



Determining the temperature profile along a plasma loop I: investigating a colour-colour method for SOHO/EIT

J.B. Noglik¹, Robert W. Walsh¹ and J. Ireland²

¹ Centre for Astrophysics, University of Central Lancashire, Preston, PR1 2HE, UK
² L-3 Communications Government Services Inc, NASA GSFC, Greenbelt, Maryland 20771, USA

1. Introduction

The solar corona is now envisaged as an incessant variable magnetically dominant plasma environment. It is an inhomogeneous, complex, dynamic system with plasma and magnetic-field interactions occurring over a wide range of scales. The fundamental building blocks of this part of the solar atmosphere are magnetic plasma loops - elemental flux tubes that allow energy to flow along but not easily across them.

Recent interest has centred upon determining the fundamental plasma properties within loops - namely their temperature ($T(s)$) and density ($\rho(s)$) 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 the TRACE EUV filters) and compare the results with observations.

Aschwanden et al (2000, 2001) use filter ratios of SOHO/EIT and TRACE EUV bands (171 to 195 Angstroms) to argue that the near isothermal loops observed indicate an $H(s)$ weighted towards heating at the loop base. However, this filter-ratio technique has been criticised as being too simplistic. For example, Testa et al (2002) state that this single filter ratio is ambiguous with TRACE temperature calculations yielding both very hot (>5 MK) and cool ($\sim 10^5$ K) loops. To counter this problem, Chae et al (2002) (from now on referred to as CH) introduce a method of not using a single filter ratio but two filter ratios to produce a possible way of determining a wide range of temperatures unambiguously. It is this method that is under investigation here.

This is the first paper in a three paper series investigating observational and theoretical aspects of thermal profiles along plasma loops. The aforementioned CH paper method is outlined in Section 2 while in Section 3 we present the observations of flare loops on the solar limb taken with SOHO/EIT in the three temperature passbands. In section 4, these are folded onto the colour-colour diagram. The implications of these results for future mission EUV imagers is discussed in Section 5.

