Blackbody emission in GRB 101219B

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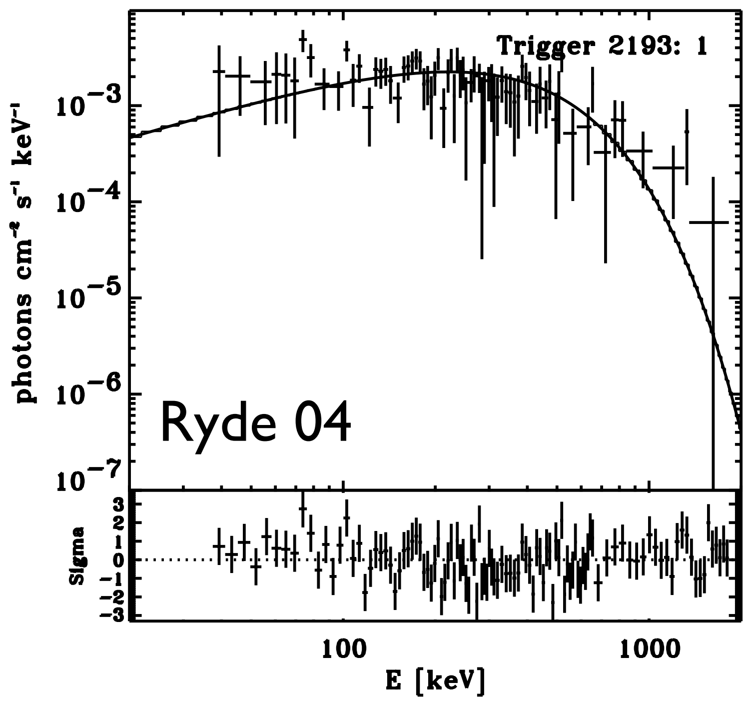
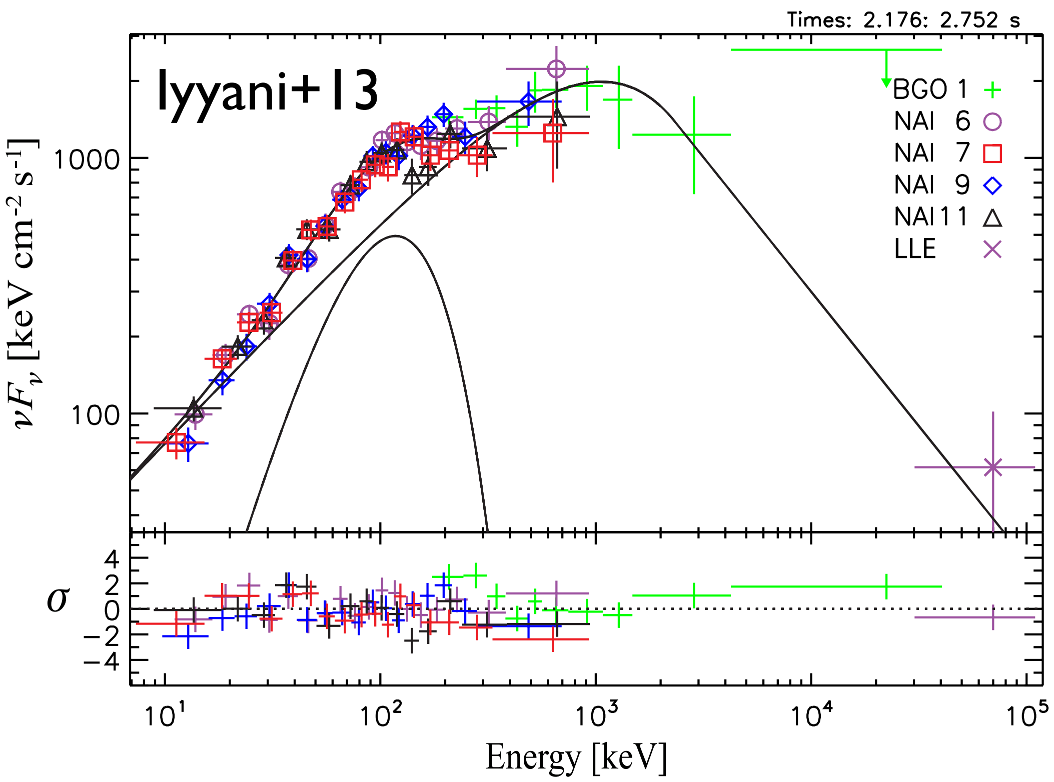
Photospheric emission in the prompt phase of GRBs

It has been known since the BATSE era that photospheric emission is important in some GRBs (Ghrilanda+03, Ryde 04).



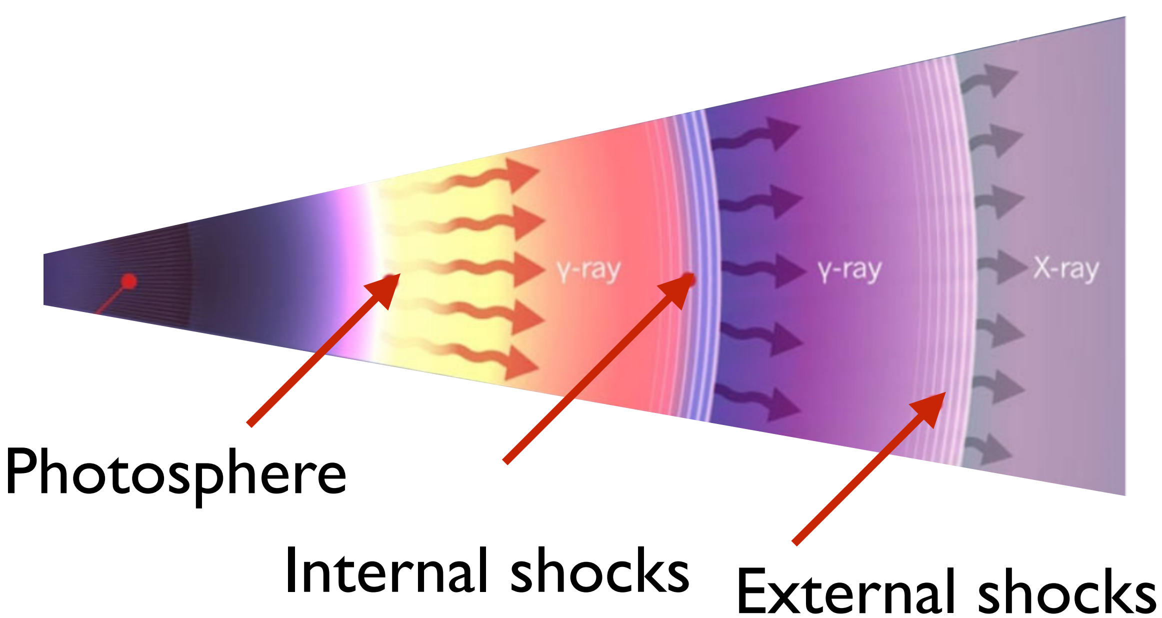
With Fermi a number of cases with sub-dominant photospheric components have also been observed (e.g., Guiriec+11, Axelsson+12, Guiriec+13).



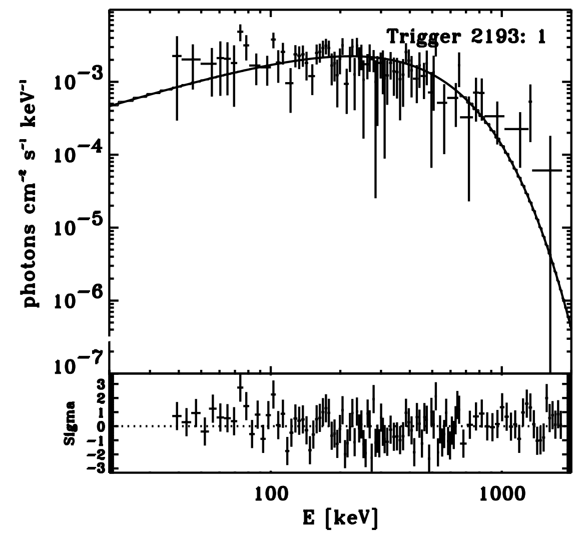
Dominant blackbody emission

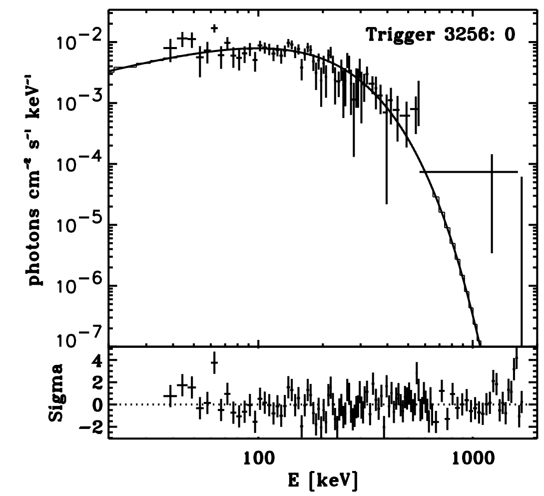
Only a handful of GRBs are well described by a blackbody throughout the burst.

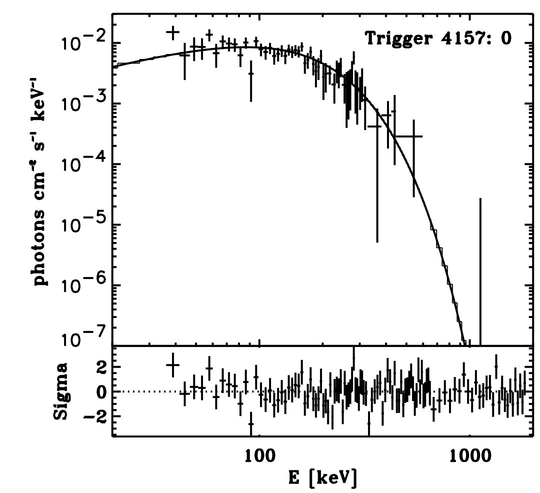
Important since emission mechanism uniquely identified.



