INCONSTANCY OF THE TRANSITION REGION - VARIABLE AND DYNAMIC ACTIVE REGION LOOPS

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ABSTRACT

Loops at transition region temperatures in active regions appear extremely time variable and dynamic, a result with profound implications for our understanding and modeling of the upper solar atmosphere. The time variability is illustrated in time series of spectral raster images taken with the Coronal Diagnostic Spectrometer (CDS) in selected EUV lines ranging in temperature from the chromosphere (He I at 584 Å) to the corona (Fe XVI at 360 Å). The variability is particularly pronounced at transition region and low coronal temperatures, i.e. below 1.5 MK, while the hot corona is much less variable. Coupled with the time variability is a highly dynamical behavior, with observed Doppler shifts corresponding to line-of-sight velocities of ±50 km/s or more for lines formed below 0.5 MK. We also note that loops at coronal and transition region temperatures to a large extent appear isothermal along their length and that loops at different temperatures often are not co-located. The results and their implications are briefly summarized and discussed.

Key words: Solar corona; time variations.

1. INTRODUCTION

This paper reports on studies of active region loops observed with the Coronal Diagnostic Spectrometer (CDS) on SOHO. We emphasize three important results for cool loops, i.e. loops with temperatures below 1.5 MK:

1. Loops at different temperatures are often not co-located or clearly connected.
2. Spectral lines emitting at temperatures below 0.5 MK may be shifted corresponding to line-of-sight velocities of 50-200 km s\(^{-1}\).
3. Strong time variability is a common feature for loops at transition region temperatures, i.e. T< 1-1.5MK. Transition region loops change considerably in 15 minutes and may occasionally turn on or off over periods as short as ~20 minutes. Coronal loops change much more slowly.

All the loops have been observed at the solar limb, where loops in the transition region, e.g. in the O V line at 529 Å, are most easily distinguished. Against the disk the O V loops are difficult to see owing to their low contrast.

2. OBSERVATIONS

The observations are made with the Coronal Diagnostic Spectrometer (CDS; Harrison et al. 1995) on board the Solar and Heliospheric Observatory (SOHO; Domingo et al. 1995). We have used the normal incidence spectrometer, NIS, in this investigation. NIS gives stigmatic spectra in two wavelength bands 310 - 380 Å and 520 - 630 Å. This allows simultaneous observations of lines formed over temperatures from the chromosphere to the hot corona at 3 MK. In this investigation we have used a 4 arc second wide slit, giving an angular resolution of 4x4 arc seconds. This makes it possible to distinguish individual loops above active regions if the density of loops is not too high, causing them to overlap. The spectral resolution amounts to values of 3/6Å between 3635 and 4500. With this resolution Doppler shifts are measured with an accuracy corresponding to ±10 km s\(^{-1}\) for lines with a good signal to noise ratio. There is no absolute wavelength reference and wavelength shifts are measured from an average value of the line position in the whole or a part of the raster image. We refer to Harrison et al. (1995) for a detailed description of the properties of the CDS instrument.

Images are made by rastering, i.e. by moving the slit parallel to its long axis in steps of 4 arc seconds, thus covering the full raster area. The spectrograms retain their full spectral information, and intensities, line shifts, and line widths may be determined at any point. To detect rapid time variations, we have used several different observing sequences for times series of rasters with cadence as high as possible. Since it takes time to build up a raster image, typically 10-17 minutes, it is not a snapshot of the full loop system as it appears at a given time. However, all points at one slit position are observed at the same time. Thus, we have simultaneous observations of corresponding regions in the north and south leg of the loops.

3. RESULTS

We will address the appearance of the loops and the question of co-location of loops at different temperatures. The observed Doppler shifts and their implications have been described by Brekke et al. (1997), and is only briefly mentioned here. Emphasis is on the time variability of cool loops in active regions and the impression they give of an inconsistent transition region.

