HEATING OF THE SOLAR CORONA: MODELING THE EUV/X-RAY EMISSION

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ABSTRACT

We use potential field extrapolations of Kitt Peak high resolution magnetograms to compute the coronal field lines of a large bright point observed on 1997, September 12. We then populate the field lines with solutions to the hydrostatic loop equations based on a form of the volumetric heating function that has been found to be consistent with observations of large active regions in previous work. We then use the computed densities and temperatures to calculate average intensities and simulated images for Yohkoh/SXT, SOHO/EIT and SOHO/CDS. The results are compared to observations and it is found that the models work well for the SXT emission and are also able to reproduce the average intensities of reliable lines over a wide range of temperatures to within ~50-80%. The morphology in the visualizations of the EUV emission, however, shows significant differences with the observations suggesting that dynamic processes play a role in the heating. The results are also applied to modeling of the quiet Corona where similar results are found.

Key words: Sun: corona, Sun: UV radiation.

1. BACKGROUND & MODELING STRATEGY

Determining the mechanism responsible for heating the solar corona to high temperatures remains one of the most important unsolved problems in solar physics. One way to address this problem is to compare numerical models with the high quality observations available from SOHO, TRACE and Yohkoh. A great deal of progress has been made focusing on the comparison between observations and simulations of active region loops (Aschwanden et al., 2000; Priest et al., 2000; Warren et al., 2003). The solar corona, however, is heated to 1MK temperatures away from active regions and at solar minimum. Our objective in this work is to attempt to simulate the EUV/X-ray emission from the quiet corona using models developed for active region studies.

Our strategy is as follows. Perform a potential field extrapolation from a high resolution magnetogram of the quiet Sun obtained from, e.g., SOHO/MDI or the Kitt Peak Vacuum Telescope. Populate the calculated field lines with solutions to the hydrostatic loop equations based on different parameterizations of the heating function. Use the density and temperature solutions combined with instrument response functions and/or line contribution functions \( G(T_e, N_e) \) to compute averaged intensities and simulated images at different wavelengths. Compare the visualizations with SOHO/EIT, SOHO/CDS and Yohkoh/SXT data and vary the simulation parameters to obtain the best match with the observations. In this way we hope to determine if, where and why the modeling is inadequate, and build up the complexity, e.g., introducing foot point/loop top heating, hydrodynamic solutions etc.

This modeling strategy has been applied previously to active regions and the results suggest that static models can reproduce the observed SXT emission well (Warren & Winebarger, 2006; Lundquist et al., 2004). The EUV emission, however, is concentrated at the footpoints of the loops (in the moss) so that there are no loop structures in the visualizations. The moss also appears too bright. For the quiet Sun, Schrijver & Van Ballegooijen (2005) found that their simulated Fe IX 171Å images were consistent with the data obtained by TRACE and that the intensities were reproduced reasonably well.

The results of this previous work suggest that a fruitful strategy would be to model the SXT emission with the static models, and see how the EUV emission then compares to the observations. If the simulations cannot reproduce the EUV emission then the manner in which this happens should give clues as to which parts of the model should be built up in complexity and which parts can remain simple to reduce the computational load. For example, if the brightness of the loops cannot be reproduced then this may suggest impulsive heating. On the other hand, if no field lines are present where there is strong EUV emission then the potential field extrapolation comes into question.

One problem with quiet Sun modeling is that although the Corona is heated to 1MK temperatures, there is a rapid fall off in the emission measure distribution at higher temperatures (Brooks & Warren, 2006). This can easily be seen from full disk Yohkoh/SXT images where there is no strong SXT signal to act as a baseline from which to start the modeling. To overcome this difficulty we decided to attempt to model a large bright point vis-
Figure 1. EIT 195Å full disk image obtained at 16:14:06UT on 1997, September 12 with the CDS FOV overlaid.

