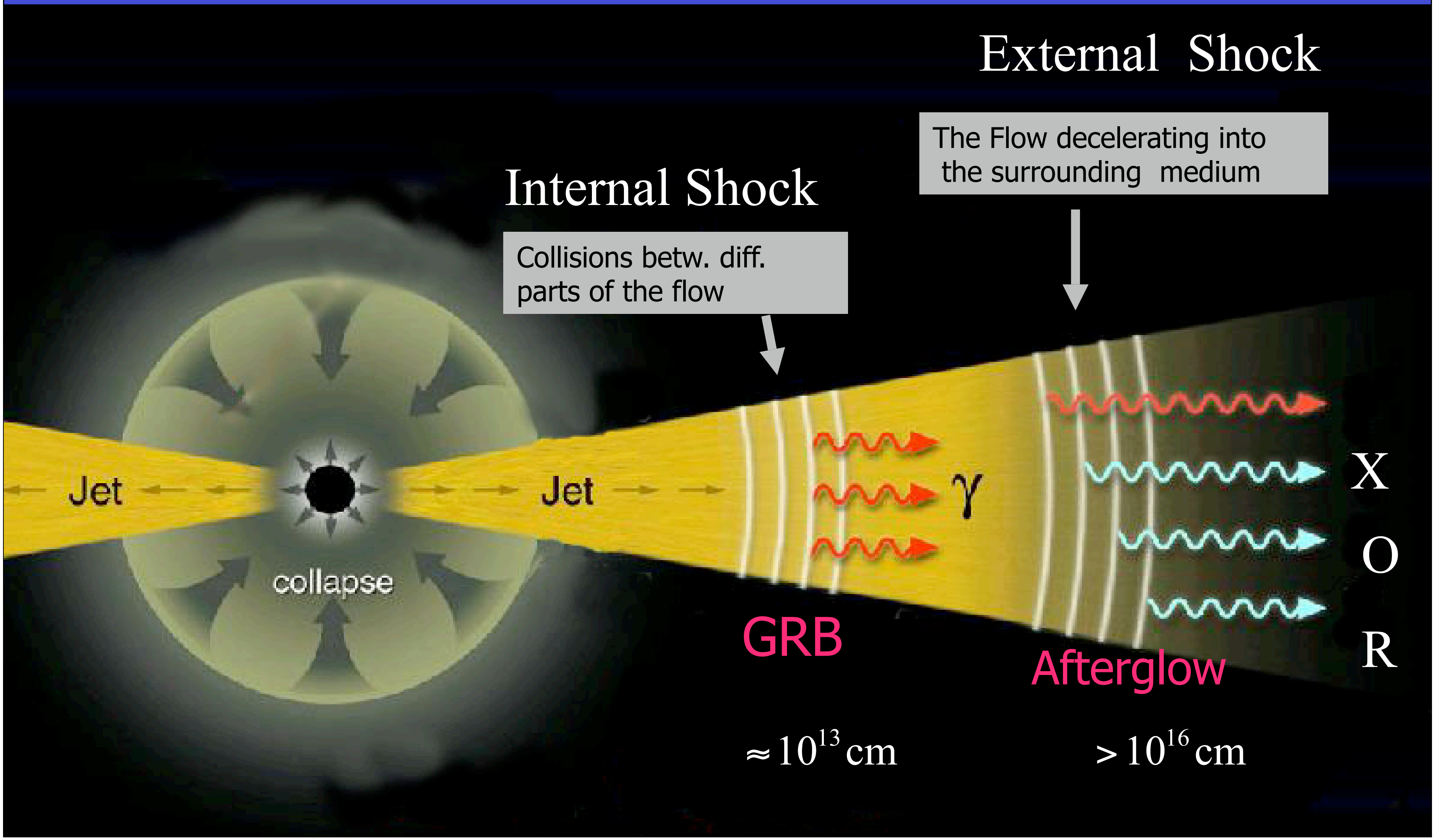
GRB

Prompt and High Energy Emission

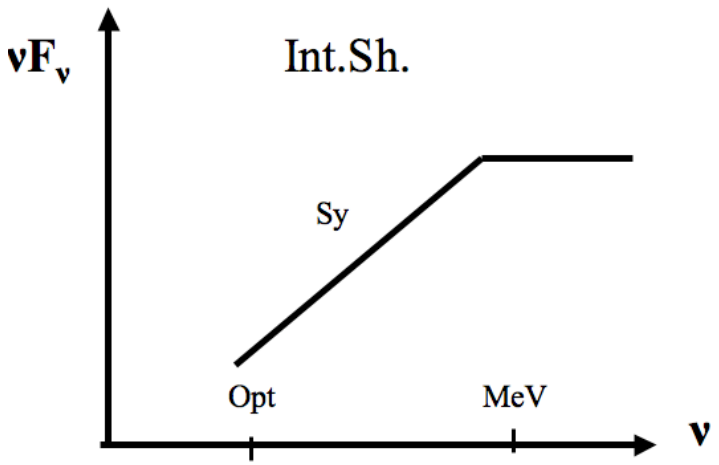
Peter Mészáros
Pennsylvania State University

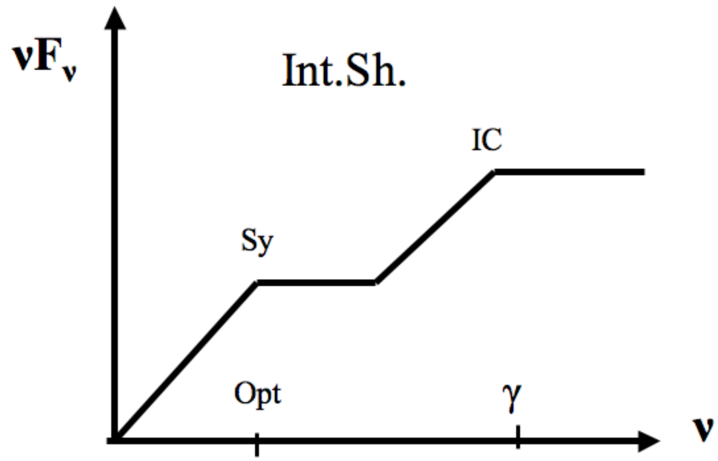
Fireball Model of GRBs

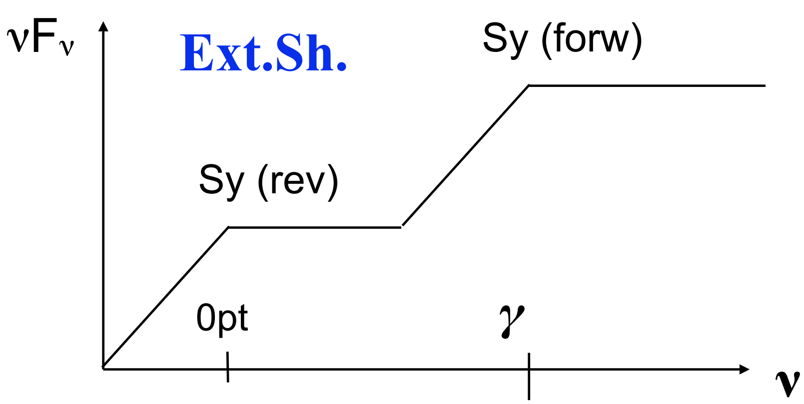


Prompt Optical Flashes : 3 models

(1994-1997)



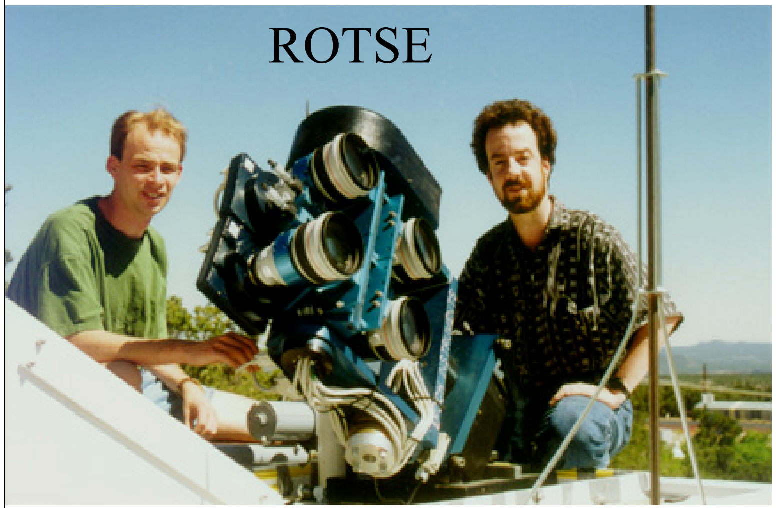


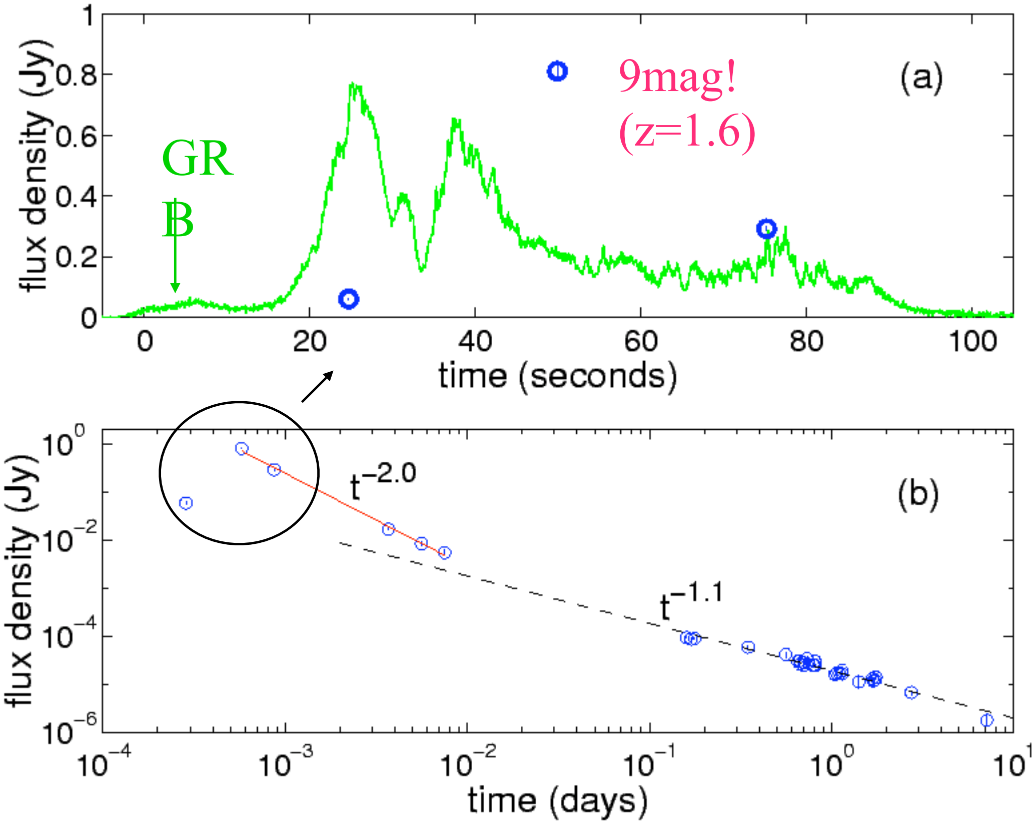


Mészáros & Rees '97

- **GRB 990123** ⟶ bright (9th mag)
  prompt opt. transient (Akerlof etal 99) .
  – 1st 10 min: decay steeper than forw.sh.
- →Interpreted as **reverse external shock**

