ON THE NATURE OF NETWORK OSCILLATIONS

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ABSTRACT

We examine time-series of spectral data obtained from the Solar Ultraviolet Measurements of Emitted Radiation instrument (SUMER), on board SOHO in the period 10–31 July 1996. Observations were obtained in lines, ranging in temperature from 12,000 K to 10⁸ K, covering the low chromosphere to the corona. In this short contribution we report on the time series analysis on one of these dataset, using wavelet methods, of small individual network regions in the quiet Sun. The wavelet analysis allows us to derive the duration as well as the periods of the oscillations. The statistical significance of the oscillations was estimated by using a randomisation method. The oscillations are considered to be due to waves, which are produced in short bursts with coherence times of about 10–20 minutes. The low chromospheric and transition region lines show intensity and velocity power in the 2-4 mHz range.

The observed 2–4 mHz network oscillations can be interpreted in terms of kink and sausage waves propagating upwards along thin magnetic flux tubes. The kink waves can be generated by random foot-point motions, e.g. by exploding granules, at the photospheric level. As they propagate within flux tubes, their amplitude grows exponentially with height and becomes non-linear. The waves can thereby undergo a mode transformation and become sausage type waves, which are more easily detected on the disk.

Key words: Sun: chromospheric oscillations—Sun: waves.

1. INTRODUCTION

It is now established that the solar photosphere is permeated with strong magnetic fields in the form of flux tubes, which occur preferentially in the network, at the boundaries of the supergranular cells on the disk. Several authors have reported that the chromosphere in the magnetic network of the quiet sun oscillates within 2 – 4 mHz range (Dame et al. 1984; Deubner & Fleck 1990; Kneer & von Uexküll 1993; Lites et al. 1993; Steffens et al. 1997; Curdt & Henzel 1998). In order to study the properties of the atmosphere, it is important to concentrate on the dynamics, e.g. the nature of the waves and the origin of the periods observed. In this short contribution we will first present SUMER observations of 31 July 1996 (dataset 203939) of O vi 1037.6 Å and C ii 1037 Å lines and finally we perform a linear numerical computation, comparing the results with our observations to shed light on the nature of the oscillations observed. The results from several other CDS and SUMER dataset will be presented in Banerjee et al. (2000).

2. OBSERVATIONS AND DATA REDUCTION

Before beginning our analysis of the SUMER data, we first have to apply the standard SUMER data reduction procedures of flat-fielding and de-stretching. All of the data reduction steps involved the use of programs obtained from the SUMER software tree. The different steps involved in the calibration of SUMER data are summarised in the SUMER data reduction cookbook (see SUMER web-page) and in Pérez (1999). We refer the reader to these publications for further details. The localised (in time) nature of the wavelet transform allows us to study the duration of any statistically significant oscillations as well as their period. So to find the most reliable periods, we performed wavelet analysis on the data. By decomposing a time series into time-frequency space, one is able to determine both the dominant modes of variability and how these modes vary in time. The statistical significance of the observed oscillations was estimated by using a Monte Carlo or randomisation method. The details can be found in Banerjee et al. (2000). The probability levels displayed in this paper are the values of (1 – p) × 100,
Figure 1. The space-time behaviour of the intensity in the C II 1037.6 Å line (top panels) and O VI 1037 Å line (bottom panels) from the same dataset. The grey scale coding has the most intense regions as white. Panel (a) represents the contrast enhanced image and (b) represents original data. The right panels show the counts summed over all time against the slit locations, which clearly show the network enhancements.

i.e. the percentage probability that periodic components are present in the data. We choose a value of 95% as the lowest acceptable probability level.

3. RESULTS

In Fig. 1, we show time slices of the observed C II 1037.6 Å line (top panels) and O VI 1037 Å lines (bottom panels) respectively. In these plots, the solar north-south (SOLAR_Y) direction is in the vertical axis, the horizontal axis is time. To bring out the details of the original intensity map we have filtered out the bright components in the image. The intensity map $I(y, t)$ is convolved in the time direction with a Gaussian $G(t)$. This results in a smoothed image $S(y, t) = I * G$ which contains no high frequencies. Then dividing the original intensity map by the smoothed map results in the contrast enhanced map, i.e. $C(y, t) = I(y, t) / S(y, t)$ (see Doyle et al. 1999 for details). The gray scale coding has the most intense regions as white. The contrast enhanced images show the fluctuations in the bright features more clearly and their appearance seems periodic. These maps also show some grain structures within the network. The total number of counts in a pixel (summed counts) during the observation is shown in the right columns, and is useful in identifying the network boundaries. We present the wavelet results corresponding to summed over network pixels 166-167, in Figs. 2 & 3 for C II and O VI respectively. Both the intensity and the velocity of C II line show very strong power around 2.6 mHz. The O VI line also shows similar behaviour. The intensity and velocity show strong peaks at 3.1 and 2.4 mHz respectively with power in the 2-3 mHz range over almost the entire observing period. This suggests that if the observed oscillations are due to waves, then they are compressional in nature. We should point out here that the overlay with the cotemporal MDI magnetograms show that, indeed the enhanced network emission in the 165-175 pixels largely lies above regions with enhanced photospheric magnetic field strengths. Thus we feel that the typical oscillations reported here are strongly influenced by the presence of the magnetic field.

