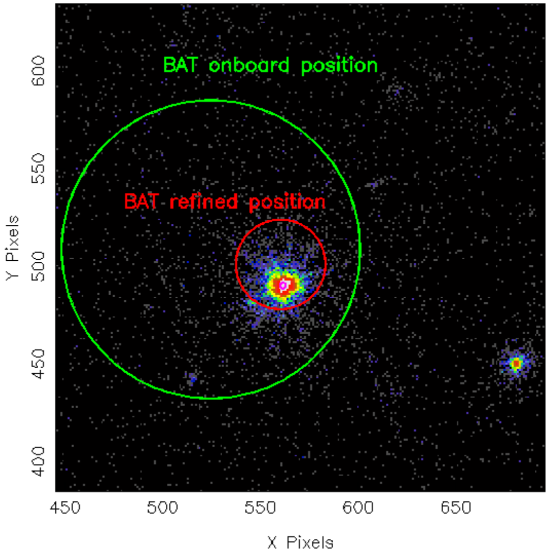
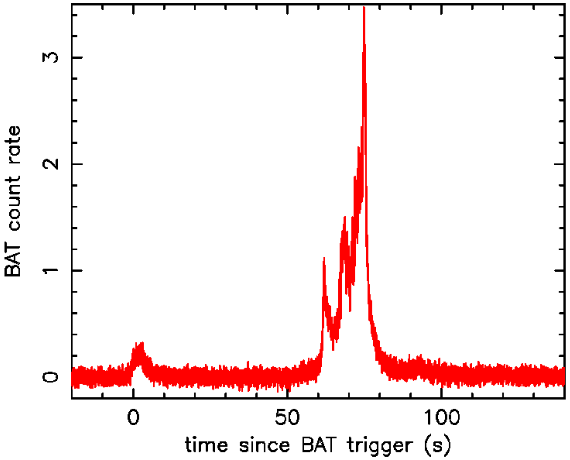
GRB 061121:

Broad-band spectral evolution through the prompt and afterglow phases of a bright burst

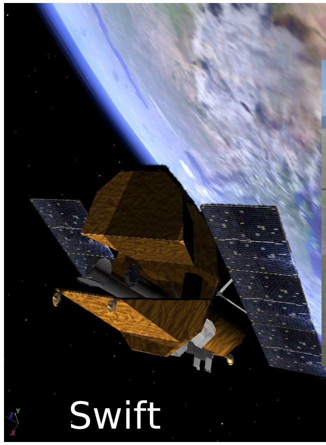


Kim Page

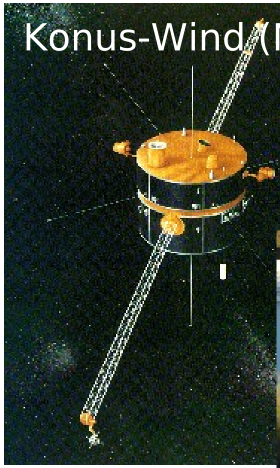
(and many, many others



Observations


Swift


VLA (NRAO/AUI)

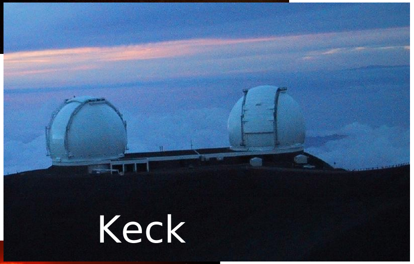

Konus-Wind (NASA)


ROTSE IIIa

Swift
Konus-Wind
RHESSI
XMM-Newton
VLA
ROTSE IIIa
Faulkes Telescope North
Kanata 1.5-m
University of Miyazaki 30-cm
MDM
P60
CrAO
SMARTS/ANDICAM
Keck

