The redshifted footpoints of coronal loops

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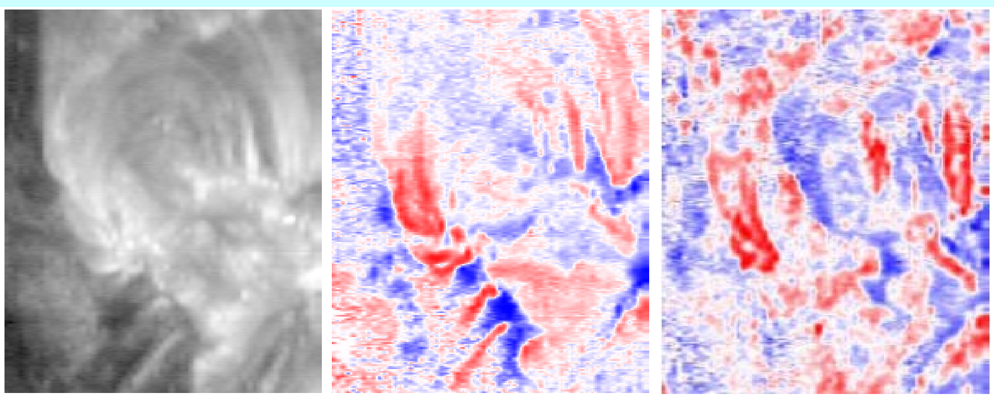
Abstract

The physics of coronal loops holds the key to understanding coronal heating and the flow of mass and energy in the region. However, the energy source, structure maintenance and mass balance in coronal loops are not yet fully understood. Observations of blue- and redshifted emissions have been widely used in the construction of viable loop models. But observations and interpretations of line shifts have been widely debated. Here we present detailed SUMER observations, which clearly show a steady downflow in both footpoints of coronal loops observed at transition region and lower corona temperatures. We also present their interpretations and implications in the light of a viable coronal loop model.

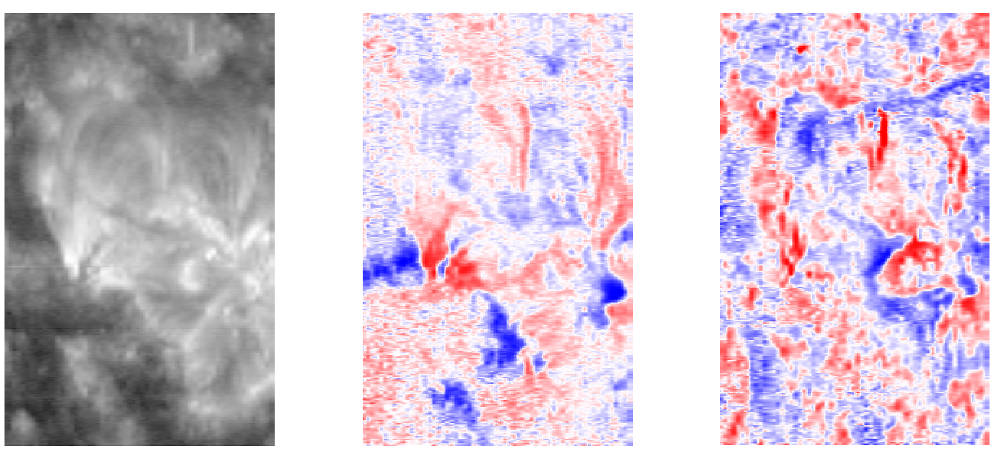
Introduction

The redshift observed in emission seems to be an inherent property of the stellar transition region (e.g., Kjeldseth-Moe 2003), indicating the presence of downflowing plasma. A mass flux at ≈10^5 K – sufficient to empty the corona in a few minutes - must rule out the possibility of a true net downflow. Consequently, the apparent downflow may likely result from a spatial and/or temporal averaging of the plasma motion. The inference of temperature, density and velocity as a function of time and space is indispensable to develop any realistic model. At the same time, accurate deduced values are still missing. For instance, one may expect upflow to appear at temperatures different from transition region. However, there seems to be a compelling physical reason to believe that the motion of material becomes more visible while it is descending and it becomes less visible while ascending, at least with the observations available. In order to understand the physics of the Sun's atmosphere from the redshifted and blueshifted emissions, a lot more effort is called for not only from high-resolution spatial and temporal observations but also theoretical modeling. A vast literature exists on the topic from the Skylab era to SOHO and TRACE (e.g., Doschek et al. 1976, Antiochos 1984, McClymont 1989, Hansteen 1993, Brekke 1993, Antiochos 1994, Müller et al. 2004, McIntosh & Poland 2004, and references therein).

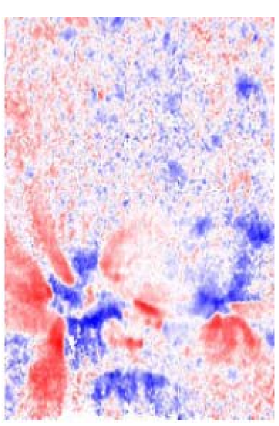
Downflows in AR loops and sunspot plumes



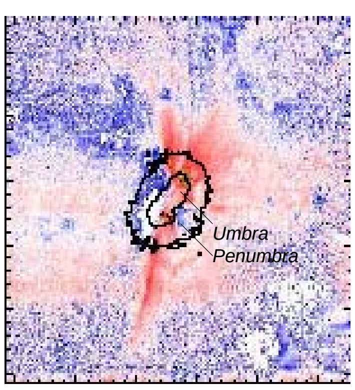
Downflows (1). This example of redshifted loop legs shows Ne VIII emission both as radiance (left) and as Doppler map (center). It is also seen in the emission of O IV (right). The Doppler map reveals strong redshift of 20-30 km/s at **both** loop legs. These observations suggest a quasi-continuous downflow at all transition region temperatures.



