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ORIGINAL ARTICLE

Radiative and conductive cooling in a solar flare

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Abstract We investigate the radiative and conductive cooling in the solar flare observed by RHESSI on 2005 September 13. The radiative and conductive loss energies are estimated from the observations after the flare onset. Consistent with previous findings, the cooling is increased with time, especially the radiation becomes remarkable on the later phase of flare. According our method, about half of thermal energy is traced by RHESSI soft X-rays, while the other half is lost by the radiative (∼38%) and conductive (∼9%) cooling at end of the hard X-rays in this event. The nonthermal energy input of $P_{\rm nth}$ (inferred from RHESSI hard X-ray spectrum) is not well correlated with the derivative of thermal energy of $\frac{dE_{\rm th}}{dt}$ (required to radiate the RHESSI soft X-ray flux and spectrum) alone. However, after consideration the radiation and conduction, a high correlation is obtained between the derivative of total thermal energy ($\frac{dE_{\rm th}+E_{\rm rad}+E_{\rm cond}}{dt}$) and nonthermal energy input ($P_{\rm nth}$) from the flare start to end, indicating the relative importance of conductive and direct radiative losses during the solar flare development. Ignoring the uncertainties to estimate the energy from the observations, we find that about ∼12% fraction of the known energy is transferred into the thermal energy for the 2005 September 13 flare.

Keywords Sun: flares · Sun: X-ray bursts · Hard

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1 Introduction

It is well known that one result of a solar flare is the existence of a hot, dense plasma confined within a coronal loop or series of loops. Observations from the YOHKOH, TRACE, SOHO, and RHESSI indicates that flaring plasma temperatures and densities can reach as high as tens MK and 10^{11} cm^{-3} during the impulsive phase. Such hot plasma would gradually cool to an usual temperature after the flare heating. The radiation and the conduction are generally thought to be the main cooling processes in the solar plasma, and they directly affects on the thermal parameters, such as temperature, emission measure (EM defined as $\int n_e^2 dV$, where n_e is the electron density and V is the volume of hot plasma), and thermal energy. After the flare onset, both the heating and cooling results into that the flaring temperature, emission measure, and thermal energy arrive their peaks at different times, with the temperature reaching a maximum a few minutes before the emission measure and the thermal energy (Ning 2008a, 2008b; Warmuth et al. 2009).

Observations shows that the radiation and conduction cooling starts to work after the flare onset, and becomes remarkably at the later phase of flare. Therefore, all the thermal parameters increase due to the heating dominating the cooling at the beginning, and then decrease their values only the cooling working after the hard X-ray end. Because the hard X-rays are generally thought to be the signatures of the flaring energy input. Based on the standard flare model, the flaring plasma is heated by the nonthermal electrons, which are accelerated by the magnetic reconnection, and propagate downward along the magnetic field, then lose their energies through Coulomb collisions with the denser medium to heat the local plasma rapidly. The resulting overpressure drives a mass flow upward along the loops at speeds of a few hundred km s^{-1} (chromospheric evaporation), which fills the