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On the dynamics of solar polar plumes observed by SoHO/UVCS

L. Zangrilli, L. Abbo and S. M. Giordano

Istituto Nazionale di Astrofisica (INAF), Osservatorio Astrofisico di Torino - Pino Torinese, Italy

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Summary. — We investigate the plasma outflow in solar polar plumes by using SoHO/UVCS observations of May 2005. Despite the fact that data have been acquired more than ten years ago, UVCS spectral observations in the intermediate corona still represent a unique opportunity of studying the plasma dynamics at those heliocentric distances. The Doppler dimming technique is applied to the O VI doublet and H I Lyman-α spectral lines, to infer the outflow speed and the electron density in plumes and interplumes. Our aim is to, investigate if plumes, in the intermediate corona, are to be considered static structures or if they dynamically expand, contributing to the fast solar wind.

1. – Introduction

Polar plumes are bright structures observed in polar coronal holes. In the scenario accepted nowadays, plumes are relatively slowly expanding structures, with higher densities and lower temperatures than the surrounding interplume plasma. The estimate of physical parameters of plumes, obtained with different instruments is episodic, sparse and sometimes in disagreement. For recent reviews see *e.g.* [1], [2]. A good opportunity of obtaining additional data is offered by the analysis of the fifteenth SoHO-MEDOC 1 campaign (Multi-Experiment Data Operations Center for SOHO at Orsay, France), which covered the observing period 16-25 May 2005, when a well-developed coronal hole was located near the South pole of the Sun. In particular, dedicated observations were performed by SoHO/SUMER and UVCS instruments.

2. – SoHO/UVCS data analysis

We analyzed SoHO/UVCS data from SOHO-MEDOC 1 campaign, during which spectra of O VI doublet and H I Lyman-α lines, have been acquired, within the heliocentric distance range 1.5 - 2.9 R_{sun}. The slit was centered at different heliocentric distances, along the South pole direction, with a width of 100 μm, and an instantaneous field of view of 28″ along the radial direction, and 2478″ along the perpendicular direction. A single pixel has a spectral resolution of 0.01 Å, and a spatial resolution of 41″.

For each slit position, the UVCS spectra were gathered in two groups, one pertaining to the latitude interval from 260 to 280 (270 deg corresponds to the South pole), the second to the interval from 240 to 260 deg, and from 280 to 300 deg, hence covering two different heliocentric distances separated by about 0.1 $R_{\rm sun}$. The spectra of each group were summed up, obtaining for each slit two pairs of spectra, being representative of plumes and interplumes at different heliocentric distances.

3. – Context Observations from SUMER and LASCO

SUMER observed the South Pole on 21, 22 and 23 May with only one slit position (no raster was possible) the O VI doublet and H I Lyman β. Analysis of SUMER DATA on 24 May 2005 from 01:17 to 12:55 UTC was published by [4], giving electron densities and temperatures, in the spatial range from 1.065 Rsun to 1.186 Rsun of the South coronal hole: line ratio of Si VIII 144.6 nm and 144.0 nm for obtaining electron density; line ratio of Mg IX 70.6 nm and 75.0 to obtain the electron temperature. No significant Doppler velocities were measured. Three main plumes were identified at 5$^{\rm o}$, 11$^{\rm o}$ and 21$^{\rm o}$, and 3 interplumes, were identified. The South pole corresponds to 0$^{\rm o}$, and the angular distances are counted counterclock-wise.

4. – Identification of plumes and interplumes

4˙1. *LASCO C2 images.* – We identified plumes and interplumes by comparing UVCS intensity profiles along the slit with data provided by the LASCO (Large Angle and Spectrometric COronagraph) C2 coronagraph onboard SoHO. The two instruments (UVCS and LASCO) explore different coronal altitudes, hence plumes and interplumes appear at different locations. We assumed that plume profiles follow the magnetic field lines emerging from the polar coronal hole, and traced back plume profiles across the field

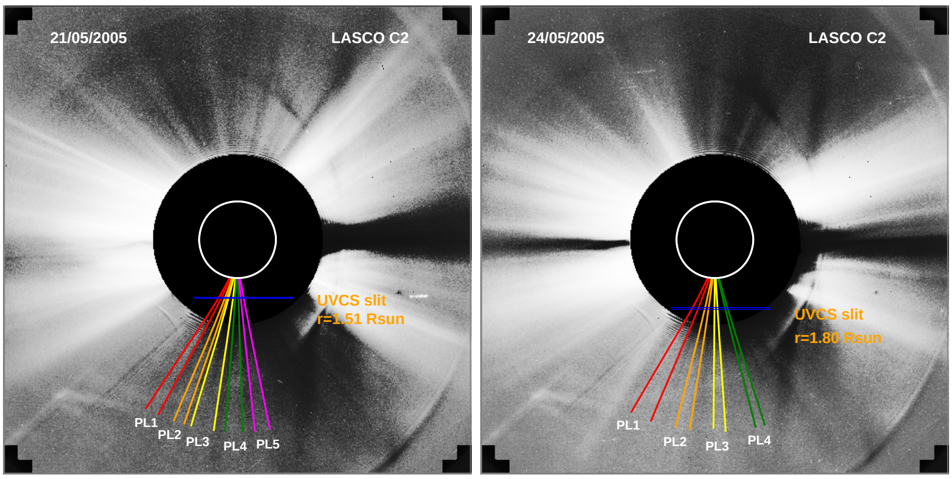

Fig. 1. – LASCO/C2 Plume identification with magnetic field model lines for day 21 and 24 may 2005.