2. BEST CASE RESULTS

Figure 2 (upper row) shows the bipolar magnetic structure of the bright point and the emission at EUV and soft X-ray wavelengths. The OV 630Å CDS line is formed at log $T_e \sim 5.35$ and images the lower transition region. The bright network emission tends to outline the magnetic flux concentrations in the photosphere. The lower row shows the coronal field lines from the potential field extrapolation overlaid on the Kitt Peak magnetogram to show the general expected morphology. The EUV and soft X-ray visualizations of the simulation results are also shown. These are discussed further below.

For this analysis we adopted a volumetric heating rate ($\epsilon_0$) which scales as $B/L$, where $B$ is the magnetic field strength averaged along a field line and $L$ is the loop length. This parameterization has been found to be consistent with observations of large active regions (Warren & Winebarger, 2006).

To obtain the best match to the observations we reduced $\epsilon_0$ to 0.3 of the value that worked best for the large active regions. We also allowed the loop cross-sections to expand proportionally to $1/B$ along the loop length.
Figure 2. Multi-wavelength observations and simulated images of the bright point. Upper row from left to right: Kitt Peak Magnetogram, Yohkoh/SXT AlMg filter image, SOHO/EIT 195Å image, SOHO/CDS OV 630Å image. Lower row from left to right: Kitt Peak magnetogram with potential field extrapolation field lines overlaid, Simulated Yohkoh/SXT AlMg image, Simulated SOHO/EIT 195Å image, Simulated SOHO/CDS OV 630Å image.

Figure 3. Ratios of simulated to observed average intensities plotted against formation temperature.
within $\sim 80\%$. Given all the uncertainties in the method, the simulations appear to work reasonably well.

Returning to Figure 2 it can be seen that the SXT visualization captures the structure and brightness of the observations. This result is consistent with the findings of Warren & Winebarger (2006) and Lundquist et al. (2004). The EIT 195Å visualization also appears to do a reasonable job modeling the morphology seen in the observations. The simulation, however, is too bright despite the agreement between average observed and predicted intensities found in Figure 3. The OV 630Å visualization shows the worst agreement with observations of the three. The intensities are too bright and the spatial distribution of the network emission seems less localized. In both the EIT and CDS simulated images the diffuse background emission is not present. This may be because emission from the magnetic canopy is not included in our model that places emission on the extrapolated field lines only.

3. CONCLUSIONS & APPLICATION TO THE QUIET SUN

We have modeled the EUV and soft X-ray emission from a bipolar bright region point using potential field extrapolations of Kitt Peak magnetograms in combination with hydrostatic loop models. We then compared the results to observations obtained by Yohkoh/SXT, SOHO/EIT and SOHO/CDS.

We find that the average simulated intensities over the CDS FOV are in reasonable agreement with those derived from the observations. The soft X-ray simulated images also show good agreement with the SXT data. The EUV visualizations, however, show significant discrepancies with the observations: although the general morphology of the emission appears consistent with the data, the intensities are significantly brighter despite the agreement between averaged observed and predicted intensities. Furthermore, there are problems with the spatial distribution of emission. In addition, the necessary expansion of the loop cross-sections is inconsistent with the observational results found from TRACE data (López Fuentes et al., 2006).

We applied the best match parameters to simulations of the quiet Sun using SOHO/MDI high resolution magnetograms. The detailed results will be presented elsewhere. We found, however, that similar results were obtained. The major difference being that we did not need to introduce the expansion of the loop cross-section in the quiet Sun case. The ratios of simulated to observed intensities showed greater scatter than in the bright point case but were found to agree to within a factor of $\sim 2$. Examining visualizations of all EIT filters revealed again that the general morphology was approximated but that the intensities were too bright in localized regions.

We are pursuing further investigations of both the bright point and quiet Sun regions adopting different heating functions such as loop top and footpoint heating, with constant and expanding cross-sections. The results may improve with these modifications but at present the results suggest that hydrodynamic models will be needed for further progress.

REFERENCES


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