VARIATION OF LINE WIDTHS IN CORONAL HOLE OFF-LIMB REGIONS: EVIDENCE FOR LONG-TERM STRUCTURING IN PLUMES

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ABSTRACT

A detailed analysis of an off-limb polar region observed over a number of weeks by the Coronal Diagnostic Spectrometer (CDS), on board the SOHO spacecraft, is presented. From a measurement of a number of coronal lines we find that polar plume regions possess a form of long-term fine structuring visible in peak intensity, line-of-sight (L.O.S.) velocity and line width measurements. Correlations found between these three measured quantities and Mg X 624/609 flux ratios suggest that small-scale continuous localised heating events are the cause of the fine structuring. A comparison of the line widths with the Mg X ratios shows that the line widths start to show a decrease in their values at exactly the same location where the dominant excitation changes from being collisionally to radiatively dominant. The resulting absence of the collisional broadening contribution to the line width is likely to be the cause of this and therefore the reported decrease of line widths in coronal ions may not simply be related to the dissipation of wave energy.

Key words: Polar plumes; Line widths; Corona.

1. INTRODUCTION

Polar plumes are linear bright plasma structures that arise from unipolar magnetic footpoints in the photosphere and which expand radially outwards at small angles to large distances above the solar limb. Fieldline reconnection or annihilation between short-lived magentic bipoles and the ambient unipolar field at network junctions may be the mechanism for plume formation (Wang & Sheeley, 1995). Plumes once formed last for about 1 day but they are observed to reappear in approximately the same location about a day later and a typical plume site can be intermittently bright in EUV over a period of up to 2 weeks (DeForest, 1998). In addition, plume structures in the lower corona (R $<$ 1.3 solar radii) are observed to be in steady-state, with little change in their large scale shape or overall structure for periods of at least 24 hours (DeForest et al.,1997).

2. OBSERVATIONS

The details of the CDS/NIS observations including pointing and start times are summarised in Table 1. The temporal series sequences SER150W and SER75W were run and data obtained for the transition region O V 629.73 Å line ($\sim$ 2.5×10^5 K) and the coronal lines of Mg X 609.79, Mg X 624.94 Å ($\sim$ 1×10^6 K) and Si XII

Table 1. A log of the datasets.

Date	Dataset	Pointing (X,Y)	Start time	End time
02/12	SER150W:26363	54,1070	07:50	10:41
02/12	SER75W :26364	54,1213	10:41	13:21
06/12	SER150W:26406	-1,1070	07:00	09:51
06/12	SER75W :26407	-1,1215	09:51	12:31
11/12	SER150W:26438	-19,1070	16:29	19:19
11/12	SER75W :26439	-21,1214	19:19	21:59
12/12	SER150W:26447	56,1070	16:30	19:20
12/12	SER75W :26448	56,1215	19:21	22:01
17/12	SER150W:26478	59,1071	18:03	20:54
17/12	SER75W :26479	60,1213	20:54	23:34
27/12	SER150W:26542	0,1070	18:10	21:00
27/12	SER75W :26543	-1,1215	21:01	23:41

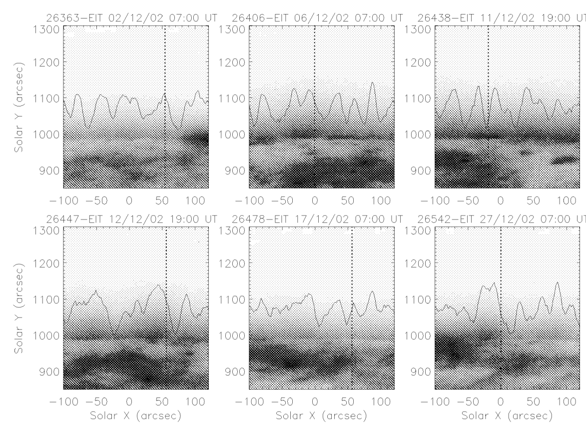

Figure 1. EIT 171 images showing the location of the CDS slit.

