VIRGO ON SOHO: STATUS AND FUTURE PROSPECTS

Claus Fröhlich
[1]Physikalisch-Meteorologisches Observatorium Davos, World Radiation Center
CH–7260 Davos Dorf, Switzerland

ABSTRACT

The more than two years of observations from VIRGO (Variability of solar IRradiance and Gravity Oscillations) yield a unique data set covering the activity minimum and the rising part of solar cycle 23. This allows not only to determine the influence of varying activity on the solar oscillation frequencies and amplitudes, but also to study the relationship between oscillations and irradiance variability.

1. INTRODUCTION

VIRGO (Variability of solar IRradiance and Gravity Oscillations) is one of the three helioseismology experiments on SOHO (SOlar and Heliospheric Observatory), a cooperative mission of ESA and NASA. The first measurements with the radiometers started in January 1996 during the cruise phase and after the opening of the LOI cover on 27 March 1996 the experiment was fully operational. Two different type of radiometer monitor the total solar irradiance (TSI), often called the solar 'constant' (PMO6V and DIARAD with a 1- and 3-minute cadence, respectively). Spectral irradiance is measured at three wavelength 402, 500 and 862 nm with two sunphotometers (SPM, 1-minute cadence). The Luminosity Oscillation Imager (LOI) measures the radiance of the sun in 16 pixels (12 cover most of the sun and 4 are on the limb for guiding; 1-minute cadence) at 500 nm. Details of the instruments and their performance can be found in Fröhlich et al. (1995); Fröhlich et al. (1997b); Appourchaux et al. (1997) and the first results in Fröhlich et al. (1997a). The experiment behaves extremely well and the data are of a quality never achieved before. This is mainly due to the fact that SOHO provides a very stable environment and that the instruments can see the sun continuously.

In the following some results from the over two years of observations with VIRGO instruments are presented. More details on some of them can be found in the 13 contributions to this meeting where VIRGO was involved: Appourchaux (1998); Fröhlich et al. (1998); Andersen et al. (1998c); Appourchaux et al. (1998); Anklin et al. (1998b); Appourchaux and the VIRGO Team (1998); Finsterle and Fröhlich (1998); Jiménez and the VIRGO, GOLF and MDI Teams (1998); Andersen et al. (1998b); Andersen et al. (1998a); Leifsen et al. (1998); Toutain et al. (1998); Pap et al. (1998).

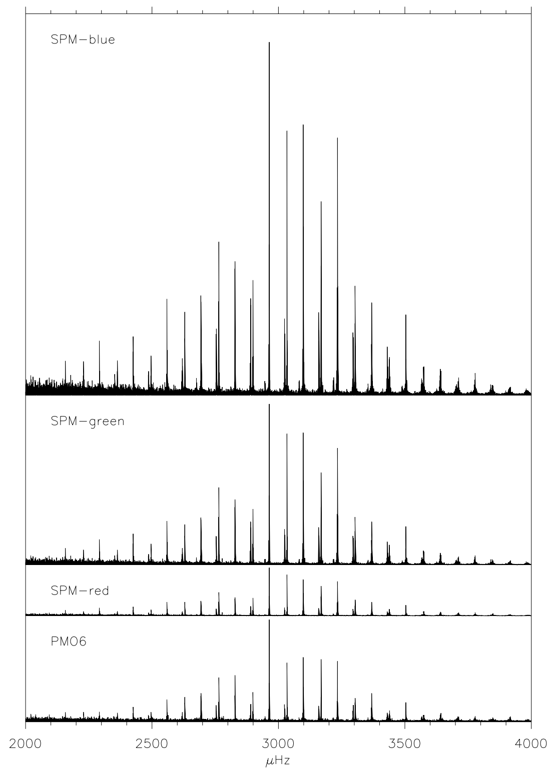

Figure 1. Power spectra from 724 days of VIRGO SPM and PMO6V observations in the p-mode range. The scale is for all the same and the highest peak in the blue channel corresponds to about 100 $ppm^2 \mu Hz^{-1}$ or about 9 ppm amplitude.

2. PRESENT STATUS

The radiometer have a very small degradation which has been characterized very accurately (Anklin et al. 1998a) with the results from the two backup instruments PMO6V-B and DIARAD-R. The average rate for the continuously operated PMO6V-A radiometer was about -3 ppm/day which decreased to about -2 ppm/day after 2 years. The rate of DIARAD-L was about -0.3 ppm/day at the beginning and

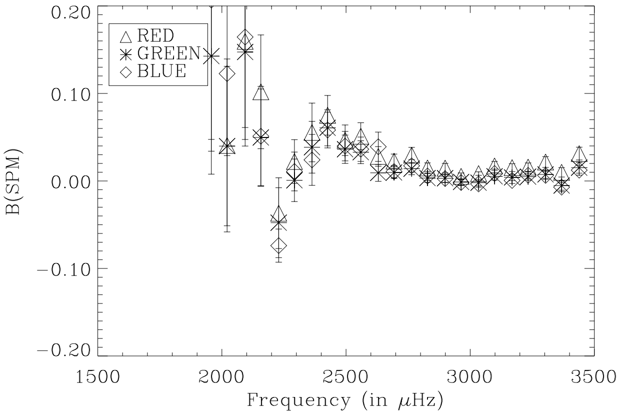

Figure 2. Asymmetry of p modes for brightness observations of the SPM on VIRGO. The parameter B defines the asymmetry according to the line shape $P(\nu) = A((1+Bx)^2+B^2)/(1-x^2)$ with $x = 2(\nu-\nu_0)/\gamma$ (from Toutain et al. 1998).

