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Line Shift Variations in Solar Transition Region Lines

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Abstract.
Two high time cadence datasets, taken in C III 977Å and O VI 1032Å were analysed in an effort to establish the extent of the variability in the Doppler-shift of typical mid-transition region lines. In C III, the shortest time-scale variability seems to occur in the network boundary regions where the line-shift can vary by 7-8 km s^{-1} in less than 1 min. The internetwork region also shows variability although this tends to be longer lived, ~2-3 mins. The average C III line-shift in all regions is for a red-shift of $\sim$ 8 km s^{-1} in very good agreement with that derived by others. Furthermore, there does not seem to be any obvious difference in the average line-shift in network and internetwork regions. On a few rare occasions, the C III line was blue-shifted. The O VI line was also red-shifted with the network region showing evidence for a periodicity. These observations were compared to model line profiles based on the response of a 2D MHD environment representing the solar transition region to micro-scale energy depositions. A variety of temperatures at which the energy deposition takes place as well as the amount of energy deposited was examined.

1. Introduction

One of the many un-resolved problems in solar physics is the observed line shift of a few kilometers per second of emission lines formed at transition region temperatures. Using SoHO/SUMER data, it has being shown that the velocities go from a redshift of $\sim$ 0 km s^{-1} at $\sim$ 20,000K to 10 km s^{-1} at 190,000K for the 'quiet Sun', and to $\sim$ 15 km s^{-1} at 100,000K for the active region. At higher temperature an opposite behaviour was observed. In the 'quiet Sun', a *blue-shift* of $\sim$ -2 km s^{-1} is observed at the Ne VII formation temperature (600,000K), while in an active region, a *blue-shifted* value around -8 km s^{-1} is observed for the same spectral line. The above work was however time-averaged and did not cover the important area of time variability (Teriaca et al. 1999).

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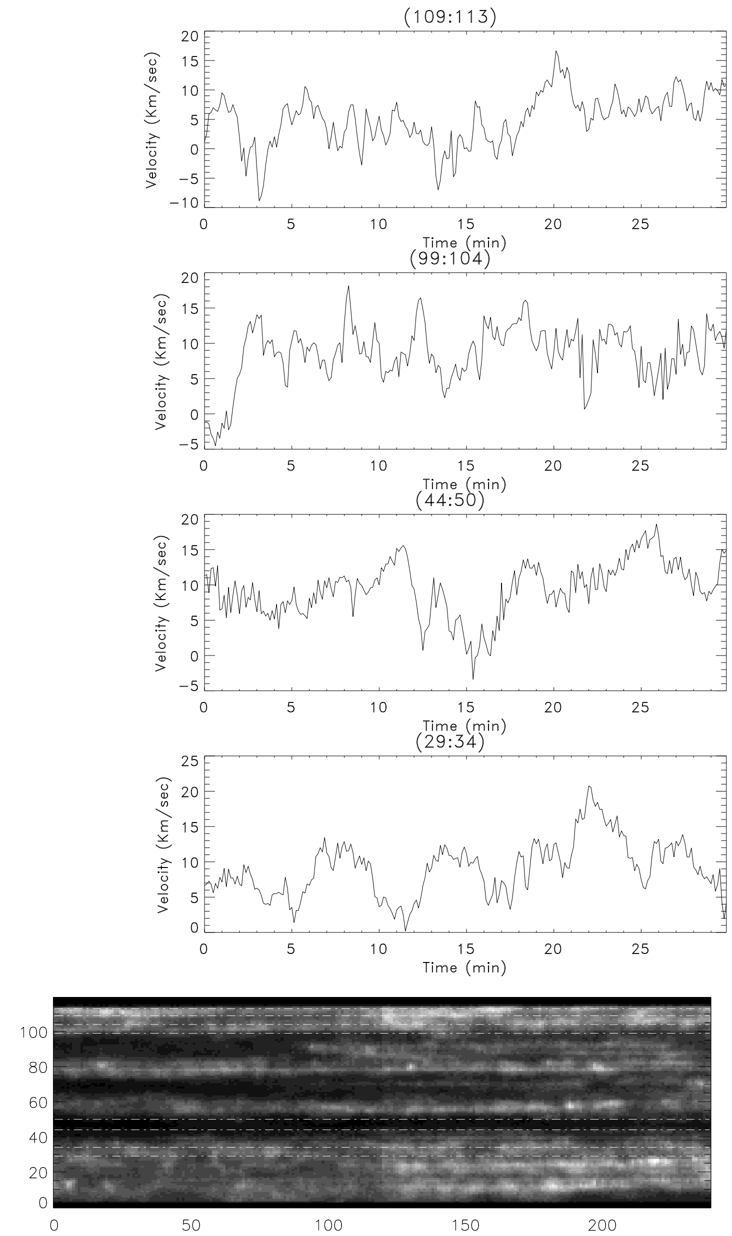