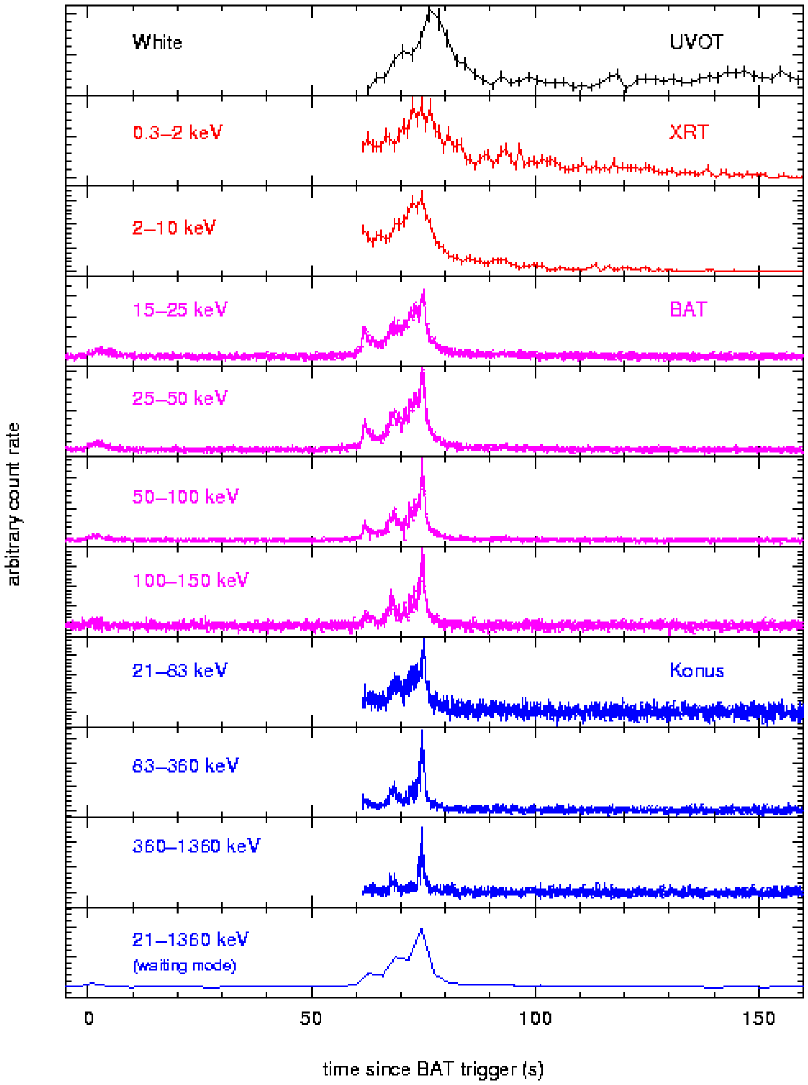

XMM-Newton (ESA)


FTN


Keck


RHESSI (NASA)

Swift and Konus Light-curves



Swift triggered on a precursor, so the NFIs were on target by the time of the main burst. The precursor was detected over all gamma-ray bands, and the optical, X-rays and gamma-rays all tracked the peak, about 75 s after the trigger.

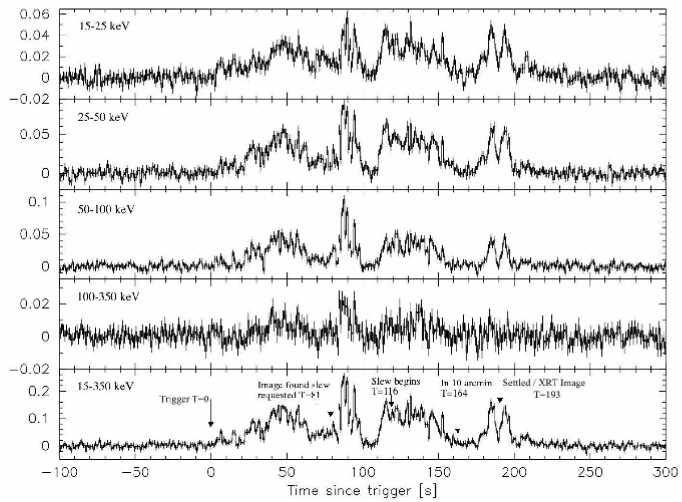
Long burst:

T_{90} ~ 81 s (precursor and main)

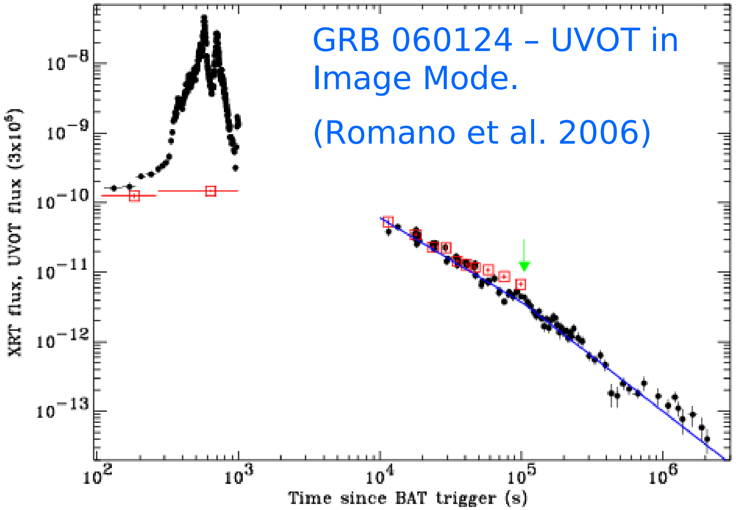
~ 7.7 s (just precursor)

~ 18.2 s (just main pulse)

Previous Observations of the Prompt Emission

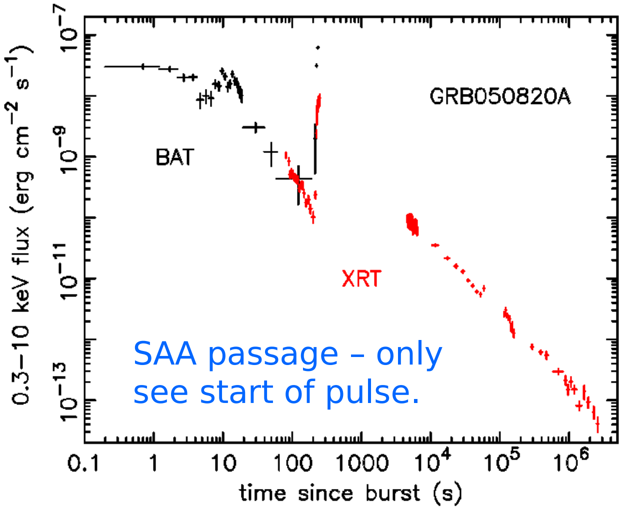


GRB 050117 – Earth constraint and SAA (Hill et al. 2006)