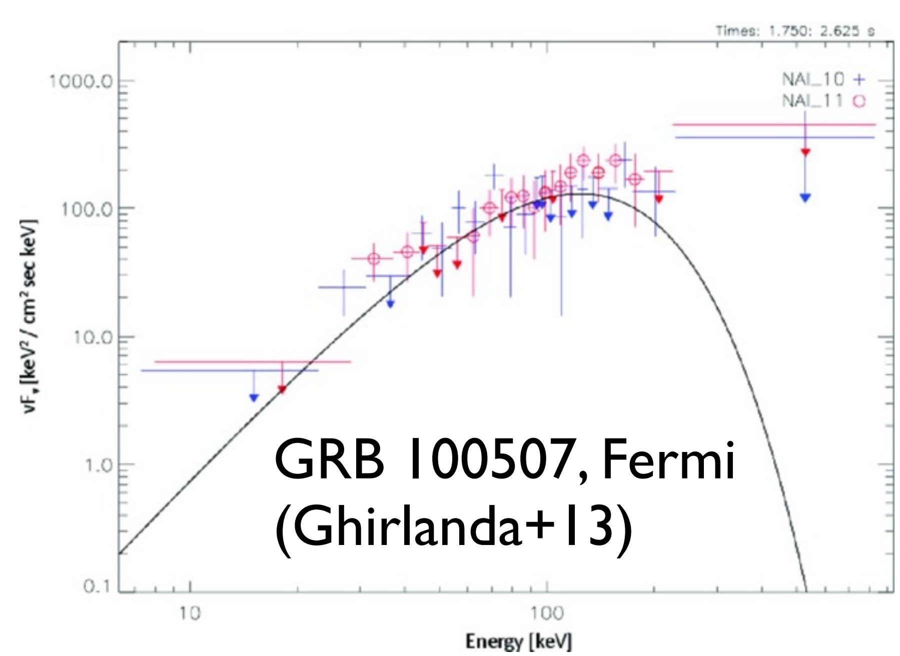
None of these GRBs have afterglow observations and known redshifts.







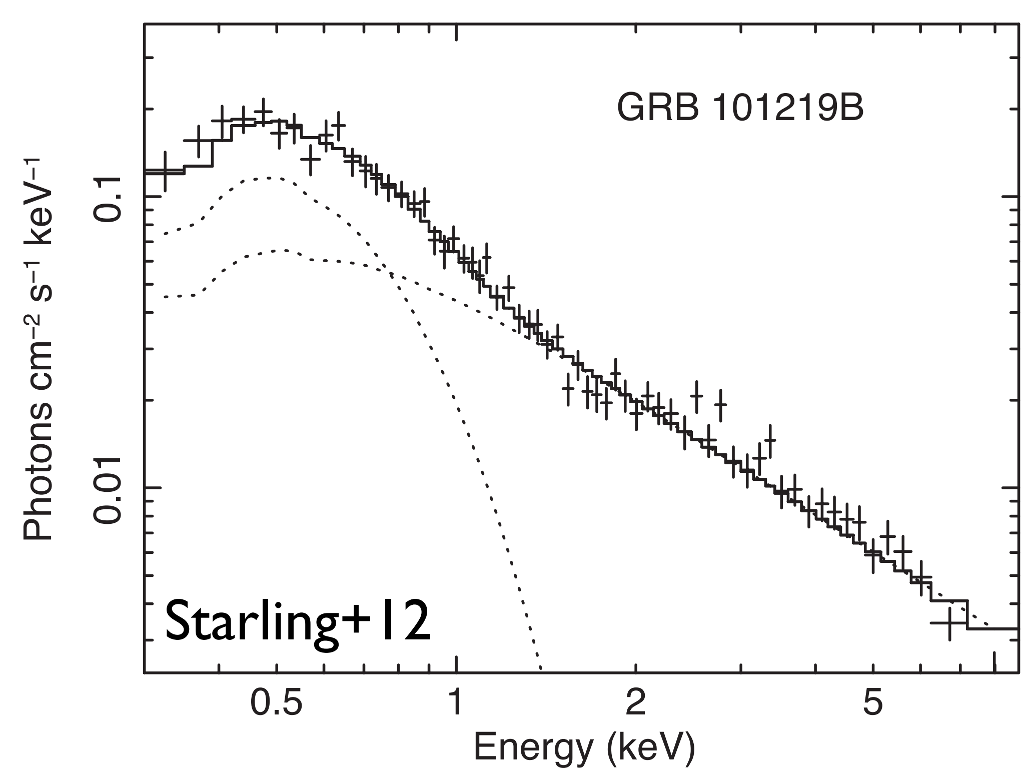
A few BATSE bursts (Ryde 04)



GRB 100507, Fermi (Ghirlanda+13)

GRB 101219B

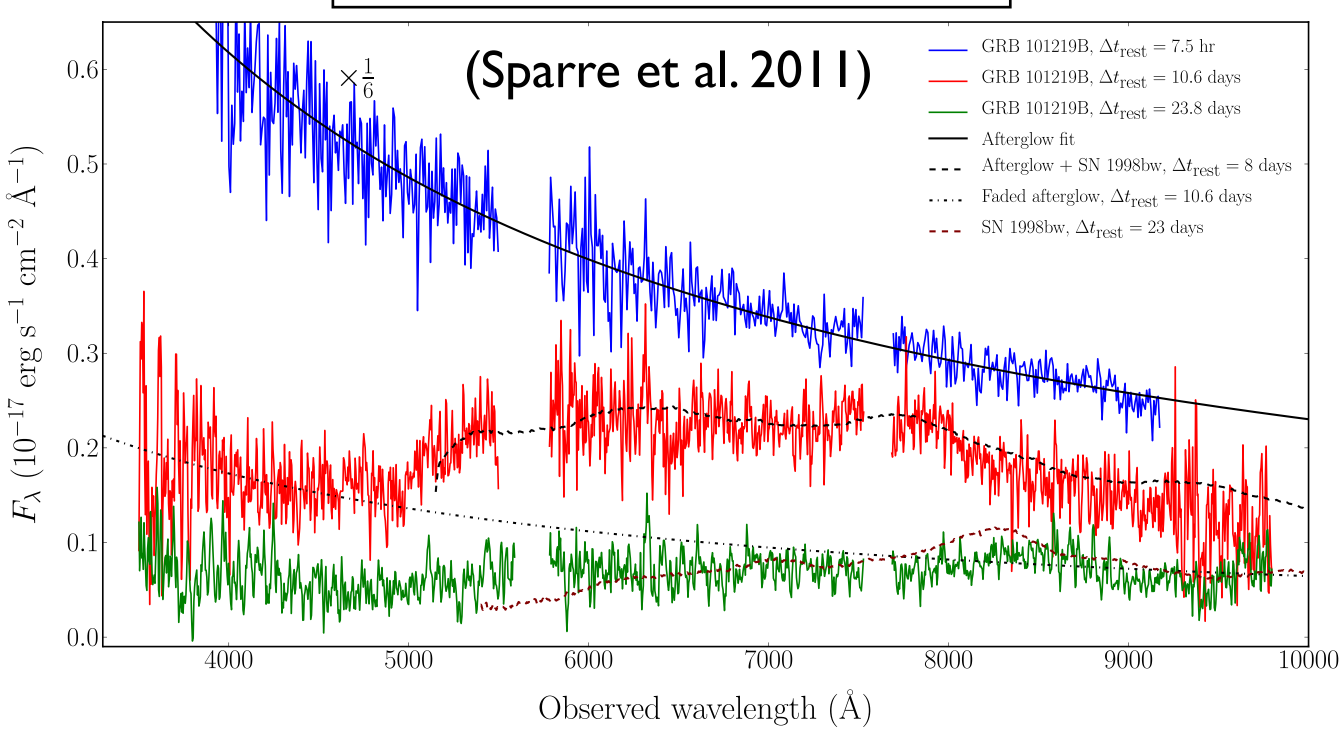
- Prompt emission triggered Fermi GBM and Swift BAT.
- Afterglow observed in X-ray - optical by Swift, GROND & VLT. Redshift=0.55 (Sparre+11).
- Blackbody component reported in the early afterglow (Starling+12).
- Associated with SN 2010ma, a broad line Ic supernova (Sparre +11,Olivares+15).