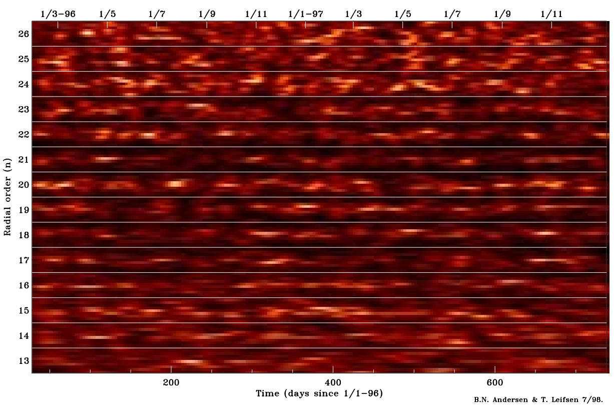

Figure 3. Amplitude variation of $l = 0$ p modes as determined by wavelet analysis. Each order $n = 13 \ldots 26$ is plotted in a range of 4 μHz. Note the 'splitting' of modes which is in this case a co-existence of two or more excitations with slightly different frequencies.

shows afterwards an increase in sensitivity of about 0.1 ppm/day. From the above analysis the degradation is known with an accuracy which allows to detect changes of TSI to better than 0.1 Wm^{-2} over the 2 years period. After 700 days of continuous exposure he degradation of the SPM is now at −78, −290 and −511 ppm/day with remaining sensitivities of 94, 80 and 66 % for the 862, 500 and 402 nm channels, respectively. The sensitivity of the backup SPM increases for the red and blue channel and is about constant for the green. This behavior seems to be instrumental and not solar; thus, these results cannot be used for the long-term correction of the continuously exposed SPM. The degradation of the LOI continues at a linear rate of about 350 ppm/day. At this rate 12% of the original pixel sensitivity will be reached in about 5 years time from now if the linear rate continues, or in about 11 years for an exponential decay. The present status and performance of the VIRGO instruments show no indication that the experiment could not continue to produce such excellent data for the next 5-10 years.

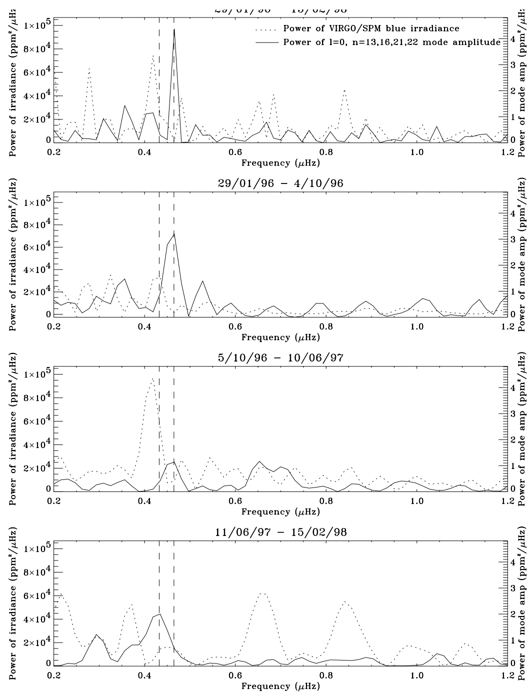

Figure 4. Spectral analysis of the temporal behavior of the p-mode amplitude of $l = 0$, $n = 13, 16, 21, 22$ and the irradiance variations (blue SPM channel). The top panel shows the analysis for the whole period and the three lower panels for three successive parts over the full period. The 'rotational' peak of the p-mode variation is shifted towards higher frequencies relative to the irradiance. The two vertical lines indicated the synodic and siderial rotational periods, respectively.

