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Radiation from accelerated particles in shocks and reconnections

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Plasma instabilities excited in collisionless shocks are responsible for particle acceleration, generation of magnetic fields, and associated radiation. We have investigated the particle acceleration and shock structure associated with an unmagnetized relativistic jet propagating into an unmagnetized plasma. Cold jet electrons are thermalized and slowed while the ambient electrons are swept up to create a partially developed hydrodynamic-like shock structure. The shocked structures are depend on composition of jets (electron-positron or electron-ions). Strong electromagnetic fields are generated in the reverse shock and provide an emission site. These magnetic fields contribute to the electron's transverse deflection behind the shock. We have calculated, self-consistently, the radiation from electrons accelerated in the turbulent magnetic fields. We found that the synthetic spectra depend on the Lorentz factor of the jet, its thermal temperature and strength of the generated magnetic fields. The properties of the radiation may be important for understanding the complex time evolution and/or spectral structure in gamma-ray bursts, relativistic jets in general, and supernova remnants.

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1. Introduction and Recent Simulations

Particle-in-cell (PIC) simulations can shed light on the physical mechanism of particle acceleration that occurs in the complicated dynamics within relativistic shocks. Recent PIC simulations of relativistic electron-ion and electron-positron jets injected into an ambient plasma show that acceleration occurs within the downstream jet [**?**].

The effects of the different mass ratios ($m_i/m_e = 1, 20$) are shown in Figure 1[**?**]. Figure 1(b, and d) are the result of simulation using the electron-positron plasma to compare with the ion-electron in Figure 1(a, and c). There are several differences between two cases. One of them is the shape of the generated shock structure. Forward and reverse shock structure is generated in both cases. In electron-ion case the sharp contact discontinuity (CD) is found with strongly enhanced magnetic field as shown in Figs. 1a and 1b, but the transition peak of the forward shock is sharply increased in the electron-positron case. In this case, both positrons and electrons in the ambient appear dragged by the jet without any strong interactions compared to the electron-ion case. So the ambient particles are just swept up in front of the jet and the jet density has small peak associated with the shocked ambient particles.

The other difference is in the magnetic field shown in Fig 1 (c, and d). For both electron-ion and pair plasmas cases magnetic fields increase in the reverse shock region, but the peak magnetic field occurs at the contact discontinuity (CD) in the electron-ion case. Magnetic (Figs. 1c and 1d) and electric field (not shown) in the transverse directions strongly fluctuate in this region.

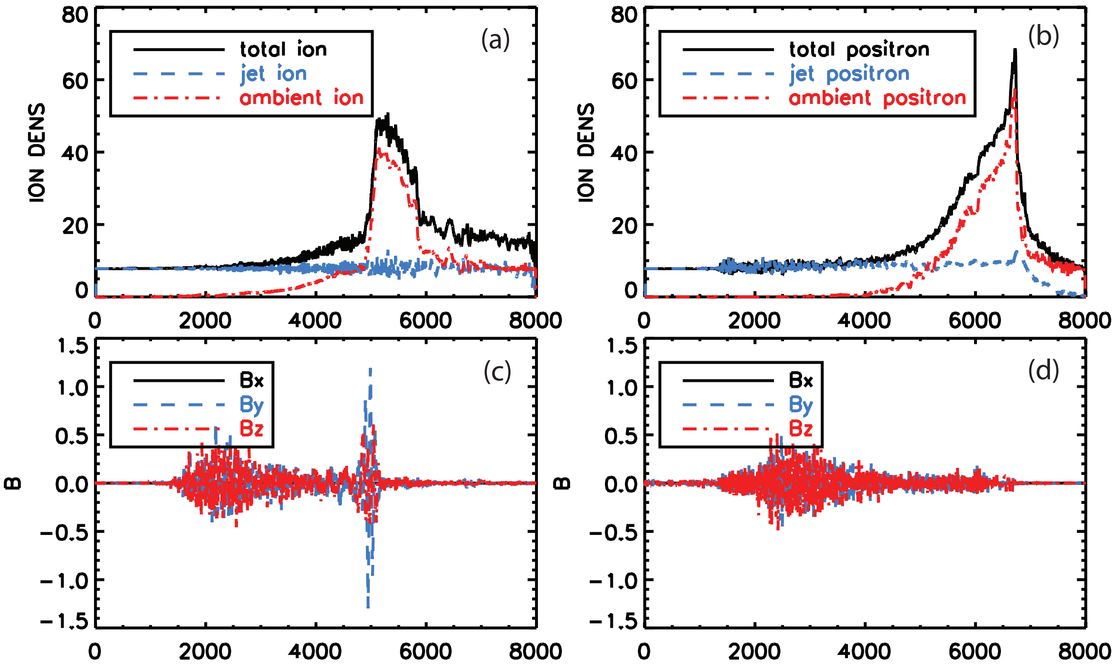

Figure 1: Ion density (a), positron density (b), and B ((c) for electron-ion plasma, and (d) for pair plasma at $\omega_{pi}T = 375$.

