Investigation of coronal loop temperatures using three EUV filters & implications for future work with Solar-B

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1. Introduction

Recently the interest in the solar corona has centred upon determining the fundamental plasma properties within loop structures - namely their temperature (T(s)) and density (ρ(s)) profiles along the structure (s) coupled with any plasma flows or driven periodicities. In particular, two avenues of investigation have been to (i) calculate loop thermal profiles from observations and then match this with a T(s) from a 1D hydrostatic model that will yield a unique localised heating profile (H(s)), or (ii) fold your model calculations through some instrument response function (such as TRACE EUV filters) and compare the results with the observations.

Priest et al. (2000), Aschwanden et al. (2001) and Reale (2002) all analysed the same Yohkoh/SXT loop on the limb of the Sun. Priest et al. (2000) found that uniformly distributed heating matched the data closest whilst Aschwanden concluded that the heating was weighted towards the loop base and Reale found cases of apex dominated heating. The single filter ratio technique previously used for calculating coronal temperatures has been criticised for being too ambiguous with TRACE temperature calculations yielding both very hot (> 5 MK) and cool (~ 10^6) loops (Testa et al. 2002). To counter this problem, Chae et al. (2002) introduce a method of using not a single filter ratio but two filter ratios to create a possible way of determining unique temperature values.

2. Two Filter Ratio Method

The Chae et al. (2002) two filter ratio method is a simple principle which assumes that the same plasma volume is filled with isothermal plasma which has a temperature T_{iso}. The emission (E_λ) which an EUV imager (SOHO/EIT) observes from this region in the three EUV lines (λ = 171, 195 and 284 Angstroms) is given by

$$E_\lambda = \rho^2(s)\ I_\lambda\,[T_{iso}(s)]$$

where I_λ is the instrument response function for a given λ.

If we then take the ratio of these filter responses assuming that the EM and therefore the density is constant, we have

$$C_1(s) = E_{284} / E_{195}\ ,$$

$$C_2(s) = E_{195} / E_{171}\ .$$

Where C_1 and C_2 are now functions of temperature and element abundances. Plotting C_1 against C_2 provides a colour-colour (c-c) curve for the unique determination of temperature (shown in Fig. 1).

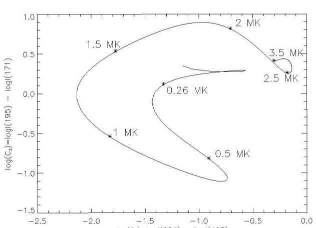

Figure 1: SOHO/EIT colour-colour diagram. The temperature at various points along the curve is indicated.

3. Observations

We now investigate the above method using a set of SOHO/EIT images taken on 18 March 1999. The EUV triplet used for this analysis was taken at around 07:00 UT.

Fig. 2 displays the three different passband images of the loop structure. The loops are marked with crosses which are the points that were chosen from this data set to test the Chae method of analysis. It can be seen that all the points chosen lie along the loop in all of the three wavelengths.

In doing this analysis we found that background noise subtraction made very little or no impact on the results. This is in line with Schmelz et al. (2003) who analysed a selection of 10 coronal loops taken with SOHO/EIT and also found that the effect of background subtraction did not affect the EIT temperature analysis.

4. Results

We would like to point out here that when using the procedure EIT_FLUX.PRO the values obtained for the standard filter responses of the three wavelengths are given in DNs^{-1} pixel^{-1}. Therefore, in order to compare the observed results with the c-c diagram it was necessary to divide the measured data points by the exposure time in seconds. The profile was measured by calculating the average intensity ratios of (logE(195) - logE(171)) and logE(284)) - logE(195)) for the 3 x 3 pixel boxes centred on the chosen points.

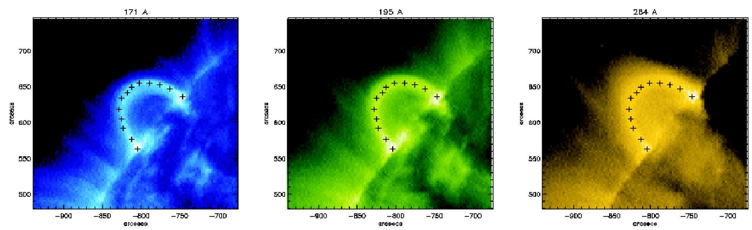

Figure 2: SOHO/EIT data in 171 A, 195 A and 284 A showing the loop structure. The crosses marked on the three images indicate the points used for the temperature analysis profile.