Figure 1. Absolute velocity shifts in $km\ s^{-1}$ as a function of time in C III 977Å for four selected regions: a network boundary in pixels 29–34, an internetwork region in pixels 44–50, a network boundary in pixels 99-104 and a network region in pixels 109–113. The position of the four regions are indicated on the raster given in the bottom panel.

2. Observations

Here, we look at a 30 minute observational sequence taken in a 'quiet Sun' region in the transition region line C III 977Å plus a longer time series taken in

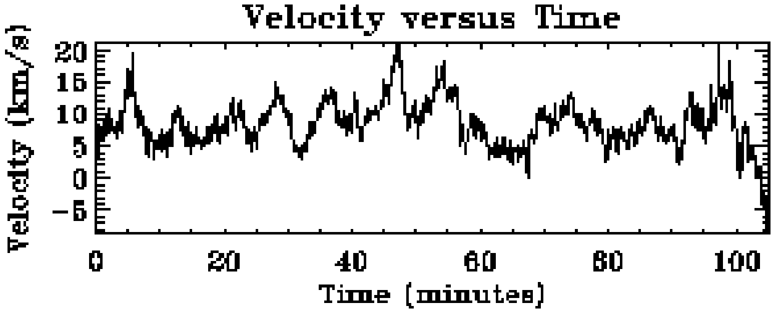

Figure 2. The Doppler-shift of the O VI 1032Å line in a network region

O VI 1032Å, obtained by the SUMER instrument on-board the SoHO satellite. We exclude any obvious explosive events in order to keep our study within the context of the 'quiet Sun'. As can be seen from Fig. 1, the slit for the C III data covered several network and internetwork structures. In order to increase the S:N, we summed over two time pixels (thus giving a time resolution of 5 seconds) and 5 spatial pixels (giving a spatial resolution of 5 arcsec along the slit.

2.1. Results

In Fig. 2, we show for C III 977Å four regions; a network boundary, an internetwork region, a network boundary and a network region. In Fig. 2 we show a 100 min. time slice for a network region as observed in O VI 1032Å. The C III 977Å line is formed in the mid-transition region at a temperature of ~80,000K while O VI 1032Å is formed at ~350,000K. The general picture is:

- **The shortest time-scale variability seems to occur in the network boundary regions**
- **The internetwork region also shows variability although this tends to be longer lived, ~2-3 mins.**
- **The average C III line-shift in all regions is for a red-shift of $\sim 8km\ s^{-1}$ in very good agreement with that derived by others.**
- **There does not seem to be any obvious difference in the average line-shift in network and internetwork regions.**
- **On a few rare occasions, the C III line was blue-shifted.**
- **The C III line-shift can vary by 7-8 $km\ s^{-1}$ in less than 1 min.**
- **The average O VI line shift in the network is ~11 $km\ s^{-1}$, there is also evidence for a periodicity.**

