Radiation Transfer Analysis on Heating Mechanism of Magnetohydrodynamic Emerging Magnetic Flux Tube

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Abstract. In spite of the large number of magnetohydrodynamic (MHD) simulations of emerging flux tubes in the solar atmosphere, radiation properties of the phenomenon remain poorly understood. This is because heating at the footpoints of the emerging magnetic field lines is significant and the effects associated with heat conduction and evaporation have largely been neglected. In this study, we have performed three-dimensional (3-D) multi-wavelength radiation transfer calculations on a MHD model of an emerging flux tube in order to examine the MHD model and also to identify a possible heating mechanism for explaining the properties of observed X-ray coronal loops. It is found that the current dissipation model is difficult for reproducing the structure of X-ray loops observed by Hinode XRT and Yohkoh SXT. This suggests that alternative models of the heating process should be incorporated into our MHD models. We left unresolved issues of the heating process as future work.

Figure 1. Calculated spectral energy distribution. The black solid curve indicates the emergent spectra whereas the gray dotted curve indicates the emissivity spectra. Bars on both curves indicate the range of values over time. A black dotted curve indicates the black-body radiation spectrum at the photosphere.
1. Method

In this study, we have carried out 3-D radiation transfer calculations (see Ohsuga, Kato, and Mineshige 2005 for a basic procedure) on a MHD model of emerging flux (Magara 2006). The calculations make use of the magnetic field structure and current density distribution from the simulation and incorporates the mechanisms of heating and evaporation in the emerging flux tubes. We take into account the continuum radiation process via thermal bremsstrahlung emission and absorption, and also the electron scattering at the surface of the solar photosphere. In order to constrain model parameters (such as number density and temperature of ion and electrons), the emergent spectra ranging from radio to gamma-ray are used to fit the black body radiation spectrum in the solar photosphere (see Figure 1).

In order to examine the heating and the evaporation processes in the flux tubes, we assume hydrostatic equilibrium in the tube for simplicity. We employ the joule dissipation model for the heating so that the temperature $T_{\text{tube}}$ of the emerging flux tube is described by

\[ n_e k_B T_{\text{tube}} = \eta |J|^2 \delta t_{\text{dis}} \]  

where $J$ is the current density taken from the MHD simulation, $\eta$ is the resistivity, and $\delta t_{\text{dis}} = 60$ sec is the duration of the heating process. Note that $\eta$ is adjusted so that the maximum temperature is $10^7$ K. Then the density in the flux tube is updated to satisfy the hydrostatic equilibrium consistent with the isothermal tube (with temperature $T_{\text{tube}}$).
2. Results and Summary

Figure 1 shows the time-averaged emergent spectral energy distribution (SED) from our MHD model. Bars indicate variability (minimum and maximum) at different times. Model parameters are constrained by the black-body spectrum for a temperature of 5100 K.

Figures 2 and 3 show perspective views of our MHD models and the simulated images by our radiation transfer calculation, respectively. Although the sigmoid structure cannot be found in the synthetic images, multiple X-ray loops can be identified. There are several possible reasons for the absence of the sigmoid structure. One primary reason is that the sigmoid is obscured by hot and dense loops above it. If this is the case, we must take into account radiative cooling of such loops in order to suppress their effects. Otherwise, we must improve the heating and evaporation model by including non-uniform resistivity, dynamical evolution of the evaporation, and so on.

In future studies, we will investigate other heating models to elucidate the mechanism of heating in the emerging flux tubes.

References