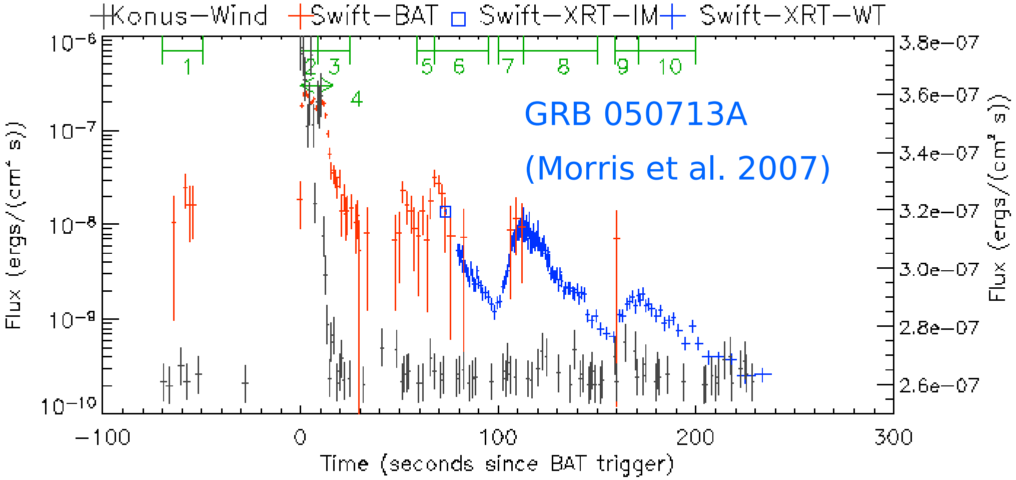


GRB 060124 – UVOT in Image Mode.

(Romano et al. 2006)



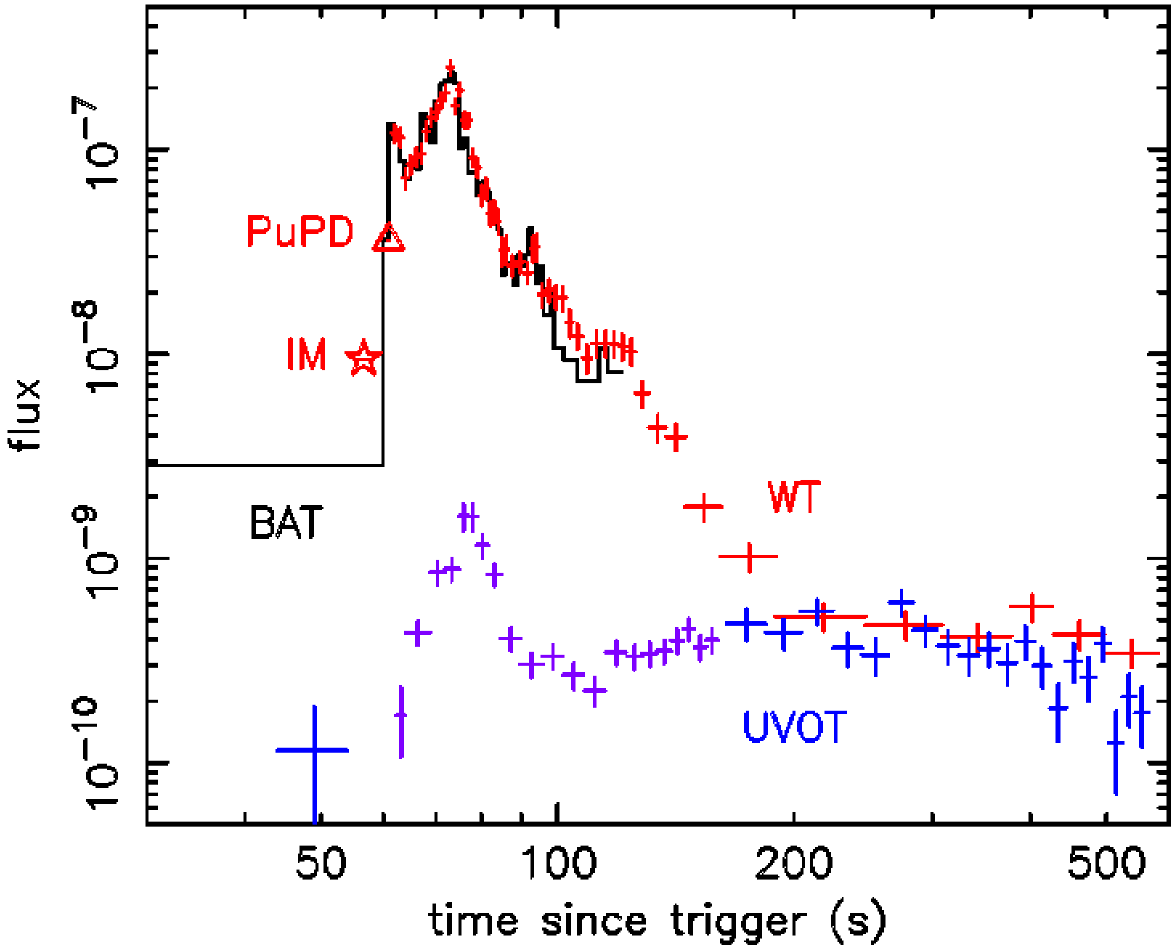
SAA passage – only see start of pulse.



