SOHO/CDS OBSERVATIONS OF QUIESCENT ACTIVE REGION LOOPS

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ABSTRACT

The CDS spectral capabilities, combined with high-resolution TRACE imaging, provide a unique dataset which enable an investigation into the overall structure of active region loops and their temporal variations. The physical characteristics of quiescent 1 MK loops, the legs of which are best seen with CDS, are discussed and related to the underlying photospheric magnetic field. We show how various diagnostic techniques can provide different results in terms of the physical parameters (e.g., elemental abundances) and we present simultaneous TRACE multi-filter and CDS observations. The limitations of current and future instrumentation, in providing good observational datasets for testing coronal heating theories, is briefly summarised.

1. INTRODUCTION

Understanding the nature of coronal loops has long been an important topic in solar physics. Physically, even simple measurements of temperatures along a loop could be used to define the heating function. The launch of TRACE (in 1998), with its high spatial resolution (1 arc second) and sensitivity has prompted a large number of studies of active region loops. A long-standing debate on the characteristics of loops is still ongoing in the literature. The aim of this debate is to answer the following questions: are loops isothermal; are they composed of many strands; what are the profiles of densities and temperatures along loops; what are the elemental abundances; what is the relation with the underlying photospheric field?

2. SOME STUDIES COMBINING SOHO/CDS AND TRACE OBSERVATIONS

We review here a few key observational studies. This work was stimulated by the coronal loops workshop at MEDOC, IAS (Nov. 2002), where preliminary results were presented. Further results were published in Del Zanna and Mason (2003), Del Zanna (2003) and also made available on-line at: http://www.damtp.cam.ac.uk/user/astro/gd232/. A series of papers (e.g. Lenz et al. 1999, Aschwanden et al., 2000) focussed on TRACE coronal loops, and found that most of them were over-dense and had very flat temperature profiles, when compared to the predictions of simple hydrostatic models. Many papers ensued, discussing the reliability in using broadband and narrow-band imaging to infer densities and temperatures, and whether the observed loops are multi-thermal, multi-stranded or not. A comprehensive review of all the recent literature is beyond the scope of this paper.

Using some examples, where simultaneous multi-band imaging with TRACE and spectroscopy with SOHO/CDS has been obtained, we have demonstrated a few key points:

- in any active region, most of the emission is ‘diffuse’, i.e. unresolved even at the TRACE resolution. This emission has different characteristics to the ‘quiet Sun’ unresolved emission. It is hotter (1-3 MK) and denser.
- For both imaging or spectroscopic observations, this diffuse background along the line of sight represents a significant fraction of the loop emission, and must be taken into account.
- Results obtained with background subtraction are significantly different from those previously published, which neglected background subtraction.
- The projection effects, the limited spatial resolution and line-of-sight contamination of the background and foreground plasma make measurements of temperature and density profiles along loops very difficult.
- In many previously-published cases, we found a lack of cospatiality between loops observed in different bands, or sometimes even a total lack of visibility in one band, thus making any temperature determination unreliable. This lack of cospatiality was also found for the loop selected for the benchmark loop workshop, held in Mondello, Sicily, in Sept 2004.
- At the workshop meetings and in subsequent publications, we pointed out the limitations of the filter ratio method (multi-value, uncertainty in the ionisation equilibrium and in the atomic data) and the fact that the TRACE response functions needed to be updated.
- We also showed how Fe VIII emission can be impor-

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tant in the 195 Å band, at the foot-points of active region loops.

Despite the lack of an in-flight TRACE calibration, we found relatively good agreement between the TRACE count rates and those predicted from the calibrated CDS lines.

Only spectroscopy can provide reliable filling factors, temperatures densities, elemental abundances. However, spectroscopy must be supported by high-resolution imaging. The resolution of SOHO/CDS (6 arc seconds) is often not sufficient to study the details of the coronal emission from the loops observed by TRACE. However, CDS observations are excellent in determining the temperature structure and the characteristics of loop foot-points.

We believe that much can be learned from studying the characteristics and evolution of the quiescent active region loops, given the fact that they are normally stable structures that last for hours or days, and also have a simple geometry.

Figure 1. TRACE 171,195 Å images of an active region loop (no. 28 in Lenz et al. 1999 and no. 24 in Aschwanden et al., 2000). Below, the filter ratios with and without background subtraction are shown. Notice the large difference, and also the fact that in the 195 Å image there is hardly any loop emission on top of the background one, which makes any filter ratio result very unreliable.

