SIMULTANEOUS Hα AND SODIUM OBSERVATIONS AT THE KANZELHÖHE SOLAR OBSERVATORY

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ABSTRACT

At the Kanzelhöhe Solar Observatory, Hα images are currently obtained simultaneously with sets of intensity, velocity and longitudinal magnetic images in the Sodium D lines. Many flares have been detected. The preliminary results of the analysis suggest the events to occur at heights in the solar atmosphere below 1100 km, where the canopy magnetic lines stressed by the photospheric motions can reconnect. The penetration of the downflowing plasma jets is investigated in order to justify the solar background in the photospheric intensity-velocity phase spectrum.

(Moretti et al. 2001a).

In this paper we investigate the perturbations induced by minor flares at different wavelengths in order to estimate the penetration of the downflowing plasma jets down to the Sodium formation layers.

We analyse the temporal, spatial and amplitude characteristics to infer the location of the events and the frequency dependence of the phase difference between the intensity and velocity signals. This last quantity is suggested to be closely connected to the source of the so-called "solar background".

2. THE SOLAR BACKGROUND

The presence of a solar background in the $\ell - \nu$ diagram of the phase difference between the intensity and velocity signals (I-V), has been associated to a possible signature of the source of the resonant oscillations (Skartlien and Rast 2000). Many of the differences in the values on the p-modes obtained from different data sets (GONG, MDI, Kanzelhöhe, VAMOS) can be attributed to different formation heights of the used solar lines and to different $\ell$ and $\nu$ resolutions in the I-V phase difference spectra. To date, these are the observational results concerning the I-V phase spectrum (Deubner 1990, Straus 1990, Oliviero 1999):

1) the phases are approximately independent of the degree $\ell$;
2) the phases on the p-mode ridges depend on the height in the solar photosphere;
3) the phases in the solar background show a step-like behaviour with negative values below about 3.3 mHz and positive values above about 4 mHz.

The background has been usually studied in its trait in the $\ell - \nu$ diagram: that is, when the contribution of the signal filtered by the spherical harmonics is displayed as a function of the spatial scale and of the frequency. In the case of the p-modes, this representation shows the global resonance of the
acoustic waves. In order to enhance the characteristic of the source of the solar oscillations, local analysis has been used (Moretti et al. 2001). The analysis and the results have been shown in detail elsewhere (Moretti et al. 2001a). The data locally show the same I-V phase values of \( \ell - \nu \) diagram.

In the five minute band, in correspondence of the high velocity power locations, the source is that found in the peaks of the \( p \)-modes while where the velocity power is low, the negative phase is found.

For the sake of analogy, the negative value obtained through the local analysis has been attributed to the signature of the solar background. The spatial distribution of the background in the frequency domain has been used in order to infer some characteristics of the source of the solar oscillations.

The obtained results and a possible interpretation are summarised as follows:

1) The background locations, in the five-minute band, are associated with those points where the velocity power is low. This could mean that the \( p \)-modes are acting as a selective filter for an uniform background distribution over the disk. At this point, the correspondence to the magnetic oscillating points is not a proof of a physical relation between the magnetic field and the background, since the magnetic points usually correspond to low velocity power locations. For this reason the spatial distribution of the background is studied at the low frequencies, where the contamination is largely reduced.

2) At low frequencies, the probability to find the background at the same location is much larger than expected. The increase in the area filled by the background is compatible with a 0.5 coverage of 4" border line of a 50" x 50" region; the non-uniform spatial distribution is confirmed by the trait of the coverage, that seems to cluster around structures of the same order of magnitude (this is consistent with the observations of Chae et al. 1998, where a preferential occurrence of 560 events per second over the global solar surface is reported). This suggests the presence of localised phenomena.

3) The autocorrelation of the phase coverage maps shows the rotation of the structures associated with the \( p \)-modes (in the five-minute band), but not for the background, whose characteristic scale is of the order of one pixel. This can be interpreted in terms of a rotating subarcsec structure during the observing run, or to structures at the limit of the spatial resolution but lasting a period whose trace during the rotation at disk center is confined in one pixel, that is, less than 30 minutes.

The characteristics of the background locations are compatible with those invoked by Skartlien and Rast (2000) to generate the background’s behaviour in the \( \ell - \nu \) diagram. The main limitation of the results obtained is the low spatial resolution (4" per pixel): it could make the determination of the phase values uncertain, but the results would not change since two distinct phases are observed, whose values are much different in comparison to the possible systematic errors. Nevertheless, the non-resolved events do not permit to establish a direct cause-effect relation with the distinct phenomena, and the investigation on the time-series (instead of the FFTs) has not achieved a successful result.

With the results shown in this paper, we try to identify the cause-effect relation within the explosive events that could be invoked as the source of the solar background. The resolution is yet low, resulting in a difficulty in isolating the perturbations of the explosive events from other phenomena. Nevertheless, encouraging results have been achieved.

3. THE DATA

The data consist of simultaneous images in the H\( \alpha \) and Sodium D lines. The H\( \alpha \) intensity images have a 2"/pix resolution and are obtained through a 0.07 nm FWHM filter (Messerotti et al. 1999). The Sodium D images consist of dopplergrams, longitudinal magnetograms and intensity images obtained with a Magneto-Optical Filter (MOF), and have a 4"/pix spatial resolution (Cacciani et al. 1997). All the images have been acquired every minute.

