Answers – and new questions - from Swift

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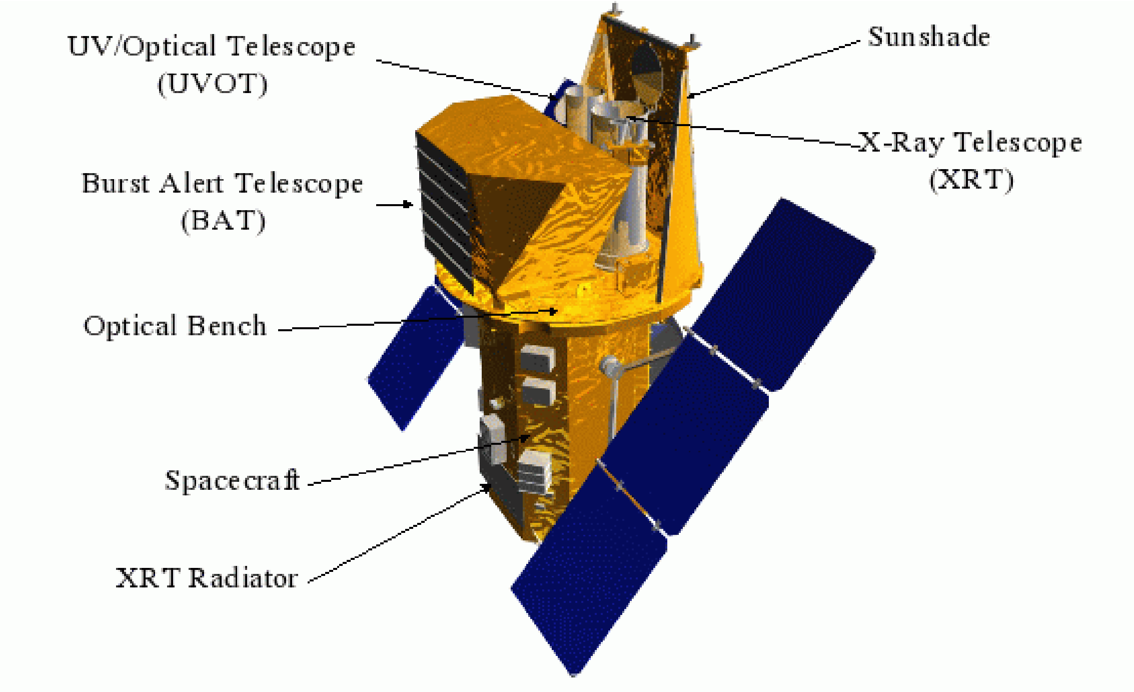
A “Swift” introduction to Swift