Figure 2. The EM Loci curves of loop legs indicate an isothermal plasma, while the background is largely multi-thermal (see Del Zanna and Mason 2003 for details).

A simple way to assess the isothermality of a source is the emission measure loci approach. The intensity of an
emission line can be written

\[ I(\lambda_{ij}) = Ab(X) \int_T C(T, \lambda_{ij}, N_e) \, DEM(T) \, dT \]  (1)

The method consists in plotting the ratio \( I_{obs}/(Ab(X) \times C(T_i)) \) for each line as a function of temperature and considering the loci of these curves in order to constrain the shape of the emission measure distribution. In many cases, we have found that the quiescent loops are: cooler (\( T = 0.7-1 \) MK) than the ambient plasma; nearly isothermal at each point; are not isothermal along their length. We also found filling factors not far from unity, indicating that the observed loops are not likely to be composed of many strands.

In Del Zanna (2003) we turned our attention to the footpoint regions. We pointed out that imaging instruments such as SOHO/EIT and TRACE are almost blind at transition region temperatures (\( T = 0.1-0.8 \) MK), hence quiescent loop foot-points are not observed. We showed the importance of using SOHO/CDS spectra to trace the locations of the footpoints in the photosphere, which are rooted in unipolar regions. Most of the active regions studies based on the Skylab NRL S082A spectrometer turned out to be on the brightest, compact transition-region emission that is located at the foot-points of loops.

We have also shown that many previous estimates of elemental abundances, based on the assumption that a continuous distribution of emission measures is present, need to be revised. In particular this is true for the applications of the Widing and Feldman (1989) method to active region loops, which are nearly isothermal. As an example, the EM Loci method applied to the Skylab observation of Widing and Feldman (1993) indicates a First Ionization Potential bias (FIP) of 3.7, 4 times lower than the value (14) published by these authors.

3. SOHO JOP 146

A collaboration to plan further observations (SOHO JOP 146) was set up at the MEDOC coronal loops workshop. We designed special fast (7m) CDS observing sequences sparse rasters), and obtained a large (and unique) dataset spanning a few weeks of simultaneous TRACE multiband and CDS observations of quiescent loops. Preliminary results are discussed in Cirtain et al. (2006), where the evolution of one particular loop is studied.

We have also compared directly the CDS monochromatic images with the TRACE ones. The CDS instrument, despite its lower spatial resolution, is far superior to TRACE in resolving the temperature stratification in loops. Fig. 2 shows a sequence of false-colour CDS images obtained from Ne VII (blue -0.7 MK), Ca X (green - 1 MK), and Si XII (red - 2 MK). These types of images

![Figure 3](image-url)

Figure 3. Top: EM results from Widing and Feldman (1993), relative to an active region loop foot-point, calculated with a FIP bias of 14. Below: EM Loci curves obtained from the same line intensities but calculated with a FIP bias of only 3.7 (see Del Zanna, 2003 for details).

![Figure 4](image-url)

Figure 4. One of the active regions observed during SOHO JOP 146, and discussed in Cirtain et al. (2006).
clearly show that the TRACE bands only show part of the whole active region emission, and that cooler and hotter loops are located nearby and fill the entire volume. The orientation of the fan of loops in Fig. ?? was particularly favourable. It is therefore obvious to expect that often loops having different temperatures will appear superimposed in the line-of-sight, and will have a multi-thermal characteristic. This is exactly what is often found.

It is interesting to note that the Solar-B instruments will be able to provide accurate measurements of active region loops, clarify their nature and their relation with the underlying photospheric fields. In particular, the EIS spectrometer (see Del Zanna and Mason 2005 for its diagnostic possibilities) will allow detailed measurements at coronal temperatures. These measurements should be supplemented with other measurements, for example from CDS/NIS or GIS which will allow a study the loop foot-points, and can provide information on elemental abundances.

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REFERENCES


Figure 5. Sequence of false-colour CDS images of the legs of the system of loops studied in Curtain et al. (2006).

4. CONCLUSIONS

We have summarised some of the complexities of interpreting imaging or spectroscopic data of active region loops, and the limitations of current instrumentation. Spectroscopic observations covering lines emitted in a wide range of temperatures and supported by multi-wavelength high-resolution imaging are needed.