TeV afterglow emission from a structured GRB jet

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Background

- Recent research around GRB afterglows has revolved around two key issues:
  - **Structured jets** with **off-axis** emission [1]
  - The detection of **very high energy (VHE)** emission from several recent GRBs [2, 3]
- While (semi)-analytical models are helpful in solving these problems [4, 5, 6], they must make simplifying assumptions about the **synchrotron self-Compton (SSC)** emission and **Klein-Nishina** effects
- **Kinetic codes** are a useful way to numerically solve these problems (see for eg. [7, 8, 9]).

Our approach

- Modify the kinetic code KATU [10] to include **adiabatic expansion** and **general IC cooling**
- Implement a shell model with the following jet options (for $E_{iso} = E(\theta) = 4\pi dE/d\Omega$) [4]:
  - **Top-hat**: $E(\theta) = E_0$
  - **Gaussian**: $E(\theta) = E_0 \exp\left(-\theta^2/2\theta_c^2\right)$
  - **Power law**: $E(\theta) = E_0 \left(1 + [\theta^2/b\theta_c^2]\right)^{-b/2}$
- Divide the angular structure of the jet into multiple zones, with each zone being evolved by KATU concurrently to obtain their photon populations and thus power emitted.
- Calculate the observed flux with respect to the **equal arrival time surface** of the jet

$$F_\nu(t_{obs},\ \nu_{obs}) \approx \frac{1+z}{4\pi d_L^2} P_\nu \int_{\text{zone}} d\Omega dr\ r^2 \delta^2 \qquad (1)$$

where P_ν is the power emitted per unit volume per unit frequency, r is the distance from origin and δ is the Doppler boosting factor. The **radial extent** of the shell is also resolved to account for travel time in the shell.

Comparison with afterglowpy

We find generally good agreement with AFTERGLOWPY [4]. What differences we observe can be explained by the inclusion of **radial integration**, a **coasting phase** and the **sensitivity of ν_c** to underlying assumptions.