GRB 050713A

(Morris et al. 2007)

Swift Flux Light-curve



Gamma-ray

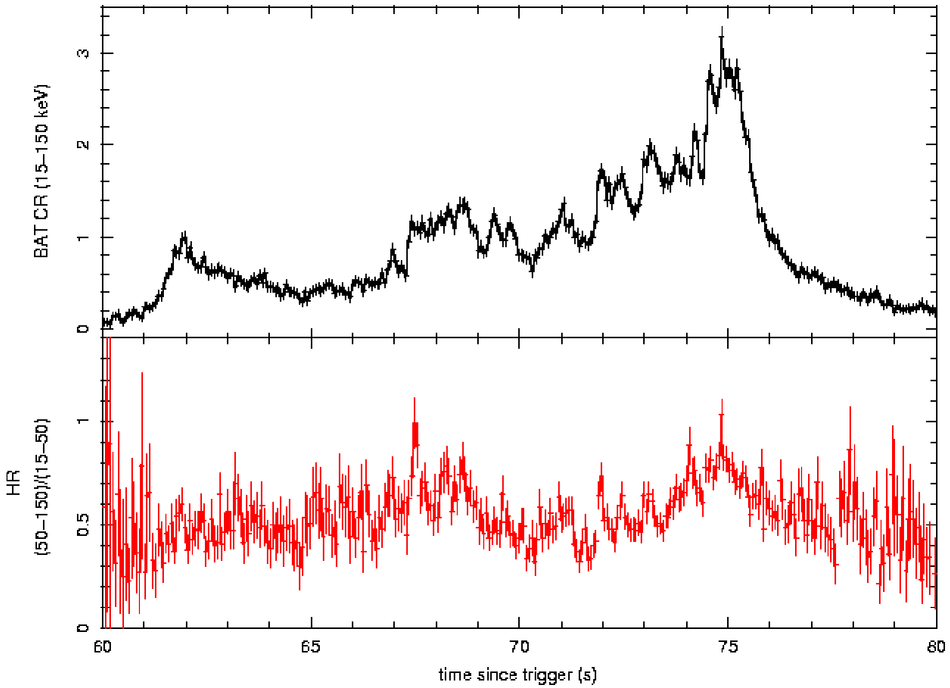
X-ray

V-band

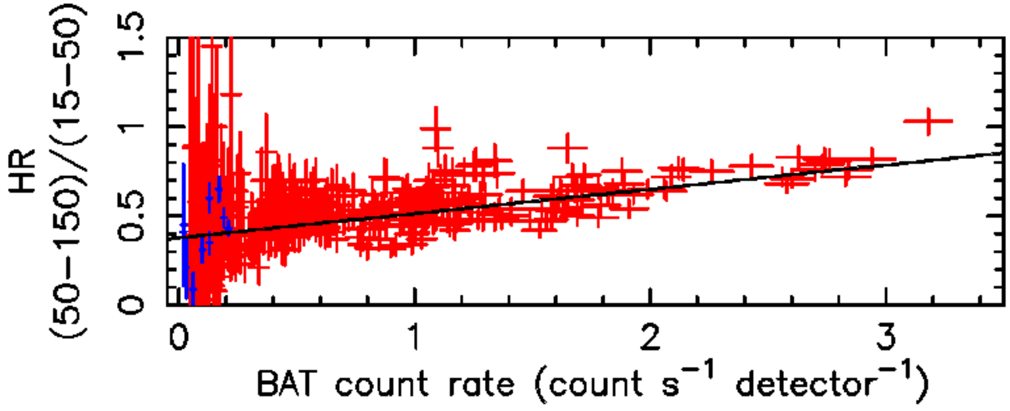
White filter

BAT

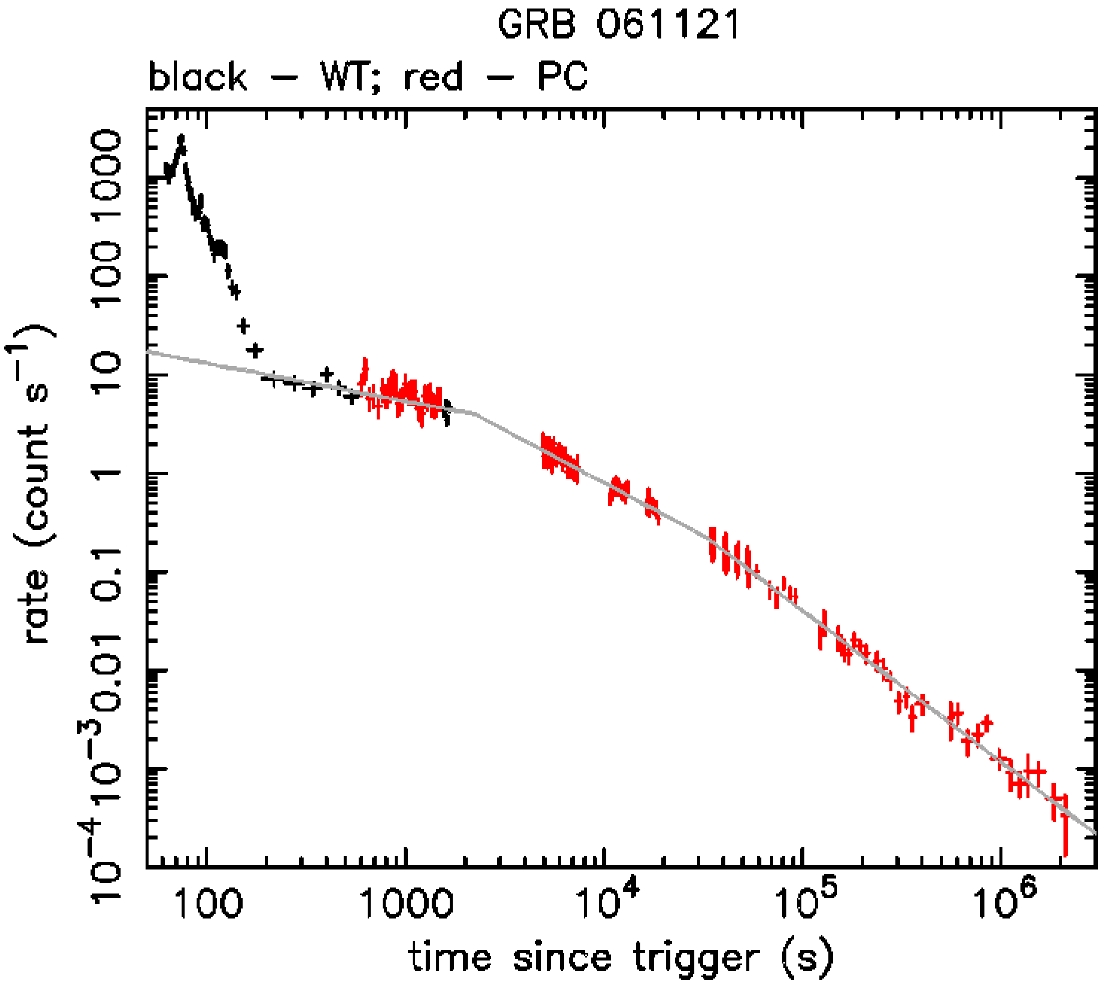
Spectral evolution occurs throughout the main burst.



