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Observed and simulated coronal UV lines at solar minimum activity: The impact of the 3D tilted coronal streamer belt

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Summary. — The aim of this study is to improve the knowledge of the slow solar wind origin. In particular, we compute the emissivities and the intensities of UV spectral lines starting from the physical parameters of a time-dependent 3D three-fluid MHD model of the tilted coronal streamer belt. The results obtained from the model are compared in the extended corona (at 1.5 and 1.9 $R_\odot$) to the UV spectroscopic data from the Ultraviolet Coronagraph Spectrometer (UVCS) onboard SOHO in the streamer belt during the minimum of solar activity (1996). The discussion is focused on the importance of the projection effects due to the integration along the line of sight in the coronal ultraviolet observations of streamer core dimming.

1. – Introduction

The slow solar wind is known to flow from the equatorial and mid-latitudes solar regions and in order to improve the understanding of its origin and acceleration, the comparison between data analysis and numerical models is crucial (e.g. [1]). During solar minimum, a characteristics of quiescent equatorial streamers is revealed by comparing the heavy ion (e.g. O VI, Mg X) and the neutral hydrogen (HI Lyα) images: most of the ion images show structures such as sub-streamers at low heliocentric distances; on the other hand, the HI Lyα streamers show a maximum brightness on the axis as clearly shown in Figure 1, adapted from [2]. What is the origin of the core dimming observed in heavy ion emission? There are many candidates for the answer, such as gravitational settling inside the closed magnetic field, Coulomb drag of heavy ions along the legs - bright structures of streamers, and also the projection effects due to the integration along the line-of-sight (l.o.s.) of the UV emissivities in the corona, or likely a combination of these processes. In this work, we compare observations from the Ultraviolet Coronagraph Spectrometer (UVCS) onboard SOHO of the streamer belt during the minimum of solar activity (1996),

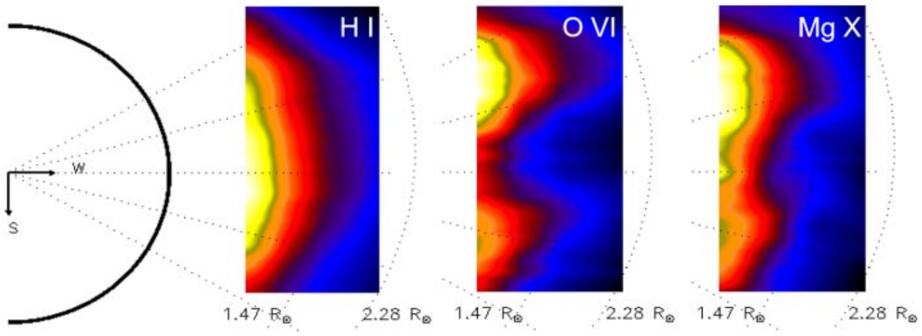

Fig. 1. – Streamer intensity images from 1.47 to 2.28 $R_\odot$, as observed by UVCS on 1997 September 26, in HI Lyα, OVI 1032 Å, and MgX 625 Å. The left panel shows the corresponding solar coordinates. Adapted from [2]. It is evident the core dimming in heavy ions, even if less marked in MgX emission.

with the intensities obtained from 3D multi-fluid MHD model published by [3]. Multi-fluid simulations are required in order to model streamers that contain heavy ions as separate fluid interacting with proton and electron fluids. A letter has been submitted in Astronomy and Astrophysics journal with the first results of this comparison and we refer to it for more details [4].

2. – Observations and data analysis

The main spectral lines detected with UVCS are the HI Lyman α line at 1216 Å and the O VI doublet lines at 1031.93 and 1037.62 Å. In this work we have analysed the spectra detected by UVCS of the equatorial streamer belt observations in the period July 29 to August 22, 1996 at 1.5 and 1.9 $R_\odot$. The observation were performed in approximately 9-12 hours per day, and the considered region of the corona corresponds to about 40^o. The counts detected by the instrument are corrected for stray light and transformed to intensity by applying the standard radiometric calibration. A spectral line is fitted with a Gaussian curve, which represents the solar line profile, convolved with a Voigt curve and an appropriate function that account for the instrumental broadening. A background linearly dependent on wavelength is summed to the function resulting from the convolution. See [4] for more details. The line intensity values are obtained by integrating over the line profile.

3. – 3D multi-fluid MHD model of a tilted dipole: computation of emissivities and intensities

The time-dependent 3D three-fluids MHD model is based on equations with full ion dynamics (see e.g. [5], [6] for the details of the model) and assumes an analytic dipole magnetic field configuration with a tilt angle of 10^o as the initial state for the streamer calculation. The model is run until a streamer with a current sheet is formed and a quasi-steady state is achieved; moreover, it includes O^{5+} ions as one of the fluids. Previous works published by [7,8,2] have shown that the 2.5D model results (ion density structure and outflow speed), are in qualitative agreement with UVCS observations. Here we apply the 3D model with the tilted dipole, allowing temperature coupling in the energy equations with $\gamma = 1.05$ for all species, modelling only the streamer belt without including the polar regions. The physical parameters obtained by the 3D three-fluid MHD model are used to compute the expected emissivities from HI Lyα and OVI 1032 Å spectral lines. The UV coronal emission is produced by two main mechanisms which are the resonant scattering of radiation coming from the bright solar disk by ions/atoms in the outer corona and the collisional excitation by electron impact on ions/atoms followed by radiative decay. Therefore, the total emissivity coming from the corona is the sum of these two components (e.g. [9] for the equations of the emissivities). See [4] for more details of the computation. We have obtained two cubes of emissivities values with 256 elements in each dimension, one for HI Lyα line and one for OVI 1032 line. The intensities of HI Lyα and OVI spectral lines have been computed by rotating of steps of 1^o the cube of the emissivities and by summing the values along the l.o.s..