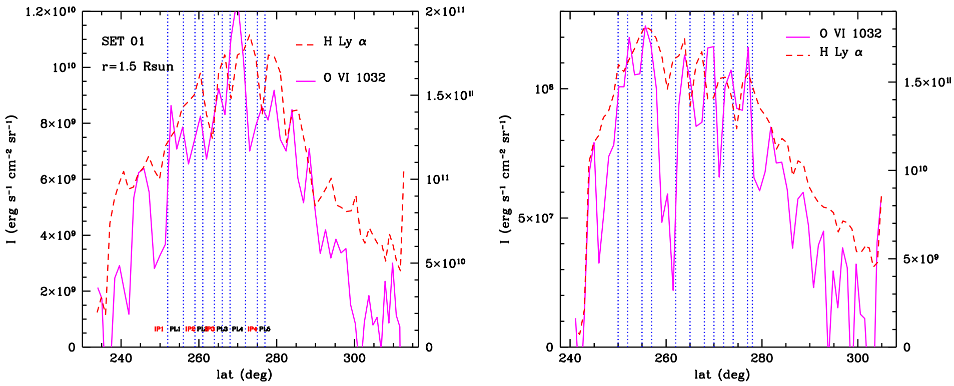

Fig. 2. – Line intensity profiles along the UVCS slit. Profiles are shown for 2 heliocentric distances, 1.5 and 1.8 solar radii. Intensity profiles of redundant H I Lyα and O VI 1031.9 Åare shown as red dashed and magenta solid lines, respectively.

of view of the two instruments by means of a coronal magnetic field model of (see [6]). Different field geometries, which are controlled by the Q parameter, were explored, and we chose that best reproducing the LASCO plume profiles. As an example, plume identification is shown in Figure 1, for the days 21 and 24 may 2005. The UVCS slit position is shown as a blue segment in the LASCO field of view.

4˙2. *H Lyman α and O VI Line intensity profiles*. – The line intensity profiles along the UVCS slit are shown in Figure 2, together with the plume-interplume identification.

5. – Outflow speed and electron density

5˙1. *O* VI *doublet line intensity ratio*. – The analysis of spectral line profiles has been performed by fitting observed spectra with a Voigt function, which is comprehensive of the instrumental function, the slit contribution and the intrinsic line width. An indication about the outflow speed regime in plumes and interplumes can be obtained from the intensity ratio of the O VI doublet, $R = I_{1032}/I_{1038}$. A comprehensive description of the use of R as a diagnostic tool can be found in [3]. The intensity ratio R is little dependent on the particular choice of a coronal model, and we can broadly state that values of about $R = 3-4$ corresponds to a almost static corona, and $R = 2$ is attained for outflow speed $v \approx 100$ km/s. The values for R are shown in Figure 3(a), for plumes and interplumes; errors are estimated assuming a Poissonian statistical distribution of counts at the detector. We can see that plumes appear to be static at heliocentric distances lower than $\sim 2\,R_{\rm sun}$, but higher up the plume plasma dynamically expands. Interplumes, instead, exhibit a continuously increasing outflow speed with the heliocentric distance.

5˙2. *O* VI *doublet and H* I *Lyα Doppler Dimming analysis*. – We inferred the radial outflow speed and the electron density of the plasma (Figure 3b) in plumes and interplumes by means of the Doppler Dimming analysis of the O VI doublet and H I Ly α lines. We inverted equation for the coronal emissivity and separated the radiative and collisional components of the doublet; for more details see [5]. By means of the Doppler

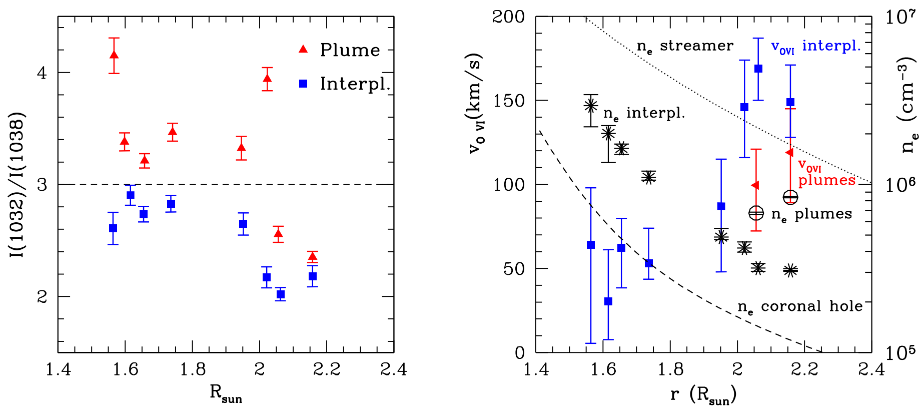

Fig. 3. – (a) left panel: O VI doublet line intensity ratio for plumes (red triangles) and interplumes (blue squares). (b) right panel: outflow speed of O VI ions, for plumes (red triangles) and interplumes (blue squares). Electron density profiles for plumes (stars) and interplumes (open circles); the dashed and dotted lines represent typical coronal hole ([7]) and streamer ([8]) electron density profiles, respectively.

Dimming analysis, we found models for plumes and interplumes, which are capable of reproducing the H I Lyman α and O VI line intensities observed by UVCS, and satisfy the mass-flux conservation constraint of protons and oxygen atoms. For a comprehensive description of the Doppler Dimming technique see [3].

6. – Discussion and Conclusions

The Doppler Dimming analysis demonstrates that plumes do not show a significant outflow speed below $\sim 2\ R_{\rm sun}$, unlike interplumes, which gradually increase their speed with the heliocentric distance. On the contrary, both plumes and interplumes are characterized, at heliocentric distances higher than $\sim 2\ R_{\rm sun}$, by dynamically expanding plasma, although plumes apparently attain speed values lower than interplumes. A study on a larger sample of coronal hole observations is in progress, in order to confirm the conclusions drawn in the present analysis.

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