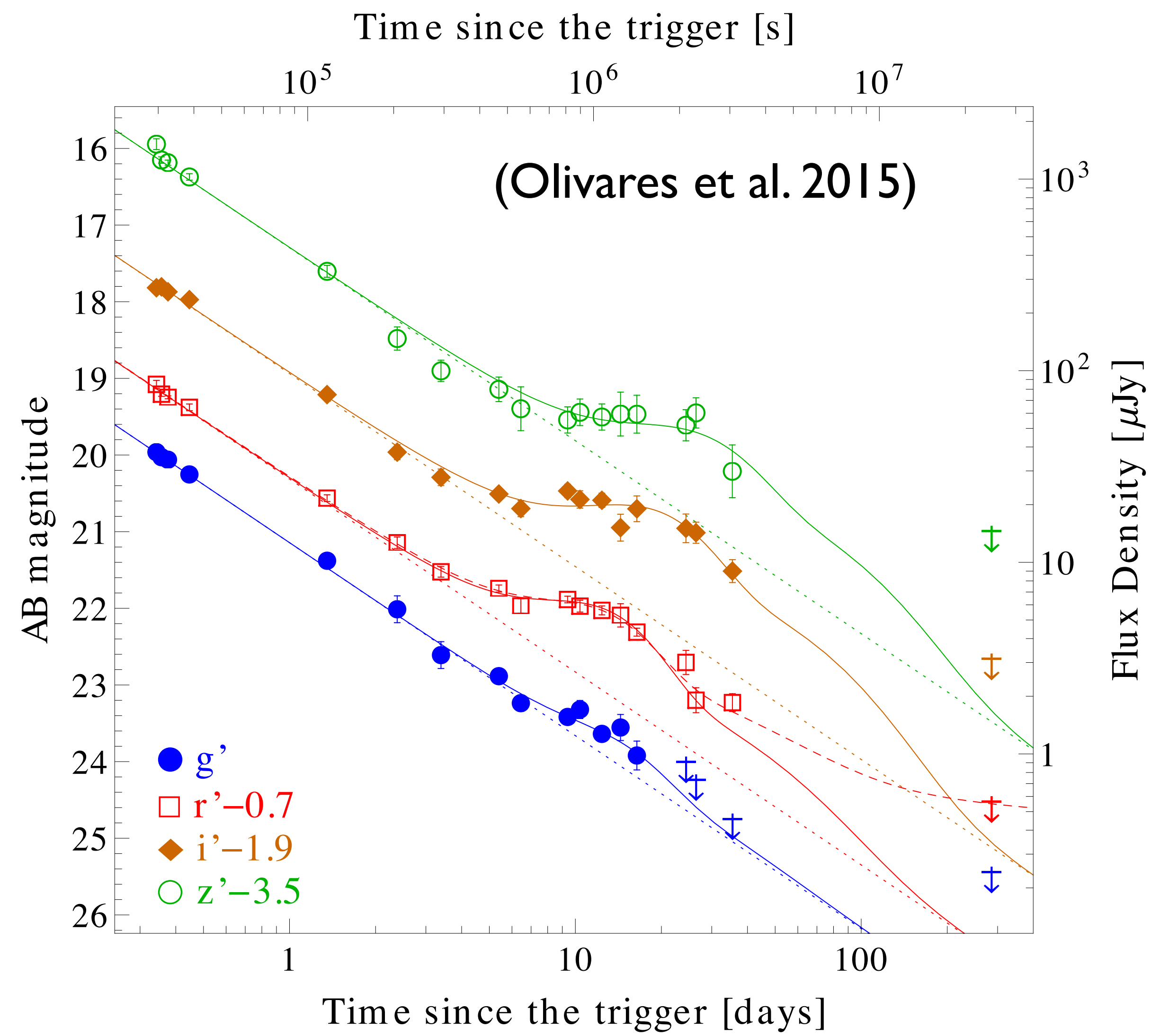


Associated with SN 2010ma

Broad-line type Ic SN. Early peak time (10 d) and rather blue spectrum. Kinetic energy of explosion: $10 \pm 6 \times 10^{51}$ erg. (Olivares et al. 2015)

X-shooter spectrum





SN "bump" observed by GROND

Prompt emission

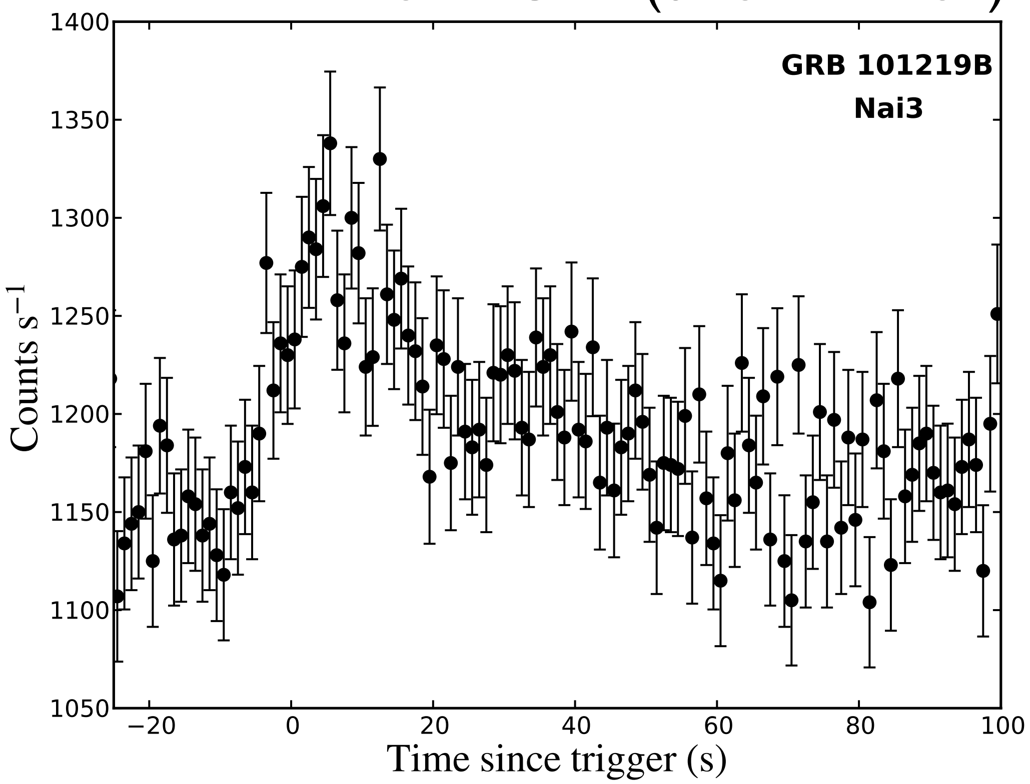
T_{90} = 51.0 s

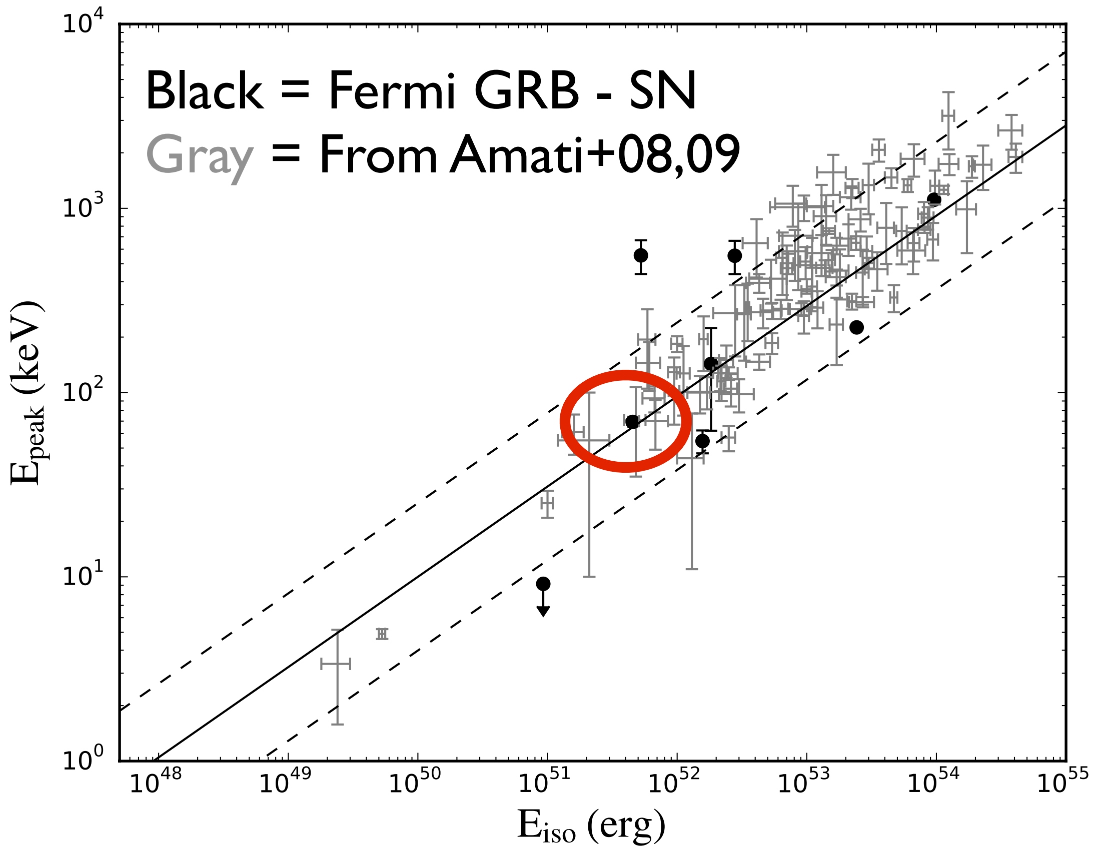
Fluence (10-1000 keV) = $3.99 \pm 0.05 \cdot 10^{-6}$ erg cm^{-2}