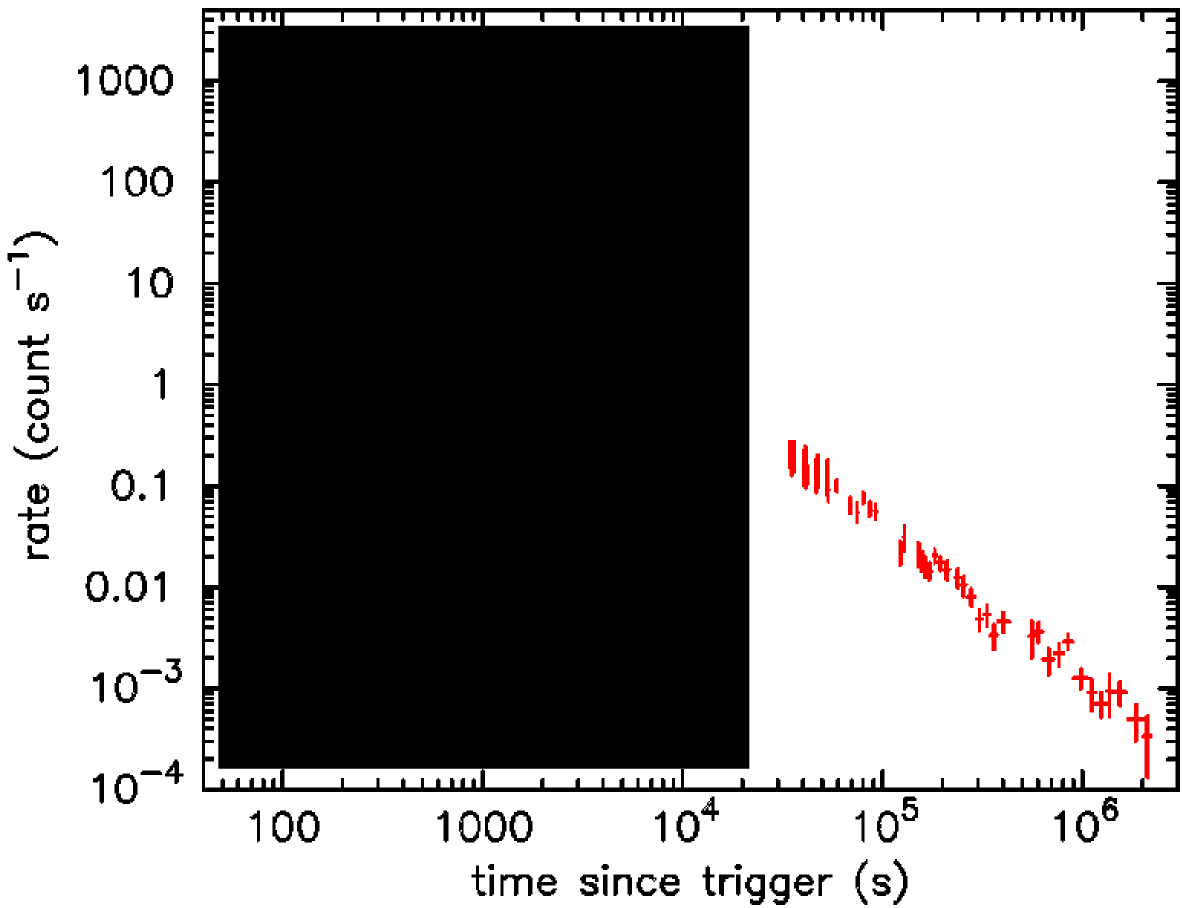


Swift is a GRB explorer, with 3 instruments covering gamma-ray, X-ray and UV/optical bands. It can slew up to a degree a second, meaning that we usually arrive on target in 60-100 s. Pre-Swift, observations of GRBs typically began hours, if not days, after the trigger.

Swift detects about 100 bursts yr^{-1}.

