Constraints on coronal parameters from remote (SOHO) and in situ (Ulysses) observations of the same plasma

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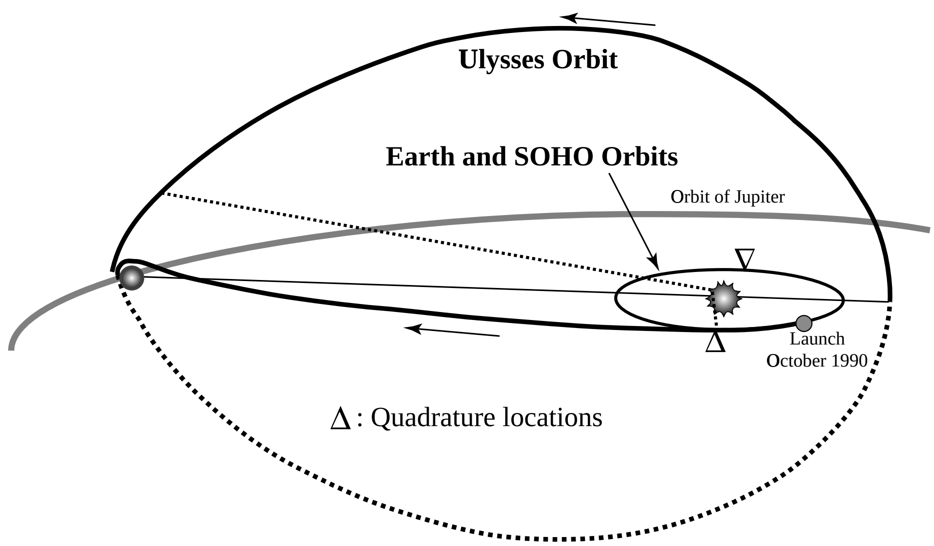
What is a "SOHO-Ulysses quadrature"?

This poster deals with coronal and wind studies made at the time of SOHO-Sun-Ulysses quadratures. A SOHO-Ulysses quadrature occurs when the SOHO-Sun-Ulysses included angle is 90°. This geometric configuration occurs twice a year as SOHO moves around the Sun.



At such times, plasma leaving the Sun in the direction of Ulysses, can first be remotely observed by SOHO experiments and later be sampled *in situ* by Ulysses instruments.

In the last 5 years several quadrature campaigns have been held. The objectives of the campaigns were manifold and were mainly dictated by the heliographic latitude of Ulysses at the time of the quadrature.

The SOHO-Ulysses quadrature campaigns

We list here the objectives of past campaigns:

→ May 1997: slow wind from low latitudes (North latitude= 10°)

→ December 1998: slow wind from low latitudes (South latitude= 17°)

→ May 1999: slow wind from low latitudes (South latitude= 27°)

→ December 1999: no data, SOHO in ESR

→ June 2000: a study of element abundances from mid-latitude structures (South latitude= 58°)

→ November 2000: polar wind, fine structures and CMEs (South latitude= 80°) MEDOC Campaign

→ May 2001: slow wind from low latitudes (North latitude= 9°)

→ November 2001: polar wind at maximum activity (North latitude= 80°)

Future Campaigns:

→ May 2002: wind from mid-latitudes (North latitude= 45°)

→ November 2002: wind from low latitudes (North latitude= 26°)

Papers on SOHO-Ulysses quadratures

We list here papers published/in press based on SOHO-Ulysses quadrature data:

→ May 1997: Suess, S.T., Poletto, G., Romoli, R., Neugebauer, M., Goldstein, B., Simnett, G.: JGR 105, 25033, 2000

→ December 1998: Poletto, G., Suess, S.T., Biesecker, D.A., Esser, R., Gloeckler, G., Ko, Y.-K., Zurbuchen, T.H.: JGR, in press

→ May 1999: not analyzed

→ December 1999: no data, SOHO in ESR

→ June 2000: Parenti, S., Poletto, G., Bromage, B.J.I., Suess, S. T., Raymond, J.C., Noci, G., Bromage, G.E.: AIP Conference Proceedings, R.F. Wimmer-Schweingruber, Ed., p. 83 (preliminary results, a full paper is in preparation)

→ November 2000: not analyzed

→ May 2001: not analyzed

→ November 2001: Aznar Cuadrado, R., Poletto, G., Teriaca, L., Suess, S.T.: SOHO 11 Proceedings, submitted (preliminary results)
Suess, S., Poletto, G.: Space Science Rev. 97, 59, 2001

What we learnt from SOHO-Ulysses quadrature data: slow wind

Problem: which is the origin of the slow wind variability?

