2002ESASP.506..545B

SPATIAL AND TEMPORAL BEHAVIOR OF THE OXYGEN ABUNDANCE IN A STREAMER COMPLEX

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ABSTRACT

The determination of the abundance of trace elements in different solar structures and in the solar wind may be crucial for the identification of the solar wind sources. In the last few years, SOHO data allowed an evaluation of the oxygen abundance at previously unattainable coronal levels (see, e.g., Zangrilli et al., 2001). Analyses of streamer data taken at the minimum of the solar activity cycle raised the question of whether streamers' legs might be the site where slow wind originates, because the oxygen abundance in the lateral branches of the streamer, at coronal levels, turned out to be similar to the slow wind abundance. In this work we analyse UVCS streamers observations, taken at $1.6R_\odot$, near the maximum phase of the activity cycle, to check whether the behavior found at minimum is shared by streamers at maximum. We derive also the abundance of oxygen in different streamers and, within a streamer, across its axis, to get more information on the spatial variability of the oxygen abundance. Our results show that the oxygen abundance in different streamers may be significantly different, implying that a more thorough analysis is needed before drawing conclusions about the site where slow wind originates.

Key words: streamer; oxygen abundance; *in situ* data.

1. INTRODUCTION

UVCS observations taken at the minimum of the solar cycle revealed streamers seen in the OVI 1032, 1037 Å doublet lines to have a quite different morphology than streamers seen in the H $Ly-\alpha$ line. The streamer core, where H $Ly-\alpha$ emission is highest, corresponds to a weakly emitting region in the OVI radiation, an effect which is most easily interpreted as being caused by a local oxygen depletion. Quantitative analyses of data taken at heliocentric distances $r \geq 1.5$ solar radii showed the oxygen abundance to be lower than its photospheric value by $\approx$ one order of magnitude, in the core of streamers, while the depletion is $\approx$ a factor 3 in the streamers' legs. These studies suggested (see, e.g. Raymond et al., 1997) streamers' legs to be the site where slow wind originates. This conclusion has been challenged by authors who point out that the slow wind oxygen abundance is higher than the abundance of the lateral branches of streamers and conclude that slow wind might not originate primarily from streamers (Marocchi et al., 2001).

The oxygen abundance, relative to hydrogen, at $r \approx 1.5R_\odot$, is, in the streamer core, about 10^{-4} (Marocchi et al., 2001), or lower - 6.3 10^{-5} - (see, e.g. Raymond et al., 1997), while, in the streamer legs, according to these authors, raises to $2.5 - 3.5\ 10^{-4}$. At higher altitudes ($r \leq 2.2R_\odot$), the oxygen abundance decreases to 2.2 10^{-4} in the streamer lateral branches (Marocchi et al., 2001). Results by other authors (Parenti et al., 2000) are consistent with these values: the latter authors, for instance, give $10^{-4} \leq A_{oxy} \leq 2.5\ 10^{-4}$ in streamers, observed in the rising phase of the solar cycle. However, these structures did not show any evidence of the OVI/$Ly-\alpha$ morphological dichotomy shown in streamers analysed by the other authors.

In the slow wind the oxygen abundance is $\approx$ 5.25 10^{-4} (Von Steiger et al., 1997). This figure may not be representative of the whole range of values of the oxygen abundance in the wind, because the ratio Fe/O is known to change as a function of the wind speed (see, e.g. Aellig et al., 1999) and, for a given speed, shows a short term variability typically larger than the proton variability by a factor ten (see, e.g. Raymond et al., 2001). The short term variability is supposed to mimic similar spatial and/or temporal variations at coronal levels of the oxygen and/or iron abundances.

The present research was motivated by these open questions. In an attempt of providing some more information on the element abundance at coronal levels, we have studied the behavior of oxygen in a streamer complex, both within a streamer and in different structures. In section 2 we briefly illustrate

Proc. 10th. European Solar Physics Meeting, 'Solar Variability: From Core to Outer Frontiers', Prague, Czech Republic, 9-14 September 2002 (ESA SP-506, December 2002)

our observational set, the morphology of the streamers we analyze and their changes with time: in section 3, after a description of the technique used to derive the oxygen abundance, we give results from our analysis. We conclude with a concise discussion of our work and future plans.