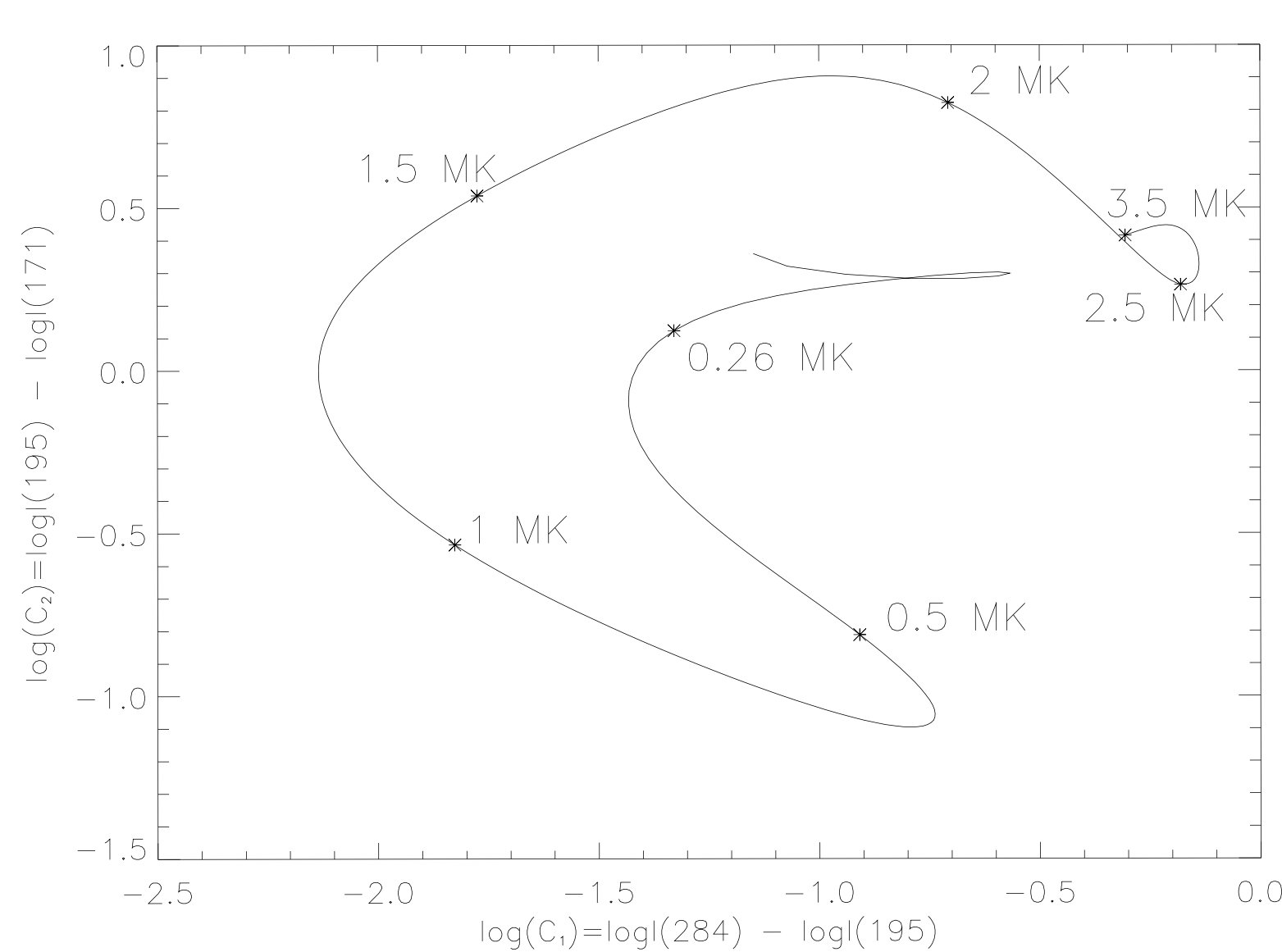


Figure 1: SOHO/EIT colour-colour diagram. The temperature at various points along the curve is indicated.

2. Two Filter Ratio Method

The CH 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 ($\lambda = 171, 195$ and 284 Angstroms) is given by

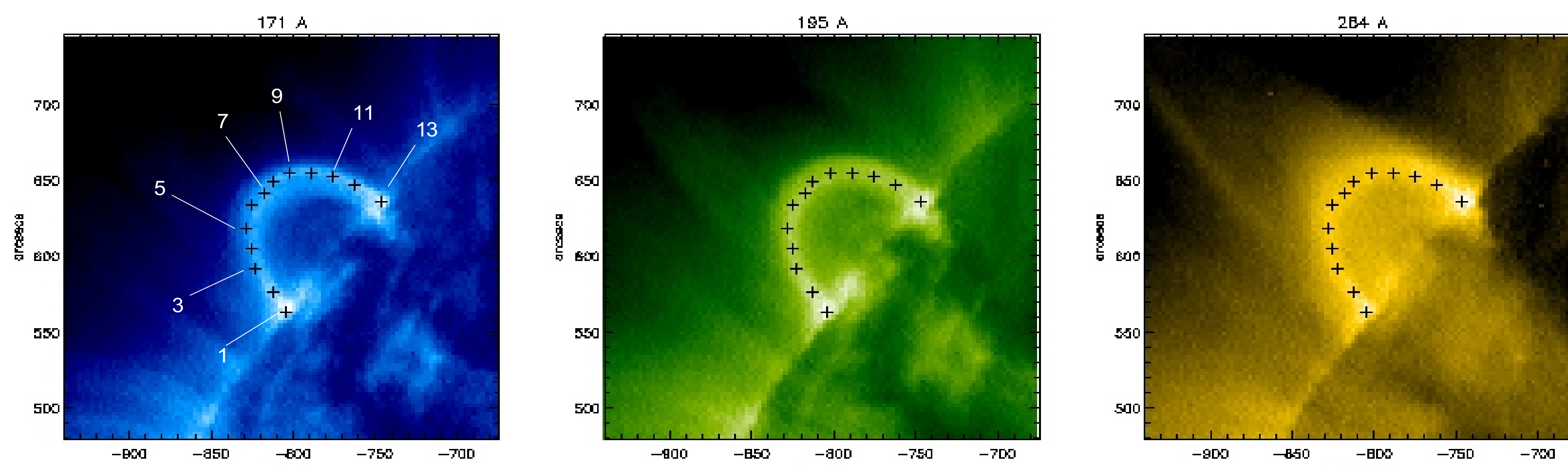


Figure 3: Diagram showing the loop structure taken by SOHO/EIT in 171A, 195A and 284A. The crosses marked on the three images indicate the points used for the temperature analysis profile.

