Origin of Universal Correlation between Temperature and Emission Measure for Solar/Stellar Flares

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We study the reconnection and the chromospheric evaporation in flares using the numerical code including nonlinear anisotropic heat conduction effect (Yokoyama & Shibata 1998; 2001). The two-dimensional, nonlinear, time-dependent, resistive, compressible MHD equations are solved. The evolution from the rise phase to (the early part of) the decay phase of a solar flare is qualitatively reproduced in this simulation. Based on the results, we obtained a relationship between the flare temperature and the coronal magnetic field strength. If we assume that the input of energy to a loop balances with the conduction cooling rate, the temperature at the loop apex is

$$T_A \approx (2QL^2/\kappa_0)^{2/7}$$

where $Q$ is the volumetric heating rate, $L$ is the half-length of the loop, and $\kappa_0 = 10^{-6}$ CGS is the Spitzer's thermal conductivity constant. In our simulations, the heating mechanism is magnetic reconnection so that the heating rate is described as $Q = B^2/(4\pi) \cdot V_{in}/L \cdot 1/\sin \theta$, where $B$ is the coronal magnetic field strength, $V_{in}$ is the inflow velocity ($\approx 0.1V_A$ from our result and also from Petschek's theory), and $\theta$ is the angle between the slow-mode MHD shock and the loop and is approximately given by $\sin \theta \approx V_{in}/V_A$. By manipulating the equations, we find

$$T_A \approx \left( \frac{B^3L}{2\pi\kappa_0\sqrt{4\pi\rho}} \right)^{2/7} \propto B^{6/7} \beta^{-3/7},$$

where $\rho$ is the mass density of the corona. The simulation results show very good agreement with this scaling law.

We also develop a theory to explain the observed universal correlation between flare temperature $T$ and emission measure $EM = n^2V$ for solar and stellar flares (including solar microflares observed by Yohkoh as well as protostellar flares observed by ASCA), where $n$ is the electron density and $V$ is the volume (Figure 1; Shibata & Yokoyama 1999). The theory is based on the above magnetic reconnection model with heat conduction and chromospheric evaporation, assuming that the gas pressure of a flare loop is comparable to the magnetic pressure. This theory predicts the relation

$$EM \propto B^{-5}T^{17/2}$$
Universal Correlation for Solar/Stellar Flares

Figure 1. The log-log plot of emission measure vs. electron temperature of solar flares, solar microflares, four stellar flares (asterisks), a protostellar flare (diamond, class 1 protostar far IR source R1 in the R CrA cloud), a T-Tauri stellar flare (diamond, weaklined T-Tauri star V773 Tau), and a stellar flare on AB Dor (K0 IV ZAMS single star) The $EM - T$ relation curves ($EM \propto B^{-5}T^{17/2}$) are superposed on the EM-T diagram. The $L = constant$ curves (dashed lines; $EM \propto L^{5/3}T^{8/3}$) are also superposed on this diagram.

which explains well the observed correlation between $EM$ and $T$ in the range of $6 \times 10^6 \text{ K} < T < 10^8 \text{ K}$ and $10^{44} < EM < 10^{55} \text{ cm}^{-3}$ from solar microflares to protostellar flares, if the magnetic field strength of a flare loop, $B$, is nearly constant for solar and stellar flares.

References