Optical Flash : GRB 990123

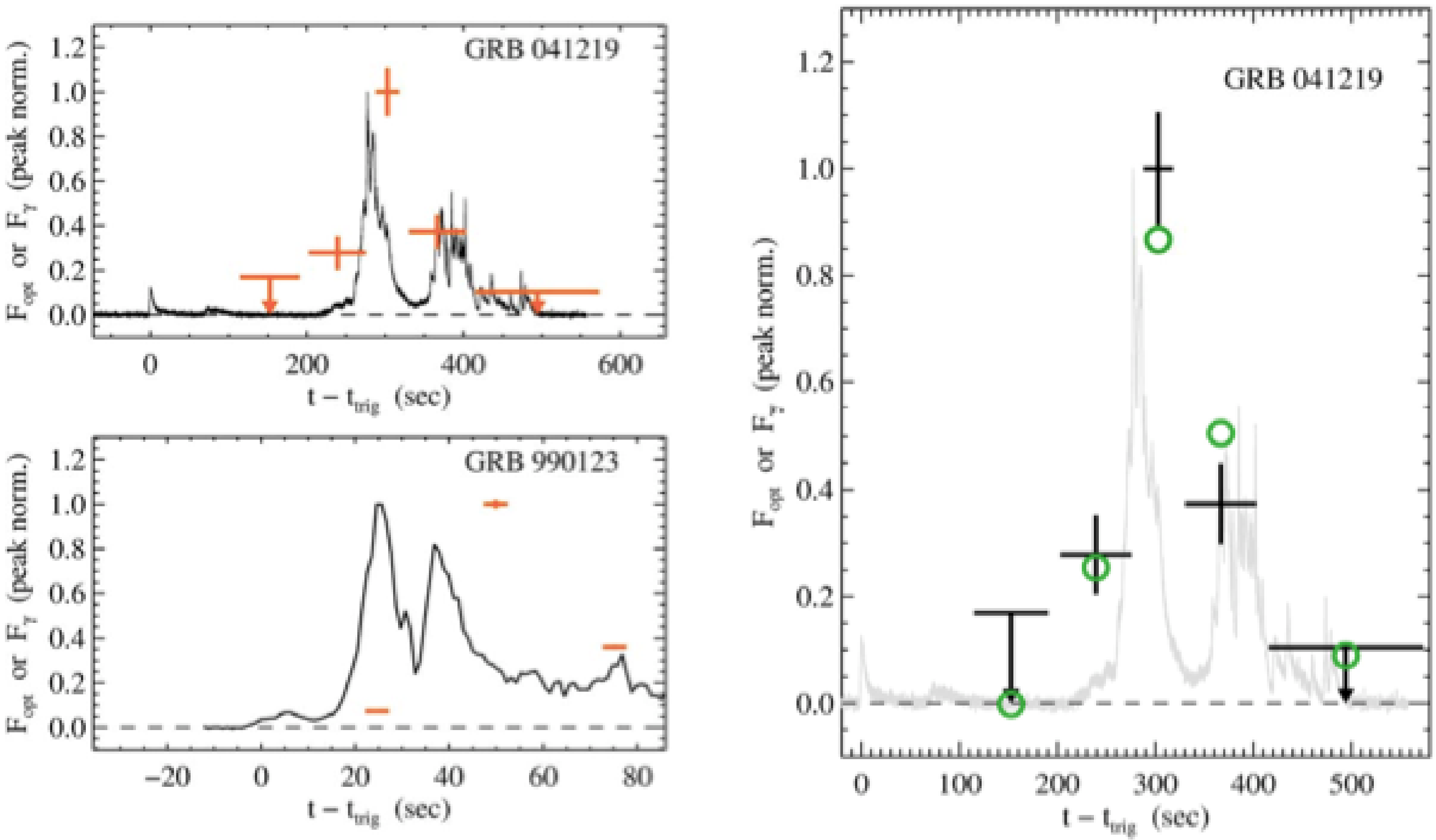




Different time dep. of γ, opt. l.c. :
→ infer opt is reverse shock

(Akerlof et al. 1999; Meszaros & Rees 1997; Sari & Piran 1999; Kobayashi 2000)

But: other prompt γ,opt ?



Sometimes same origin, sometime not ? (Vestrand et al, 06)

Mészáros

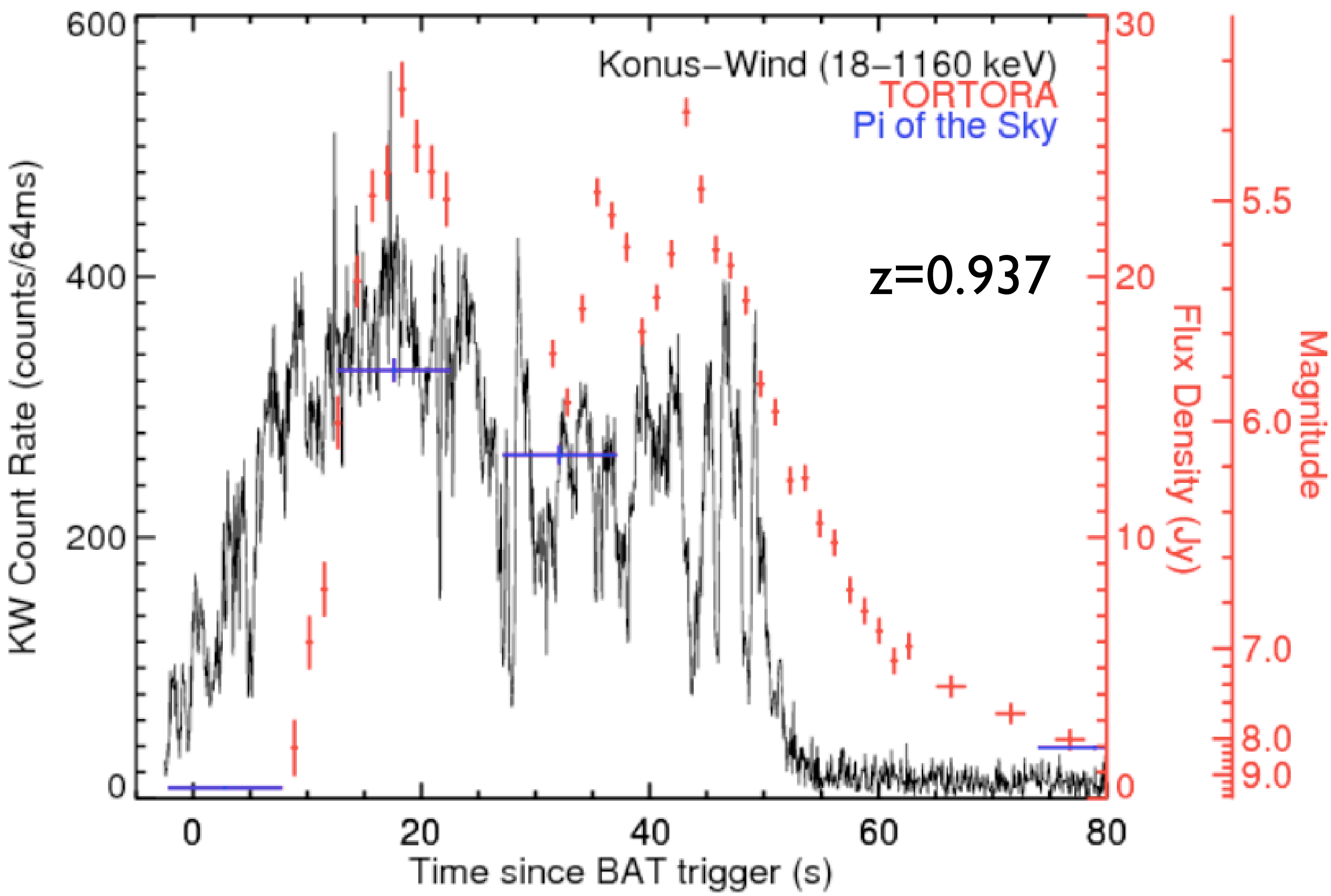


Figure 1 | Prompt Emission Light Curve. The Konus-Wind background-subtracted γ-ray lightcurve (black), shown relative to the *Swift* BAT trigger time, T_0. Optical data from "Pi of the sky" (blue) and TORTORA (red) are superimposed for comparison. The optical emission begins within seconds of the onset of the burst. The TORTORA data have a gap during the slew of the REM telescope to this field, but show 3 sub-peaks in the optical brightness, reaching a peak brightness of 5.3 magnitudes (white). The γ-ray light curve has multiple short peaks; these are not well correlated with the optical peaks in detail (cf. ref 25), but the optical pulses may be broader and peak somewhat later than the γ-ray pulses, if the optical is slightly below the synchrotron self-absorption frequency, which may account for the lack of detailed correlation. The optical flash, however, begins and ends at approximately the same times as the prompt γ-ray emission, providing strong evidence that both originate at the same site. See

GRB 080319B

"naked eye" optical GRB

Racusin et al, 2008 Nature 455:183

γ,opt l.c. similar→ same emiss. region, but mechanism?

Interpret prompt as:

i) optical synchrotron

ii) 0.1-1 MeV IC (SSC)

