EUV EMISSION FROM A 3D MHD CORONAL MODEL:
TEMPORAL VARIABILITY IN A SYNTHESIZED CORONA

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ABSTRACT

We synthesized emission line spectra from a 3D coronal model with heating through flux braiding, and study the temporal fluctuations of this synthetic corona as well as implications for the interpretation of real observations. While the line emissivity is changing only gradually in the corona, the Doppler shifts directly react to the heating mechanism, and thus we can see a remnant of the photospheric driver in the coronal Doppler shifts. The rms fluctuations we see in line intensity compare well with those observed on the Sun. Besides the good match to the averaged observed Doppler shifts and emission measures, this gives yet another piece of evidence that flux braiding is the dominant heating process in the coronae of cool stars. A side product of these investigations is the possibility to create raster maps as obtained by present EUV spectrometers. This investigation shows the limitations of present instrumentation to investigate the Doppler shifts and sets clear requirements for future instrumentation.

Key words: Sun: corona — Sun: UV radiation — MHD.

1. INTRODUCTION

The EUV observations in the early 1970s showed that the emission in the transition region is concentrated above the magnetic chromospheric network, while this correlation is fading into the corona (Reeves, 1976). Based hereupon Gabriel (1976) constructed a 2D static model of the transition region and the corona consisting of magnetic funnels expanding rapidly with height. Confronted with problems e.g. concerning the emission measure at low temperatures Dowdy et al. (1986) proposed that a hierarchy of cooler and hotter loops in-between and below the funnels could account for the missing emission measure.

To understand the complex structure and the dynamics of the corona, especially the interaction of the various coronal structures, it is of vital importance to use complex coronal modeling in a forward approach, i.e. starting from a physical model observable quantities are derived. Only recently complex 3D MHD models of a (small) active region became available (Gudiksen & Nordlund, 2002, 2005a,b). Based on these models Peter et al. (2004a,b) presented first results from a spectral analysis from those models, showing a good match to the observed Doppler shifts and emission measures.

In this paper we present first results on the investigation of the temporal variability of the properties of transition region and coronal emission lines as derived from the MHD model. After a brief introduction to the MHD model and the spectral synthesis (Sect. 2) we will first discuss the temporal variation in two selected active and quiet regions (Sect. 3) before investigating the rms fluctuation of line intensity and shift (Sect. 4). Finally we discuss how a current EUV spectrometer would see the model corona (Sect. 5).

2. CORONAL MODEL AND DATA PROCESSING

The 3D MHD model is solving the mass, momentum and energy balance along with the evolution of the magnetic field in a 3D box extending 60×60 Mm² in the horizontal directions and 37 Mm vertically including the whole atmosphere from the photosphere to the corona. The 150³ computation includes Spitzer conductivity and optically thin radiative losses with a Newtonian cooling scheme in the photosphere and chromosphere. The heating is due to braiding of the magnetic field lines through footpoint motions in the photosphere as suggested by Parker (1972). The horizontal motions of the photospheric driver are constructed to match the observed geometrical pattern and the amplitude power spectra of velocity and vorticity in the solar photosphere. For a detailed description of the 3D coronal MHD model see Gudiksen & Nordlund (2002, 2005a,b).

Based on the MHD model results we calculate the emissivity at each grid point under the assumption of ioniza-
Figure 1. Maps in line intensity and Doppler shift in the transition region (left two panels) and the corona (right two panels) as derived from a snapshot of a 3D MHD coronal model. In these maps the computational box is viewed from above, i.e. this represents the situation when observing near disk center. The middle panel shows the vertical magnetic field at the bottom of the computational domain, i.e. in the photosphere. The solid and dashed rectangles outline areas further discussed with respect to the temporal variation of line intensity and shift (cf. Fig. 2 and Sect. 3).

Figure 1 shows in the middle panel the vertical magnetic field at the bottom of the computational box, i.e. in the photosphere. To the left and right are maps in line intensity and line shift as derived from the spectra computed from the MHD model. They represent a view from the top onto the box, corresponding to an observation at disk center. As found with observations the spatial structures in the transition region line C IV (1548 Å) at 10^5 K are much smaller and finer than in the corona seen in Mg X (625 Å) formed at 10^6 K.

3. TEMPORAL VARIABILITY: IMPRINT OF PHOTOSPHERIC DRIVER

To study the temporal variations of the emission line properties as following from the MHD model, we first concentrate on the evolution in different areas, which are outlined in Fig. 1. One is a region between the two magnetic concentrations forming the footpoint region of the loop system, where strong coronal as well as transition region emission is found, which can be characterized as active area emission (solid rectangles in Fig. 1). The other area is located where only weak emission is found in the corona and transition region, i.e. a quiet Sun region (dashed rectangles). As in Fig. 1 we concentrate on typical lines from the transition region and corona, i.e. C IV and Mg X.

