First results from the SPM of the VIRGO/SOHO experiment

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Abstract. The VIRGO experiment aboard SOHO is observing the Sun continuously since more than 9 months. VIRGO includes two instruments dedicated to helioseismology: a triple sunphotometer (SPM) and a luminosity oscillation imager (LOI). Performances and first results of the SPM are presented and compared to those of SPM of the IPHIR space experiment.

1. Introduction

SOHO was successfully launched on December 2, 1995 with onboard the VIRGO experiment. VIRGO is an experiment dedicated to helioseismology and to measurements of the solar constant (see Fröhlich et al., 1995 for more details). After some preliminary tests during the commissioning of SOHO the VIRGO experiment started in January 1996 a mode of continuous observation of the Sun. The data up to now gathered form a continuous timeseries of about 9 months which is comparable to the 10 months obtained with ACRIM in 1981 (Hudson, 1991) and the 6 months with IPHIR in 1988 (Fröhlich et al., 1988). VIRGO is composed of four kinds of instruments: 2 radiometers dedicated to measurements of the solar constant a triple sunphotometer (SPM) and a luminosity oscillation imager (LOI) dedicated to measurements of solar oscillations. This paper is focused on the SPM instrument. In the next section are described the instrument and its on-flight performances. Section 3 treats the first results obtained with the SPM data about characteristics of p-modes (frequency, linewidth, amplitude). Moreover these characteristics are compared to those obtained with the SPM aboard the IPHIR experiment launched in 1988 aboard the PHOBOS interplanetary russian probes (Toutain and Fröhlich, 1992).

2. The SPM instrument and its on-flight performances

The SPM instrument is composed of a triple sunphotometer with three interference filters (330,500 and 862 nm) and a silicon photodiode detector measuring the spectral irradiance in the solar continuum. This instrument has already proven its fiability and efficiency in 1988 as a part of the IPHIR space experiment. Its relative accuracy better than 1 ppm allows detection of solar acoustic waves (so-called p modes) in the integrated sunlight signal. The IPHIR version of the SPM was suffering two problems: a strong degradation of the 330nm-filter and pointing-depend diffused light. Both of these problems have been fixed in the VIRGO version. Figure 1 shows filter degradation for VIRGO and IPHIR.

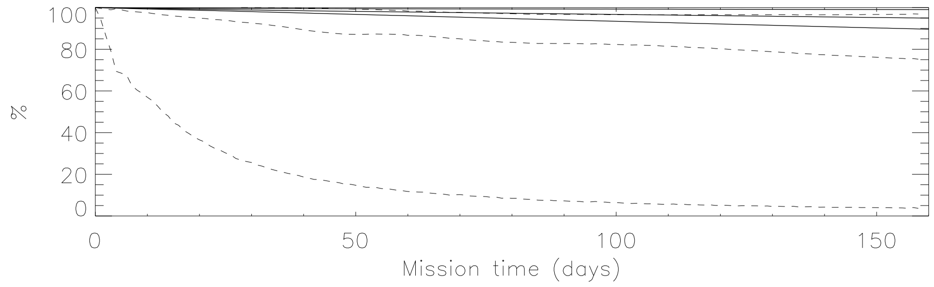

Figure 1. Filter degradation for SPM (VIRGO:solid line, IPHIR: dotted line)

Assuming that the signals are proportionnal to $exp(-t/\tau)$ we derive lifetimes of 50, 8 and 4 years for the red, green and blue channels, respectively. These lifetimes are of the order or larger than the current duration of the SOHO mission which is 3 years. If it turns out that lifetimes are shorter than those previously derived or if the SOHO mission is extended it is always possible to switch from the SPM currently working to the SPM backup instrument embarked on VIRGO in order to continue observations.

The SPM data are acquired once each minute. This process should be interrupted as less as possible, because data gaps are confusing for the analysis of solar oscillations. The SPM has gathered up to now more than 9 months of data with a duty cycle better than 99%. There are only few and small gaps due to action on other instruments and one long gap of two days due to a disruption of the VIRGO power supply last September.