(and)

iii) predict 2nd order IC @ ~100 GeV

Mészáros

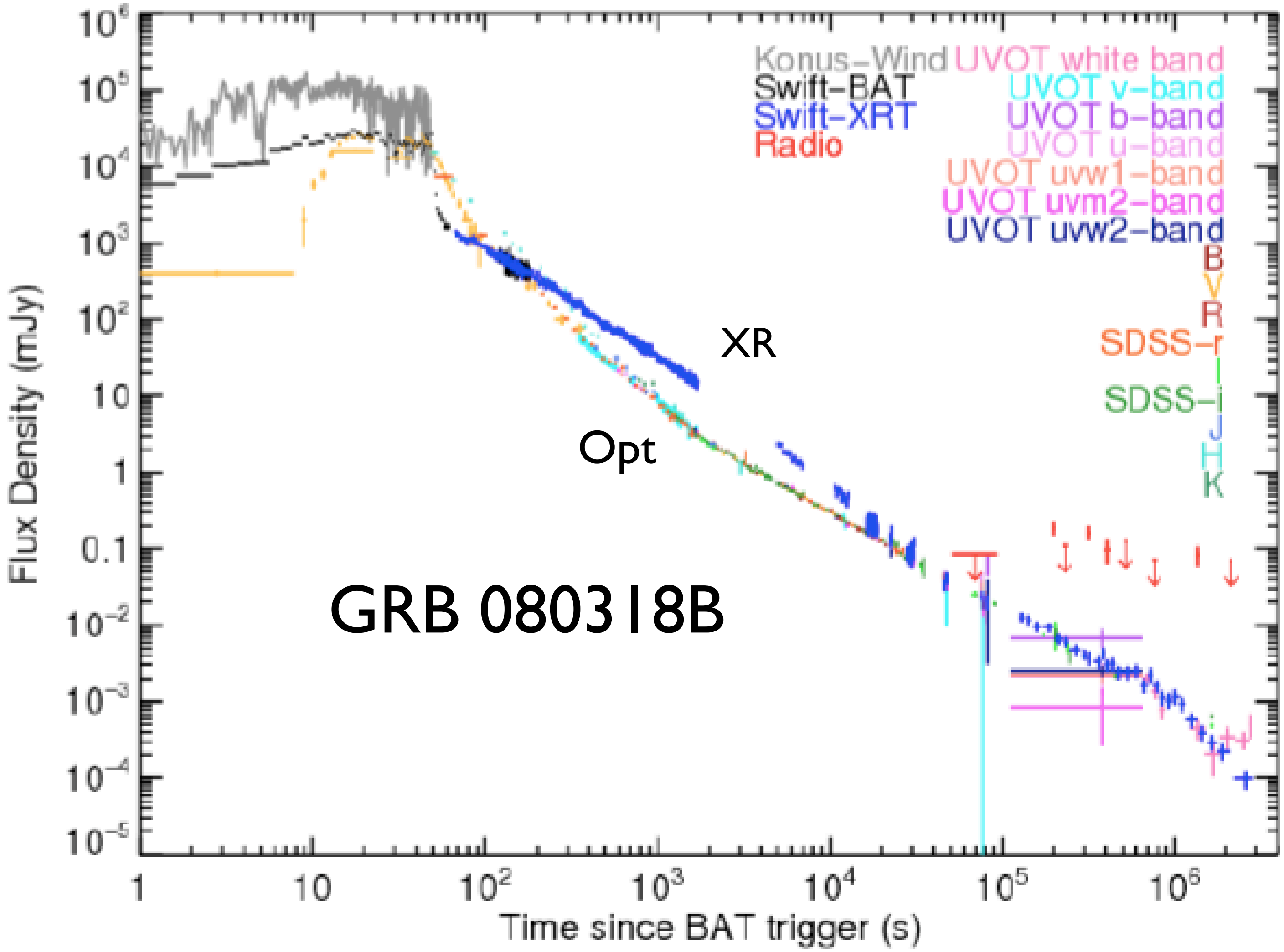
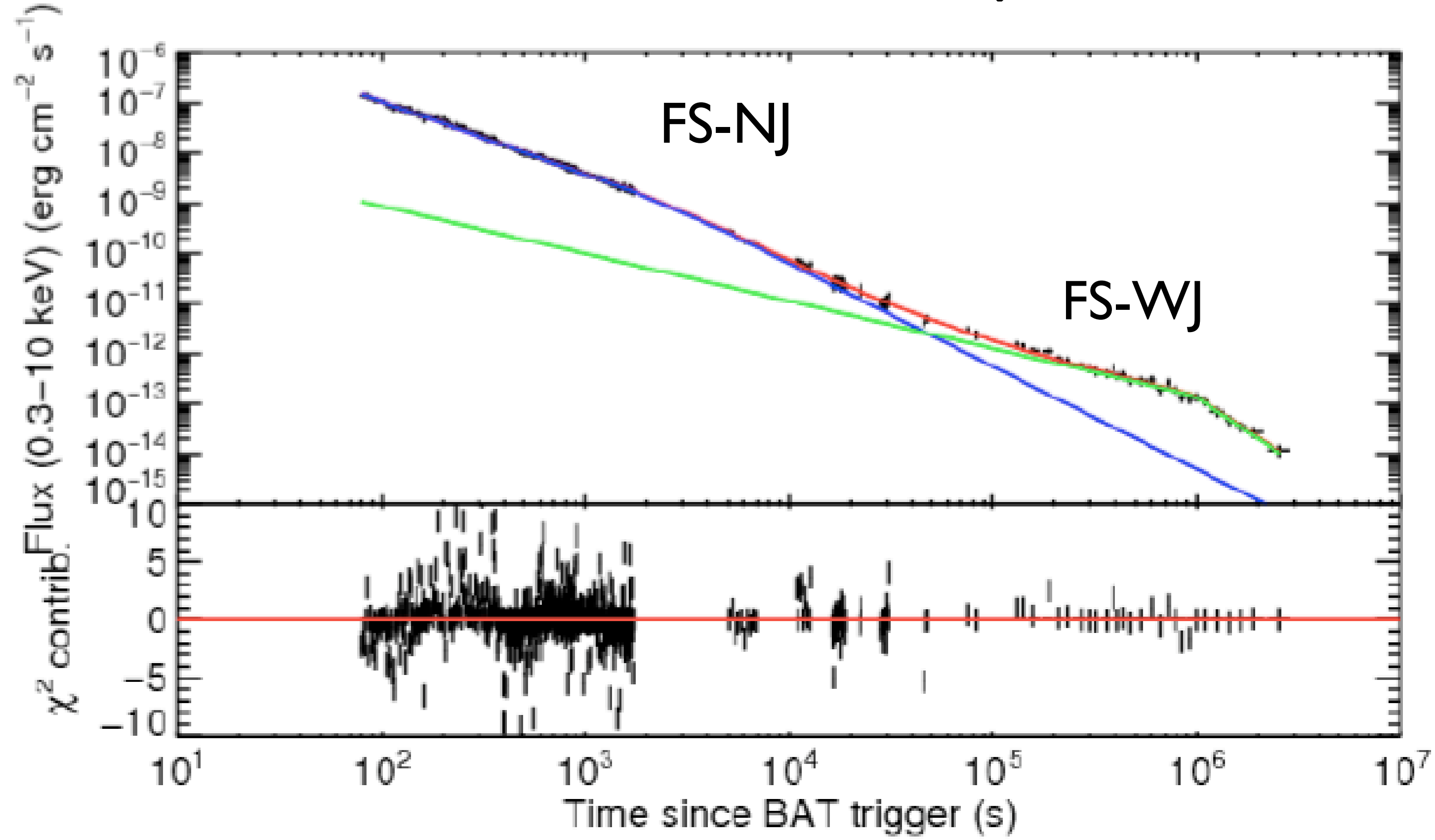


Figure 2 | Composite Light Curve. Broadband light curve of GRB 080319B, including radio, NIR, optical, UV, X-ray and γ-ray flux densities. The UV/optical/NIR data are normalized to the UVOT v-band in the interval between T_0+500 s and T_0+500 ks. The *Swift*-BAT data are extrapolated down into the XRT bandpass (0.3-10 keV) for direct comparison with the XRT data. The combined X-ray and BAT data are scaled up by a factor of 45, and the Konus-Wind data are scaled up by a factor of 10^4 for comparison with the optical flux densities. This figure

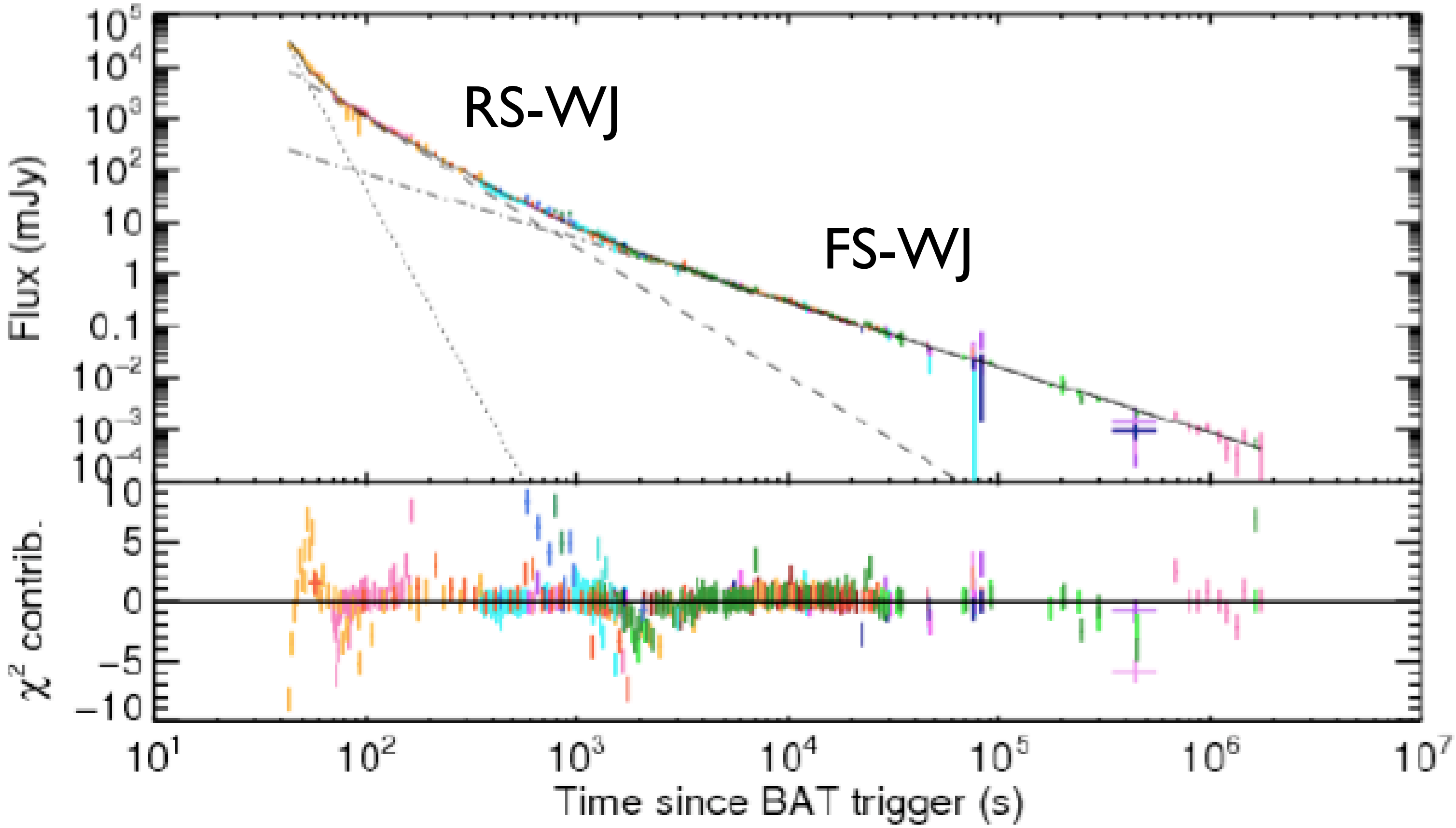
080319B XR 2 jet fit



Supplementary Figure 7 | Two-Component Jet Model fit to X-ray Afterglow. The X-ray afterglow is best described by the superposition of two broken power-laws, which is consistent with the narrow and wide jets of a two-component jet expanding into a stratified wind environment. The narrow jet dominates the first ~40 ks of the afterglow as indicated by the blue line, which shows the fit to the narrow jet component. After the narrow jet break decays, the wide jet dominates as indicated by the green line fit to late afterglow. The red line shows the superposition of both components and the overall fit to the X-ray light curve.

