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Long duration off limb observations of a polar coronal hole with the HINODE/EIS spectrometer

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Abstract. Between February 24-25, 2009, the EIS spectrometer onboard HINODE performed more than 22 hours of continuous "sit & stare" observations over the South polar coronal hole, with an exposure time of 500s. Spectra were acquired with the 1" slit placed off-limb, in order to cover altitudes up to 0.48 solar radii (1.74×10^5 km) above the limb. Spectral lines such as Fe XII λ186.88, Fe XII λ195.12, Fe XIII λ202.04, He II λ256.32, and Ca XVII λ192.81 have been observed with good statistics up to higher altitudes. From the observed line profile widths we have derived ion kinetic temperature profiles: these have been used to investigate the presence of waves in the coronal hole. Results show evidence of wave energy decay (hence energy deposition in the corona) above ~ 0.2 $R_\odot$ from the limb.

Key words: Sun: corona Sun: oscillations Sun: UV radiation line: profiles waves

1 Introduction

Many different physical processes have been proposed to explain the properties of plasma emanating from polar coronal holes and resulting in the fast solar wind streams. Basically two competing theories have been proposed: the first one try to explains plasma heating and acceleration by envisaging ubiquitous magnetic reconnections occurring at the base of the corona, while the second one invoques the propagation along open magnetic fieldlines of different types of MHD waves (magnetoacoustic and Alfvén waves). Recently it has been demonstrated by HINODE/XRT data that coronal X-ray polar jets occurs at a larger rate than previously reported ($\sim$ 10 events per hour) and that these jets are associated with small scale mass ejections propagating at velocities close to what expected for Alfvén waves [1]. More recently the signature of slow magneto-acoustic waves has been identified in EUV spectra observed with HINODE/EIS spectrometer in a polar coronal hole [2], a signature also previously reported with data acquired by sounding rocket experiments, SOHO/SUMER and /CDS [3–6]. These waves appears to propagate undamped up to $\sim 0.15-0.20$ $R_\odot$ above the limb, while it

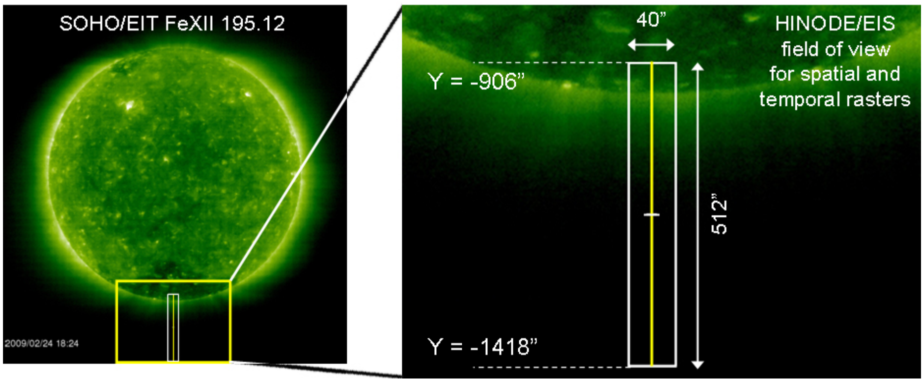

Fig. 1. Left: the lower EUV corona as seen by the SOHO/EIT telescope on February 24, 2009 with the Fe XII λ195 filter. The white box shows the spatial raster's FOV, while the yellow vertical line shows the slit position during the "sit & stare" study. Right: a zoom on the region surrounded in the left panel by a yellow box. Meaning for the white box and yellow vertical line are the same as in the left panel.

is at the moment unclear whether energy deposition in the corona occurs above this altitude.

In order to investigate the above problems, between February 24–25, 2009 an off-limb study of a polar coronal hole has been performed with the HINODE/EIS spectrometer (HOP 103, EIS study 340). In this paper we describe the preliminary results we obtained from data analysis: after a description of the datasets and of the procedure we followed to analyze them (§ 2), we summarize our results and conclusions in § 3.

2 Data description and analysis

Between February 24–25, 2009 the 512" long slit of the HINODE EUV Imaging Spectrometer (EIS) [7], oriented along the North–South direction, was centered above the South polar coronal hole at 202" above the limb, covering a range of altitudes going from $\sim$ 0.05 $R_\odot$ below the limb up to $\sim$ 0.48 $R_\odot$ above the limb. At these altitudes the instrument acquired, in sequence: 1) a $\sim$ 1 hour spatial raster covering 80" in the X direction with the 2" slit centerd on X=0 (100 s exposure time - context study); 2) a $\sim$ 21.6 hours "sit & stare" study with the 1" slit fixed at X=0 (500 s exposure time); 3) another $\sim$ 1 hour spatial raster identical to the first one. The field of views (FOVs) covered with the spatial and temporal rasters are shown in Figure 1. For this study, 10 spectral panels (32 spectral bins per panel, equivalent to $\sim$ 0.71Å) have been acquired centered over the following lines: O VI λ184.00, Fe XII λ186.85, Ca XVII λ192.82, Ca XIV λ193.87, Fe XII λ195.12, Fe XIII λ202.04, He II λ256.32, Fe XIV λ264.78, Fe XIV λ274.77, Fe XV λ284.16. Over these spectral intervals, the following Fe lines have been all well detected and identified: Fe X λ193.71, Fe XII λ195.12, Fe XII λ193.51,