3.1. Location and Structure of Cool Loops

Figure 1 shows CDS rasters of an active region on the East limb taken on 19 June 1996. The lines from He I, O IV, Ne VI originate in the low transition region, with formation temperatures of 10 000 K, 150 000 K, and 425 000 K, respectively. The Si VIII, Mg IX, Mg X, and Fe XII lines are formed at 875 000 K, 960 000 K, 1.1 MK and 1.4 MK, while the hot lines from Si XII, Fe XIV and Fe XVI show structures at temperatures of 1.9 MK and 2.7 MK. Temperature values are equilibrium ionization temperatures compiled and calculated by Monsignori-Fossi (1995, private communication). Original sources for these calculations include data from Arnaud & Raymond (1992) for iron and from Landini & Monignori-Fossi (1991) for other ions. Structural differences are clear, particularly between the cool loops, $T < 500 000$ K, the medium hot structures, $T \sim 1$ MK, and the hot coronal loops, $T > 1.5$ MK. However, detailed studies show differences also between loops within these sub-categories.

These raster images supplied with similar results from other studies show that:

- loops emit at the same temperature along their full length as if they are isothermal structures in this direction,
- loops observed in lines at different temperature are not necessarily co-located, and
- hot coronal loops, i.e. $T > 1.5$ MK, are generally different from loops in the transition region, $T \leq 500 000$ K, with emission extending to altitudes well above the top of the cooler loops.

3.2. Line Shifts and Velocities

The first observation of large Doppler shifts in active region cool loops was reported by Brekke et al. (1997). They measured Doppler shifts in the O V 629 A line corresponding to line-of-sight velocities of $\pm 50$ km s$^{-1}$. The high shifts were present in parts of loops, but not along their full length, and different parts of the loop system showed oppositely directed shifts. If the measured shifts were caused by axial flows, the true velocities would be considerably higher than the measured values since the line-of-sight was not along the loop axis, but more perpendicular to it. Brekke et al. (1997) therefore considered interpretations involving magneto-sonic waves.
Later observations have confirmed that high Doppler shifts are common in active region loops. Strong shifts are present in parts of loops for temperatures up to 0.5 MK (i.e. emission in lines from Ne VI). Regions with both red and blue shifts are seen. Typical values correspond to velocities of ±50-100 km s⁻¹ but much higher values of the shifts have been found. The present speed record is 200 km s⁻¹. At temperatures T>1 MK, i.e. in Mg IX 368 A or Fe XVI 360 A, no shifts are seen. The high Doppler shifts thus seem to be restricted to the chromosphere and low transition region.

3.3. Time Variability of Cool Loops

Cool loops always appear time variable whenever they occur in active regions. Figure 2 gives an example from the series of rasters observed with CDS on 14 September 1997. The images run with time from the start in the upper left corner and to the right in the horizontal rows. Time between images is 17 minutes. We include only rasters in O V 629 Å, emitting at 240 000 K, and the field of view is 240×240 arc seconds. Loops occur over a range of sizes, with altitudes above the limb of ~25 Mm to ~100 Mm.

Several types of change take place. We may note how loops suddenly come into existence or disappear between frames, i.e. in 10-20 minutes. On the other hand they may also show a relative stability. We may follow one loop in the series through 7 images, i.e. for more than 2 hours. During this period it goes through several changes in intensity, but stays in the same place. It may, however, deform slightly.

Other structures in the system of loops are coming and going to the south of this strong and comparatively stable loop. Here we see examples of loops appearing and disappearing from frame to frame. Other observations frequently contain examples of loops that appear to change slightly, but significantly, in altitude between frames. It is difficult to decide if we really see the same structure in the sense that it is the same magnetic tube we are seeing, or if the loop has disappeared and been replaced by another. The same question may be raised regarding the change in shape of the "stable" loop in Figure 2, described above. From what we have seen so far we would estimate that typical loop life times range from less than 20 minutes to several hours. It should be noted that the level of activity is changing with time and place. In some locations we find loops that are stable for hours, while loops in another location, even near by, undergo rapid changes. It seems to be characteristic that loops, even those that are quiescent, are turned on and off suddenly, i.e. in less than 10-15 minutes. The intensity and intensity distribution along loops will change equally rapidly. Finally, Figure 2 illustrates how an entire system of active region cool loops is strongly altered over a period of a few hours.

