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Detection of cooler loop-tops in a coronal structure

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We have obtained off the limb spectroscopic observations covering a coronal region of 200″ × 500″ in [Fe x] 6374 Å and [Fe xi] 7892 Å emission lines simultaneously. Yohkoh soft X-ray images of the sun showed two independent coronal structures in the observed coronal region on the North-West limb. The structure at 20° N, overlying a sunspot group showed an increase in FWHM of both the lines and increase in the intensity ratio of 7892 Å to 6374 Å line with height above the limb, implying an increase in temperature with height in the coronal loops. Whereas the coronal structure at 32° N showed decrease in the FWHM of both the lines and also decrease in the intensity ratio with height. These variations with height imply that coronal loop-tops were cooler with respect to the foot points in the coronal structure at 32° during the observing period of about 11 hours. The reason for such a behaviour of this structure may be absence of an associated sunspot group, or the magnetic field configuration of the underlying region or coronal structure itself, or the beginning of formation of the structure or the decay phase of the structure.

1. Introduction

The study of hotter loop-tops or cooler loop-tops in a coronal structure are important for the dynamics and heating of solar corona. It is generally believed that coronal loops are hotter at the top as compared to their foot points. Kano & Tsuneta[1] showed that the temperature and emission measure peaks around the loop-top and decrease towards the foot point of the steady coronal loops, using the soft X-ray images of the sun obtained from Yohkoh. Moses et al.[2] have found that the intensity ratio of [Fe xii] 195 Å to [Fe ix,x] 171 Å increases to a maximum at the coronal loop-top, suggesting that coronal loops are the hottest at their top (T = 1.7 MK). Others have measured the line-width of several coronal emission lines at different times with height above the limb (e.g. Tsubaki [3]; Mariska, Feldman & Doschek [4]; Koutchmy, Zhugzda & Locans [5]; Singh [6]; Hassler et al.[7] ; Wilhelm et al.[8]; Doyle, Banerjee & Perez [9]; Doschek & Feldman [10]; Doschek et al.[11]) and interpreted the variation of line-width in terms of variation in the non thermal velocity. Tsubaki[3]) from the measurement of [Fe xiv] 5303 Å line, representing plasma at 1.8 MK found that line-width decreases with height. Whereas others have used mostly EUV emission lines observed from space and emission lines in the visible part of the spectrum representing plasma below and around a temperature of 1.0 MK, and reported increase in line-width with height. Generally it has been interpreted in terms of increase in the non thermal velocity due to waves assuming the constant temperature in coronal loops. We have obtained the emission line profiles of a coronal region in the [Fe xi] 7892 Å and [Fe x] 6374 Å lines simultaneously. These lines represent plasma at temperatures of 1.3 MK and 1.0 MK and thus are best suited to study the variation of temperature and non thermal velocity in coronal loops with height. We determined the variation of FWHM of both these lines with height and variation of intensity ratio of 7892 Å to 6374 Å line simultaneously in the coronal loops. In this paper we discuss the implications of these variations and report that one of the coronal structure shows cooler loop-tops as compared to the foot points of the coronal loops.

2. Observations and Data Analysis

Simultaneous spectroscopic observations of a coronal region of $200'' \times 500''$ above the North-West limb were obtained in [Fe xi] 7892 Å and [Fe x] 6374 Å lines on September 19-20, 1998 with the 25cm coronagraph, the details of the observations may be seen in a paper by Singh et al[12]. Here we list important features of these observations. The raster scans were obtained with a step of $4''$, equal to the width of the slit used, the length of the slit being $500''$. The exposure time for the 6374 Å line was 20s and 40s for the 7892 Å line. Thus the raster scan of 50 steps could be completed in about 35 minutes. The observations of the same coronal region were repeated 9 times at irregular interval and lasted for 11 hours from morning to evening. The spectra were obtained with a resolution of 47 mÅ per pixel at the 6374 Å line and 48 mÅ per pixel at 7892 Å line but the slit width of 160 microns reduced the spectral resolution by a factor of 2.3.

