2006ESASP.617E..83B

OFF-LIMB CORONAL LOOP DYNAMICS AS SEEN FROM CDS, EIT AND TRACE

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ABSTRACT

Observations have revealed the existence of weak transient disturbances in extended coronal loop systems. These propagating disturbances (PDs) originate from small scale brightenings at the footpoints of the loops and propagate upward along the loops. In all cases observed, the projected propagation speed is close to, but below the expected sound speed in the loops. This suggest that the PDs could be interpreted as slow mode MHD waves. Interpreting the oscillations in terms of different wave modes and/or plasma motions always depend on the line of sight as we observe on the limb or on the center of the disk. The JOP 165 campaign will address some of these questions. MDI, SPIRIT and TRACE photospheric and UV images have been acquired simultaneously with high temporal and spatial coverage along with spectroscopic data from CDS.Some of the off-limb active region dynamics and oscillations observed during this JOP campaign is presented here. Particularly, detection of plasma condensations and temporal variations in active region loops are discussed.

1. INTRODUCTION

Recent observations, have revealed that magnetically closed structures in the upper solar atmosphere, commonly referred to as coronal loops, exhibit intrinsically dynamic behavior. Even in quiescent, non-flaring conditions, loops show strong temporal variability of emission in UV spectral lines and substantial plasma flows. Spectroscopic investigations show that these intensity variations have different signatures in UV spectral lines formed at different temperatures and exhibit Doppler shifts of v = 20 - 100 km s^{-1} (Fredvik et al., 2002). In an overview of observations of the temporal variability of active region loops with the Coronal Diagnostic Spectrometer (CDS), Kjeldseth-Moe and Brekke (1998) report significant changes of coronal loops over a period of one hour, in particular those seen in emission lines in the temperature range between T = 1-5 10^5 K. This variability is accompanied by large Doppler shifts, typically around v = 50-100 km s^{-1}. Recent observations with the Extreme ultraviolet Imaging Telescope (EIT) with high temporal cadence (De Groof et al., 2004) reveals spatially localized brightenings in coronal loops, moving rapidly down towards the footpoints of the loops. The fact that coronal loops can undergo rapid evacuation has been known for decades: Levine and Withbroe (1977), e.g., reported Skylab spectroscopic observations, compatible with "dramatic evacuation" of active region loops triggered by rapid, radiation dominated cooling. A detailed study of "catastrophic cooling" and evacuation of quiescent coronal loops observed with the TRACE instrument was presented by Schrijver (2001). He analyzed image sequences taken in different spectral passbands and finds that loop evacuation occurs frequently after plasma in the upper parts of the loops has cooled to transition region or lower temperatures. The cooling process is often accompanied by emission in Ly-α and C IV (154.8 nm), developing initially near the loop top. Thereafter, cool plasma is observed to slide down on both sides of the loop, forming clumps which move with velocities of up to 100 km s^{-1}. The downward acceleration of these plasma clumps as inferred from the observations is significantly less than the gravitational acceleration on the solar surface. According to the observations of Schrijver (2001), this process of dramatic cooling and evacuation is a rather common one. Further observational evidence of "blobs" of plasma falling down towards the solar surface along magnetic field lines is presented by De Groof et al. (2004), based on high cadence time series of simultaneous EIT (30.4 nm) and Big Bear data. In this short presentation we will report on the detection of plasma condensation as seen from CDS on SoHO.

2. OBSERVATIONS

In the JOP165 campaign we used several instruments, namely, CDS, MDI, EIT (Shutterless), TRACE and SPIRIT/CORONAS-F. For details please refer to the web-page: http://perswww.kuleuven.ac.be/∼u0005791/werk/EITshutt/jop.html. In this short presentation we used data from TRACE, in addition to data from

Proc. SOHO 17 – 10 Years of SOHO and Beyond, Giardini Naxos, Sicily, Italy
7 – 12 May 2006 (ESA SP-617, July 2006)