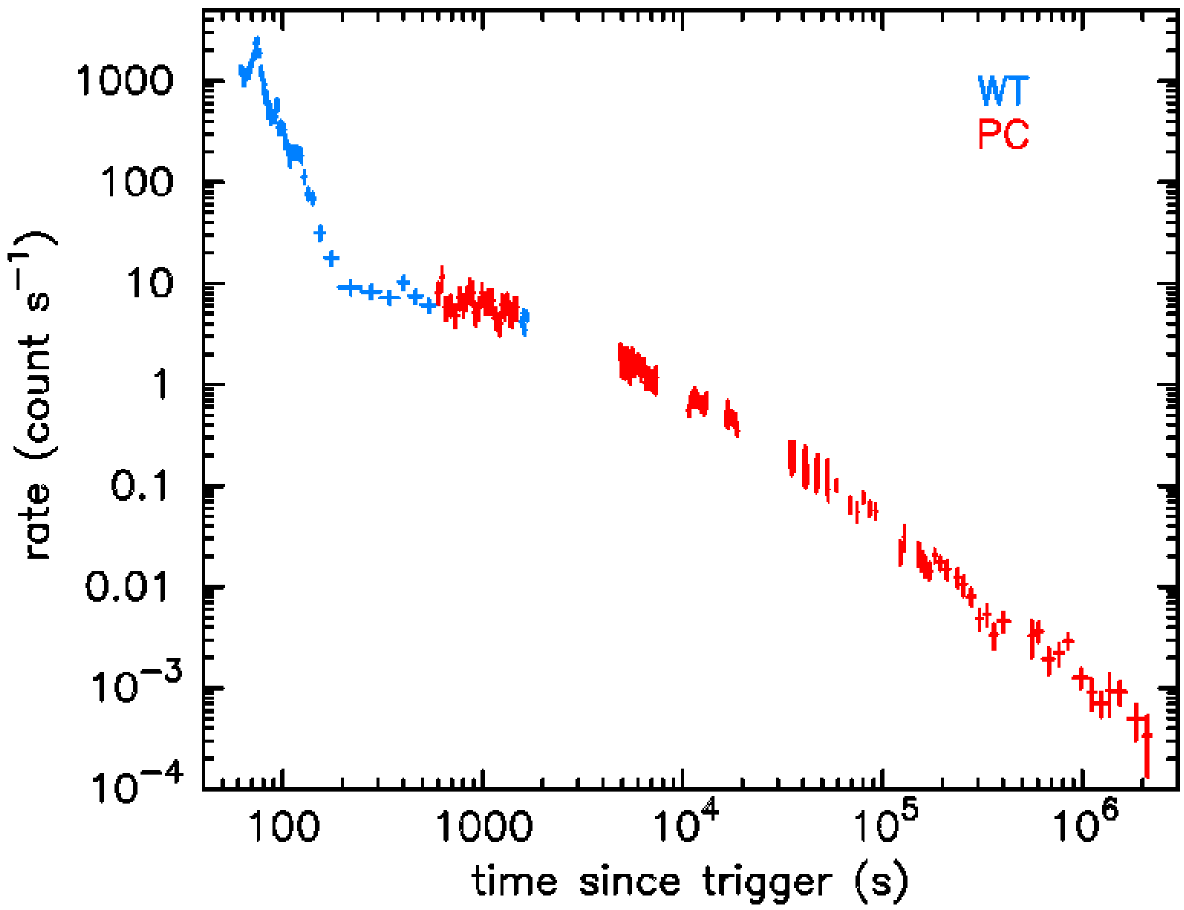
Pre-Swift

~ 5 hours

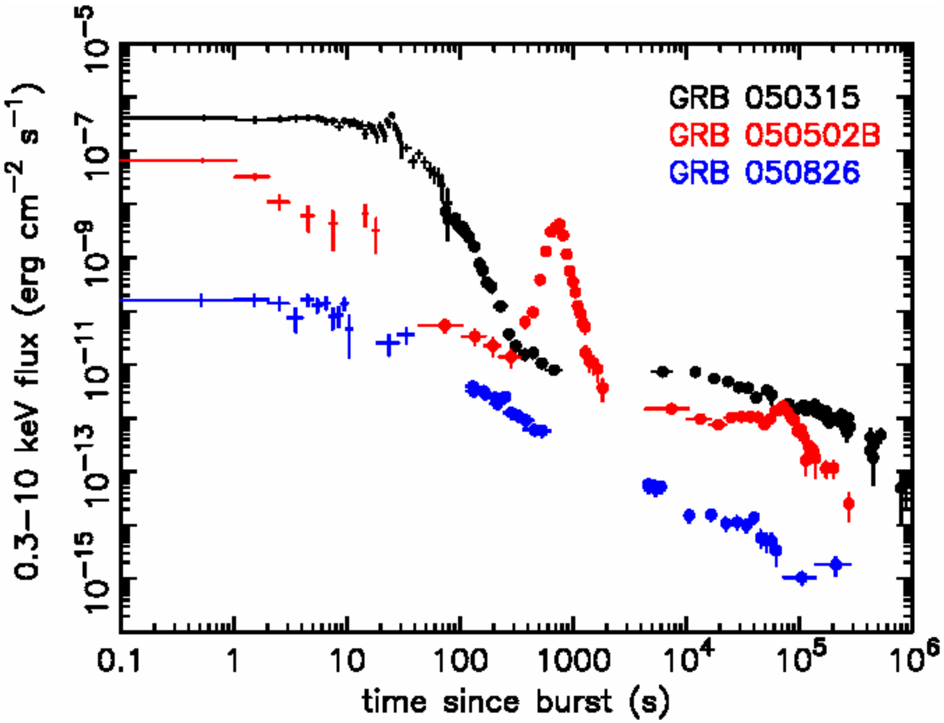


Swift era: GRB 061121

On target from 56 s



Some Swift discoveries …



GRB 050826 points divided by 100 for clarity.