Figure 3 shows the c-c curve with the SOHO/EIT data results overplotted in crosses, there is a dashed box surrounding these points, depicting the area of c-c space occupied by the results, an error analysis of the curve is also shown. The error analysis on the c-c curve was done by using a simple monte carlo simulation of the filter ratio data obtained from the procedure EIT_FLUX.PRO. Each filter ratio value for all three wavelengths was given a Poisson distribution consisting of 10000 points. These "clouds" of points produced by this method were then plotted over the c-c curve (Fig. 3). There are extremely large errors associated with the cooler and to a lesser extent the hotter end of the curve. This is due to the fact that predicted counts from a 284 A image at these temperatures can be as low as 1-2 DNs^{-1} pixel^{-1}. Therefore, we feel it is necessary to limit the range of the curve to only include temperatures which lead to a count of more than 1 sigma of the maximum count for that bandpass, namely 0.7 MK - 4 MK.

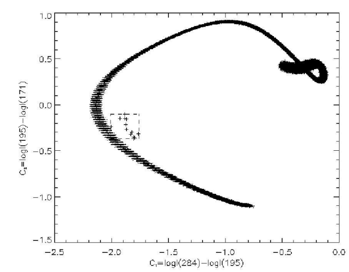

Figure 3: SOHO/EIT colour-colour diagram showing the results from the observed data surrounded by a dashed box and a Poisson distributed error around the curve.

From Fig. 3 it can be seen that the data points along the loop structure do not sit at all on the c-c curve, the points going along the loop also appear to move around the c-c curve in a completely random way. Hence, it is very difficult to associate a particular temperature with each chosen location. Therefore, using EIT data with this method, has proved difficult.

From the box plotted in Fig. 3 it can be seen that even after plotting errors on the curve the points do not seem to fall in an area that can be easily assigned a temperature. Therefore it appears likely that there is another factor contributing to the location of these points. One idea is that of a multi-thermal plasma which is discussed in the next section.

5. A multi-thermal atmosphere

The question as to whether we are resolving spatially the structural elements of coronal loops is still unanswered. It has been suggested that the observed loops are highly fragmented consisting of many filamentary loop threads (Lens et al. 1999; Cargill & Klimchuk 2004; & Priest et al. 2002).

Thus, we have investigated whether a multi-thermal atmosphere could be responsible for the position of the points sitting off the c-c curve. Considering a multi-thermal atmosphere, the points would be pushed off the c-c curve as;

$$\frac{\sum E_i}{\sum i} \neq E_{T_{av}}$$

where E_i is the emission from a specific temperature at a given wavelength, *i*, and $E_{T_{av}}$ is the emission that would be given from the average of all the temperatures viewed along the line of sight. If these inconclusive SOHO/EIT results are due to a multi-thermal atmosphere being present in an optically thin environment, a sum of intensities from a number of different EUV emitting sources would be seen.

As a first approximation, consider the case where there are only two distinct temperature plasmas (T_1 & T_2) along the line of sight. Also let us assume that the plasmas are at the same density. Thus, we have

$$C_1 = \frac{E_{284}(T_1) + E_{284}(T_2)}{E_{195}(T_1) + E_{195}(T_2)}$$

$$C_2 = \frac{E_{195}(T_1) + E_{195}(T_2)}{E_{171}(T_1) + E_{171}(T_2)}$$

for C_1 & C_2 respectively. In Fig. 4 there is a dashed box drawn around the observed data points from the SOHO/EIT data, indicating the region of space on the diagram that we took to overlap with the data points. We found temperature pairings (for T_1 & T_2) which would place the combined filter ratio point (C_1, C_2) at each corner of the box. The temperature pairings were found by doing a simple search of all the possible two temperature solutions and matching the solutions with the co-ordinates inside the box. These are listed in Table 1. Hence, it is possible with a two-temperature atmosphere to reproduce the observed c-c result.

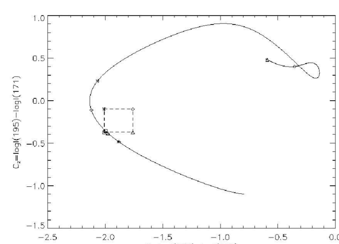

Figure 4: SOHO/EIT limited temperature c-c diagram, the box depicts the area where the observed points lay and the symbols show 4 temperature pairings that coincide with the corners of this box.

T_1 (MK)	T_2 (MK)	mark on c-c diagram
1.08	1.08	square
4.36	1.07	triangle
3.67	1.18	diamond
1.34	1.03	star

Table 1: Temperature pairings found in multi-thermal atmosphere analysis.

6. Future work with Solar-B

Once Solar-B is launched in 2006, Solar-B/EIS observations in coordination with TRACE and EIT observations will allow us to use this triple filter ratio technique in combination with the enhanced spectroscopic temperature diagnostics available from Solar-B/EIS. One avenue of investigation will be to look at an active region over a series of spectral lines to get the temperature and velocity field evolution. This will allow us to see where along the loop structure or within the active region the heat is being deposited, and therefore what heating mechanism is being employed. Also the high temporal resolution (a few seconds) observations of one part of a coronal structure (say the footpoint or the apex of a loop) will be possible by keeping the EIS slit fixed in one location.

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