EUV SPECTRAL OBSERVATIONS OF ACTIVE REGION FLARES

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ABSTRACT

We present EUV spectral observations of C-M class flares performed with the Coronal Diagnostic Spectrometer (CDS) onboard SOHO during the Cambridge active region (AR) campaigns in 1999 and 2001. With the CDS spectral data, complemented by other space observations (mainly TRACE, YOHKOH SXT), we investigate the physical properties of ARs, and study the development of small-scale flares. We discuss the importance of spectral observations in relation to the correct interpretation of broad band images. In particular, we present co-spatial simultaneous YOHKOH SXT and CDS flare observations and discuss the validity of the temperatures derived from the SXT filter ratios. In addition, we present sample results that can only be obtained with spectral data, such as measurements of densities, elemental abundances and post-flare flows, associated with slow chromospheric evaporation. All these results are important observational constraints for flare modeling.

Key words: Solar corona; spectroscopic diagnostics..

1. INTRODUCTION

It is essential to compare spatial- and time-resolved spectral observations to flare model predictions, in order to understand the geometry of the events and to test the various theoretical models that have been put forward in the last decades.

The relationship between the structures as seen in the higher corona and those at lower heights, in the transition region and chromosphere, can be studied with CDS. The potential of the CDS instrument is fully exploited when plasma diagnostic techniques are applied to determine the plasma characteristics (temperatures, densities, velocities, chemical abundances) across an active region.

2. SPECTROSCOPIC DIAGNOSTICS

The intensity $I(\lambda_{ij})$, of an optically thin spectral line of wavelength λ_{ij} can be written (see, e.g., Mason and Monsignori Fossi, 1994):

$$I(\lambda_{ij}) = A_b(X) \int_T C(T, \lambda_{ij}, N_e)\ DEM(T)\ dT \quad (1)$$

where $DEM(T) = N_e N_H (dV/dT)$ is the differential emission measure, $C(T, \lambda_{ij}, N_e)$ is the *contribution function*, $A_b(X)$ is the element X abundance (assumed constant over the emitting volume V), N_e, N_H are the electron and hydrogen number densities.

The CHIANTI atomic database (Dere et al., 2001, Young et al., 2002) is used to calculate the line emissivities and to derive the plasma parameters. The DEM distribution is derived from a set of observed intensities $I_{\rm ob}$, once the element abundances $A_b(X)$ have been chosen and the contribution functions calculated assuming ionization equilibrium.

3. OBSERVATIONS AND RESULTS

3.1. Earlier SOHO/CDS observations

During the third Whole Sun Month Campaign (August 18 - September 14, 1999), the evolution of the Active Region NOAA 8668 was followed during its meridian passage and at the limb, with simultaneous observations with SOHO and other instruments, both satellite and ground-based. This active region presented a sigmoidal (S-shaped) structure as seen in the X-rays, had a filament associated with it, and was very active.

On August 21st, a small flare occurred (at $\simeq$ 17:40 UT). This was associated with a brightening of the sigmoidal structure and a later disappearance of the filament. Details can be found in Del Zanna et al. (2002) and Gibson et al. (2002).

