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# Magnetic nature of coronal loops

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**Abstract.** It is generally believed that the magnetic pressure is much higher than the gas pressure in the coronal loops and these loops are isothermal in nature. We made systematic observations of four strong coronal emission lines in the visible and near infrared part of the spectrum for about 8 years. Two emission lines were observed at a time, making raster scans of a steady coronal region. We studied the variation of line widths of these lines and intensity ratios as a function of height. The relationship between the widths of these lines and intensity ratios indicates that the steady coronal loops are not magnetically isolated. These findings put restrictions on coronal loop models and indicate that the magnetic pressure in coronal loops may be much less than assumed. These results strongly suggest that magnetic field strength in the corona needs to be measured accurately.

*Keywords* : solar corona – coronal loops – emission lines – spectroscopy – line width – intensity ratio

## 1. Introduction

The identity of the mechanism for coronal heating remains a very big puzzle even though the role of magnetic field has been accepted in heating the coronal plasma. It is necessary to understand the nature of coronal loops to understand the heating of the solar corona. Coronal loops are considered to be in hydrostatic equilibrium and isothermal in nature because of magnetic pressure being much larger than the gas pressure. Furthermore, the loops are thin and are magnetically shielded from other temperature loops. Most of the time physical and dynamical properties studied pertain to well developed quiescent loops

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when on the solar limb (Singh et al. 1999, 2003, 2006; Aschwanden et al. 2000; Doschek et al. 2001). Following the discovery (Tousey et al. 1973; Vaiana et al. 1973) that the hot plasma of coronal loops is contained in closed magnetic structures, Rosner et al. (1978) recognized that the corona could be approximated as a set of one-dimensional loops that are thermally insulated from the surroundings. They solved the one-dimensional energy balance equations by assuming constant pressure, uniform heating and a static semicircular loop with a constant cross section deriving two scaling laws that related loop half-length and volumetric heating rate to the resulting apex temperature and base pressure. Serio et al. (1981) extended the scaling laws to allow non-uniform pressure and subsequently many additions have been made to the loop models.

Kano & Tsuneta (1996) found that temperature and emission measures are the highest at the loop top as compared to the foot points. On the contrary Singh et al. (2004a) found that some of the loops have cooler loop tops as compared to the foot points as deduced from a decrease in the intensity ratio of the green to the red coronal emission lines with height in the coronal loops. The variation of line width and intensity ratios of coronal emission lines with height in coronal loops tells us about the physical nature of coronal loops. Mostly an increase in line width of coronal emission lines with height has been interpreted in terms of increase in non-thermal velocities with height due to coronal waves and some times the decrease in line width at larger heights due to dissipation of coronal waves. Here, we ask whether systematic observations of coronal emission lines confirm this idea via simultaneous spectroscopic observations of steady coronal structures.

## 2. Observations and data analysis

Spectrographic observations of several coronal regions were obtained in the [FeX] 6374, [FeXI] 7892, [FeXIII] 10747 and [FeXIV] 5303 Å emission lines with the 25 cm coronagraph at the Norikura Solar observatory on several days during the years 1997-2004. The Coude type coronagraph provided coronal image with an image scale of 25″ per mm and the 7m focus Littrow type spectrograph provided a spectrum with a dispersion of 2.17 Å per mm at the third order red. By choosing different orders for different coronal emission lines, we could observe the 6374 Å line in the third order and the 5303 Å line in the fourth order simultaneously by using two CCD cameras. Similarly, we could obtain spectra in the other pair of emission lines simultaneously. The binned CCD camera provided a dispersion of 31.8 mÅ at the green line, 58.4 mÅ at the red line, 25 mÅ at the 7892 Å and 121 mÅ per pixel at infrared lines. The slit width of 160 microns restricted the spectral resolutions to 77 mÅ, 128 mÅ, 58 mÅ and 291 mÅ for the green, red, 7892 Å and infrared emission lines respectively. The spatial resolution was 4″. The inclination of the glass block installed in front of the entrance slit was changed to obtain successive spectra at different locations in the solar corona to build a two-dimensional image. One raster scan could be completed in 10-100 minutes depending on the exposure time and number of steps to cover a coronal region of 200 × 500 arcsec. Some raster scans covered a coronal region of 500 × 500 arcsec with shorter exposure times for the inner corona

