On the sharpness of gamma-ray burst prompt emission spectra

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**GRB prompt emission**

**Afterglow synchrotron spectrum in $F_\nu$ (specific energy flux), Sari+98**

**GBM observed prompt spectrum in $\nu F_\nu$ (energy flux)**

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**GRB 100414A**

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**same?**

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This work

The sharpness of gamma-ray burst prompt emission spectra*

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Statistics from the catalog

<table>
<thead>
<tr>
<th>Model</th>
<th>GOOD</th>
<th>BEST</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>N</td>
<td>percentage</td>
</tr>
<tr>
<td>BAND</td>
<td>939</td>
<td>52.1%</td>
</tr>
<tr>
<td>SBPL</td>
<td>1,201</td>
<td>66.6%</td>
</tr>
<tr>
<td>COMP</td>
<td>1,276</td>
<td>70.8%</td>
</tr>
<tr>
<td>PL</td>
<td>1,488</td>
<td>82.6%</td>
</tr>
<tr>
<td>ALL</td>
<td>1,802</td>
<td>-</td>
</tr>
</tbody>
</table>

- Take the 1,802 spectra from the 1st official Fermi GBM GRB time-resolved spectral catalog

- Extract the spectra with a peak or break in \( vF_v \) (energy flux) space, and re-fit them in energy domains concentrating on the peak or break position

** BAND and SBPL are two kinds of smoothly broken power laws, COMP is a simple power law with high-energy exponential cutoff

Yu+submitted to A&A, see poster GRB#12
Method - construct the sharpness angle
Which emission process could possibly fit the spectral curvature around the $v F_v$ peak?

Consider two simplest processes:

Blackbody?
(Very sharp)

Optically thin synchrotron from a Maxwellian distribution of electrons?
(Sharpest physical synchrotron case)
Comparing to the **best-fit** model, **optically thin synchrotron** is too broad, **blackbody** is too narrow…

**broadening is easy (adding up spectra), narrowing is impossible!**
Time-resolved spectra within a single burst are not consistent with optically thin Maxwellian synchrotron…

Fig. 6. Spectral evolution of GRB 100414.097 with the normalised blackbody (red), Maxwellian synchrotron (green), and the best-fit model (black) overlaid. Time evolves from top left to bottom right, and the time since trigger is labeled at the top of each snapshot spectrum, in units of seconds. The peaks of the models are all normalised to $(x, y) = (1, 1)$. Data points and the shaded regions are plotted as described in Fig. 4.
Sharpness angle evolution of 6 example bursts

<table>
<thead>
<tr>
<th>Emission models</th>
<th>θ (degrees)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blackbody</td>
<td>43</td>
</tr>
<tr>
<td>Single-electron synchrotron</td>
<td>97</td>
</tr>
<tr>
<td>Maxwellian synchrotron</td>
<td>135</td>
</tr>
<tr>
<td>Synchrotron with $p = 2^3$</td>
<td>170</td>
</tr>
<tr>
<td>Synchrotron with $p = 4$</td>
<td>128</td>
</tr>
</tbody>
</table>

BAND SBPL COMP
Optically thin synchrotron emission is clearly not consistent...

- Blackbody limit
- Single-electron synchrotron limit
- Maxwellian synchrotron limit

Re-fitting results (0.1Ep - 3.0Ep)
- ALL
- COMP
- BAND
- SBPL

Cumulative distribution function (%) vs. sharpness angle (degrees)

- 35% angle uncertainties
- 91% angle uncertainties
So, how much synchrotron is allowed?

- The limiting case, single temperature Maxwellian synchrotron, can only contribute up to $58^{+23}_{-18}\%$. 

![Graph showing distribution of spectra](image_url)
Even if (1) the whole GBM energy range is taken to be the data domain, and (2) the Band function (typically broader than cutoff power law) is assumed…
Different fitting functions comparing to the data points

- Maxwellian synchrotron
- Band function
- Smoothly broken power law
- Cutoff power law
How about fitting the Maxwellian to data points?

smoothly broken power law fit to a Maxwellian synchrotron

best-fit cutoff power law
Comparing to other heuristic semi-empirical models

GRB 090926A, T0+6 - T0+8 s

Maxwellian synchrotron
BEST fit model (Yu+15)

Guiriec+15 this work
How resolved are the time-resolved spectra?

- 96% of our time-resolved time bin may still be wider than the intrinsic minimum variability time-scale (Bhat13, Golkhou+14,15)
How resolved are the time-resolved spectra?

average sharpness angle (this work)

sharpness angle computed using best-fit models from time-integrated catalog (Gruber+14)
- Optically thin synchrotron cannot explain the observed prompt spectral peaks (only contribute up to 58$^{+23}_{-18}$%)

- Blackbody is too sharp, however a simple distribution function of blackbodies may be constructed

- Time-integrated spectral analysis can underestimate the sharpness of the observed spectra

- Beloborodov (2013) argues that the Poynting-flux models shares the same problems of the synchrotron model, suggesting that the outflow is not magnetically dominated
Back-up slides
GRBs are isotropically and *cosmologically* distributed

Isotropic distribution from catalogs

*CGRO/BATSE GRBs*, Briggs+96

*Fermi/GBM GRBs*, von Kienlin+14

Redshift measurements

Spectroscopic, GRB 970508, Metzger+97

Photometric, GRB 121217A, Elliott+14
Why people favor the synchrotron theory?

**afterglow**: synchrotron (e.g., Sari+98)

**prompt**: also synchrotron? There is the “line-of-death” problem: spectral index = 1/3 or photon index = -2/3

**remember**: photon index + 1 = spectral index

what about index > -2/3? Very difficult, require extra blackbody and/or evolving B-field (Burgess+14, Yu+15)

**But all previous works have only considered the low-energy spectral slope! What about the high-energy slope and the curvature around the spectral peak/break?**
Full angle or left-hand-side angle results are consistent.
Angle difference between re-fits and catalog fits
Choice of the triangle domain is a good one.
How resolved are the time-resolved spectra?

average sharpness angle (this work)

sharpness angle obtained from time-integrated catalog (Gruber+14)
Mathematical but not physical limits

Maxwellian synchrotron

single-electron sync.
integrated over polarization directions

Single-electron sync.
polarization perp. to projected B-field

Single-electron sync.
polarization para. to projected B-field