RESULTS FROM THE LUMINOSITY OSCILLATIONS IMAGER ON BOARD SOHO: LOW-DEGREE P-MODE PARAMETERS FOR A 4-YEAR DATA SET.

T.Appourchaux

Space Science Department of ESA, ESTEC, NL-2200 AG Noordwijk, (thierrya@so.estec.esa.nl)

ABSTRACT

I report on the results from a 4-year VIRGO/LOI data set. I have analysed independently four 1-year time series mainly for minimizing the effect of solar activity. For $l \leq 3$ the p-mode data are fitted using the Fourier spectra taking into account the mode leakage and noise correlations. For $l \geq 4$, the data are fitted using simultaneously the power spectra of l=4,7, l=5,8 and l=1,6. The effect of solar activity upon frequencies, linewidths, mode amplitude, energy rate, asymmetry and splitting is studied. Most of these results in intensity confirms earlier measurements made in velocity.

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

1. INTRODUCTION

The Luminosity Oscillations Imager (LOI) is a small instrument part of the VIRGO instrument aboard SOHO. The instrument was described by Appourchaux et al. (1995) and its in-flight performances were given by Appourchaux et al. (1997). One of the scientific goals of the LOI is to detect low-degree solar p modes in intensity. In this paper I report on the results of 4 years of LOI data. In the first section, I explain how the data are reduced, and how the spectra are fitted. In the second section, I report on the results for the various parameters fitted, and their dependence upon solar activity, and then conclude.

2. DATA REDUCTION

The LOI time series analysed here starts on 27 March 1996 0:00 TAI and ends on 26 March 2000 23:59 TAI. The level 1 data reduction has been described by Appourchaux (1998). For studying the effect of activity, I have extracted four 1-year time series from the initial 4-year data set. The modes are extracted using simple spherical harmonics as described by Appourchaux (1998).

The p-mode data are fitted using Maximum Likelihood Estimation on 2 type of spectra: Fourier for $l \leq 3$ and power for $l \geq 4$. For the latter technique, modes of higher degrees produce aliasing that is taken into account in the fitting procedure. Both techniques have been described in detail by Appourchaux (1998).

3. RESULTS

I have fitted the data using the techniques described above. The model of the p-mode profile was assumed to be an asymmetrical profile (Nigam & Kosovichev 1998) but a Lorentzian profile was also used for comparison. The splittings were decomposed using Clebsh-Gordan coefficients as in Ritzwoller & Lavely (1991). Three pixel noises were used for modeling the solar noise (Appourchaux et al. 1998). The leakage and noise covariance matrix were derived from Appourchaux et al. (1998). I have compared the 1999.74 time series (27 March 1999-27 March 2000) to the 1996.74 time series (27 March 1996-27 March 1997), e.g. a 3-year difference in time.

Figure 1 shows the frequency, linewidth, amplitude and energy rate difference as a function of frequency for $l = 1$ to 8. The amplitudes were averaged over m to provide the mean amplitude difference for each (l, n) mode; the average was done using optimal weights.

The frequency shift increases with the frequency as predicted and depends weakly on l for these low degree modes. The shift is consistent with shifts measured in velocity (Libbrecht & Woodard 1990; Elsworth et al. 1994). The shift is related to a surface effect which needs to be corrected for giving low-activity frequency results (See also Chaplin *et al.*in these proceedings). There is a systematic increase in the linewidths that was already observed by Appourchaux (1998), and a systematic decrease in the mode amplitudes; there is no apparent energy rate change. Similar results were reported by