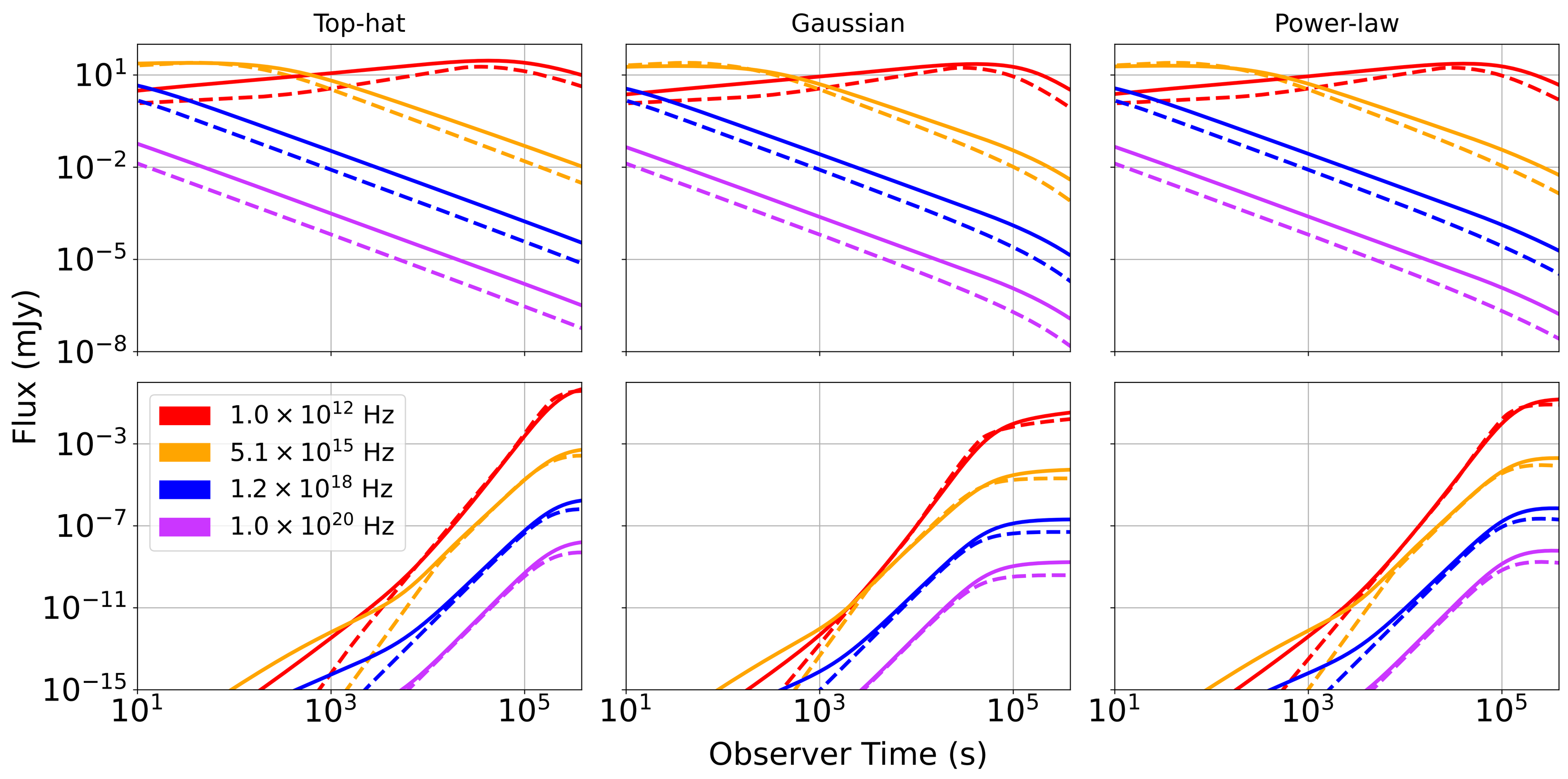

Fig. 1: Light curves from the top-hat, Gaussian and power law jets for on-axis (top) and off-axis ($\theta_{obs}/\theta_w = 1.5$, bottom). Solid lines are KATU, dashed lines are AFTERGLOWPY. Note that AFTERGLOWPY only includes synchrotron emission.

References

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[12] Hendrik J. van Eerten and Andrew I. MacFadyen. DOI: 10.1088/2041-8205/747/2/L30.
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SSC emission

Observed TeV emission is sensitive to structure and observing angle, with **steeper jet energy structure** leading to **earlier peak times**, while **increasing observer angle** leads to **later peak times**. Both effects decrease overall **peak flux**.