520.67 Å ($\sim$ 2.5×10^6 K). All the data were obtained with the 4×240 arcsec slit with exposure times of 60 sec. for the SER150W sequences and 120 sec. for the SER75W sequences, corresponding to 150 and 75 time frames respectively. We then summed over these time frames to produce the required high signal-to-noise line profiles along the Y direction. The SER75W sequences with their higher exposure times were designed to obtain data at higher altitudes off-limb, to complement (and slightly overlap) those obtained closer to the limb by the SER150W sequences. In order to further increase the signal-to-noise ratio we binned by 2 along the slit to produce 70 pixels in Y in the SER150W sequences and by 4 to produce 35 pixels in Y in the SER75W sequences. The resulting line profiles were then each fitted with a single Gaussian in order to measure the intensity, line width and

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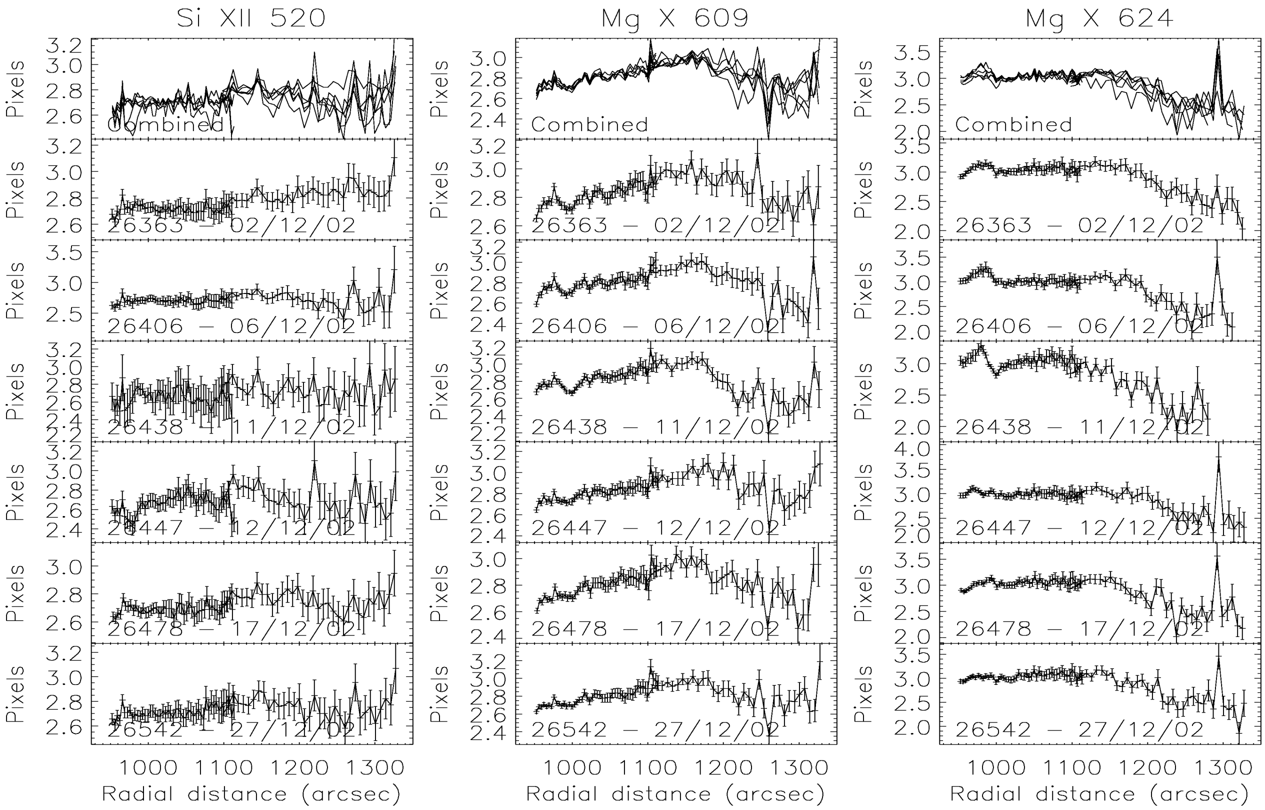

Figure 2. Variation of line widths versus height.