3. Characteristics of p modes

As previously explained data gaps influence the determination of the characteristics of the p modes. We have therefore filled these gaps in the timeseries using a forecasting method based on a autoregressive method which is efficient as far as the gaps are seldom. The data are then detrended with a low degree polynomial. Finally the detrended data are Fourier transformed, the square of the modulus of the transforms leading to the so-called power spectra. Figure 2 shows as bottom curve the corresponding smoothed power spectrum for 160 days of green channel data in a frequency range corresponding to the five-minute oscillations. All the p modes with degree l from 0 to 3 are visible in a frequency range spanning from 2 to 4 mHz. The signal-to-noise ratio is very good, highest modes have a ratio better than 100. Power spectra for red and blue are similar with slight differences in the ratio of peaks of different l due to the wavelength dependence of the limbdarkening function

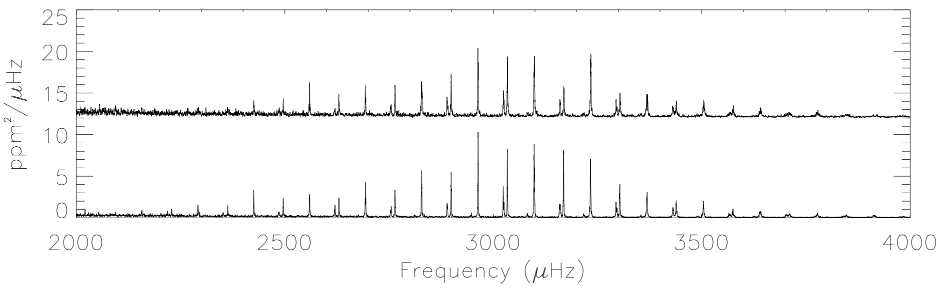

Figure 2. Power spectra of the IPHIR (top curve) and VIRGO (bottom curve) green channels

The top curve of figure 2 is the smoothed power spectrum of the green channel of IPHIR obtained with 160 days of observations. The improvement in terms of signal-to-noise ratio with VIRGO is of a factor of 3. P-mode lines are fitted using a maximum likelihood method (Duvall and Harvey 1986) leading to measurement of frequency, amplitude linewidth and rotational splitting of p modes. Figure 3 shows a typical l=0-2 doublet both for IPHIR and VIRGO green spectra with superimposed the fitting curve. From a practical point of view l=0 and 2 lines are fitted simultaneously because of their proximity assuming a unique linewidth for both lines. In addition to the signal-to-noise ratio, the main difference between IPHIR and VIRGO spectra is the width of the lines which seems larger in the case of IPHIR.

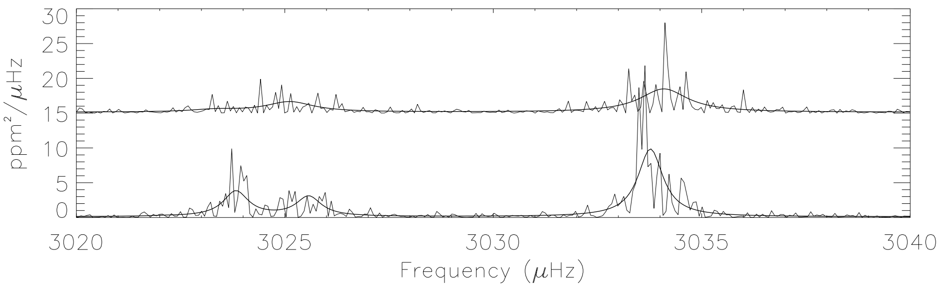

Figure 3. A typical l=0-2 doublet with the corresponding fitting curve for IPHIR (top) and VIRGO (bottom)

This fact is confirmed with figure 4 which shows the difference of IPHIR linewidths and VIRGO linewidths. It is not yet clear is this effect is an artefact of the data analysis or if it is a real effect. If it is really a solar effect one possible explanation is that p modes were more excited during the IPHIR period of observation (high solar activity) than during the VIRGO period (low solar activity).

