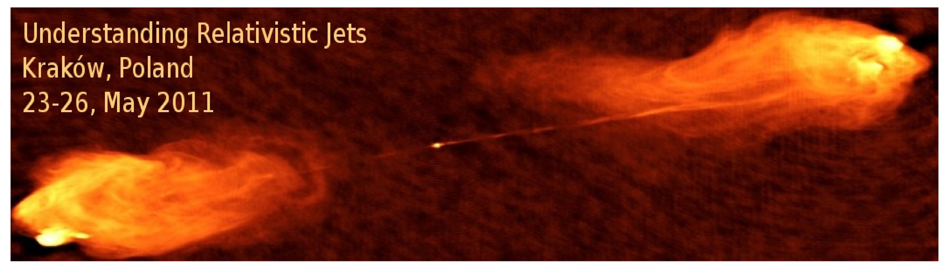

GAMMA-RAY BURSTS FROM MAGNETIZED COLLISIONALLY HEATED JETS

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ABSTRACT

Gamma-ray burst jets likely carry a significant neutron component [1], which inevitably leads to strong collisional heating of the jet. We investigate radiation produced by this heating using a new numerical code. We confirm the recent claim that collisional heating generates the observed Band-type spectrum of GRBs, extending to tens of GeV [2, 3]. In magnetized jets the low-energy part of the spectrum softens (photon index attains $\alpha \sim -1$), and a visible soft excess appears in the keV band. Strong magnetization steepens the spectrum above the peak and weakens GeV emission.

COLLISIONAL DISSIPATION

Decoupling of neutron and proton flows can lead to migration of the two species relative to each other, forming a compound flow. Resulting nuclear n-p collisions dissipate flow kinetic energy via two channels [2]:

- Elastic collisions heat protons to mildly relativistic energies, Coulomb collisions drain energy from protons to $e^{\pm}$
- Inelastic n-p collisions generate $e^{\pm}$ pairs with $\gamma \sim 300$ via pion production and their subsequent decay

Both channels dissipate comparable amount of energy. Pair distribution attains a hybrid shape: Maxwellian with a power-law tail.

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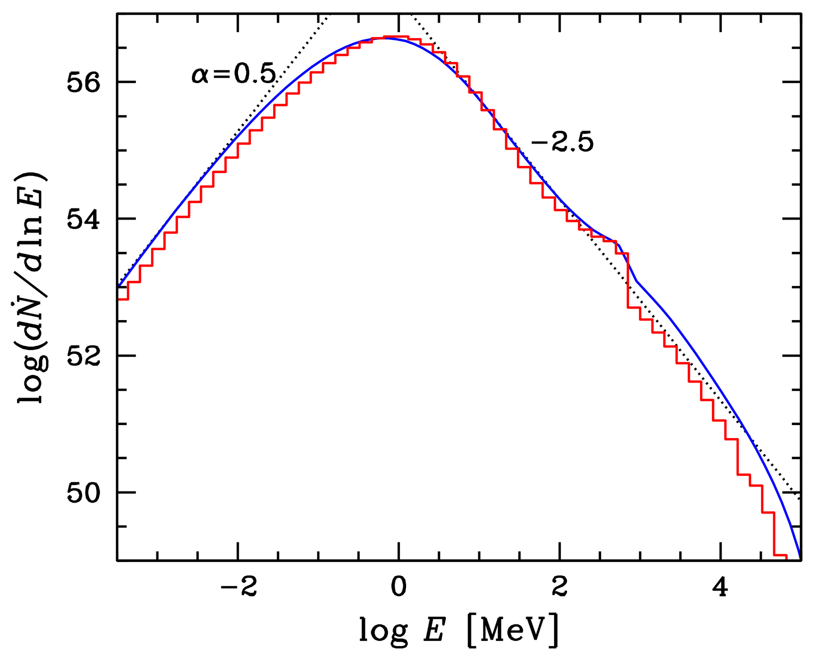
SPECTRA FROM NON-MAGNETIZED JETS