2. Synthetic spectra from simulations

We have calculated the radiation spectra directly from our simulations by integrating the expression for the retarded power, derived from the Liénard-Wiechert potentials for a large number of representative particles in the PIC representation of the plasma[**?**]). In order to obtain the spectrum of the synchrotron/jitter emission, we consider an ensemble of electrons selected in the region where the Weibel instability has fully grown and where the electrons are accelerated in the self-consistently generated magnetic fields.

Figure 2 shows how our synthetic spectrum matches with spectra obtained from Fermi observations. Figure 2a shows the observed spectra in νF_ν as modeled by[**?**] at five different time intervals.

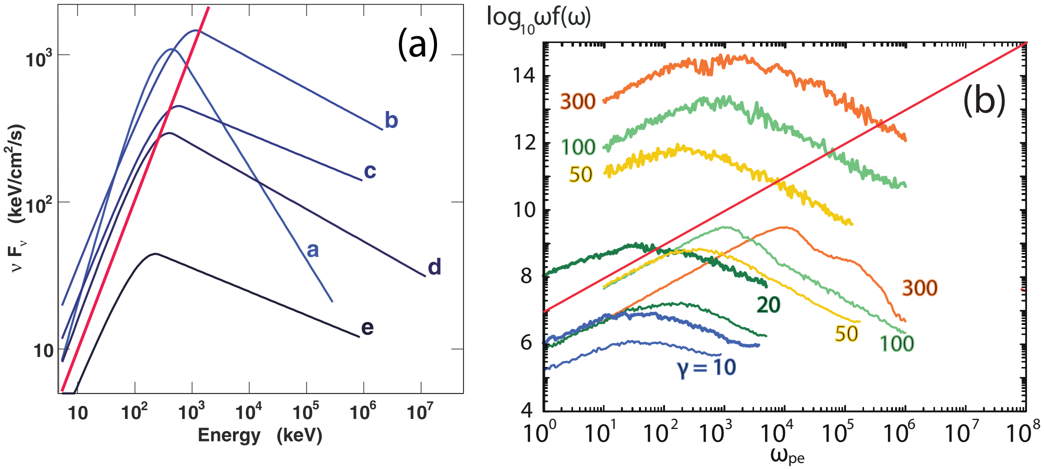

Figure 2: Comparison of a synthetic spectrum with spectra obtained from Fermi observations. Figure 2a shows the modeled Fermi spectra in νF_ν units for five time intervals. A flat spectrum would indicate equal energy per decade in photon energy. The changing shapes show the evolution of the spectrum over time. Figure 2b shows the spectra for the cases of $\gamma =$ 10, 20, 50,100, and 300 with cold (thin lines) and warm (thick lines) electron jets. The low frequency slope is approximately 1.

The red line in Fig. 2a indicates a slope of one, and except for the spectrum at time "a" the low frequency slopes are all approximately one. This is similar to a Bremsstrahlung-like spectrum at least for the low frequency side. As shown in Fig. 2b the slope at low frequency is very similar to the observed spectra. The peaks and slopes at high frequencies change over time.

Behind the reverse shock the electrons are accelerated and strong magnetic fields are generated as shown in Fig. [**?**, **?**]. Therefore, this region seems to produce the emission that is observed by satellites. We will examine the observed spectrum changes over time using different plasma conditions such as jet Lorentz factors, jet thermal temperatures, plasma compositions and other parameters.

In order to investigate the time evolution of spectra as observed by Femi, we need to simulate a large system so that we will be able to obtain synthetic spectra at different time periods where different nonlinear stages are established with different particle acceleration rates and magnetic field strengths. This investigation is in progress.

3. Discussion

A double shock structure (bow and jet shocks separated by a contact discontinuity region) is formed and electrons can be accelerated due to the Weibel instability in both shocks. Since we calculate the radiation from the electrons in the observer frame, and calculated spectra can be compared directly with observations. As shown in Fig. 1, the strongest electron acceleration and strongest magnetic fields are generated in the reverse shock. Therefore, in this simulation this region would produce the emission that is observed.

Emission obtained using the method described above is obtained self-consistently, and automatically accounts for magnetic field structures on the small scales responsible for jitter emission. By performing such calculations for simulations using different parameters, we can investigate and compare the different regimes of jitter- and synchrotron-type emission[**?**]. Thus, we should be able to address the low frequency GRB spectral index violation of the synchrotron spectrum line of death[**?**].

We will investigate the radiation in transient stage as a possible generation mechanism of precursors of prompt emission. In our simulations we calculate the radiation from electrons in the shock region. The detailed properties of this radiation are important for understanding the complex time evolution and spectral structure in gamma-ray bursts, relativistic jets, and supernova remnants.

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