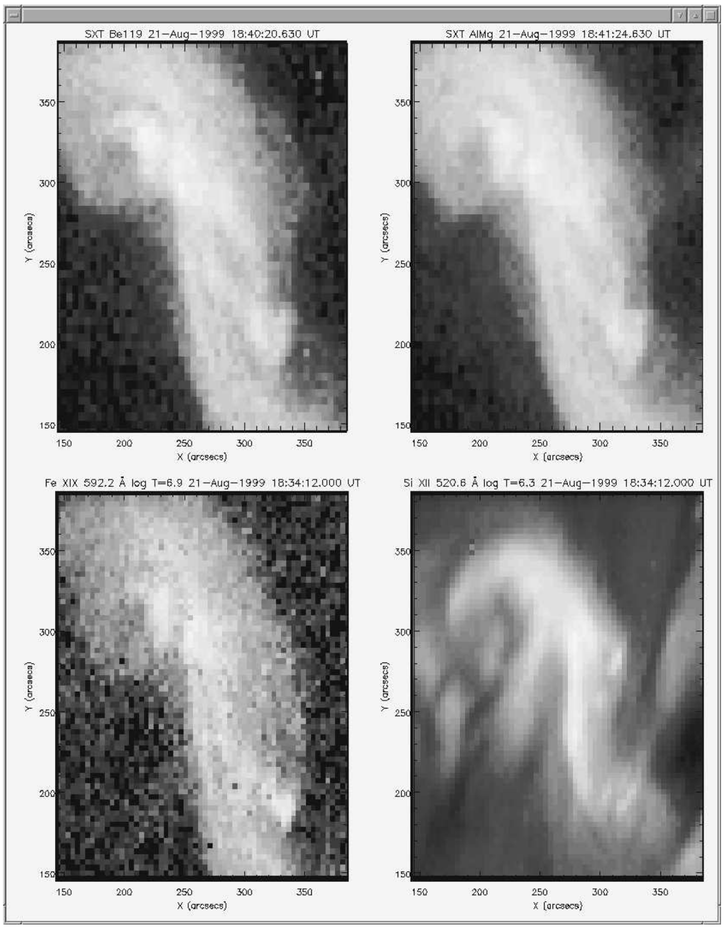

Figure 1. Images of the flare observed on 21-Aug-99, for two SXT bandpasses (top, Be 119 and AlMg filters) and a comparison with CDS images (bottom, Fe XIX and Si XII).

For the first time, spatially-resolved maps of blue-shifts in coronal lines during the decaying phase of a small flare were presented. These blue-shifts were located at the two ends of a small loop system and can be interpreted as indirect evidence of chromospheric evaporation. Fe XIX emission showed some interesting properties, including a pre-flare enhancement along the loop structure.

SXT vs. CDS

Two high-resolution SXT images were taken after the flare, in the AlMg and Be119 filters. The images were taken around 18:40 UT. One of the CDS rasters was taken at about the same time, with the central exposure taken at 18:34 UT (the slit was moved from West to East in about 25 minutes).

Note the similarity between the Fe XIX emission (log T=6.9) and the SXT images. At first, one might be tempted to say that all the SXT emission must have come from lines emitted at temperatures similar to FeXIX emission. In order to verify this, and the CDS-SXT cross-calibration, a central area (Solar X=250, Solar Y=300) in the CDS raster was selected, and averaged line intensities extracted. An emission measure was then calculated and synthetic X-ray spectra were constructed using CHIANTI v.3

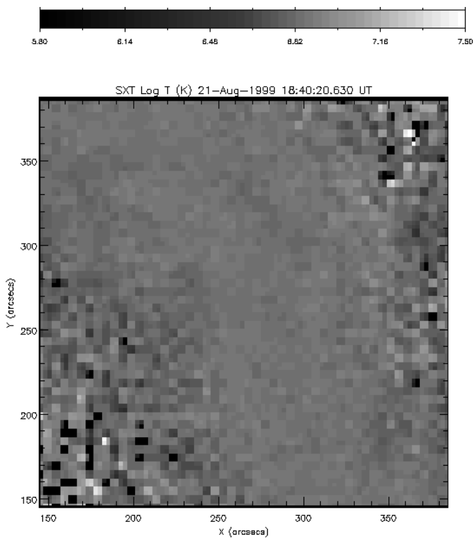

Figure 2. Isothermal temperature map derived from the two SXT filter images of Fig. 1 (21-Aug-99).