$E_{\gamma,iso} = 3.4 \pm 0.2 \cdot 10^{51}$ erg

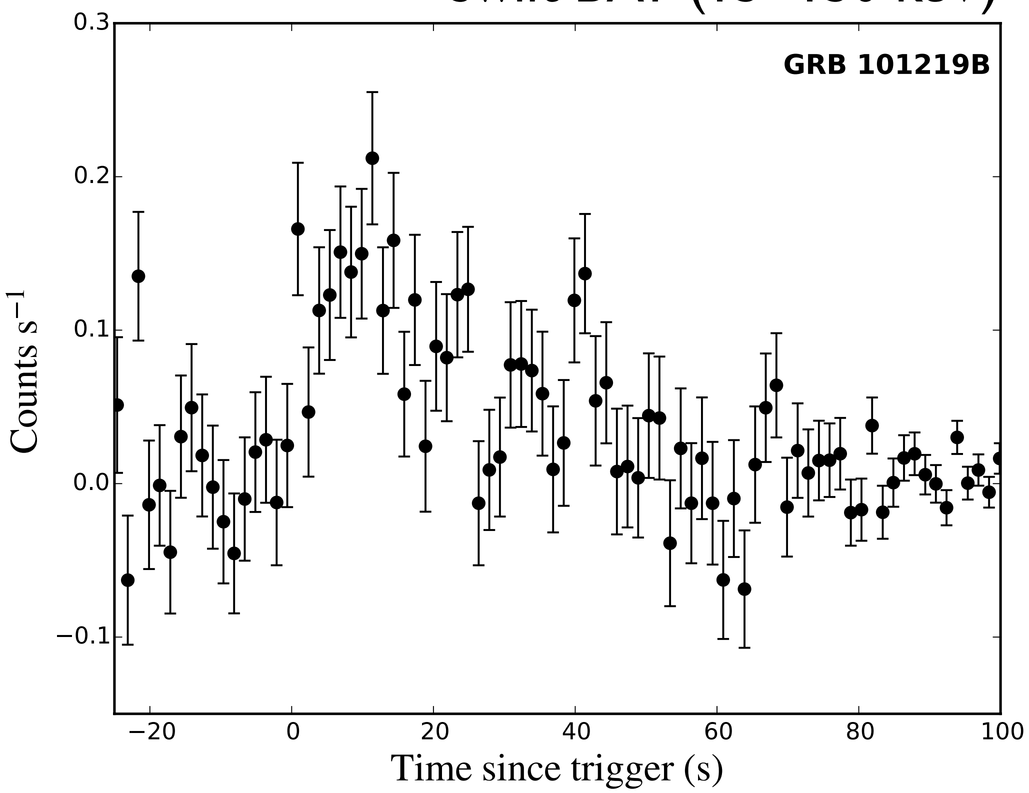
No detection in Fermi BGO (200 keV - 40 MeV) or LAT (30 MeV - 300 GeV)

Fermi GBM (8 keV - 1 MeV)

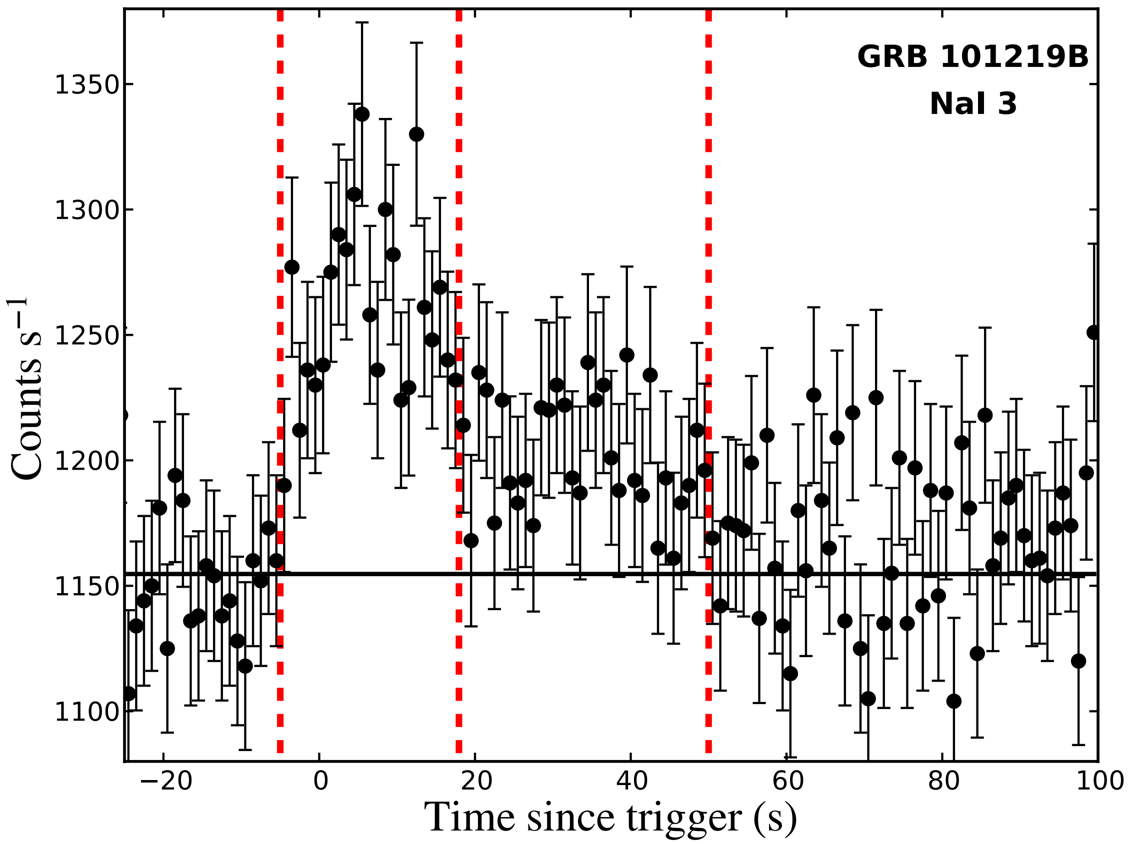


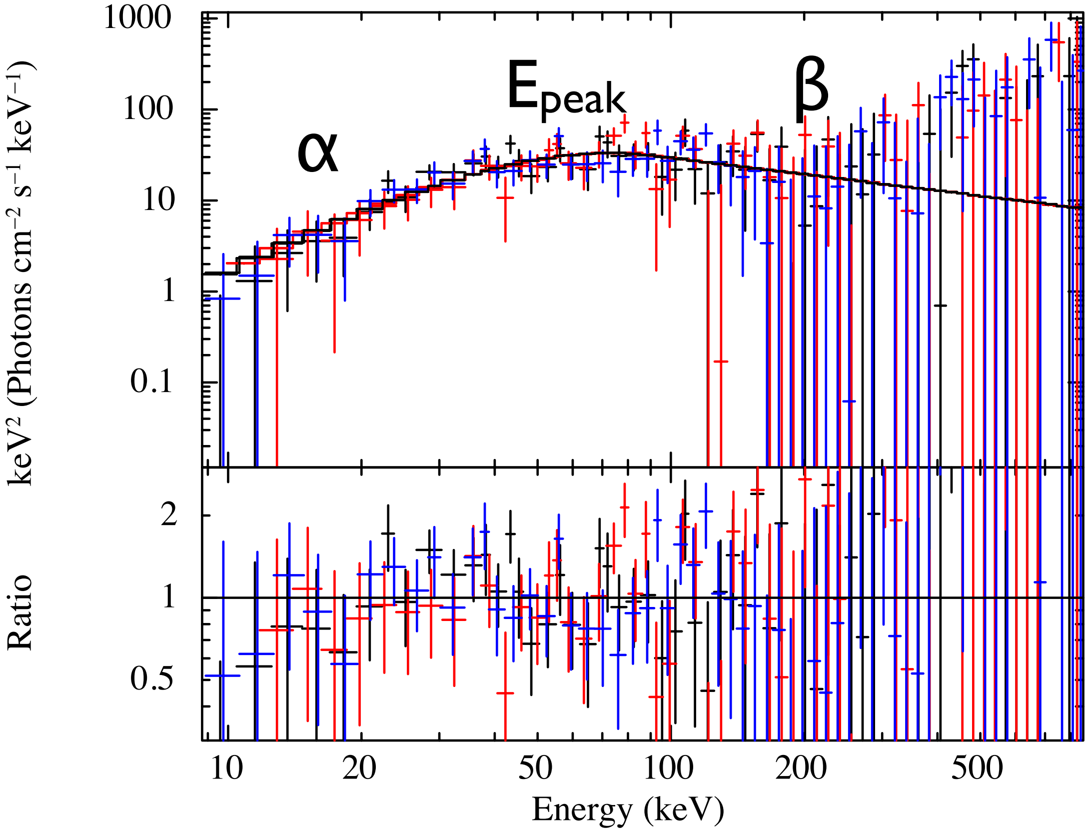


Swift BAT (15 -150 keV)