The early X-ray data join up with the end of the gamma-ray emission.

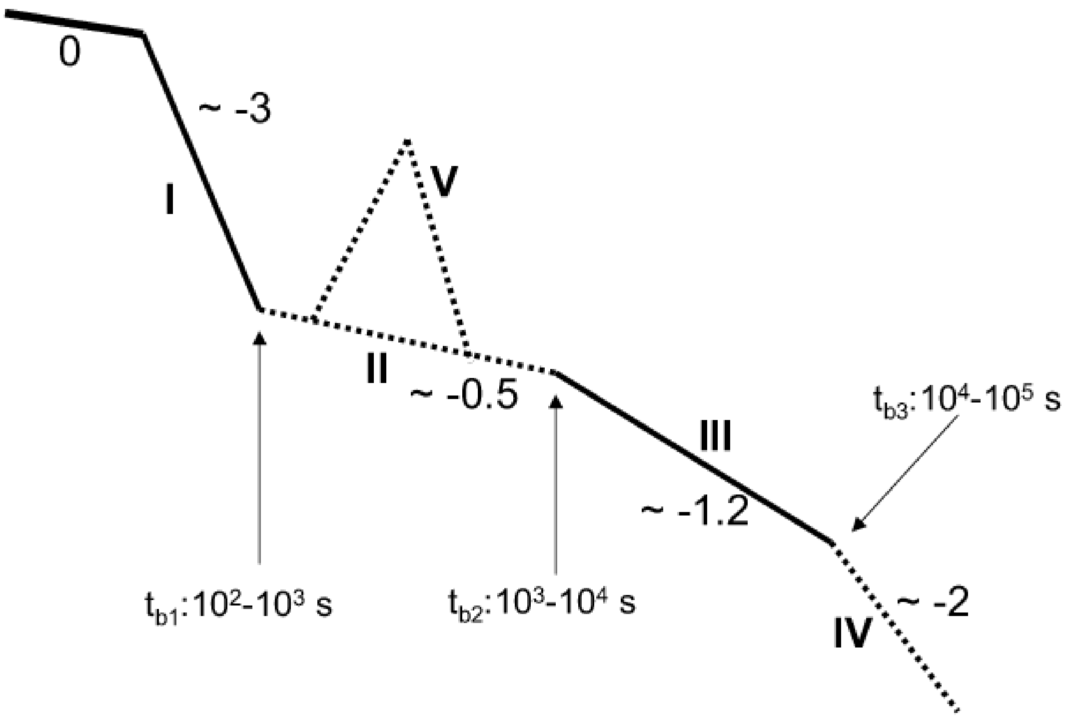
There is often a steep power-law decline ($F_\nu \sim \nu^{-\beta} t^{-\alpha}$ where α = 2-5) at the start of the X-ray light-curve.

A "plateau" phase usually follows the steep decline.

X-ray flares are seen in the first few hours for about 50% of GRBs.

Short bursts show similar X-ray light-curves to the long duration ones though are, on average, fainter. They can also show flares.

Cartoon X-ray light-curve



From Zhang et al., 2006, ApJ, 642, 354

… and more unanswered questions

Although the BAT and XRT data join up, what causes the steep decay? Spectral evolution is often seen during the steep decay – but not always.

What causes the plateau? Energy injection? Hidden rise of afterglow?

Some flares are also seen at late times – continued engine activity?

Where are the jet breaks?