The 1997 and 1998 quadratures are related to slow, low-latitude wind. In 1997 the radial to Ulysses, at coronal levels, lay, throughout the campaign, on the edge of a streamer. In 1998 the radial to Ulysses, at coronal levels, crossed first through an unstructured region, then through the edge of a streamer.

In 1997, the wind speed at Ulysses was unusually steady ($v = 375 \pm 25\ km/s$), in 1998, the wind speed reached $\approx 500\ km/s$, then slowed to $\approx 420\ km/s$.

We may look for the **source regions** of the observed solar wind.

In both cases, the slower wind, extrapolated back to the Sun, appears to originate from streamer areas, while the faster wind originates from the equatorward extension of a polar coronal hole.

Conclusions: from the sample we analyzed, we surmise that open field regions, interspersed amidst closed coronal loops/streamers are responsible for the slow wind variability. This conclusion has obviously to be verified on a more extended data set.

Question: what can we say about the slow wind characteristics at coronal levels?

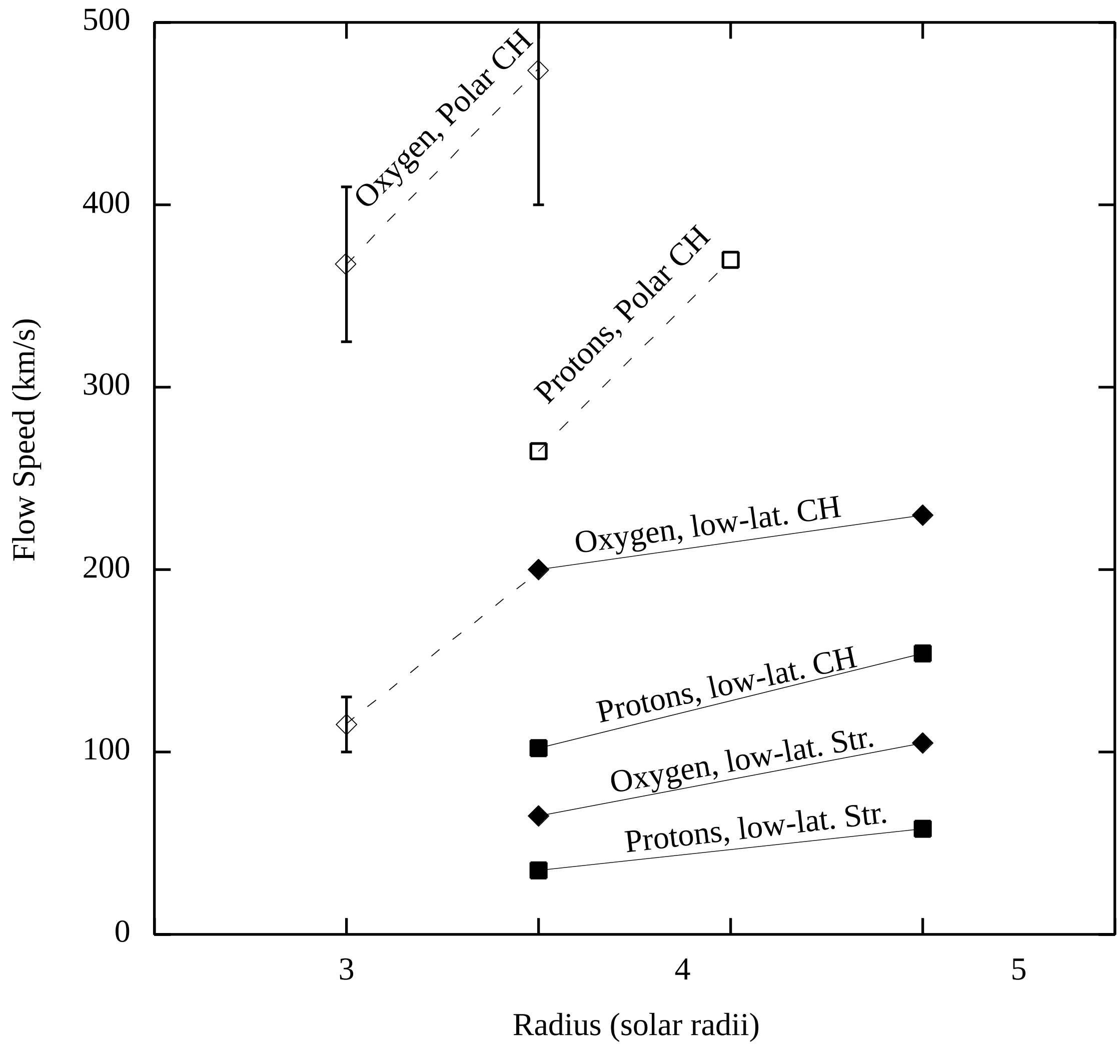
Data acquired by UVCS during the 1997 and 1998 quadrature campaigns, when combined with *in situ* data, allow us to establish the properties of low latitude wind at coronal levels.