Meszáros

080319B opt. 2 jet fit



Supplementary Figure 6 | Three-Spectral Component Fit to the Decaying Optical Transient Following the peak of the prompt optical flash, the optical transient light curve displays three distinct components that dominate in the intervals t<50s, 50s<t<800s, and t>800s. The initial decay of the bright optical flash is a power-law with α_1=6.5±0.9 (dotted line). This is superimposed on a power-law with decay index α_2=2.49±0.09 (dashed line) that dominates in the middle time interval and a third power-law with α_3=1.25±0.02 (dot-dashed line)

Mészáros

GRB 080319B

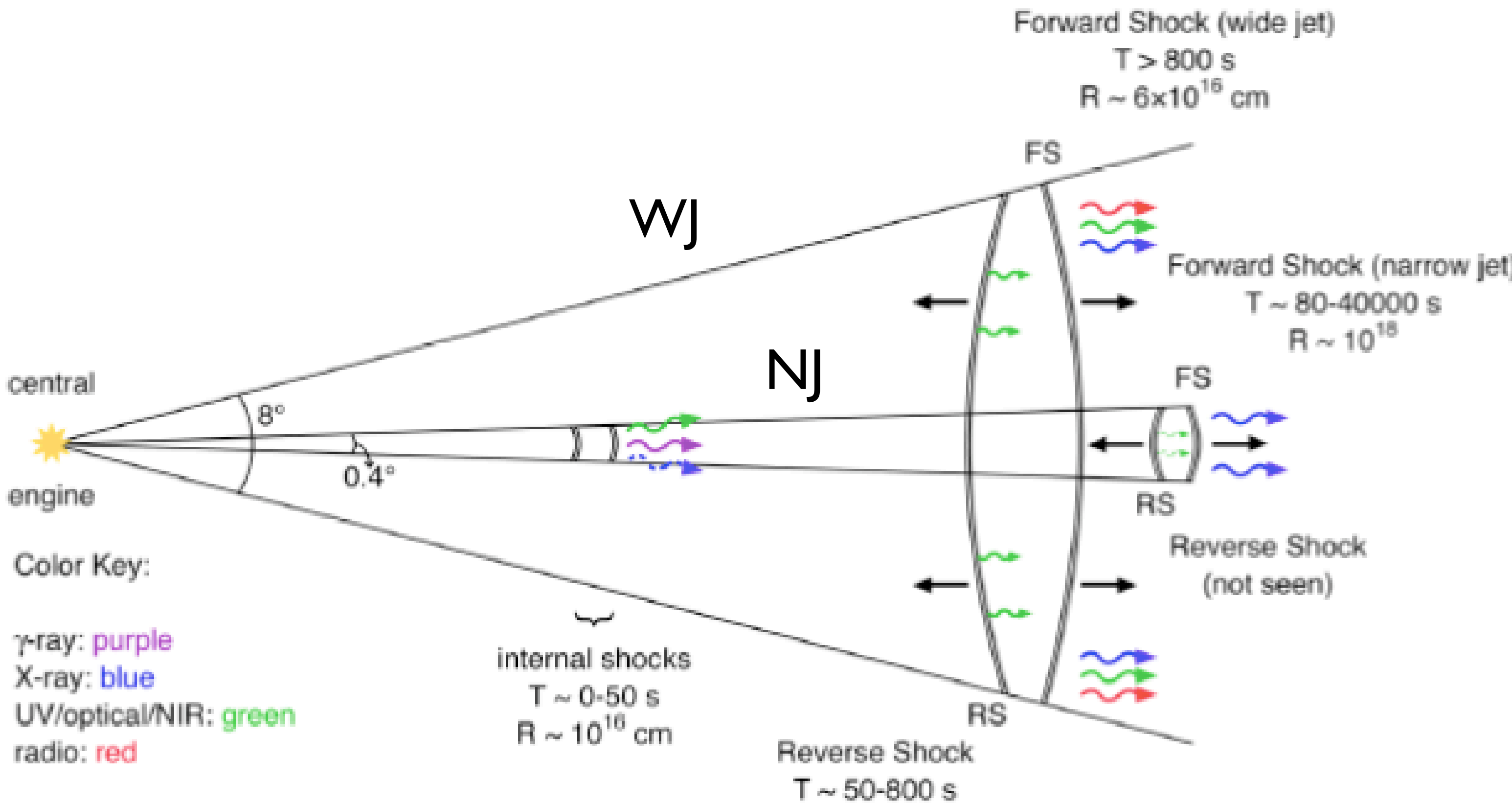
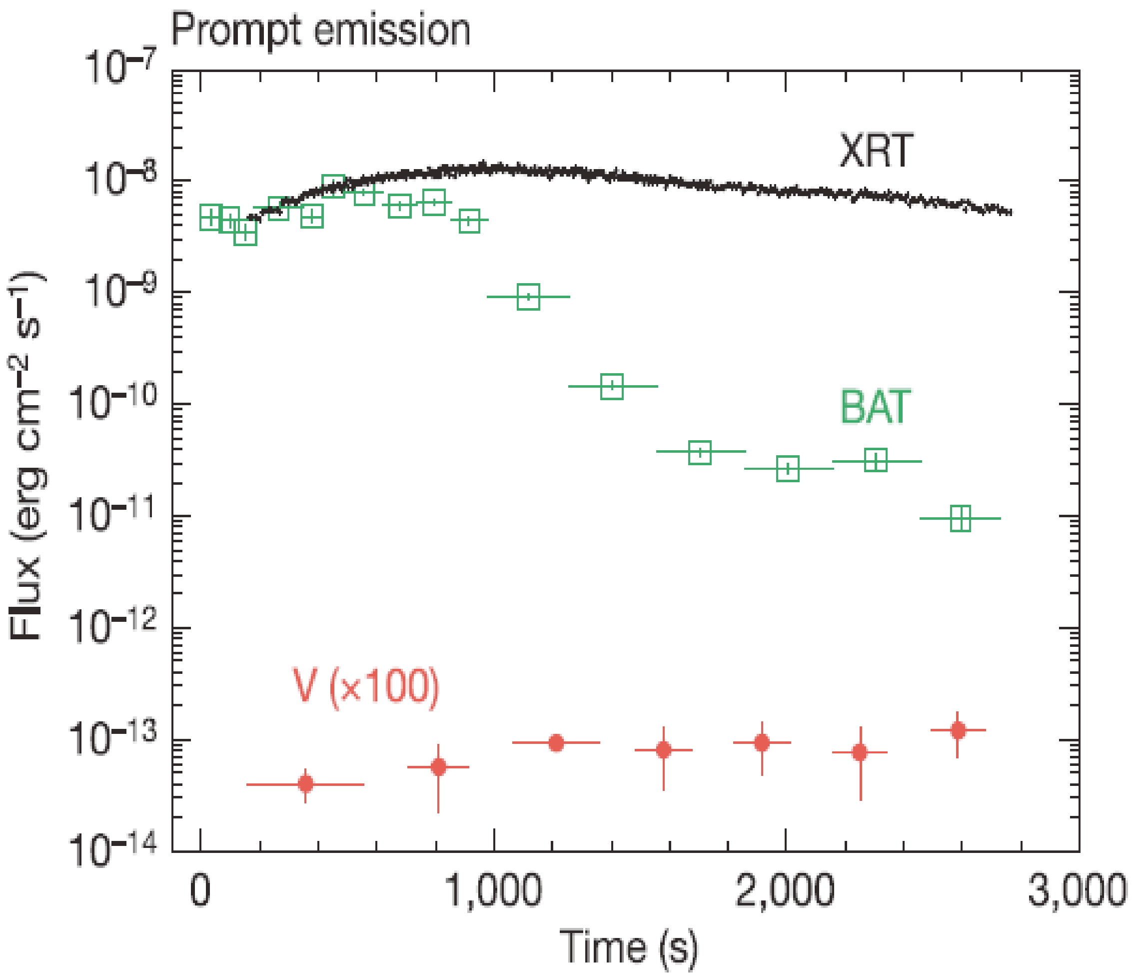


Figure 4 | Schematic of Two-Component Jet Model. Summary diagram showing spectral and temporal elements of our two-component jet model. The prompt γ-ray emission is due to the internal shocks in the narrow jet, and the afterglow is a result of the forward and reverse shocks from both the narrow and wide jets. The reverse shock from the narrow jet is too faint to detect compared to the bright wide jet reverse shock and the prompt emission. If X-ray observations had begun earlier, we would have detected X-ray emission during the prompt

Mészáros

GRB060218/SN2006aj –initial explosion



- An unusually long, smooth burst, T_{90}~2100±100 s
- Low luminosity, low energy : E_{iso}~6x10^{49} erg
- z=0.033, second nearest GRB (138 Mpc)

