Magnetic Field Dissipation in GRBs

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Abstract. We report on the first steps towards the three-dimensional simulation of magnetic field dissipation in gamma-ray burst prompt emission. The model is based on magnetically driven Poynting flux outflow.

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INTRODUCTION

While the *internal shock* model has had some success in reproducing gamma-ray burst (GRB) characteristics, it suffers from an *efficiency problem* (the relatively low efficiency with which the central engine's energy is converted to prompt gamma-rays), and a *field strength problem* (generating the field strength needed to produce efficient synchrotron emission).

In several of the more promising models of the central engine, a rotating relativistic object powers the outflow. These objects naturally have strong magnetic fields, and the transmission of rotational energy to the outflow via the field (Poynting flux) is also the the most effective ways of satisfying the *baryon loading constraint* (the large energy-to-rest-mass ratio needed to explain GRBs). Such magnetically powered outflows come in two basic varieties: the DC model (axi-symmetric, e.g.[**?**]), and the AC model (flow generated by a central engine with a non-axisymmetric magnetic field, e.g. [**?**]). Their advantage over the internal shock model is that they can produce prompt emission with high (50%) efficiency, naturally provide the strong magnetic field needed for synchrotron emission, and are very effective at accelerating the flow through the energy dissipation of magnetic energy by magnetic reconnection.

MODEL

The key feature of our model (suggested by [**?**]) is that magnetic field dissipation can solve both the global acceleration of the jet and the radiation mechanism at once. The law of the energy conservation yields $\partial_t u_m + \nabla \cdot \mathbf{S} = -\mathbf{j} \cdot \mathbf{E}$, where $u_m = (E^2/8\pi + B^2/8\pi)$ is the electromagnetic energy density and $\mathbf{S}$ is the Poynting vector. Thus the energy trapped in the magnetic field and available to dissipate is not only the magnetic energy density $B^2/8\pi$ but the energy driven by $|\mathbf{S}| = cB^2/4\pi$. Defining the magnetic enthalpy $w_m = u_m + p_m$, part of the magnetic energy is converted into the internal energy u_m which is radiated away (almost immediately) through synchrotron radiation mechanism if it happens in the optically thin region above the photosphere, or it heats the plasma and let it expand if it occurs within the photosphere. The other part leads to the magnetic pressure gradient ∇p_m that accelerates the flow.

We study the resistive MHD processes in a small box within a baryon polluted Poynting flux outflow, assuming the alternating magnetic field configuration – striped wind – of a non-axisymmetric pulsar or a magnetar [**?**]. Let this cube be far enough from the central engine to use cartesian coordinates, to assume initially parallel poloidal magnetic field component only, self-similarity of the box to other part of the jet and let steady state holds macroscopically in the jet - saying this we can extrapolate the result from the small box along the whole jet.

To overcome the highly relativistic nature of the GRB explosion and to keep the computer resources bearable with a given level of detail we introduce spatially homogeneous anisotropic linearly expanding co-moving frame $\mathbf{x}$. We have rewritten the MHD equation set according to the (newtonian) transformation $\mathbf{x} \to A\mathbf{x}$ and $t \to t$, where $A = A(t)$ is the matrix describing the expansion in each coordinate. It yields $\mathbf{v} \to A\mathbf{v} + \dot{A}\mathbf{x}$, $\nabla \to \frac{1}{A}\nabla$ and $\partial_t \to \partial_t - \frac{\dot{A}}{A}(\mathbf{x}\cdot\nabla)$.

SIMULATION

3D calculation allows to capture more complex topological structure but are extremely expensive in cost of CPU. We are building resistive MHD code based on finite grid method, modifying the 5th order in spatial derivatives and 3rd order predictor–corrector time integration scheme from [**?**]. As initial conditions we set anti-parallel magnetic field multi(N)-layers separated by $\lambda = \Gamma_0 2\pi c/\Omega$, where Γ_0 is the mean Lorentz factor of the flow and Ω the rotational velocity of the progenitor.

As a preview we show a simplified 2D result of dissipation for N=2 layers and with no feedback to acceleration $\ddot{A} = 0$ in Fig. **??**.

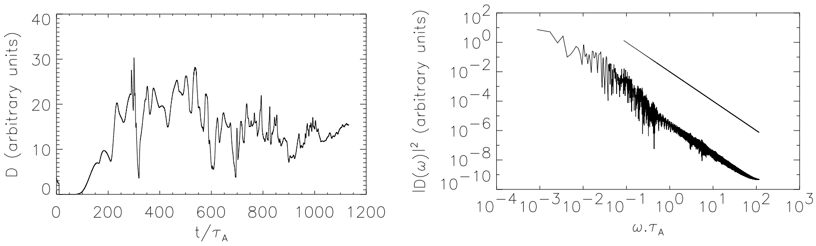

FIGURE 1. Time variations (smoothed) of the dissipated power D (left) and its Fourier power spectrum (right). The line corresponds to the power-law index of -2. $\tau_A \equiv \lambda/v_A$ is the Alfvén transit time.

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