On the Signature of Alfvén Wave Dissipation in the Localized Coronal Funnel as a Source of Nascent Solar Wind

B.N. Dwivedi[1], A.K. Srivastava[2], Anita Mohan[1]

1. Department of Physics, IIT (BHU), Varanasi-221005, India.
2. Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital-263002, India.

Abstract

We analyse *Hinode*/EIS 2″-spectroscopic scan data containing the spectral lines formed around typical coronal and transition region temperatures. They show the existence of a funnel-like expanding flux-tube which exhibits the signature of the out-flowing plasma in the off-limb equatorial corona as a possible source of the slow solar wind. This coronal funnel is expanding in the form of open magnetic field channel that may be a part of a large-scale and closed magnetic fields existing higher in the diffused equatorial corona. We also find the signature of decreasing line-widths with altitude in the observed coronal funnel which may be the signature of Alfvén wave dissipation. We conclude that the Alfvén wave dissipation along the expanding field lines of the coronal funnel may impart its energy to the out-flowing plasma and may contribute to the formation of the nascent solar wind in the inner corona.

1. INTRODUCTION

The equatorial corona, in all likelihood, is the source of large-scale but slow-speed solar wind (Habbal et al. 1997; Sakao 2007). However, the problem of energy sources to power the nascent slow solar wind particles in the equatorial inner corona remains unsettled. Several studies suggest the role of Alfvén waves in heating and the acceleration of coronal wind in the inner solar atmosphere, while ion-cyclotron waves, at kinetic scales, in the outer solar atmosphere (e.g., Ofman & Davila 1995; Tu & Marsch 1997; Suzuki & Inutsuka 2005; Srivastava & Dwivedi 2006, Jian et al. 2009, and references cited therein).

Accordingly, it provides a ground for compelling debate as to how the Alfvén waves leave the signature of their presence in the solar corona. As far as the equatorial corona is concerned, Harrison et al. (2002) have detected the presence of such waves using the spectroscopic observations from SoHO/CDS in terms of the line width reduction with height, and found that these waves can be dissipated in the equatorial corona. Therefore, such waves may provide their energy to heat the nascent solar wind and facilitate their formation. However, Wilhelm et al. (2005) could not find any further clues about such wave activities because they could not get any significant line-width variations of the various lines as observed by SUMER and CDS in the equatorial corona. In the present work, we detect the presence of the localized low intensity regions in the equatorial corona from where the plasma outflows are observed. The line-width decrement of Fe XII 195.12 Å with height is also evident. We suggest that the line-width decrement may be associated with the reduction in the non-thermal component associated with the formation of the particular line (in the present case Fe XII 195.12 Å ; constant line formation temperature $T_f \sim 1.2$ MK). This is attributed to the presence of dissipative Alfvén waves. A brief summary of these preliminary results are outlined below.

2. Hinode/EIS Observations

An equatorial corona is observed in the 2” slit scan of EUV Imaging Spectrometer (EIS: Culhane et al. 2006) on-board the Hinode spacecraft on 07 February 2007. The EIS is the imaging spectrometer of which 40- and 266-arcsec slots are used for the image analyses using the light curves and emissions per pixel, while the 1- and 2-arcsec slits are utilized for spectral and Doppler analyses using spectral-line profiles. The EIS observes in two modes: (i) scan; (ii) sit-n-stare. It observes high-resolution spectra in two wavelength intervals, 170-211 Å and 246-292 Å using respectively its short-wavelength (SW) and long-wavelength (LW) CCDs. The spectral resolution of the EIS is 0.0223 Å per pixel. The analysed observations were taken on 07 February 2007 and the data-set contains spectra of various lines formed at chromospheric, transition region (TR), and coronal temperatures. The scanning observation started at 16:51:00 UT on 07 February 2007. The scanning steps were without any off-set in the region containing an off-limb active region and the low intensity regions in between showing the plasma outflows.

We apply the standard EIS data-reduction procedures and calibration files/routines to the data obtained at the EUV-telescope which is the raw, i.e., zeroth-level data. The subroutines can be found in the sswidl software tree working under the IDL environment. These standard subroutines reduce for dark-current subtraction, cosmic-ray removal, flat-field correction, hot pixels, warm pixels and bad/missing pixels. The data are saved in the level-1 data file, while associated errors are saved in the error file.

