SEARCHING FOR THE ORIGINS OF THE FAST SOLAR WIND

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Abstract. Here we present the lowest evidence, observed in the solar atmosphere, of the fast solar wind streams. They originate from coronal holes (CH) network boundaries, as seen in the low transition region (TR) line, O III 703.87 Å ($T_e \approx 8 \times 10^4$ K). Higher in the solar corona, the plasma outflow is seen in the Mg IX 706.02 Å line ($T_e \approx 10^6$ K), as an increased blue-shift inside the CH region. An interesting change in behaviour is observed at the quiet Sun (QS)/CH boundaries, where plasma from the network changes its velocity sign, and, following the closed magnetic structures, falls back to the Sun. This is also the site where signature of magnetic reconnection between the open CH lines and the closed QS loops is seen, in the form of an increased number of bi-directional jets, which represent evidence for the slow solar wind origins.

1. Introduction

Today there is general agreement that the fast solar wind originates mainly from magnetically open regions in the coronal holes (CHs) (Krieger et al., 1973). In order to find more precisely what are the small-scale features responsible for the development and rise of the fast solar wind streams, one needs to correlate the plasma motions with the fine structures inside the CHs, which are only seen from the transition region (TR) downward.

Hassler et al. (1999) reported correlations between the plasma outflow as deduced from the coronal Ne VIII 770 Å line (originating at 63×10^4 K) and the chromospheric network as seen in the Si II 1533 Å line (1.3×10^4 K).

The results we present here indicate that we indeed see the fast solar wind streams originating from the magnetic network boundaries, at a temperature as low as $\approx 8 \times 10^4$ K (that means, not far away from the base of the TR). This constitutes the lowest temperature (and height) at which those outflows have ever been observed. Moreover, we also see an increased number of bi-directional jets at the quiet Sun (QS)/CH boundary, which

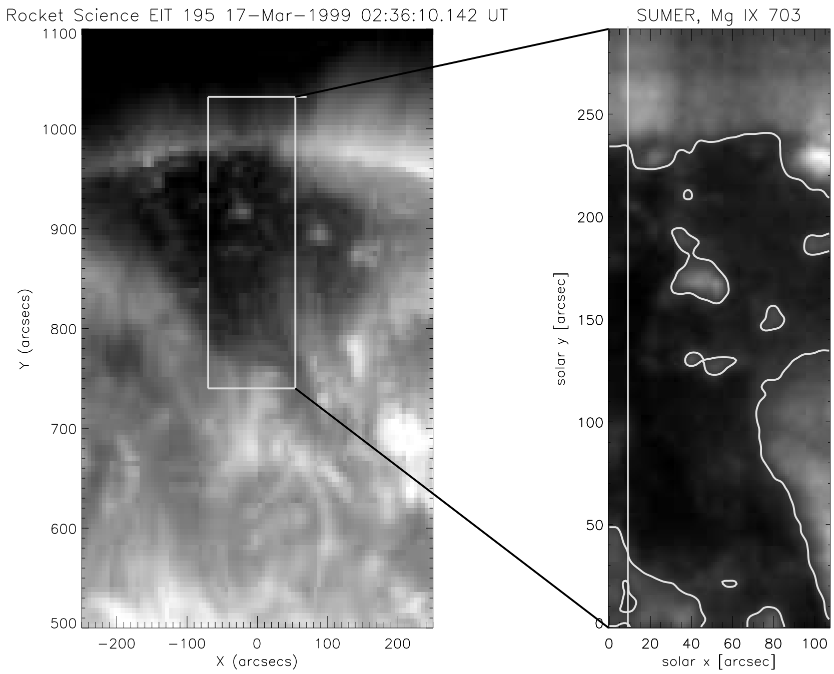

Figure 1. The raster location as seen on the EIT Fe XII 195 Å image (left), together with the raster intensity in the SUMER Mg IX 706 Å line (right). The white contour represents the QS/CH boundary.

represent evidence for the slow solar wind origins, as very recently observed for first time by Madjarska et al. (2004).

2. Data

We analysed a solar on-disk raster taken in a northern polar CH region on 17 March 1999 with detector B from the Solar Ultraviolet Measurements of Emitted Radiation (SUMER) grating spectrograph on SoHO. The final image has a dimension of (108 $\times$ 292) arcsec^2, with a spatial resolution of $\approx$ 1 arcsec and a spectral resolution of 22.4 mÅ. Each spectrum has an integration time of 150 s. We studied a low TR line O III 703.87 Å ($\approx 8 \times 10^4$ K) and a coronal line, Mg IX 706.02 Å($\approx 10^6$ K).