Spectral analysis





Time intervals for spectral analysis

Defined using Bayesian blocks

Low signal prevents finer binning

Band function fit to first interval

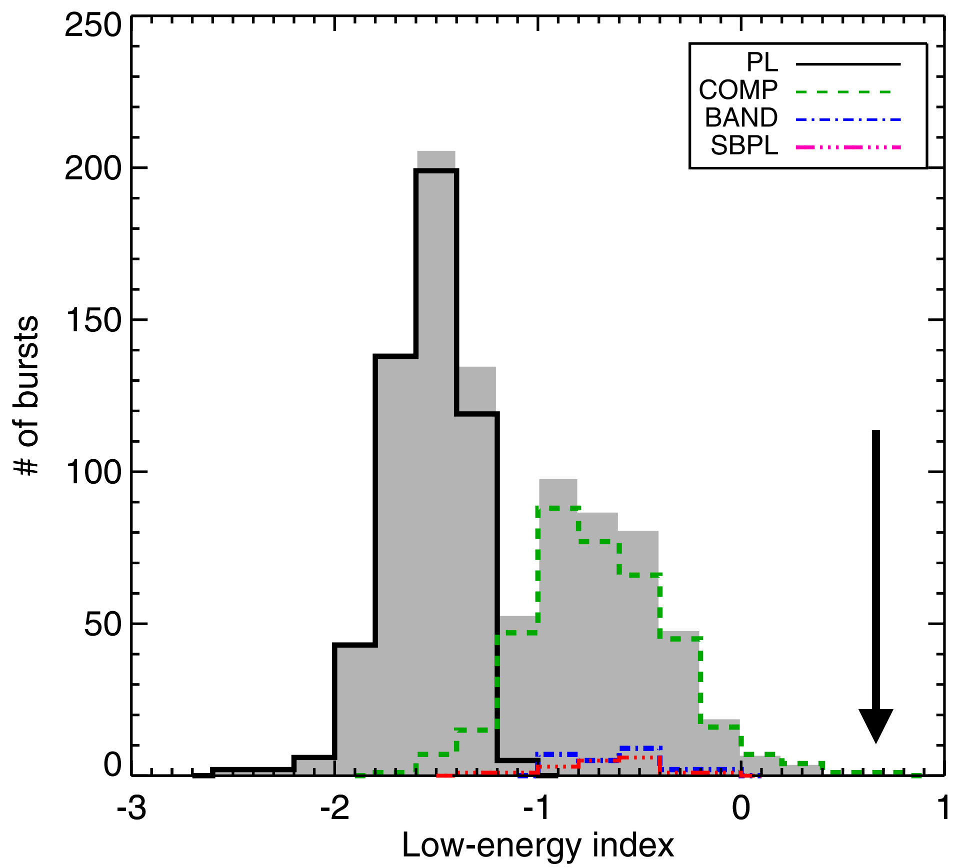
$\alpha = 0.63 \pm 0.05$

$\beta = -2.6 +0.18/-0.37$

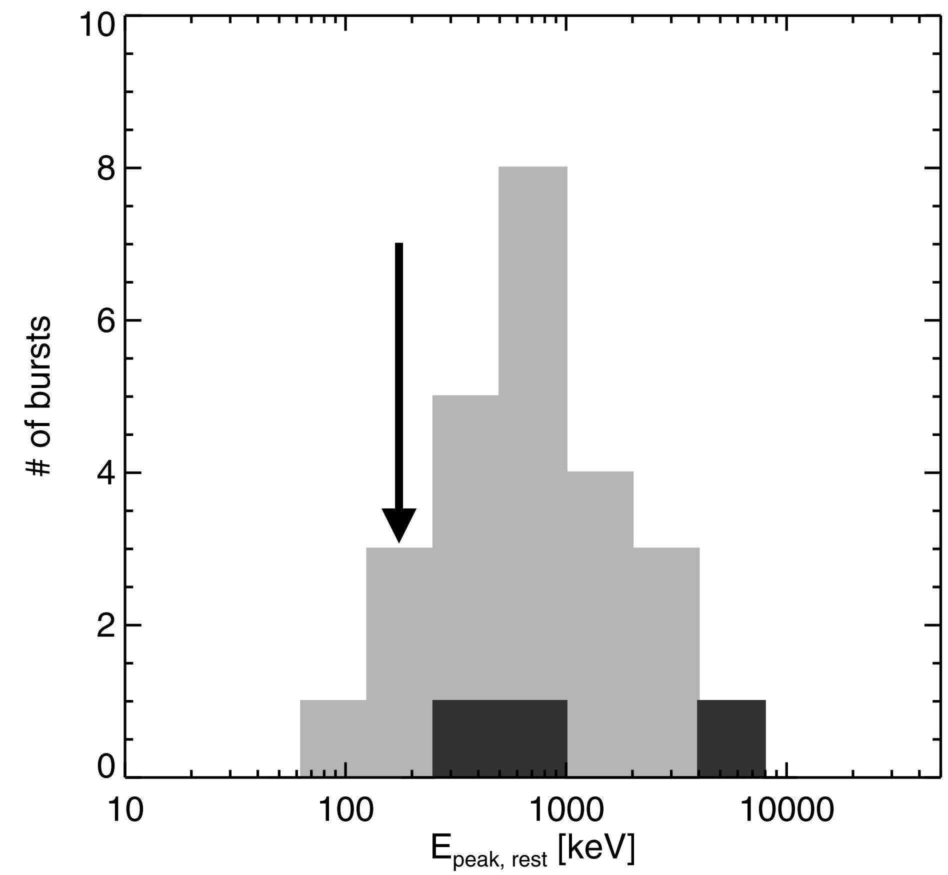
$E_{peak} = 72.9 \pm 14.8$

Comparison with GBM catalog

Extremely hard α!



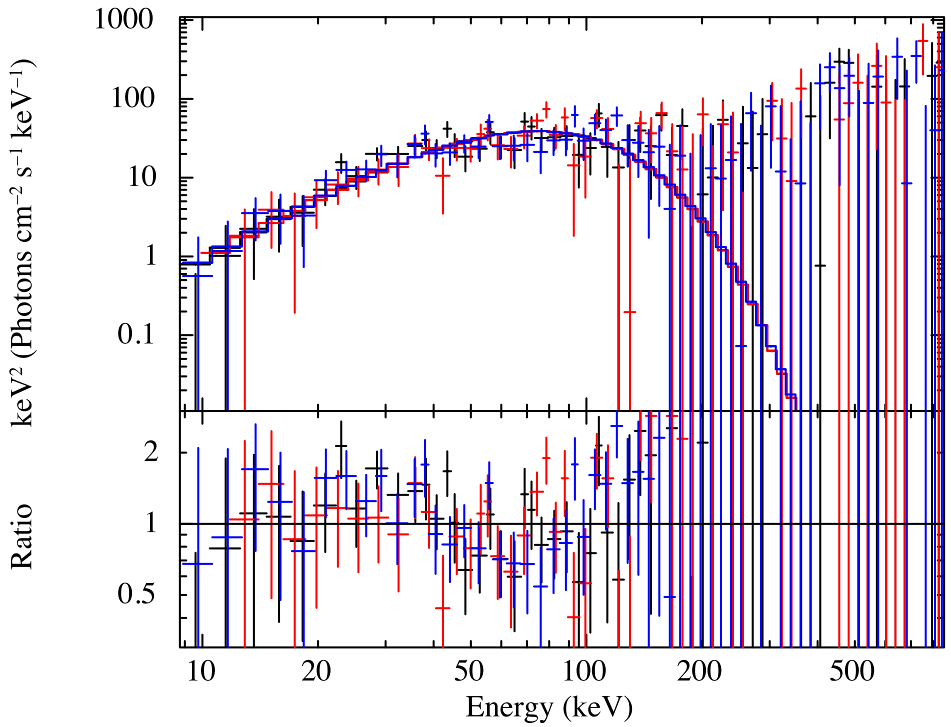
Low $E_{peak,rest}$



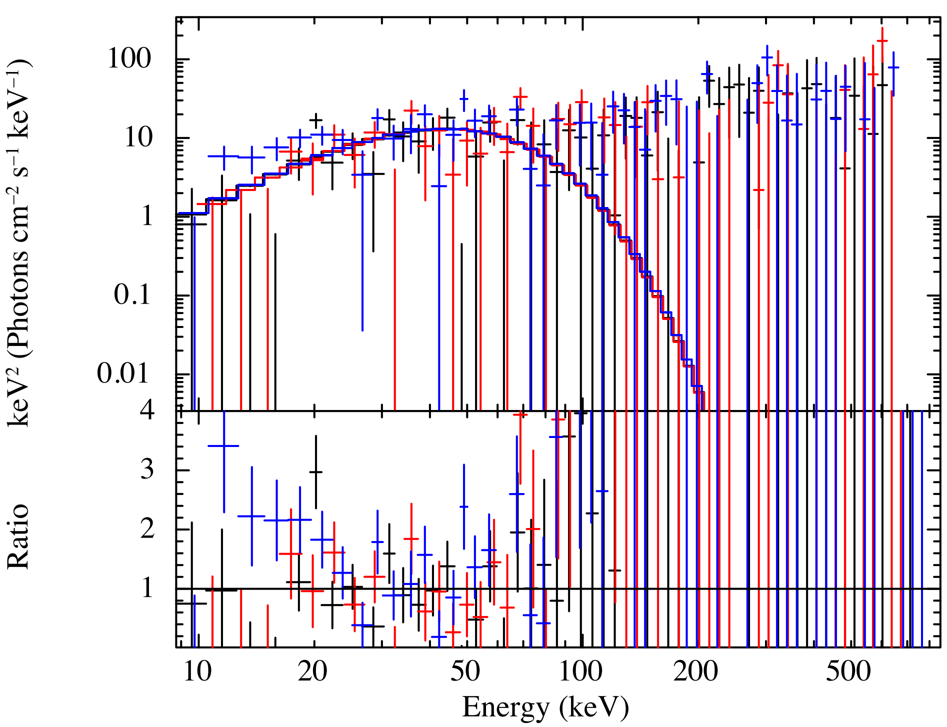
Comparison with peak flux spectra in GBM catalog (Gruber et al. 2014).