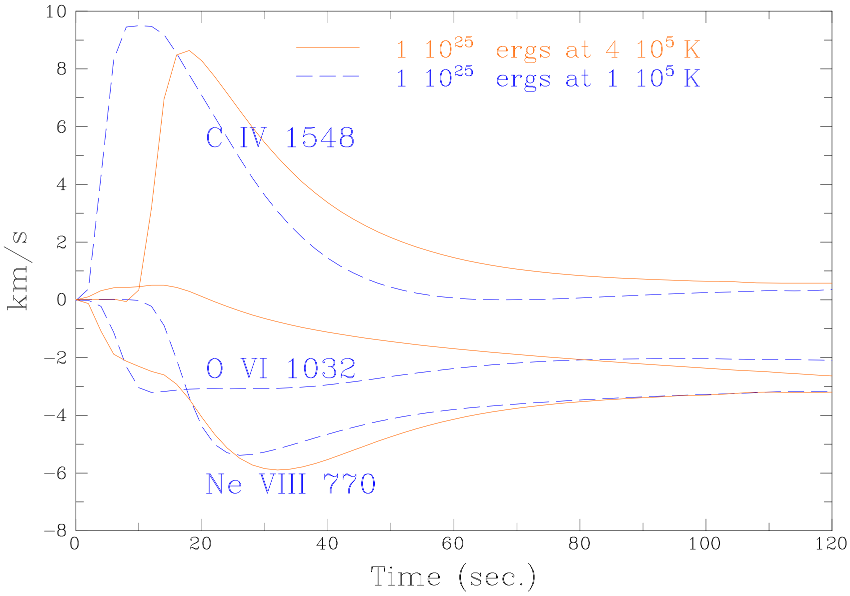

Figure 3. MHD simulations in C IV 1548Å, O VI 1032Å & Ne VIII 770Å for an energy input of 1 10^{25} erg at 100,000K & 400,000K

3. Modelling

We look at the dynamic response to small-scale energy depositions of different magnitudes taking place at different heights in a 'quiet Sun transition region' environment. All numerical experiments are performed using a 2D compressible MHD code based on staggered meshes. These values could, in principle, represent either a nano-flare event as a result of undergoing magnetic reconnection, or, alternatively, resonant absorption of Alfvén waves. Each of these energy depositions is then considered to occur at three different plasma temperatures, i.e. 100,000K, 200,000K, and 400,000K, respectively. An exponential decay model is used for the energy deposition where 90% of the total energy is released in the first 26 sec. In order to compare these results with the observational data, the output is converted into line profiles. Time-dependent ion populations are calculated in order to describe the emitting properties of the plasma involved more accurately. Further details on the MHD code plus the line synthesis may be found in Roussev et al. (2001).

The line-shift in each of these three lines as a function of time are presented in Fig. 3.

3.1. Results

With the onset of the energy release, both the kinetic plasma pressure and temperature start increasing. As the pressure gradient enforced by the energy release grows in time, the plasma heated at the site of the explosion starts expands into the yet non-affected surrounding plasma. Furthermore, the onset of this small-scale event also initiates a fast MHD wave that propagates away from the site of the explosion. Apart from the spreading of the hot temperature region along the current sheet, the peak temperature at the site of the explosion continues to rise as a function of time. While the hot temperature region expands, the cool plasma surrounding the current sheet is pushed away. Since increasing amounts of energy is deposited in the system, the hot plasma blown out from the site of the explosion is gradually accelerated, and bow shocks are subsequently formed at the locations where the unperturbed plasma is hit. Two sets of high outflow velocity peaks appear on each side of the density depletion region. It is found that the peak velocity first increases in time, and then starts to decline after reaching some maximum value. The latter is found to depend on the amount of energy release. Converting into line profiles show:

- **The C III line always shows a red-shift for all energy depositions.**
- **The line-shift scales in proportion to the energy deposition.**
- **The Ne VIII line is always blue-shifted.**
- **The O VI line is close to a zero line-shift.**
- **Depositing the energy at higher temperatures leads to a delay in the peak intensity.**

4. Conclusions

The Doppler-shift of transition region lines in the solar atmosphere is highly variable. Calculations suggest that the observed variability could be produced by a series of energy depositions (reconnection events).

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