FINE STRUCTURE AND THE EMISSION FILLING FACTOR

O. KJELDSETH–MOE, N. BRYNILDSEN, P. BREKKE and P. MALTBY
Institute of Theoretical Astrophysics, University of Oslo, Norway

Abstract. There is observational evidence for an extreme fine structure in the solar transition region, much smaller than 1" in size (Dere et al., 1987, 1988) Corresponding to this extreme fine structure there appear to be an equally complex dynamical structure. We review the evidence for such dynamical extreme fine structure as demonstrated by the frequent appearance of multiple velocities, i.e. distinctly different velocities in the transition region occurring within the angular resolution element. Multiple velocities are prominent in active regions and particularly near sunspots, where velocity components may be supersonic. However, multiple velocities are frequent also in quiet regions. The consequences of such fine structure for modeling the transition region will be outlined. Finally the appropriate CDS and SUMER observations needed to extend our knowledge of a finely structured transition region and corona, spatially or in time, are discussed.

1. Introduction

We wish to emphasize the observed multiple velocities in the transition region as clear evidence of its fine scale structure on a scale $\phi \ll 1"$. Multiple velocities are the simultaneous existence of distinctly different velocities seen within an angular resolution element of $1" \times 1"$.

A filamented transition region may consist of twisted strands or fibrils inside complex loops. Each fibril has a velocity associated with it. These may range from near zero in fibrils where the gas is not flowing, to supersonic velocities in fibrils where one has a standing shock. The flows may go in several directions, since both the fibrils and the enveloping structure may be twisted. Since a number of fibrils, with individual sizes of 4-40 km, are likely to occur within a resolution element, the resulting line profiles may show the multiple velocities.

Multiple velocities thus constitute new evidence for a transition region with an extremely fine spatial scale, and give an additional opportunity for studying the properties of this fine structure. Furthermore, the complex dynamics of the transition region is in itself of great significance for the understanding and modelling of its structures and properties.

2. Evidence for a Filamentary Fine Structure

The likely presence of a very fine scale structure has been pointed out on several occasions, based on energy considerations (e.g. Nicolas and Kjeldseth–Moe, 1979; Kjeldseth–Moe et al., 1984), and on the presence of transition region emission at high altitudes above the limb (Feldman, 1983).

Lately, and most thoroughly, the sub–resolution fine structure has been discussed by Dere et al. (1987, 1988). Their analysis derives filling factors
by comparing observed emission measures, measured or estimated electron densities, and spatial extent of emitting regions of the C$^{+}$ lines at 155 nm, using spatially resolved UV spectrograms from the High Resolution Telescope and Spectrograph – HRTS.

The observed extent of emission features on the disc in the C$^{+}$ lines is typically $L \approx 2500$ km. From limb observations the vertical extent is of the same order. This "macro" structure may correspond to the size of an individual, small magnetic loop. The electron density was found from the density sensitive O$^{+}$ intercombination lines near 140 nm. Where these lines were too weak, an electron pressure of 0.14 dyn cm$^{-2}$, appropriate for the quiet Sun, was assumed. Filling factors were derived for each "macro" structure, obtaining values of $\approx 0.0001$–0.01. Depending on the number of fibrils inside a "macro" structure the corresponding fibril diameters are 4 to 40 km.

3. Multiple Velocities and a Dynamical Transition Region

The HRTS spectrograms shows that areas with a complex velocity structure, i.e. multiple velocities, occur frequently. In these regions the line profiles cannot by any close approximation be represented with a single Gaussian. Examples of such line profiles are given in Figure 1.

Multiple velocities were first observed in or near sunspots, where they are commonly occurring in the sunspot downflow regions (Kjeldseth-Moe et al. 1988, 1993) At these locations one or more of the components show supersonic downflow velocities typically in the range 50–80 km s$^{-1}$, but speeds as high as 200 km s$^{-1}$ have been observed (Brekke, Kjeldseth-Moe and Brueckner, 1990). The high flow velocity is the reason why multiple flows were first recognized in these observations.

