The properties of the outflow and prompt emission of 14 LAT GRBs

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Abstract

The composition of the jet and the nature of the prompt non-thermal emission are open questions in gamma-ray bursts astrophysics. In this work, we study the degree of magnetisation of the jet and the prompt emission for 14 Fermi LAT GRBs with sub-dominant black-body components. We first carry out the joint spectral analysis of these GRBs with the GBM and LAT data using multi-component spectral models. We then use the results of the spectral analysis to study the characteristics of the jet and the prompt non-thermal emission in various scenarios.

Sample of GRBs

We identified 14 GRBs in the 2nd LAT GRB catalog whose fit† of the time-integrated prompt emission spectrum improved significantly with the addition of a sub-dominant black-body component.

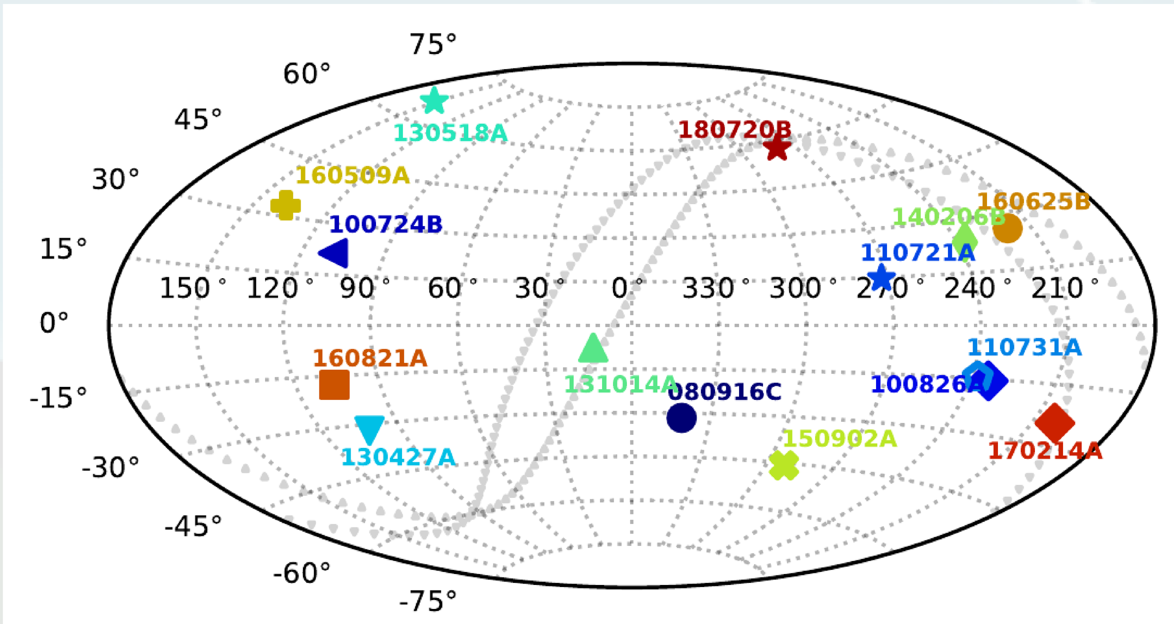


Fig. 1: The 14 GRBs in the sample shown in galactic coordinate system.

Applying the model

Based on the work of Pe'er et al. 2007 [3] and Hascoet et al. 2013, Guiriec et al. 2013 [4] obtained the following expressions.

$$R_0 \simeq \left[\frac{D_{\rm L}\mathcal{R}}{2(1+z)^2}\left(\frac{\phi}{1-\phi}\right)^{3/2}\right] \times \left[\frac{f_{\rm NT}}{\epsilon_{\rm Th}}\right]^{3/2},$$

$$\Gamma \simeq \left[\frac{\sigma_{\rm T}}{m_{\rm p}c^3}\frac{(1+z)^2 D_{\rm L} F_{\rm BB}}{\mathcal{R}}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times [(1+\sigma)f_{\rm NT}]^{-1/4}$$

$$R_{\rm ph} \simeq \left[\frac{\sigma_{\rm T}}{16 m_{\rm p}c^3}\frac{D_{\rm L}^5 F_{\rm BB}\mathcal{R}^3}{(1+z)^6}\frac{1-\phi}{\phi}\right]^{\frac{1}{4}} \times [(1+\sigma)f_{\rm NT}]^{-1/4}$$

$$\mathcal{R} = \left(\frac{F_{\rm BB}}{\sigma_{\rm SB}T_{\rm BB}^4}\right)^{1/2} \qquad \phi = F_{\rm BB}/F_{\rm Tot}$$