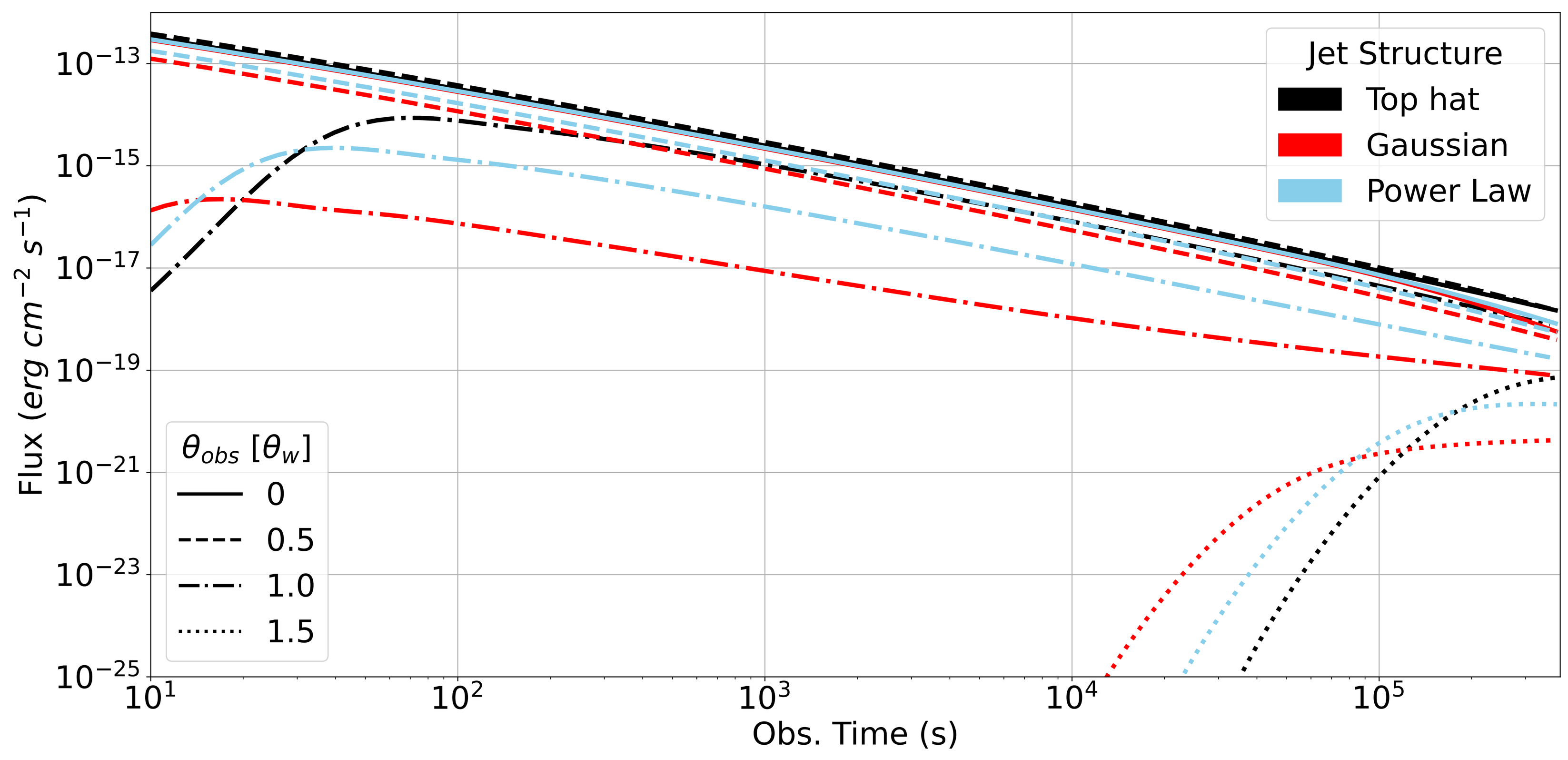

Fig. 2: 2 TeV light curves for a series of jet structures and observer angles. Due to the fixed E_0, the on-axis results are almost identical

The **Compton Y-parameter** (as a measure of SSC to synchrotron emission), is also affected by structure and observing angle.

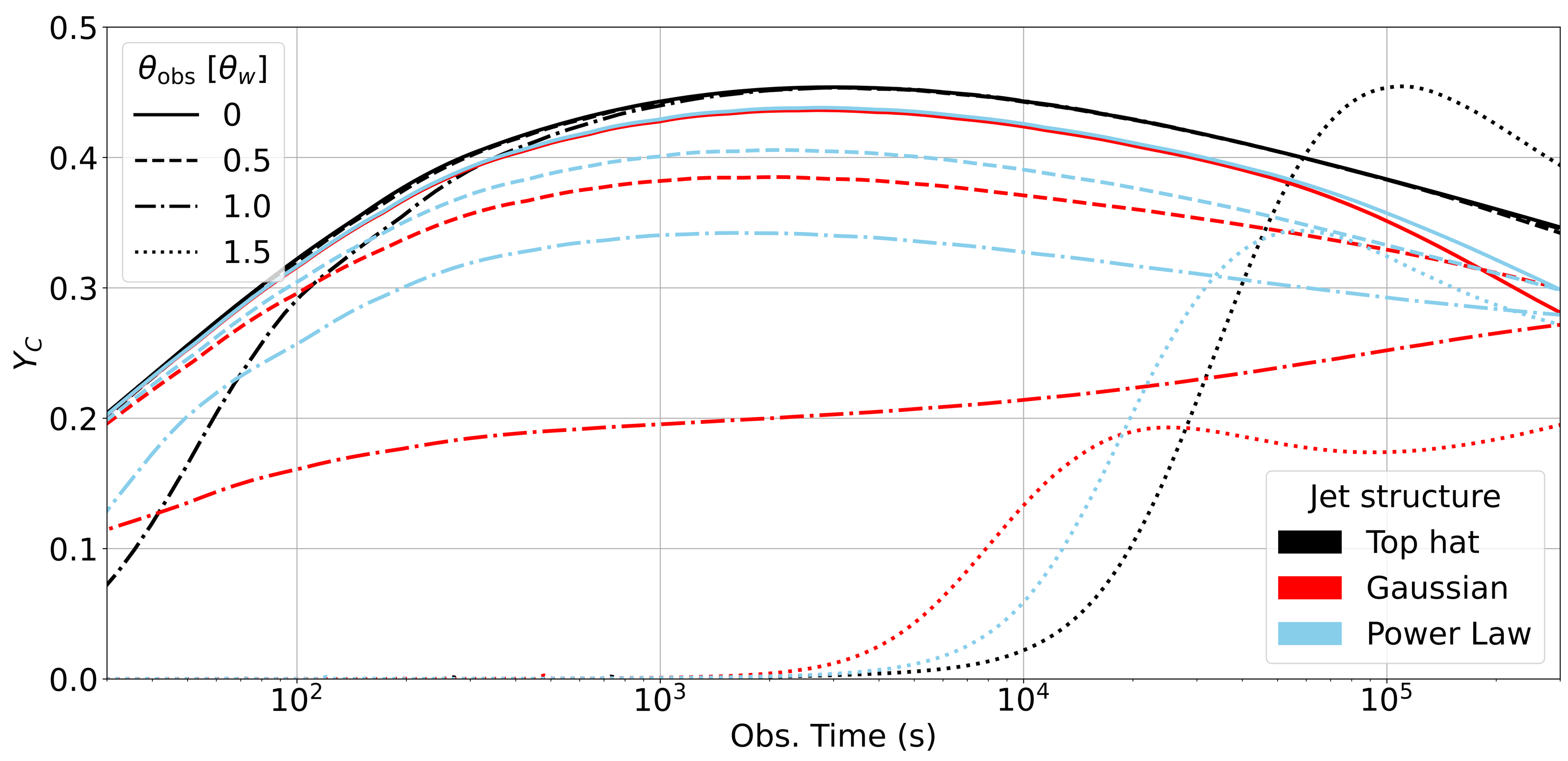

Fig. 3: Compton Y parameter at cooling break ν_c for a series of jet structures and observer angles