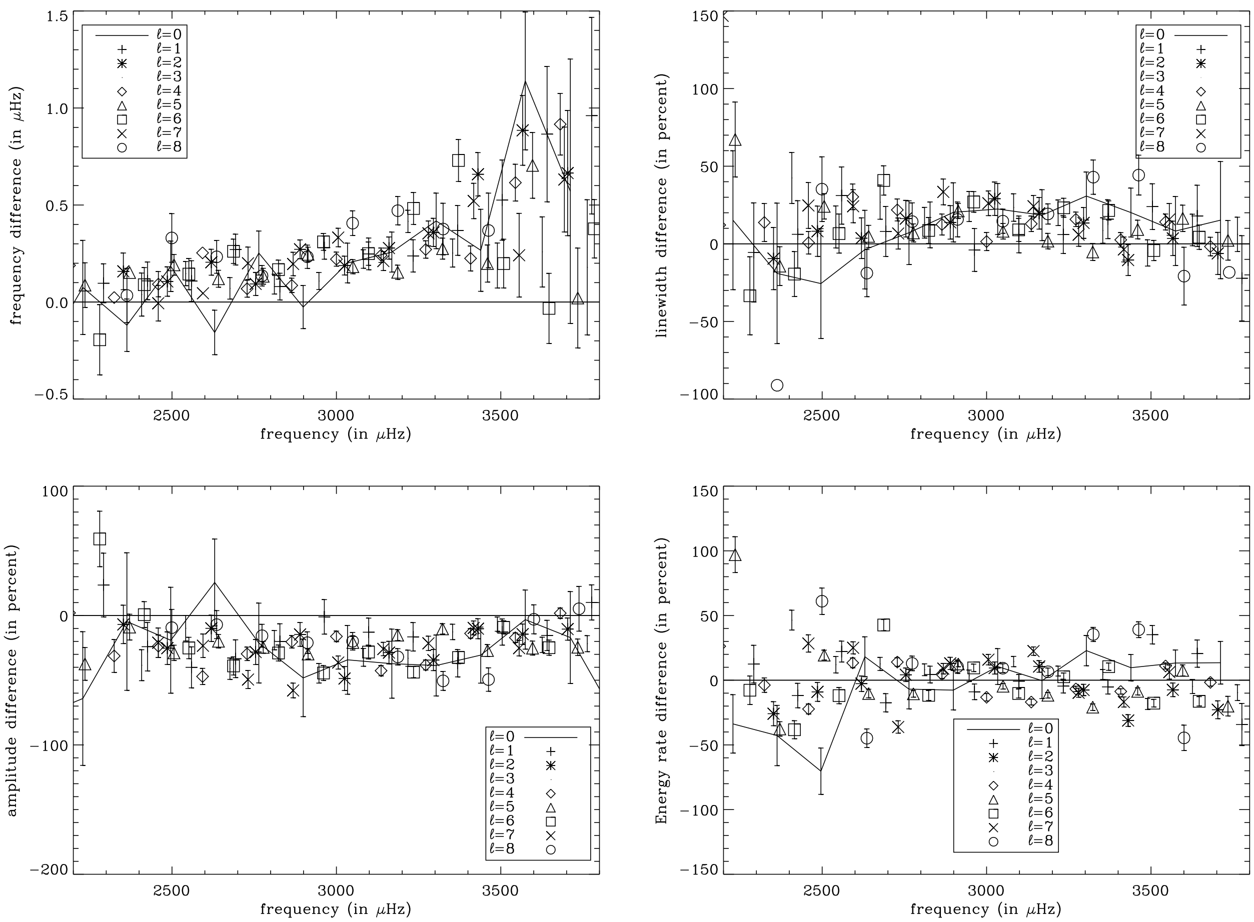


Figure 1. Changes as a function of frequency of p-mode parameters for various degree between the 1999.74 *time series and the* 1996.74 *time series: Frequencies (Top, left), Linewidths (Top, right), Amplitudes (Bottom,left), Energy rates (Bottom, right). The systematic errors that could have been introduced by the different fitting methods (especially for $l > 3$ are minimized at least to the first order. Second order effects related to a combination of frequency shifts and mode aliasing are yet to be studied. The frequency shifts are consistent with prediction that can be made with the results of Elsworth et al. (1994).*

Komm et al. (2000) for the GONG data and by Chaplin et al. (2000b) for the BiSON data. You will also find several contributions in these proceedings by Chaplin and Appourchaux, Komm, Roca-Cortés *et al.*, Toutain and Kosovichev which confirm the findings for VIRGO/LOI, GONG, VIRGO/SPM and SOI/MDI data respectively.

Figure 2 shows the frequency difference produced by fitting an asymmetrical mode profile to the spectra, together with the associated change of the asymmetry parameter with the solar cycle. I must point out that the frequency difference depends strongly on the degree of the mode. This dependence is related to the fact that the turning points location varies with the degree of the mode. This dependence on the degree disappears when the frequencies are compared with the ones derived in velocity. Therefore the asymmetry mimic an additional surface effect which can be taken into account in the structure inversion, thereby having no impact on whether the inversions are performed with a velocity or an intensity data set (Rabello-Soares et al. 1999).