UVCS made observations at 3.5 and 4.5 $R_\odot$, with a spatial resolution of 3 pixels ($21''$). The brightest lines in the UVCS spectra are the Hydrogen Lyman-α and the OVI doublet lines at 1031 and 1037 Å. Because Ulysses is in quadrature, we know precisely the mass flux value associated with the plasma sampled by UVCS. This crucial information allows us to reproduce the observed hydrogen and oxygen intensities, taking into account the Doppler dimming effects caused by the outflow plasma speed at those levels. We refer the reader to Poletto, Suess et al. (JGR) for detailed information on the procedure by which line intensities were simulated.

The **figure** shows the outflow speed we derived for protons and OVI ions when i) the radial to Ulysses was crossing the streamer areas and when ii) the radial to Ulysses was crossing the dark unstructured regions. Results for polar coronal holes are given as a reference and have been taken from the literature (Cranmer et al., 1999)

Answer: the low latitude slow wind, at heliocentric distances of 3.5 and 4.5 $R_\odot$

- **originates from either coronal holes or bright regions overlying streamer complexes**
- **has a proton outflow speed on the order of 100-150 km/s in coronal holes and 35-60 km/s in bright areas**
- **has an OVI ion outflow speed higher than the proton outflow speed by a factor ≈ 2 at the lower level, of $\approx 1.5 - 1.7$ at 4.5$R\odot$**
- **is accelerated at higher levels and through a more extended region, than fast polar wind, independent of the region where it originates**



Poletto et al., JGR, in press, 2002.

Typical setting for data acquisition at the time of SOHO-Ulysses quadrature campaigns

SOHO-Ulysses quadrature campaigns have been lead by the SOHO/UVCS team, with the help of the SOHO/LASCO and of the Ulysses SWOOPS/SWICS teams, with the occasional collaboration of SOHO/CDS and SOHO/SUMER.

The UVCS slit is set normal to the solar radii, with its central position lying along the radial to Ulysses. The heliocentric distance at which the UVCS slit is set is dictated by the objective of the campaign: for wind studies, the distance is usually on the order of 3-4$R_\odot$; for element abundances, when weak lines have to be detected, a lower distance on the order of 1.5-2$R_\odot$, is usually chosen.

Typically, a SOHO-Ulysses quadrature campaign lasts for about 2 weeks, during which UVCS makes observations for about 9 hours per day. This means that we make observations for several days on either side of the quadrature. Over this time interval the Ulysses-Sun-SOHO angle changes by less than the uncertainty met when extrapolating backward from Ulysses.