The observed line profiles were corrected for the dark current, pixel response and the scattered light component. We made Gaussian fit to the corrected emission line profile to compute the peak intensity, line-width and Doppler shift at each location of the observed coronal region. Top right and left hand side panels of Figure 1 show the intensity distribution of 7892 Å and 6374 Å lines respectively in the observed coronal region. Due to different pixel size of the two CCD cameras used, image scales per pixel were different. The image of the 7892 Å line was rescaled to match the dimensions of the image in 6374 Å line. More details of the data analysis are given in the paper by Singh et al[12]. From the appearance of Yohkoh soft X-ray images of the sun for the period of September 16-20, 1998 (Solar Geophysical Data[13]), we found that coronal region we have observed on September 19-20, 1998 has two independent coronal structures, one at a mean latitude of 20^o N and other at 32^o N. We, therefore, split the observed coronal region in two parts according to the two coronal structures observed on the North-West limb of Yohkoh soft X-ray images, for the purpose to study the variation of line-widths of both these lines as a function of height and the intensity ratio of 7892 Å line to 6374 Å line (here after called as 'intensity ratio') with height. We selected 250 locations covering most of the coronal structure at 20^o N latitude as shown by + marks in the middle two panels of Figure 1 and 100 locations on the other structure as shown by + marks in the lower most two panels of Figure 1, the number of locations being according to the extent of the coronal structure, to study the variations with height above the limb.

3. Results

Figure 2 for the coronal structure at 20^o N was generated from the locations selected by the + marks shown in the middle panels of Figure 1. The top panel of Figure 2 shows the FWHM of 7892 Å and 6374 Å emission lines as a function of height above the limb along with linear fit to the respective data sets and the bottom panel shows the intensity ratio as a function of height along with a linear fit. This figure shows that FWHM of both these lines and intensity ratio increases with height. The slope of the linear fit to the FWHM of 6374 Å line data is larger than that of the 7892 Å line data. Top panel of Figure 3 for the coronal structure at 32^o N shows the FWHM of 7892 Å and 6374 Å emission lines as a function of height above the limb and the bottom panel shows the intensity ratio. To our surprise Figure 3 shows opposite behaviour to that of Figure 2. Here the FWHM of both these lines decreased with height and also the intensity ratio decreased with height above the limb. Also in this case slope of the linear fit to FWHM of 6374 Å line data is less than that of 7892 Å line data. The intensity ratio increased in the structure at 20^o by a factor of about 1.6 over a distance of about $140''$ whereas it decreased by a small amount in the structure at 32^o N. Figures 1-3 are the typical examples of the observations made at different epochs. The mentioned trend in the data was seen through out the period of observations of about 11 hours. Of course there were some small

