Dynamical Nature of The Quiet Solar Outer Atmosphere

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Abstract. We examine spectral properties of the network and internetwork chromosphere and transition region from the SUMER instrument on the SOHO spacecraft. Observations were obtained for a number of lines ranging in temperature from Log T=4.1 K to 5.5 K. The lower chromospheric line N I 1319Å show intensity oscillations at frequencies between 3 and 6 mHz. The C II 1335Å lines generally show oscillations in the 3 to 5 mHz range. For network regions, the intensity oscillations observed in N I are often accompanied with a blue-shifted line profile of 2–3 km s⁻¹. These oscillations in the network regions can be interpreted in terms of magnetoacoustic waves propagating upwards along thin magnetic flux tubes. However, for internetwork regions the simulations of Carlsson & Stein (1995, 1997) are not consistent with the observed lines. Perhaps this can also be explained in terms of some MHD effects, rather than in terms of upward propagating p-modes.

1. Introduction

In the last few years our understanding of the transition region and the chromosphere has changed dramatically with the realization that these are very dynamic and not static. Up till now only a limited number of analyses, based on SOHO data, have been published (see Doyle et al. 1999 for details). We present here an analysis of EUV lines formed in the vicinity of the transition region observed with SUMER onboard SOHO at disk center of the quiet Sun. An overview of typical lightcurves and power spectra of a large number of lines observed in different sequences with SUMER are presented.
2. Observations

The Solar Ultraviolet Measurements of Emitted Radiation (SUMER) instrument is a stigmatic normal-incidence spectrograph operating in the range 400 – 1610 Å (Wilhelm et al., 1995) The observations reported here were obtained with the 1 \times 300 arc sec slit (slit 2). 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 380 seconds (2.65 mHz). A log of the observations is given in Table 1. The overall field-of-view for one of the datasets is given in Fig. 1 where we show the SUMER slit position on a full disk magnetogram, taken in Na I 5896Å on 31 July 1996 at 20:55 UT. Due to the time difference between the N I and Na II images, solar rotation compensation has been used for proper superposition. We have also compared the slit position with several EIT images. Though the region observed by SUMER was a typical quiet Sun area, we do notice occasional concentrations of magnetic fields in the synoptic map (see Fig. 1) corresponding to the bright regions. Presumably the magnetic flux tubes are located in the chromospheric network and are responsible for these brightenings. The small patch in the central part of the slit in Fig. 1
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(presumably the active network) corresponds to the brightening in region 190-202 (31 July) of Fig. 2. The morphology of network and internetwork has also been checked with Ca II images obtained from Big Bear Solar Observatory. Details of the Fourier analysis can be found in Doyle et al. (1999). Power

Table 1. Log of the datasets considered here. The observed lines in different sets are N I 1318.99 & C II 1334.53/1335.71 and O VI 1037.6 & C II 1037.2 Å. N is the number of data points.

<table>
<thead>
<tr>
<th>Date</th>
<th>Pointing X,Y</th>
<th>Start UT</th>
<th>End UT</th>
<th>N</th>
<th>Lines observed</th>
</tr>
</thead>
<tbody>
<tr>
<td>30 July '96</td>
<td>+54,0</td>
<td>18:38</td>
<td>19:09</td>
<td>62</td>
<td>N I, C II</td>
</tr>
<tr>
<td>31 July '96</td>
<td>+54,0</td>
<td>20:39</td>
<td>21:17</td>
<td>150</td>
<td>C II, O VI</td>
</tr>
<tr>
<td>31 July '96</td>
<td>+84,0</td>
<td>22:47</td>
<td>23:49</td>
<td>124</td>
<td>N I, C II</td>
</tr>
</tbody>
</table>

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. Note that when we refer to a ‘normalized’ lightcurve this implies a lightcurve with its mean subtracted and then divided by the square root of its variance. This results in normalized lightcurves which facilitate comparison of curves from lines with different emissivities.

3. Results

The spatial and temporal properties of the data are revealed in Fig. 2, 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. Fig. 2a,c indicate that there is more ‘structure’ in the emission of N I than in C II. The brightest features, which appear as almost horizontal streaks in Fig. 2 are related to network magnetic fields and 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. The typical dimensions along the slit are 5–8 arc sec. If circular in shape these features would be visible for 32–50 minutes, i.e. for the larger part of our observing runs. Fluctuations in the bright features are clearly visible and their appearance seems periodic. Due to the dominance of the network emission in Fig. 2a,c we used a standard contrast enhancement technique to bring out the weak features in Fig. 2 and to filter out the effect of strong long-lasting (network) features. The data were smoothed in the time direction with a running Gaussian of $\sigma = 15$ minutes. Then the original data were divided by the smoothed dataset. The results are shown in Fig. 2b,d. From the figure it is clear that the slowly varying network emission has been largely removed. The contrast enhanced intensity maps show a fairly uniform pattern of grain-like brightenings down to scales of a few arcseconds. This is especially found in the N I maps. In the C II maps the pattern is less regular and the individual grains are slightly larger. These grain brightenings have sizes of 2–4 arc sec along the
Figure 2. The line intensity as a function of position along the slit (y-axis) and time (x-axis) for the N I ([a,b] top) and the C II ([c,d] bottom) line. The left panel shows the observed line intensity and the right panel shows the contrast enhanced intensity (31 July data).
slit and last from less than one minute to a few minutes. The grains appear to be repetitive in time and, at a fixed position along the slit, show the same pattern of in- or egress as the bright network features discussed above. Over distances of a few arcseconds along the slit, the moments of maximum intensity in different ‘streams’ of these grains appear to be shifted by one to a few minutes. In Figs. 3 & 4, we show for two selected network and internetwork regions respectively, the normalized N I and C II lightcurves and their power spectra. Fig 5 shows the light curves and power spectra for simultaneous observation of O VI 1037.6 Å and C II 1037.2 Å, corresponding to another network region of dataset taken on 31st July 1996. The power spectra 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 (Figs. 3,5) 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. Discussion