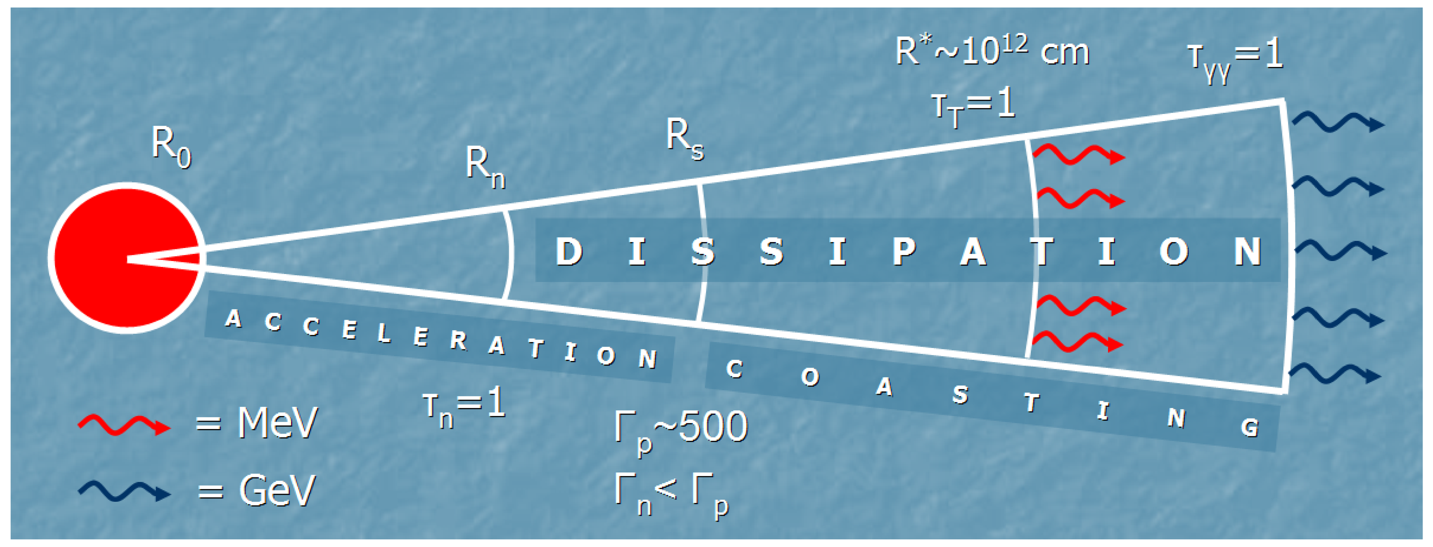
- Band-like spectra peaking near 1 MeV
- Low-energy spectrum determined by thermal radiation advected from the central source, modified by Comptonization. Slope *not Rayleigh-Jeans*, due to softening by large-angle emission
- Thermal Comptonization above the peak responsible for power-law up to ~ 20 MeV
- High-energy spectrum determined by pair-cascades initiated by the injected $e^{\pm}$ pairs
- *Steepening* in the GeV range due to pair-production opacity. *No cutoff* up to ~ 100 GeV

Observer frame spectrum: kinetic vs. Monte Carlo [2]



Parameters: $L = 10^{52}$ erg/s, $L = 2\times10^{51}$ erg/s, $\Gamma = 600$, $\Gamma_n = 100$, $r_0 = 10^7$ cm.

SIMULATION SETUP



- Simulations are done in the hot fireball picture [4, 5]
- Dissipation starts at R_n, where n-p flows decouple and operates throughout the region $R > R_n$ with decreasing efficiency
- Radiation released at the energy-dependent photosphere
- Model parameters: Kinetic luminosities L, L_n and Lorentz factors Γ,Γ_n of the neutron and proton flows, size r_0 of the central source, magnetization ϵ_B

RADIATIVE TRANSFER EQUATION

RTE in the comoving frame of an ultra-relativistic spherically symmetric flow [6, 7]:

$$\frac{1}{r^2}\frac{\partial}{\partial \ln r}\left[(1+\mu)\, r^2 I_\nu\right] = \frac{r}{\Gamma}\left(j_\nu - \kappa_\nu\, I_\nu\right) + (1-\mu^2)\frac{\partial I_\nu}{\partial \ln \nu} - \frac{\partial}{\partial \mu}\left[(1-\mu^2)(1+\mu)\, I_\nu\right]$$

