THE NATURE OF NETWORK OSCILLATIONS IN THE SOLAR CHROMOSPHERE

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Abstract

We examine the simultaneous time-series spectral data for N i 1319 Å, C ii 1335 Å, C ii 1037.6 Å and O vi 1037.0 Å, obtained from the SUMER instrument on the SOHO spacecraft. The observed 4-5 mm network oscillations can be interpreted in terms of kink and sausage waves propagating upwards along thin magnetic flux tubes. We propose that for the network bright regions these sausage waves are responsible for the 3.5 mHz power peak. Numerical results based on thin flux tube equations will be compared with observations. Our two layer isothermal atmospheric model predicts a coupled oscillator frequency which matches fairly well with the network observations.

Key words: SOHO-Sun; Chromosphere; Oscillations.

1. INTRODUCTION

In the last few years only a limited number of analysis of EUV lines formed in the transition region observed with SUMER on board SOHO has been published (see Doyle et al. 1999). Steffens et al. (1997) found that there was a peak in the cell boundary/cell interior intensity power ratio near 3 mHz for the He II 304 Å and He I 584 Å lines, although there were no similar peaks in the Doppler-shift power ratio. They interpreted this as sausage modes compressing and heating network elements without vertical displacement. Carlsson et al. (1997) found oscillatory behaviour in lines of C I, N I, O I and C II analogous to the Ca II three minute oscillations. Evidence was found by these authors that intensity brightenings were accompanied by blue-shifts of 5 km s⁻¹. They interpreted this as upward propagating waves. They also found that the oscillations appeared to be present in ~50% of the area studied and to be coherent over 3-8 arcsec regions. In addition they found a time delay between C II 1334 Å and N I 1319 Å lines of 13 seconds.

Choudhuri et al. (1993) pointed out that when the footpoints of the flux tubes moves rapidly for a short time, much of the energy is fed into the kink modes at well above the cut-off frequency and hence can propagate upwards. In a more recent paper Kalkofen (1997) has interpreted the oscillations in the H and K lines of Ca II in network bright points as magneto-acoustic waves propagating upwards along thin flux tubes. Kalkofen et al. (1994) has also shown that at the generation site in the velocity spectrum there is a high peak at the cut-off with a large amount of energy at higher frequencies. Whenever a pulse propagates through a stratified medium, it is known to leave a wake behind it oscillating with the cut-off frequency of the atmosphere (Lamb 1932). Until recently there was no direct observational evidence as to the nature of the foot-point motions. Berger & Title (1996) and Berger et al. (1998) has reported the dynamics of the small scale solar magnetic field. Their data show that the bright points move in inter-granular lanes and are primarily driven by the evolution of the local granular convection flow field. It has also been observed (Muller et al. 1994) that these bright points occasionally undergo rapid motions with velocities of the order of 3 km s⁻¹ typically lasting for 3 mins. Kalkofen’s (1997) scenario is consistent with our observations and numerical modeling. The waves are generated impulsively in the photosphere as kink waves. As they propagate upward their amplitude grows exponentially and become non-linear in the chromosphere, transferring power to the sausage modes through mode-transformation.

2. OBSERVATIONS & DATA REDUCTION

The datasets analysed here were acquired on 31 July '96 using SUMER on SOHO. Two pairs of spectral lines were observed simultaneously, N I 1318.99 Å C II 1334.53/1335.71 Å, and O vi 1037.6 Å, C ii 1037.0 Å covering 50 wavelength pixels (~2.5 Å) and 360 arcsec in the North-South direction. Here, we report on SUMER data searching not only for evidence of oscillations but also whether there are any time-lags between lines formed at different temperatures. Details of the Fourier analysis and data reduction procedures can be found in Doyle et al. (1999).

Power spectra are obtained from the Fourier transforms of the auto-covariance function, multiplied by a window function to reduce the variance of the noise. Power spectra are normalized in such a way that the expected mean noise level equals 2. For power spectra we normally use a 99.9% confidence level.

Figure 1. Time slices of the N I (top panels) and C II (bottom panels) intensity observations of 31 July 1996. The panels in the left column show the observed intensity. The panels in the second column show the smoothed intensity resulting from a convolution of the original data with a Gaussian with $\sigma = 150$ sec. All frequencies above $\sim 6.7$ mHz are suppressed in these graphs. The third and fourth column show the contrast-enhanced time slices for $\sigma = 150$ sec and $\sigma = 510$ sec, respectively. This implies that in the third column frequencies below $\sim 6.7$ mHz are suppressed and in the fourth column frequencies below $\sim 2$ mHz (see Doyle et al. 1999).
Figure 2. Power spectra (per pixel along the slit) of the N\textsc{i} intensity (top left) the N\textsc{i} velocity (top right), the C\textsc{ii} intensity (bottom left) and the C\textsc{ii} velocity (bottom right). Black indicates power above the detection level and white zero power. Also shown are the summed counts per pixel during the observation and the mean velocity per pixel during the observation. In the graph of the summed counts of C\textsc{ii} the thick vertical lines indicate some internetwork regions and the thin lines some network regions (from Doyle et al. 1999).
3. RESULTS

Spatial/temporal properties of the data is revealed in Fig. 1, which shows the total line intensity for the N I and the C II lines as a function of position along the slit and time. The time slices indicate that there is more 'structure' in the emission of N I than in C II. The brightest features, which relate to network magnetic fields, are observable in both N I and C II. Often these features are observed for the whole length of the observation but sometimes the in- or egress of a feature in the slit is observed. Fluctuations in the bright features are clearly visible and their appearance seems periodic. These structures are so bright that in a gray-scale presentation it is difficult to identify weakly emitting structures. To bring out details in the intensity map we use a technique based on enhancing the contrast of these structures, thereby filtering out the bright components in the brightness evolution displays. The bright structures in these maps show a wave-like patterns but closer inspection indicates that a granular-like pattern is present.

