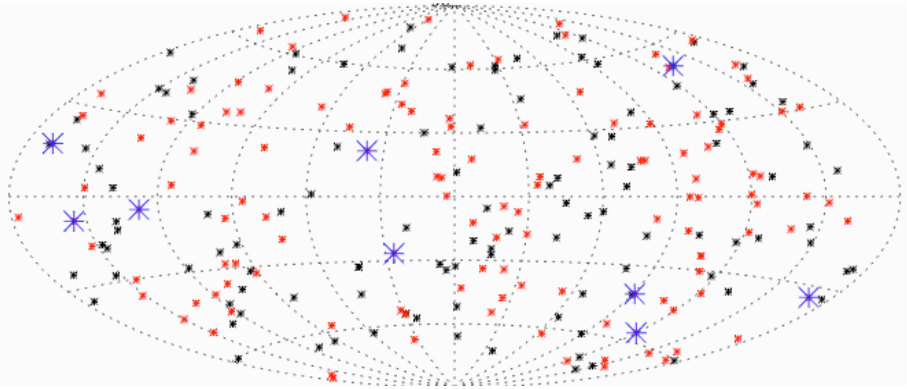
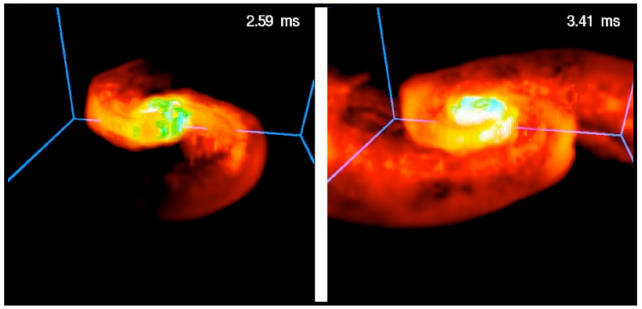
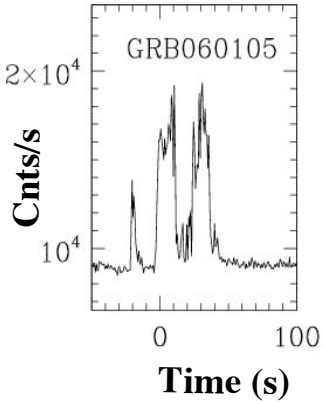




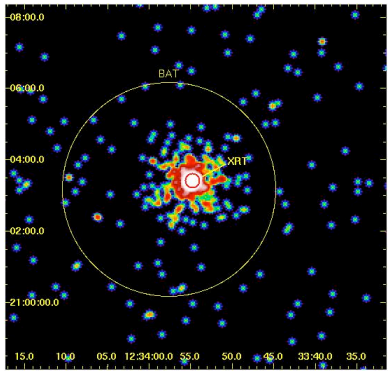
Gamma Ray Bursts - Observations



Neil Gehrels

NASA-GSFC

October 30, 2009
HEPRO II - Buenos Aires



Outline

Theme is comparing **short** and **long** GRBs.

→ GRB backgroud

→ Swift comparisons
- Duration
- Host galaxies
- Distance distributions
- Energetics
- Beaming

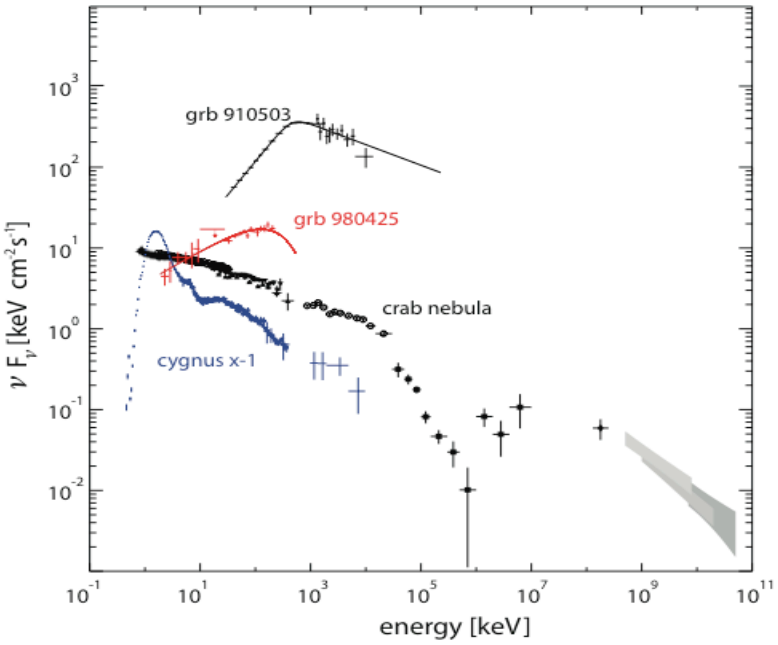
→ *Fermi* comparisons
- GeV emission
- Lags