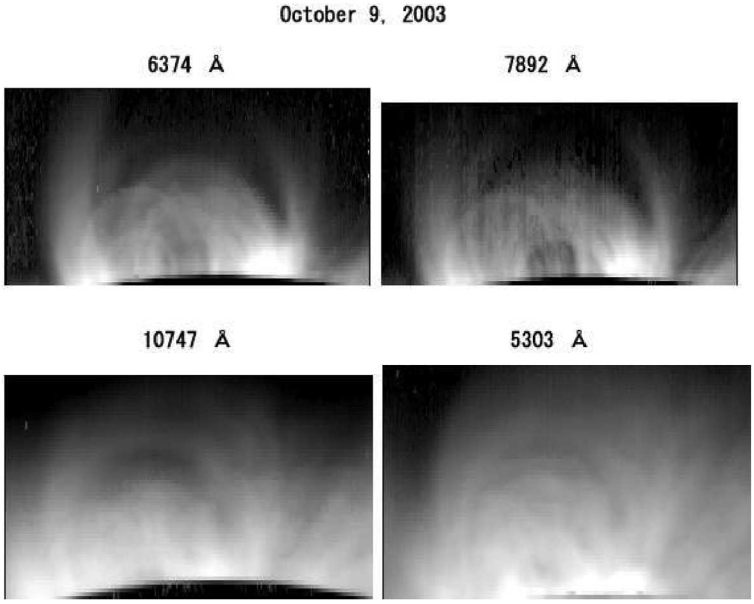


**Figure 1.** Intensity distribution in the coronal region observed on October 9, 2003 at different times in 6374 (on 09 10 03 at 01:25 UT), 7892 (on 09 10 03 at 00:03 UT), 10747 (on 08 10 03 at 22:31 UT) and 5303(on 08 10 03 at 22:05 UT) Å emission lines.

and longer exposure times for the outer corona. More details on the observations and the data analysis may be seen in Singh et al. (1999, 2002, 2003 and 2004).

All the spectra were corrected for the dark current, flat field and scattered light component due to sky brightness. A Gaussian fit was made to the observed emission line profile at each location of the observed coronal region to compute its peak intensity, central wavelength and width of the emission line. Fig. 1 shows typical examples of the intensity distribution of the coronal region observed on October 9, 2003 in the 6374, 7892, 10747 and 5303 Å lines. It may be noted that the intensity distribution appears similar in the 6374 and 7892 Å emission lines as both represents plasma at similar temperature of about 1 MK but differs by a small amount from other lines. The images in the 10747 and 5303 Å emission lines appear similar as both of these represents plasma around 1.8 MK.

To investigate the variation of the emission line parameters in a coronal loop, we selected 15-20 locations depending upon the length of the coronal loop visible in the red line intensity image. The corresponding locations in other images, e.g. 5303 Å 7892 Å or 10747 Å were selected automatically using software programme (see Fig. 2). Similarly to see the general trend in variations we have done the analysis by selecting 200-300 locations depending upon the area occupied by the coronal structures, with a spatial resolution of