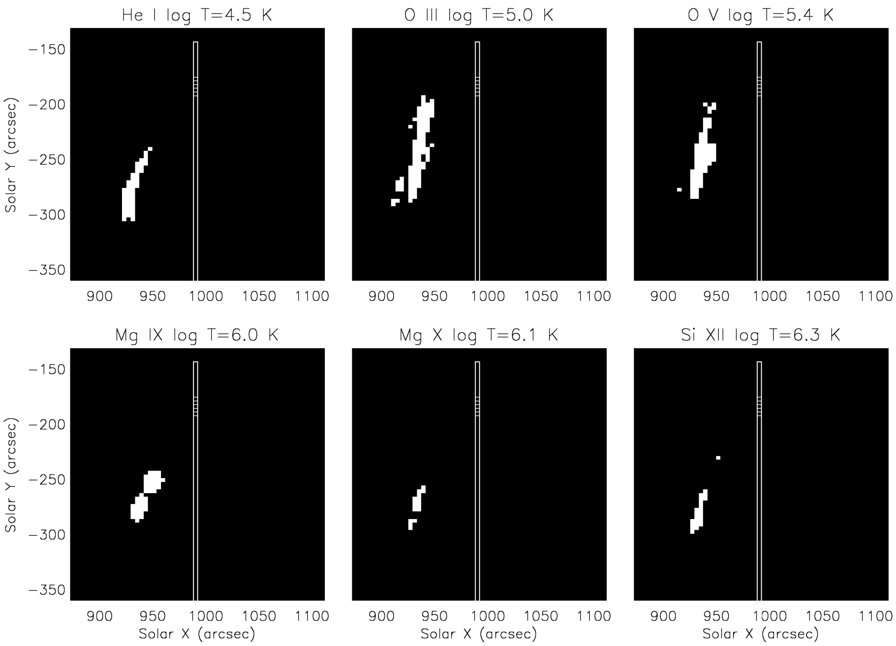

Figure 1. Raster image (from dataset s27153r00). The vertical lines show the location of the CDS slit, corresponding to the temporal series dataset s27152r01 and the white boxes mark the location of pixels 55-59. The raster image was obtained at a start time of 11:50:04, approx. 50 minutes after the end of the temporal sequence

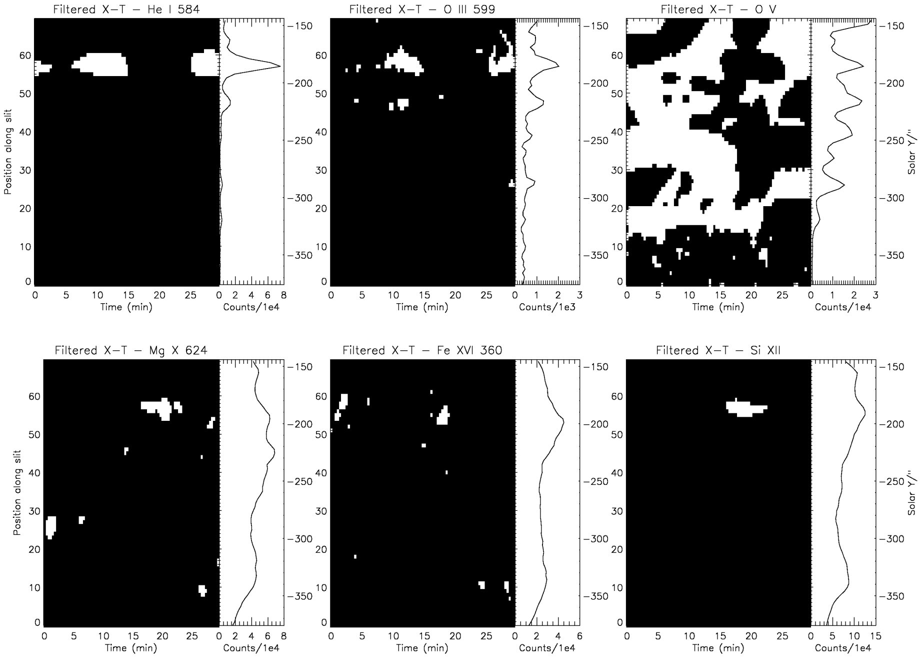

Figure 2. Space-time behaviour of the intensity in the different temperature lines. The right panels show the counts summed over all time against the slit locations.

