SUMER Observations of Doppler Shifts in the Quiet Sun and an Active Region

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Abstract. The UV spectral lines formed at transition region temperatures in the solar atmosphere, shows a prevailing red-shifted emission. Using the Solar Ultraviolet Measurements of Emitted Radiation spectrometer flown on the Solar and Heliospheric Observatory spacecraft, we measure the amount of line-shift as a function of the temperature for several spectral lines formed in the range between $10^4$ and $10^6$ K. We analyze spectrograms relative to the ‘quiet’ Sun and to the active region NOAA 7946. The velocities derived are increasing from $\sim 1$ km s$^{-1}$ at $\sim 20,000$ K to 10 km s$^{-1}$ at 160,000 K for the ‘quiet’ Sun, and to $13 - 15$ km s$^{-1}$ at 125,000 K for the active region. At higher temperatures a different behaviour is observed. In the active region a blue-shift of 8 km s$^{-1}$ is observed at the Ne VIII formation temperature (580,000 K) while in the ‘quiet’ Sun we have a blueshift of 2 km s$^{-1}$.

1. Introduction

One of the most interesting problems in solar physics is the observed red-shifted emission of lines formed at transition region (TR) and coronal temperature. During the last two decades, observations of this phenomenon have been reported by many authors, observed with several UV instruments with different spatial resolution. In the earlier investigations the magnitude of the redshift has been found to increase with temperature, reaching a maximum (around 8 km s$^{-1}$ in the ‘quiet’ Sun) at $T = 10^5$ K, and then to decrease towards higher temperatures. Doschek et al. (1976) found no significant shift in the O V line at 1218 Å at disk center and the commonly quoted average velocity variation with temperature above $10^5$ K depends to a large extent on this particular observation of the 1218 Å line. Chae et al. (1998), have shown that, for the ‘quiet’ Sun, the redshift is peaked around $1.5 \times 10^5$ K with a value around 11 km s$^{-1}$ but it is also present at higher temperatures with a value around 5 km s$^{-1}$ for Ne VIII 770.409 Å in the ‘quiet’ Sun. More recently Peter & Judge (1999) (hereafter, PG) have found blue-shifts in disk center for three coronal lines in the dataset (Ne VIII at 770 Å and 780 Å and Mg X at 625 Å, in contradiction to Chae et al. (1998). PG have suggested a rest wavelength of 770.428 Å for Ne VIII, which we have used for this paper. In this short contribution we also focus our attention to the difference in line of sight velocity between an active region and a ‘quiet’ sun region.
2. Observations

SUMER is a normal incidence spectrograph operating over the wavelength range 450 Å to 1610 Å. It is a powerful UV instrument capable of making reliable measurements of bulk motions in the chromosphere, TR and low corona with an error better than 1 km s\(^{-1}\) (Chae et al. 1998). Observations consist of a series of spectral images covering the wavelength range between 800 and 1590 Å. Every spectrum is partially overlapping the previous and the following, in order to ensure that the spectral lines are recorded on both the bare and the KBr parts of the detector. This allows us to recognize the second order lines from the first order ones using the different wavelength-dependent sensitivity of KBr compared to the bare part. Every single spectrum was exposed for 100 seconds using the 1 × 300 slit in ‘quiet’ Sun and in Active Region NOAA 7946. Reduction of SUMER raw images follow several stages, i.e. flat field subtraction, correction of geometrical distortion and radiometric calibration (in order to pass from count px\(^{-1}\) s\(^{-1}\) to erg cm\(^{-2}\) s\(^{-1}\) Sr\(^{-1}\) Å). Particular attention needs to be paid to the problem of the wavelength calibration. For SUMER there is no on-board calibration source, so the wavelength calibration is done using some chromospheric lines of neutral atoms. These lines are formed in the chromosphere at temperatures around 6500 K (e.g. Si I and S I, Chae et al. 1998) and are supposed to be at rest (Samain, 1991). These should therefore allow the determination of an absolute wavelength scale. In any case it is important to remember that all the absolute velocity measurement made with SUMER will be relative to the chromospheric reference lines. The necessity to have chromospheric reference lines reduces the wavelength range in which it is possible to make an absolute measurement of velocity to 900 – 1600 Å (practically only the first order). In fact the chromospheric line disappear below 900 Å. In Figure 1 an example of the first order spectra of NOAA 7946 is shown. It is possible to see some second order lines superimposed as well as the chromospheric lines used for wavelength calibration. The measurement of the central wavelength was per-
Figure 2. SUMER measurement of Radial Velocities on Active Region NOAA 7946 (top panel), 'quiet' Sun (middle panel) and differences between Active Region and 'quiet' Sun (lower panel).
formed using a multi-Gaussian fit technique. For each spectral line of interest we have calculated the local spectral dispersion using at least two chromospheric lines or two lines of the same ion.

3. Discussion

For active Region NOAA 7946 (top panel, Figure 2), we find that the radial velocity is increasing from $\sim 1$ km s$^{-1}$ at $T \sim 2 \times 10^4$ K to $\sim 13 - 15$ km s$^{-1}$ at $T \sim 1.25 \times 10^5$ K. At higher temperature the velocity decreases, leading to a blue-shift at $T \sim 5 \times 10^5$ K. The behaviour at high temperature is well represented from the measurement of 3 different spectral lines (i.e. Ar VIII, Ne VIII and Na IX). PG have also reported red to blue-shift transition at $T \sim 5 \times 10^5$ K for 'quiet' Sun (from roll data of SUMER). In our 'quiet' Sun data (see middle panel of Figure 2) we observe a similar trend; a maximum velocity of $\sim 10$ km s$^{-1}$ is reached at $T \sim 1.6 \times 10^5$ K and drops down to $-1.9$ km s$^{-1}$ for Ne VIII at $5.8 \times 10^5$ K.

Achour et al. (1995), introduced the idea of 'differential redshift measurement', i.e. to compare 'quiet' Sun and active region Doppler shift measurement. This method has the advantage of being independent of laboratory wavelengths. They found that the differential velocity increases with increasing temperature, reaching a maximum of 7 km s$^{-1}$ at a temperature of $1.0 - 1.35 \times 10^5$ K where the N IV 1486 Å and the O IV 1401 Å lines are formed. Above this temperature the velocity difference decreases abruptly with increasing temperature. It should be noted that they did not use measurements of lines formed above $2.5 \times 10^5$ K, so they inferred the disappearance of the differential redshift in the high transition region by extrapolating the result from the O V line. Our results show (see lower panel of Figure 2) a differential velocity of $4 - 5$ km s$^{-1}$ around $10^5$ K, smaller than the one observed by Achour et al. Furthermore we find a differential blue-shift after $T \sim 5 \times 10^5$ K. We hope to pursue the origin of the observed blue-shift in a subsequent study.

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References