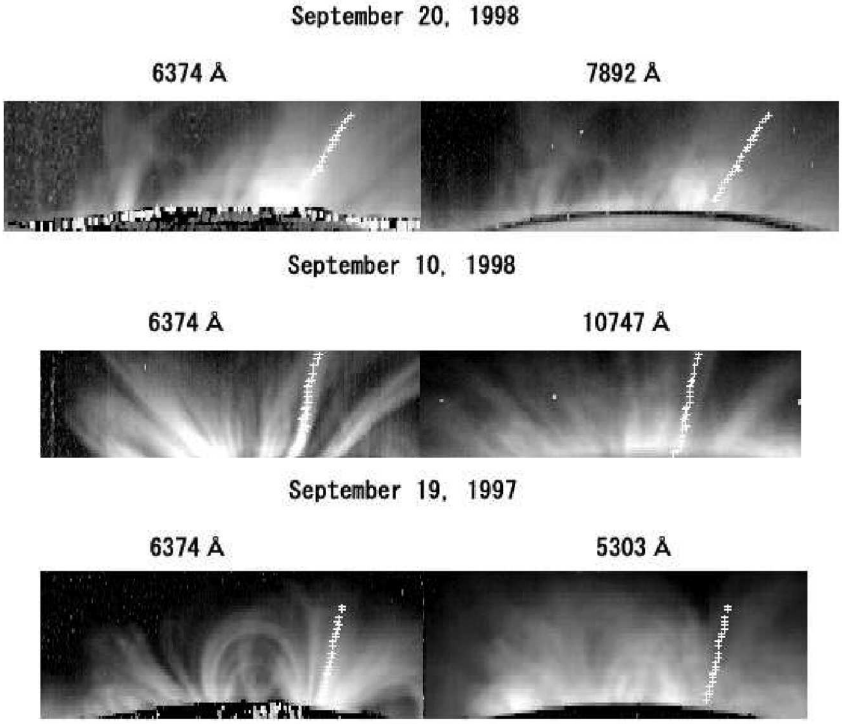


**Figure 2.** Images of the coronal structures obtained in 2 emission lines simultaneously. Choosing one 6374 Å emission line and the other from the other three 7892, 10747 and 5303 Å lines on three different days.

$4'' \times 4''$ on all the coronal structures visible in the red line intensity image. Fig. 2 shows three different coronal structures observed on three different days in 1997-98. Raster scans in the 6374 Å was always made choosing one of the other three emission lines. Plus marks in Fig. 2 indicate the three typical examples of loops selected to show the variation of FWHM of the emission lines with height. To study the variation of line width of these lines with height above the limb a linear fit to the FWHM data at various locations along the length of the individual coronal loop was made even though the linear fit may not be the best fit to the data as shown in Fig. 3. The linear fits to the data of FWHM with height appears reasonable.

## 3. Results

From the large amount of observations made over many years it is found that the width of the 6374 Å emission line increases with all types of coronal loops with height above the limb while that of 7892 Å line also increases with height but less steeply as compared

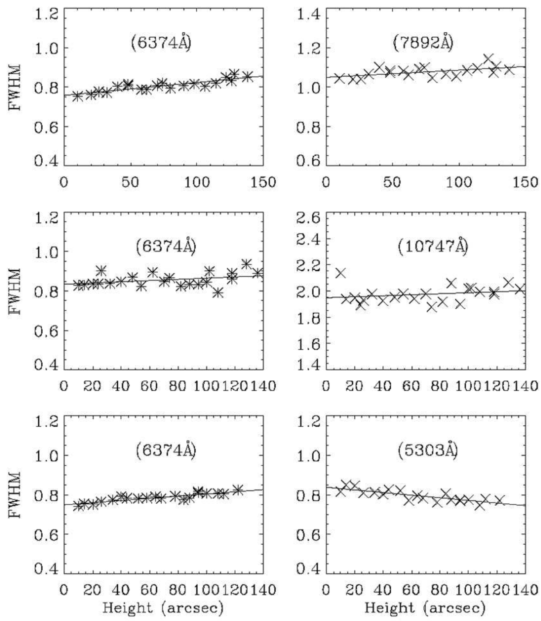


**Figure 3.** Variation of line widths with height above the limb in coronal loops observed in the 6374, 7892, 10747 and 5303 Å emission lines.

to the gradient of 6374 Å. The width of the 10747 Å line does not vary significantly with height above the limb and surprisingly the width of the 5303 Å line decreases with height above the limb. Fig. 4 shows that width of the 6374 Å emission line increases up to about 200 arcsec, and then does not vary with height up to about 500 arcsec, the maximum height of observations made, whereas that of 5303 Å line decreases up to about 200 arcsec, and then remains the same with height above the limb. All the locations with intensity more than some minimum intensity have been considered in making the plot of the FWHM as a function of height above the limb. Fig. 5 indicates that the line widths of the 6374 and 5303 Å lines, respectively, vary similarly in the coronal loops and the diffused plasma around the coronal loops. Therefore, the observed variations of FWHM of coronal emission lines with height cannot be explained by assuming different temperatures of coronal loop plasma and diffused plasma. Also one would have expected that the FWHM of lines increase with height at larger heights due to the larger velocity of the solar wind at larger heights.