4. – Discussion

In order to compare the observations and the model results, we have produced Carrington maps of the intensities observed by UVCS (latitude as a function of time) and computed from the model (latitude as a function of longitude, originating by the rotation of the cube). Carrington maps from the observations are built by extracting a profile of each coronal image reconstructed from UVCS spectral data at a certain radial distance from the Sun center (at 1.5 and 1.9 $R_\odot$ in the top panels of Figures 2 and 3, respectively; left: H I, right: O VI); hence, each column represents one image of one day in the period July 29 - August 22, 1996 of the coronal region across the streamer belt. The dotted white line shows the neutral line as computed by Wilcox Solar Observatory. From the model, we have built a 14 days (half rotation) Carrington maps of H I and O VI intensity. The results are shown at 1.5 and 1.9 $R_\odot$ in the bottom panels of Figures 2 and 3, respectively (left: H I, right: O VI) in normalized units. It is evident the effect of the tilt angle of the streamer belt present in the model, in both of the intensity images. Moreover, the latitudinal width of the streamer is wider in the model than in the observations, due to the simple magnetic dipole assumption. The interesting result is that the core dimming in the streamer belt is present only in some O VI latitudes and not in the H I Lyα ones. Thus, the magnitude of the dimming of the O VI emission due to gravitational settling

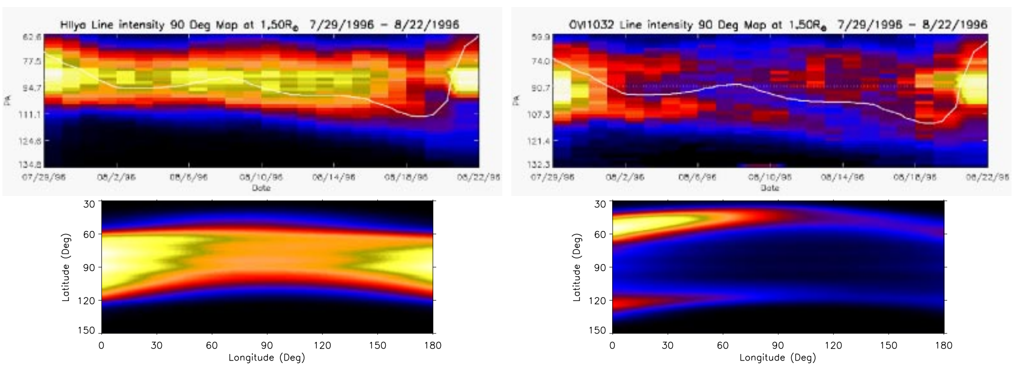

Fig. 2. – Top - Carrington maps (latitude as a function of time) of the intensities of HI Lyα (left) and O VI 1032 (right) spectral lines observed by UVCS in the period July 29 - August 22, 1996 at 1.5 $R_\odot$ (normalized units). The white line shows the neutral line as computed by Wilcox Solar Observatory. Bottom - Carrington maps (latitude as a function of longitude) of the computed intensities from the model for the same spectral lines at 1.5 $R_\odot$ (normalized units).

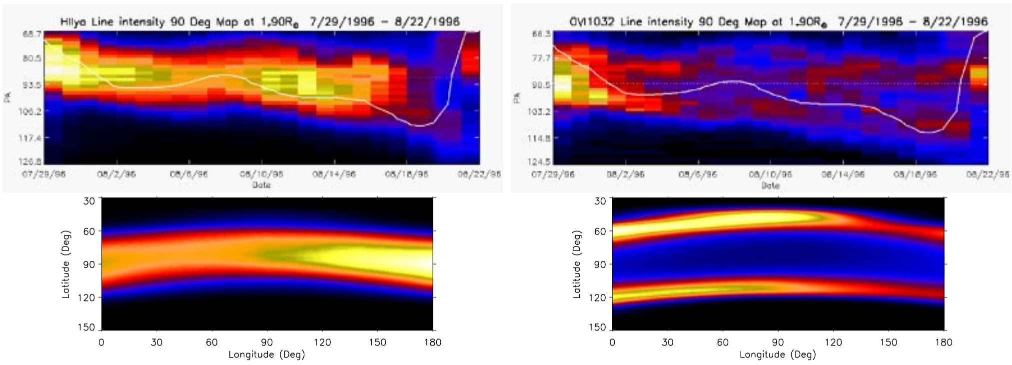

Fig. 3. – The same as Figure 2 at 1.9 R$_\odot$ (normalized units).

in the core of the streamer and Coulomb friction at the bright structures (legs) found in azimuthally symmetric 2.5D model, could be diminished or enhanced due to l.o.s. integration effects in 3D. In the work by [4], they discussed the results at 1.7 R$_\odot$, but here similar conclusions are related also at the altitudes of 1.5 and 1.9 R$_\odot$. The shape of the streamer belt changes with distance, becoming narrower, and at 1.9 R$_\odot$ the legs in O VI emission are closer to each other than below. In conclusion, the core dimming in heavy ions is visible only in some cases due to projection effects of multiple structures streamer and due to the tilted magnetic dipole. The initial conditions of the magnetic field applied in this work are related to an idealized tilted dipole model. In a future study, we would like to investigate other more complex magnetic configurations of the streamer belt, initialized with PFSS model, such as the sub-structures proposed by [10].

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