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Diagnostics of Active Region Loops Observed with *Hinode*/EIS

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Abstract. The Extreme Ultraviolet Imaging Spectrometer (EIS) on board *Hinode* provides us with an excellent opportunity to study the physical parameters in spatially resolved coronal structures. In this paper we have carried out a study of active region loops using observations from the EIS. The active region was observed on 2007 Ma 19 using the 1″ slit of EIS. At coronal temperatures, we find that electron densities measured from Fe XII and Si X line ratios decrease along the loop length, being $\approx 10^{10}$ cm^{-3} at foot point and $\approx 10^{8.5}$ cm^{-3} at a height of about 75 Mm. However, the electron densities measured from the Mg VII line ratios (at a transition region temperature) show significantly lower values at the foot point. The electron temperature along the loop increases with height from $\approx$ 0.8 MK (at foot point) to $\approx$ 1.5 MK (at a height of 75 Mm). The temperature diagnostics using EM-loci at different locations along the loop show that the loop is "nearly isothermal" or "mildly multi-thermal" along the LOS. These measurements provide important constraints on the theoretical modelling of coronal loops.

1. Introduction

The problem of solar coronal heating remains one of the most challenging problems in the field of astrophysics since the 1940s. Coronal loops are the basic building blocks in the solar atmosphere, particularly in active regions. Since there is no cross-field information exchange in the corona, the problem of coronal heating can be reduced to a clear understanding of the heating mechanism in a single isolated coronal loop. This requires a proper understanding of physical plasma parameters in the coronal loops. There have been many attempts to carefully derive these parameters using observations from previous spectrometers such the Coronal Diagnostic Spectrometer (CDS) on board the *Solar and Heliospheric Observatory* (*SOHO*). However, the results have been hotly debated, due to various ambiguities.

The Extreme Ultraviolet Imaging Spectrometer (EIS; Culhane et al. 2007) aboard *Hinode* is providing observations with excellent spatial and spectral resolution, which enable us to measure the physical plasma parameters in spatially

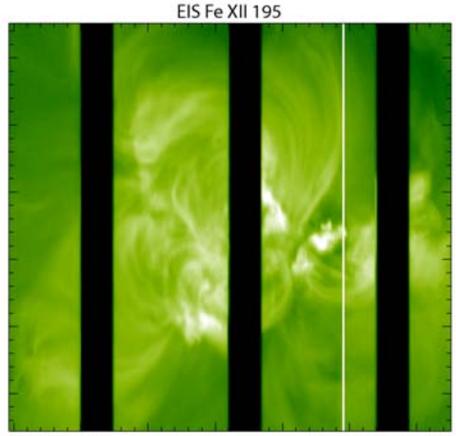

Figure 1. EIS image obtained on 2007 May 19, in the Fe XII line at λ195. The black stripes are data gaps due to *Hinode* eclipses. The times are the start and end times of the EIS raster. Adopted from Tripathi et al. (2009).

resolved coronal structures. In this paper, we study the electron density, filling factor, and electron temperature along a loop observed by *Hinode*/EIS on 2007 May 19.

2. Observations and Results

On 2007 May 19, EIS observed an active region near the disk center using its 1″ slit. The observation sequence used was *AR_velocity_map*. The exposure time for this study was 40 s with a delay of 12 s. The long exposure time prohibited a good cadence observation. However, it provided excellent count rates even for very weak spectral lines helping us to study the active region in a range of temperatures. The raster of the active region started at 11:42:23 UT and was completed at 16:35:01 UT. Figure 1 shows an image of the active region obtained in Fe XII λ195 line. This study contains many useful spectral lines for plasma diagnostics such as electron densities and temperatures and flows. For more details on this active region see Tripathi et al. (2009).

We measured the electron densities along *loop A* shown in the left panel of Figure 2. For measuring electron density and temperature, it is mandatory to estimate the contamination from the background emission. For this purpose we chose a path named 'BG' in the left panel of Figure 2 and subtracted the intensities along BG for each corresponding pixel along the *loop A*. It is worth mentioning here that estimation of the exact contamination of background emission is a critical issue (see e.g., Del Zanna and Mason 2003). Therefore, we chose different regions on the raster as a background and obtained similar results to within about 5-10%.