The strongest variability occur in the low transition region, i.e. for T<0.5 MK, but raster images in lines formed at higher temperatures, e.g. Mg IX 368 A emitted from gas at 1 MK, show similar variations with time. The variability is not as pronounced at these temperatures. The hot coronal emission in the Fe XVI line at 360 A, formed at 2.7 MK, may also show some changes, but it is often difficult to distinguish individual features, probably because we commonly see through a complex system of optically thin loops. The impression is that the hot corona is much
more stable than the cool loops with $T \leq 1.5$ MK.

4. DISCUSSION

Loops are the dominant structures above active regions, as was clear already from observations made on Skylab, 1973-74, e.g. Tousey et al. (1973). The appearance of loops as isothermal structures along their full length was remarked by Foukal (1976), who used observations with SO55 on Skylab. He also found that loops at different temperatures were co-spatial and his result has been supported by other investigations (i.e. Cheng et al. 1980, Sheeley 1980, and Dere 1982). On the other hand, Cheng (1980) found that some loops in Ne VII and Mg IX differed in position by more than their observed loop diameters.

Our investigation clearly confirm that cool loops, $T \leq 1.5$ MK, emit along their full length, having an isothermal appearance. On the question of whether cool loops at different temperatures are co-located or not, the picture is more complex. The cool loops all lie in the same general region, and often appear co-located as far as we can see. However, there are numerous counter examples of loops at different temperatures that are not in exactly the same place at the same time.

Large Doppler shifts, or velocities, were first reported by Brekke et al. (1997), as mentioned above. Other investigators have found much smaller line-of-sight velocities of $\pm 5$ to $\pm 40$ km s$^{-1}$; see e.g. Athay et al. (1983), or Kopp et al. (1985). Very high velocities have been indirectly inferred by Habbal et al. (1985) to explain spatial changes in observed transition region surges.

Appreciable changes with time of active region cool loops over a few hours were found by Cheng et al. (1980), and Athay et al. (1983). A more rapid change in individual loops were reported by Sheeley (1980) and by Levine & Withbroe (1977). Sheeley's loop system, observed on the disk, showed changes in individual cool loops in an active region over as little as 34 minutes. He gave a lifetime for the Ne VII 465 A loops ($T \approx 0.5$ MK) of 30 minutes, while more diffuse structures in Mg IX 368 A ($T \approx 1$ MK) lived for typically 1 hour. Habbal et al. (1985) gave examples of changes over 10 minutes in surges. Activity was less pronounced at higher temperatures.

The rapid and dramatic changes in the loop systems that we observe at the limb, with individual loops being turned on and off or considerably shifted in position in a few minutes, amount to a novel impression of the physical conditions in the solar atmosphere. While rapid variations of loop systems were seen already in Skylab data by Sheeley (1980), our observations considerably highlight and amplify his results.

5. CONCLUSIONS AND PROVOCATIONS

The transition region is not a layer in any sense. There are no temperature stratifications along the observed structures, with temperatures increasing from cool foot-points to a hot apex. The structures are, however, extremely time variable, and in a dynamic state caused either by gas flows or by high amplitude waves, most likely propagating magneto-sonic disturbances; see Brekke et al. (1997) for a discussion. The time variable emission over a full range in temperatures in a volume filled with transient loops, also points to a connection between regions of various temperatures. We shall probably be able to understand more of the active region corona if we consider loops as consisting of a bundle of much thinner cords or strands (see e.g. Dere et al. 1987, Dere et al. 1988). These may have different temperatures and temperature distributions along their length, be in different phases of their development, and develop at different rates. A loop consisting of many strands will be more likely to show the observed properties, such as quasi-isothermal appearance or co-location over a range in temperatures. The time variability will not be explained this way, but may have external causes.

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