R_0: initial/jet launching radius
R_{ph}: photospheric radius
Γ: Lorentz factor

Parameters from spectral fits:
F_{BB}, F_{tot}:observed BB and total fluxes
T: temperature of the BB component

Assumed values:
σ: Magnetisation at the end of acceleration
f_{NT}: efficiency of non-thermal emission process

z, D_L, c, mp, σ_T, σ_{SB} are the redshift, luminosity distance, speed of light, proton mass, Thompson cross-section, Stefan-Boltzmann constant, respectively.

†Spectral analysis

We fitted the combined GBM and LAT data of the 14 GRBs over their T90 duration measured in the GBM with a set of 12 spectral models.

Energy range: GBM: 8 keV - 40 MeV; LAT: 100 MeV - 100 GeV

Tools used: Fermitools, Rmfit

Spectral models:

CPL	Band	SBPL
CPL + PL	Band + PL	SBPL + PL
CPL + BB	Band + BB	SBPL + BB
CPL + PL + BB	Band + PL + BB	SBPL + PL + BB

Where PL, CPL, Band, SBPL and BB stand for power-law, power law with an exponential cutoff, the Band function [1], smoothly broken power-law and black-body functions, respectively.

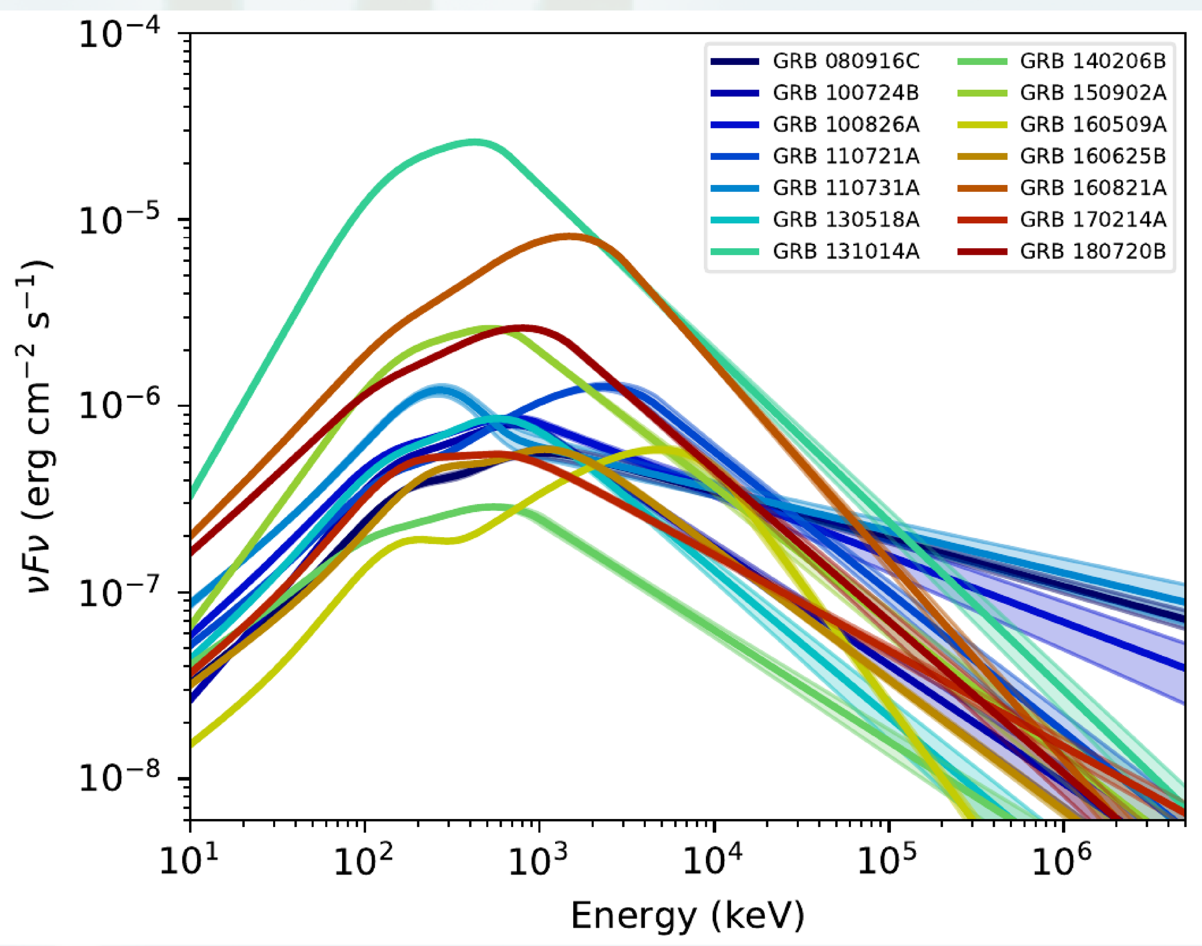
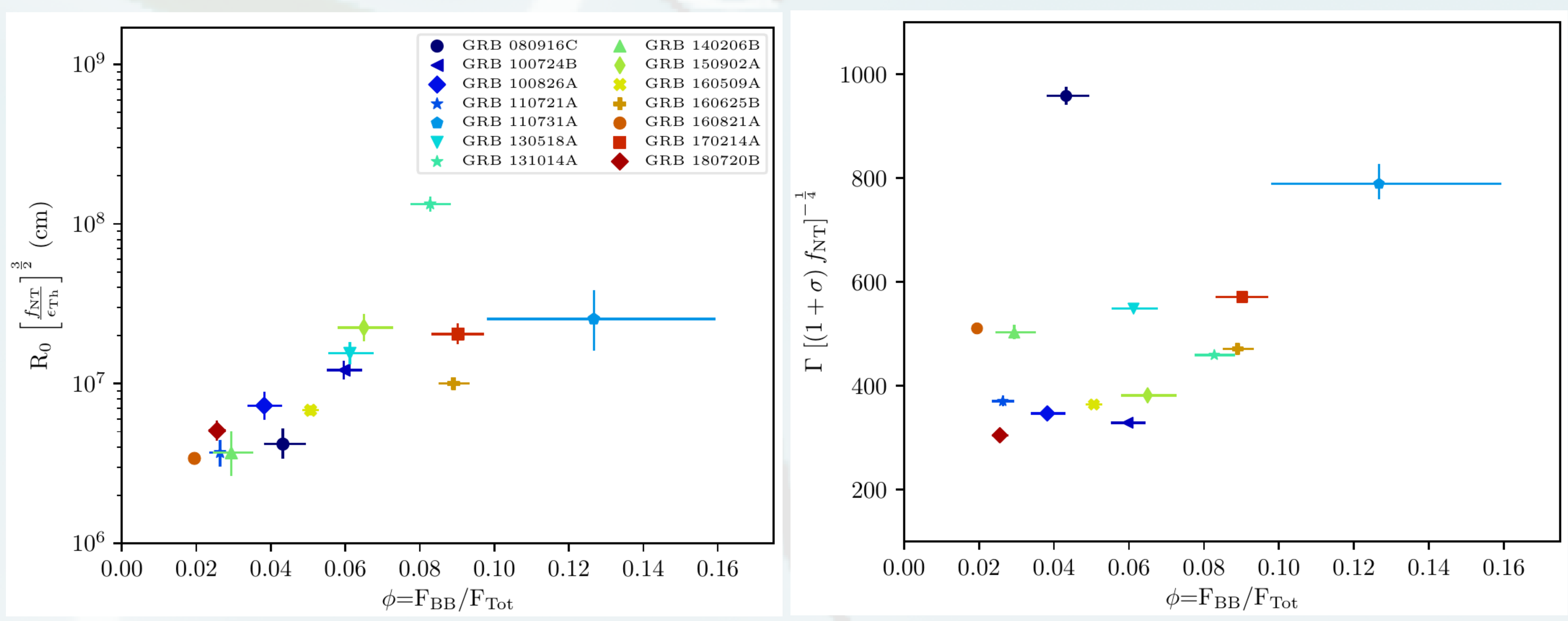


Fig. 2: The spectral energy distributions obtained from the best-fit models. The 68% confidence intervals are given through the shaded region.