The final aim of our study was to calculate the intensities and the Doppler velocities (LOS velocities) of both lines considered. More details

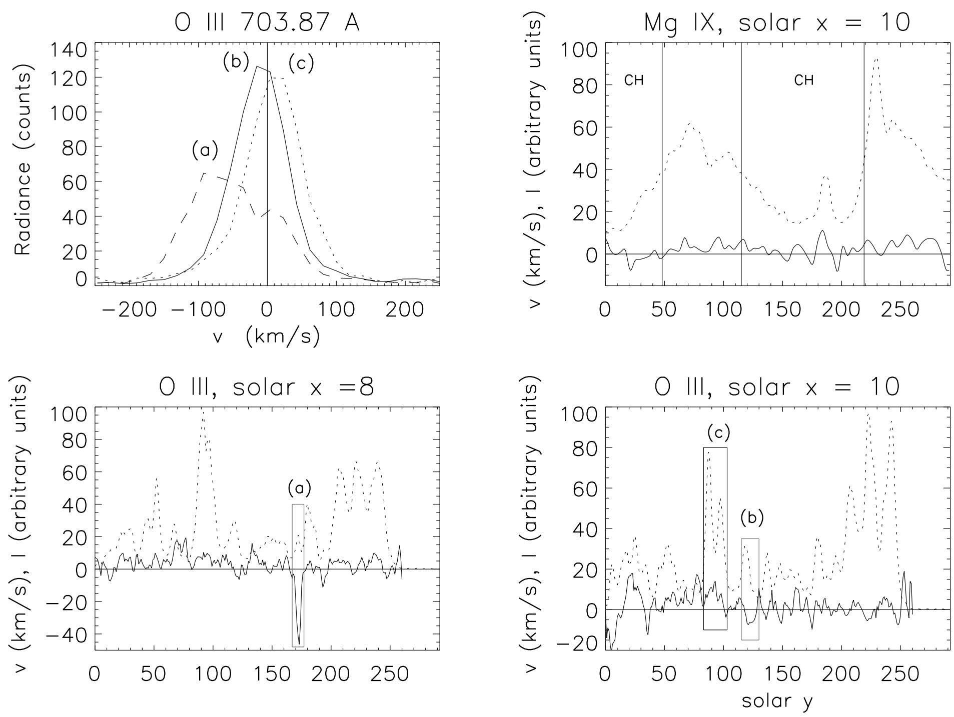

Figure 2. Top left: three example spectra, representing (a) a bi-directional jet, (b) a CH network boundary blue-shift and (c) a QS network boundary red-shift. Top right: intensity (dotted line) and Doppler velocity (continuous line) for the Mg IX line at *solar* $x = 10$. The vertical lines mark the QS/CH boundary. Bottom: intensity and Doppler velocity for the O III line, where the selected examples are again marked.

on the calibration procedures applied, as well as on how we extracted the information from the data, are given in Popescu & Doyle (2004).

The location of the raster on the Sun is given in Figure 1, as seen in the EIT Fe XII 195 Å image (left). To the right of the figure, we give the Mg IX 706 Å intensity, as derived from our data.

3. Results

In the coronal line, the CH is seen as a reduction in the intensity, surrounded by the brighter QS, and very well correlated with negative Doppler velocities (outflows) of about –4 km s^{-1}.

In order to see the correlation between the Doppler velocity and the intensity for the O III line, we made a one dimensional cut at *solar* $x = 10$ (see the vertical line in Figure 1, right).

We selected as examples three type of phenomena, where the O III intensity has high values, but the plasma moves different (see features (a), (b) and (c) on Figure 2, bottom). On the top left plot of Figure 2, we also present the spectra of the selected features.

In the bi-directional jet (a), plasma undergoes rapid movements, both up and down. The spectrum shows a double peak structure, and when fitted with a double Gaussian, the outflow velocities are about –100 km s^{-1}.

In the CH network boundaries (b), plasma is blue-shifted. In the chosen example, the highest outflow is –15 km s^{-1}. This blue-shift represents the plasma up-ward motion seen originating from the CH network boundaries, representing evidence of the fast solar wind origins. In the CH, one can see that every time there is an increase in the intensity, it corresponds to a decrease in the velocity, which generally becomes blue-shifted.

In the QS network boundaries (c) the plasma behaviour is completely changed. The spectrum of the feature (c) is red-shifted up to 13 km s^{-1}. Also, here signature of magnetic reconnection between the open CH lines and the closed QS loops is seen, in the form of an increased number of bi-directional jets, which represent evidence for the slow solar wind origins.

4. Conclusions

Our results (see also Popescu & Doyle, 2004) constitute the first precise indication of fast wind streams seen originating from the CH network boundaries at such a low height in the TR. We have derived this conclusion from direct correlation between the O III 703 Å Doppler velocity and the intensity of the same ion.

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