3. Results and Discussions

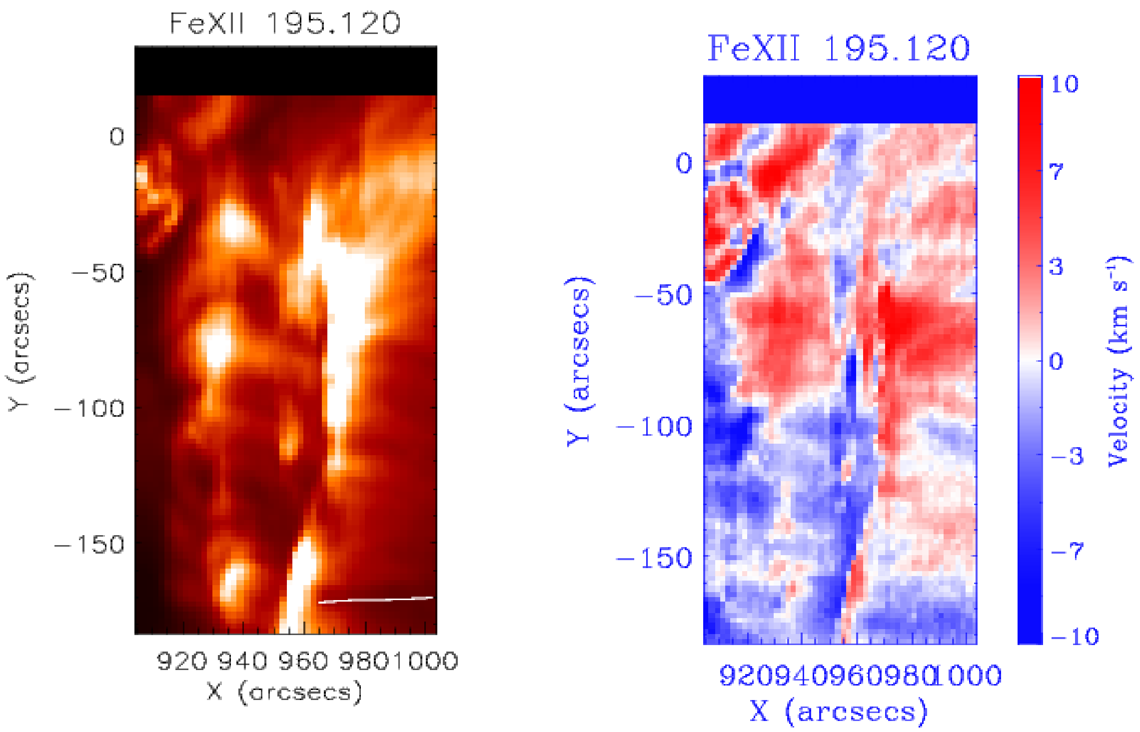

Figure 1. The intensity (left) and velocity (right) maps of the equatorial corona.

We fit the single Gaussian on the clean line of Fe XII 195.12 Å, and derive the intensity, Doppler velocity, and FWHM maps of the observed western equatorial corona (Young et al. 2009; Software Note 17 of Hinode/EIS). Figure 1 displays the intensity map (left) which shows the off-limb active region loops, as well as the diffused small and localized regions which are having less intensity (e.g., the one upon which we have selected the slit). The Doppler map (right) shows that the denser core loops of the active regions with the signature of the downflows, while the diffused, expanding, and less intense regions in between exhibit the signature of the plasma outflows. Therefore, such regions at the periphery of the active regions may be the source of the outflowing plasma that may constitute to the formation of nascent solar wind. However, these regions are small and localized, compared to the previously observed big loop arches, especially at the boundary of the active regions (Harra et al. 2007). Inspite of it, these regions (cf., our selected region in the south-most part of the FOV) are the diffused expanding outflowing plasma that are the part of the ambient near the core active region lying in the equatorial corona. These localized structures may be considered as the part of the coronal funnels opening in the outer parts of the corona.

