PROCEEDINGS OF SCIENCE

Modelling Electron/Positron distributions in the HEART code

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We present a three dimensional radiative transfer model (the High Energy Astrophysics Radiative Transfer (HEART) code) to explain the broadband spectra from various high energy astrophysical objects. Our code can recreate many emitting region geometries, including inhomogeneous plasma distributions, as well as take into account all the important radiative transfer mechanisms such as Compton scattering, synchrotron radiation, bremsstrahlung radiation and Coulomb scattering. The kinetic equation is used to accurately model evolving electron/positron distributions. With time-dependent modelling of these phenomena we attempt to further our understanding of the underlying mechanisms giving rise to the broadband spectra.

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The HEART code models various physical processes taking place in the corona above an accretion discs. For a discussion of the HEART code structure and use to fit spectra please see Rogers et al, these proceedings.

1. The code design

The HEART code is capable of modelling 3D geometries of a corona. The user can choose various geometries e.g. hemisphere, hemicube, cube, sphere etc. These geometries are combined with different models like internal corona, external corona and so forth. The corona is modelled by splitting it up into a number of cubic cells. The number of cells can be varied. All the physical processes take place in individual cells. The HEART code creates a time dependent model and all the processes act during each time step to model radiative evolution. A time step is calculated to be the length of time it takes light to travel across one cell. All the cells are connected and radiation transfer takes place within the cells. Radiation is only transfered perpendicularly to each cell face. So in effect there is a time evolution of photons as they are not only 'acted upon' in each cell, but they are also transferred through the corona until they finally escape and we can obtain a spectrum. The photons are modelled in terms of flux and not in terms of single photon paths as in Monte Carlo based methods. The idea is to obtain flux spectra over a wide range of frequencies. At present all the physical processes in HEART involve electrons in some manner (positron distributions have also been added to the code). Therefore electron/positron distributions and their evolution are important to the evolution of the photon distribution.

1.1 Electron/Positron Distributions

In the HEART code both electron and positron distributions are modelled in a similar manner. They are subject to the same scattering, emission and absorption mechanisms. The energy distributions of electrons/positrons injected into computational cells can be thermal, power-law or a hybrid of the two. The relativistic form of the Maxwell-Boltzmann equation is used to model the thermal distribution,

$$n_{\gamma} = \frac{n_e}{\theta_e K_2(1/\theta_e)} \gamma p e^{-\gamma/\theta_e}, \tag{1.1}$$

where K_2 is the modified Bessel function of order 2, $\theta_e = kT_e/m_e c^2$ is the relativistic temperature of the electron distribution and k is the Boltzmann constant. Integrating (1.1) over all energies gives the total number density.

A simple power-law relation is used to model the non-thermal distribution.

$$n_{\gamma} = n_0 \gamma^{-q}, \tag{1.2}$$

where n_0 is the normalisation factor ($n_0 = n_e(q-1)$)[m^{-3}] and q is the power-law index with values ranging from 2 in the case of mildly-relativistic shocks to around 2.25 for the ultra-relativistic limit ([2]). γ_{min}, γ_{max} and q are all user defined.

The power-law distribution can be important for producing high energy radiation observed from the astrophysical sources without requiring very high plasma temperatures. Both electrons and positrons can be injected either during the first time step only, continuously or in short ’bursts’ at any time during the simulation. Below we show examples of the thermalisation of electrons/positron injected in a single event with various energy distributions.

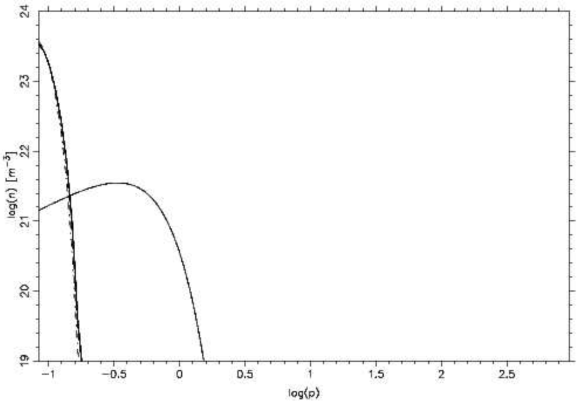

Figure 1: Thermal electron/positron distribution. The curve extending to higher energies shows the initial electron/positron distribution.

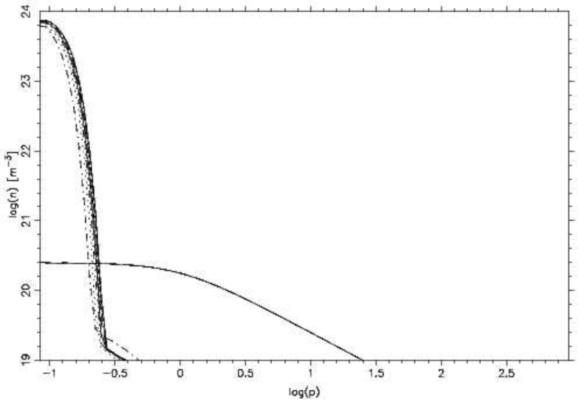

Figure 2: Powerlaw electron/positron distribution. The curve extending to higher energies shows the initial power-law electron/positron distribution. This then thermalises to a lower energy Maxwellian distribution.

