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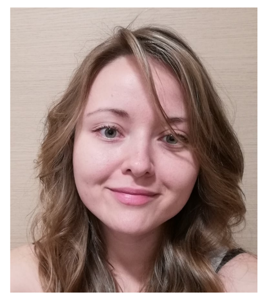

High energy photon and neutrino emission from GRBs in the Hadronic Supercriticality expanding model

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Introduction

Hadronic Supercriticality (HSC) is a property of hadronic systems according to which relativistic protons lose the energy stored in them abruptly and very efficiently through the emission of photon outbursts. We investigate HSC in the context of an expanding system and show its direct analogy to Gamma Ray Bursts (GRBs). We simulate a variable GRB engine that injects a series of blobs, each of them having initial parameters leading to the onset of HSC. For low expansion velocities, e.g. $u_{\rm exp}<0.01c$, one blob can produce a quasi-periodic light curve. The superposition of all the light curves results in the production of a multi-pulse long duration light curve with a power spectrum similar to that of red-noise processes.

First Principles

Relativistic protons, with a power law distribution, are injected in an expanding spherical source of instantaneous radius, $r(t) = r_{\rm in} + u_{\rm exp}t$, containing a tangled magnetic field, $B(r) = B_{\rm in}(r_{\rm in}/r)^q$. HSC manifests itself when the proton energy density inside the source exceeds some critical value. Furthermore HSC arises as a result of specific networks of physical processes [1, 3] (see Fig. 1).

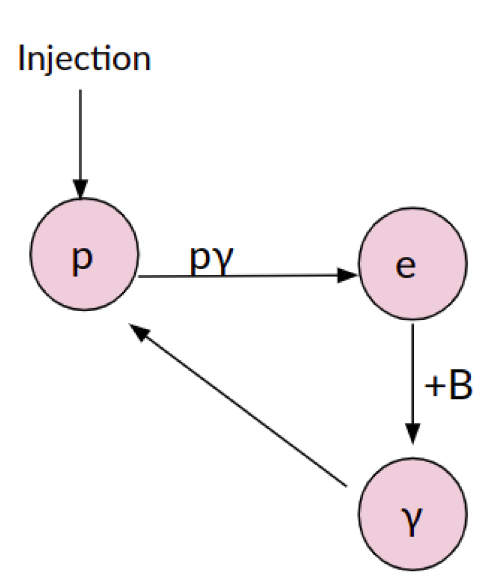

Figure 1:A schematic illustration of a feedback loop [1].

Once the appropriate conditions are satisfied, abrupt photon outbursts are generated that have usually a quasi oscillatory temporal behaviour, which reminds of a prompt GRB emission.

Numerical Code

We develop a numerical code that computes the evolution of the stable particle populations in a spherically expanding volume, by solving a system of time dependent equations for each species:

$$\frac{\partial n_{\rm j}}{\partial t} + u_{\rm exp}\frac{3n_{\rm j}}{r(t)} + \frac{n_{\rm j}}{t_{\rm esc,j}} + \mathcal{L}_{\rm j} = \mathcal{Q}_{\rm j}. \quad (1)$$

Here, $n_{\rm j}$ is the number density of each species, $\mathcal{L}_{\rm j}$, $\mathcal{Q}_{\rm j}$, the loss and injection per volume terms, which include the processes shown in [2] and adiabatic losses. The main parameters of the problem are:

1. Initial proton luminosity
2. Initial magnetic field and magnetic field profile
3. Initial source radius
4. Distribution index and maximum proton energies
5. Expansion velocity

Parameters for a GRB-like event

- Initial radii, $r_{\rm in} \approx 10^{11}$ cm
- Expansion velocities, $u_{exp} \leq 10^{-2}c$
- Initial magnetic fields, $B_{\rm in} \approx 10^4$ G
- Decreasing profile of B, $q = 1$
- Maximum proton Lorentz factors, $\gamma_{\rm max} = 10^4 - 10^5$
- Proton injection index, $p = 2$

Synthetic light curves and spectra

- We assume a regular engine emits 10 HSC blobs. The Bulk Lorentz factor of the outflow is assumed $\Gamma = 100$. The blobs are observed on-axis by the observer.
- We numerically compute the bolometric electromagnetic signal from each blob and superimpose them (Fig 2).
- The superposition of photon spectra results in a broadband photon spectrum that peaks at ~ 1 MeV (Fig. 3).
- The total energy emitted in photons is computed $E_{\gamma,\rm tot} = 9 \times 10^{51}$ erg.
- We compute the all-flavour neutrino spectra emitted by each expanding blob (Fig. 4). The total neutrino emission of the burst peaks at $\simeq 10$ TeV.