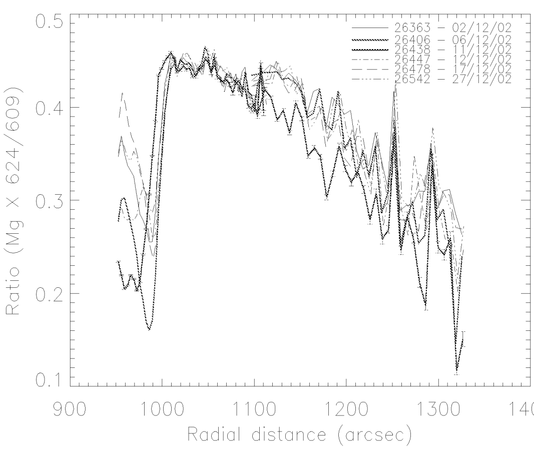

Figure 3. Mg X *624/609 ratio.*

line-of-sight (L.O.S.) velocity.

The data was reduced and calibrated using the standard CDS routines. Further and fuller details on cleaning and calibrating CDS data may be found at http://solg2.bnsc.rl.ac.uk/software/uguide/uguide.shtml. Often scattered light contributions are significant while making observations off-limb. Harrison et al. (2002) have shown that, for the Mg X line, the scattered light contribution is very small, so we do not consider any scattered light effects to be relevant in this analysis.

3. RESULTS

In these observations the CDS slit was pointed to the six locations in X shown by the dotted lines in the EIT 171 images shown in Fig.1. The limb in these colour-inverted images is at about 980 arcsec and the intense plume regions are visible as the dark patches just above the limb in some of the images. The black line curves in these images show the summed (background subtracted) intensity between 980 and 1200 arcsec above the limb. It can be seen from these plots that the CDS datasets are all pointed in or on the edge of plumes which are identified by peaks in the summed intensities. In Fig.2, for each of these six plume regions, we show the variation of line widths with height for the three coronal lines, that is, the Si XII 520 and the two Mg X lines at 609 and 624 angstroms. In the top three panels are plotted combined plots showing the overplotted width variations from the six datasets plotted in the panels below. Note that the data shown here were obtained over a three week observation period.

In these plots it is possible to see, especially in the Mg X 609 and 624 plots, that there is a slight increase in line width with height above the limb before a subsequent decrease at the higher altitudes, starting at a height of about 1150 arcsec. This result is also seen in some of the Si XII datasets but in many cases there is little or no change of line width in this line, or else a continuous increase with height. It is known that, for Alfvén waves, the energy flux is proportional to line width (Doyle et al., 1998). So, the question is; are the decreases in the line widths at the higher altitudes above 1150 arcsec due to some form of

