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Origin of Universal Correlation between Temperature and Emision 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 $T_{\rm A} \approx (2QL^2/\kappa_0)^{2/7}$ 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 $Q = B^2/(4\pi) \cdot V_{\rm in}/L \cdot 1/\sin\theta$, where B is the coronal magnetic field strength, $V_{\rm in}$ is the inflow velocity ($\approx 0.1V_{\rm A}$ from our result and also from Petschek's theory), and θ is the angle between the slow-mode MHD shock and the loop and is approximately given by $\sin\theta \approx V_{\rm in}/V_{\rm A}$. By manipulating the equations, we find

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

where ρ 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 emisssion 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 coduction and chromospheric evaporation, assuming that the gas pressure of a flare loop is comparable to the magnetic pressure. This theory predicts the relation

$$EM \propto B^{-5}T^{17/2}$$

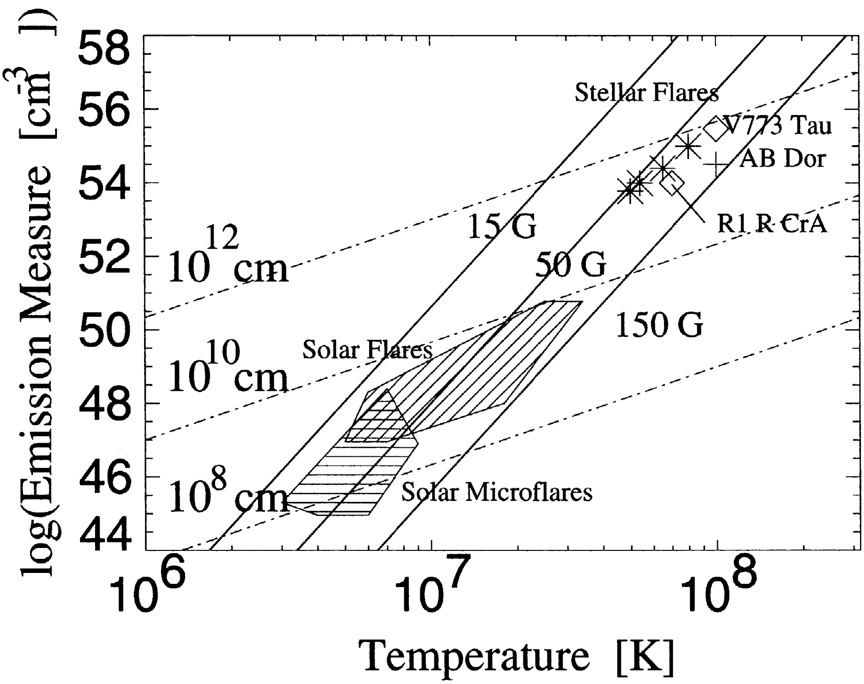

Figure 1. The log-log plot of emission measure vs. electron temperature of solar flares, solar microflares, four stellar flares (asterisks), a protostellar flare (diamond, class 1 protostar far IR source R1 in the R CrA cloud), a T-Tauri stellar flare (diamond, weaklined T-Tauri star V773 Tau), and a 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 6×10^6 K $< T < 10^8$ K and $10^{44} < EM < 10^{55}$ 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

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