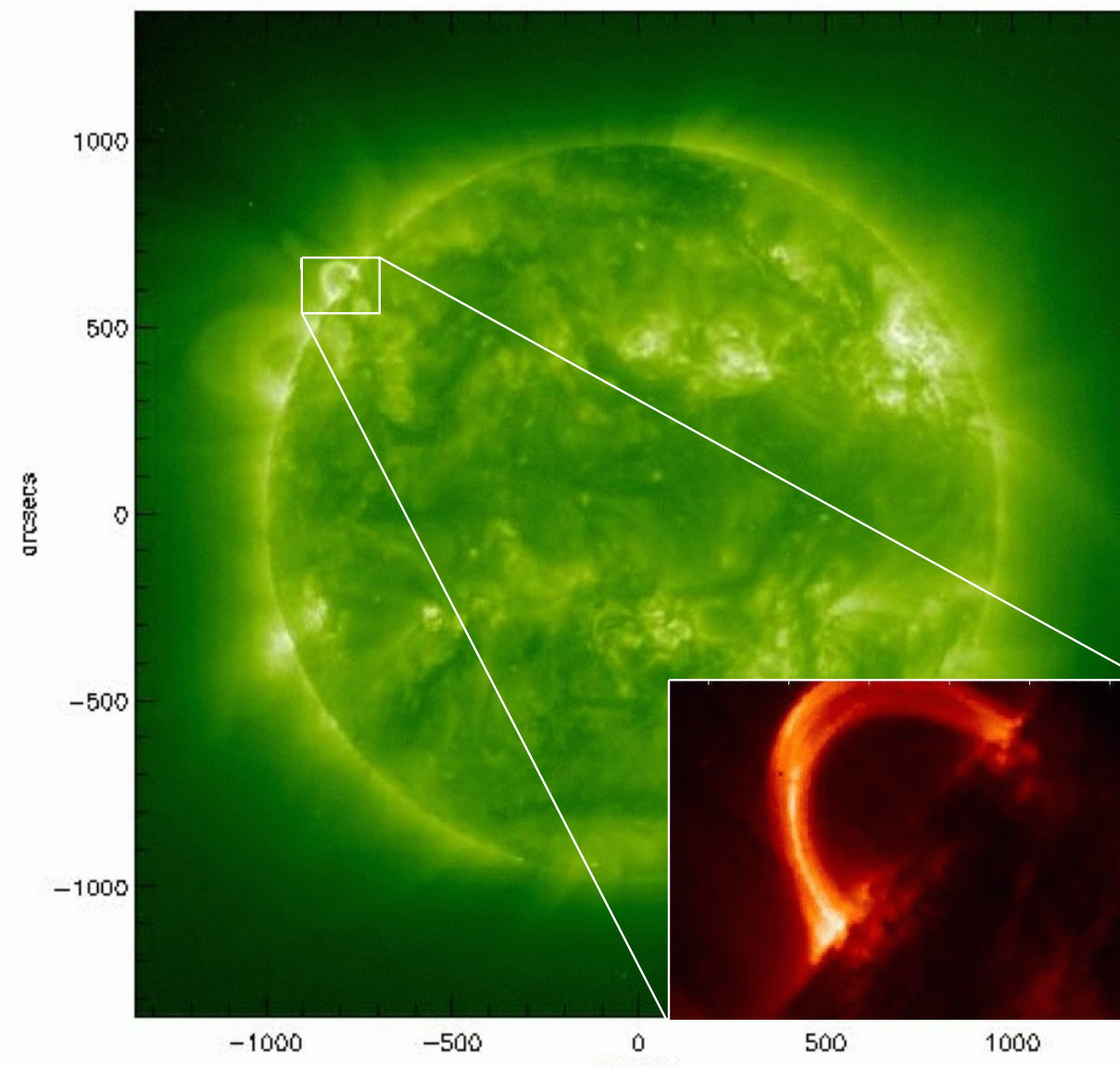


Figure 2: Location of the loop on the northeast limb. The whole sun image is a SOHO/EIT image at 195A and the image of the loop is a TRACE 171A image, both images were taken shortly after 06:00 on 1999 March 18.