We measured the electron densities at two different temperatures simultaneously using the line intensity ratios of Fe XII (186/195) $\log T = 6.1$ MK, Si X (258/261) $\log T = 6.1$ MK, and Mg VII (280/278) $\log T = 5.8$ MK. The right

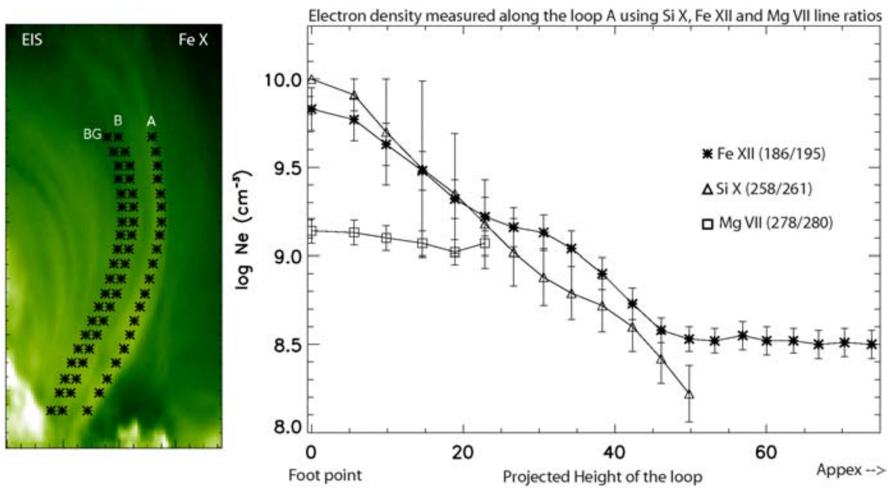

Figure 2. Left panel: A portion of the active region, where the loops are best seen, extracted from the complete raster. A and B are the two loops which were selected for our study and BG was considered as the background. In this paper we only have presented results for *loop A*. The results for *loop B* were similar. Right Panel: Electron densities along *loop A* measured using the line ratios annotated in the plot. Adopted from Tripathi et al. (2009).

panel of Figure 2 shows a plot of electron densities obtained using the above mentioned lines. Since the peak formation temperature for Fe XII and Si X is the same, we expect to obtain similar densities. The Fe XII and Si X line ratios give similar densities as anticipated. The densities measured at the foot point using Fe XII and Si X line ratios are as high as 10^{10} cm^{-3}. However, the densities obtained using the Mg VII line ratios give significantly lower values towards the foot point region.

For estimation of filling factors, electron density and the column depth are the basic ingredients. We consider the diameter of the loops as the column depth. We find that for coronal temperatures the filling factor increases with height being 0.2 at the foot point. However, for transition region temperature the filling factor is close to 1 at the foot point and decreases with height. For more details see Tripathi et al. (2009).

Given the excellent spatial resolution of EIS and the broad temperature coverage, we have estimated temperature along the LOS at many given points along the loop length from EM-loci using the spectral lines which are not sensitive to electron densities. In the EM-loci method we plot $I_{obs}/(A(b)\ G(N_e, T_e))$ as a function of temperature. The contribution function $G(N_e, T_e)$ was calculated with CHIANTI, v.5.2, (Dere et al. 1997; Landi et al. 2006) using the coronal abundance of Feldman (1992) with a density of 10^9 cm^{-3} and the ionization fractions of Arnaud and Rothenflug (1985). Similar results were obtained using the ionization fractions of Mazzotta et al. (1998).

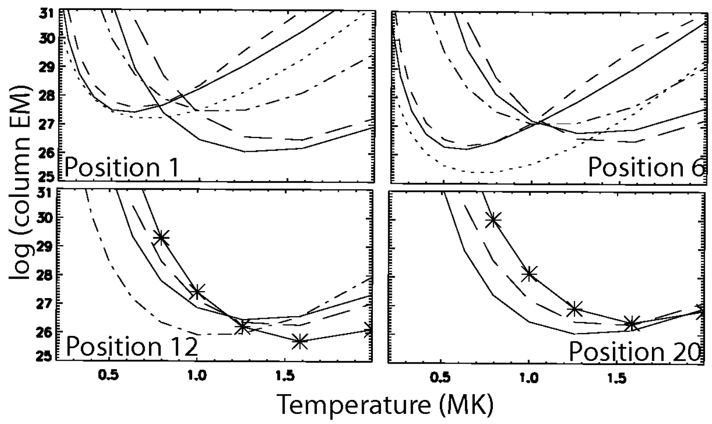

Figure 3. Emission measure curves obtained from the background subtracted line intensities for *loop A*. Different plots correspond to different data points chosen along the loops. In the plots, solid lines represent the EM-loci of Si VII, dotted lines Fe VIII, dashed lines Mg VII, dashed-dotted Fe X, dash-dot-dot-dot Fe XII, and long-dashed lines represent Si X. The solid lines over-plotted with asterisks and diamonds represent the EM-loci of Fe XIII and Fe XIV, respectively. The emission measure was calculated using Arnaud and Rothenflug (1985) ionization fraction and coronal abundances of Feldman (1992). After Tripathi et al. (2009).

3. Summary and Discussion

We have investigated electron density, filling factor and electron temperature along an active region loop observed by EIS on 2007 May 19. The low filling factors at coronal temperatures and nearly isothermal or mildly multi-thermal temperature profile along the line of sight suggest that the loop is comprised of many unresolved strands. The measurements given in this paper provide very important constraints on the modelling of coronal loops.

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