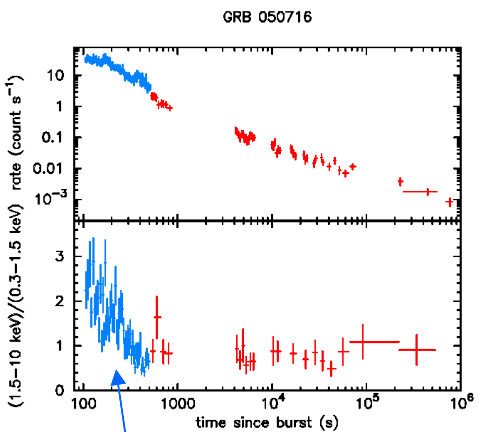
Early Steep Decay - 1

The BAT and/or early XRT light-curves often show a steep decay.

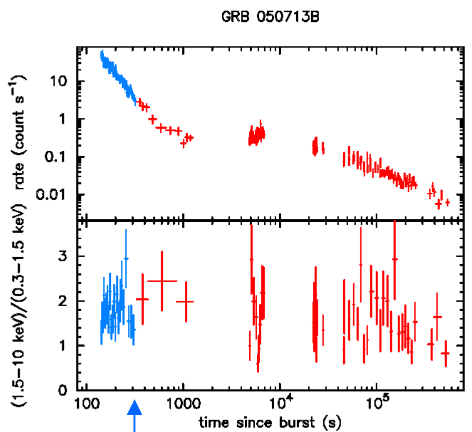
This is generally explained as high-latitude emission (the "curvature effect"), produced after the internal shocks stop. Here $\alpha = \beta+2$.

- The classical afterglow can begin within minutes, so a combination of prompt and afterglow emission could explain why $\alpha < \beta+2$.

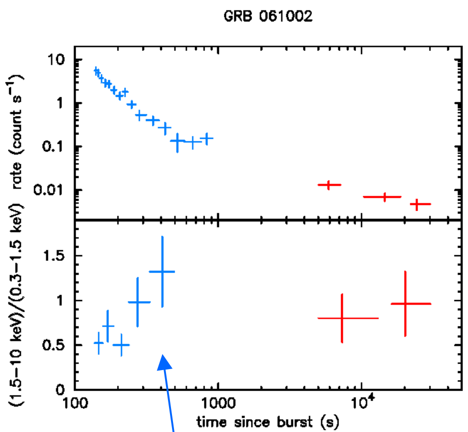
Early Steep Decay - 2



Softens.



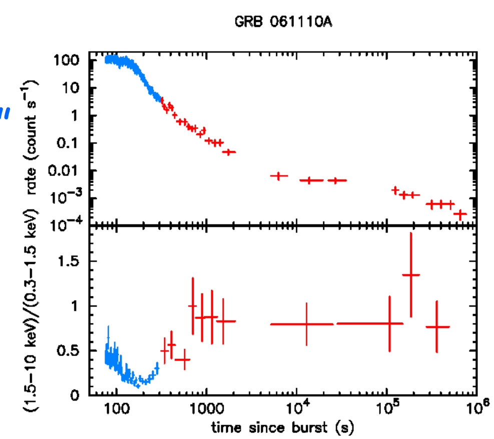
No change.



Hardens.

Spectral evolution is seen in ~1/3 of bursts during the steep decay which is not easily explained by the high latitude interpretation when considering a simple power-law spectrum.

Softens, "overshoots" and re-hardens.



(See Zhang et al., 2009, ApJ, 690, L10 for consideration of a cut-off power-law.)

Light-curves available for all bursts at http://www.star.le.ac.uk/xrt_curves

Plateau - 1

The slow decay seen in many X-ray light-curves cannot easily be accounted for with an adiabatic evolution of the forward shock – and radiative losses would serve to steepen the flux decay.