The gamma-ray emission is harder when brighter. The blue points show the precursor data, which are consistent with the relationship for the main burst.



XRT Light-curve



Fitting beyond 200s:

$\alpha_1 = 0.38 \pm 0.08$

$t_{break,1} = 2260 \pm 500$ s

$\alpha_2 = 1.07 \pm 0.05$

$t_{break,2} = (3.2 \pm 1.5)\text{x}10^4$

$\alpha_3 = 1.53 \pm 0.07$

The spectrum appears to harden slightly over the ~32 ks break.

Lags and ACF

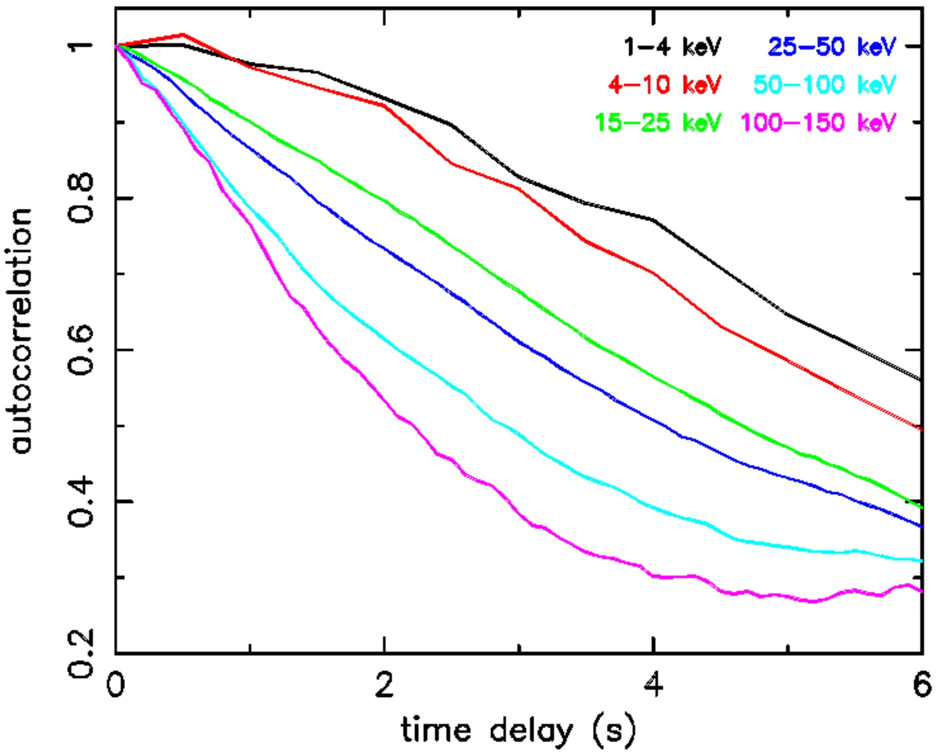
As is usual for long bursts, the harder data lead the softer by a short time span. Comparing 50-100 keV with 15-25 keV, we find:

Precursor lag: 600 ± 100 ms

Main burst lag: 1 ± 6 ms

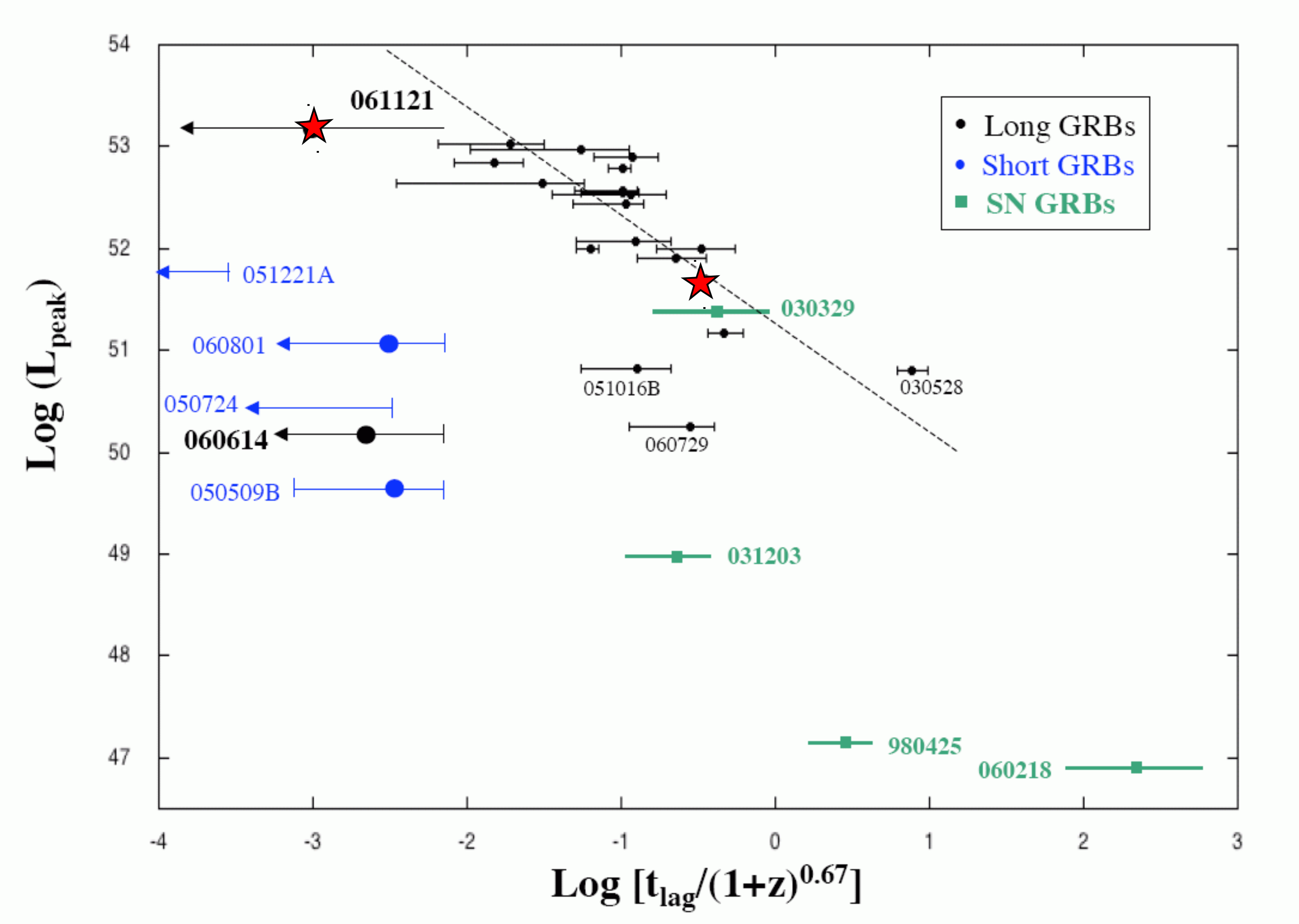
Could be due to different luminosities and viewing angles.

Both values lie on the luminosity-lag relation for long bursts.



The autocorrelation function shows that the peaks in the emission are narrower at higher energies.

Lag-Luminosity relation



Precursor Emission

Precursors are not well understood, though there are a number of theories, including:

- Fireball interacting with massive progenitor?

Spectra should be thermal. (Ramirez-Ruiz et al. 2002)

- Jet breakout of stellar surface?

How could this also cause later, postcursor emission?

(Ramirez-Ruiz et al. 2002; Lazzati et al. 2007)