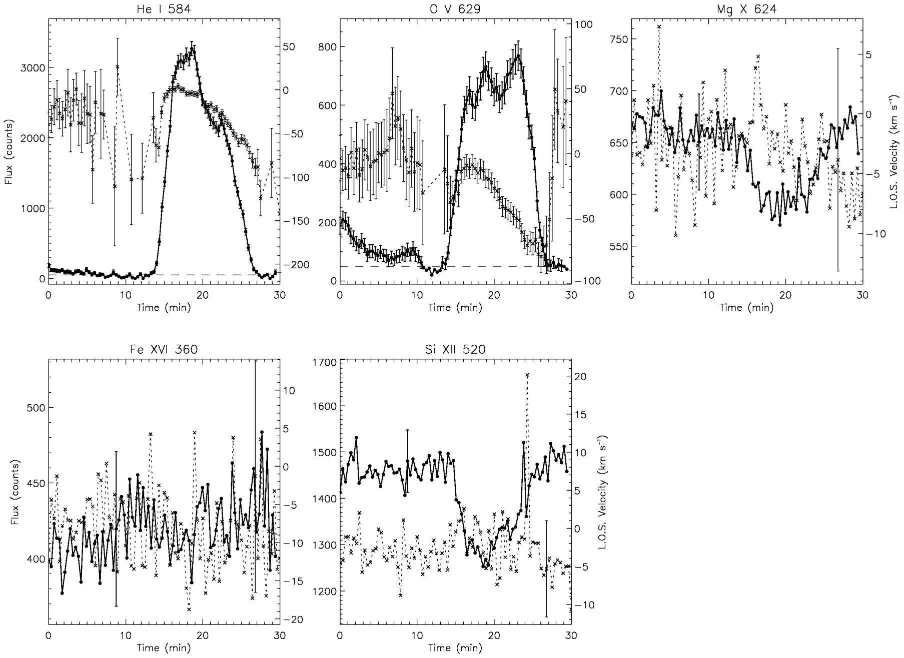

Figure 3. Variation of intensity (bold lines) and velocity (grey lines) with time as recorded by different temperature lines as marked (corresponding to pixel 57 of s17521r01 dataset).

the normal incidence spectrometer (NIS), which is one of the components of the Coronal Diagnostic Spectrometer (CDS) on board the Solar and Heliospheric Observatory (SOHO), (Harrison, 1995). The temporal series OS_AR85 sequence was run in active regions at the limb.The dataset which will be studied here, s27152r01 was obtained on the 21st March 2003 between 10:32–11:01 UTC. Data were obtained for 6 transition region and coronal lines; He I 584.33 ($\approx 3\times 10^4$ K), O III 599.59 Å ($\approx 1\times 10^5$ K), O V 629.73 Å ($\approx 2.5\times 10^5$ K) and the coronal lines of Mg X 624.94 Å ($\approx 1.25\times 10^6$ K), Si XII 520.67 Å ($\approx 2\times 10^6$ K) and Fe XVI 360.76 Å ($\approx 2.5\times 10^6$ K). The data were calibrated using the most up-to-date standard calibration routines in SolarSoft[1], with the offset between NIS1 and NIS2 corrected using the routine `nis_rotate`. Binning by 2 along the 143 pixel slit on-board SOHO resulted in 70 usable pixels of size 4 arcsec × 3.36 arcsec in Y. As explained in CDS Software Note No. 53 [2], NIS/CDS line profiles were broadened after SoHO's recovery in October 1998. Therefore, each spectral line was fitted by a broadened Gaussian (BGauss) function, and the line fluxes computed accordingly. The errors in the fluxes were computed based on the equations in CDS Software Note No. 49. All line-of-sight (LOS) velocities in this work were measured relative to an 'averaged' fitted line, obtained by summing together all the individual lines at each pixel position along the slit (a total of 70) and at each time frame (a total of 85). The measured wavelength position of this 'averaged' line is then taken to be the reference wavelength, and all velocities are measured relative to it. In this work we, therefore, make use of relative velocity values.

3. RESULTS

In Fig. 1 we show the raster images (from dataset s27153r00) in different temperature lines as marked. The vertical lines show the location of the CDS slit, corresponding to the temporal series s27152r01 and the white boxes marks the location of the pixels 55-59, the pixels of interest along the CDS slit. Note that the raster image was obtained at a start time of 11:50:04, approx. 50 minutes after the end time of the 27152r01 dataset. So, the rasters are not very close in time to the time series, which show short-lived events (which will be discussed later). However, note that in the raster images the slit (and pixels 55-59) passes through a system of off-limb loop like system only seen in the lower temperature He I 584.33 ($\approx 3\times 10^4$ K), O III 599.59 Å ($\approx 1\times 10^5$ K), O V 629.73 Å ($\approx 2.5\times 10^5$ K) lines.