UVCS takes spectra which include lines from hydrogen, oxygen, iron, magnesium, silicon and other elements, in different stages of ionization. The brightest lines are those of hydrogen and of the O^{5+} doublet at 1032 and 1037 Å.

We remind the reader that i) UVCS lines are likely to be affected by Doppler dimming effects -in other words, the resonant component of lines is dimmed because of the plasma outward speed- and that ii) the ratio of the intensities of the 1032 to the 1037 O^{5+} lines may be considered a probe for the plasma outflow speed (see, e.g. Noci, Kohl and Withbroe, 1987).

What we learnt from SOHO-Ulysses quadrature data: elemental abundances

Questions:

→ **which is the distribution of element abundances vs. altitude?**
→ **can we trace down to coronal levels the variation of element abundances with the plasma speed?**
→ **can we provide further evidence in favor of the origin of slow wind from the edges of streamers?**
→ **is there any evidence at coronal levels of the rapid fluctuations in the Fe/O ratio observed by *in situ* experiments?**

Questions like those listed above prompted the 2000 spring quadrature campaign, which became the object of a JOP, with the participation of SOHO UVCS, LASCO, CDS and SUMER, in addition to the usual Ulysses experiments. This data are being analyzed, and results presented here are only preliminary.

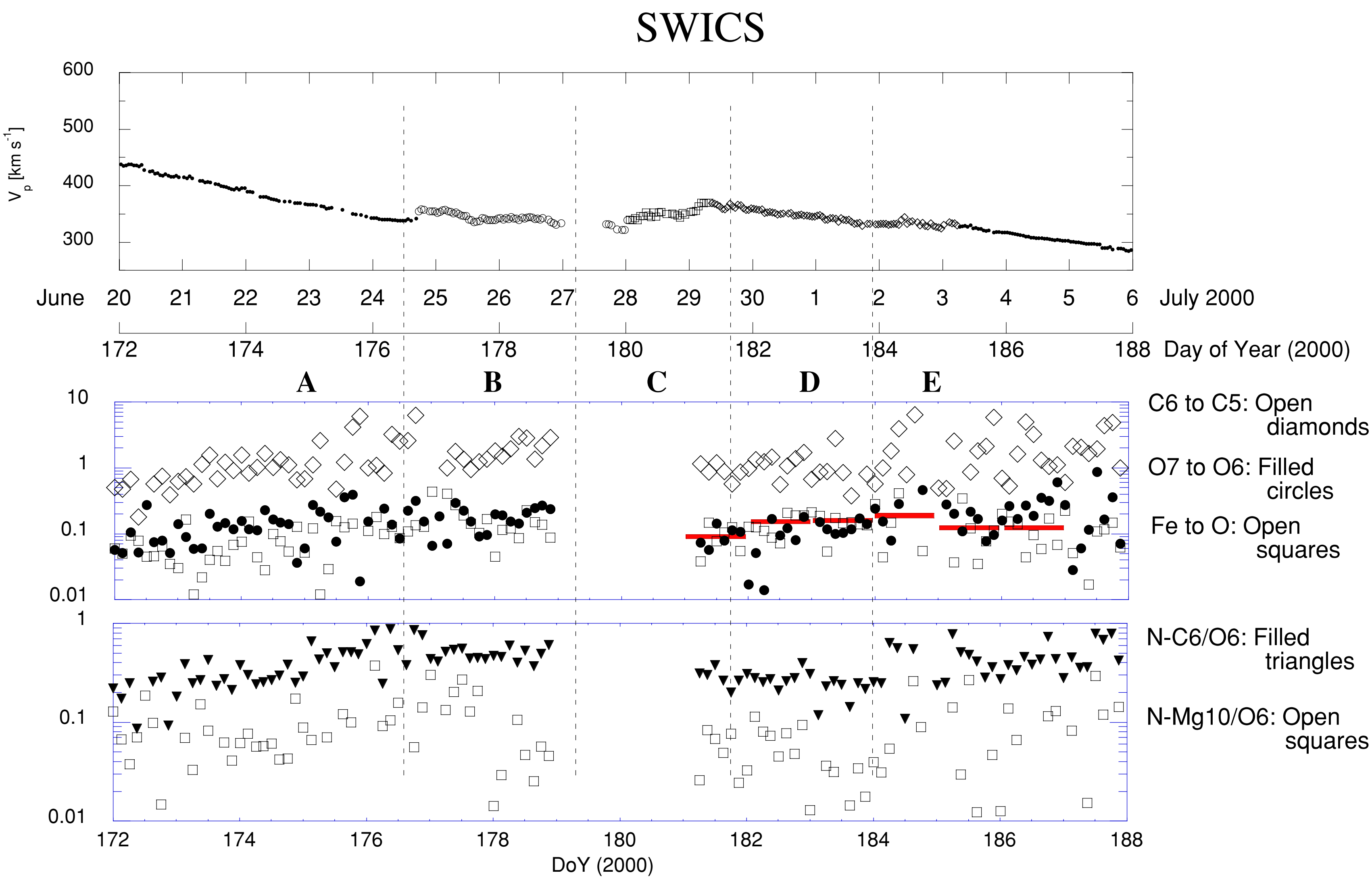
We point out that from an analysis of UVCS data we can provide also plasma densities and electron temperatures, in addition to element abundances. As an example of our achievements, we show in the **Table** and **Figure** the plasma densities, temperatures, Oxygen and Iron abundances for 3 days within the 2000 quadrature campaign, together with *in situ* plasma parameters from SWICS. All the UVCS parameters refer to streamer regions, at an altitude of 1.6 $R_\odot$.