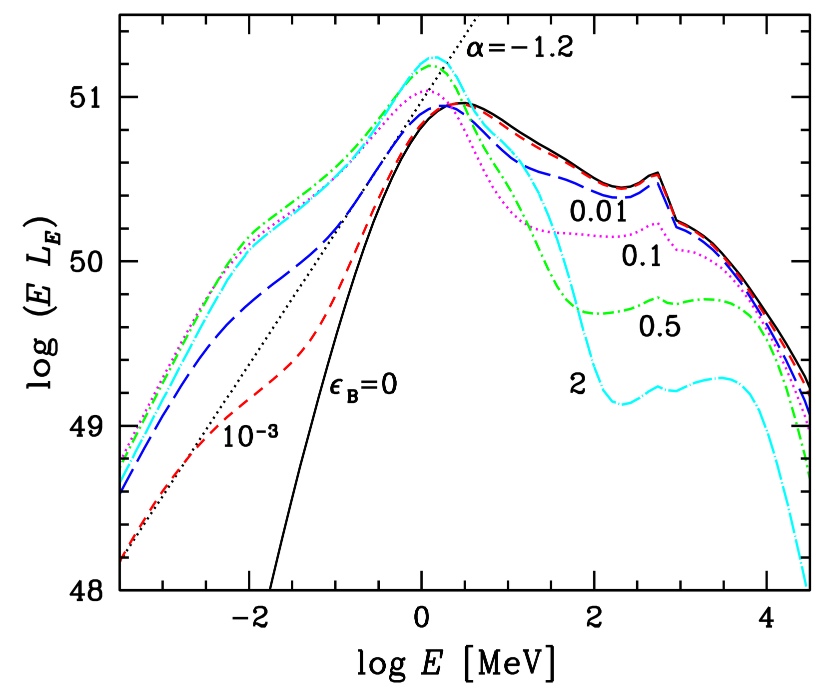
Comoving-frame quantities: I_ν - specific intensity, μ - cosine of the angle relative to the radial direction, ν - photon frequency, j_ν - emissivity due to synchrotron, Compton and pair-production processes, κ_ν - extinction due to the same processes.

External quantities: r - radius from the central engine, Γ - flow Lorentz factor.

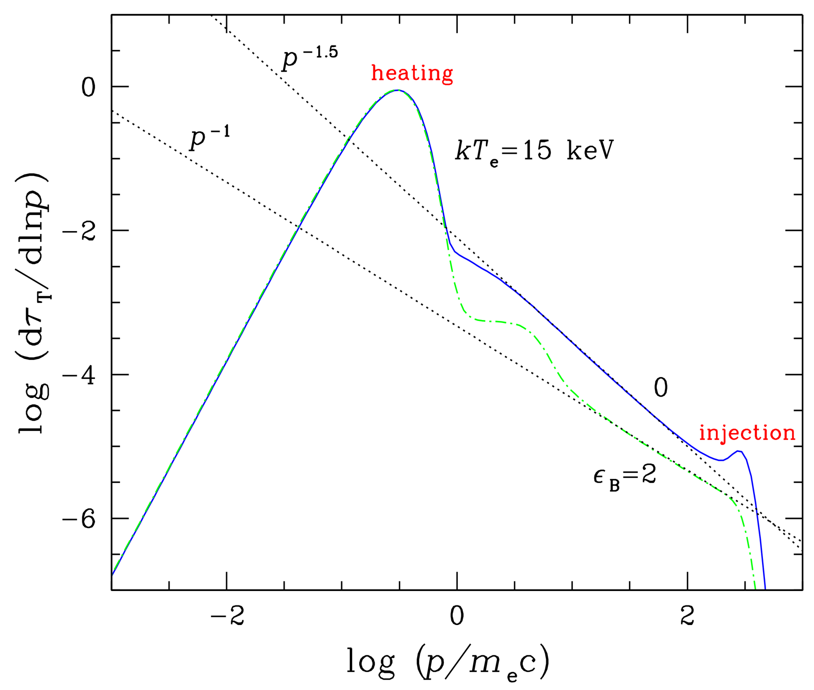
- The RTE automatically accounts for effects arising from relaticistic beaming, large-angle emission, dependence of the optical depth on the viewing angle etc.
- The RTE is solved simultaneously and self-consistently with the comoving-frame kinetic equations for electrons and positrons

SPECTRA FROM MAGNETIZED JETS

Observer frame spectra



Pair distributions (normalized)



In most plausible scenarios GRB outflows are expected to be at least moderately magnetized. We study the effect of magnetization on the collisional dissipation mechanism [3]. Magnetization is parametrized as the fraction ϵ_B of energy carried by the B-field, relative to the flow kinetic energy. The explored range is $0 < \epsilon_B < 2$.