Campana et al. 2006

Subsequent evolution—SN emerges

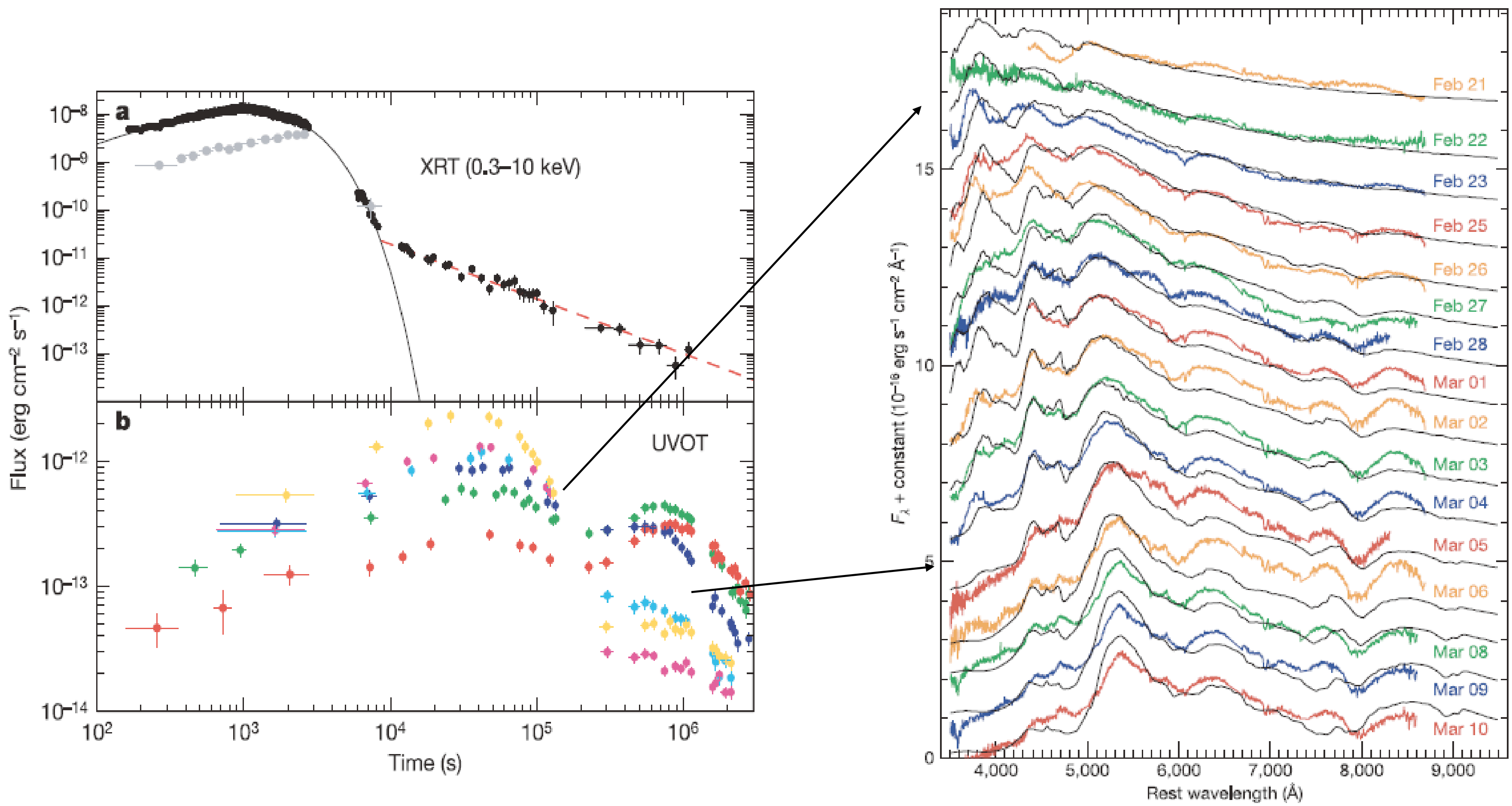
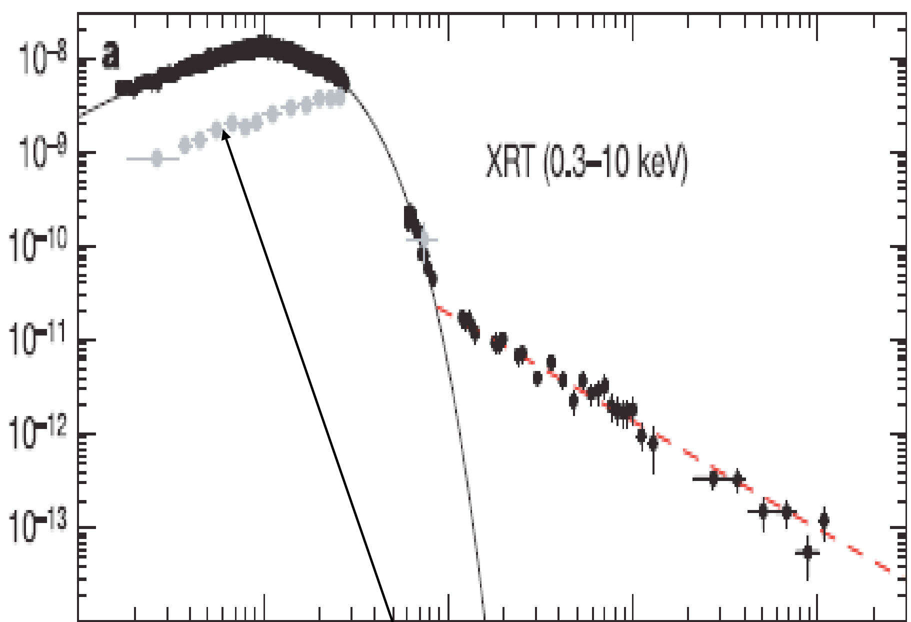


Figure 1 | Spectra of SN 2006aj and synthetic fits. The observed spectra of

Campana et al, 06, Nat 442:1008 Mazzali et al.2006 Pian et al, 2006

A closer look at the XRT spectrum



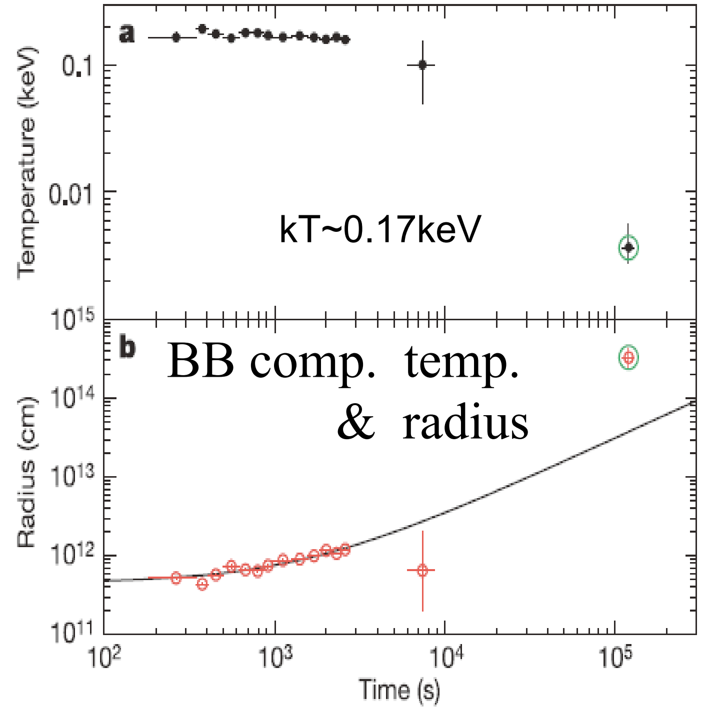


Figure 3 | Evolution of the soft thermal component temperature and radius. a, Evolution of the temperature of the soft thermal component. The

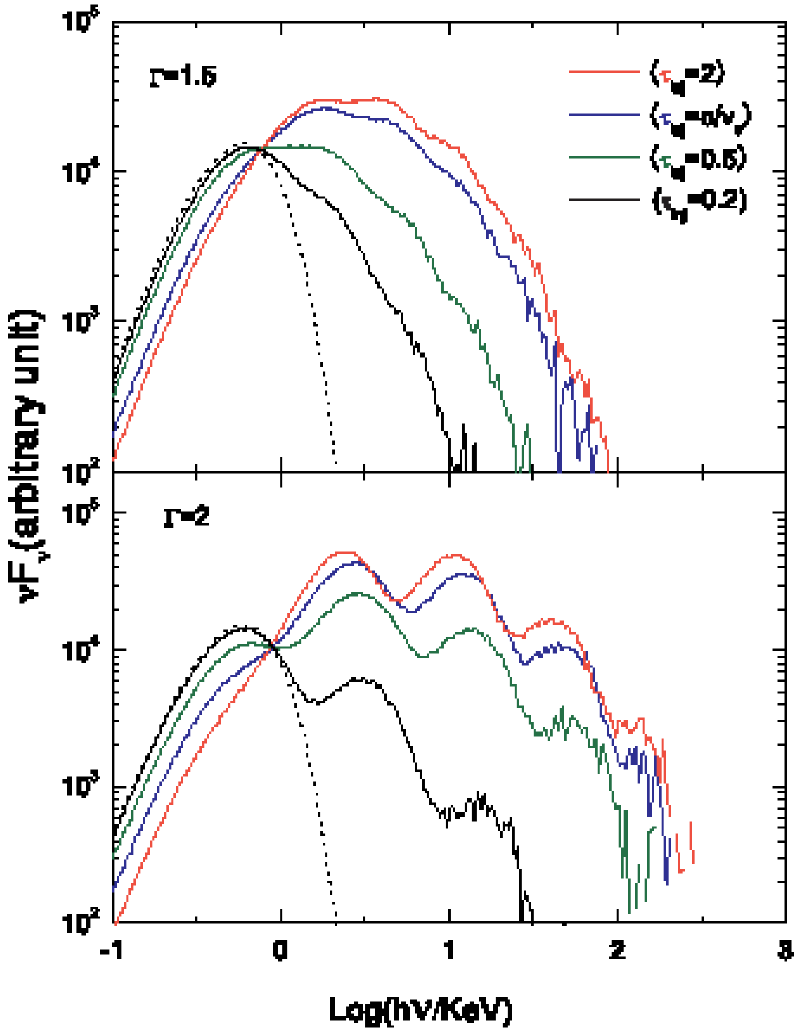
Contribution of a fitted **black-body component** to the 0.3-10KeV flux

Constitute 20% of the total XRT fluence

(1) BB XR Component: GRB060218/SN2006aj

- BB Interpreted as **break-out** of an **anisotropic**, ***semi-relativistic, radiation-mediated*** **shock** from opt. thick ***stellar wind*** (Campana et al 06, Nat. 442:1006; Waxman, Mészáros & Campana, astro-ph/0702450 -ApJ in press)
- ***Anisotropy*** is a crucial ingredient: timescale $\sim 10^3$ s is attributed to ***sideways*** pattern expansion speed, ***not*** to radial speed.
- Breakout when $\tau_T \sim c/v_s$, ocurring (in the wind) at $\mathbf{R_{ph}} \sim 7\times10^{12}\,(T/0.17\ \mathrm{keV})^{-4/7}\,(E_{th}/10^{49}\ \mathrm{erg})^{3/7}$ cm, for mass loss $dM/dt > 10^{-4}$ Msun/yr when $v_w \sim 10^3$ km/s
- Note : corresponds to mass loss within last day before explosion- no data on such winds
- Anisotropy of semi-relat. shell & wind compatible with & expected from rotation effects (e.g. Burrows et al, aph/0608033, Metzger et al, aph0608682, Burrows et al, aph/0702539, etc

060218 : non-thermal XR



Origin of non-termal gamma, X-rays:
Bulk comptonization
of semi-relativ. shock thermal photons scattering against progenitor wind
(i.e., do not need highly relativistic jet in low lum GRB/SN)

