SOHO OBSERVATIONS OF THE NORTH POLAR SOLAR WIND

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ABSTRACT

The north polar coronal hole and the wind originating from it have been the target of a week-long observing campaign with UVCS. The observations with UVCS in the Lyα and O VI (1032 Å and 1037 Å) lines have covered the heliocentric distance from 1.5 \( R_\odot \) to 3.5 \( R_\odot \). The corresponding inner corona has been observed, during part of the campaign, with CDS and SUMER in several chromospheric and coronal lines, including those observed with UVCS. Several EIT images and some EIT fast sequences, taken during the observing campaign, provide the overall scenario of the polar coronal hole at a high level of detail.

Key words: fast solar wind; coronal holes; spectroscopy.

1. INTRODUCTION

One of the outstanding puzzles of solar physics is the mechanism which accelerates the fast solar wind streams, originating from the coronal holes, to a terminal speed of \( \approx 800 \) km s\(^{-1}\). Several mechanisms have been proposed, including the acceleration by Alfven waves, (Hollweg, 1973, 1978; Leer et al., 1982; Holzer et al., 1983; An et al., 1989, 1990; Hollweg, 1990; Barnes, 1992; Simlon and Zargham, 1992; Velli, 1993; Lou, 1993; Rosner et al., 1991; Lou and Rosner, 1994; MacGregor and Charbonneau, 1994; Lau and Siregar, 1995; Orlando et al. 1996), but such a problem is still quite controversial and far from being settled. It is certain that a thermal mechanism alone cannot drive the wind up to such high speeds and some measurements have shown that the acceleration should take place within a few \( R_\odot \) from the Sun and well within the observing range of UVCS (Kohl et al. 1995).

In the light of the importance of such a problem, and of the radically new capabilities of the SOHO coronal instruments to address such an issue, we have dedicated a week-long observing campaign to study the polar coronal hole. The polar coronal holes have been preferred for several reasons: because the fast stream originating there is quite steady as shown by high–latitude observations from the Ulysses spacecraft (Phillips et al., 1995; Geiss et al., 1995; Smith et al. 1995; Balogh et al., 1995; Grall et al., 1996), because the observations are not affected by significant changes both in orientation and in apparent geometry of the stream which, instead, occur in non–polar coronal holes and because observations are relatively free from chance alignment of the tenuous wind with bright coronal features of entirely different coronal origin. Furthermore, the relative steadiness of the polar region typically allows prolonged (or repeated) observations needed to gain enough signal to noise when observing the tenuous emission at relatively large heliocentric distances.

This campaign has been performed with the scope to set up an observational scenario describing the conditions of the solar wind plasma from its origin to high heliocentric distances with EIT, CDS, SUMER and UVCS, i.e. taking full advantage of the new instrumental capabilities of SOHO to observe the inner and outer corona simultaneously and providing a template for future detailed comparisons with existing solar wind models.

The workhorse of the present project is UVCS, thanks to its capability to perform accurate spectroscopic measurements routinely from 1.5 \( R_\odot \) to 3.5 \( R_\odot \). (UVCS can observe up to 10 \( R_\odot \) but observations of the tenuous solar wind beyond 3.5 \( R_\odot \) are exceedingly difficult).

2. OBSERVATIONS

In order to provide a scenario as detailed and complete as possible with SOHO, we have taken spectrallines in several lines and spectra with all the coronal instruments, namely SUMER, CDS and UVCS. Several images taken with EIT complete the set of data, some making a sequence of the polar region at a relatively fast cadence.
The north polar coronal hole was selected, at the start of the observing campaign, because it appeared significantly wider than the South Polar Coronal Hole in EIT images, and therefore better suited, for the reasons mentioned in the Introduction.

After a series of preliminary observations aimed at optimizing the instrumental parameters (mostly the selection of UVCS exposure times and slit widths at several heliocentric distances), on September 18, 1996 15:30 UT we began observing the north coronal hole from the solar disk up to an heliocentric height of 3.5 \( R_\odot \). The observation was a joint campaign: CDS and SUMER observed the solar limb and the outer atmosphere in a region centered on the north solar pole and within the coronal hole, UVCS scanned higher up in the corona and EIT supported the observation with synoptic data plus some fast sequences of small frames of the north coronal hole in the band of Fe IX–X 171 Å. A sketch of the various pointings is shown in Fig. 1. We selected, for the observations with CDS, SUMER and UVCS spectrometers, a set of spectral lines covering a range of temperatures from 4.3 to 6.3 K therefore providing detailed diagnostics of plasma densities, temperatures and velocities right at the base of the fast solar wind and solar plumes, from the base of the transition region up to the corona.

![Figure 1. Pointings made with UVCS, SUMER and CDS. EIT observed either the entire Sun or the north pole region.](image)

More specifically the CDS/NIS spectrometer observed a region of 236" × 240" around the north pole for 80 min taking exposures of 150 s each. The region was scanned in 30 locations with step of 8" each through an entrance slit of 4" × 240". We selected 20 spectral windows around the main spectral lines of Mg VIII 315.26 Å, Si VIII 319.83 Å, Si IX 341.95 Å, Fe XIV 334.20 Å, Si IX 345.00 Å, Si X 347.25 Å, Si IX 349.67 Å, Fe XII 364.47 Å, Mg IX 368.00 Å, Si XII 520.66 Å, Al X 580.01 Å, O IV 554.40 Å, Si X 356.23 Å, Fe XIII 359.64 Å, Ca X 557.74 Å, Ne VI 562 Å, He I 584.32 Å, O III 559 Å, Mg X 624.95 Å, O V 629.73 Å. Fig. 2 shows the relevant images taken in the Mg X and O V lines, i.e. a coronal and transition region line, respectively.