Blackbody fits

Interval 1: kT = 19.1 ± 0.6



Interval 2: kT = 11.2 ± 0.7



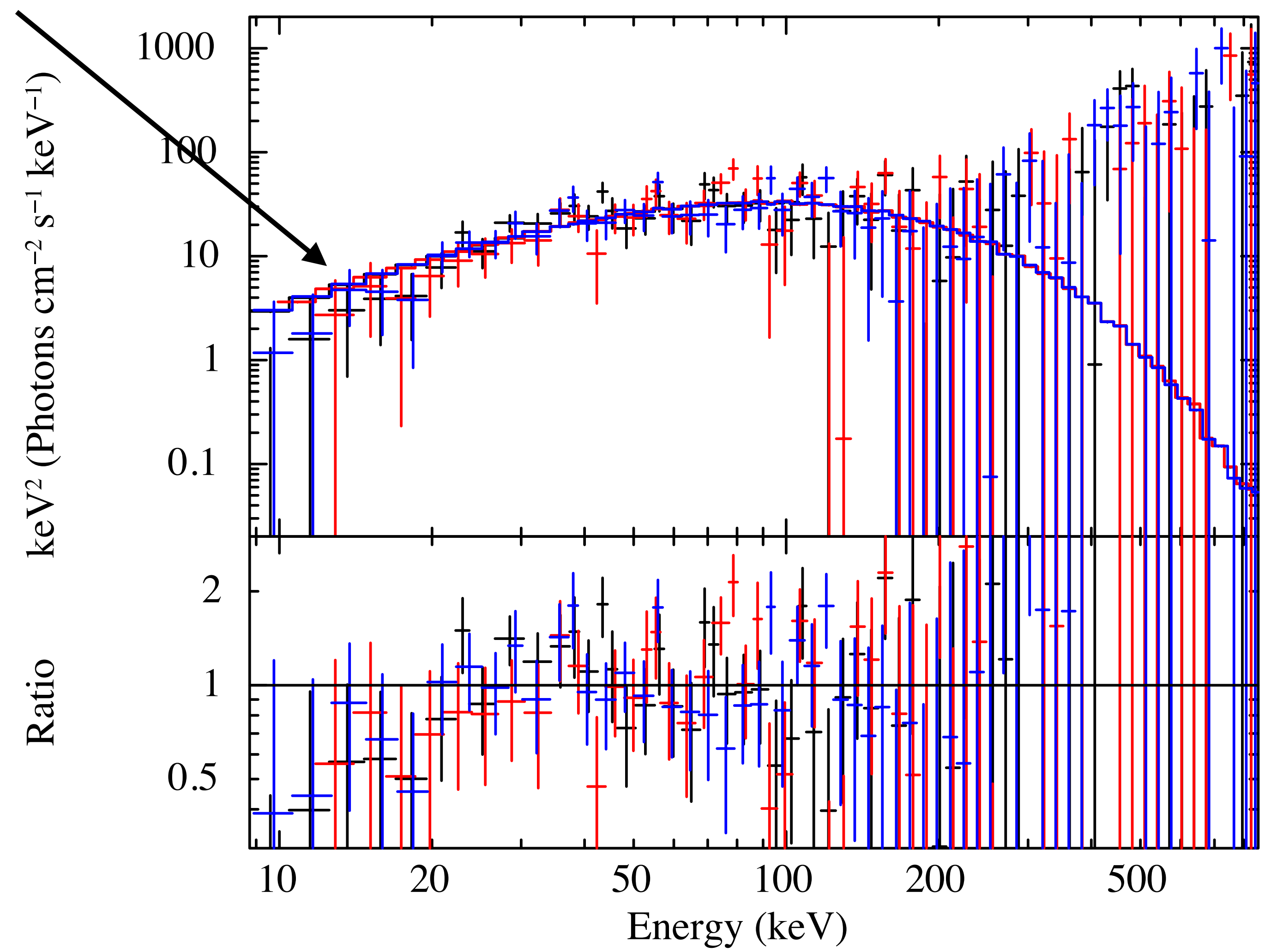
The spectra are well described by Blackbody emission. But signal-to-noise is low. Can we rule out alternative scenarios?

Simulations show that obtaining such a hard α by chance if the true α=-0.67 (i.e. slow cooled synchrotron emission) is only $6 \cdot 10^{-4}$.

A pure blackbody?

Model: Photospheric emission from a spherically symmetric wind. (Lundman+13).

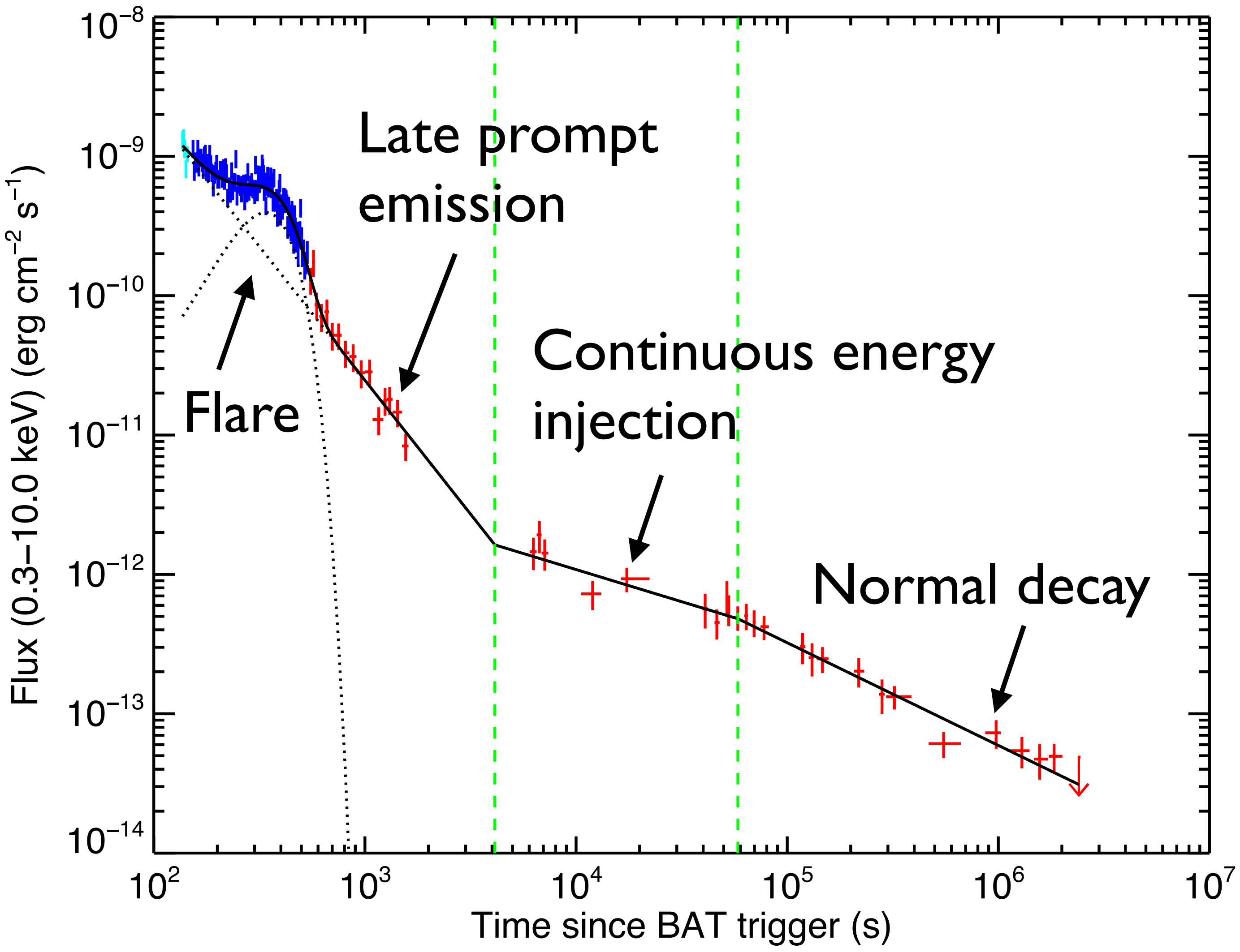
Even in the case of no dissipation within the jet, the spectrum is expected to be broader than a BB due to geometric effects and time evolution.



Estimate of broadening by comparing BB and Band function fits. The latter has a flux that is ~1.6 times higher (almost all the difference at high energies where there are only upper limits).

Afterglow emission

Swift XRT afterglow light curve



Light curve described by three power-law segments ($F \propto t^{-\alpha}$):

α_1 = 1.92 (±0.07)
α_2 = 0.46 (+0.13/-0.22)
α_3 = 0.74 (+0.13/-0.09)