Figure 3 shows the a_i coefficient difference between the 1996.74 time series and the 1999.74 time series. It seems that the mean rotation rate (a_1) has significantly decreased during the period. It must be pointed out that such an effect was not observed for the 1998.74 time series. In addition, most of the bias comes from modes with $l > 3$. Owing to larger error bars, the contribution of the $l = 2$ modes although quite prominent is rather negligible. It is still premature to infer that there are no other systematic effects related to solar activity that may produce a similar shift (i.e. related to linewidth, amplitude) or related to correlated a_i coefficients (e.g. due to a lack of independence of the Clebsh-Gordan coefficients).

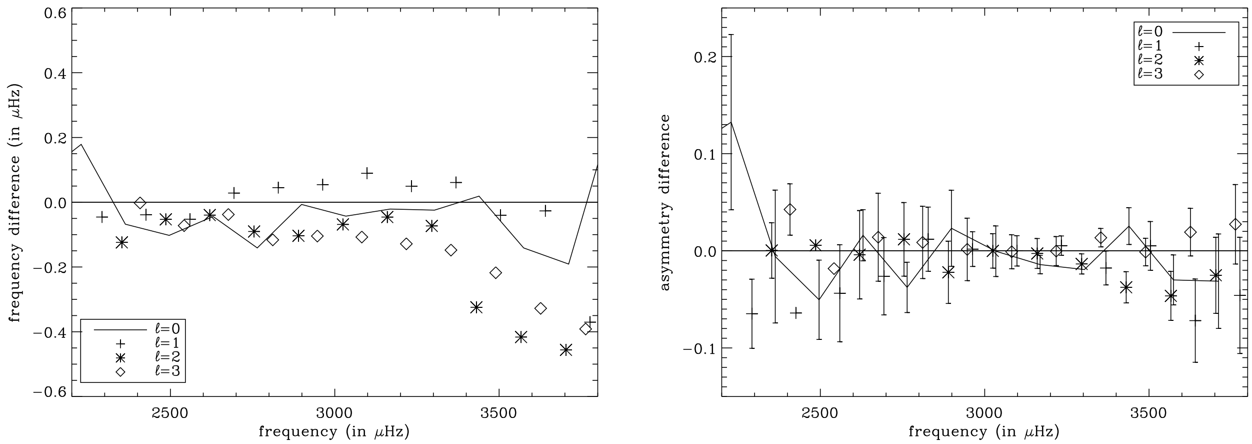
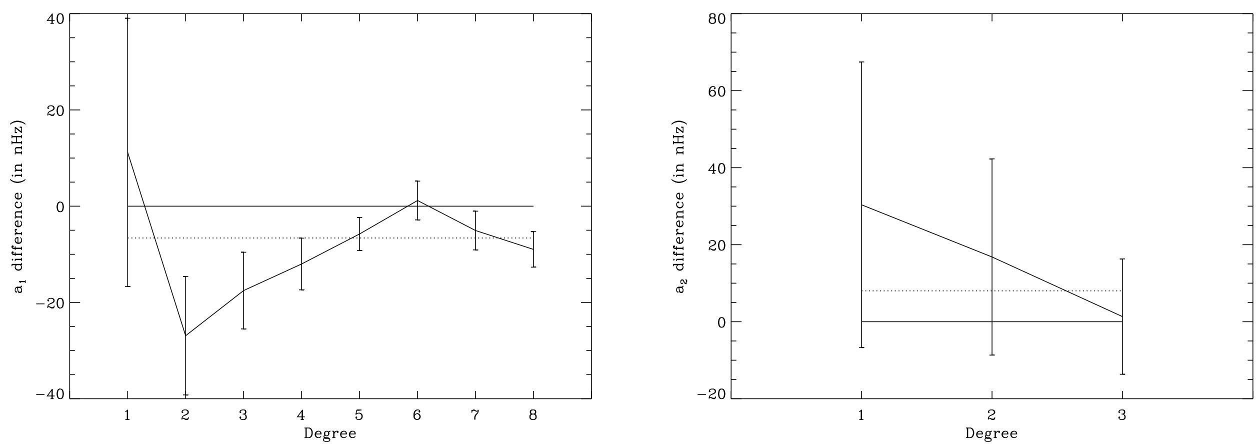


Figure 2. Left: differences as a function of frequency, for $l = 0$ to 3, between frequencies obtained by fitting p-mode spectra with an asymmetrical profile and a lorentzian profile. Right: differences as a function of frequency between the 1999.74 time series and the 1996.74 time series of the asymmetry parameter for $l = 0$ to 3.