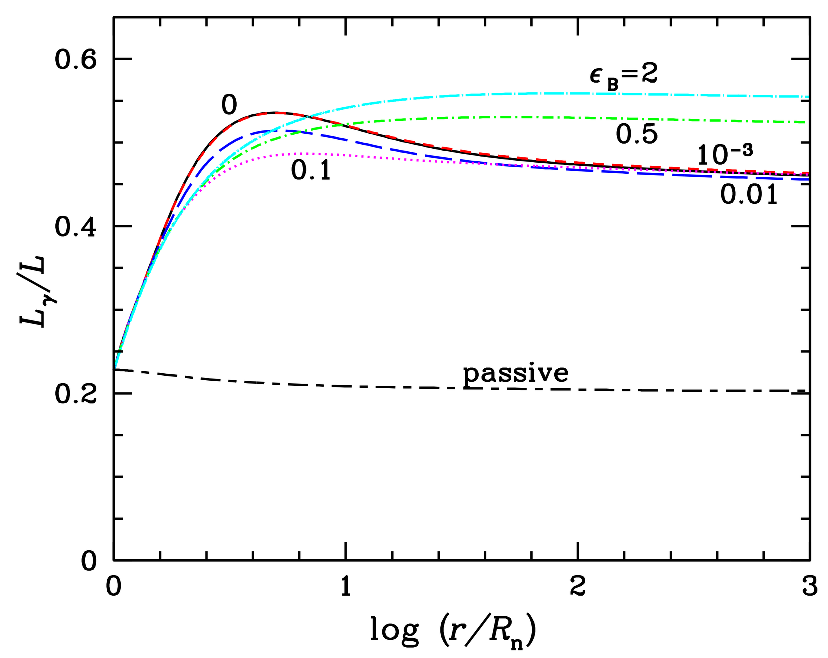
Effects of magnetization:

- Adds a sychrotron emission component from non-thermal electrons to the spectrum, visible as a soft excess below ~ 10 keV.
- Softens the spectrum below the peak, photon indices remain near $\alpha \sim -1$ for a wide range of magnetizations
- Stronger magnetization ($\epsilon_B \sim 1$) quenches the high-energy pair-cascades due to fast synchrotron cooling, the spectrum above the peak steepens
- A separate spectral component appears above 100 MeV, from inverse Compton scattering on non-thermal pairs
- The spectral peak remains near 1 MeV for the whole range of explored magnetizations $0 < \epsilon_B < 2$

RADIATIVE EFFICIENCY

- Radiative luminosity increases rapidly at $r \gtrsim R_n$ where collisional heating is strongest (compare to the passively cooling flow)
- The final efficiency is given by the asymptotic value of $\varepsilon_{\rm rad} = L_\gamma/L$ at large radii, and is determined by the combined effect of heating and adiabatic cooling
- Radiative efficiency remains high (close to 50 %) in magnetized flows

Fraction of flow energy carried by radiation as a function of radius

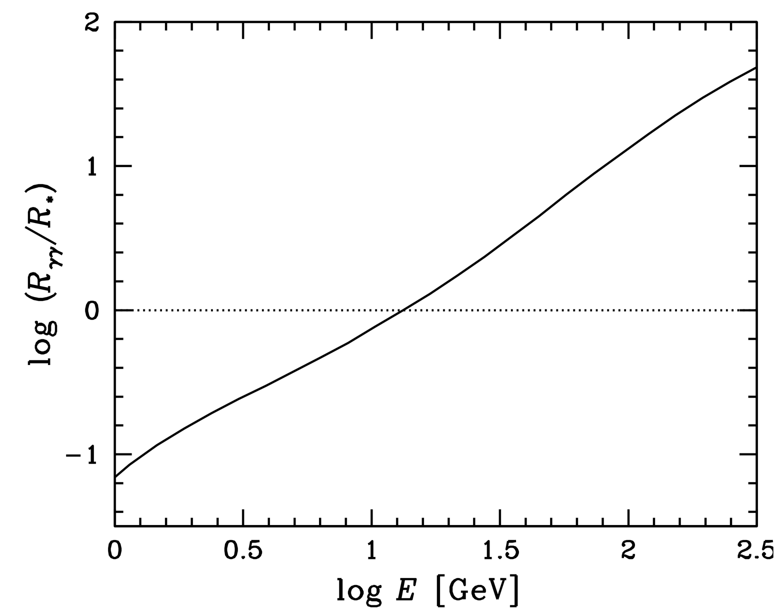


GEV EMISSION

The spectra from collisional dissipation extend well into the GeV range without a cutoff, because

- Dissipation operates over a wide range of radii, including those where the source becomes optically thin to pair-production
- For typical parameters, the pair-production photosphere is outside the Thomson photosphere only for photon energies above ~ 10 GeV

Radius of the pair-production photosphere relative to Thomson, as a function of photon energy



SUMMARY

- Collisional dissipation constitutes an efficient mechanism of dissipating kinetic energy in GRB outflows
- The resulting emission resembles the Band spectrum, peaking close to 1 MeV
- Hard low-energy slopes are easily produced, in contrast to synchrotron shock models
- Low energy photon indices of magnetized jets are close to the observed average value $\alpha = -1$
- Synchrotron emission below ~ 10 keV might provide explanation to the soft excesses seen in a number of BATSE bursts [8], as well as the recent GRB 090902B
- High-energy spectrum extends to ~ 100 GeV without a cutoff, easily accommodating the highest energy photons detected by LAT