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

Where I_{λ} is the instrument response function for a given λ (shown in Fig. 1 for SOHO/EIT).

If we take the ratio of these filters then, 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 curve for the unique determination of temperature. Therefore the principle is that we can now use a pair of observed C_1 and C_2 to try and determine the unique temperature profile along a plasma loop.

3. Observations

We will now investigate the above method using a set of SOHO/EIT data taken on 18 March 1999. Fig 2, a 195A image taken using SOHO/EIT, shows the exact location of the loop on the northeast limb. SOHO/EIT data (171, 195 and 284A) is available of this region from before a flare occurred and continues until the postflare loops are no longer visible, ~ 6 hours later. The EUV triplet used for this analysis was taken at around 07:00.

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 on 10 coronal loops taken with SOHO/EIT and also found that the effect of background subtraction did not affect the EIT temperature analysis.

It should be noted that CH's paper stated that this temperature method requires the simultaneity of images taken at different passbands. These SOHO/EIT images are taken successively but it takes a few minutes to get a full set of EUV images in the three passbands. However, the loops do not appear to change significantly during this time period of <10 mins.

This loop was chosen for two reasons; firstly it is seen to be very bright in all of the three passbands (171A, 195A and 284A), and secondly because of its fortuitous location on the north east limb of the Sun (shown in Fig2). Shown in Fig3 are the three different filter passband images displaying the loop structure, taken on 18 March 1999, at around 07.00 hrs, with a cadence of ~ 3 mins. The loops are marked with crosses which were the points chosen for the CH analysis. It can be seen that all the points chosen lie along the loop in all of the three passbands.