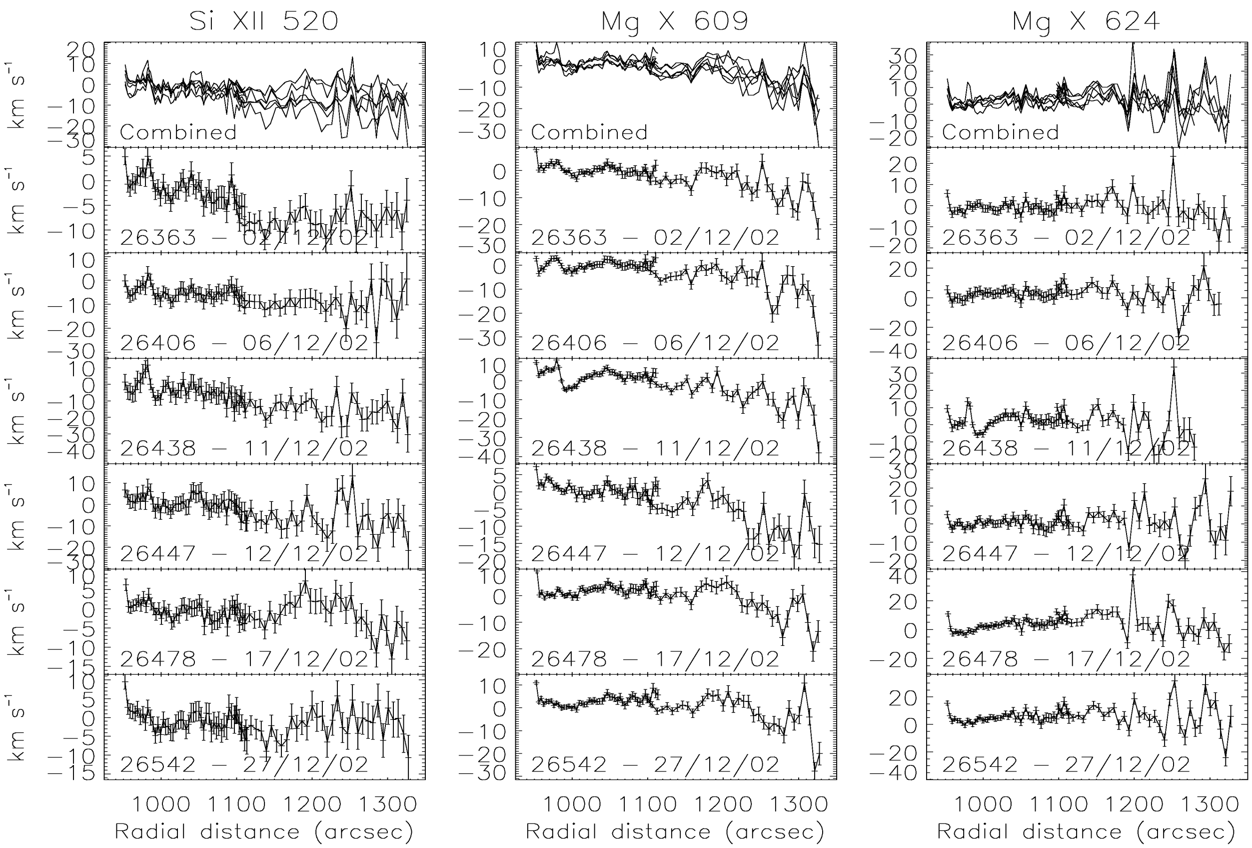

Figure 4. Variation of line-of-sight velocity with height.

