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Stochastic Acceleration and Nonthermal Radiation in Clusters of Galaxies

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Abstract. We study the possibility that the recently detected hard X-ray excess from some clusters of galaxies is due to bremsstrahlung emission of a nonthermal tail in the electron distribution produced by stochastic acceleration in a background of MHD waves. We find that this scenario requires an overall level of fluctuations which is only $\delta B^2/B^2 \sim 3\%$ for a magnetic field B on the order of μG. Despite the reasonable values for these parameters, a large rate of injection of waves is needed to compensate the damping of the waves.

1. Calculations and Results

The recently detected hard X-ray emission from several clusters of galaxies poses a serious challenge to our understanding of the cosmic ray (CR) energy content in clusters of galaxies. According to Fusco-Femiano et al. (1999), the combined analyses of the radio emission and hard X-ray excess from the Coma cluster imply a magnetic field $B \approx 0.13\,\mu$G, which in turn requires cosmic rays to be in near-equipartition with the thermal energy in the intracluster gas (Lieu et al. 1999) if the radio and X-ray emissions are due, respectively, to synchrotron radiation and inverse Compton scattering (ICS) of relativistic electrons.

Ensslin, Lieu, & Biermann (1999) first proposed that the hard X-ray excess could be produced by bremsstrahlung emission of slightly suprathermal electrons if some stochastic acceleration process generates a nonthermal tail in the thermal electron distribution. Here, we study the process of stochastic acceleration in a detailed way, solving the Fokker-Planck equation that describes the processes responsible for the thermalization and acceleration of the gas (see Blasi 2000 for details). The latter is due to resonant interaction of MHD waves with the electrons in the gas. The waves are assumed to have a Kolmogorov spectrum with the largest scale $L_c \approx 10\,\mathrm{kpc}$, comparable with the size of a galaxy. The process of acceleration, as discussed in detail by Dermer, Miller, & Li (1996), can be described as a diffusion process in momentum space. On the other hand, the Coulomb scattering, responsible for the thermalization of the gas, can also be described as diffusion with losses in momentum space, as discussed by Nayakshin & Melia (1998). The Fokker-Planck equation can then be used to account for both processes. The parameters that determine the rate of acceleration are the magnetic field B in the intracluster medium, the fraction ξ of the magnetic energy density in the form of MHD waves, and the value of L_c. These parameters must be chosen in such a way that the acceleration time scale is shorter than the

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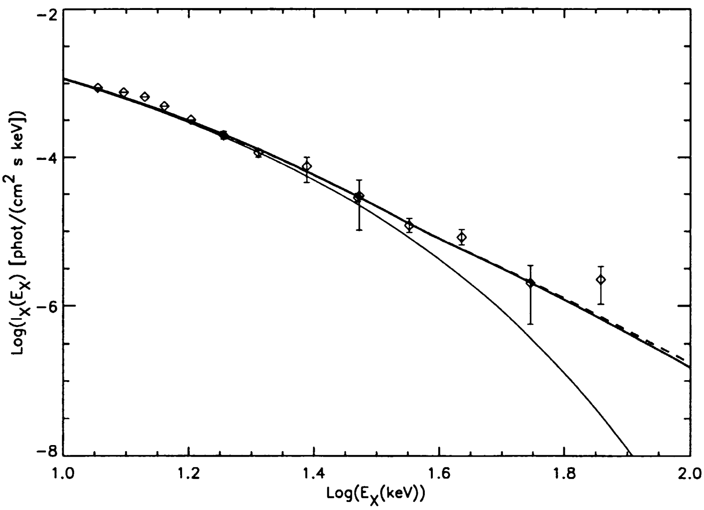

Figure 1. X-ray flux due to thermal bremsstrahlung (thin solid line) added to the bremsstrahlung from a nonthermal tail produced by stochastic acceleration. The thick lines represent the total emission at $t = 3 \times 10^7$ yrs (solid line) and 10^9 yrs (dashed line).

Coulomb cooling time scale at the energy where the nonthermal tail appears. We find that the X-ray data from the SAX satellite (Fusco-Femiano et al. 1999) can be well described assuming $B = 1.5\,\mu$G and $\xi = 0.03$. Our resulting X-ray spectrum (thermal plus nonthermal) is plotted in Figure 1, together with the data points from GINGA (Hughes et al. 1993) and SAX. The parameters mentioned above look very reasonable, but they correspond to a very large rate of energy injection into the system in the form of waves. This is due to the fact that the spectrum of waves is required to not change in our treatment, so that a continuous energy input is required to compensate the damping of the waves. A complete time-dependent, nonlinear calculation of the coupling between particles and waves is needed to have a satisfactory picture of the role of stochastic acceleration in the production of nonthermal tails in clusters of galaxies.

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