2. MORPHOLOGY OF THE STREAMER COMPLEX

Observations used in this analysis have been acquired by UVCS between June 6 and 19, 2000, at three heliocentric distances (1.6, 1.9, 2.2 solar radii), with a slit set normal to the radial, at 58° below the equator, in the South-East quadrant. Here we analyse a subset of this data, using those acquired at 1.6 solar radii on June 10, 11, 12, 13, and 16/17. Other observations were either taken at different altitudes, or with too long time gaps to allow us to identify the time evolution of structures, which, at the time of maximum activity, may change sensibly over short time scales. UVCS data have been typically taken at 5 grating positions, covering lines from ions which form over different temperature ranges.

The overall coronal configuration is provided by LASCO data, which show two streamers, in the south-east quadrant. One of them, dubbed streamer B, is in the front side of the solar disk, and is disrupted by a CME on June 10. It reforms and rotates westwards throughout our observations. We will refer to this structure as streamer B'. The second streamer, dubbed streamer A, is on the back side of the Sun and is taken by solar rotation eastward, going through the East limb around 16/17 June. Fig. 1 gives two LASCO C2 images, representative of the coronal configuration on June 10 and June 12, and the corresponding plots of the profile, along the UVCS slit, of the OVI 1032 and the SiXII 1040 Å lines. Although LASCO data refer to a level 0.4 solar radii higher than that represented by UVCS data, LASCO structures on June 10 are easily recognized in the intensity peaks of the OVI and SiXII UVCS lines (streamer B, at a latitude of ≈ 45°, streamer A at a latitude of ≈ 70°). However, a dramatic change in the UVCS structures is apparent from the June 12 data: while the SiXII component of streamer A is well recognizable (although at a latitude lower than on June 10, because of solar rotation), the SiXII component is apparently completely missing in streamer B', which is bright only in the OVI line emission. Because the SiXII 1040 line forms at much higher temperatures than the OVI line, this behavior may hint to a difference in the temperature of the two streamers, streamer B' being a 'cold' streamer and streamer A, being a 'hot' streamer.

Neither streamer A, nor B/B', show the OVI/Ly-α dychotomy described in Section 1. This may be ascribed to a physical, or to a geometrical effect: the streamer weak OVI 1032 emission core disappears, when seen edgeways. The two streamers, because of the solar rotation, are superposed along the line-of-sight on June 13, streamer B' being no longer visible on June 16/17 UVCS maps, because solar rotation takes it off its field of view. Streamer A, on the other hand, is, on June 16/17, at the solar limb, hence in the best position for studying its structure. The profile of the oxygen abundance, across the streamer axis will be given for this day only.

3. THE OXYGEN ABUNDANCE

UVCS data allow us to derive the *absolute* abundance of oxygen, once the radiative and collisional components of the OVI and H Ly-β line are identified. We refer the reader to (see, e.g. Raymond et al., 1997) for details on the procedure; here we like only to point out that the technique can be used only in a static plasma. This is certainly the case for streamers at 1.6 solar radii (Strachan et al., 2002). If R is the ratio of the disk intensities in the Ly-β and OVI 1032 radiation ($R = \frac{I_{disk}(L\beta)}{I_{disk}(1032)}$), the value of the oxygen abundance from the radiative ($\frac{N_O}{N_H}$) and the collisional components ($\frac{N_O}{N_H}$) are given, respectively, by

$$(\frac{N_O}{N_H})_{rad} = R\frac{I_{rad}(1032)}{I_{rad}(L\beta)}\frac{C_{HI}}{C_{OVI}}\frac{b_{L\beta}}{b_{OVI}}\frac{f_{L\beta}}{f_{1032}}\frac{\delta\nu_{OVI}}{\delta\nu_{HI}} \tag{1}$$

and:

$$(\frac{N_O}{N_H})_{col} = \frac{I_{col}(1032)}{I_{col}(L\beta)}\frac{C_{HI}}{C_{OVI}}\frac{b_{L\beta}}{b_{OVI}}\frac{q_{L\beta}}{q_{1032}} \tag{2}$$

where I_{col} and I_{rad} are the collisional and radiative components of the intensity in phot/cm^2/s/sr; f is the oscillator strength; b is the branching ratio; $\delta\nu$ is the line width and q the excitation rate. Because C_{OVI}/C_{HI}, which is the ratio of ion concentrations, in the log T interval 6.1-6.3 (appropriate for streamers, (Gibson et al. , 1999)) changes by only $\leq 16\%$, we may use the previous relationships even without a precise knowledge of the streamer temperatures.

