau_0)^b)$ (Harvey 1993). The fit was made between 1 μHz and 7000 μHz excluding the region with significant p-mode signal. Significant variations, both with time and pixels, are seen in the fit parameters. To check for possible effects caused by the instrument and/or data reduction, the parameter time variation of the East/West and North/South halves of the solar disc were compared, respectively. For all parameters, these comparisons fall well within the calculated error bars. The comparison of the time variations of the fit parameters between the polar and equatorial pixels is shown in Fig 2.

5. STRUCTURE INVERSION

Reliable structure inversion using only low-degree frequency data is not feasible. The LOI data set needs to be complemented by higher-degree frequency data in order to properly take into account the contributions from the convection zone and surface layers. This latter data set is available from GONG and also from MDI. Unfortunately, these data sets are only available for modes detected in velocity, while the LOI detects the modes in intensity. Both sets are known to have asymmetric profiles providing systematic errors of opposite signs (Toutain et al. 1998). We are then facing several issues that are not easy to deal with:

- The intensity and velocity data sets are inhomo-

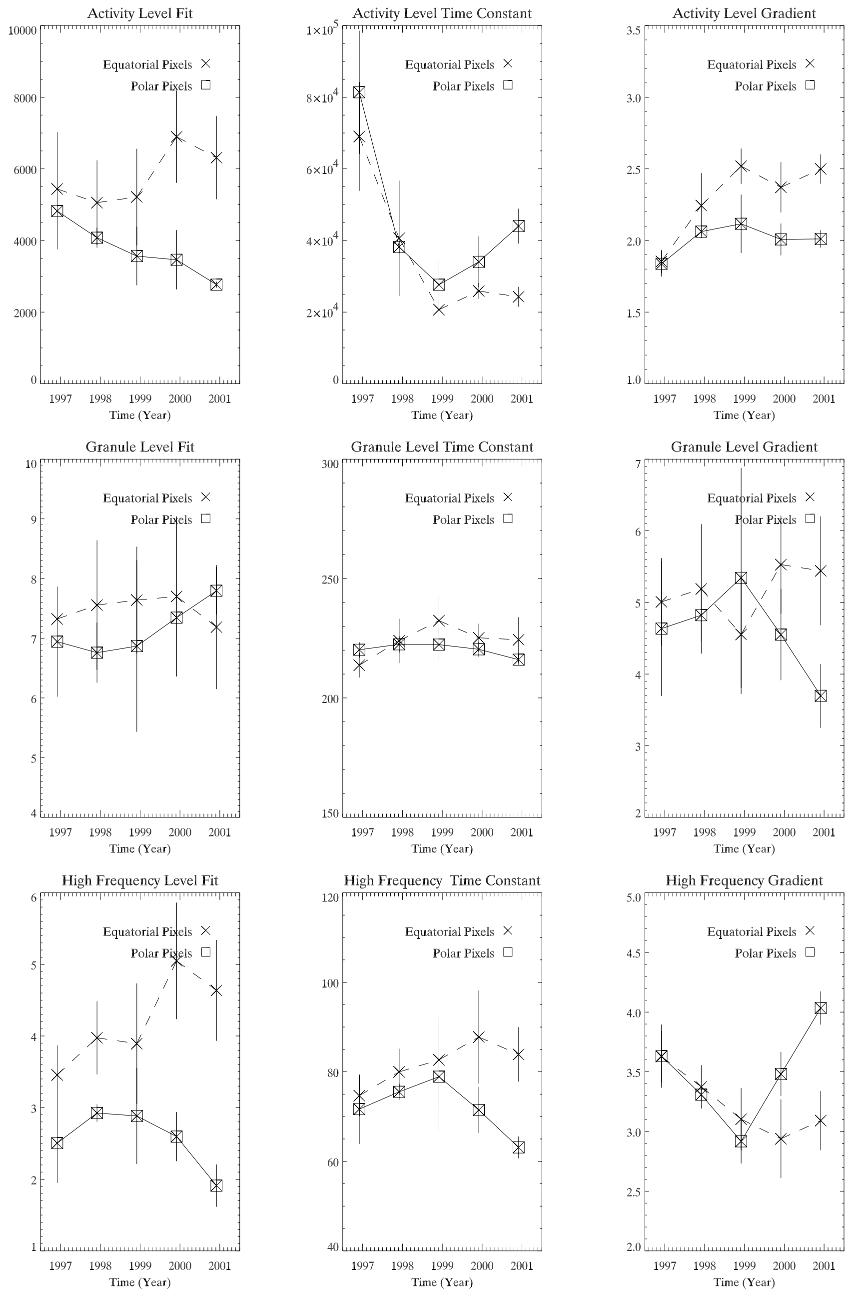

Figure 2. The nine panel figure above show the time variation of the averaged fit parameters for the four polar pixels and the eight equatorial pixels. Each of the three rows show the parameters for the fits to different time constants, the longest at the top. The left column gives the maximum value of the fit in ppm$^2/\mu Hz$ (A in the function), the middle column gives the time constants in seconds (τ_0) and the last column gives the gradient of the fit (b).

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- Few low-degree modes are available in the GONG data set ($l > 2$)
- The modes are fitted using symmetric profiles (GONG $l > 2$; LOI $l > 3$)
- The modes are fitted using asymmetric profiles (LOI, $l < 4$)
- The LOI mode frequencies for $l > 3$ have large systematic errors due to mode aliasing (Appourchaux 1998)