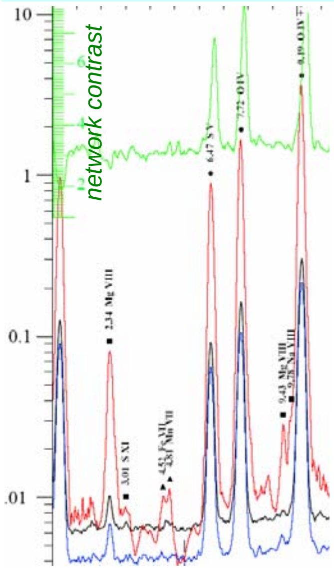
Downflows (2). Another example similar to (1). The redshift in both legs seems to be a common feature of AR loops.



Downflows (3). Sunspot plumes can live for days and have always systematic downflows of up to 25 km/s. Often elongated red-shifted features terminate in the plume area. In both cases shown here (left on 18 Mar 1996, right on 16 Nov 2006) the sunspot was observed in Ne VIII. We infer that sunspot plumes are nothing else than the common footpoint of several AR loops, and that the processes are similar to those in normal AR loops.



Downflows in the quiet Sun network



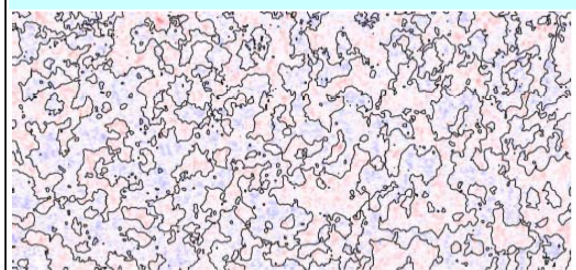
Downflows (4). Cutout of the SUMER spectral atlas (Curdt et al 2001) showing radiances of: average QS (black), sunspot (red), CH (blue). The network contrast (ratio bright-network / cell-interior in green) increases by a factor of >2 in TR lines and the peaks are clearly red-shifted. There are two immedeate implications, in the network:

- TR emission is enhanced
- TR emission is redshifted,

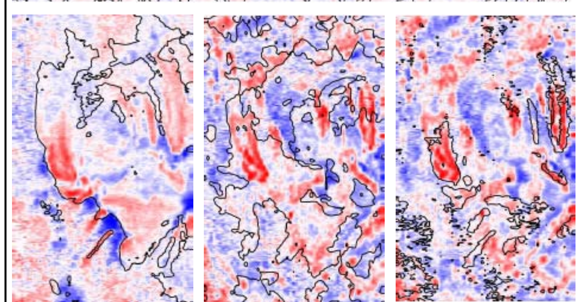
which are both well-known observational facts.

As suggested by Feldman (2001) for AR loops, it is likely that unresolved fine-structured loops are anchored in the network. A statistical analysis was done to reveal more details.

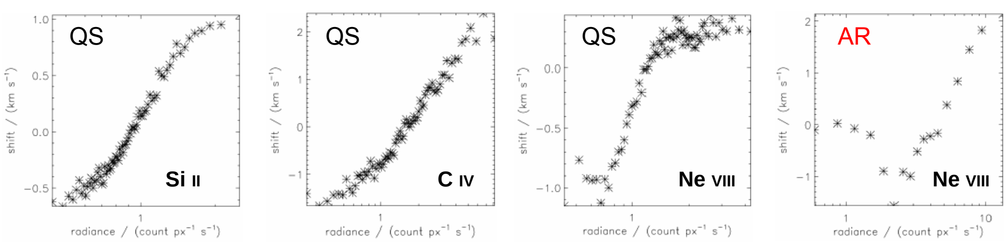
Redshift-brightness relationship



Left: QS raster in Si II (Nov 1999): brightness contours, which are overlapped on shifts nicely outline the redshift/blueshift boundary. There is a clear trend of brighter pixels towards redshift.



In AR maps a similar relationship is found in chromospheric and TR lines. In coronal lines, however, an additional effect observed. Here some small and dim less blueshifted patches seem to result from upflows in confined structures. We have excluded explosive events from this analysis, since they behave differently and confuse our statistical result.



Interrelation between brightness and Dopplershift from a QS study of November 1999 in Si II 1533 (left), C IV (middle), and Ne VIII 770 (right). For comparison we also show the Ne VIII plot from an AR study in May 2004. Pixels are sorted according to brightness, 1000 pixels averaged. The interrelation between brightness and redshift holds for the chromosphere, for the transition region (except in explosive events), and for the lower corona. Here, one has to differentiate between QS (partial relation) and AR (strong relation). This analysis expands the work reported by Brynildsen et al. (1998) and Doschek et al. (2003).

Synopsis

Our observations clearly show the signature of the downflow at both footpoints of AR loops in all TR emission lines observed by the SUMER spectrograph. We now infer that this phenomenon occurs in all the magnetically confined structures which is in agreement with the interpretation of plumes being the common footpoints of many loops. We also infer that the same may be valid for unresolved fine structures (UFS), already noted by Feldman et al. (2001). If we assume that the bright network consists of UFSs, we may explain the average redshift in TR lines (Chae et al. 1998, Brekke et al. 1997), since the footpoint pixels are inherently brighter. This finding is supported by statistical analyses of Brynildsen et al. (1998) or Doschek et al. (2004, 2006) and by the bright network/cell interior ratio presented by Curdt et al. (2001). More extensive work is underway

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