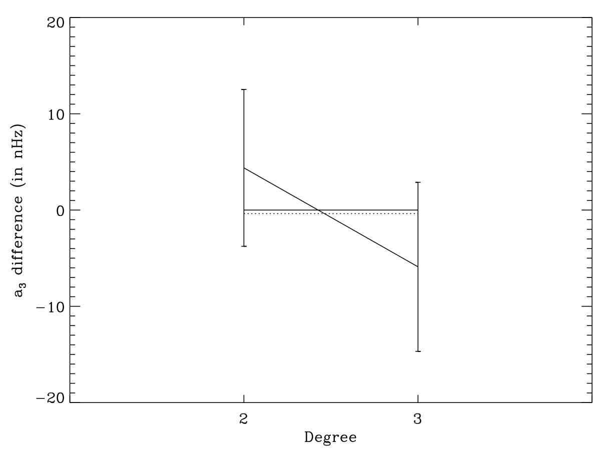


Figure 3. a_i difference between the 1996.74 *time series and the* 1999.74 *time series as a function of the degree: (Top, left) a_1; (Top, right) a_2; (Bottom, left) a_3. For each degree the a_i were averaged over the $2500 - 3500$ μHz range using optimal weights. The error bars are one σ. The dashed line is the mean over the degree which is respectively 6.6 ± 1.7 nHz for a_1, 8 ± 12 nHz for a_2; -0.4 ± 6 nHz for a_3.*

4. DISCUSSION AND CONCLUSION

Besides the usual frequency increase, there are strong evidence that the mode energy decreases with solar activity, while the energy rate remains the same. The energy blocked might be used in emerging active regions. Since most of the energy of the mode comes the excitation source about 200 kms below the surface (Chaplin et al. 2000a), it could be useful to study the relation of the excitation source with emerging active regions. An other interesting direction is to study the dependence of the linewidths increase as a function of frequency. It has been pointed out by Appourchaux (1998) that the linewidth dip located at 2800 μHz seems to have disappeared in the VIRGO data between 1997.74 and 1996.74. The location of this dip is associated with a resonance of convection with the p modes (Gough 1977). A change in this resonance may indicate that granulation is affected by magnetic activity, and thereby that excitation processes are also affected.

The changes in p-mode parameters, observed by other helioseismic instruments, are confirmed with the VIRGO/LOI instrument.

ACKNOWLEDGMENTS

I would like to express my thanks to the VIRGO team as a whole for putting together this wonderful instrument. I would like to thank Bo Andersen, Bill Chaplin, Claus Fröhlich, Thierry Toutain for endless discussions. The LOI instrument could not have been put together without the help of Thierry Beaufort, Jos Fleur, Samuel Lévêque, Didier Martin and Udo Telljohann. SOHO is a project of international collaboration between ESA and NASA.

REFERENCES

Appourchaux T., 1998, In: Korzennik S., Wilson A. (eds.) Structure and Dynamics of the Interior of the Sun and Sun-like Stars, 37, ESA SP-418, ESA Publications Division, Noordwijk, The Netherlands

Appourchaux T., Telljohann U., Martin D., Fleur J., Lévêque S., 1995, In: Hoeksema J., Domingo V., Fleck B., Battrick B. (eds.) Helioseismology, 4th SOHO workshop, 359, ESA SP-376, ESA Publications Division, Noordwijk, The Netherlands

Appourchaux T., Andersen B., Fröhlich C., et al., 1997, Sol. Phys., **170**, 27

Appourchaux T., Gizon L., Rabello-Soares M.C., 1998, A&A Sup. Series, **132**, 107

Chaplin W.J., Appourchaux T., Elsworth Y., et al., 2000, MNRAS, **314**, 75

Chaplin W.J., Elsworth Y., Isaak G.R., Miller B.A., New R., 2000, MNRAS, **313**, 32

Elsworth Y., Howe R., Isaak G.R., et al., 1994, ApJ, 434, 801

Gough D.O., 1977, ApJ, **214**, 196

Komm R.W., Howe R., Hill F., 2000, ApJ, **531**, 1094

Libbrecht K.G., Woodard M.F., 1990, Nature, 345, 779

Nigam R., Kosovichev A.G., 1998, ApJ Let., 505, L51

Rabello-Soares M.C., Christensen-Dalsgaard J., Rosenthal C.S., Thompson M.J., 1999, A&A, **350**, 672

Ritzwoller M.H., Lavely E.M., 1991, ApJ, **369**, 557