Possibilities:

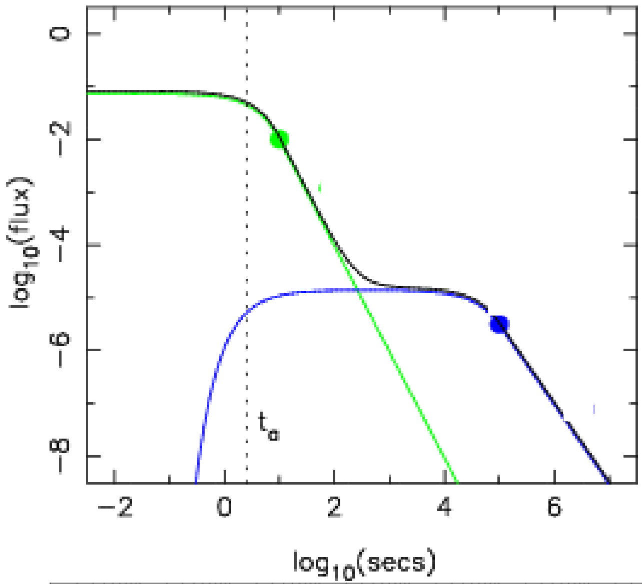
- Continued energy injection from central engine
    - Long-term central engine activity with smoothly varying luminosity
    - Distribution of Lorentz factors

(e.g. Nousek et al., 2006, ApJ, 642, 389; Zhang et al. 2006, ApJ, 642, 354)

- "Late Prompt" emission
    - – the central engine could continue producing shells of decreasing bulk Lorentz factor.

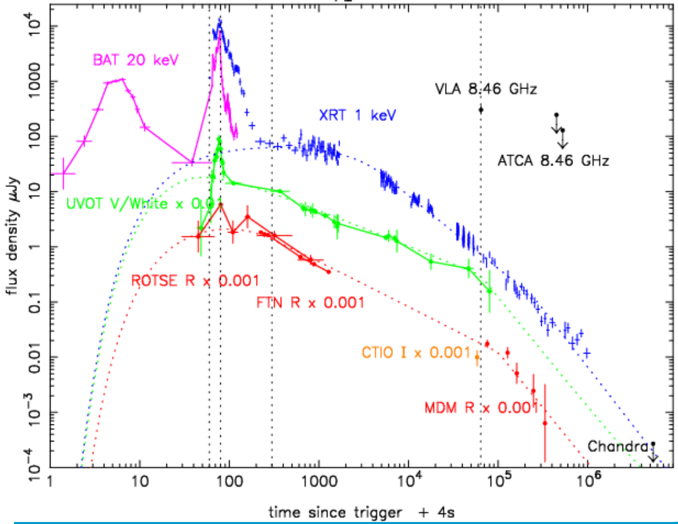
(Ghisellini, Ghirlanda, Nava & Firmani, 2007, ApJ, 658, L75)

Plateau - 2

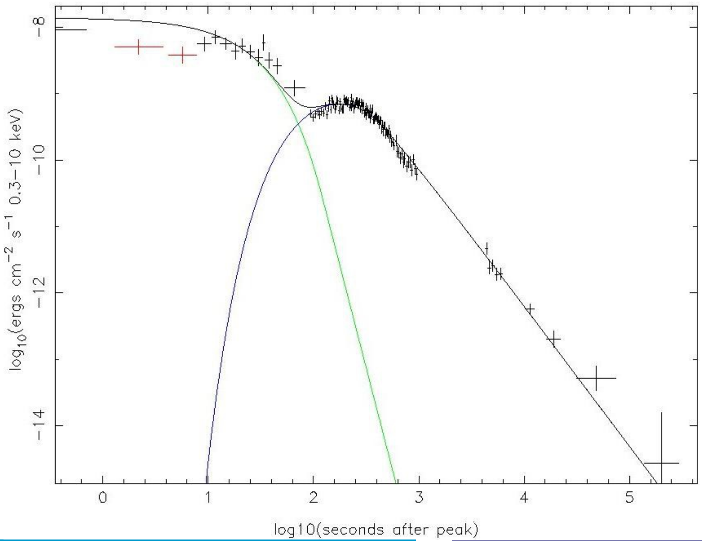


O'Brien et al. (2006) and Willingale et al. (2007) propose a method of modelling BAT-XRT light-curves using exponential-to-power-law components.