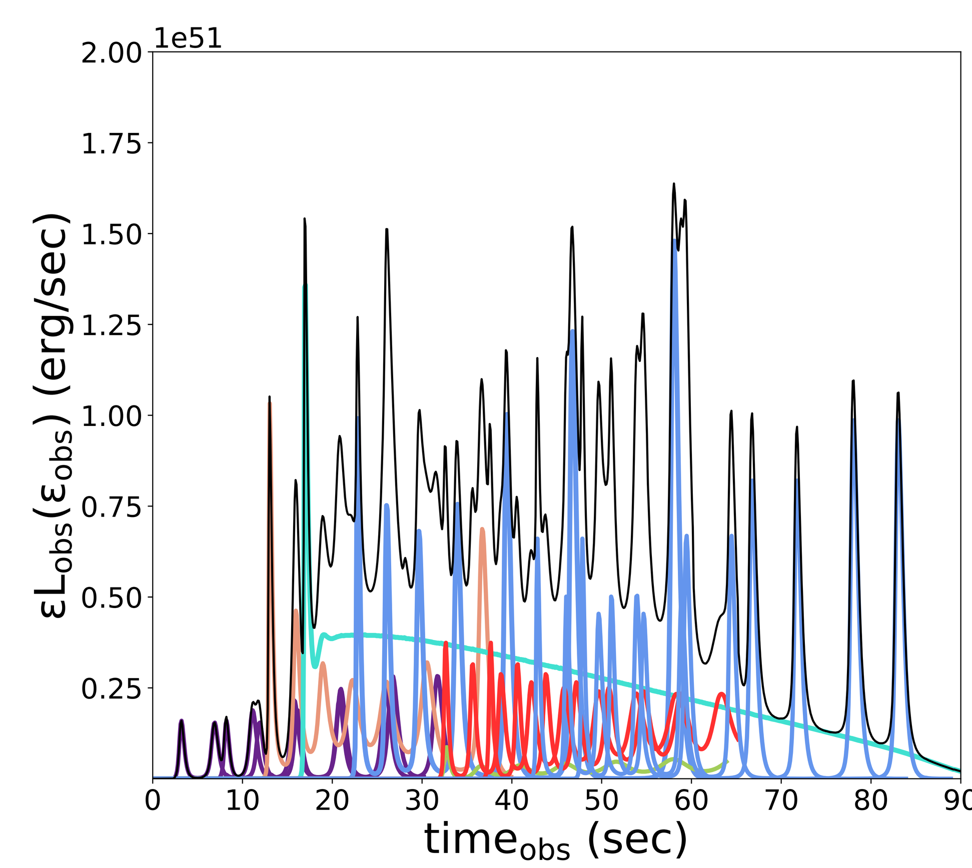

Figure 2:The total light curve produced by the HSC model (black solid line), assuming $\Gamma = 100$, $z = 2$. The coloured curves show the contribution of each blob.

