THE DYNAMICAL NATURE OF THE CHROMOSPHERE

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ABSTRACT

The power spectra for line intensities of lower chromospheric lines N i 1319 Å and C ii 1335 Å are presented. On a number of occasions, intensity oscillations were seen to occur in N i at ~ 3.7 mHz while C ii over the same spatial location showed oscillations close to ~ 2.7 mHz. In a network region, the C ii line intensity was time-delayed by ~1 min., compared to the N i line intensity. For network regions, the 5 min. intensity oscillations observed in N i are often accompanied with a blue-shifted line profile of 2–3 km s⁻¹. These oscillations can be interpreted in terms of kink and sausage waves propagating upwards along thin magnetic flux tubes. These waves can be generated by random foot-point motions driven by exploding granules at the photospheric level.

Key words: Sun; chromospheric oscillations; SOHO; waves.

1. INTRODUCTION

With the launch of SOHO, new opportunities have arisen for studying the dynamical nature of the solar chromosphere and transition region. In two previous papers, Doyle et al. (1997, 1998a) reported 5–10 minute periodicities based first on ultraviolet continuum observations at 1370Å taken with the UVSP instrument flown on SMM and more recently on upper transition region data taken with CDS on SOHO. In all datasets examined, there is excess power below 4 mHz everywhere along the slit, although the observed periods do not always come from the most intense regions. In ~40% of instances clear periods are observable in the 2–5 mHz range within the larger power peak at 3.0 mHz. Hansteen (1997) reports a 3 min periodicity in the appearance of bright grains in the wings of Ly α. Betta et al. (1997) suggest that the network region is dominated by low frequency (< 2 mHz) oscillations in both intensity and velocity while the internetwork shows oscillations at 7 mHz in velocity.

It is believed now that the physics of the phenomenon in the network is different from that in the internetwork. The chromosphere in the quiet Sun as shown by N i 1318 Å and C ii 1335 Å lines (see Fig. 1) is structured by magnetic fields, revealing supergranulation cells and differentiating between network and internetwork. In this short contribution, we concentrate on the magnetic network regions. Here, we report on SUMER data searching not only for evidence for oscillations but also whether there are any time-lags between lines formed at different temperatures. We consider two lower chromospheric lines due to N i 1318 Å and C ii 1335 Å. The results are compared with magneto-acoustic waves, in particular the kink and sausage waves.

2. OBSERVATION

The Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument is a stigmatic normal-incidence spectrograph operating in the range 400 to 1610 Å (Wilhelm et al. 1995), with a spatial resolution close to 1 arc sec (~ 715 km on the Sun) and spectral pixels of 40 mÅ (with sub pixel resolution). The observations reported here were obtained with the 1 x 300 arc sec slit (slit 2). In order to get good time resolution the instrument was operated in a sit-and-stare mode with the SUMER standard rotation compensation switched off. For disk center pointing, this implies a new 1 arc sec region every 377 seconds.

The datasets analysed here were acquired from 22:47 UT to 23:18 UT on 31 July '96 at 84 arcsec West of disk center, zero arcsec North. Two spectral lines were observed simultaneously, N i 1318.99Å and C ii 1334.53/1335.71 Å, covering 50 wavelength pixels (~2.2 Å) and 360 arcsec in the North-South direction. The region observed by SUMER was a typical quiet Sun area. A full description of the Fourier technique can be found in Doyle et al. (1997).

3. RESULTS

The low temperature line of N i 1319Å show intensity oscillation frequencies of between 3 and 5 mHz. The line of C ii at 1335Å show similar values of oscillation (Fig. 1) to those found for the N i line. On a number of occasions, oscillations were seen to occur in N i but not in C ii. It was noted that oscillations of ~4mHz is visible in the latter half on the time series.
in N I but only rather weakly in C II, furthermore, oscillations occurred all along the slit and were not confined to the brightest areas (see Fig. 1). Typically the oscillations came from small regions, although in some instances they were present for up to 10 arcsec along the slit. Packets of oscillations were seen to last for between 10 minutes and the full length of the observation, ~30 minutes. An example is given in Fig. 2 for a 10 arcsec region from 317-326 arcsec along the slit. An oscillation at ~4 mins. is clearly present in N I during the last 30 mins. of the observations. These oscillations correspond to brightenings in the network regions. Corresponding peaks are also visible in the C II intensity, although these are mostly delayed by ~1 min. To search for line shifts, an average wavelength was derived via summing the data along the entire slit (25 to 325 arcsec) for each data time-point. The spectral data was then fitted with a Gaussian for each spatial pixel at each data time-point. An example is given in Fig. 3 where both the N I and C II lines show a period of ~4 min for the last 30 mins. in the same region as outline in Fig. 2. The amplitude in N I is ± 2 km s⁻¹.