It is more interesting that multiple velocities are frequently seen away from sunspots, in both quiet and active locations. In quiet regions multiple velocities are observed at approximately 15% of all locations (Brekke et al., 1992). In active regions they are even more prevalent. This estimate of the frequency of multiple velocities is conservative. Only distinct multiple components, with intensities well above the noise level, have been included.

Line profiles with multiple velocity show varying degrees of complexity, having two or three distinguishable components, in addition to emission from gas nearly at rest, which is always present. Typically the higher speed for a pair of multiple velocity components is in the range 30–50 km s$^{-1}$, i.e. near the sound speed. Very high velocities of 100 km s$^{-1}$ are present in about 1% of the quiet regions (Brekke et al., 1992).

Both red- and blue-shifted components are present at a number of locations between Sun center and limb. Thus, we have flows occurring in all
Fig. 1. Sample profiles of the C\textsuperscript{+3} at 154.8 nm, in active and quiet regions, showing multiple velocities. Figure shows the observed profiles and the results of a 2 and a 3 component fit.

directions. Flow velocities are both sub– and supersonic, and as many as three distinct multiple components can be distinguished in some cases.

Furthermore, there may be more multiple velocities than is possible to distinguish in the data. Multiple components have only been fitted to line profiles that show an obvious complex velocity structure or asymmetry.

4. A Dynamical Model of the Transition Region

Our proposed model depicts a transition region consisting of fine strands or fibrils inside larger "macro" structures, which are also of a limited size, L \leq 3000 km. Each fibril would then be nearly isothermal, but individual fibrils might exist with a range of temperatures. The fibrils would be thermally isolated from each other by the magnetic field. This might tie in with the model of Antiochos and Noci (1986) for the low transition region.

Flows in the fibrils might be caused by the siphon mechanism. With the high electrical conductivity in the solar atmosphere, it is likely that the flow is directed along the magnetic field lines. The velocities will be either subsonic throughout the fibril loop or the flow could become supersonic at a critical point, which, for a twisted fibril, may not be near its summit, and remain so until a shock is reached.

Line profiles consisting of one or more subsonic Gaussian line components, may be compatible with one or several siphons with subsonic velocities.

Observed line profiles with one subsonic and one supersonic component may be interpreted as caused by a shock. Since the transition region lines are formed within a restricted range in temperature, the temperature change through the shock will have to be small.

In some cases, particularly near sunspots, the observed line profiles have 3
components, of which one or two may be supersonic. These types of line profiles suggest that gas in more than one flux tube contributes to the observed line emission. The fraction of observed line profiles that require 3 components amounts 30\%, which is too large to be neglected (Kjeldseth-Moe et al., 1993).

It is obvious that the flows might become very complex in a fibril siphon flow. With simple siphon flows along typical loops we might expect regular patterns of upward and downward directed flows. This is not found in the HRTS-rasters from Spacelab 2 which we have studied.

5. Observing Multiple Velocities with CDS and SUMER

SUMER has sufficient angular and spectral resolution to register transition region fine structure and to study multiple velocities. It will extend the available range in temperature in the lower transition region to f.ex. include the O$^{+5}$ resonance lines at 103.2 nm and 103.7 nm.

With CDS a temperature range from 10$^5$ K to 10$^7$ K is available, i.e. the instrument covers both the transition region and the corona. The spectral resolution of CDS is sufficient to observe the supersonic components of multiple velocities in the transition region.

Both instruments have sufficient S/N to allow the detection of multiple velocity components, and their time resolution is a few seconds in the stronger lines allowing them to study a fine structured, non-static transition region and corona.

References

Breke, P., Kjeldseth–Moe, O., and Brueckner, G.E.: 1990, Astrophysics and Space Science 170, 135

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