In Fig. 2 we show the space-time behaviour of the intensity along the slit as recorded in the different temperature lines. To bring out the details of the

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[1] http://www.lmsal.com/solarsoft/

[2] http://solar.bnsc.rl.ac.uk/

original intensity map we filtered out the bright components in the image and plotted in reverse color, that is, with, black meaning brighter. In this contrast enhanced image (Fig. 2), the solar north-south (SOLAR_Y) direction is on the vertical axis, the horizontal axis is time. The total number of counts in a pixel (summed counts) during the observation is shown in the right columns of Fig. 2. Note the strong brightenings seen for part of the sequence corresponding to pixels 55-59. In Fig. 3 we plot the variation of intensity (bold lines) and velocity (grey lines with error bars) with time corresponding to pixel 57, as recorded by different temperature lines. Large enhancements in intensity for He I and O V is recorded along with strong blue-shifts up to 100 km s^{-1}, whereas for coronal lines of Mg X 624.94 Å ($\approx 1.25 \times 10^6$ K) and Si XII 520.67 Å ($\approx 2 \times 10^6$ K) we see a drop in intensity, without significant velocity-shifts. Note that from Fig. 2 it is clear that the black patches (intensity enhancements) in the top panels (i.e. lower temperature lines) correspond to white patches (evacuation) in the lower panels (i.e. coronal lines). To investigate what may be occurring, we also analysed the TRACE data. This was only in the 171 Å filter at around 1 million K, i.e., at the same temperature as the Mg IX line in the rasters. From the TRACE movie, it can be seen that at the beginning of the sequence there is a loop draining at roughly X=940, Y=–250. However, at the time of the event (~ 10:48) nothing much seems to be occurring. The location of the CDS slit in these TRACE images/movies can be seen from the TRACE plot, where again the selected pixels 55-59 are highlighted as white boxes. The location of the CDS slit was obtained by cross-correlating the CDS raster image of Mg IX with a similar size TRACE 171 image, covering the same field of view (TRACE results are not shown here because of lack of space).

4. CONCLUSIONS

Simultaneous observations with CDS and TRACE have been used to investigate plasma condensation processes in active region loops observed at the solar limb. Sudden intensity enhancements at transition region temperatures and a decrease in coronal temperatures within the coronal loops has been attributed to a rapid evacuation of plasma and here we show evidence of plasma condensation through a spectroscopic diagnostics. We realised that at coronal temperatures the intensity changes are too small (see Fig. 3) to be detected from the TRACE intensity movies or difference movies, whereas the CDS temporal sequence allows us to detect simultaneously the behaviour at different temperature lines and for the first time (to our knowledge) we report here such detection through a time series analysis. For active region loops dynamics, CDS raster sequences have only been used in earlier studies (Fredvik et al. (2002);Kjeldseth-Moe and Brekke (1998)). These intensity enhancements are probably the result of plasma condensation: hot coronal plasma is cooled to transition region or even chromospheric temperatures and slide down the loop legs at speeds up to 100 km/s. This process has also been known in the literature as *coronal rain*. We should also point out here that we looked for the GOES X-ray data and also LASCO data to find any possible link with flares or CMEs, but within this time no major flares and/or CMEs were detected. This leads to a deeper question, what causes these plasma condensations? Recently Müller et al. (2005) have presented a comparison of observed intensity enhancements from an EIT shutterless campaign with non-equilibrium ionization simulations of coronal loops in order to reveal the physical processes governing fast flows and localized brightenings. They show that catastrophic cooling around the loop apex as a consequence of footpoint-concentrated heating offers a simple explanation for these observations.

ACKNOWLEDGEMENTS

CDS is part of SOHO, the Solar and Heliospheric Observatory, which is a project of international cooperation between ESA and NASA. DB wishes to thank the organisers for local support. EOS is supported by PPARC grant number PP/D001129/1. We wish to thank the Royal Society and the British Council for funding visits between Armagh Observatory and the Indian Institute of Astrophysics. This work was supported in part by a PRTLI research grant for Grid-enabled Computational Physics of Natural Phenomena (Cosmogrid).

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