Next we consider power spectra of the observed intensities and velocities. Because variations of these quantities in neighboring pixels are not in phase, we study power spectra of individual pixels along the slit and do not average over groups of pixels in order to increase the signal-to-noise ratio. Intensity and velocity power spectra for N I and C II on 31 July are shown in Fig. 2 together with the total number of counts in a pixel (summed counts) during the observation and the average velocity in a pixel. The summed counts are useful to identify network (NW) and internetwork (IN) regions. Also shown are the smoothed power spectra.

Fig. 3 shows the time slices and the corresponding power spectra for the O VI 1037Å and C II 1037Å for the dataset starting at 20:39 UT on 31 July 1996. Now we concentrate on a typical network region and look at the intensity variations and power spectra in Fig. 4. An overview of all the power spectra (Figs. 2,3,4) indicate that there is considerable power all along the slit so that the power is not confined to the brightest areas. Above 2 mHz, power is found between 3 and 6 mHz. For network regions (see Fig. 4) the dominant power peaks coincides for both the lines (around 3.5 mHz). Our results indicate that for both network and internetwork regions the bulk of the power in the intensity power spectra is below 5 mHz and most likely in the range 3–<5 mHz.

4. NUMERICAL MODEL

Assuming that the pulse generated by the foot-point motion has a Gaussian velocity profile, and that the kink waves propagate within a thin flux tube embedded in a two-layer isothermal atmosphere, the displacements of the flux tubes at different heights for different velocity of the foot-point motion, is shown in Fig. 5. The parameter space is characterized by,

- \( \tau = \omega_c t \) (time) and \( s = z/4H_1 \) (height).
- \( \alpha = h/4H_1 \) (thickness of the first layer), where \( h \) is the height of the first layer in kilometers.

Figure 3. Surface plots for the summed counts (first and third row) and the resulting power spectrum for O VI 1037Å and C II 1037Å (second and fourth rows) respectively for the dataset starting at 20:39 UT on 31 July 1996.
Figure 4. The light curve and power spectrum for O i 1037.6Å (top two row) and C ii 1037.2Å (bottom two row) respectively for a typical network region 202-207 (of Fig. 3) of dataset taken on 31 July 1996. The horizontal line in the power spectra corresponds to the 99.9% confidence level.

Figure 5. Displacement of the flux tube as a function of time in units of cut off frequency at rough temperature formation heights as labeled.

- \( r = \sqrt{I_1/I_2} \) (temperature contrast).

We choose our parameter space so as to compare with the observations. The cut-off frequencies of the two layers are also related as, \( \omega_{c2}/\omega_{c2} = r \). We place the temperature jump around 2000 km (\( \alpha = 2 \)) above the photosphere and the temperature contrast corresponds to the temperature jump in the transition layer.

4.1. Inferences from Modelling

- The wake oscillates with a frequency which is neither the cut-off frequency of the lower layer (\( \omega_{c1} = 12.6 \text{mHz} \)) nor the upper layer (\( \omega_{c2} = 10.4 \text{mHz} \)). Instead it oscillates with a frequency \( \omega = \omega_{c1} + \omega_{c2} = 23.0 \text{ mHz} \). Thus this layer is oscillating with a cyclic frequency (\( \omega/2\pi \)) of 3.66 mHz, which is similar to the observed N I 1319 frequency 3.7 mHz.

- The periods are slightly different at different heights of the atmosphere and the amplitude of oscillation grows as we go higher in the atmosphere (s corresponds to height). For \( s = 2.5 \), which corresponds to a height around the higher chromosphere, the wave becomes non-linear. Thus at these locations the non-linear mode transformation will take place (Ulmschneider et al. 1991). Kalkofen (1997) has shown that in the middle chromosphere the displacement of
the flux tube becomes comparable to the diameter of the tubes, thus non-linearity has to be taken into account.

5. CONCLUSIONS

Simulations by Steiner et al. (1998), of magnetic flux sheets embedded in nonstationary, radiative convection have identified a number of dynamical phenomena, e.g., occasional strong bending and rapid horizontal displacement of a magnetic flux sheet by the action of the convective motion of the external plasma, the appearance of shock waves within the magnetic structures. They found strong dynamic interaction between the flux sheet and the surrounding nonstationary convection. These events possibly excite transverse MHD waves, which propagate along magnetic structures and transport mechanical energy in to higher layers of the atmosphere (Choudhuri et al. 1993). Our observations suggest that the lower chromospheric intensity oscillations come from small regions (presumably magnetic flux tubes) of at most 10 arcsec along the slit and lasts for 10-30 mins. These intensity oscillations could be related to the impulsive motions at the photospheric level. Detailed observational results are presented in Doyle et al. (1990) and O'Shea et al. (1990). The network oscillation could be caused by sausage waves, where the dominant frequency matches well with the theoretical value of $\omega_c + \omega_2$. This would indicate a strong coupling between adjacent layers. The sausage waves can be produced by kink waves via a non-linear mode conversion, as obtained by Zeigler & Ullmschneider (1997) in their numerical simulation. The detailed analysis of the propagation of transverse magnetoeacoustic waves in a magnetic flux tube will be presented in a forthcoming paper (Banerjee et al. 1999).

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