3. HELIOSEISMOLOGY

Figure 1 shows the p-mode power spectra for the three SPM and the PMO6V channels. Note the high signal-to-noise ratio which is highest for the red channel. In the p-mode range all the observed noise of the SPM is of solar origin, their instrumental noise is about two orders of magnitudes lower; for the radiometers on the other hand a significant part is instrumental, which is partly due to the way of operation. Note the relative increase of the $l = 2$ modes from red to blue, which is an effect of the increasing limb darkening which favors the visibility of higher order modes. These data are the basis for the detailed analysis of the characteristics of p modes. Among others the unambiguous detection of an asymmetry of the p-mode lines in velocity and brightness observations was possible. The asymmetry is due to the interaction with correlated noise (Toutain et al. 1998 and references therein) and an example for low degree modes as observed by the SPM is shown in Fig. 2. As the asymmetry is of opposite sign for velocity and brightness observations this effect produces a difference in the center frequency of as much as 0.15 μHz if a symmetric line profile is fitted. The SPM data have also been used to analyse the temporal behavior of the p-mode amplitudes. Figure 3 shows the evolution of the amplitudes for $l = 0$ modes of orders $n = 13...26$. The most striking result of the spectral analysis of the temporal behavior is that there is a distinct period around the 27-day rotational period which is illustrated in Fig. 4. It is interesting to note that the 'rotational' peak of the p-mode variation is shifted towards higher frequencies relative to the one of the irradiance. The latter is close to the synodic rotation whereas the former is close to the siderial. In any case, an $l = 0$ mode should not see the rotation at all.

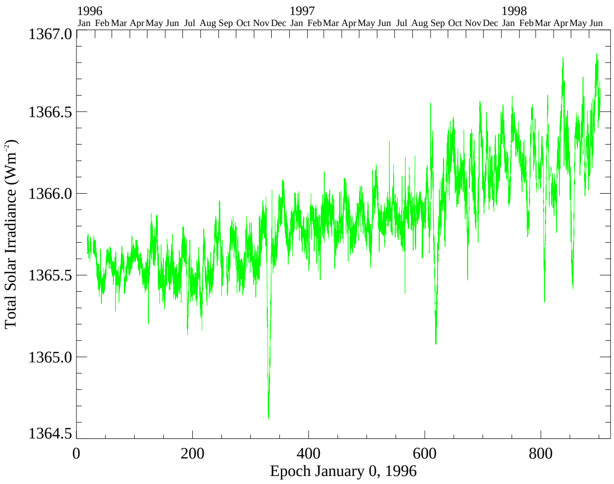

Figure 5. Total solar irradiance (hourly averages) as observed by VIRGO.

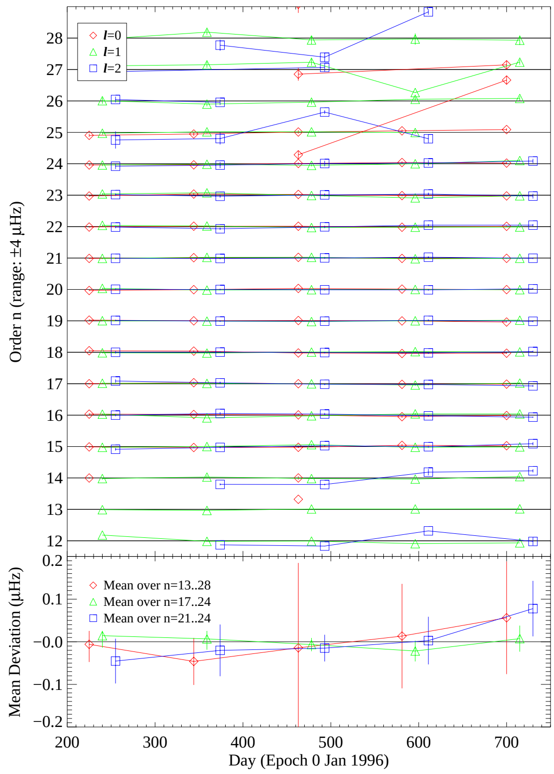

Figure 6. Frequency changes of solar p modes from the red channel of VIRGO/SPM during the period 1996-98. The upper panels show the changes for the different degree and orders, the lower panel the evolution averaged over degree and various ranges of orders.

4. IRRADIANCE VARIATIONS

Another objective of VIRGO is to investigate the variability of total solar irradiance (TSI). As a result of the excellent observing conditions the VIRGO TSI time series is the most accurate and precise available (Fig. 5). These measurements cover the end of the activity minimum between solar cycle 22 and 23 (August 1996) and the onset of cycle 23. During the same period the frequencies of the p modes have changed as expected (e.g. Elsworth et al. 1994); they are shown in Fig. 6. The analysis has been done for 5 periods of 119 days equally spaced over the period from 1 May 1996 until 12 February 1998 for the red channel of the SPM. As the frequency change increases with increasing frequencies the effect is best seen in the average over the orders $n = 21...24$ which shows a very similar behavior as the irradiance: a first small increase during the second period of the analysis (16 November 1996 – 14 March 1997) and then the start of the upward trend into the new solar cycle after September 1997. This is different from the evolution of the influence of magnetic fields on irradiance as monitored by e.g. the MgII core-to-wing ratio shown in Pap et al. (1998). This comparison may be a hint that at least part of the influence of solar activity on irradiance and p-mode characteristics in non-magnetic. Kuhn (1998) comes to a similar conclusion from the evolution of the even a-coefficients of the p-mode splitting determined from SOI/MDI data.

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