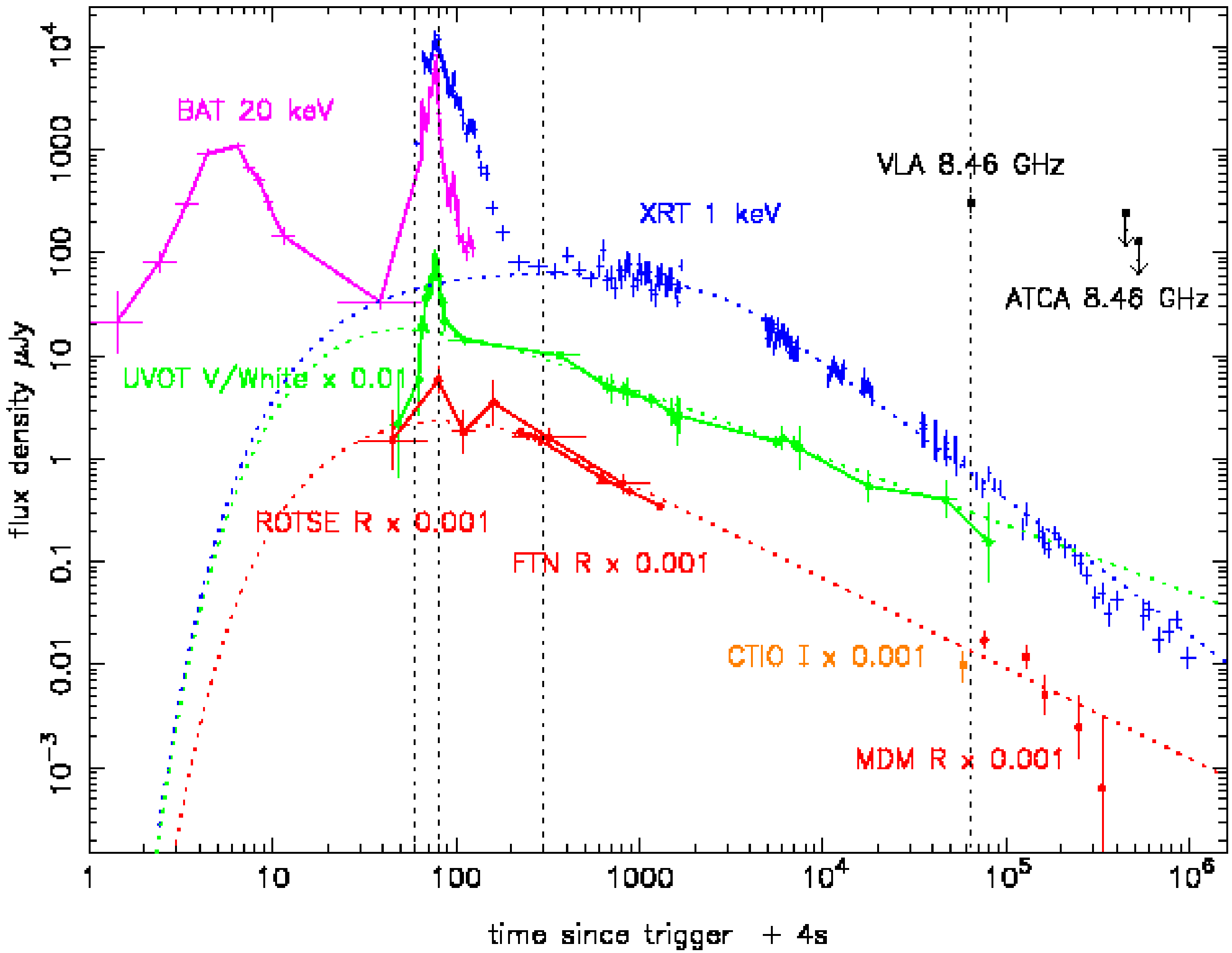
- Deceleration of faster front shells, so that slower ones catch up and collide?

(Fenimore & Ramirez-Ruiz 1999; Uemeda et al. 2005)

- Continuing activity of the central engine – as for flares?

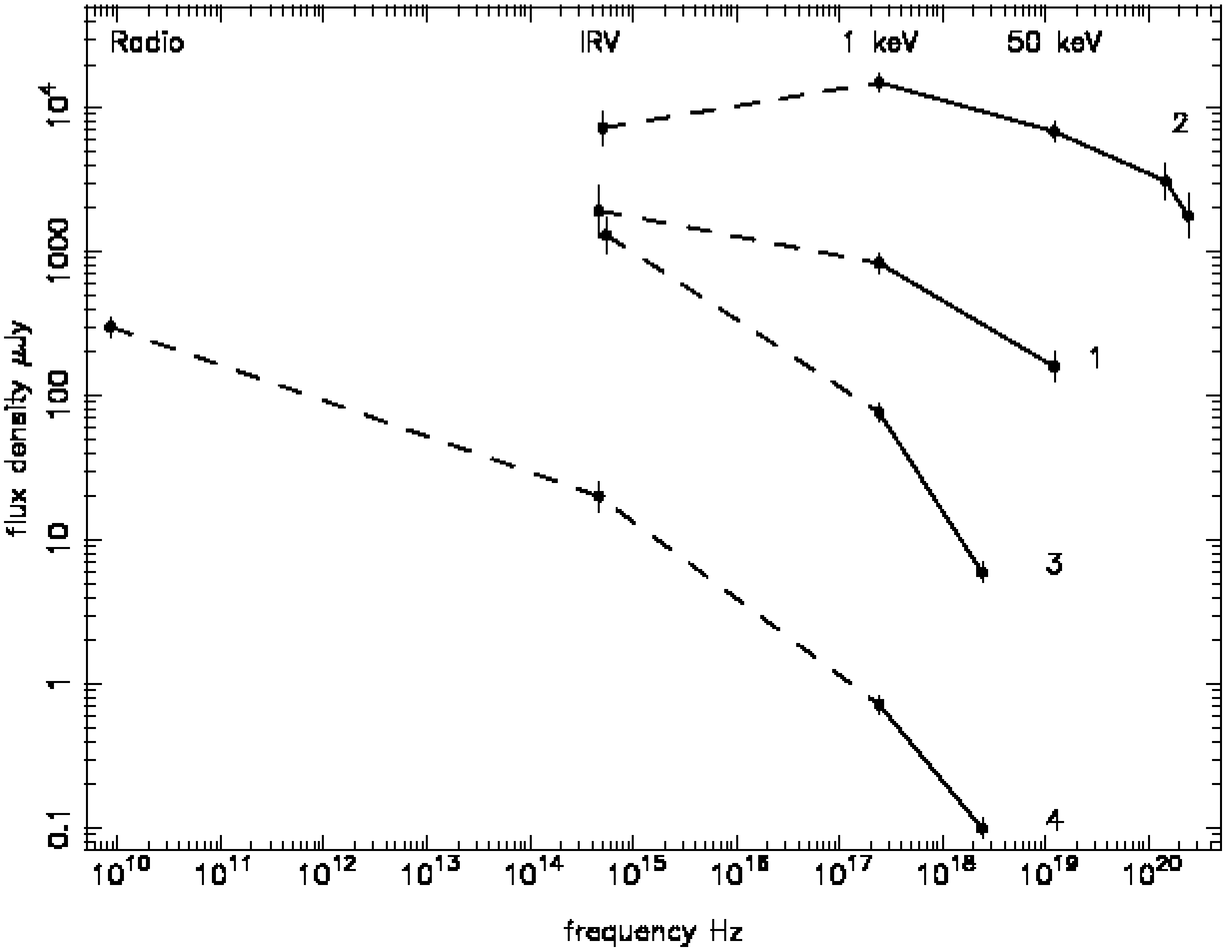
Conclusion: can’t decide from the data for this burst.

