GRB Structured Jet

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Flow Chart for getting interesting results from structured jet model:

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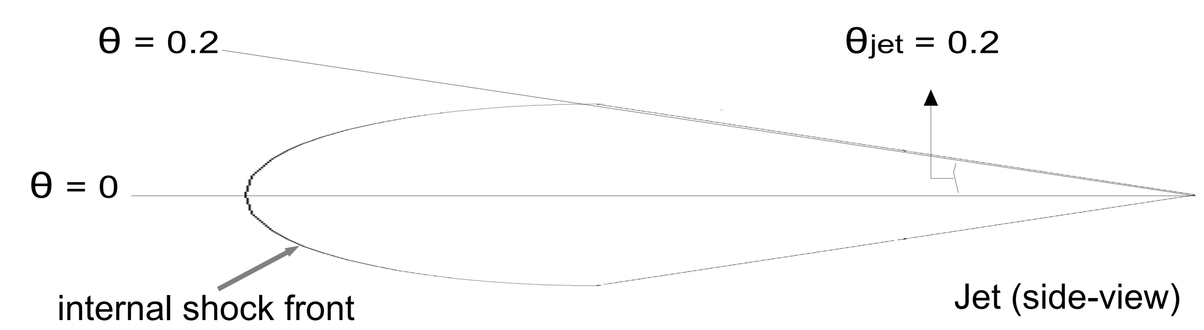
Based on structured jet model of Gamma-ray Burst, we are able to reproduce: a) spectral lags; b) Amati relation, both of which are already observed phenomena in GRB.

So what's the model?

Structured Jet Model



The idea of structured jet model is that the emissivity and bulk Lorentz factor Γ are not uniform at internal shock front, but a function of θ. They are smaller at larger θ.

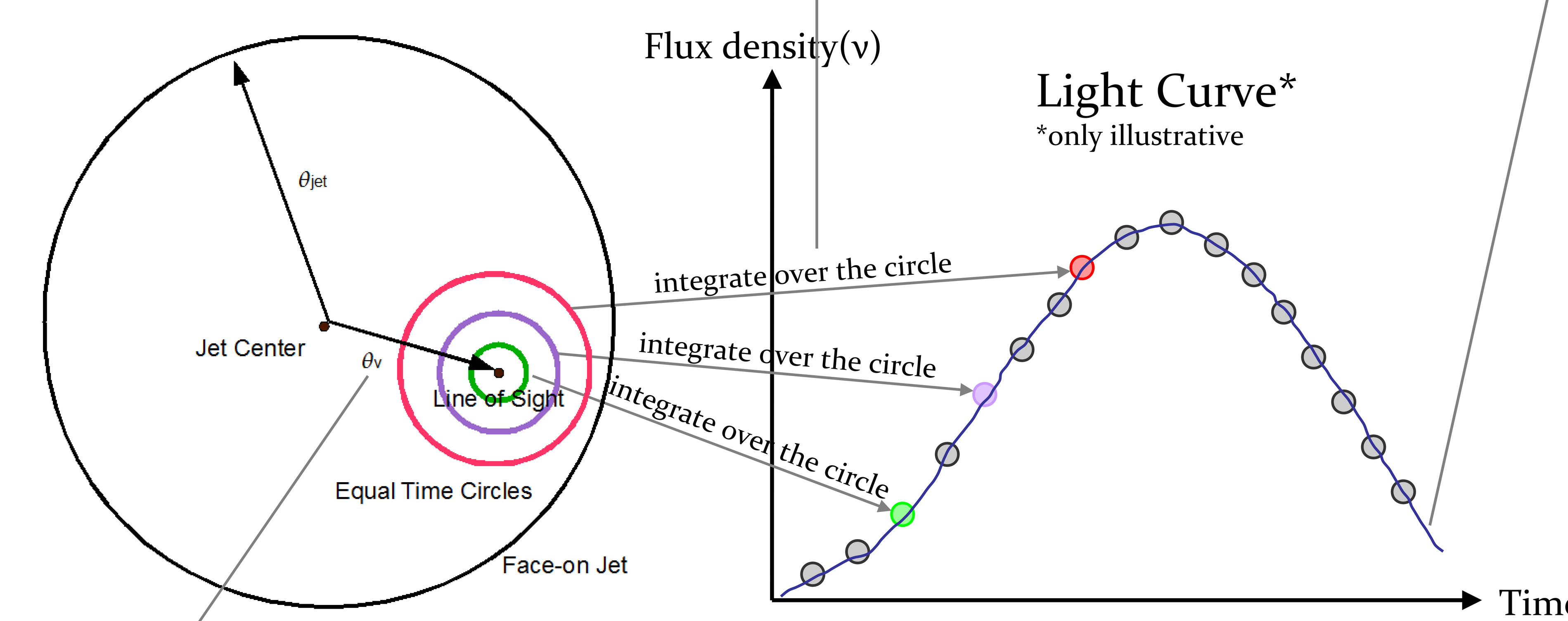
We mainly focus on Gaussian jet in our work, which takes the form[1]:

$$E(\theta) \propto \exp\left(-\frac{\theta^2}{2\theta_{C,E}^2}\right) \qquad \Gamma(\theta) = 1 + (\Gamma_0 - 1)\cdot\exp\left(-\frac{\theta^2}{2\theta_{C,\Gamma}^2}\right)$$

$\theta_{C,E}$ and $\theta_{C,\Gamma}$ determines the width of the Gaussian profiles for $E(\theta)$ and $\Gamma(\theta)$, respectively. They are different because the mass load at shock front is not even. Here $\theta_{C,E}=\theta_{C,E}=0.04$, and $\Gamma_0=1000$.

Flip for face-on view for further calculation

Light Curve (for one frequency ν)



The integral over one equal time circle is basically the flux density observed. It takes the form:

$$\int \varepsilon'_{\nu'} \cdot D^2 d\varphi$$

where D is the doppler factor, and emissivity

$$\varepsilon'_{\nu'} \propto \left(1+\frac{\nu'}{\nu'_p}\right)^{-1.2} \cdot E(\theta)$$

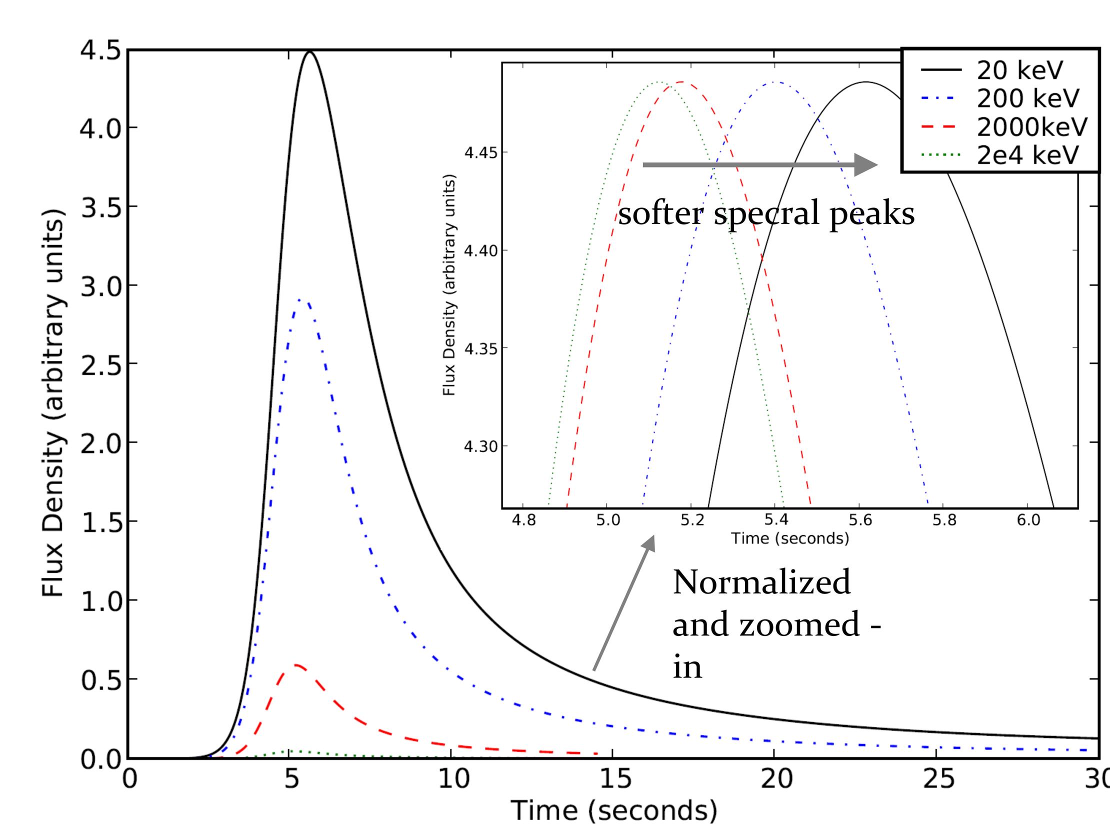
with ν'_p the break frequency for local "Band function", whose form will be discussed later.