The steps for understanding the various drawbacks exposed above are the following:

1. Invert structure for GONG data only
2. Invert structure for GONG data ($l > 9$) + low-degree GONG mode frequencies home fitted ($l < 10$, with or without asymmetric profile)

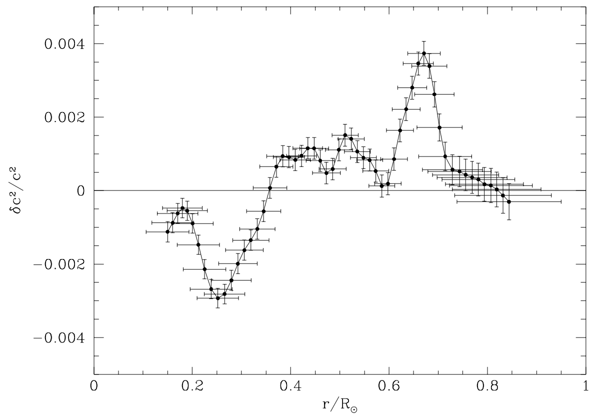

Figure 3. Inversion of the square of the sound speed for GONG + LOI ($l < 9$) data; the refer model is the so-called Model S. The inversion were performed using the standard strategy of linearization, and using optimally localized average (Gough 1996). This was used as the basis for the first VIRGO inversion in Fröhlich et al. (1997). The decrease in sound speed close to the core might be a manifestation of excess of helium abundance (Kosovichev et al. 1997). Please note that this feature could not be detected in the first VIRGO inversion (Fröhlich et al. 1997). It is likely that the inclusion of asymmetry in the profiles helped to reduce the discrepancy between the velocity and intensity data sets.

3. Invert structure for GONG data ($l > 9$) + low-degree GONG mode frequencies home fitted ($l < 4$, with or without asymmetric profile) + LOI frequencies ($3 < l < 9$)
4. Invert structure for GONG data ($l > 9$) + LOI frequencies ($l < 10$)

We have only been able to perform step 1 and step 4, the results are shown in Fig 3. Obviously, additional work is needed that is not directly related to the LOI instrument. But this is what it will take to ensure a proper derivation of the internal structure of the Sun close to the core.

6. CONCLUSION

We have reviewed the results of 6 years of LOI data. We have derived the dependence of the solar background noise upon solar activity. We have shown that we confirm most of the previous results obtained in velocity regarding the dependence of the p-mode parameters upon solar activity. There is still a lot of work to be done regarding structure and rotation inversion. For the latter great care should be taken to derive whether the core rotates more slowly that the radiative zone.

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