Figure 2 shows the temporal evolution of the average intensity (top panels) and Doppler shift (bottom panels) in the active region area (thick solid) and the quiet Sun area (thick dashed) as outlined by the ~8×8 Mm² rectangles in Fig. 1. The respective thin solid and dashed lines show the variation in the center of the respective rectangle (a single resolution element from the model). For comparison the thick dotted lines show the variation when averaging over the whole computational domain, i.e. ~60×60 Mm².

The intensity variation in the corona is rather smooth as compared to the transition region, in the quiet as well as in the active area. The Doppler shift shows a very strong
variation in the corona, which is also found in observations, and is also substantiated by the analysis of the rms variations (next section). The fluctuations in the transition region as well as in the coronal Doppler shifts are on a time scale of the order of 5 minutes, which is a signature of the driving of the coronal heating process in the photosphere.

One conclusion from this is that it is very profitable and necessary to study the line shifts in the corona to investigate the coronal heating process. Due to the large cooling times in the corona and the efficient redistribution of the energy input through heat conduction, the intensity depends relatively weakly on the heating process. In contrast, the coronal line shifts show the direct reaction of the plasma to the heating process and the induced mass flows. The Doppler shift and intensity fluctuations in the transition region behave similarly, even though the variation of the transition region lines and the coronal Doppler shifts are not well correlated.

This shows the vital importance of the inclusion of line shifts for further observational studies of the coronal heating mechanism. When performing (broad band) imaging studies of the corona, where Doppler shifts are not (yet) accessible, one should include emission from the transition region.

4. RMS FLUCTUATIONS: MODEL VS. OBSERVATIONS

To investigate the *global* variability of the corona we study the rms fluctuations of the intensities and Doppler shifts. Figure 3 shows these for a number of EUV lines as a function of line formation temperature. Based on the maps of line intensities and shifts generated from a line of sight integration along the vertical direction, we evaluate the rms fluctuations at each grid point within the respective map. The diamonds show the average values for the rms fluctuation for each line and the bars represent the scatter of the rms values (standard deviation).

This is exactly the same procedure as used by Brković et al. (2003) to reduce their observational data from CDS and SUMER on SOHO. The trend they found with their observations is over-plotted as the thick dashed line in Fig. 3. It has to be emphasized that we reduced the spatial resolution of the maps in line intensity and shift derived from the MHD model to match the spatial resolution of the SOHO instruments.

Together with the good match between the average Doppler shifts and emission measure from observations and the spectra computed from the MHD model we presented earlier (Peter et al., 2004a,b, 2005), this is yet another strong indication that the magnetic field line braiding underlying 3D MHD model is a good description for the coronal heating mechanism.

![Figure 3. RMS fluctuations in line intensity and shift as following from the spectra derived from the MHD coronal model for a number of EUV lines as a function of line formation temperature. The thick dashed line shows the trend as found in observations (see Sect. 4).](image)

5. OBSERVATIONAL LIMITATIONS: SIMULATED SUMER RASTER SCANS

To illustrate the limitations of current instrumentation we simulated what SUMER/SOHO would see from the coronal emission as derived from the 3D MHD model. Here we show results for the Mg X (625 Å) line formed at about 10^6 K, i.e. at a similar temperature as represented by the 171 Å passband of TRACE or EIT, dominated by Fe IX/X.

For this experiment we have been optimistic and assumed that a 10 s exposure time would be sufficient, so that we could raster the whole ~60×60 Mm area within some 10 minutes (with such a short exposure time the Mg X line is just visible for SUMER in brighter areas, with some 10 counts per 1″ pixel within the 10 s exposure). We then produce two consecutive raster scans of a 20 minutes series of spectra computed from the 3D coronal MHD model, in the same fashion as SUMER on-board SOHO would see the corona, i.e. we have reduced the spatial resolution with “pixels” of a bit less than 1 Mm squared. Actually, one would have to add a considerable amount of noise to the data to be more realistic, as with such a short exposure time the signal to noise ratio would be quite bad for SUMER.

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intensities. Thus when studying the coronal heating process it is of vital importance to have access to the Doppler shifts of lines formed in the corona around $10^6 \text{ K}$ as well as to the low temperature transition region emission.

The study of the rms fluctuations show a good match between the spectra derived from the MHD model and the observations. This provides further support for the coronal heating process being through braiding of magnetic field lines due to photospheric footpoint motions as first suggested by Parker (1972) and implemented in the MHD coronal model of Gudiksen & Nordlund (2002, 2005a,b).

The simulation of spatial maps as to be observed with an EUV spectrometer is another potential for the forward modeling technique. On the one hand this shows the limitations of current instrumentation, especially with respect to the time it takes to raster a sufficient area on the Sun. On the other hand the forward modeling studies as presented here can be used to help in defining requirements for future instrumentation.

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6. CONCLUSIONS

One main result of this study of the temporal variability of the spectra derived from a 3D MHD corona models is that an imprint of the photospheric driver of the coronal heating process can be seen in the transition region and corona. While the emission from coronal lines does show only little response to the driver, the coronal line shifts react sensitively, as do the transition region line shifts and