Table I gives the results of our work for 11, 12, 13 and 16/17 June; unfortunately we do not have, on June 10, observations at the grating position of the Ly-α line, which is used to identify the collisional and radiative components of the Ly-β line. Hence we are unable to derive the Ly-β components and the oxygen abundance. For 11, 12 and 13 June we give in the table the values of the abundance for streamer A and B', together with the position (expressed in bins along the UVCS slit) where these have been evaluated. For June 16/17 we show values of the oxygen abundance in the core and lateral branches of the streamer.

Abundances given in table 1 are generally different if derived from the radiative or the collisional component. This may be ascribed to uncertainties in

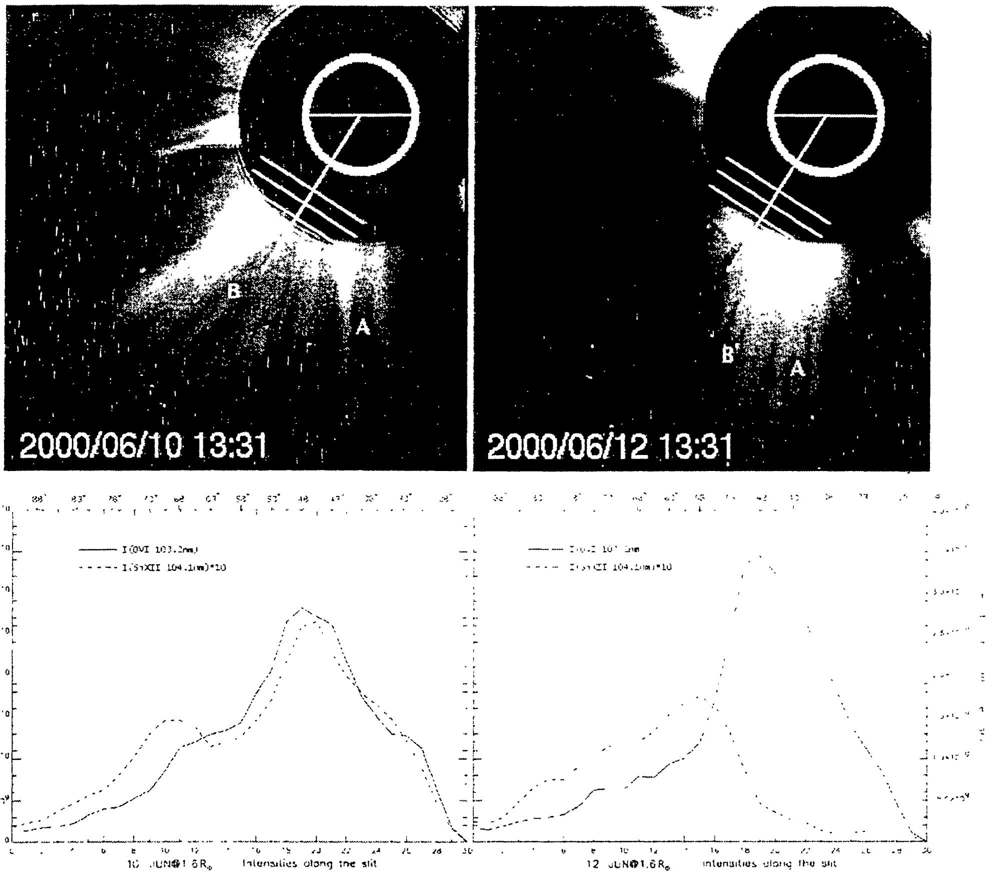

Figure 1. Top: LASCO C2 images for the south-east quadrant on June 10 and 12. Streamer B, disrupted by a CME, reforms as B' as shown by the June 12 image. The position of the UVCS slit, normal to the radial through 58° below the equator (bin 15 of the UVCS slit), at altitudes 1.6, 19, 2.2 solar radii, is also shown. Bottom: profiles of the OVI 1032 and SiXII 1040 line intensities along the UVCS slit. The SiXII intensity has been multiplied by 10; latitudes corresponding to the UVCS slit bins are given at the top of the panels.

the evaluation of the OVI and Ly-β components, but may well be ascribed to a physical effect, being the collisional component of the line (which depends on the square of the electron density) more affected by density dishomogeneities than the radiative component (which depends linearly on electron densities). In the following, we assume the oxygen abundance to be given by an average over the two determinations.