$t_{br,1}$ = 4.1 (+1.3/-0.9) ks
$t_{br,2}$ = 58 (+57/-36) ks

Lack of a "jet-break" puts a limit on the opening angle of the jet of >17°

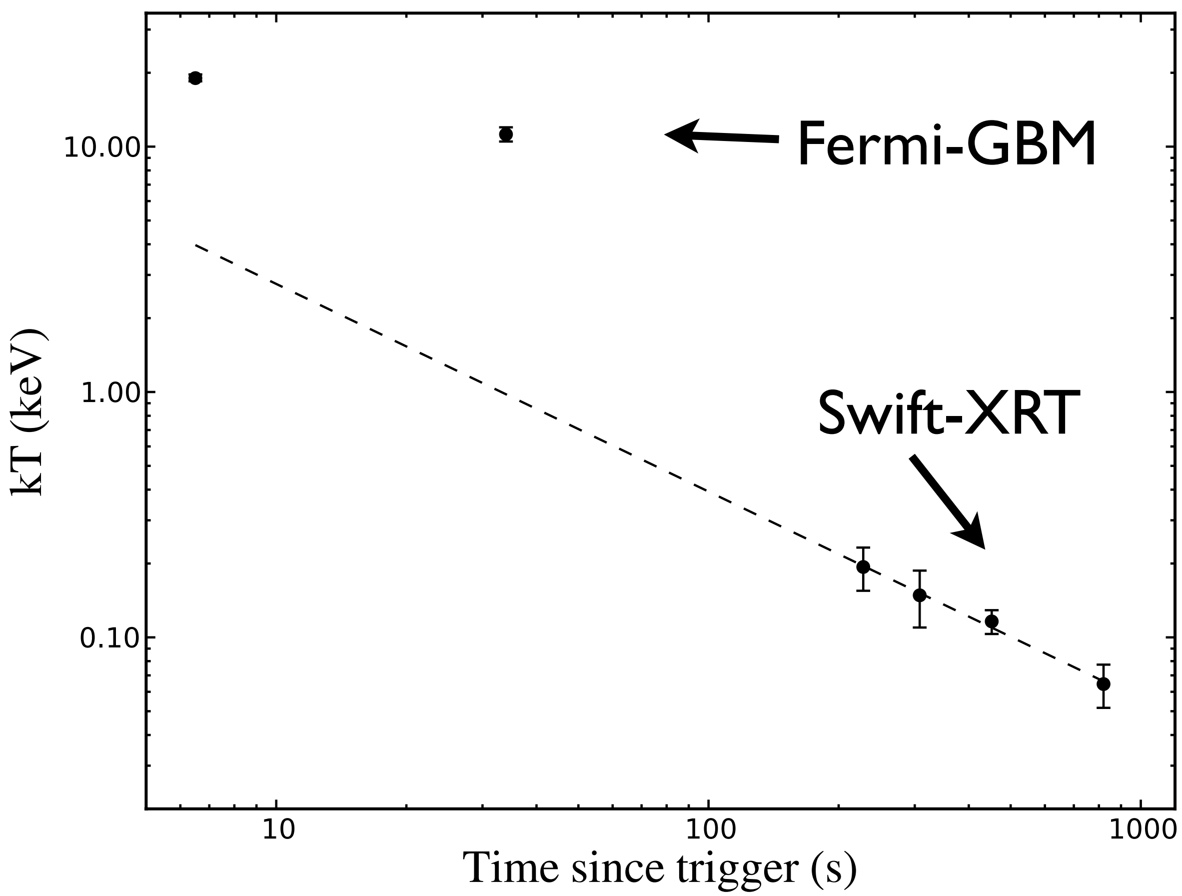
Kinetic energy and efficiency

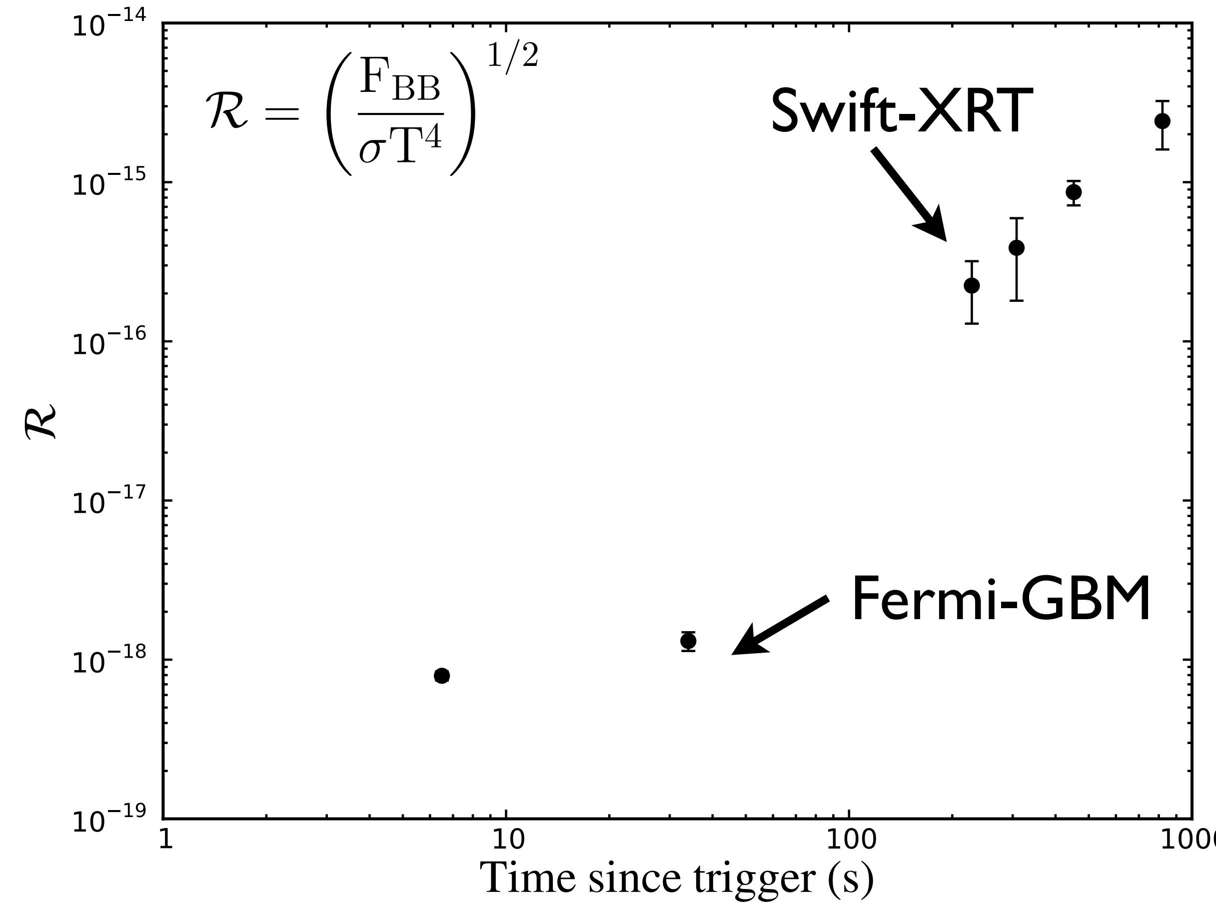
Estimate the kinetic energy of the jet from the X-ray spectrum at the start of the normal decay phase (following Zhang+07, Racusin+11).

$E_k = 6.4 \pm 3.5 \cdot 10^{52}$ erg *(Assuming $\varepsilon_b = 0.01$ and $\varepsilon_e = 0.1$)*

Radiative efficiency $\eta = E_{\gamma,iso}/(E_{\gamma,iso} + E_k) = 5 \pm 2$ %

Connection between the BBs?





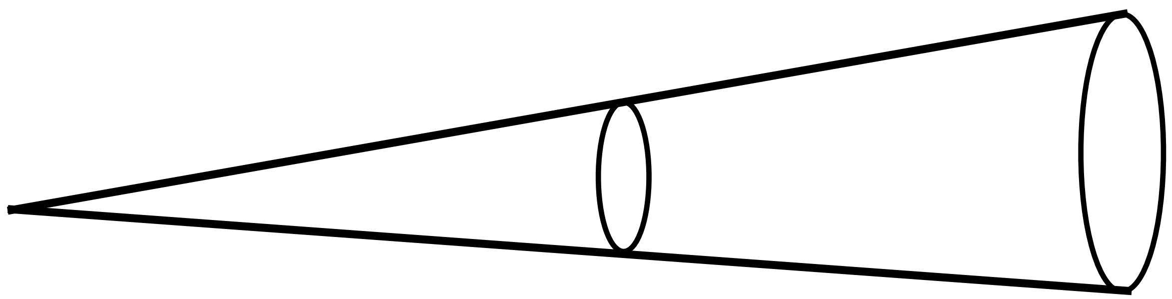
Origin of the 2nd BB component?

- High-latitude emission from the jet after the central engine has died? No.
- SN shock breakout? No (R~ 10^{13} cm too big, Starling+12)
- Breakout from a wind? Maybe.
- Emission from a cocoon surrounding the jet? Maybe.
- Late central-engine activity? Maybe.

Fireball parameters

Can calculate absolute values of fireball parameters (Peer et al. 2007) using observed blackbody properties and standard "fireball model".