The last column of the **Table** gives values of the Fe/O ratio, both from UVCS and SWICS data. The present results seem to indicate that the **Fe/O ratio has its *in situ* value already in the low corona. However, we didn't find any indication for rapid changes of the Oxygen abundance at coronal levels.**

UVCS temperatures/densities and Fe/O

We tabulate the electron temperature, electron density, and Fe/O ratio derived from UVCS line intensities. This has so far only been completed for 11, 12, and 13 June and are preliminary. **The Fe/O compared for the first time with the same quantity measured with SWICS** with the result that the two are very close for this physically important quantity except, perhaps, for 11 June.

	Temperature (e^-)	**Density (e^-)**	**Oxygen abs. abundance** (relative to H)	**Iron abs. abundance** (relative to H)	**Fe/O**
11 June	10^6 K	1.06×10^7 cm^{-3}	4.17×10^{-4}	6.76×10^{-5}	0.16 (**SWICS**=0.09)
12 June	1.26×10^6 K	1.0×10^7 cm^{-3}	2.88×10^{-4}	4.17×10^{-5}	0.14 (**SWICS**=0.14)
13 June	1.26×10^6 K	1.2×10^7 cm^{-3}	5.01×10^{-4}	7.41×10^{-5}	0.15 (**SWICS**=0.15)



SWICS
600
500
400
300
V_p [km s^{-1}]
June
20
21
22
23
24
25
26
27
28
29
30
1
2
3
4
5
6
July 2000
172
174
176
178
180
182
184
186
188
Day of Year (2000)
A
B
C
D
E
10
1
0.1
0.01
C6 to C5: Open diamonds
O7 to O6: Filled circles
Fe to O: Open squares
N-C6/O6: Filled triangles
N-Mg10/O6: Open squares
DoY (2000)

What can we learn from SOHO-Ulysses polar quadrature data?

