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The role of internal shocks in prompt gamma-ray emission: implications for synchrotron radiation and spectral breaks

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Abstract

Synchrotron radiation is the main candidate to explain prompt emission in gamma-ray bursts (GRBs), whose spectra are normally modeled by connecting power laws (PL) with different spectral indices on both sides of the peak energy. Recent analysis based on observations with *Swift*/XRT + BAT and *Fermi*-GBM shows the appearance of another spectral break, at lower energies, such that the spectra would be better described by the connection of three PLs, with spectral indices commonly denoted by α_1, α_2 and β. These studies have obtained average values for these indices consistent with synchrotron emission in the fast cooling regime, namely $\alpha_1 \simeq -2/3$, $\alpha_2 \simeq -3/2$, and $\beta < 2$. One recent model suggests that the three PLs can be due to the superposition of two spectral components, namely the synchrotron emission due to the forward shock, and the one due to the reverse shock. We compare results of one such approach to the spectral indices obtained by analyzing *Swift* and *Fermi* data, and discuss shortcomings in the predicted values for α_1 and α_2.

GRB prompt emission observations: spectral breaks

- Using a sample of 14 GRBs, [1] performed a time-resolved spectral analysis of *Swift*/XRT + BAT data and found that an additional power law, for energies in the low keV range, is required to fit over 60% of the prompt GRB spectra, due to another spectral break in lower energies. These results were confirmed by time-integrated analysis of a larger sample (34 bursts) [2] as well as optical data, when available [3]. A similar analysis, now using *Fermi*-GBM data [4], strengthened the results of [1, 2, 3] for long GRBs – see Figure 3.

GRB prompt emission modeling: contributions from both forward and reverse shocks

- The formation and propagation of internal shocks upon the collision of shells in GRB jets is a natural byproduct of varying speeds within the jet;
- Similar to [5], we build a hydrodynamical model describing the evolution of both forward (FS) and reverse (RS) shocks that develop upon the collision of two cold shells – see Figure 1 for a sketch of the post-collision scenario;
- Using the hydrodynamical model above, we apply a broken PL model in which the slopes are those expected from synchrotron radiation to obtain the expected spectral contributions of both FS and RS;
- We consider the emission from the equal arrival time surfaces (EATS), i.e., the regions whose emitted photons arrive at the observer at the same time.

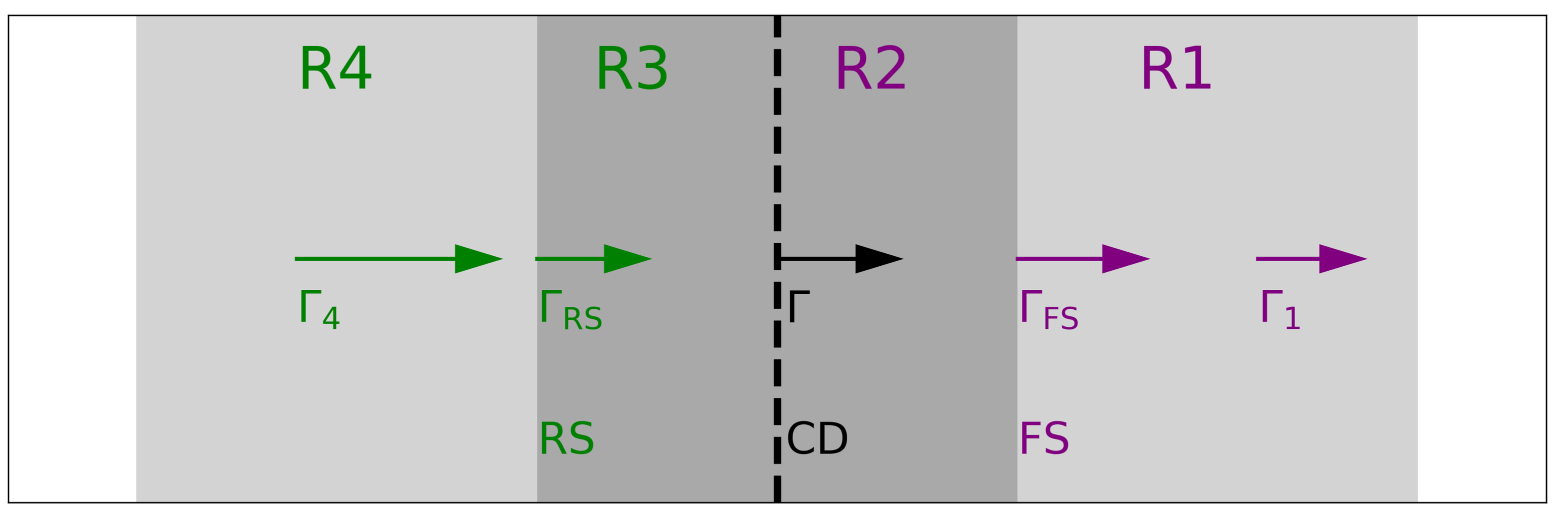

Figure 1: Cartoon depicting the post-collision scenario, with the contact discontinuity (CD) separating the two shocked regions (R2 and R3, dark grey), while regions R1 and R4 (light grey) are not shocked (yet). The arrows show the Lorentz factors (to scale) of (left to right): the unshocked part of the trailing shell, the reverse shock front, the contact discontinuity, the forward shock front, and the unshocked part of the leading shell.