The table suggests streamers A and B' to have a different oxygen abundance, streamer B', i.e. the purportedly cold streamer, being overabundant by a factor ≈ 2 than the hot streamer A. We remind the reader that the June 16/17 feature is essentially streamer A, hence it is quite reasonable to obtain abundances typical of this streamer, on this day as well. The difference is less apparent in the June 13 values, simply because, as we mentioned, the two streamers are superposed along the line of sight, on this day. Errors in the values quoted in the table are on the order of 21% and 32%, for, respectively, the radiative and collisional components of streamer B', and 23% and 54% for, respectively, the radiative and collisional components of streamer A. These have been calculated taking into account statistical errors in the line intensities (which may reach 20%, for the weak Ly-β line) and uncertainties in the separation of the line components. Occasionally abundances in streamer A might be considered to be, within the error, the same as in streamer B': however, the systematically higher values found in streamer B' hint to a real different abundance in the two streamers. Analogously, the slight difference we found between legs and streamer core, in the June 16/17 structure, may well be within the uncertainties of the technique. It is interesting to notice that, in this day, we have little discrepancy between the collisional and radiative determinations, as it is likely to occur when the streamer is on the plane of the sky, as we suggested in our morphological analysis.

The values of the oxygen abundance for streamer A compare favorably with those found by (see, e.g. Raymond et al., 1997) in the streamer legs or in an active streamer, while there is no structure in our sample with as low an abundance as those au-

DOY	June 11, 2000		June 12, 2000	
	Streamer B′	*Streamer A*	*Streamer B′*	*Streamer A*
bins	20	13	18 – 19	14 – 15
$\log[N(O)]_{Ly\beta r}$	8.66	8.44	8.84	8.58
$\log[N(O)]_{Ly\beta c}$	8.84	8.41	8.84	8.30
DOY	June 13, 2000		June 16/17, 2000	
	Streamer B′	*Streamer A*	core	leg
bins	15	15 – 17	19	24
$\log[N(O)]_{Ly\beta r}$	8.60	8.67	8.36	8.51
$\log[N(O)]_{Ly\beta c}$	8.78	8.68	8.41	8.47

thors found in the streamer core. We have no way to ascertain whether this is due to a difference between streamers at maximum vs. streamers at minimum, or whether this is a common characteristic of streamers where the weak oxygen core doesn't show up (or whether our results are affected by geometrical effects, as we mentioned). Another interesting property of our sample is the stability of the abundance values over the duration of the observations. With the warnings we mentioned, we may conclude that streamers abundances are constant over time, although different features may have different abundances.

4. DISCUSSION AND FUTURE WORK

Our results apparently show that only a factor ($\leq$) two difference in solar wind abundances may possibly be traced back to coronal abundance variations, in the hypothesis that transient openings of the streamer flux tubes release streamer plasma in the interplanetary space. This is a provisional conclusion, inasmuch as we checked the behavior of oxygen only, while the observed variability of the Fe/O ratio in the solar wind might be due to a higher Fe abundance variability in coronal structures. Because UVCS data include lines from FeX, FeXII, FeXIII, a check on the iron behavior will confirm/discard this possibility.

However, we would like to draw the reader's attention on an alternative possibility. Our results obviously refer to the oxygen abundance integrated along the line of sight, while *in situ* data refer to plasma parcels. Hence it is quite likely that our result is simply to be interpreted in a scenario of a filamentary solar wind, that only *in situ* data can detect.

Keeping this possibility in mind, much can be done to extend our work. Apart from the determination of the Fe abundance, evaluating abundances of other elements as well, allow us to check on the behavior of FIP effects in streamers vs. FIP effect in solar wind. Our data include lines from both high and low FIP elements, such as Si, Mg, Ca, N, Ar. It is well known that fast wind streams show no or little FIP effect, while a FIP bias of 4 is observed in slow wind (Geiss, 1998). There are only a few works on FIP effects in streamers at coronal altitudes (see, e.g., Schmelz, 1999): thus our data may provide us with a good opportunity to check on the behavior of the FIP effect in the core vs. lateral branches of streamers. This analysis is underway at present and results will be available shortly.

ACKNOWLEDGMENTS

The work of G.P. and M.R. has been partially supported by the Italian Space Agency (ASI) and Italian Ministry for Education, University and the Scientific Research (MIUR). SOHO is a mission of international cooperation between ESA and NASA.

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