Results: Preliminary

Using the results of the spectral analysis, we obtain the following preliminary results.



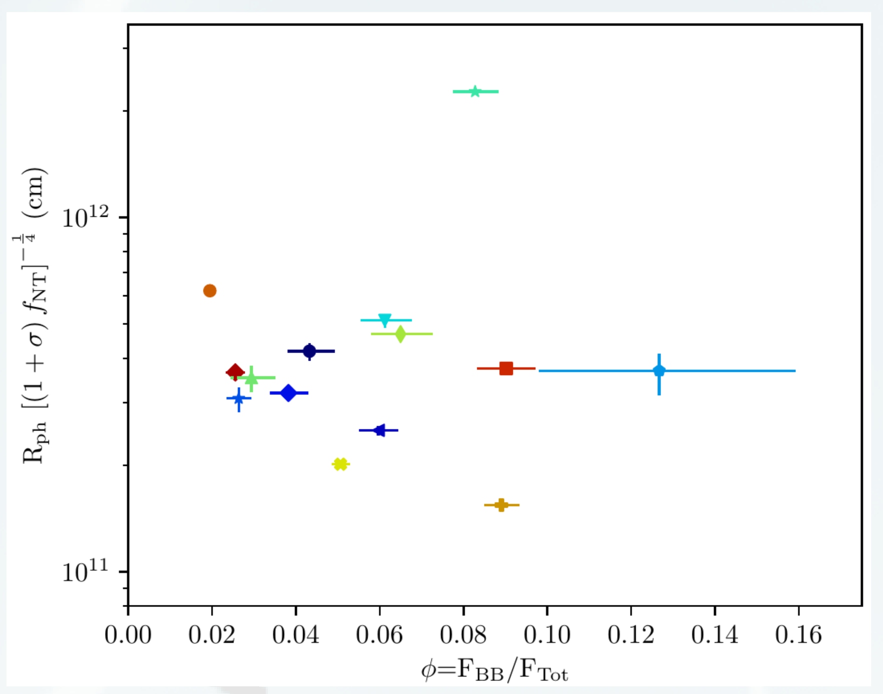


Fig. 3: The dependence of R_0 (top left), Γ(top right) and R_{ph} (bottom left) on the ratio of the BB and total fluxes.

Summary and future direction: The spectral fits of 14 GRBs show significant improvement with an additional BB component. The results of these fits can be used to study the outflow of GRBs.

Hybrid outflow model used

We use the results of the spectral analysis to study the outflow of the GRBs through a hybrid jet model proposed by Hascoet et al. 2013 [2].

In this model, the total power injected at the onset of the outflow (at radius R_0) can have both thermal (ϵ_{th}) and magnetic fractions (ϵ_M) such that

$$1 = \epsilon_{th} + \epsilon_M$$

Other assumptions include:

- The outflow becomes spherical at a certain radius R_{sph}.
- The acceleration ends at a radius R_{sat} such that $R_{sat} < R_{ph}$, where R_{ph} is the photospheric radius.
- The prompt non-thermal emission occurs above the photosphere.
- There is no dissipation below the photosphere.

→ This allows the study of a particular class of models. Alternative models allow dissipation below the photosphere or acceleration above it.

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References

[1] Band, D., Matteson, J., Ford, L., et al. 1993, The Astrophysical Journal, 413, 281
[2] Hascoët, R., Daigne, F., & Mochkovitch, R. 2013, Astronomy & Astrophysics, 551, A124
[3] Pe'er, A., Ryde, F., Wijers, R. A., Mészáros, P., & Rees, M. J. 2007, The Astrophysical Journal Letters, 664, L1
[4] Guiriec, S., Daigne, F., Hascoët, R., et al. 2013, The Astrophysical Journal, 770, 32

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