Results

- Using the prescription outlined above, we were able to find spectra showing two breaks, as observed in [1, 2, 3, 4], similar to what was found in [6];
- However, using this model, we found $\alpha_1 \simeq -3/2$, $\alpha_2 \simeq -1.86$, as seen in Figure 2, in tension with $\alpha_1 \simeq -2/3$, $\alpha_2 \simeq -3/2$ inferred from observations – see Figure 3 – which points to limitations in this approach.
- The slope between $E_{\rm break}$ and $E_{\rm peak}$, i.e. α_2 in the example of Figure 2, will vary according to the importance assigned to the FS and/or RS contributions, but nonetheless α_2 will be softer than inferred from observations.

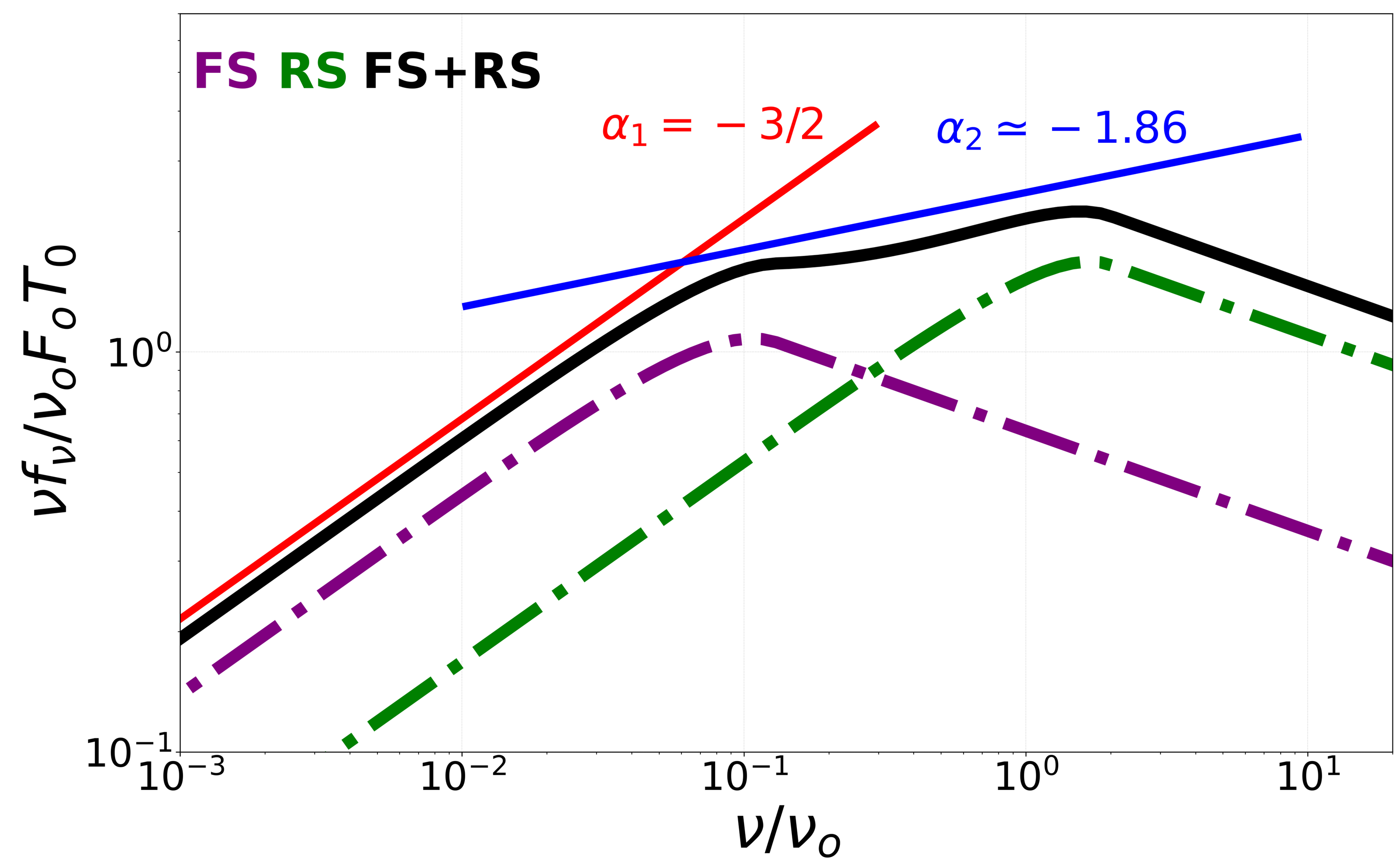

Figure 2: Example of a time-integrated spectrum showing the contributions of forward shock (FS, purple), reverse shock (RS, green) and the sum of these components (FS+RS, black). The blue and red lines correspond to the spectral indices α_1 and α_2 obtained with this approach.