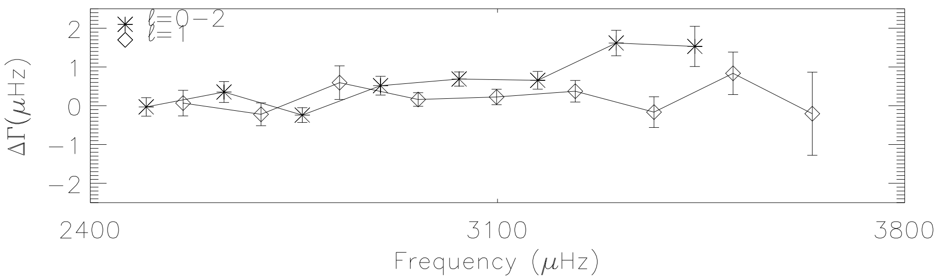

Figure 4. Difference of IPHIR linewidths and VIRGO linewidths as a function of mode frequency

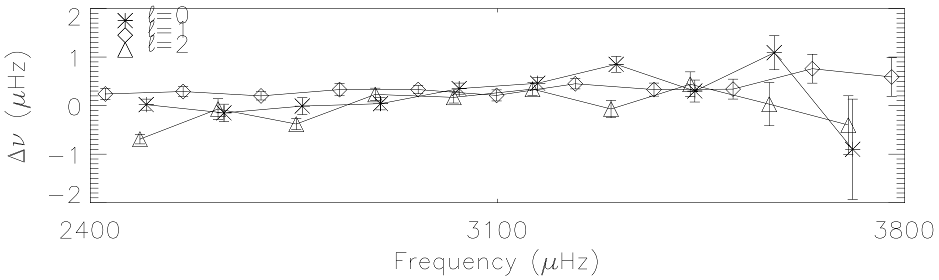

Figure 5. Difference of IPHIR frequencies and VIRGO frequencies as a function of mode frequency

An other interesting comparison is the comparison of the fitted frequencies. The difference IPHIR-VIRGO is plotted on figure 5. The IPHIR frequencies seem systematically higher. This effect already known (Pallé, 1992) is due to solar activity. The p-mode frequencies increase with activity with a variation about 0.5μHz over the solar cycle. The time-dependence of p modes is also visible in amplitude. Cutting the total VIRGO timeseries in pieces of 1 day it is possible to look at daily changes of p-mode amplitudes. Figure 6 shows how the highest p-mode amplitudes are changing with time over about 9 months. This effect already observed with IPHIR (Toutain and Fröhlich, 1992, Leifsen et al., 1995, Baudin et al., 1996) and confirmed with ground-based observations (Baudin et al., 1995) is likely due to excitation of modes by interaction of the acoustic waves with convection.

4. Conclusions

The SPM instrument of the VIRGO experiment aboard the SOHO satellite is performing very well since 9 months. The long continuous observation of the Sun as well as the good performance of the SPM have allowed integrated sunlight measurements of solar acoustic oscillation with a signal-to-noise ratio as high as

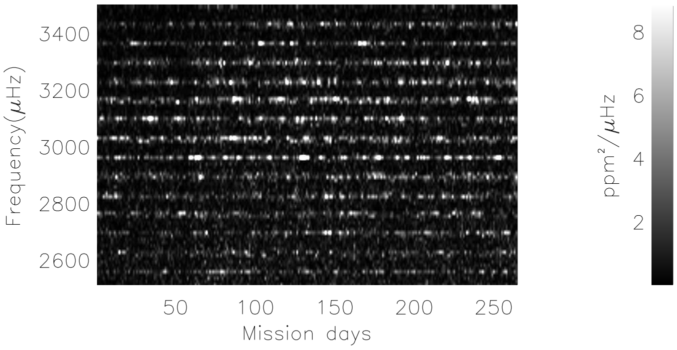

Figure 6. Amplitudes of p modes vs mission time

100. Frequency, linewidths and amplitudes of p modes have been measured with a good precision. A comparison of these quantities to those measured with the IPHIR space experiment in 1988 has shown that:
- IPHIR frequencies are larger than VIRGO frequencies as expected because of the different condition of solar activity at the time of observations.
-IPHIR linewidths are larger than VIRGO linewidths. This unexpected effect could be due to a bias in data analysis and has to be confirmed by the other experiments of helioseismology aboard SOHO (GOLF and MDI) or ground-based networks (GONG, IRIS, BISON). If it so, a possible explanation is an increase of the excitation of p modes at high activity periods.
- P-mode amplitudes are changing on timescale of days likely due to the interaction of the acoustic waves with solar convection.

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