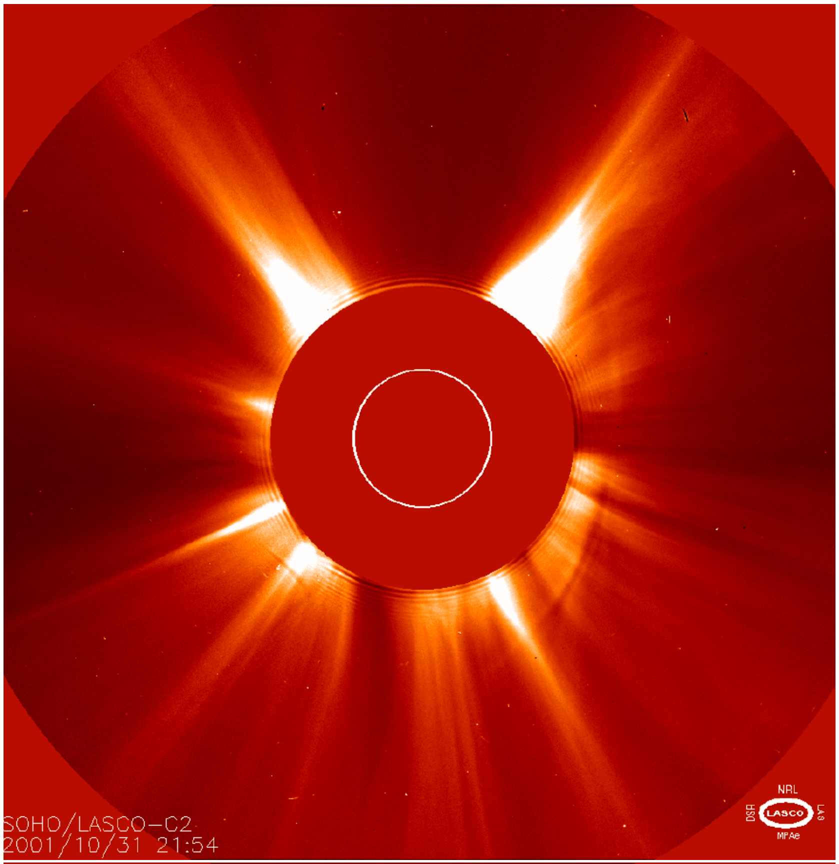
So far, only two campaigns have been held at the time of Ulysses polar passes and only a very preliminary analysis of the data taken in the 2001 fall quadrature has been done.

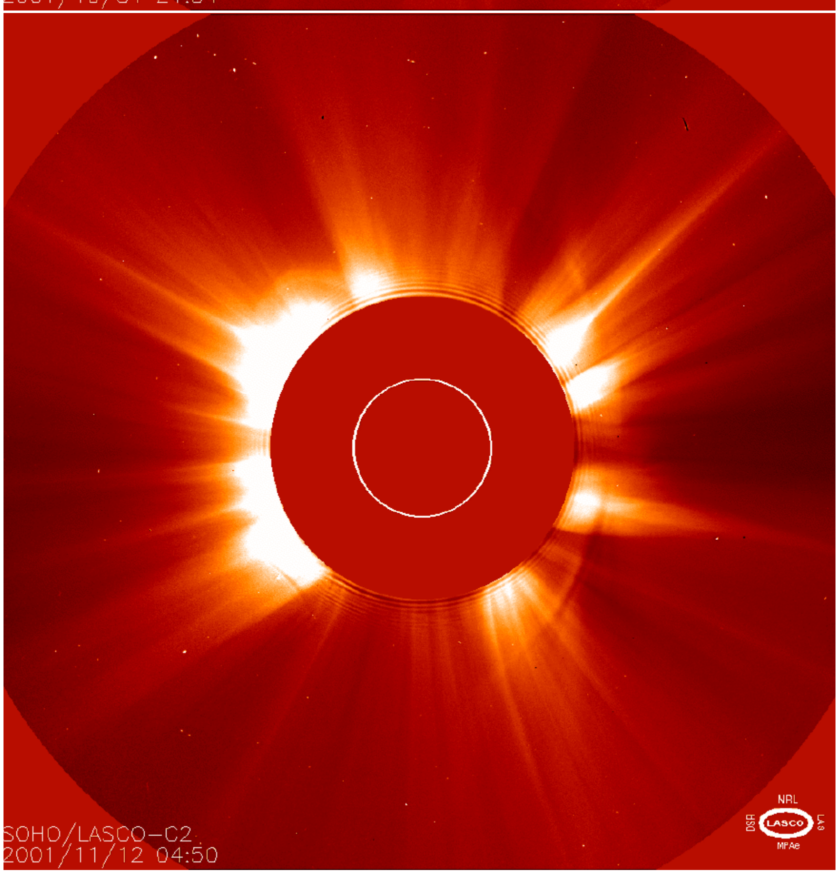
Depending on the size of the polar holes sampled by Ulysses at the time of polar passes, and on the latitude of the radial to Ulysses, we may expect *either a uniform behavior* of the outflow plasma speed and of the other physical parameters, as typically occurs in fast wind streams, *or a more complex situation*, in case we cross a *hole/streamer boundary*.