Dopplergrams and magnetograms have been calibrated accordingly to Moretti & the MOF Development Group (2000). Many Sodium flares have been detected at the Solar Kanzelhöhe Observatory (first reported in Warmuth et al. in correspondence with the impulsive brightenings, 25 min long time-series have been selected for the intensity, velocity and longitudinal magnetic field signals. Particular care has been devoted to the possible effects introduced by emission lines. In fact, when narrow passband filters are used to build the velocity and magnetic images (Cacciani, Moretti and Rodgers 1997), any localised emission profile produces a sign reversal in both the magnetic and velocity signals as a result of the inverted slopes of the opposite wings of the line. Many perturbations induced by flares have been analysed (1 June, 6 June, 19 July, 22 July 2000 and 2 April 2001): the geometrical asymmetry and the complexity of the structures introduce some problems in isolating the contribution of the flare pulse in the velocity signal from the surrounding
oscillations. We have chosen the case of 1 June 2000 as the clearest and simplest example of the induced perturbations (see figure 1). In this case, no reversal in the magnetic field has been observed (the flare occurred close to a neutral line where a sudden flux cancellation has been detected). A clear downflowing plasma motion has been observed in correspondence with the flare occurrence.

4. THE I-V PHASE DIFFERENCE AND THE RECONNECTION REGIONS

The one-minute cadence time-series have been interpolated to a 8 s sampling and extended to a 9 h observing run in order to obtain a reasonable frequency-resolved phase difference (figure 2). The phase behaviour in the low frequency range (between 0 and 4 mHz, where the solar background is easily recognised in the observed power spectra) mimics that of the observations in the $\ell - \nu$ diagram. Other events show a slightly different power spectra but they all show the negative phase at low frequencies. The step-like trait in the $[-180^\circ, 180^\circ]$ range is the result of an approximately linear frequency dependence in the $[-360^\circ, 360^\circ]$ range. This dependence is mainly due to the delay between the intensity and velocity pulses which, in this case, can be roughly estimated as 30 s for a 5 minute period (see figure 2).

Note that an upward velocity pulse preceding the intensity pulse is also often observed in the Sodium D lines, as well as a following downflow. Nevertheless, the phase trait is mainly similar in both cases. When thousands of pulses are averaged in a long observing run, the characteristic phase of the phenomenon survives. We simulated a "pure" single event as suggested by the observations, and computed the velocity, intensity and phase observed signals. The phase between the intensity and velocity signals depends on the reference system chosen for the velocity axis: we have chosen an "out of the sun" pointed velocity axis, that is a positive velocity for upward flows. The results of the I-V phases agree with those shown in the $\ell - \nu$ diagram at the same formation heights (for details, Moretti et al. 2001a).

From the timing of the perturbations at the two different wavelengths, we can roughly estimate the height where the energy related to the explosive events has started to be released. The contribution formation layer for the Hα have been taken from Vernazza et al. (1981), while for the Sodium data the heights related to the measure have been computed taking into account the real acquisition procedure and the transmission bands of the MOFs. In practice, the Hα data are assumed to be originated in a layer from 500 to 2000 km, while the Sodium data from 500 to 900 km (Moretti and Severino 2001c).

The time delay between the Hα and the Sodium

\begin{figure}[h]
\centering
\includegraphics[width=\textwidth]{image.png}
\caption{The one-minute cadence observed (solid thick) intensity (top) and velocity (bottom) on a 12" x 12" area centered on the brightest pixel have been interpolated (solid) to a 8 s cadence and used for computing the I-V phase difference. The time-series have been extended to obtain a 9 h observing run. The plots refers to data obtained in the Sodium D lines on 1 June 2000. The intensity signal has been scaled to a 0 to 1 interval, where zero is the intensity averaged in a surrounding 100" x 100" area and 1 is the maximum intensity (approximately 1.7 times the mean). In the lower two panels the I-V phase difference is plotted in a $[-360^\circ, 360^\circ]$ range and in the usual $[-180^\circ, 180^\circ]$ range, where the step-like behaviour is visible.}
\end{figure}
Figure 3. From simultaneous Sodium and Hα images taken on 1 June 2000, the intensity brightenings in the Sodium D lines (solid) and in Hα (dashed) are shown. Left: the very first brightening. The Hα pulse precedes the Sodium one by 90 s. The intensities, normalised to the mean central one, span from 1.1 to 2.1 and from 1.0 to 3.2 for the Sodium and Hα respectively. Right: the pulses for the maximum intensity pixels. The Hα pulse precedes the Sodium one by approximately 30 s. The intensities, normalised to the mean central one, span from 1.1 to 1.6 and from 1.2 to 2.6 for the Sodium and Hα respectively.

data depends on the location, since the flare impulse propagates at different speeds. For the very first brightenings, the delay amounts to approximately 90 s (figure 3).

The measured velocity perturbation induced in the layers where the Sodium line is originated, is always less than 200 m/s.

The velocity pulses of the downflowing plasma jets strongly depend on the height where the magnetic reconnection occurs (Sarro et al. 2000); it is computed and reported to amount to some km/s close to 3000 km and decreases rapidly down to the lower chromospheric layers. Moreover, the intensity perturbation in the Sodium data always shows as a single pulse while in the Hα is often accompanied by waves.

Assuming a maximum mean 10 km/s penetration speed for the first 10 s and 1 km/s for the rest of the flight down to the Sodium layers, we then conclude that the reconnection causing the energy release can be located above 900 but not higher than 1100 km. At these height in the solar atmosphere the net decrease in the density leads the magnetic lines to spread and the probability of reconnection to become higher (Gabriel 1976).

5. CONCLUSIONS

Some examples of the simultaneous Sodium and Hα data obtained at the Kanzelhöhe Solar Observatory are shown. The analysis has been focused on the study of the downward plasma penetration related to the explosive events detected during 2000 and early 2001. The penetration of plasma jets below 900 km is assessed and the intensity and velocity profiles for the Sodium time-series can be invoked as the source of the so-called solar background in the I-V phase spectrum.

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REFERENCES