4. NUMERICAL MODEL

Choudhuri et al. (1993a) 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. Kalkofen et al. (1994) have also

Figure 1. Surface plots for the summed counts and the resulting power spectrum for N I 1318Å and C II 1335.71Å in the dataset starting at 22:47 UT on 31 July 1996 (first and second row respectively). The bright horizontal stripes are regions of concentrated magnetic fields, in network passing under the slit (no tracking of features was used).

Figure 2. The line counts for N I 1318Å and C II 1335Å in the region 317–326 in the dataset taken on 31 July 1996. The C II intensity was divided by 2.0 in order to over-plot with N I.
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. Until recently there was no direct observational evidence as to the nature of the foot-point motions. Berger & Title (1996) reported the dynamics of the small scale solar magnetic field. Their data showed 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. It was suggested by Choudhuri et al. (1993a) that such jerky motions of foot-points could give rise to kink waves in a flux tube. In a followup paper, Choudhuri et al. (1993b) studied how the energy transport to the higher atmosphere is influenced by the temperature jump in the transition layer. Below we use their formulation to perform a linear numerical computation, comparing the results with our observation (see Doyle et al. 1998b for details).

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 a particular maximum velocity of the foot-point motion, e.g. $v_{o} = 3$ km s$^{-1}$, is shown in Fig. 4. The parameter space is characterized by, $\tau = \omega_{c1} t$ (time), $s = z/4H_1$ (height), $\alpha = h/4H_1$ (thickness of the first layer), and $r = \sqrt{T_1/T_2}$ (temperature contrast), where $h$ is the height of the first layer in kilometers. We choose our parameter space so as to compare with the observations of N I and C II lines, i.e. $T_1 = 15,000$K for N I and $T_2 = 22,000$K for C II. $H_1$ is the scale height of the first layer. The cut-off frequencies of the two layers are also related as, $\omega_{c2}/\omega_{c1} = r$. We place the temperature jump around 2000 km ($\alpha = 2$) above the photosphere and the temperature contrast corresponds to the temperature jump between these two lines. 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 1922; Rae & Roberts 1982). A closer inspection of Fig. 4 reveals that the wake oscillates with a frequency which is neither the cut-off frequency of the lower layer ($\omega_{c1} = 12.6$Hz nor the upper layer ($\omega_{c2} = 10.4$Hz). Instead it oscillates with a frequency $\omega = \omega_{c1} + \omega_{c2} = 23.0$ Hz. Thus this layer is oscillating with a cyclic frequency ($\omega/2\pi$) of 3.66 Hz, which is similar to the observed N I 1319 frequency 3.7 Hz. Furthermore, 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 (Ullmscheider 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. DISCUSSION

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 and He I 584 Å lines, although there were no similar peaks in the Doppler-shift power ratio. This they interpreted 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. Recently Curdt
and Heinzl (1998) have presented observations of the temporal evolution of hydrogen Lyman series made by SUMER. In the bright network regions, they detect oscillations of 6.4 to 6.9 min, which they interpret in terms of an upward propagating wave with phase speed \( \sim 3 \text{ km s}^{-1} \). 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.

Our observations suggest that the lower chromospheric intensity oscillations come from small regions (presumably magnetic flux tubes) of at most 10 arsec along the slit and lasts for 10–30 mins. These intensity oscillations could be related to the impulsive motions at the photospheric level. The clear presence of a blue-shift in the N I profile (Fig. 3) indicates an upward propagating wave. For an intermediate field strength, the tube speed of the kink wave is \( \sim 6.9 \text{ km s}^{-1} \). At the formation height of the C II line, the wave speed is almost equal to the tube speed \( v \sim v_K \). The time lag as observed in Fig. 2 could correspond to the wave travel time between the line formation height.

Kalkofen (1997) have presented a scenario which is consistent with our observations in the magnetic network regions 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.

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