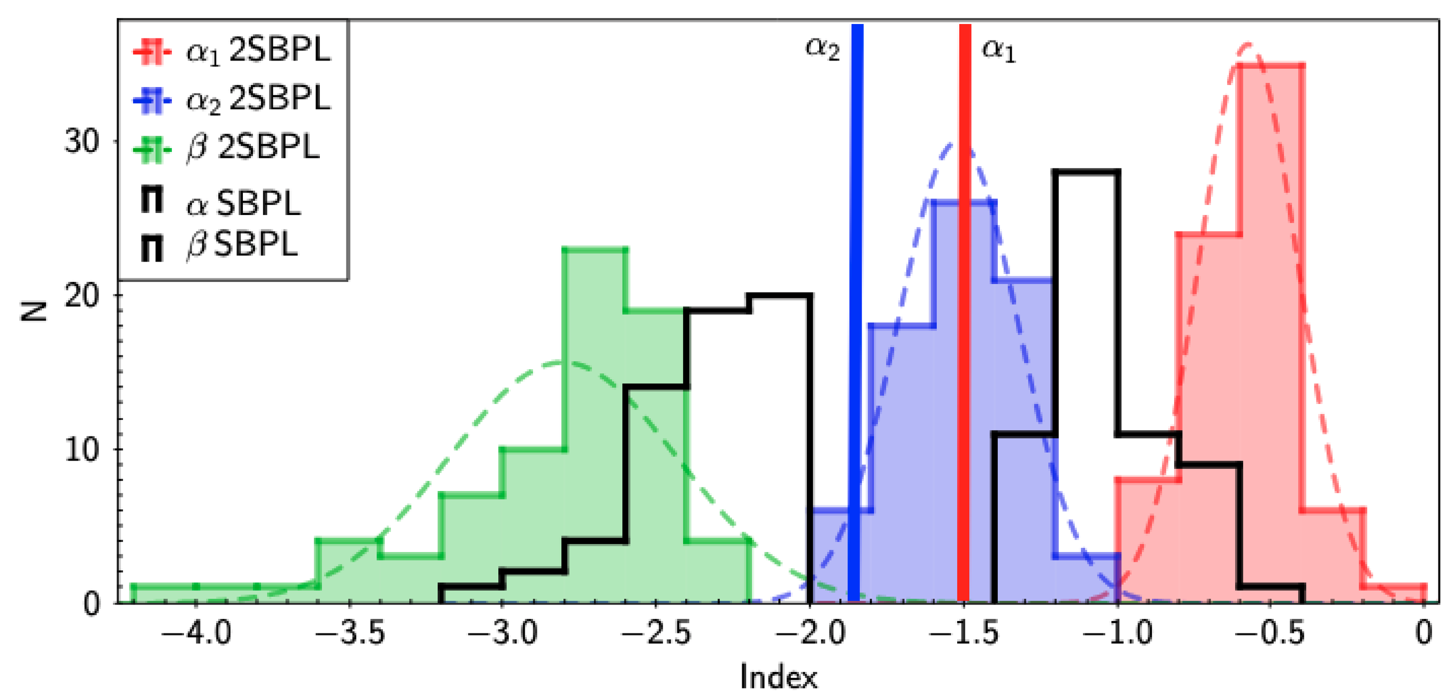

Figure 3: The values we obtain for α_1 and α_2 from the spectrum shown in Figure 2 (black line) are added (red and blue vertical lines) to this figure adapted from [4], where their distributions inferred from *Fermi* GBM bursts are shown.

Conclusions

- Modeling the prompt emission of GRBs by including separate contributions of synchrotron radiation from both forward (FS) and reverse (RS) shocks naturally shows the appearance of breaks in the spectrum of GRB prompt emission, as seen in Figure 2;
- When compared to *Swift* and *Fermi* observations of multiple long GRBs, however, the spectral indices arising from the sum of the contributions of FS and RS fall well outside those obtained by empirical fitting over those data (e.g. [4]), as seen by our reported values of $\alpha_1 = -3/2$ and $\alpha_2 \simeq -1.86$ (Figure 3);
- Our preliminary findings suggest that a composition of forward and reverse shocks, even though able to reproduce the qualitative shape of the three-PL spectra, fails to reproduce the correct photon indices below and above the break energy.

References

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