GRB 170817A

We used **best fit** parameters determined by AFTERGLOWPY [11], which were **rescaled** (see eg. [12, 13]) for our model. We found that **no TeV emission** would be detected by CTAO, even if **on-axis**.

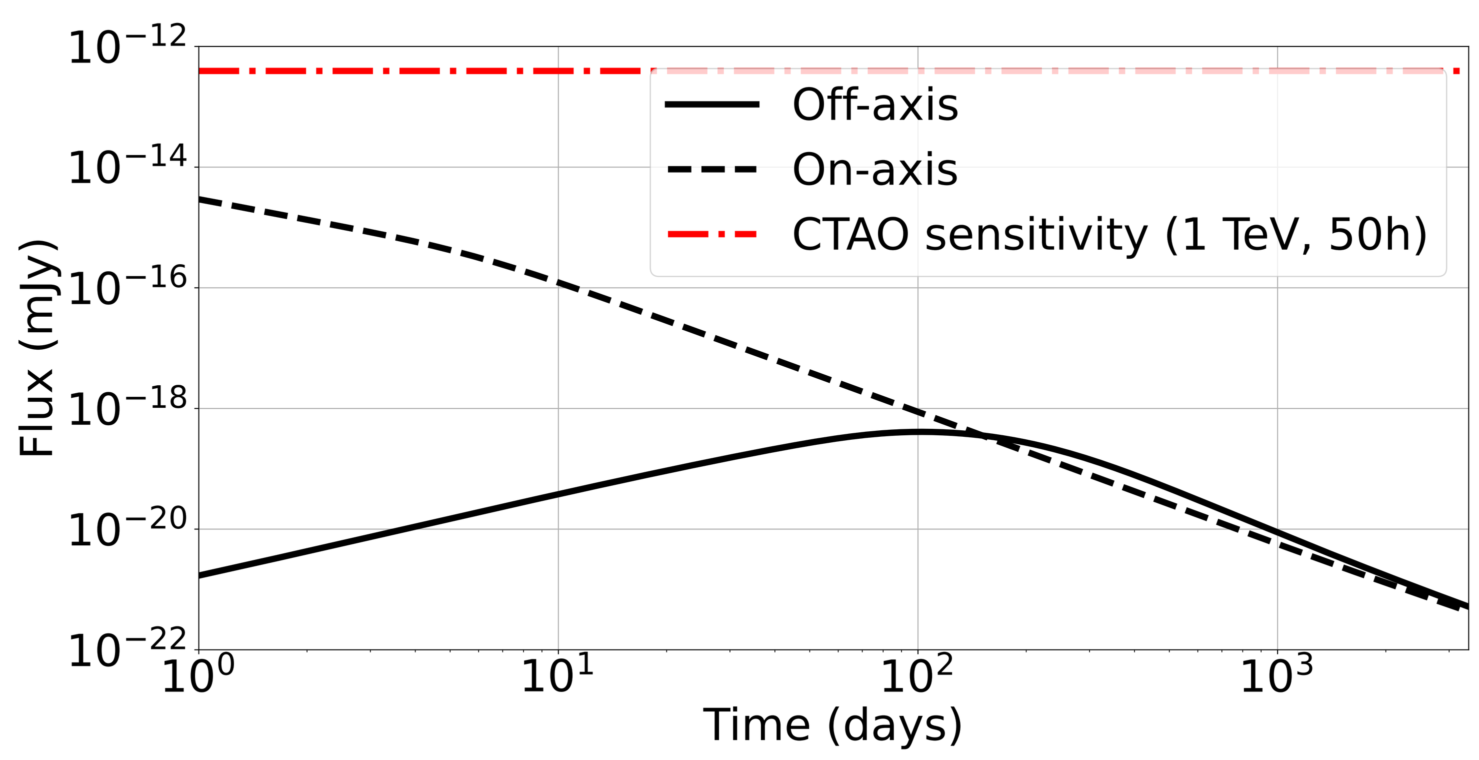

Fig. 4: 1 TeV light curves for GRB 170817A (rescaled). CTAO performance obtained from: https://www.ctao.org/for-scientists/performance/

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