Fig. 6 shows that the intensity ratio of 7892 to 6374 Å line increases with height above the limb indicating that the temperature in a coronal loop increases with height. The intensity ratio of 10747 to 6374 Å line remains more or less the same with height indicating that coronal loops are isothermal in nature. Surprisingly, the intensity ratio of the 5303 to 6374 Å lines decreases with height indicating that temperature in coronal loops

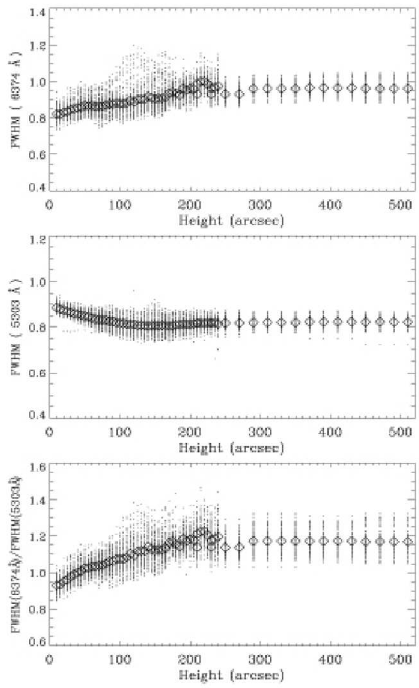


**Figure 4.** Top and middle panels of the figure show FWHM of the 6374 Å and 5303 Å emission lines as a function of height above the limb. The bottom panel shows the ratio of FWHM of these two emission lines with height.

decreases with height. It may be noted that the 5303 and 6374 Å lines represent different temperature plasma at 1.8 MK and 1.0 MK. This needs to be verified by investigating the intensity ratios of 5303 to 10747 Å line as both of these lines represent similar temperature plasma.

## 4. Discussions

Most of the coronal loops show a decrease in the width of the 5303 Å line whereas the 6374 Å line is observed to increase in width with height above the limb. The width of 7892 Å line shows an increase with height but with less slope as compared to that of the 6374 Å line. The width of the 10747 Å line shows a negligible change with height. The trend in the variation of line width is independent of the shape, size and topology of the coronal loops. To explain it further, the line width of the 5303 Å line decreases in all types of loops such as small or big; open or closed; face-on or end-on; radial or non-radial and that of 6374 Å increases with height. The magnitude of the variation may be different for different coronal loops, for example, it may depend upon the underlying magnetic

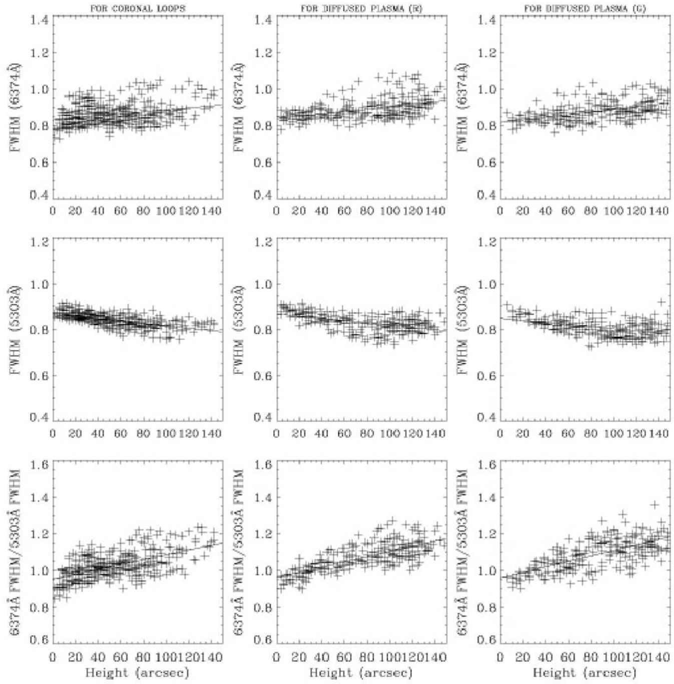


**Figure 5.** The variations in line widths of 6374 and 5303 Å lines with height above the limb in the coronal loop and the diffused plasma around the coronal loops.