The integration ends when the equal time circle has no overlap with the jet, which is 0.2 rad in radius.

Note that we are presenting a general case here, where the line of sight does not go through center of the jet. This viewing angle, θ_v, is the only difference of different bursts in our model.

For multiple frequencies, plot their light curves

Spectral Lag



This is a series of light curves for $\theta_v = 0.11$. It is clear that the light curve of different frequency peaks at different time. Higher energy light curve peaks earlier, as observed[2].

From the zoomed-in view, it can be read out that the spectral lat time is around 100*ms*, which is also roughly of the same order as observation[2].

Integrate the light curve of each frequency to obtain the spectrum

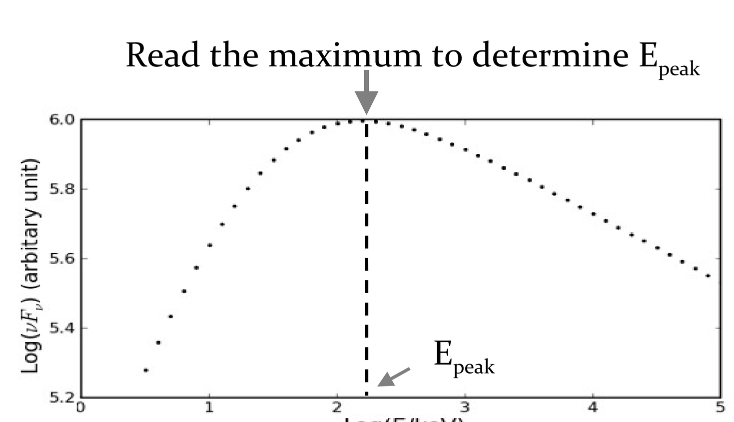
Spectrum for one GRB

It is not surprising that the result spectrum has a Band function form, since we have Band function in our input.

Things we need from the spectrum:

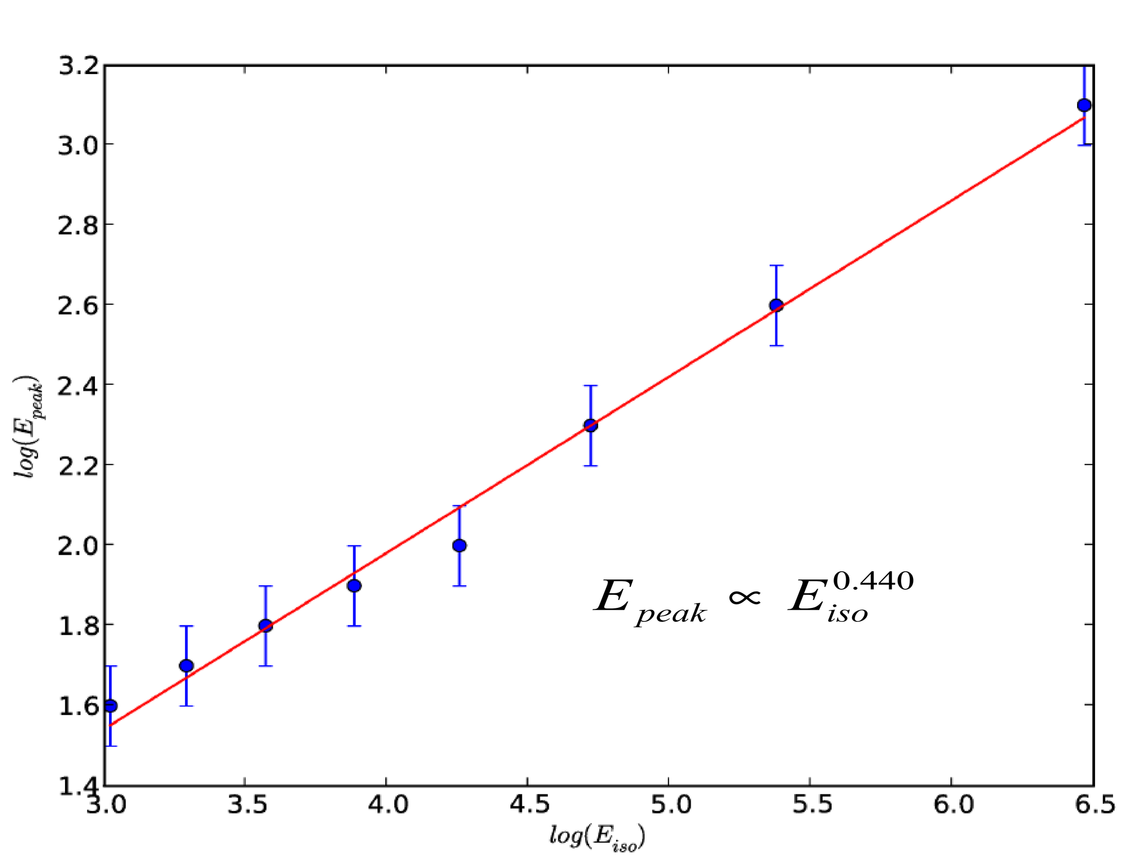
E_{iso}: We obtain E_{iso} by integral over the whole spectrum (the final value is up to a normalization factor).

E_{peak}: As shown on the right, we obtain E_{peak}, which is the break frequency in the Band function, by directly reading the maximum of spectrum. The error of E_{peak} is the integration step of frequency, Δν.



Obtain spectra etc. for multiple GRBs

Amati Relation (involving multiple GRBs)



On the left we show an example of obtained "Amati relation". We change the viewing angle θ_v for generating different GRBs, and calculate their spectra and thus E_{iso} and E_{peak}. Each dot on the plot represents one burst. The viewing angles used here are: 0.05, 0.07, 0.09, 0.11, 0.13, 0.15, 0.17, and 0.19.

This observed power-law relationship between E_{iso} and E_{peak} is reproduced. The power-law index depends on the input power-law index in:

$$\nu_p'(\theta) \propto E(\theta)^x / \Gamma(\theta)$$

In this specific example, $x = 5.0$. The obtained Amati relation index will increase as we increase x.

The observed value is roughly 0.5[3,4], and thus we conclude that we are able to reproduce the observed Amati relation using structured jet model.

The observed Amati relation is not so tight as shown here[3,4]. Our result is so because those bursts share the same coefficients in the model only except for θ_v.

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