Results for first time interval



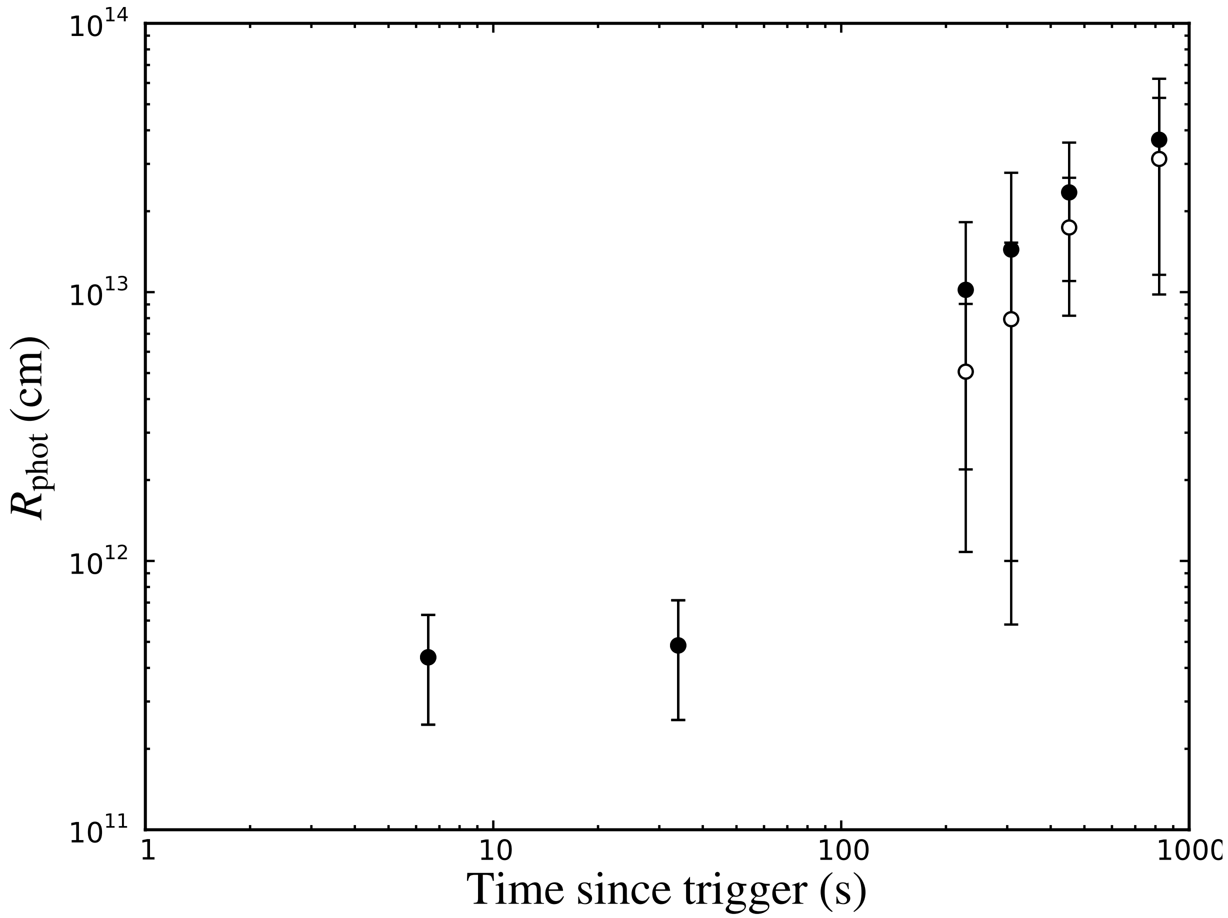
Lorentz factor = 138±8

Acceleration radius	Saturation radius	Photospheric radius
$3\pm2\times10^{7}$ cm	$4\pm2\times10^{9}$ cm	$4\pm2\times10^{11}$ cm

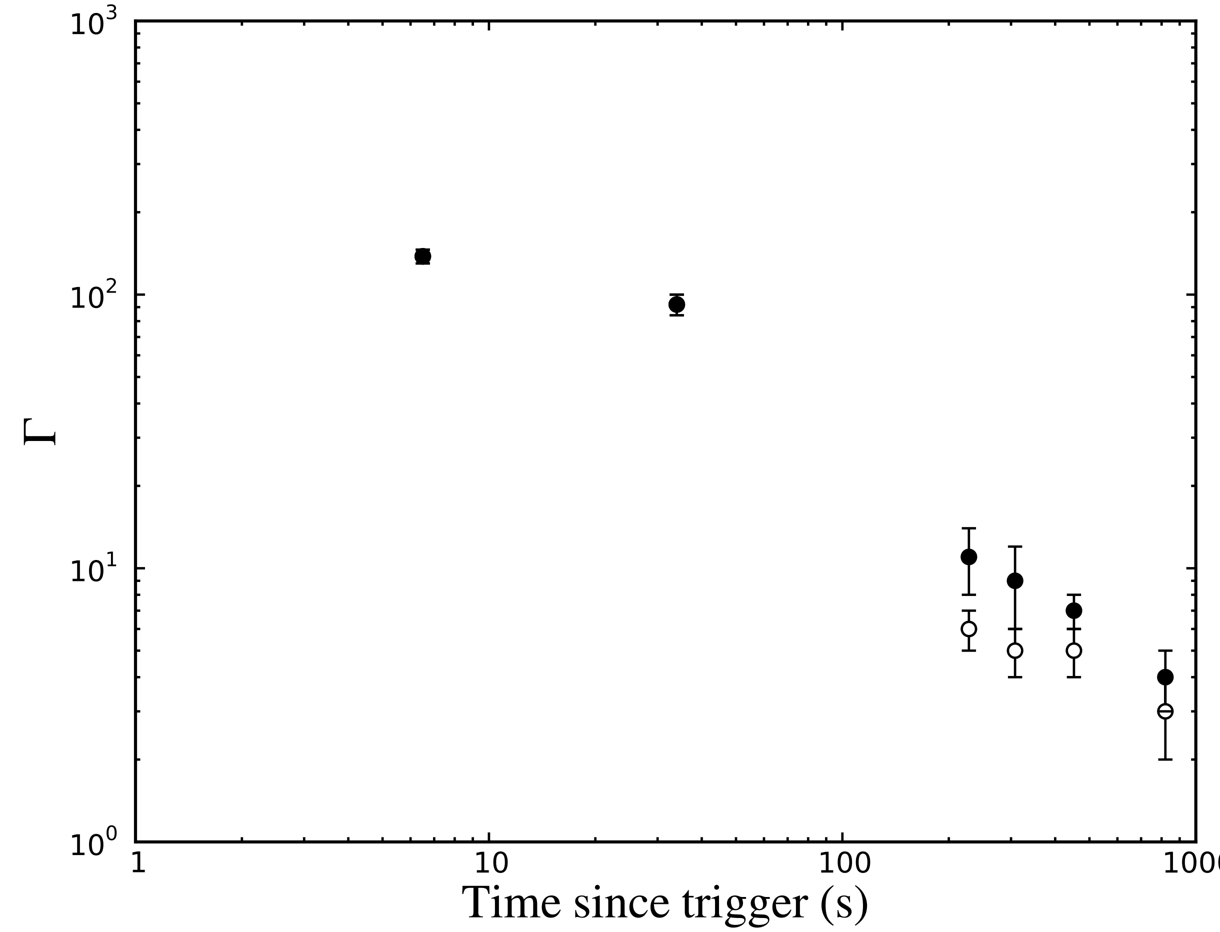
Main uncertainties lie in estimate of η and the possible contribution from non-thermal emission.

Fireball parameters

Time evolution of R_{phot}

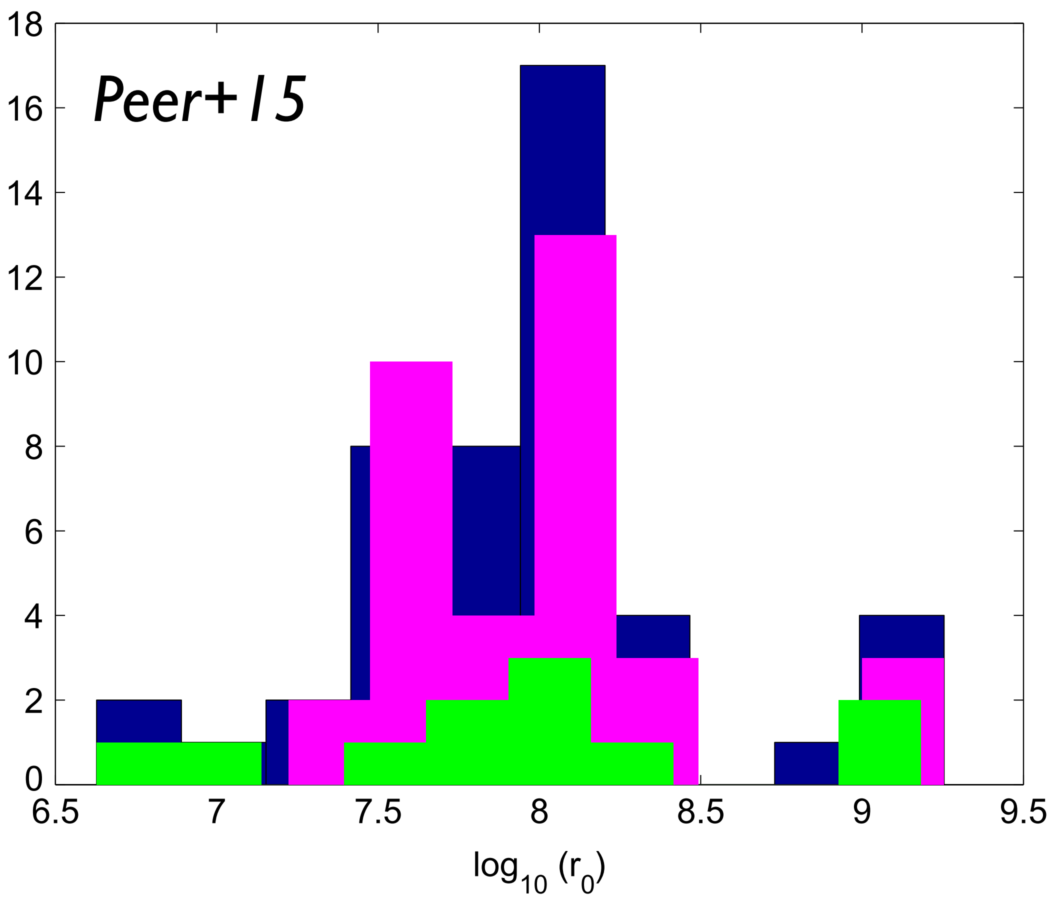


Time evolution of Γ



Open symbols for XRT data: assuming only the BB component is prompt emission from the jet.

Fireball parameters in other GRBs



Distribution of r_0 for GRBs with thermal components collected from the literature (Peer+15).

All
BATSE sample (z=1 assumed, from Ryde & Peer 2009)
9 Fermi (5 with known z) + 2 BATSE (z known)

The inferred r_0 for GRB 101219B is close to the black hole.

The full distribution has a larger mean r_0 (and a large spread).

- Assumptions of fireball model not valid?
- Evidence for the jet propagating through the progenitor star?

Conclusions

- Prompt emission in GRB 101219B is well described by a blackbody. Clear evidence for emission from the photosphere.
- No clear connection with the blackbody at soft X-ray energies seen in the early afterglow. Different origin of the components?
- Properties of prompt emission and afterglow, plus known redshift, makes it possible to calculate properties of the jet within the fireball model. Evidence for jet launching close to the black hole.
- GRBs which are close to pure BBs are extremely rare. Special conditions required: lack of dissipation, wide jet viewed along line of sight ….