4. NUMERICAL MODEL

A number of authors have proposed that the corona is heated by transverse tube or kink waves (Spruit 1981; Choudhuri et al. 1993a,b). Muller et al. (1994) have reported a mean speed of the network bright points of 1.4 km s$^{-1}$ and concluded that there is significant energy in these motions to heat the quiet corona. Hasan & Kalkofen (1999) have argued that network oscillations can be efficiently excited through a buffeting action, by external granules, on flux tubes, with intermittent motions (of about 2 km s$^{-1}$) occurring on a time scale of less than about half the cutoff period of the kink waves.

In this section we follow the formalism developed in Choudhuri et al. (1993b) and study the response of the footpoint motions on the propagation of kink waves in an idealized solar atmosphere. We assume that the flux tubes situated in the network boundaries are isothermal and ‘thin’ compared to the pressure scale height $H$. The parameter space is characterized by dimensionless variables, $\tau = \omega_c t$ (time) and $s = z / 4H_1$ (height), where $\omega_c$ is the cut off frequency of the kink waves and $H_1$ is the scale height of the first layer. The parameter, $\alpha = H / 4H_1$ is the measure of the thickness of the first layer, where $H$ is the height of the layer in kilometers, $r = \sqrt{T_1 / T_2}$ is the measure of the temperature contrast between the two layers, $\lambda = \frac{\omega_c L}{\omega_c t_0}$ is a measure of the strength of the footpoint motion, where $L$ is a typical displacement of the flux tube and $t_0$ is the maximum velocity of the foot-point (see Choudhuri et al. 1993b).
Figure 2. Wavelet results corresponding to pixel 166-167 of 31st July dataset for the C II 1037Å line

Figure 3. Same as Fig. 2, but for O VI 1037Å line corresponding to the same pixel position as Fig. 2.
for details). We consider the effect of an average footpoint motion with velocity $v_0 \sim 1.5 \text{ km s}^{-1}$, a life time of the order of 300 s and a typical displacement 450 km. This gives $\lambda = 0.279$. We place the temperature jump around 2000 km ($\alpha = 3.34$) above the photosphere and choose a temperature contrast corresponding to $\tau = 0.24$ ($T_1 = 6,000 \text{ K}$ and $T_2 = 105,000 \text{ K}$). 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. Fig. 4 shows the oscillations at different heights corresponding to our idealized solar atmospheric model. Note that the wake oscillates with a frequency which is neither the cut-off frequency of the lower layer ($n_1 = 1.9 \text{ mHz}$) nor the upper layer ($n_2 = 0.46 \text{ mHz}$). Instead it oscillates with a period $\tau = 390 \text{ s} = 2.55 \text{ mHz}$. For a single layer solar atmosphere, Choudhuri et al. (1993a) have shown evidence of a wake with the kinks characteristic frequency. In a two layer model, however the situation is somewhat more complicated, since each layer has its own characteristic frequency. For different combinations of $\alpha$ and $\lambda$, we have found that if the $\alpha$ and $\lambda$ values are both small, then the wake mainly oscillates with the cut-off frequency of the upper layer (also see Choudhuri et al 1993b), but for larger $\alpha$ (as in our solar case,) we find that the wake oscillates with a value close to $\omega_{e1} + \omega_{e2}$.

5. CONCLUSIONS

Our observations suggest that the chromospheric intensity and velocity oscillations come from small regions (presumably magnetic flux tubes situated on the network boundaries) of a few arc sec along the slit. These oscillations could be related to the impulsive motions at the photospheric level. The oscillations are considered to be due to waves, which are produced in short bursts with coherence times of about 10-20 minutes.

The numerical model presented here exhibits the nature of the oscillations. The theoretical frequency also indicates a strong coupling between the two idealized isothermal cavities, namely the chromospheric and coronal. The idealized model predicts a frequency of the flux tube oscillation of around 2.5 mHz, which falls within the observed range. Note that depending on the chosen value of $\beta$ this can vary slightly. The scenario which we propose here is that the jostling of the magnetic elements in the network boundary can excite oscillations in flux tubes, which can then in principle be an important mechanism for chromospheric and coronal heating. As kink waves excited at the photosphere travel upwards, their velocity amplitude increases (see Fig. 4). In chromospheric layers, the amplitude becomes comparable to the tube speed for kink waves, leading to an efficient coupling with sausage waves (Kalkofen 1997).

REFERENCES


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