In this model, the plateau phase could be the turn-over of the rise of the afterglow before it starts to decay.



The light-curve of GRB 080307 may show the onset of the X-ray afterglow!



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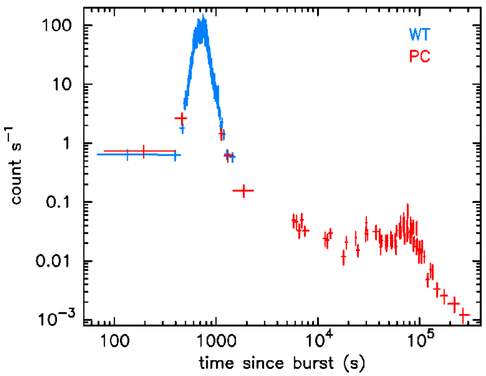
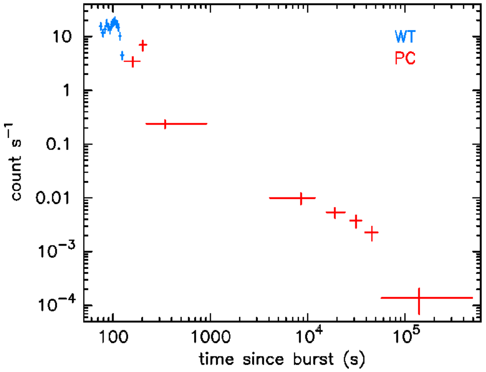
Flares

GRB 050502B had as much (if not more) energy in its flare as in the burst itself. The results showed that the flare almost certainly had an internal origin.



Long burst

GRB 050502B



Short burst

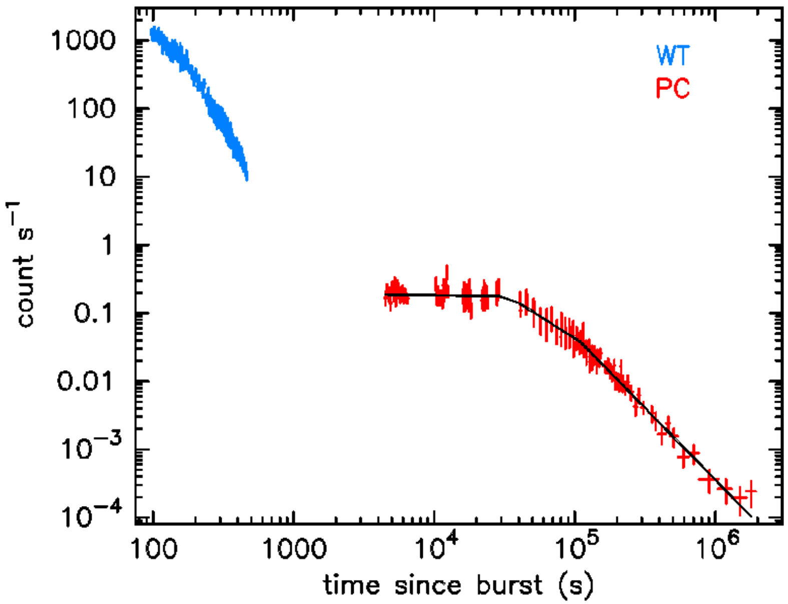
GRB 070724A

Flares are sometimes seen at late times, and various investigations have suggested that these are a sign of continued engine activity – up to as long as 100 ks after the burst.

Is this also why we see the plateau phase?