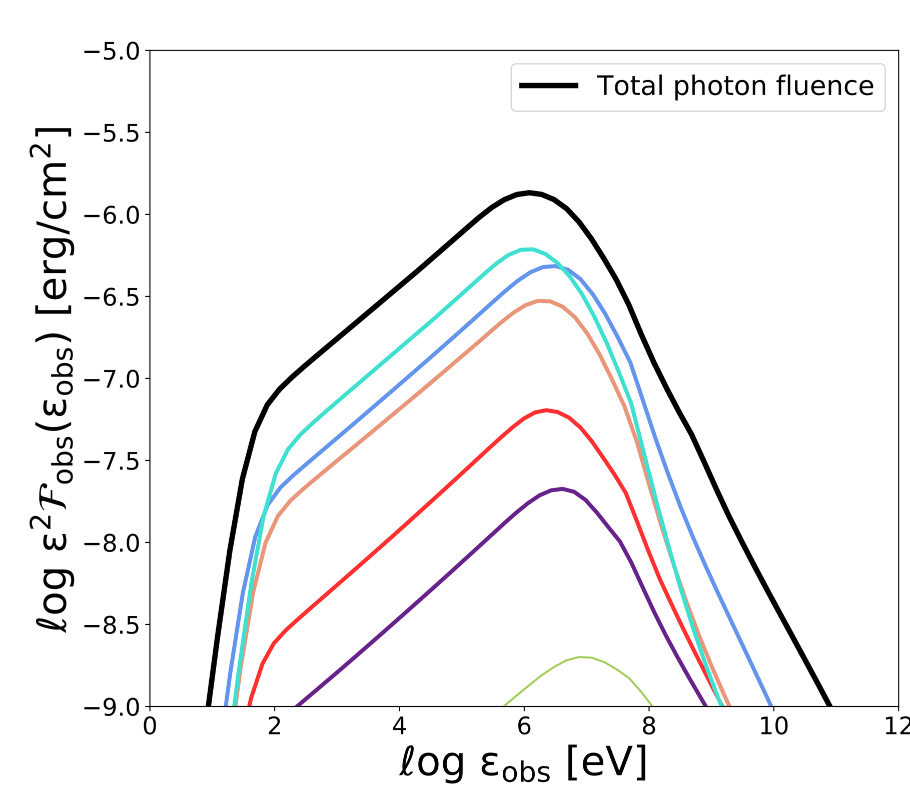

Figure 3:The total fluence per photon energy (solid black line) and the photon spectra produced by each blob (same colour coding as in Fig.2).

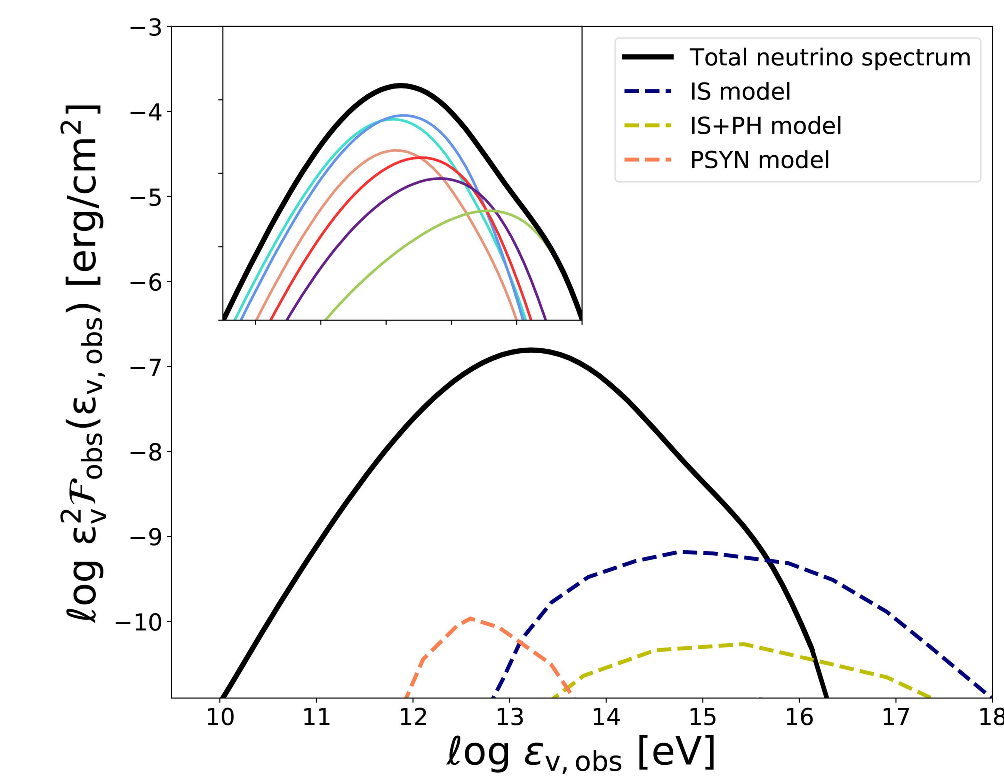

Figure 4:The all-flavour neutrino fluence (solid black line), plotted together with neutrino spectra, computed with other models (see label).

Conclusions

- The peak photon energy is ~ 1 MeV for maximum proton energies $\sim 1 - 10$ PeV assuming a Lorentz factor 100.
- The peak γ-ray luminosities are in the range $10^{49} - 10^{52}$ erg s^{-1}.
- The neutrino spectrum, with an all-flavour fluence $\sim 10\%$ of the γ-ray one, is about two orders of magnitude higher than the expected neutrino spectrum of the IS model, and peaks at about two orders of magnitude lower energy.

References

[1] J. G. Kirk and A. Mastichiadis, A&A, Nov 1992
[2] A. Mastichiadis and J. G. Kirk, A&A, Mar 1995
[3] M. Petropoulou and A. Mastichiadis, MNRAS, Apr 2012

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