Flux density Light-Curves



Curved dotted lines: exponential-to-power-law model fits to the X-ray, V-band and R-band data

Spectral Energy Distribution



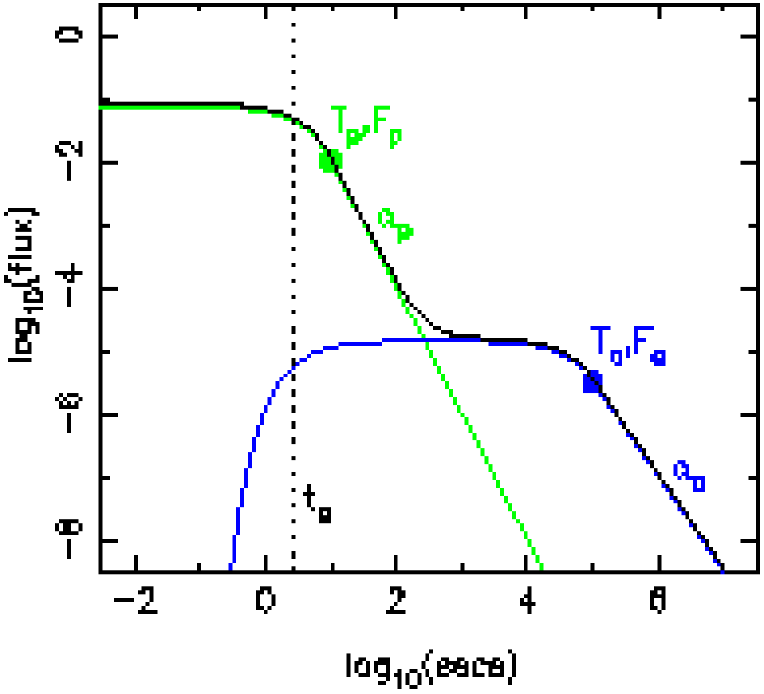
Optical emission was relatively faint during the main pulse.

Solid lines: fits to the X-ray/gamma-ray data Dashed lines: join up separate points

Afterglow Emission - 1

The “standard” afterglow model closure relations (e.g. Zhang & Mészáros 2004) don’t fit all “segments” of the broken power-law model.

From O’Brien et al. (2006) and Willingale et al. (in press), one or two exponential-to-power-law models can be used to fit the entire



$$f_c(t) = F_c \exp\left(\alpha_c - \frac{t\alpha_c}{T_c}\right) \exp\left(\frac{-t_c}{t}\right), \quad t < T_c$$

$$f_c(t) = F_c \left(\frac{t}{T_c}\right)^{-\alpha_c} \exp\left(\frac{-t_c}{t}\right), \quad t \geq T_c$$

The transition from exponential to power-law occurs at (T_c,F_c), where the functional sections have the same value/gradient. t_c is the time of the initial rise.

Afterglow Emission - 2

This functional form was applied to the X-ray, UVOT and combined R-band data.

The X-ray data show the “roll over” to the final decay, whereas the optical decay is established earlier – no “plateau” is seen in the UVOT or ROTSE data.

In the X-ray and V-band cases, the decay is slower than expected from the closure relations obtained from the measured spectral parameters. Both bands are in best agreement with being below the cooling frequency.

Afterglow Emission - 3

Over time, the spectra appear to be hardening:

- R-band decays faster than V-band ($\alpha_{R\text{-}X} \sim 0.84$, cf. $\alpha_{V\text{-}X} \sim 0.66$), so the optical spectral index becomes harder
- X-ray spectral index appears to harden from $\Gamma \sim 2.1$ to ~ 1.9 round about 32 ks.

Such spectral hardening from the “plateau” to the final decay is a feature of many X-ray afterglows (Willingale et al. 2007).

Possible explanation: Synchrotron Self-Comptonisation.

The surrounding density would need to be very high, though: 5×10^3 to 10^5 cm^{-3} This is similar to that found in the core of a molecular cloud.

Might therefore expect greater reddening than that estimated from the UVOT data ($A_v \leq 1$), but dust destruction can occur (e.e Waxman & Draine 2000).

Still to be understood…

- What causes precursors?

- The SEDs show a break between the optical and X-ray bands, but both seem to be below the cooling frequency. What is the origin of this break?

- The X-ray and optical spectra harden over time. What causes this hardening? Did the burst go off in the core of a molecular cloud?