1.2 Coulomb scattering

Coulomb scattering can play an important role in the evolution of an electron/positron energy distribution. Similarly to bremsstrahlung, Coulomb scattering describes the energy exchange when electrons/positrons interact via their electrostatic fields. However, in the case of Coulomb scattering it is the energy exchange between the net electric field produced by all the electrons/positrons and the individual particles. This process has the overall effect of thermalising the electron/positron energy distribution.

In the HEART code we use the treatment of Coulomb scattering by Nayakshin et al ([5]). Their method allows the thermalisation of an arbitrary initial electron energy distribution via the Coulomb interactions by defining a kinetic equation. The thermalisation occurs on a characteristic timescale usually much shorter than the timescales associated with matter-photon interactions. The temperature of the final thermal distribution depends on the average energy of electrons/positrons in the initial non-thermal distribution. Figure 3 shows the thermalisation process evolving a non-thermal distribution to a Maxwellian thermal distribution.

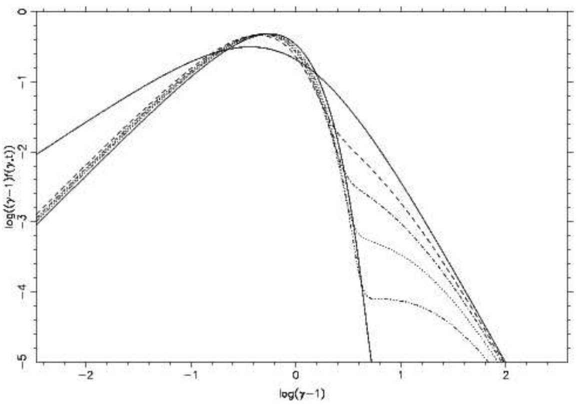

Figure 3: Thermalisation of a power-law distribution to a Maxwellian distribution as calculated by the HEART code.

1.3 The Kinetic Equation

Various scattering, emission and absorption processes result in the evolution of electron/positron energy distributions contained in hot plasmas. This evolution can be modelled by the kinetic equation. Ghisellini et al ([4]) present the kinetic equation without ultra-relativistic assumptions. It takes the synchrotron, bremsstrahlung and Compton cooling rates into account. Blumenthal & Gould ([1]) give the Compton cooling rate that takes energy gains as well as energy losses into consideration. The kinetic equation also has 'Source' and 'Sink' functions. These account for the electron/positron injection (non-thermal) and escape respectively. If non-thermal (or power-law) electrons are continuously injected, then the electron escape can play an important role for reaching equilibrium. In physical terms this can be justified by the fact that electron movement will result in their escape from the plasma.

Radiative cooling causes an initially power-law distribution to 'age'. For example, in the case of synchrotron radiation, the highest energy electrons cool faster than the lower energy electrons. If the electrons are continuously injected then a superposition of different 'aged' electron distributions can occur. Figure 4 shows the synchrotron ageing of an electron distribution.

1.4 Spatially Inhomogenous Distributions

The HEART code has been adapted to model spatially inhomogeneous electron/positron distributions. This can help to create a different geometry for the corona. Conventionally the corona is modelled to be a homogeneous hemisphere or slab above an accretion disk. Various covering factors are therefore required to correctly model the Hard and Soft states. With spatially inhomogeneous electron/positron distributions, the covering factor problem can be eliminated naturally. With 'pockets' of plasma within the cellular structure of our model, we aim to simulate the effect of particle acceleration by localised magnetic reconnection events ([3]). The principle behind magnetic reconnection events is similar to that observed in the solar corona.

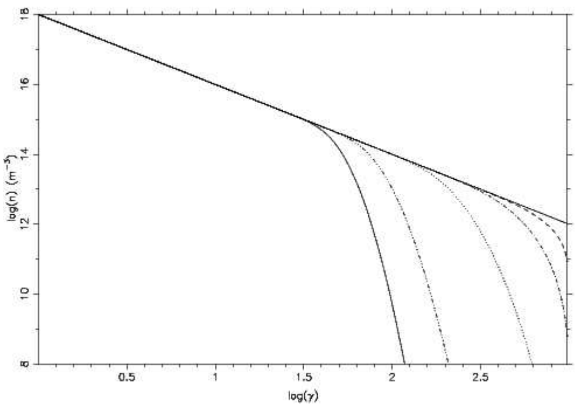

Figure 4: Radiative cooling causing 'ageing' of an electron distribution. The figure shows the case of synchrotron radiation causing the highest energy electrons to lose energy first.

1.5 Work in Progress

We are currently implementing pair production and annihilation in the HEART code. As we model the electrons and positrons thermalising to lower energies, we expect them to eventually annihilate. This may produce an annihilation line. We hope to investigate the role various mechanisms (e.g. Bremsstrahlung and thermal broadening) might have in suppressing the observation of distinct annihilation lines ([6]).

References

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