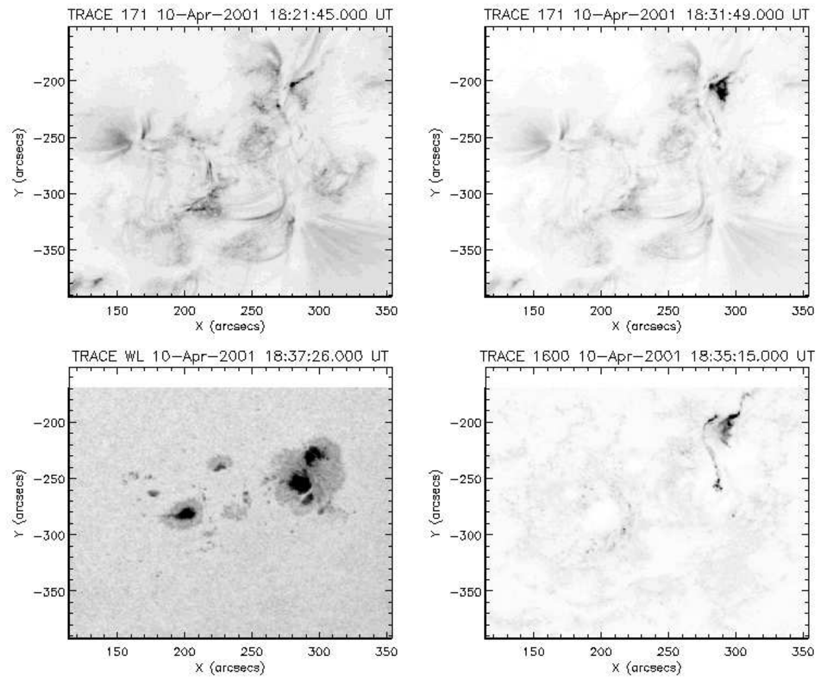

Figure 3. TRACE observations of April 10th 2001. Top: TRACE negative images in the 171 Å filter. Bottom: TRACE images in white light and in the 1600 Å filter (negative).

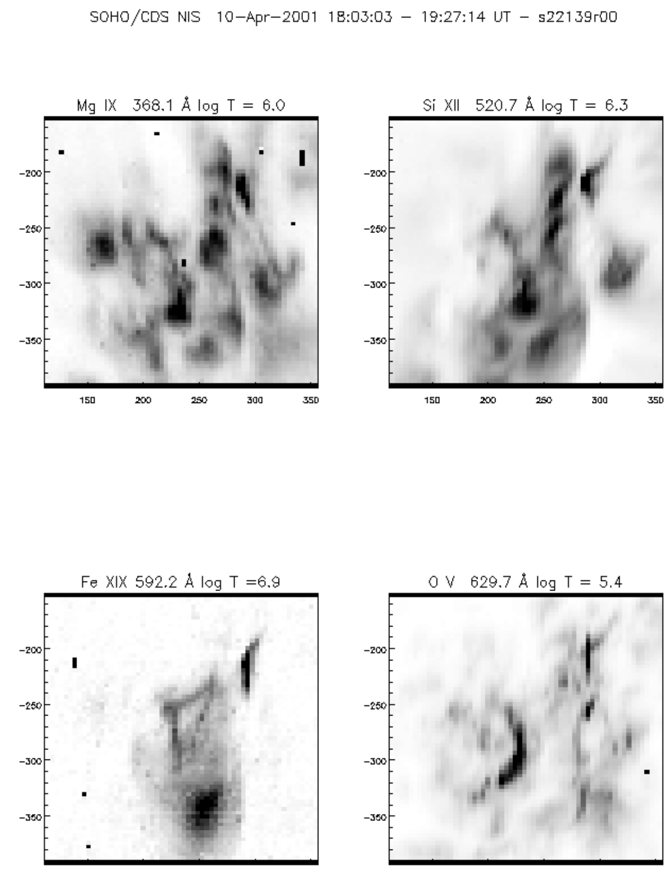

Figure 4. CDS monochromatic images of the C2.7 flare of April 10th 2001.

(Dere et al., 2001), and folded through the SXT effective areas. Indeed most of the lines which contribute significantly to the SXT bands are emitted at similar temperatures.

SXT filter ratio temperature maps were calculated with the standard procedures available within SolarSoft. They indicate an uniform distribution of temperatures for the loop. However, the plasma along the line of sight is obviously not isothermal, as a comparison of the CDS monochromatic images (eg Fe XIX and Si XII) clearly shows.