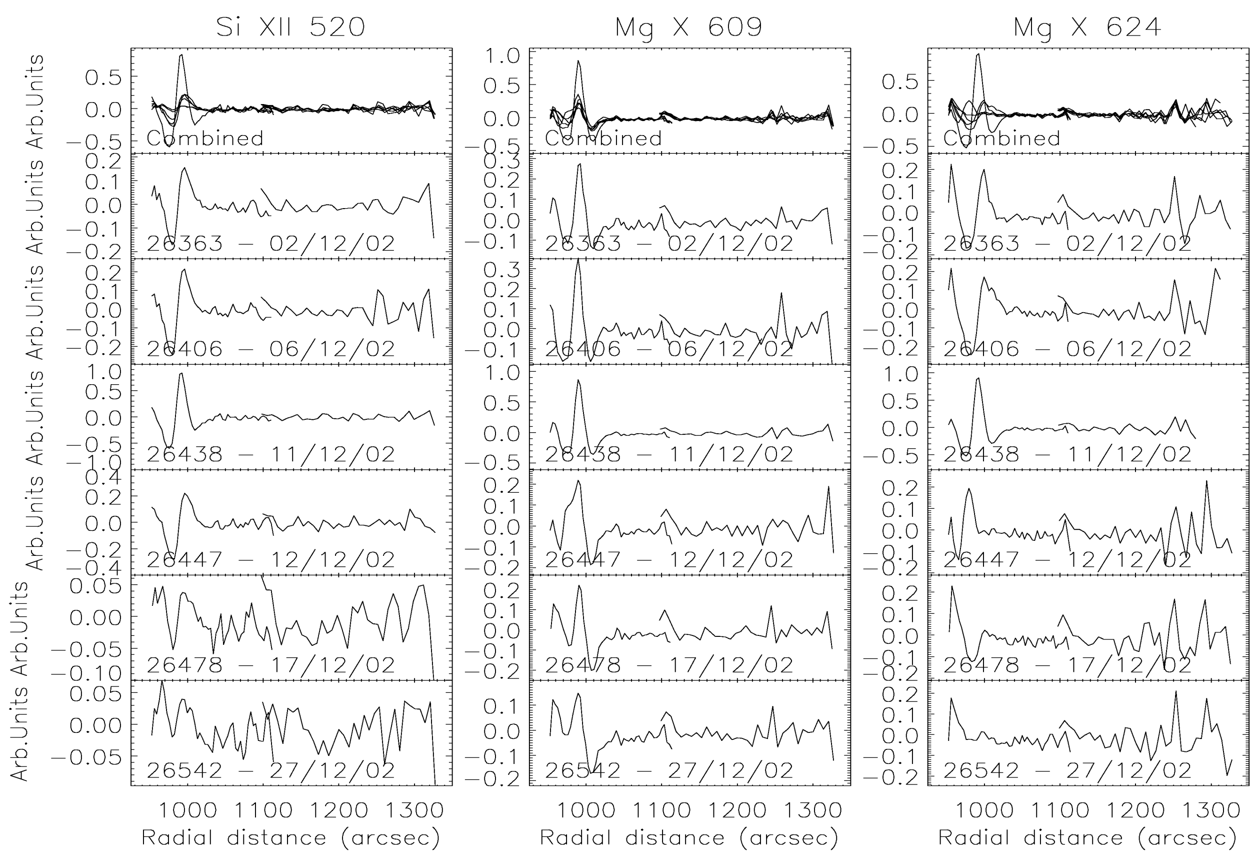

Figure 5. Variation of (relative) peak intensity with height.

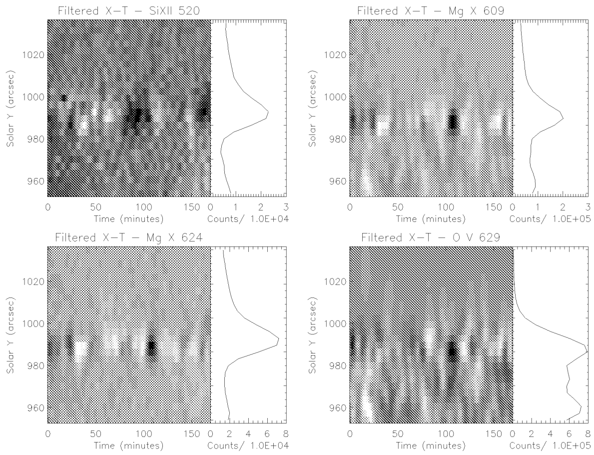

Figure 6. X-T plot for 11th Dec. data. Lo-pass filtered at 2mHz.

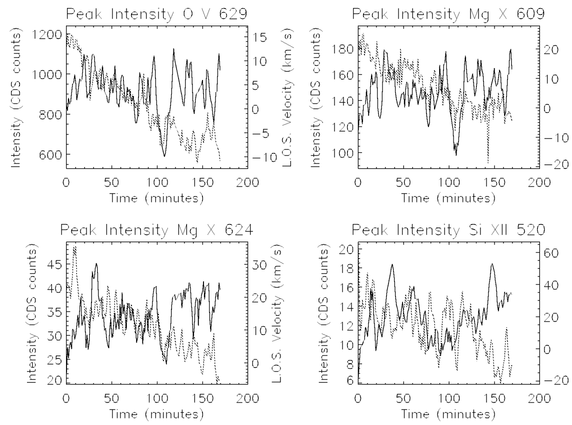

Figure 7. Time series plots at height of 982 arcsec on 11th Dec. L.O.S. velocities are plotted in red.

wave dissipation?

To examine this, we plot in Fig.3 the ratio of the two Mg X lines, versus height above the limb, for each of the six datasets. These Mg X lines are two resonance lines whose intensity fluxes should be in the ratio of 2:1 for purely collisionally excited processes and in a ratio of 4:1 for purely radiatively excited processes. In this plot, in the region from 1000 up to about 1150 arcsec, the ratios show values close to those expected from purely collisionally dominated excitation, that is, values of almost two to one. Above 1150 arcsec the values decrease to those expected for radiatively dominated excitation.

If we compare these ratios with the line widths in Fig. 2 it is clear that there is a decrease in the line width values at exactly the same location where the dominant excitation changes from being collisionally to radiatively dominant, that is, above about 1150 arcsec. The decrease in the line widths above 1150 arcsec is probably due then to the absence of the collisional broadening contribution to the line widths at these heights. So, in answer to the question; is the decrease in line widths above 1150 arcsec found in this work due to wave dissipation; we can say, probably not. These results would suggest that caution must be taken in attributing decreases in line width to wave dissipation at least at high altitudes above the limb.