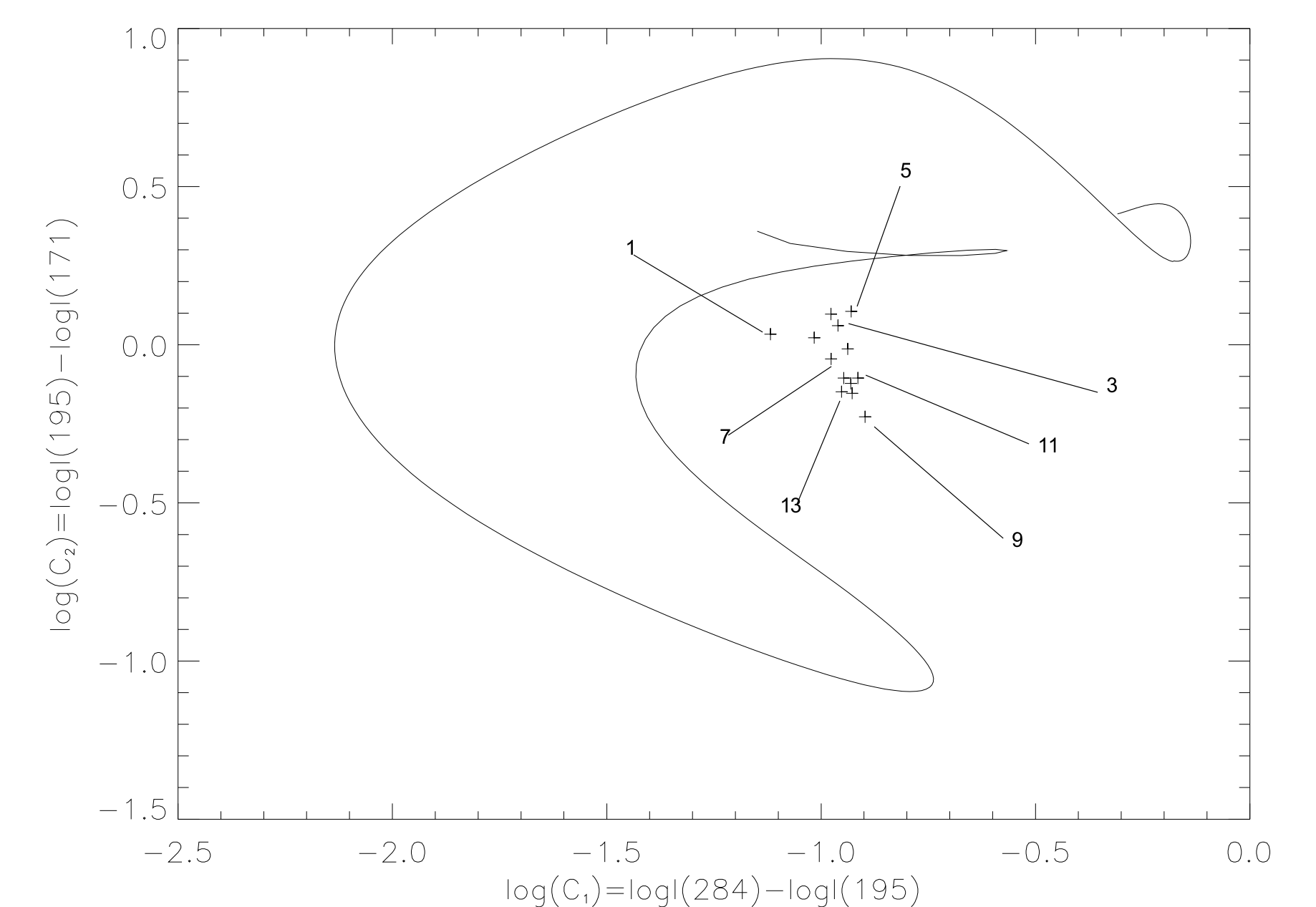


Figure 4: SOHO/EIT colour-colour diagram, the crosses depict where the calculated ratios from the data lie.

4. Results from the colour-colour diagram

Fig 4 displays the thermal profile of the loop plotted on the c-c diagram. The profile was calculated by the ratios of the intensities ($\log I(195) - \log I(171)$) against ($\log I(284) - \log I(195)$) of the points chosen along the loop in the three passband images. The points along the loop are also numbered on the diagram showing the change in positions.

The data points along the loop structure in the three bands appear to cluster below the cooler end of the c-c curve; they do not sit at all on the curve. Hence it is very difficult to associate a particular temperature with these loops.

There may be a number of reasons for this frustrating result. Firstly, the optically thin nature of the corona means that the target is being observed through a multi-thermal atmosphere. This would mean that when looking at a loop structure on the disc of the Sun, a sum of intensities from a number of different EUV emitting sources would be seen. However, this problem should have been reduced given our location on the limb. The effect on the c-c method of having two loops along your line of sight at very different temperatures is examined further in Paper III.

Secondly, we must pose the question whether we are resolving spatially the basic structural elements of coronal structures such as loops. The c-c method at this EIT resolution ($5''$ pixel size) may mean we are averaging our temperature analysis across a bundle of different temperature fibres.

Thirdly, and maybe most importantly in this postflare loop case, in using the c-c method, one is assuming that the plasma is in thermal equilibrium. However, we know from corresponding, high time resolution TRACE observations of this loop system, that the loops are rising and in continual motion (see Noglik, Walsh & Ireland 2004 in these proceedings).

5. Future Work & Future Missions

The need for simultaneous EUV images is vital given current instrumental cadence capabilities relative to the timescale of the evolving plasma. SOHO/EIT observes these three wavelengths every day but as mentioned previously with many minutes between passbands. TRACE does much better with the possibility of EUV images observed successively with tens of seconds in between. TRACE has not undertaken this 171-195-284 triplet very often but a recent campaign of Joint Observing Programme 83 (August 2004) has obtained several triplets which will be reported upon in the near future. The impact of flows and dynamic heating bursts on the c-c diagram will also be investigated. The sensitivity of the c-c method to spatial variations in the heat input to a loop target is already tackled in Paper II.

Considering the above method and its challenges in the light of future instrumentation, then although the problem of background subtraction/contamination will remain, improving the temporal resolution (SDO is planned to observe the three EUV wavelengths considered here at a 10sec cadence) along with pixel size (Orbiter should get down to 70km and hence be able to determine possible individual flux tubes) this c-c method could still be a very useful diagnostic tool.

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