![Figure 2. Polar scan taken with CDS in the Mg X 624.95 Å, and O V 629.73 Å on September 18 1996.](image)

The SUMER instrument mapped a region of 228" centered on the north pole. The slit (300" × 1") drifted regularly by 3" with an exposure time of 60 s and took approximately 1 hour to complete a scan. The slit was centered at 1130" and covered a region from 980" to 1280" poleward from the Sun's center. The observation started at 15:31:14 UT and ended at 19:42:08 UT on September 18 1996. Two different spectral bands were covered: four 50 pixels windows were observed simultaneously during two complete scans, from west to east and then from east to west. The spectral band was then changed and two more complete scans were taken in the other four lines. The lines covered in the first spectral band were H I Ly\(\beta\) 1025.722 Å, O VI 1031.912 Å, O VI 1037.44 Å, Si XII 520.66 Å, and in the second spectral band N V 1238 Å, Fe XII 1242.400 Å, Mg X 625 Å, O V 629.729 Å.

![Figure 3. Polar scan taken with SUMER simultaneously in the Ly\(\beta\) 1025.722 Å, O VI 1031.912 Å, and O VI 1037.44 Å lines on September 18 1996. The first scan (top) from West to East started at 15:31:14, while the second one (bottom) in the opposite direction started at 16:32:25.](image)

Fig. 3 shows an example of raster maps made in the Ly\(\beta\) and in the two O VI lines, namely the same lines observed
Figure 4. UVCS spectra (and their fitting with gaussians) of the north polar wind. The lower section of each panel shows the fitting residuals.

at higher heliocentric distances with UVCS. It is worth noting that SUMER observations show that significant variability of the north pole.

UVCS observed the coronal hole from 1.5 to 3.5 $R_{\odot}$, with a very fine step (0.05 $R_{\odot}$) between successive slit exposure in the lower region ($r < 2.0$ $R_{\odot}$) while we used larger step (0.2 and 0.5 $R_{\odot}$) higher in the corona. The entrance slit was 50 $\mu$m (14") in the Ly$\alpha$ channel, while in O VI channels we chose slit width values ranging from 14" close to the Sun (in order to obtain detailed line profiles of the O VI doublet in the lower corona) to 84" (i.e. 300 $\mu$m) higher than 2.0 $R_{\odot}$, in order to increase significantly the signal to noise of the measurement at the expenses of the spectral resolution, since the observed intensity at such high heliocentric distances is very faint.

In the Ly$\alpha$ channel we chose a spectral binning of the pixels of $\sim 0.14$ Å, and in the O VI channel $\sim 0.20$ Å and $\sim 0.30$ Å, depending of the entrance slit width; a spatial binning of 28" was used in both channels. We started the observation at 15:30 and completed the coronal scan in 34 h with exposures of 10 minutes each (a complete observation at any heliocentric distance is typically composed by several exposures).

Lines of OVI 1031.91 Å and 1037.61 Å, Ly$\alpha$ 1215.67 Å and Ly$\beta$ 1025.72 Å have been measured.

3. UVCS DATA ANALYSIS

We have started to analyze the UVCS observations above the north pole of the Sun to study in detail the region where quite likely the fast solar wind is accelerated. The detailed study will be the subject of a paper; here we present some preliminary results.

In Fig. 4, we show examples of UVCS spectra detected in the Ly$\alpha$ (left panels) and in the O VI (right panels) channels at heliocentric distances of 1.5 $R_{\odot}$ (lower pan-
els) and 3.0 $R_\odot$ (upper panels). The figure also shows the spectral fitting with gaussians and, in the lower section of each panels, the fitting residuals. In the figure, we have identified the strong coronal emission lines: Ly$\alpha$ (1216 Å), Ly$\beta$ (1026 Å), the O VI doulet (1032 Å and 1037 Å) and Si XII (520 Å). Note that the line intensities decrease dramatically, from 1.5 to 3.0 $R_\odot$, especially in the O VI channel, as a consequence of the lower plasma density for higher heliocentric distances.

Since our primary scientific objective is to investigate mechanisms of solar wind accelerations, we determined the amount of Doppler dimming (Hyder and Lites 1970) along the radius for various heliocentric distances to determine the outflow velocity in the extended corona.

There are several ways of determining the Doppler dimming. For this work, we have used the dimming of the O VI doublets, particularly useful because its velocity sensitive range includes values from $\sim 50$ km s$^{-1}$ to $\sim 250$ km s$^{-1}$ (Noci, Kohl and Withbroe 1987), i.e. the velocity range in which the wind acceleration occurs. In Fig. 5, we present preliminary results of the ratio of the O VI lines raw count $c(1037)/c(1032)$ from UVCS observation of the solar wind outflowing from the north coronal pole. Note that the minimum and maximum in the line ratio correspond approximately to velocities of $\sim 60$ km s$^{-1}$ and $\sim 180$ km s$^{-1}$ respectively.

**Figure 5. Ratio between the raw counts, background subtracted, of O VI (1037 Å) and O VI (1032 Å) vs. heliocentric distance.**

We are at an advanced phase of removing the background, correcting for the flat field and performing the line fit so as to complete the accurate determination of the line ratio. The complete work will be the subject of future paper which should consider the analysis of the complete data sets of the four instruments.

The first step will encompass a phenomenologically complete description of the wind and its base region, including an examination of the morphology of structures in the wind and how they can be traced down to the Sun’s surface. Another aspect should include the description of spectra, most notably O VI lines, from the solar limb out to 3.5 $R_\odot$. Finally the knowledge of lines forming at temperatures ranging from the base of the transition region up to coronal values, should allow to reconstruct accurately the temperature and density structure at the base of the solar wind and its acceleration region.

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