Photospheric spectra from jetted outflows

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What emission process(es) can reproduce the GRB spectrum?

- **Difficulties** for optically thin emission to explain observations (however, see talks by B. Zhang, F. Daigne)

- **Photospheric emission** is a natural alternative
Challenge: How to broaden the photospheric spectrum?

Two ways:

- **Physical broadening** (energy dissipation)
- **Geometrical broadening**
We calculate: Photospheric spectra from jetted outflows

(see also talks by K. Ioka, N. Kawanaka)
Understanding geometrical broadening: Beaming of photons
Understanding geometrical broadening: Fuzzy photosphere

- Wide distribution in last scattering radius
- Outflow temperature is a function of radius

Exact radial dist. found by Beloborodov (2011)
Understanding geometrical broadening: **Non-zero viewing angles**

Observer at $\theta_v \approx \theta_j$ sees edge of jet, $\Gamma$ is changing across the whole photosphere.
Approaches: Numerical & analytic

Monte Carlo simulation

- Tracks photon propagation within regions of varying electron density and Lorentz factor
- Full photon propagation below the photosphere, naturally includes non-thermal effects (i.e. Comptonization)
**Analytic model**

Uses approximate expression for the comoving emission coefficient

\[
F_E^{ob} = \left(1/d_L^2\right) \int D^2 j'_E \exp(-\tau)dV
\]

\[
E_{\text{peak}} = 540 \left(\frac{L}{10^{52}}\right)^{-5/12} \left(\frac{r_0}{10^8}\right)^{1/6} \left(\frac{\Gamma_0}{300}\right)^{8/3} \text{keV}
\]

\[
E_j/E_{\text{peak}} \geq \left(1 + \frac{\Gamma_0^2 \theta_j^2}{2}\right)^{-1} \left(1 + \frac{\Gamma_0^2 \theta_j^2}{3}\right)^{-2/3}
\]

\[
E_D/E_{\text{peak}} = \left(\frac{p + 3}{2}\right)^{2/3} \left(\Gamma_0 \theta_j\right)^{-8p/3(p-1)}
\]

\[
\alpha \approx -(1/4)(1 + 3/p)
\]

\[p \geq 1\]

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**Approaches: Numerical & analytic**

Lundman et al. 2013
From simulation: **Beaming of photons**

Spherical symmetry

Narrow jet ($\theta_j \leq \text{few/}\Gamma_0$)
Main results: $\alpha \approx -1$ for narrow jets

$(\theta_j \leq \text{few}/\Gamma_0)$

Photon index insensitive to exact jet parameters

$$\alpha \approx \left(-\frac{1}{4}\right) \left(1 + \frac{3}{p}\right) \quad p \geq 1$$

Lundman et al. 2013
Main results: $\alpha \approx -1$ for wider jets viewed at $\theta_v \approx \theta_j$

Narrow jet

Wide jet

Lundman et al. 2013
Main results: High energy tail for jets with large Lorentz factor gradient

- Caused by repeated scattering in the shear layer
- Will be explored further (Lundman et al. 2013, in prep.)
Conclusions

- Under realistic assumptions, we obtain $\alpha \approx -1$ for narrow jets ($\theta_j \leq \text{few}/\Gamma_0$) at any viewing angle.

- For wider jets, $\alpha \approx -1$ when observed at $\theta_v \approx \theta_j$.

- Similar to the average low energy photon index observed in GRBs.

- High energy tail for jets with large LF gradient.

Goldstein et al. 2012