Wang, Li, Waxman, Meszaros
aph/0608033

Other supernova-GRBs

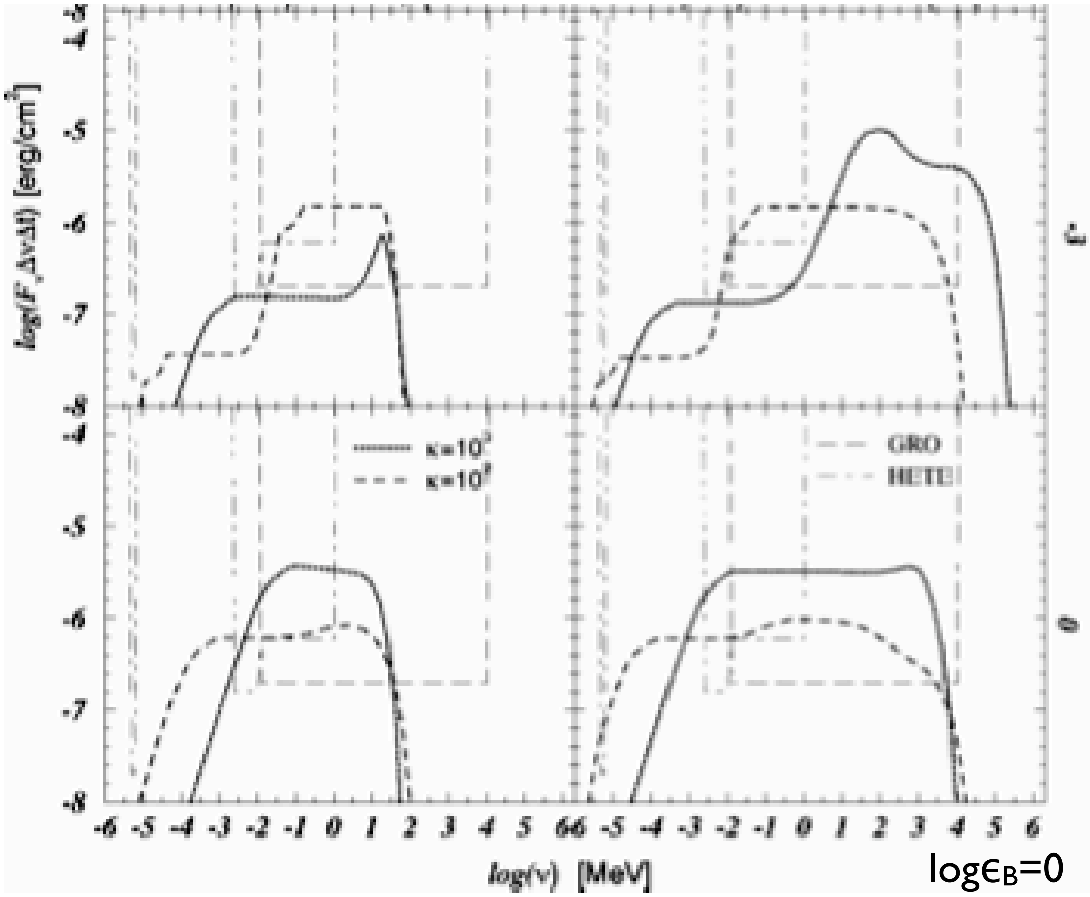
Table 1: The spectrum of three nearby low-luminosity GRBs

GRB/SN	z	$E_{\gamma,\mathrm{iso}}$(erg)	α	ε_c(KeV)
GRB980425/SN1998bw	0.0085	$8.5 \pm 0.1 \times 10^{47}$	0.45 ± 0.22	~ 200
GRB031203/SN2003lw	0.105	$4 \pm 1 \times 10^{49}$	0.63 ± 0.06	> 190
GRB060218/SN2006aj	0.0331	$6.2 \pm 0.3 \times 10^{49}$	0.45	$\sim 30^{\S}$

- 1) Low-luminosity GRB (& often high luminosity SN..)
- 2) Smooth light curves
- 3) Spectrum: a simple power-law with a high energy cutoff
- Shorter T_90 duration for GRB980425 and GRB031203: possibly shock breakout from the star envelope (i.e. no optically thick wind)

GRB prompt broadband emission (CGRO era)

logϵB=-3



logϵB=0

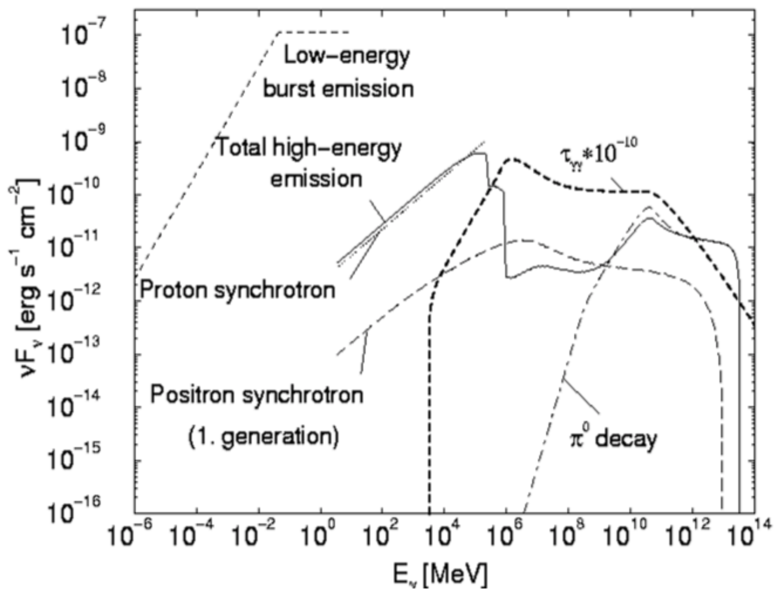
FIG. 1.—Spectra for $E_{51} = 1$, $\theta = 0.1$, $t_w = 100$s, $t_{var} = 40$ ms, $\eta = 63$ (*left*), $\eta \approx 160$ (*right*), and for different values of the magnetic field and the electron acceleration efficiency. The long dashed line shows the approximate threshold and window for *CGRO*'s BATSE and EGRET experiments, while the dotted-dashed one is for all the experiments on board *HETE*.

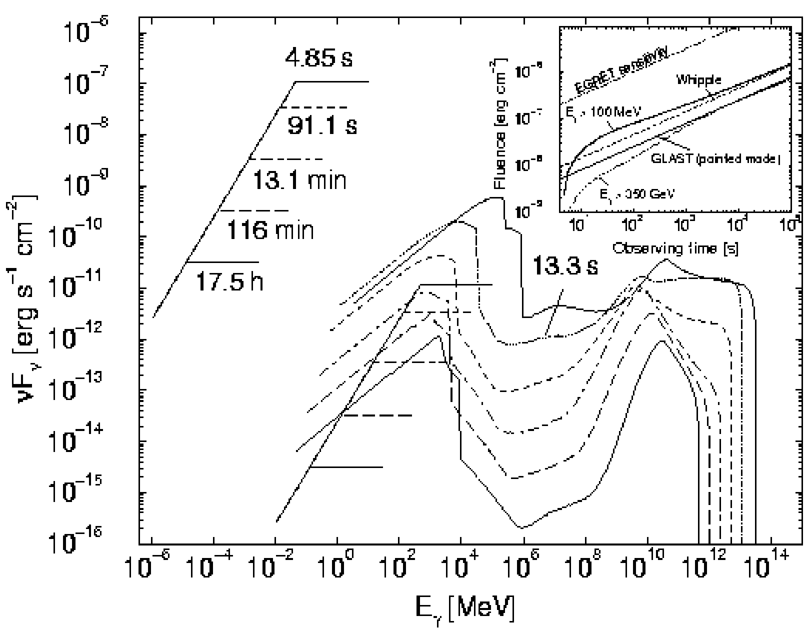
Papathanassiou, PM 96

- Internal shock standard leptonic emission (sy, IC)
- Details depend on $\gamma_{e,min}=\varepsilon_e(m_p/m_e)\Gamma_{sh}$ and ε_B (i.e. Compton Y)
- $\gamma\gamma$ cutoff @ GeV depends on t_{var} (i.e. $r_{sh}\sim ct_{var}\,\Gamma^2$)

Mészáros

But:





GRB GeV emission: hadronic ? pγ EM cascades

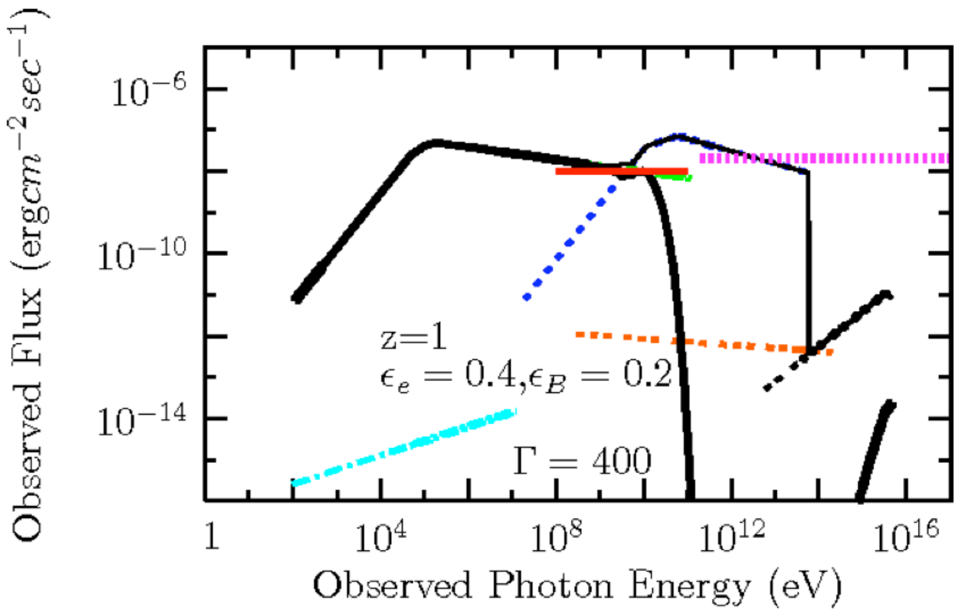
- Ext. forw. shock synchrotron → MeV γs
- Proton acceleration (Fermi), spectral index -2, $U_p \sim U_e$,

  ⇒ p-synchr. & ***pγ cascades,***

  → e^+ sync, π^0 dec.
- Time decay of cascade radn, slower than afterglow decay (p's have less rad. losses) → distinguish from leptonic, detect with GLAST

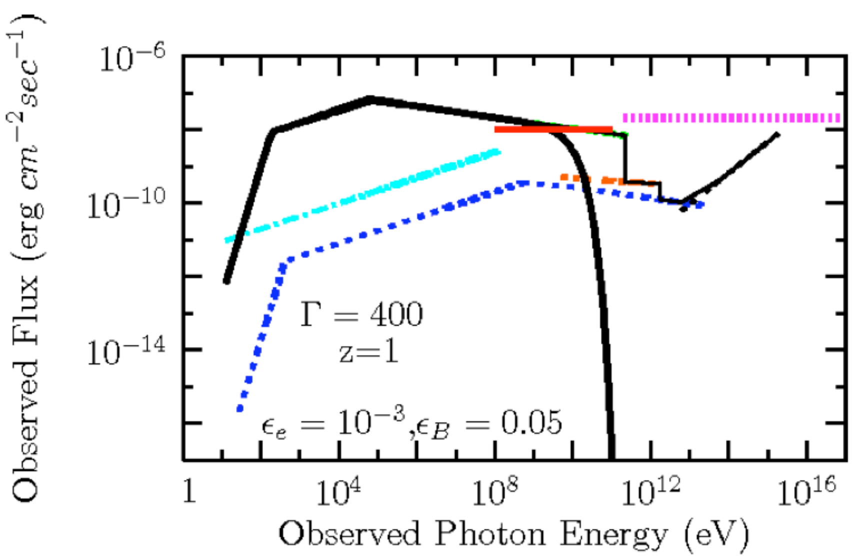
Boettcher & Dermer 98 ApJ 499, L131 ;
Dermer, Atoyan 03, PRL 91, 1102;
Dermer, Atoyan 04, AA418, L5

GRB: prompt GeV



Slow-cool leptonic $E_{iso}=10^{53}$ erg

basic int. shock model :



Slow-cool hadronic $E_{iso}=10^{56}$ erg!