There has been a great deal of debate recently about the validity of SXT temperatures (see e.g. Schmelz et al., 1999). Indeed many factors affect the derived values. For example, instrument calibration, elemental abundances, ionization fractions, continuum emission and atomic data in general. A direct comparison of CDS calibrated spectra and of SXT filter images provides important constraints, since CDS observes spectral lines emitted at the same temperatures as those that contribute to the emission recorded by SXT.

3.2. The Cambridge AR flare campaign of SOHO/CDS observations

During 2001 and 2002, we pursued a long-term campaign aimed at following small active regions, that could be studied in detail with the CDS Normal Incidence Spectrometer (NIS). By rastering the CDS slit, monochromatic images (plus density and velocity maps) of the field of view ($4' \times 4'$) can be constructed.

Two types of NIS 'studies' were used. One study takes a long time (1hour 20 mins) but extracts many diagnostic lines. The other study is faster (20 mins) but only extracts a few lines, selected to cover a wide range of temperatures (He I 584 Å, log T =4.5; O IV 625.9 Å, log T = 5.3; O V 630 Å, log T = 5.4; Mg X 625 Å, log T = 6.0; Si XII 520.8 Å, log T = 6.3; Fe XIX 592.2 Å, log T = 6.9). The fast raster is normally repeated a few times, to allow a good temporal coverage of the flare evolution.

On 10 April, 2001, AR 9415 produced one of the biggest flares of this solar cycle, of class X2.3. The soft X-ray emission began to increase around 05:00 UT. The synoptic CDS observations recorded a high-velocity event close to the flare site (see Pike and Mason, 2002).

The Cambridge AR campaign was planned to observe AR 9415 that day, but observations only started at 14:08 UT, i.e. 9 hours after the flare. The activity, however, was still at high levels with continuing new small flares occurring. The overall cusp-like Fe XIX emission lasts for most of the sequence, that ended at 23:21 UT, as are post-flare TR loops. TR densities in the post-flare loop seen at the centre of the FOV were estimated directly from O IV ratios to be 1.5 x 10^{11} cm^{-3}.

During the CDS observations, two small GOES C2 flares occurred. The first flare was of class C2.7. The GOES X-ray event peaked at 18:37 UT (18:15–18:50 UT). Clear signatures are seen in the CDS diagnostic raster, taken in between the fast rasters. The location of the flare emission is at the footpoint of a system of loops, near the sunspot. The CDS observed a very compact Fe XIX emission, followed later on by strong blue-shifts (50-60 km/s) in coronal lines.

4. SUMMARY AND CONCLUSIONS

A very large dataset has been collected, and further analysis is ongoing. A large number of medium-class flares (GOES class C1 to M1) have been recorded, in some cases with full temporal coverage of the pre- and post-flare activity. The main features that appear to be common are:

- Active regions produce recurrent flares on all timescales. Some are associated with filament eruptions and/or CME's. Normally, the general plasma characteristics before and after the flare are very similar.

- The signatures of the GOES X-ray flux are usually traceable to corresponding emission in the hot (T=8 MK) Fe XIX CDS spectral line. This Fe XIX emission is initially spatially confined, but then tends to diffuse on timescales of minutes to hours. In many cases, Fe XIX precursor emission is seen before the flares.

- The Fe XIX emission is highly correlated with the YOHKOH SXT broadband images.

- The 1-5 MK AR emission does not appear to be dramatically affected by flares, if we except blue-shifts of tens of Km/s that are usually located at the base of the hot loops seen in Fe XIX. These blue-shifts sometimes last for quite long (hours), and are probably associated with slow chromospheric evaporation.

- Post-flare TR brightenings are ubiquitous and show strong red- or blue-shifted emission (in general large non-thermal velocities).

- Electron densities in the TR brightenings are quite high, in the range 1-6 x 10^{11} cm^{-3}.

The CDS instrument has a great potential for studying compact AR flares occurring on timescales of hours. It allows direct estimates of plasma temperatures, densities and velocities. However, the observed structures are very complex, and careful analysis of multi-wavelength observations, with the aid of extrapolations of the photospheric magnetic field is required.

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