field, density, temperature etc. All these observations indicate that the variation in line width is related with the temperature of the ion the line represents. The emission line with temperature of maximum abundances greater than 1.6 MK shows a decrease in line width and less than 1.6 MK show an increase in line width with height. The slope of the variation depends on the associated temperature and is negligible for emission line around 1.6 MK. The normalized FWHM ratios with respect to wavelength indicate that the ratio is 1 for the 7892 to 6374 Å line near the limb as expected because the temperature of maximum abundances for both these ions are nearly equal (1.2 and 1.0 MK, respectively). But it decreases with height above the limb and becomes 0.85 at 150 arcsec. If the loops are magnetically isolated and isothermal what makes the ratio decrease with height?

The intensity ratio of 7892 to 6374 Å line generally increases with height above the limb indicating an increase in temperature with height. This agrees with the findings of Kano and Tsuneta showing that the emission measure is highest at the loop top. The intensity ratio of the 10747 to 6374 Å line shows a small variation with height above the limb. One would have expected a larger variation with height considering the similar change in temperature with height as observed from the variation in the 7892 to 6374 Å line ratio and the abundances of ions as a function of temperature. To our surprise the intensity ratio of the 7892 to 6374 Å line decreases with height above the

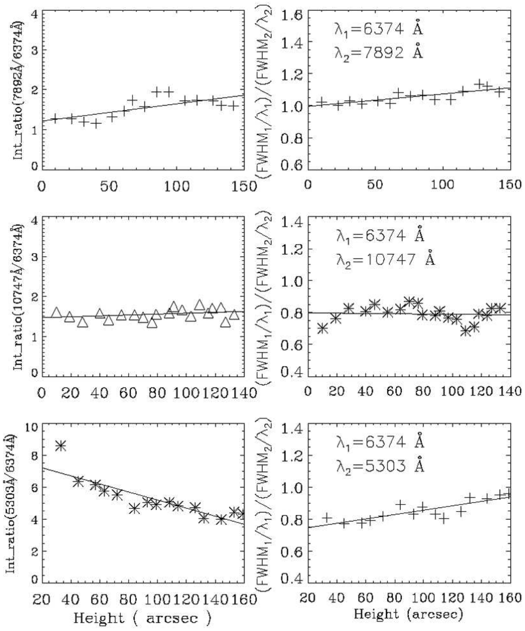


**Figure 6.** Intensity ratios of the 7892, 10747, and 5303 Å lines with respect to the 6374 Å line with height above the limb.

limb. Considering the above mentioned logic it should have increased with height much steeply. The decrease in this intensity ratio implies the loop top is cooler if observed in the 5303 Å emission line.

The observed variations considering one line at a time can be explained as follows. The increase in line width of the 6374 Å line can be explained in terms of an increase in the non-thermal velocity due to the existence of waves as has been done for EUV emission lines (Doyle et al. 1998). They report that non-thermal velocity shows an increase from 24 km $s^{-1}$ at the limb to 28 km $s^{-1}$ at about 25000 km above the limb and interpret this increase in terms of un- damped radially propagating waves. Similarly the decrease in line width of the 5303 Å with height can be explained in terms of dissipation of waves as some authors have tried. The assumption here is that the different types of plasma behave differently but we have shown that the properties of different temperature plasmas are correlated. The monotonic increase in temperature or non-thermal velocity with height above the limb cannot explain the observed variations in line widths and intensity ratios with height in all the lines simultaneously. The observed variations can be explained if we assume that the thin coronal loops are not magnetically shielded.

## 5. Conclusions

In conclusion we may say that the thin coronal loops are not magnetically shielded and different temperature plasmas interact to reach a common temperature and non- thermal velocities at larger heights above the limb. The gas pressure might be comparable to or more than the magnetic pressure. It implies that coronal structures are highly dynamic in nature.

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