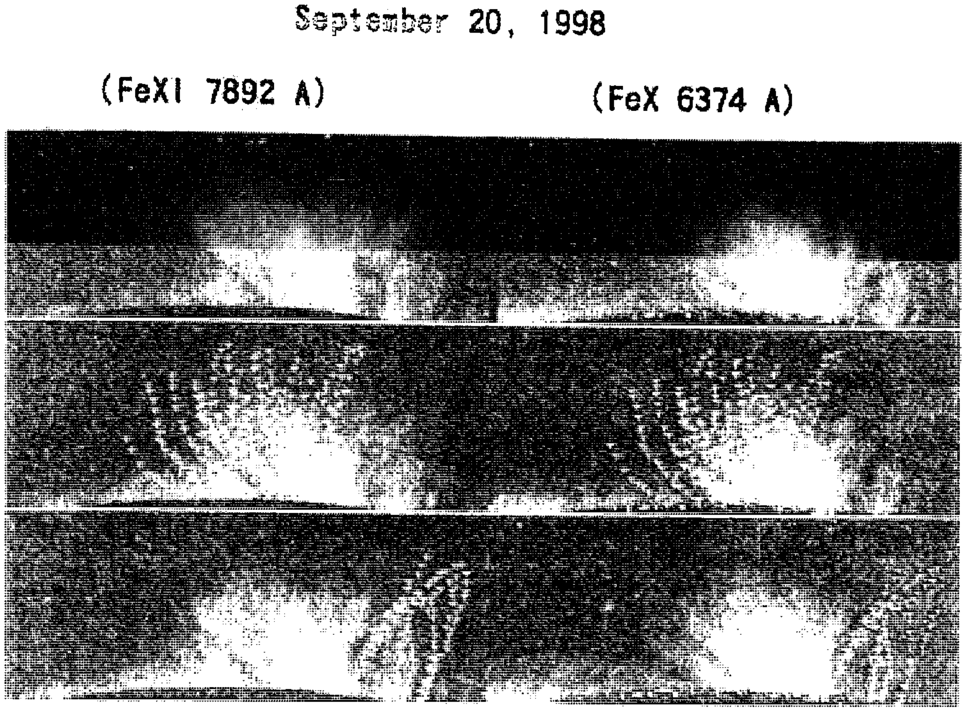

Figure 1: Top right and left hand panels of the figure show intensity distribution of [Fe xi] 7892 Å and [Fe x] 6374 Å emission lines of the observed coronal region on September 19-20, 1998. In the middle two panels, + marks show locations selected on the coronal structure at 20° N to generate Figure 2 and the + marks in the bottom most panels indicate the coronal structure at 32° N and the locations chosen to generate Figure 3.

variations in the values of the slopes with time. It is difficult to say if these variations were periodic in nature as the interval between successive observations was large. It may be noted that our results are valid upto a height of about 150″ above the limb and for the steady coronal structures and may not be possible to extend far in the corona as the decrease in line-width has to stop at some height in the corona.

4. Discussion and Conclusion

If there is an increase of temperature from certain value, the abundance of [FeX] ions responsible for 7892 Å line emission will increase as compared to that of [FeIX] ions causing the 6374 Å line emission. Thus the intensity ratio of 7892 Å to 6374 Å will increase with increase in temperature. The increase in temperature will also cause the increase in FWHM of the coronal emission lines due to increase in the thermal velocity of ions. Similarly the decrease in temperature will cause decrease in the above mentioned parameters of emission lines. Therefore, the observed increase in FWHM of both the emission lines and simultaneously observed increase in the intensity ratio with height above the limb in the coronal structure at 20° N latitude imply that temperature in the coronal loops increased with height. There might be some variations in the non thermal velocities

