THE SYNCHROTRON BOILER: A THERMALIZER IN SEYFERT GALAXIES

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ABSTRACT. There are difficulties in understanding what keeps the plasma thermalized in compact sources, especially during rapid variations of the emitted flux. Particle–particle collisions are too inefficient in hot rarefied plasmas, and a faster process is called for. Synchrotron absorption is such a process. We show that relativistic electrons can thermalize in a few synchrotron cooling times by emitting and absorbing cyclo-synchrotron photons. The resulting equilibrium distribution is a Maxwellian at low energies, with a high energy power law tail when Compton cooling is important. Assuming that the particles emit completely self absorbed synchrotron radiation while they at the same time Compton scatter ambient UV photons, we calculate the time dependent behavior of the distribution function, and the final high energy spectra.

1. Set-up of the system

- In a source of dimension $R$, relativistic electrons are injected at a rate $Q(\gamma)$ [cm$^{-3}$ s$^{-1}$] between Lorentz factors, $\gamma_{\text{min}}$ and $\gamma_{\text{max}}$, corresponding to an injected compactness, $\ell_i = L_i \sigma_T / (R m_e c^3) = 4\pi R^2 \sigma_T \int Q(\gamma) \gamma d\gamma / (3c)$.
- A tangled magnetic field $B$ of energy density $U_B$ makes the injected particles radiate synchrotron photons.
- These photons, together with photons produced externally to the region, interact with the electrons by the inverse Compton process.
- If the particle distribution extends to a $\gamma_{\text{max}}$ of the order of a few, the synchrotron spectrum is completely self absorbed, and the total radiation energy density ($U_r$) may be dominated by the externally produced photons.
- The particle distribution $N(\gamma)$ is the result of the injection, S and IC losses, and the energy gain due to self absorption (Ghisellini et al. 1988).
- We assume that the radiation energy density, $U_r$, is dominated by the ‘hard’ radiation produced by Comptonization of an external soft photon distribution. The latter is assumed to arise from the reprocessing of half of the hard radiation by cold matter in the vicinity of the active region. We assume that the spectrum of this component is a (diluted) blackbody with a typical temperature of 50 eV. This is consistent with a disk–corona geometry, as discussed by Haardt & Maraschi (1991).
Fig. 1. (Left:) Equilibrium particle distributions resulting from different injected power. Labels indicate the injected compactness. The magnetic field is in all cases $B = 1.8 \times 10^4$ Gauss, $R = 10^{13}$ cm, $< \gamma >_{\text{inj}} = 4.5$. Fig. 2 (Right:) Comptonized spectra corresponding to four of the particle distributions shown in Fig. 1. Soft photons are assumed to be a blackbody at $kT = 50$ eV, with a luminosity equal to half of the injected power. A face-on line of sight is assumed and reflection is neglected.

2. Results

Time evolution — The Maxwellian shape is reached in $t \sim R/c$, which is equal to a few synchrotron cooling times of the electrons with the lowest energies.

Equilibrium distributions — In Fig. 1 the injection function is constant with energy, and the different equilibrium distributions correspond to different injected luminosities. By increasing the injected power we increase the relative importance of Compton cooling with respect to synchrotron reheating: thermal equilibrium is then reached at lower energies (see also Ghisellini & Svensson 1989). In this case, the particle distribution is a Maxwellian at low energies, with a quasi power law tail at higher energies.

High energy spectra — In Fig. 2 we show the resulting Comptonized spectra corresponding to the particle distributions shown in Fig. 1. The spectra exhibit a quasi-exponential cut-off, similar to the pure thermal case. This is true even when the injected power is large, and the corresponding particle distribution (see Fig. 1) is Maxwellian only at low energies. The value of the spectral index is close to $\alpha = 1$. The reflection bump is neglected in Fig. 2. Once accounting for this extra contribution, the spectra are in agreement with the average shape shown by Seyfert galaxies. For small values of the injected power the spectrum is bumpy: this is due to the small value of the optical depth and the large temperature, resulting in well separated scattering orders.

References

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