Spectrum depends on whether leptonic or hadronic;
if e, cooling regime;
also B, Γ, r, etc.
(semi-analytical)

Gupta-Zhang 07 MN 380:78

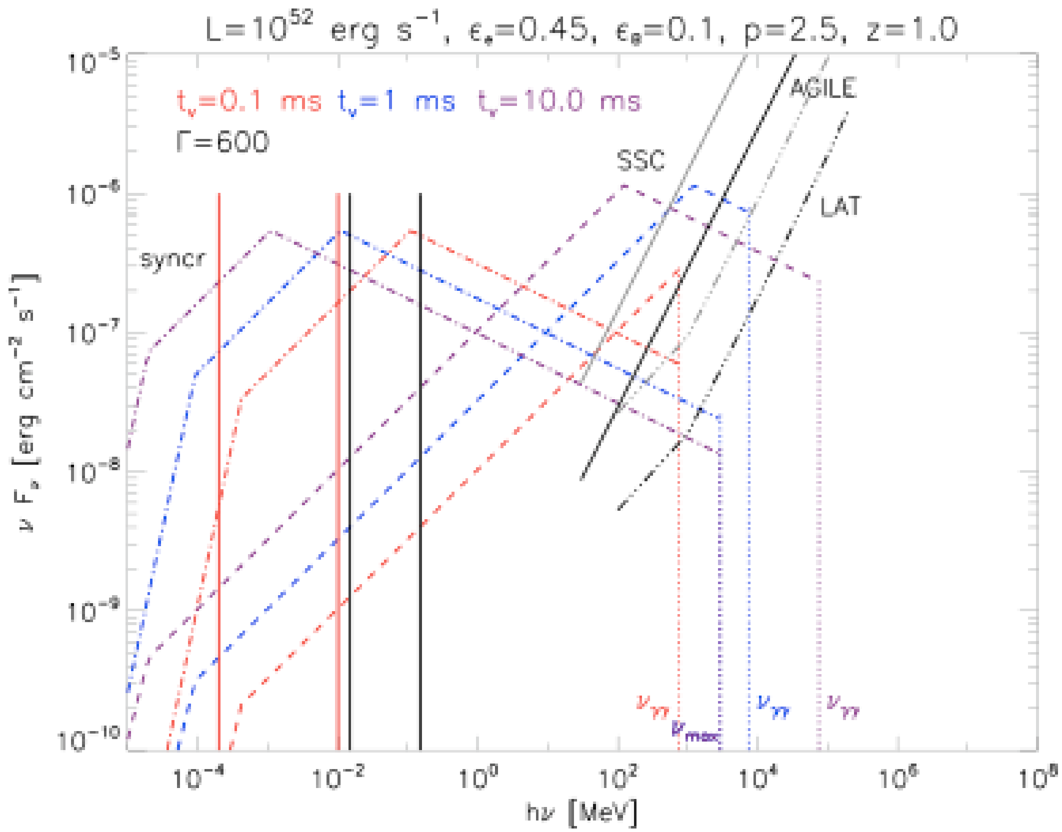


Fig. 2. Synchrotron (dot-dashed lines) and SSC (dashed lines) prompt emission spectra for a burst at redshift $z = 1.0$. The fireball Lorentz factor is fixed to $\Gamma = 600$, and the other parameters are the same as in Fig. 1. We display the predicted spectra for three different values of the burst temporal variability t_v: 0.1 ms (red), 1.0 ms (blue) and 10 ms (purple). The solid lines and the dot-dot-dot-dashed lines represent AGILE and GLAST sensitivity for an integration time of 10 s (in grey) and 50 s (in black). The solid vertical lines refer to the *Swift* XRT (red) and BAT (black) energy ranges.

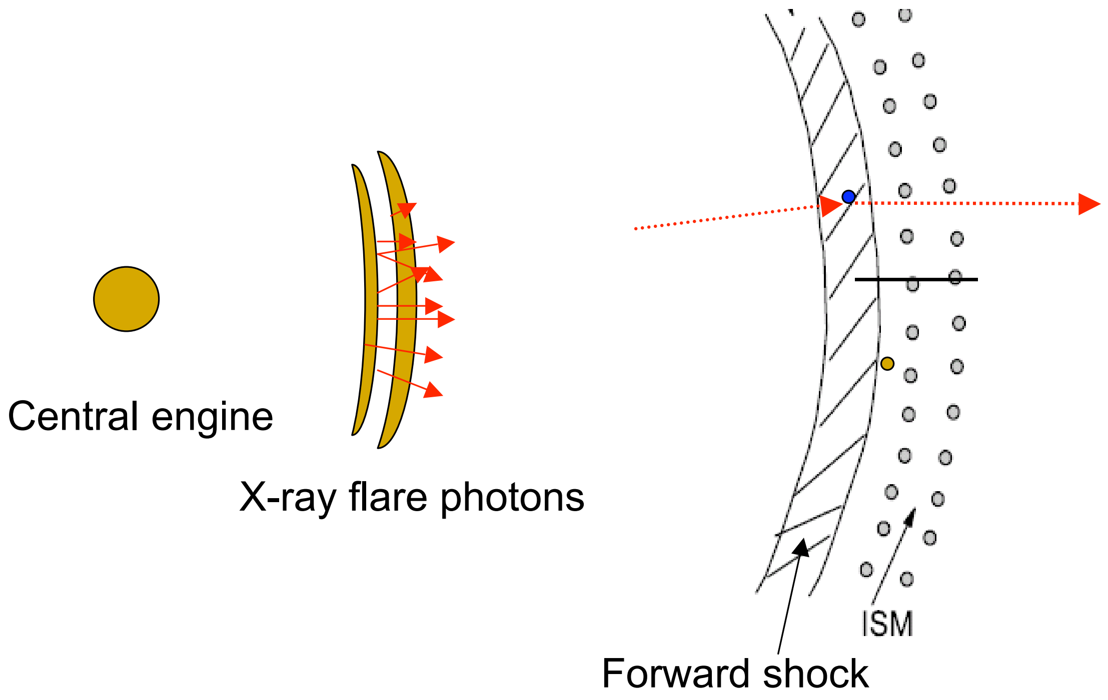
GRB prompt (lepto) GeV

simple SSC Broadband spectra

Galli, Guetta 08
arXiv:0709.4568

Mészáros

XR Flares ⇒ GeV γ Flares?



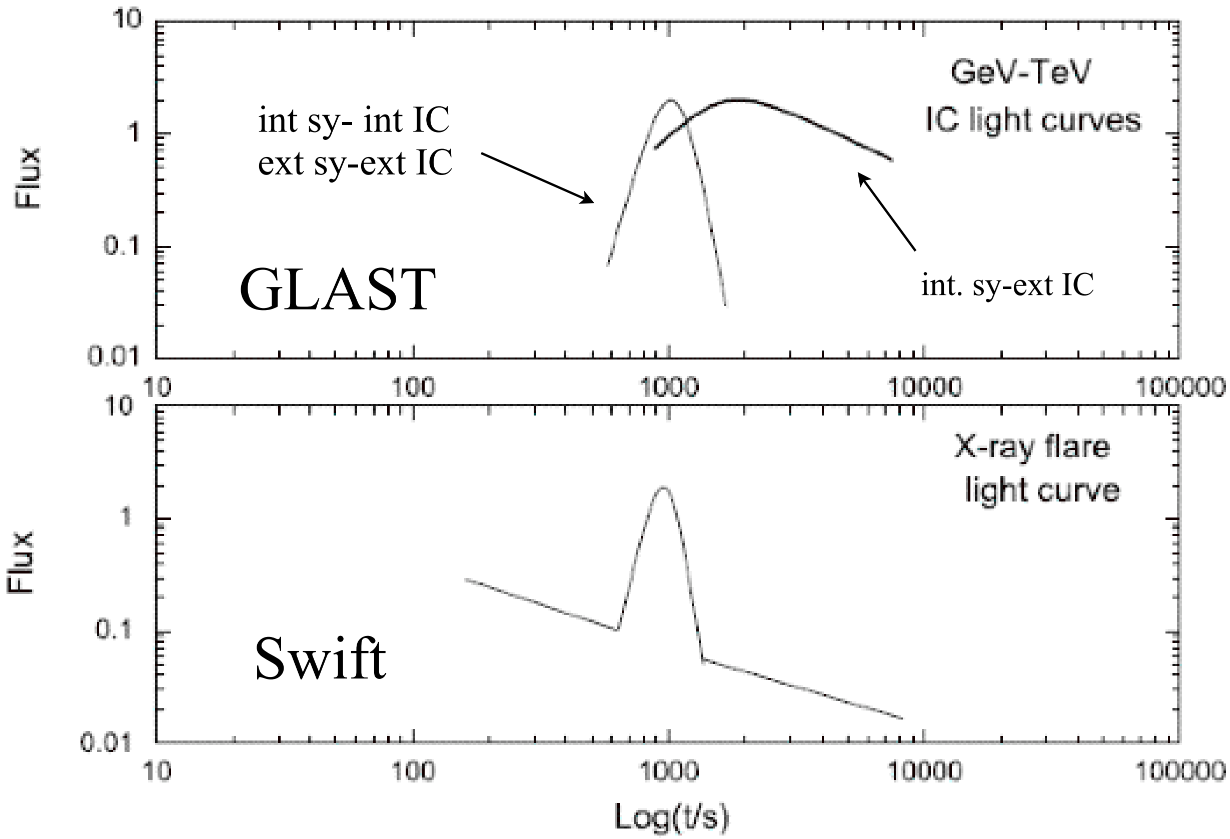
XR flares ubiquitous in Swift XR ; thought to be late internal shocks (or mag diss)

If so,
→ XR emission is inside the external shock

→ IC upscatter XR photons by ext shock e^- → GeV flares → GLAST det

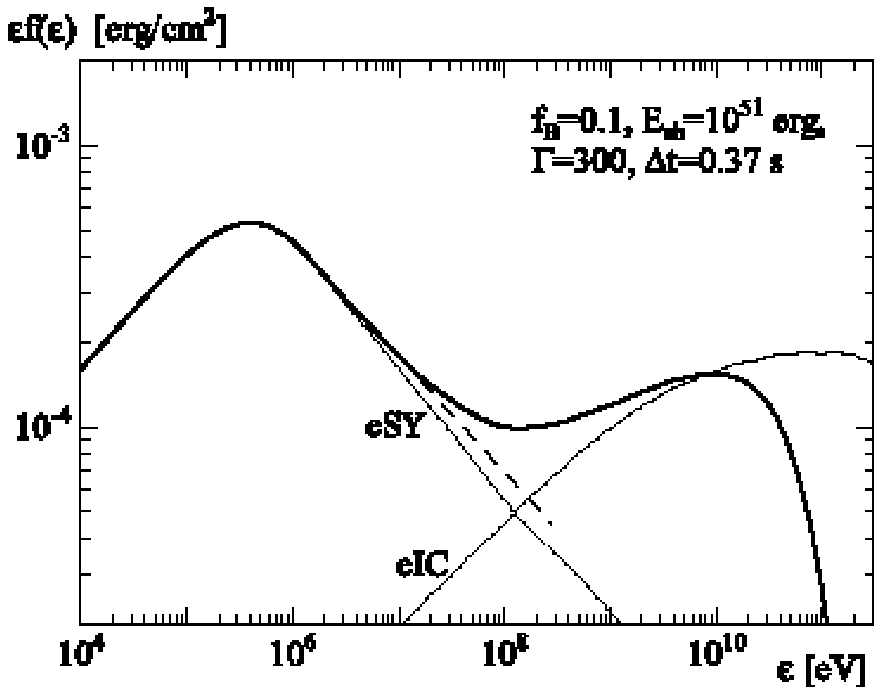
X.Y. Wang, Li, Mészáros 06 ApJ 641:L89

XR → GeV Flares



Delay caused by anisotropic IC from higher lat.