Even in the first case, we expect to be able to check on the role of fine structures in the fast wind and examine issues such as the persistence of coronal density structures to large distances.

An analysis of the fall 2001 polar quadrature data has been initiated: the figure shows how the Ulysses position, with respect to the polar hole, was marginally consistent with the possibility of a hole/boundary crossing.

However, data analysis gave no indication for a boundary crossing. Most probably, because the coronal hole area expands superradially, the radial to Ulysses, at the heliocentric distance of 1.6 solar radii, where the UVCS slit was set, was continuously immersed in the polar hole plasma.


SOHO/LASCO-C2
2001/10/31 21:54
NRL
LASCO
MPAe


SOHO/LASCO-C2
2001/11/12 04:50
NRL
LASCO
MPAe

Preliminary results from the fall 2001 polar quadrature

The figure shows how the fall 2001 polar quadrature campaign, when Ulysses was at a northern latitude of $\approx 80°$, was getting data from a polar hole, at the beginning of the campaign (top image) and from a superposition of hole and streamer plasma at the end of the campaign.

However, an UVCS data analysis shows, rather unexpectedly, that even in the first half of the campaign, line intensities, widths, and OVI 1032 to 1037 line intensities ratios, are typical of equatorial, rather than polar, holes. Because the OVI 1032/1037 is a probe of the outflow plasma speed, there is an apparent indication for lower outflows than typically found in polar holes. Without Ulysses quadrature data, the hypothesis of imaging a polar hole, from which slow wind streams are emanating, might be tenable, because slow polar wind has been observed in the maximum phase of the solar activity cycle (see, e.g., Ohmi et al., 2001)

Ulysses quadrature data, however, unequivocally dismiss this interpretation, as the wind speed associated with the polar hole we examine is always ≥ 600 km s^{-1}. Polar quadrature data give us a strong warning against interpreting coronal wind data without the support of *in situ* observations.

A modeling effort, to interpret the 2001 coronal quadrature data in a scenario where different amounts of bright streamer material, along the line of sight, prevent us from seeing the polar hole plasma, is now in its initial phase.

CMEs, Quadratures and STEREO

During the quadratures campaigns, we have been observing CMEs as well. The **Figure** assembles a few LASCO images from the fall 2001 polar quadrature, providing evidence for CMEs. More have been observed at the time of the June 2000 quadrature: Ulysses data showed clear changes associated with these events. Some of the CMEs were of the halo type.

Analysis of this data has not started, yet. The role of **STEREO** in improving CMEs modeling is crucial: we will be able to follow the CME evolution from the corona through the interplanetary medium, bridging the gap from the corona to the 1AU distances, so far little covered.

In the analysis described in previous panels, events have been traced back from Ulysses to the Sun, mostly on the basis of the ballistic approximation. **STEREO** strong drive towards 3-D models of the corona will help us trace back to the Sun the observed interplanetary events, limiting ambiguities arising from the simplistic approximation we use.

UVCS analysis of plasma in the 1.4 to 2.2 solar radii regime, is heavily affected by uncertainties in the electron densities values over that range of altitudes. This lack of information may strongly affect modeling efforts meant at identifying the plasma outflow speed vs. heliocentric distance, and its solar cycle variation. As a consequence, also the levels where most of the energy is being released to solar wind, have not been unambiguously identified. **STEREO**'s coronagraphs, operating in the lower corona, may solve these problems.