So, we cannot always attribute the decrease in line width to wave dissipation. What else then can we say about this data and the results shown here? If we concentrate now on the combined plots in the upper panels of Fig. 2 then it will be noted that the variations of line width with height for each dataset are unusually similar, showing the same general pattern of variation with height. This correlation between the different datasets immediately suggests that there must be a stable structure present in the polar plumes, persisting over the three weeks represented by the data here. It will also be noted that there is a definite increase in the line widths, particularly for the Mg X 624 line, at heights below 1000 arcsec.

In Fig.4 it can be seen that similar structuring is also present in the line-of-sight velocities. From the combined plots for the three coronal lines the shared structure between the different datasets for the different days can again be seen. Each of the lines shows an increase in blueshifted velocity in the height range below 1000 arcsec, but particularly the Si XII line. We note that this is the same region where the three coronal lines showed a noticeable increase in line width. If we now turn to measurements of peak intensities, in Fig. 5, we find a similar story. The solid lines plotted here are the relative intensity, obtained by dividing the original intensity by its trend and subtracting one. For these relative intensities we also find that there is a shared persistent structure present in each dataset. However, this is perhaps difficult to see due to the large brightenings occurring at the lower altitudes in these plots, below about 1000 arcsec. These brightenings occur in the same region, close to the limb, where we have also previosuly seen increases in line width and blueshifted velocity. In order to investigate what is happening in this region at the limb we show a X-T plot in Fig.6, that is, the variation of the intensity with time and as a function of position along the slit in the Y direction. This plot is for the 11th December when the largest brightening in the region close to the limb was seen. It is instantly clear that there is some sort of dynamic event occurring between heights of about 980 and 1000 arcsec, that is, the region where we have already seen the significant increases in intensity, line width and blueshifted velocity in Figs. 2, 4 and 5. The bright and dark patches are indicators of quasi-periodic oscillations, with the bright patches the peaks of the oscillations and the dark patches the troughs. At a time of around 110 minutes in each of these plots there is a very clear darkening in the intensities, causing a large black spot in these images. We believe this darkening to be due to an evacuation of plasma, perhaps caused by a reconnection event, occurring within the general brightness variations. If we look now, in Fig. 7, at the intensity and velocity variations at a single height within this X-T plot, at a height of 982 arcsec, it can be seen that this darkening at 110 minutes coincides with a noticeable blueshift in the ve-