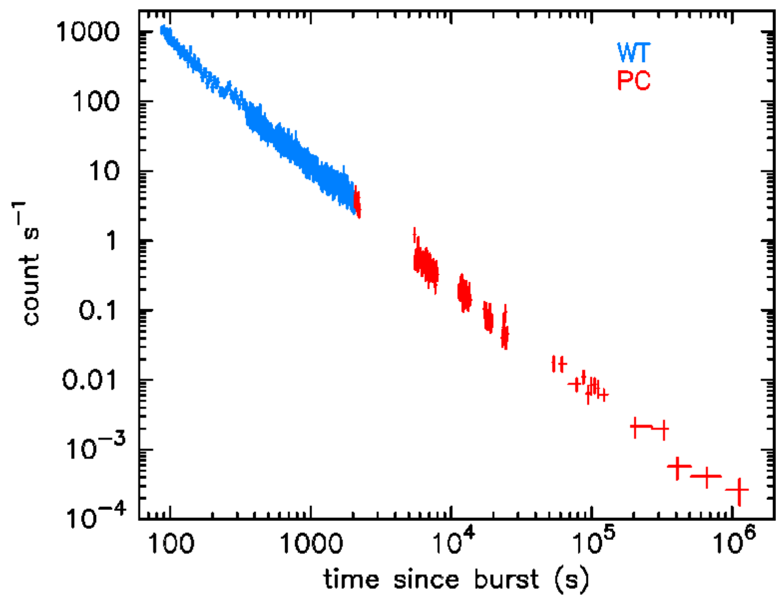
Breaks: Achromatic or otherwise - 1

Jet breaks should be achromatic – seen at the same time across different wavebands. Pre-Swift, breaks seen in the optical were assumed to be jet-breaks.



GRB 060614 (above) shows good evidence for a jet break around 104 ks after the trigger.

Below we have GRB 061007, which shows no sign of jet break for more than 1 Ms (observed frame).

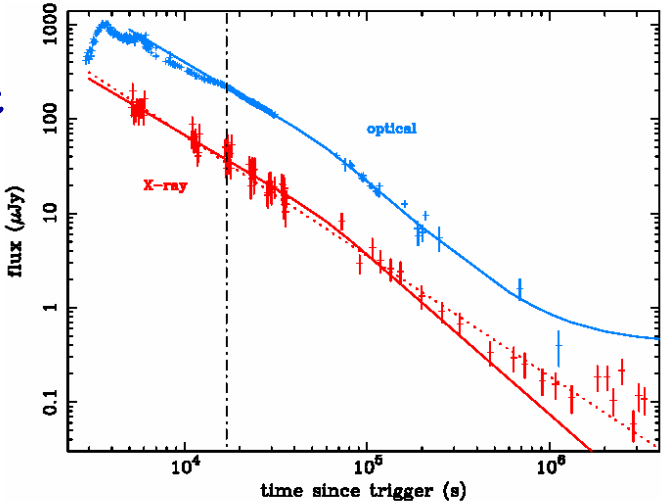


Breaks: Achromatic or otherwise - 2

Jets are needed to help explain the energetics of GRB systems – therefore jet breaks are expected!

So where are they all??

Sometimes the X-ray curves can accommodate the same breaks as seen in the optical, so some jet breaks may be “hidden”.
(See Curran et al., 2007, MNRAS, 381, L65, & 2009, MNRAS, 395, 580; Racusin et al., 2009, arXiv:0812.4780v2; Evans et al., 2009, arXiv:0812.3662v2)



Some of the breaks seen are actually chromatic, occurring at different times in the X-ray and optical…

- Multiple component jets? (Oates et al., 2007, MNRAS, 380, 270)
- Optical emission caused by interaction between ejecta and circumburst medium, while X-ray is internal shocks within late-time collimated shells? (Ghisellini et al., 2007, ApJ, 658, 75)
- Reverse shocks? (Genet et al., 2007, MNRAS, 381, 732; Uhm & Beloborodov, 2007, ApJ, 665, 93)

Conclusions

Swift is speedy and has revealed what happens in the first few minutes to hours after the actual GRB explosion, showing previous theories are incomplete (if not wrong).

We may sometimes refer to the "canonical" X-ray light-curve, but very few bursts follow this pattern exactly.

When you've seen one GRB light-curve…

you've seen one GRB light-