For internetwork regions we find a strong peak around 3 mHz and a weaker peak around 5.5 mHz for N I, but for C II the 5.5 mHz peak seems to be
absent. Steffens & Deubner (1999) have analysed velocity oscillations of 15 spectral lines observed with SUMER. For internetwork regions, they found that the chromospheric 3 min (5.5 mHz) oscillations increases with respect to the 5 min (3.3 mHz) oscillations with increasing formation height until a maximum is reached in lines formed at about 50,000 K. The absence of 5 min or 3 min peak in their power spectra, for lines formed at coronal heights lends supports to the assumption that the transition layer acts as a reflecting barrier for the internetwork waves. Ground based polarimetric data obtained recently by Lites, Rutten & Berger (1999) provide evidence that magnetic fields are very weak and dynamically insignificant in typical internetwork regions. Though the observation suggests that the gas dynamics changes radically in character, as the upward propagating shock waves interact with the overlaying magnetic fields, not much work has been done on the theoretical side for the interaction of shocks with magnetic canopy kind of structure. More recently, from the measurement of degree of polarization in the sodium doublet, Landi (1998) have ruled out the existence of turbulent magnetic fields and of horizontal, canopy-like fields stronger than \( \sim 0.01 \) G. The simulations by Carlsson & Stein (1995, 1997) are reliable for heights below 1500 km for the quiet chromosphere and the non-magnetic internetwork. But the C II and O VI lines are formed higher in the atmosphere and can not be compared with existing simulations in the literature. Thus it is not at all surprising that we don’t see any grain oscillation with 3 min period for higher chromospheric lines. Gouttebroze et al. (1998) also did not find any evidence of oscillations for lines formed at higher than \( 5 \times 10^5 \) K.
They conclude that the waves in the frequency range 2.5 - 7 mHz are entirely reflected (or dissipated) by the chromosphere-corona transition region.

Simulations by Steiner et al. (1998), of magnetic flux sheets embedded in nonstationary, radiative convection have identified a number of dynamical phenomena. They found strong dynamic interaction between the flux sheet and the surrounding nonstationary convection. For example, occasional strong bending and rapid horizontal displacement of a magnetic flux sheet by the action of the external convective motion and the appearance of shock waves within the magnetic structures. These events possibly excite transverse MHD waves, which propagate along magnetic structures and transport mechanical energy into higher layers of the atmosphere (Choudhuri, Dikpati, & Banerjee 1993).

Our network observations suggests that the lower chromospheric intensity oscillations come from small magnetic regions of at most few arc sec 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 indicates an upward propagating wave. The observed 4-5 min network oscillations can be interpreted in terms of longitudinal magnetoacoustic sausage waves propagating upwards along thin magnetic flux tubes. Kink waves can be generated by random foot-point motions at the photospheric level. As they propagate within flux tubes, their amplitude grows exponentially with height and become non-linear, thereby undergoing a mode transformation becomes sausage waves, which are detected on the disk. The detailed analysis of
the propagation of transverse magnetoacoustic waves in a magnetic flux tube will be presented in a forthcoming paper (Banerjee, Doyle, & O'Shea 1999). However we should point out that in a more extensive analysis, Doyle et al. (1999) have produced the power spectrum for individual pixels and then taken average over several pixels, in contrast to summing the pixels first and then producing the power spectrum (as we have done here). For the regions examined here, they show that the power at higher frequencies cancel, as expected if the oscillating regions are small in size. Although they find that individual regions (as chosen in this paper) show evidence of oscillations, the overall picture is somewhat confusing. On a statistical basis, there seems to be little difference between the bright (network) and dark (internetwork) regions. We hope to pursue this analysis in greater detail.

References

Lites, B.W., Rutten, R.J. & Berger, T. 1999 (in preparation)
Steffens, S. & Deubner, F.-L. 1999 (this volume)
Steiner, O., Grossmann-Doerth, U., Knölker, M. & Schüssler, M. 1998, 495, 468

Group Discussion

Zirker : Do you take into account the reflection at the temperature jump?
Banerjee : Yes, the transmission of power depends on the jump location. We also see a tunneling effect. We have considered the reflection at the transition layer. The energy transmission depends on the location of the transition layer and the temperature contrast. Due to the lower cut-off frequency of the upper layer as compared to the lower layer we observe a tunneling effect.