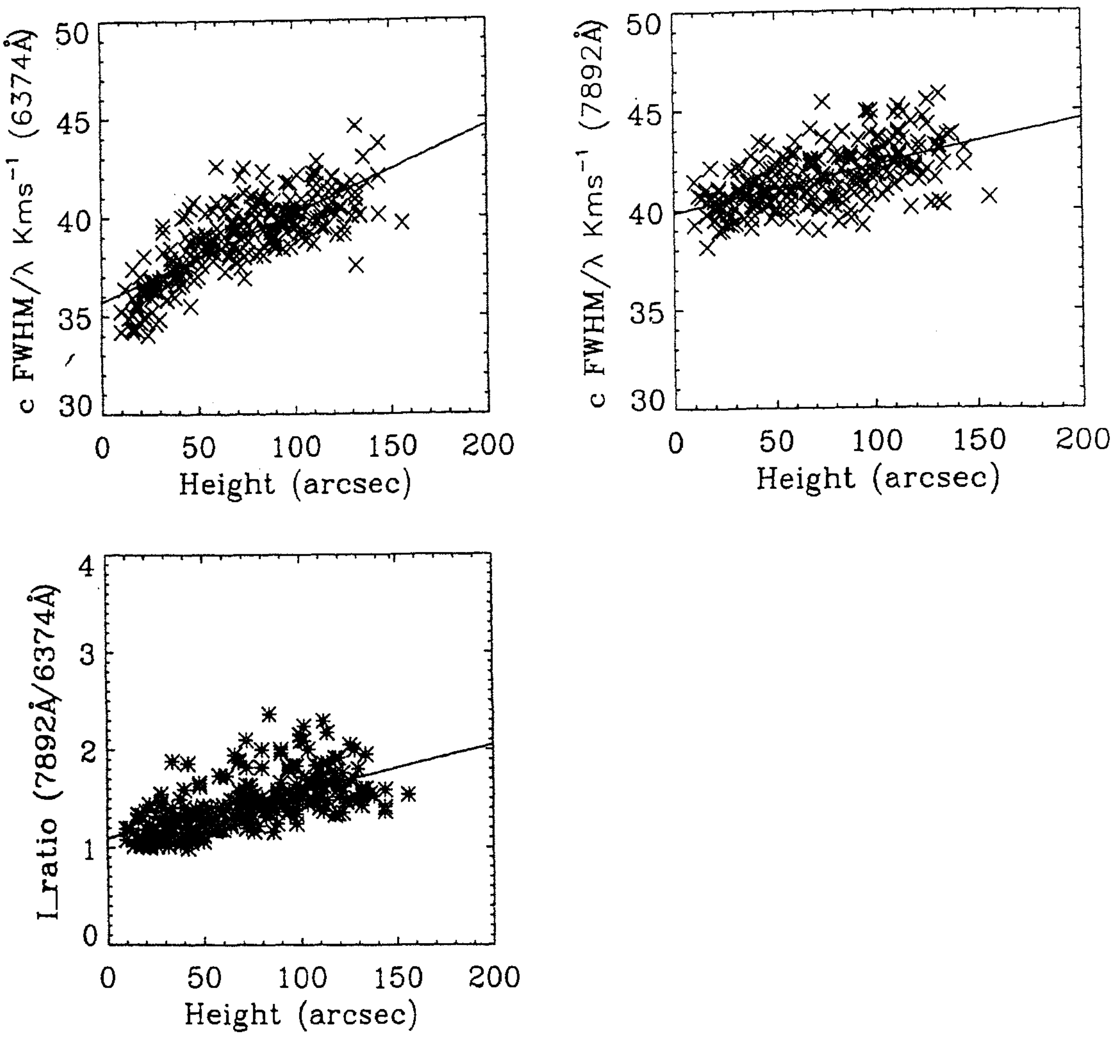

Figure 2: Top panel of the figure shows the FWHM of 7892 Å and 6374 Å emission lines as a function of height above the limb along with the linear fit to the respective data sets and the bottom panel shows the intensity ratio of 7892 Å line to 6374 Å line as a function of height for the coronal structure at 20° N latitude.