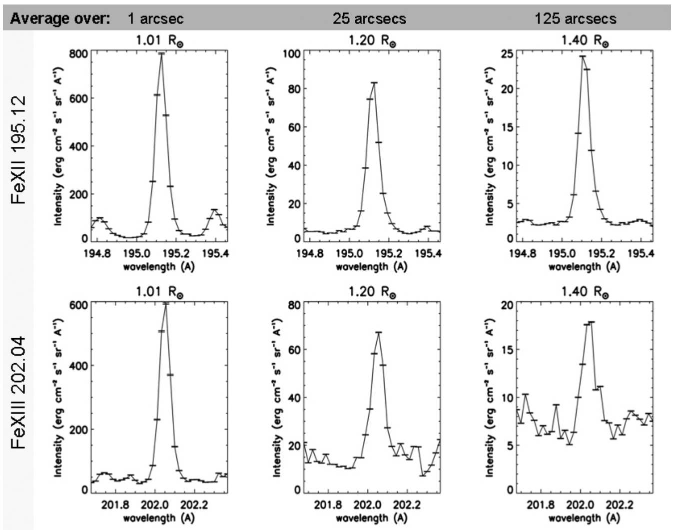

Fig. 2. An example of Fe XII λ195.12 (top) and Fe XIII λ202.04 (bottom) line profiles obtained at 1.01 (left), 1.2 (middle) and 1.4 $R_\odot$ (right) by averaging over 1", 25" and 125", respectively.

Fe XII λ186.88, and Fe XIII λ202.04. Acquired data have been first calibrated with the standard routines provided with the *SolarSoftware* package, aimed also at removing instrumental effects such as the tilt of the EIS slits relative to the detector column's orientation and the line centroid shifts related to the HINODE spacecraft Sun-syncronous orbit, occurring with a period of $\sim$ 100 minutes. Second, each one of the identified lines has been fitted with a gaussian profile in order to derive the evolution with time of the integrated emission at each altitude covered by the 512 slit spatial bins. Third, a further correction has been applied to the intensity versus time maps in order to remove a periodic desplacement of $\pm \sim$ 6" observed in the Y direction, likely related again to the spacecraft orbit and observed as an apparent periodic limb oscillation. Resulting intensities do not show clear plumes/interplume structures at this time; we were then unable to distinguish in this dataset between these different structures. For this reason, in order to have a better statistics, in this first analysis we simply summed over time all data acquired during the "sit & stare" study. Physical parameters we derived are considered as representative of an average plume/interplume plasma. Moreover, at larger altitudes, summing over $\sim$ 21.6 hours of observations was not sufficient in order to have a good statistics: Hence, as also done by [2], profiles at the southern edge of the slit were obtained by averaging over different spatial intervals, summing over a larger number of pixels at larger altitudes. An example of line profiles obtained at 3 different altitudes is shown in Figure 2. The ion kinetic temperatures $T_k(Fe)$ of Fe ions at different heights have been derived by simple gaussian fitting over the average line profiles. In particular in this work we employed the Fe XII λ195.12 profiles, which give the better signal to noise ratio at all altitudes. After the fitting procedure, the FWHMs values have then been corrected for the instrumental profile broadening, by assuming an instrumental FWHM = 2.42 pix = 0.054 Å. Corrected FWHMs provide an estimate for the broadening due at the same time to ion kinetic temperatures and plasma wave oscillations. By assuming (as also done by previous authors) that the unknown ion temperature equals the peak in the line formation temperature as provided by CHIANTI ($T_k = 10^{6.1}$K for Fe XII λ195.12), we estimate the broadening due to wave propagation alone.

3 Results & Conclusions

Results show that the line profile broadening due to the plasma oscillations increases from the limb up to $\sim$ 0.2 $R_\odot$ above it, reaching a peak value of $\simeq$ 0.075Å, which corresponds to a non thermal velocity $v_{nth} \simeq 42$; this result is in agreement with what obtained by [2]. Thanks to the FOV of the EIS off-limb study we performed (Figure 1) we were able also to study the v_{nth} versus altitude profile up to futher distances than those ever explored by previous authors with the same instrument. It turns out that above $\sim$ 0.2 $R_\odot$ a progressive decrease of v_{nth} is observed, down to $v_{nth} \simeq 34$ at 0.4 $R_\odot$ above the limb. In conclusion, this work demonstrates that, if the observed non-thermal velocities are due to plasma wave oscillations, these waves are progressively damped above $\sim$ 0.2 $R_\odot$, hence deposition of wave energy occurs in the corona above this altitude.

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