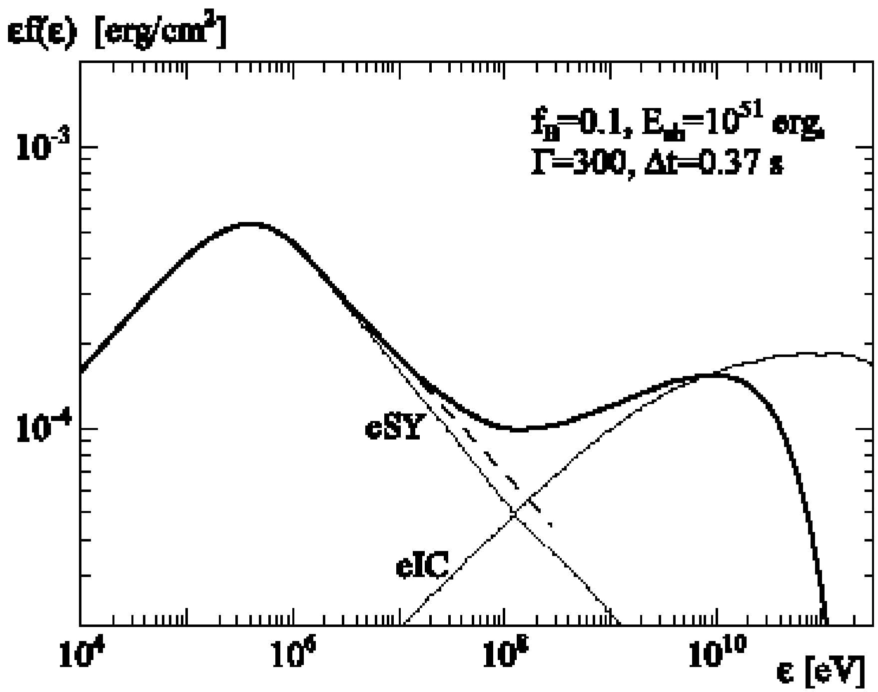
X.Y. Wang, Li, Mészáros 06 ApJ 641:L89
(c.f. Galli, Piro et al 06: same shock self-SSC)

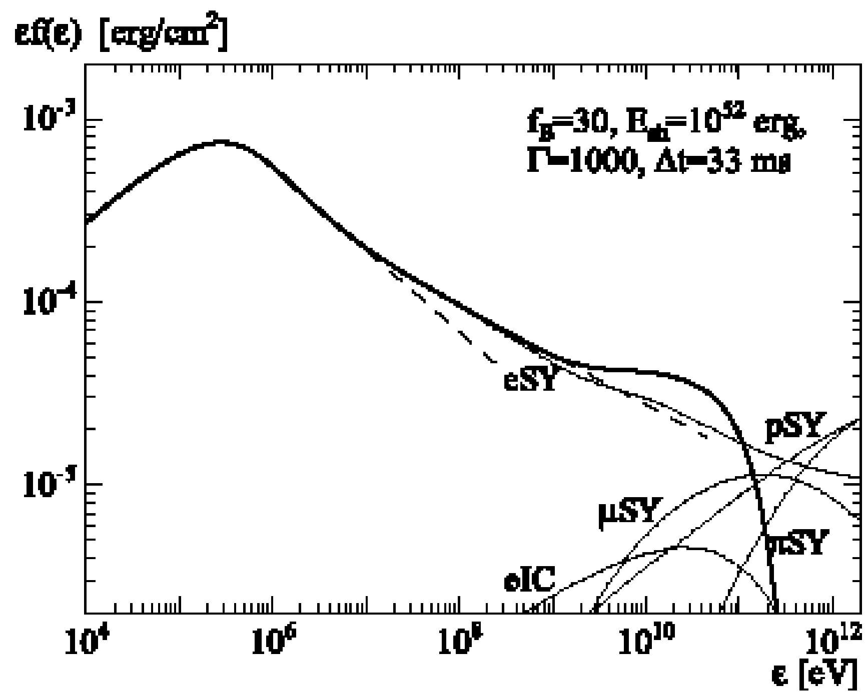


Prompt hadronic secondary photons

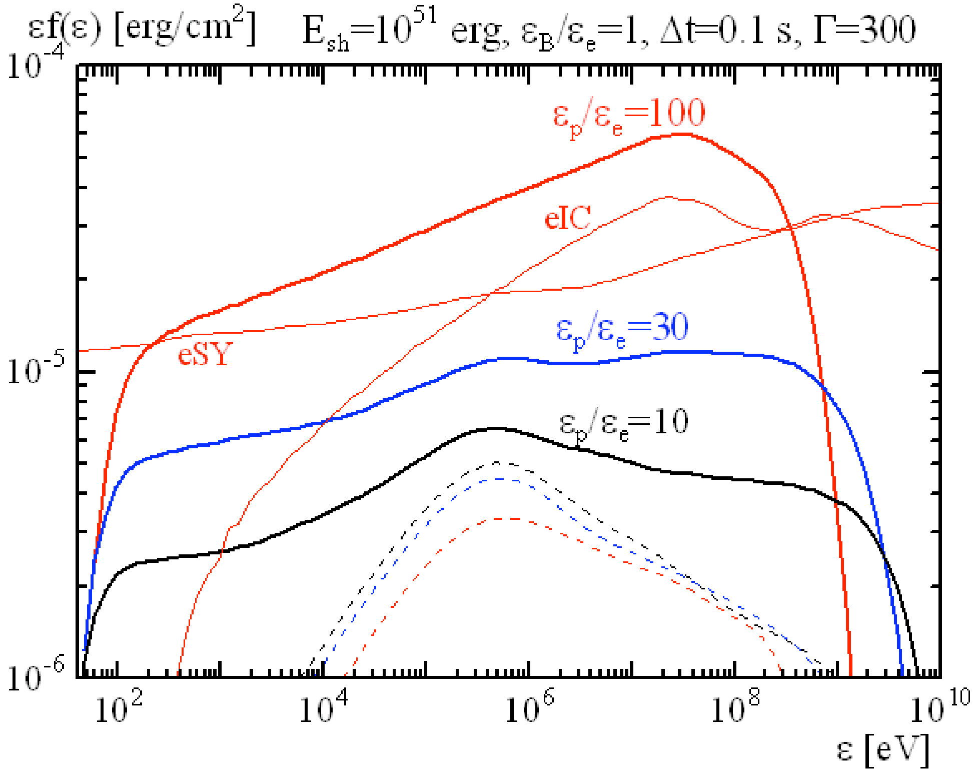
Asano & Inoue 07 ApJ 671:645

Monte Carlo simulations:
Photon signature of protons may be easier to find than neutrinos!



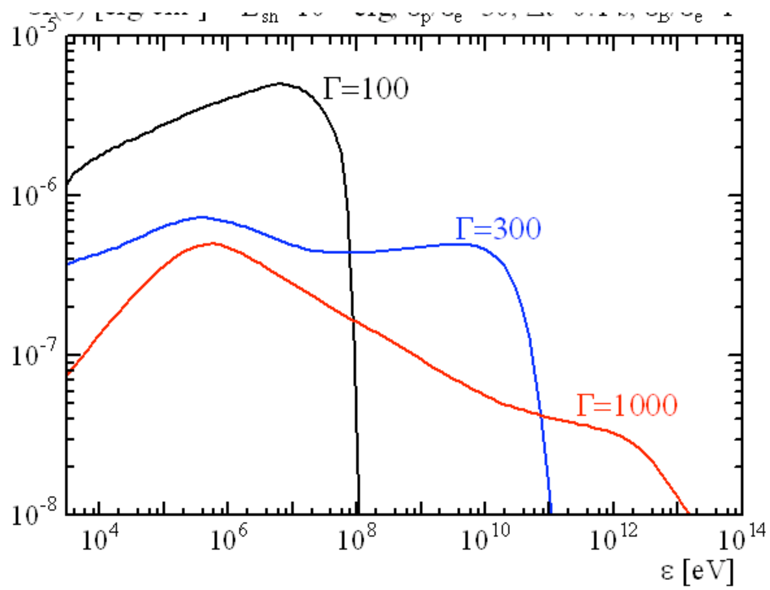


Prompt hadronic secondary photons (GeV)



Asano, Inoue & Mészáros arXiv:0807.0951

If GRB are UHECR sources, may need $\epsilon_p/\epsilon_e \gtrsim 10$ → tends to give photon peak at higher energies

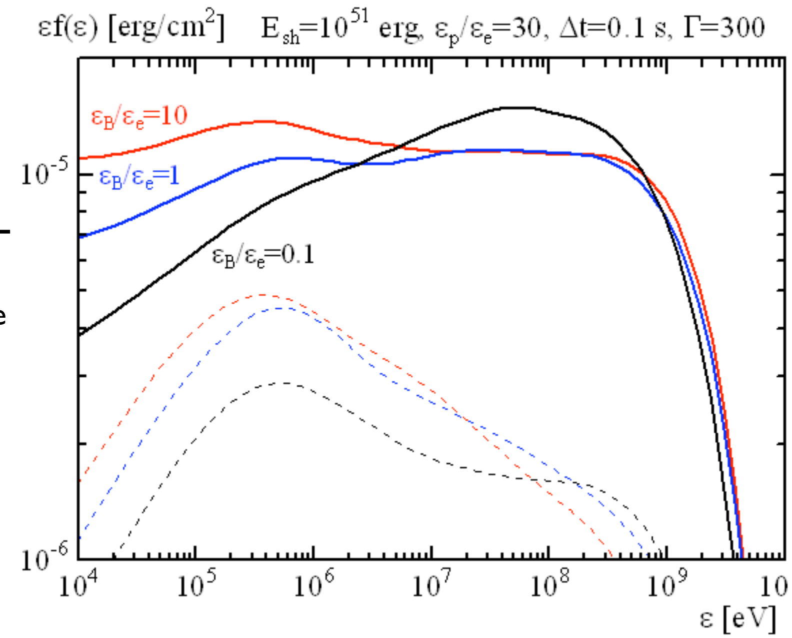


Diagnostic for

↑: high ϵ_p/ϵ_p

←: high bulk Γ

→ : high ϵ_B/ϵ_e



Conclusions

- Will learn much from coordinated sub-MeV / GeV obs.
- GRB 0980916c is the first high quality GeV GRB... now need find others with simultaneous Swift/ground obs.
- Will be able to constrain electron and proton acceleration / shock parameters, compactness of emission region (dimension, magnetic field,...)
- Will constrain total energetics & fraction in UHECR, UHENU components
- Do GRB contribute significantly to UHECR? At what E?
- Geometry of jet(s): progenitor & total GRB spatial density needs will be better understood / constrained
- Are there VHE-bright, MeV-dark GRBs? Relation to un-ID TeV?