A Statistical Investigation of GRB X-ray and Optical Afterglows

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Comparison of the Average Optical/UV light curve with XRT canonical model

Optical/UV afterglows do not follow the same behaviour as the X-ray afterglows, at least in the early afterglow.
Using the sample of 26 GRBs from Oates et al. (2009):

- **Optical to X-ray hardness ratio**
  - Compares the individual data points

- **Root Mean Square Deviation**
  - Compares the small scale differences
    - Using a sliding window 1 dex wide (bottom panel)
    - Using data within 4 specific time periods (labeled (a),(b),(c),(d))

- **Temporal Indices**
  - Compare the overall behaviour of the X-ray and optical/UV light curves
    - (a) <500s, (b) 500s-2000s, (c) 2000s-20000s, (d) >20000s
Mean Properties: RMS Deviation Distribution

- Distribution widens during last epoch

Monte Carlo simulation of data in 2000s-20000s epoch convolved with average error of >20000s epoch:

- >20000s is consistent with being wider due to larger data uncertainties.
From 500s onwards optical and X-ray light curve consistent with being produced by the Standard GRB afterglow model. Can this apply to individual GRBs?

Mean Temporal Indices

Average temporal indices residing above the line of equal temporal index imply: constant density medium.

After 500s, the temporal indices are consistent with closure relations for constant density medium with

\[ \nu_m < \nu_o < \nu_c < \nu_X \]

Can this apply to individual GRBs?
Individual GRBs: Temporal Indices, $\alpha$

Optical and X-ray light curves behave similarly indicating similar production mechanism for both components.

Constant density favoured, but energy injection appears to be required for some GRBs.

X-ray temporal indices are steeper → Chromatic breaks?
Temporal Changes in the Late time Afterglow

- Chromatic breaks:
  - 3 GRBs have a break in the X-ray light curve
  - 4 GRBs have strong indications of a break in the X-ray light curve
- 2 GRBs cross line of equal temporal index

Difficult to explain behaviour of some of the GRBs in terms of a single component outflow. Require complex jet geometry or additional emission components to explain these GRBs.
Conclusions

• X-ray and optical aftergows behave:
  – Most differently before 500s
  – Most similarly between 2000s and 20000s

• Mean properties indicate constant density medium is favoured with: \( \nu_m < \nu_O < \nu_C < \nu_X \)

• Individual properties: require additional energy injection

• Chromatic breaks: 3 GRBs (>12%), strong indication 4 GRBs.

• Complex jet structure and/or additional emission components required to explain at least a few of the GRBs in this sample.
  (e.g. Peng et al. 2005, Ghisellini et al. 2007 Panaitescu et al 2008)