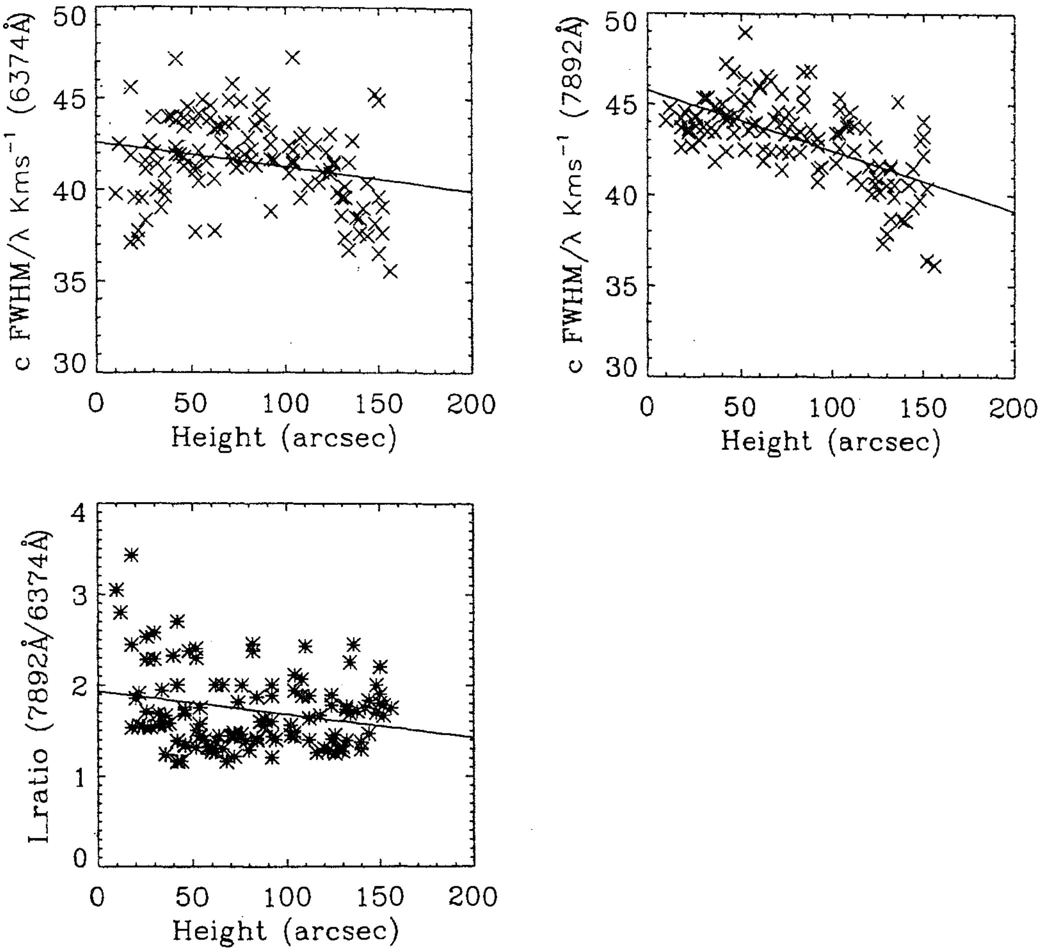

Figure 3: Same as that of Figure 2 but for the coronal structure at 32° N latitude.

also. More similar observations especially in three emission lines are needed to separate out the two components. The increase in temperature in the coronal loops agree with the findings of Kano & Tsuneta[1] and Moses et al[2] . It may be noted that there was a sunspot group No. 8331 (Solar Geophysical Data 1998) associated with this structure.

Whereas the observed decrease in the FWHM of both these lines and decrease in the intensity ratio with height above the limb in the coronal structure at 32° N certainly imply a decrease in temperature with height. The loop-tops in this coronal structure show minimum values of FWHM of these lines and of the intensity ratio, implying that loop-tops are at minimum of temperature. Hence, we may say that we have discovered a coronal structure where loop-tops are cooler than the foot points of the loops. To find out the reason for this we have scanned the broad band images (Solar Geophysical Data 1998) and soft X-ray images of the sun obtained from Yohkoh for the period of September 1998. There was no sunspot group on the visible part of the solar disk at 32° N latitude close to the west limb where this coronal structure was observed on September 19-20, 1998

at the limb. Also the soft X-ray images did not show any activity in the corresponding region of the sun prior to September 19, 1998. Soft X-ray images obtained on September 19-20 show active structure at 32° N corresponding to coronal structure observed by us in 7892 Å and 6374 Å lines simultaneously above the limb. From these observations we may say that the coronal structure at 32° was formed at the limb on September 19, at the most one day earlier than our observations and if any sunspot activity was associated with this structure, it must be on the limb or behind the limb, not visible on the solar disk to us. It is also possible that this structure was short lived and was in the decay phase when we made observations. With these circumstances and observations it is difficult to find out the reason for the cooler loop-tops in this coronal structure. May be some peculiar magnetic field configuration at the photospheric level or in the coronal structure itself caused it.
To conclude, we may say, we have probably for the first time found a coronal structure with loop-tops cooler as compared to the temperature of the foot points. The cause for this can be beginning of of formation of the coronal structure, decay phase of the coronal structure or peculiar magnetic field configuration of the region. More observation of such type, better in three lines are needed to delineate the cause of cooler loop-tops.

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