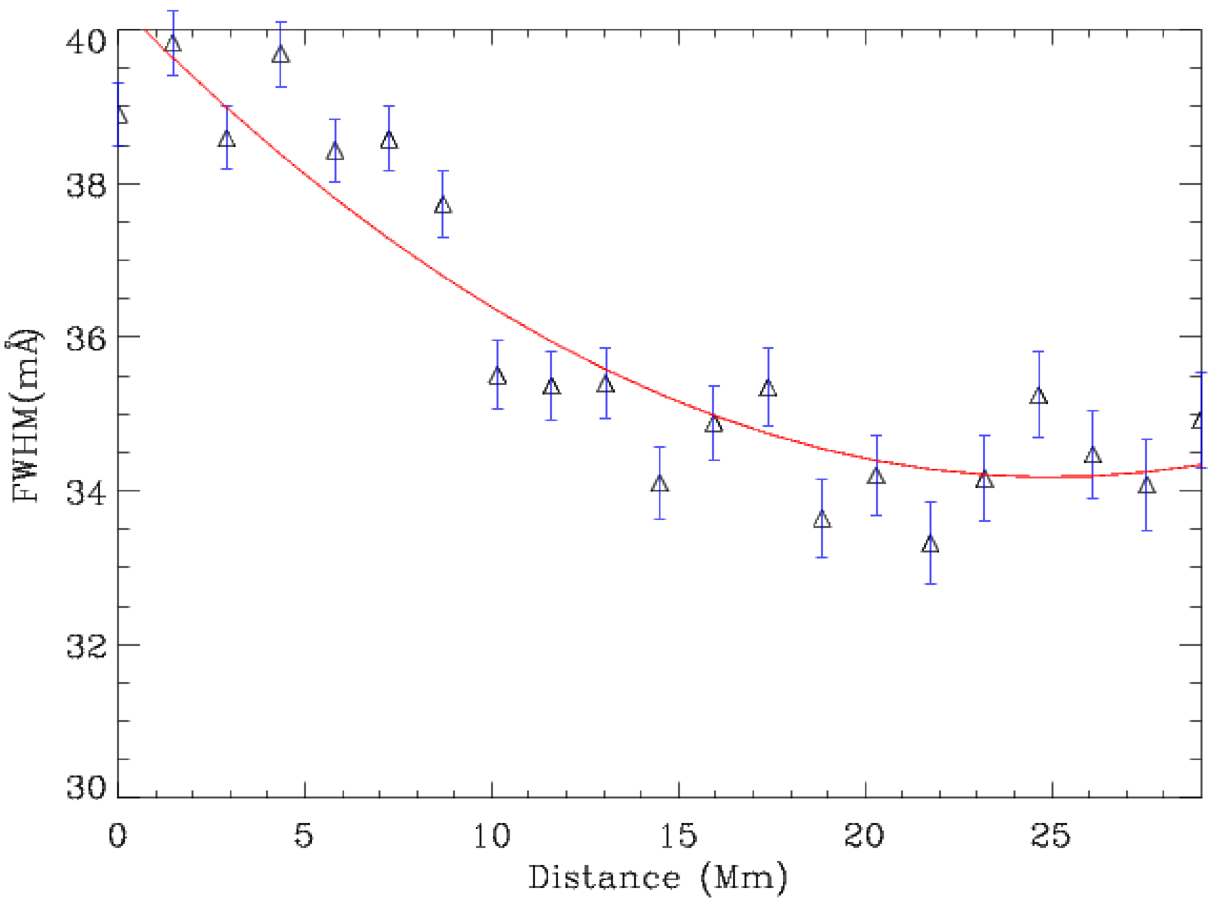

Figure 2. Variation of the line-width along the selected path in the expanding and outflowing plasma region in the western equatorial corona. The 2nd order polynomial fir depicts the decreasing trend of the width.

Figure 2 shows the variation of the line-width along the selected path in the expanding and outflowing plasma region in the western equatorial corona. If the Fe XII 195.12 Å line is formed at typical coronal temperatures. Therefore, its thermal width in the equilibrium will be constant (cf., Eq.1; Imada et al. 2009) :

$$W_{\rm obs} = \sqrt{W_I^2 + 4\log 2\left(\frac{2k_B T_{\rm ion}}{M} + \xi^2\right)},$$

Therefore, the reduction in the resultant line-width along the expected path may attribute to the reduction in the non-thermal velocity most likely supplied by the Alfvén waves in the equatorial corona at different heights (Harrison et al. 2002). However, in the present case, it is not evident in the large-scale equatorial loop system, while it is is shown in the localized plasma outflowing region. Such type of the regions may act as a passage for the dissipative propagating Alfvén waves that can energize the nascent plasma outflowing and most likely contributing to the formation of the nascent solar wind. These preliminary results will be further analyzed taking more such regions and the detailed statistical results will be published elsewhere.

REFERENCES

Culhane, J. L.; Doschek, G. A.; Watanabe, T.; Smith, A. et al., 2006, SPIE, 6266, 22
Dwivedi B. N., Srivastava A. K., 2006, SoPh, 237, 143
Habbal S. R.,Woo R., Fineschi S., O'Neal R., Kohl J., Noci G., Korendyke C., 1997, ApJ, 489, L103
Harrison, R. A.; Hood, A. W.; Pike, C. D., 2002, A&A, 392, 319.
Harra L. K., Sakao T., Mandrini C. H., Hara H., Imada S.,, Young P. R., van Driel-Gesztelyi L., Baker D., 2008, ApJ, 676, L147
Imada, S., Harra, H., Watanabe, T., 2009, ApJ, 705, L 208
Jian L. K., Russell C. T., Luhmann J. G., Strangeway R. J.,Leisner J. S., Galvin A. B., 2009, ApJ, 701, L105
Ofman L., Davila J. M., 1995, JGR, 100, 23413
Suzuki T. K., Inutsuka S.-i., 2005, ApJ, 632, L49
Tu C.-Y., Marsch E., 1997, SoPh, 171, 363
Wilhelm, K.; Fludra, A.; Teriaca, L.; Harrison, R. A.; Dwivedi, B. N.; Pike, C. D., 2005, A&A, 435, 733.
Young P. R., Watanabe T., Hara H., Mariska J. T., 2009, A&A, 495, 587