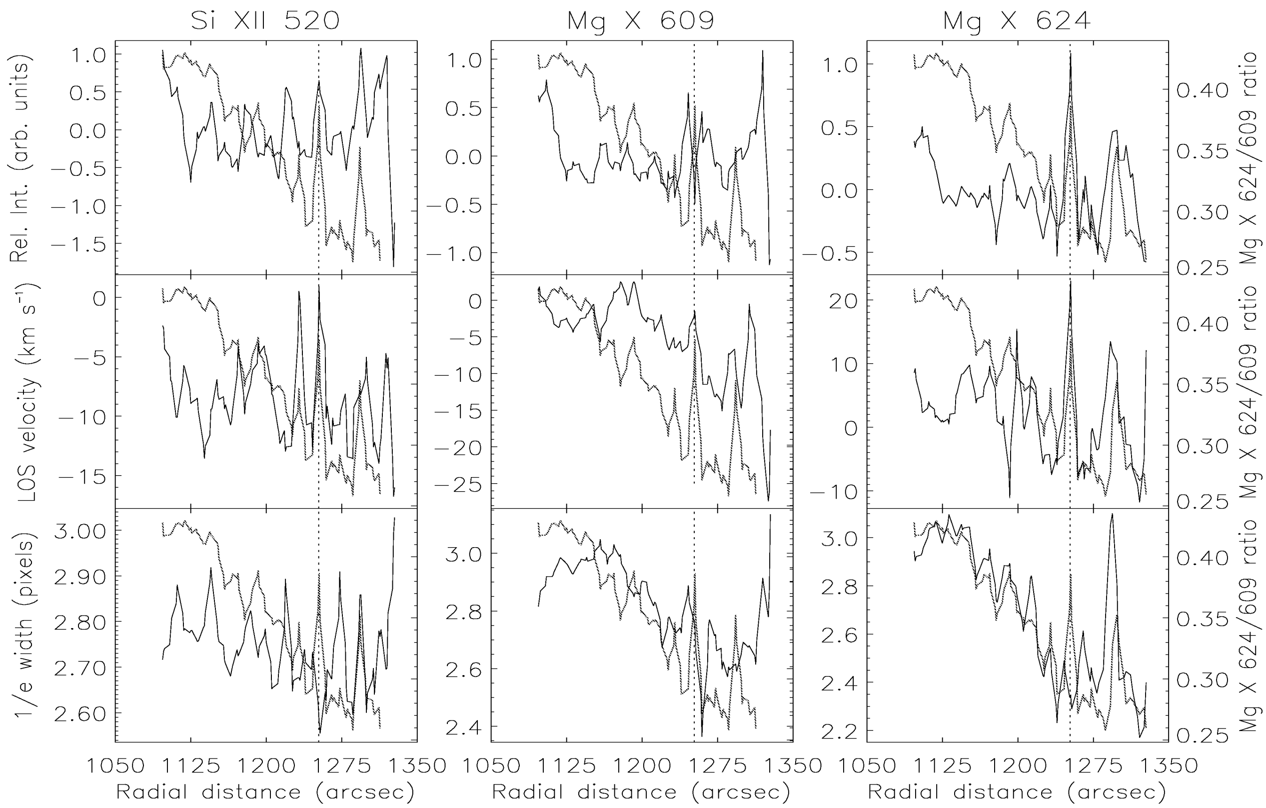

Figure 8. Averaged plots of intensity, L.O.S. velocity and line width. Mg X ratios are plotted in red.

locities of the O V and Mg X lines (plotted in red), but not the Si XII line, at the same time. We note that plumes are thought to be formed from the reconnection of unipolar to bipolar fields and this may be a signature of such a reconnection.

As mentioned previously long-term structure is present in the line widths, the velocities and the intensities in plume regions. In order to examine this effect in more detail than before we show in Fig.8 averaged plots for intensity, velocity and line width at heights only above 1100 arcsec. These are averaged plots of the six datasets we have seen in the previous figures. This averaging allows us to more easily see the general overall structure present in these plume regions, for each of the measured quantities. The fact that the fine structure is preserved in this averaging indicates its continued presence in each of the datasets over the three week period of the observations. Overplotted in red on each of the plots is the averaged variation of the Mg X 624/609 ratio for the six datasets. Note in the Mg X ratios that there are locations, e.g., at about 1250 and 1300 arcsec, that show short-term increases back to values expected for a more collisionally dominant excitation. These small areas may be locations of enhanced density common to each of the six averaged datasets.

Comparing the averaged plots of intensity, velocity and line width to the Mg X ratios it is possible to see that the peak in the Mg X ratio at about 1250 arcsec (marked with the dotted line) is correlated with a corresponding peak in intensity and blueshifted velocity. The line widths, however, are anti-correlated, showing a minimum at this height. The effect is perhaps most easily seen in the Si XII and Mg X 624 plots. At other locations, e.g. at about 1300 arcsec the increase of the Mg X ratio values is accompanied by increases in line width for the Si XII and Mg X 624 line, together with correlated increases in velocity and intensity. The picture is a bit less clear for the Mg X 609 line. These results, that is, correlated increases in intensity and velocity together with changes in line width and evidence for a localised increase in density, through the increases in the Mg X ratio, suggest that we may be looking at evidence of localised heating events, perhaps caused by the dissipation of waves. The fact that these results are found from averaged results from datasets covering a period of three weeks suggests that the localised heating processes are continuous and yet static; the increases in blueshifted velocity and intensity, for example, always occurring at the same altitude in each of the six datasets.

4. CONCLUSIONS

We have found that decreases in line width at high altitude are due to the absence of the collisional broadening contribution to the line width and cannot simply be attributed to the dissipation of wave energy.

We found evidence for a long-lived dynamic event occurring just above the limb in the plume regions, suggested by large increases in intensity, velocity and line width. A possible evacuation event is also observed as a large reduction in intensity coupled with a blueshifted velocity at a certain time within this larger dynamic event. We suggest that these dynamic events may be evidence for reconnection taking place in the plume.

Evidence is found for long-term structure in the off-limb plume regions lasting for the full three weeks of the observations. Measurements of intensity, velocity, line width and Mg X resonance line ratios suggest the presence of continuous localised heating within these plume structures.

These results will be presented in full in O'Shea et al. (2005)

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