ARAA Annual Reviews 2009 Gehrels, Ramirez-Ruiz and Fox

Background

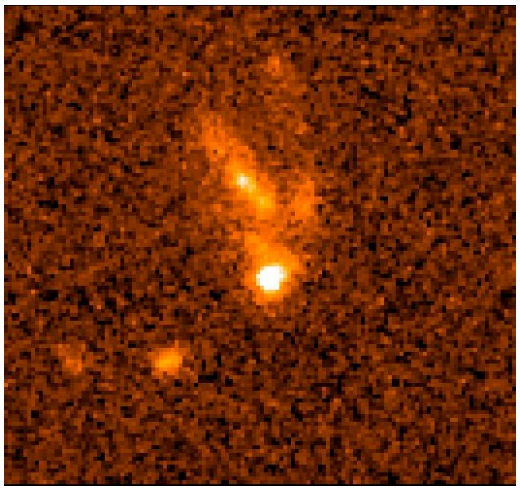
GRB Properties

ARAA article



GRB 990123 HST image

Fruchter et al.



Two types:
Short GRBs (t < 2s)
Long GRBs (t > 2s)

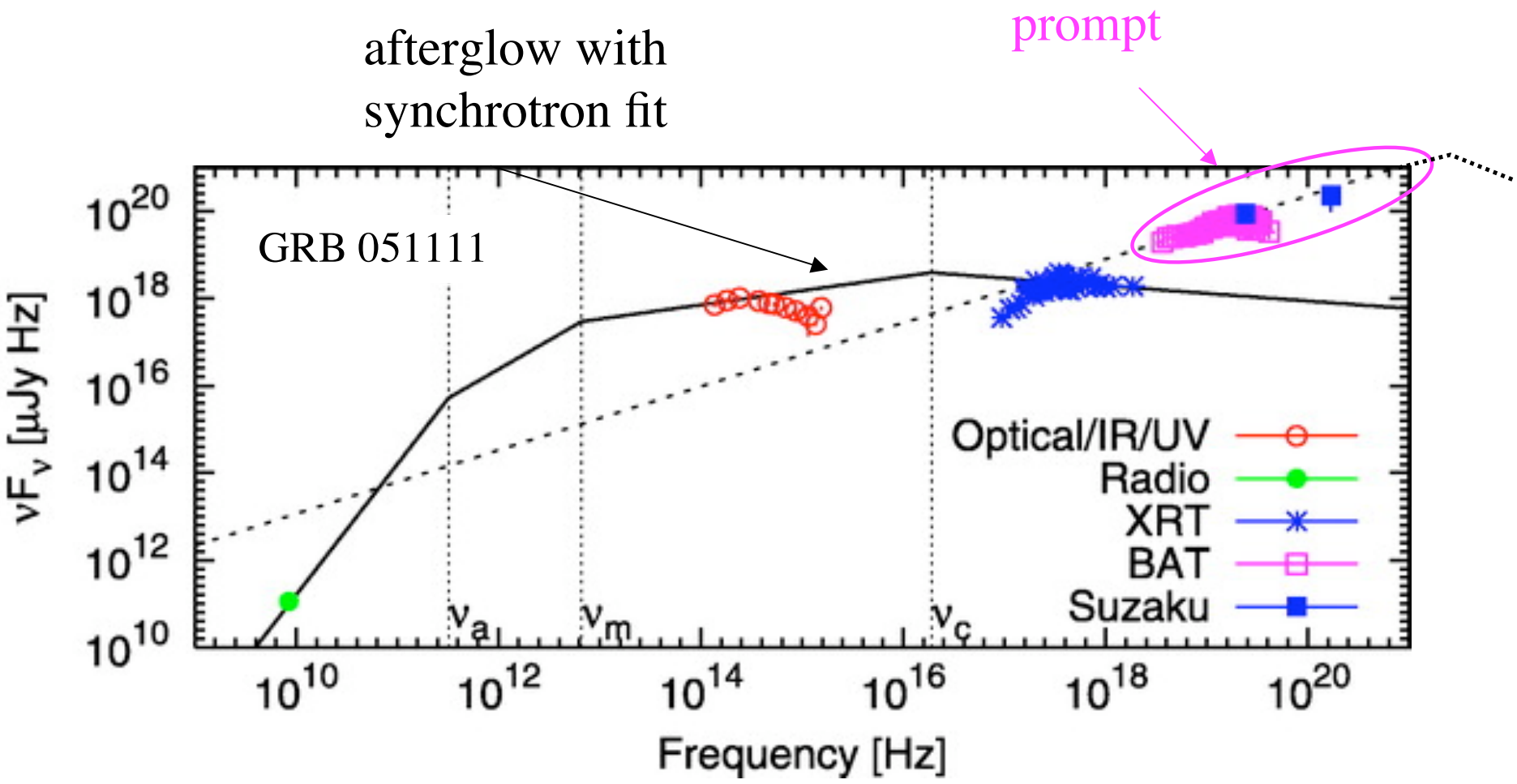
Redshift range:
0.2 - ~2 SGRBs
0.009 - 8.2 LGRBs

Energy release in γ-rays:
10^{49}-10^{50} ergs SGRBs
10^{50}-10^{51} ergs LGRBs

Jet opening angle:
~15 deg SGRBs
~5 deg LGRBs

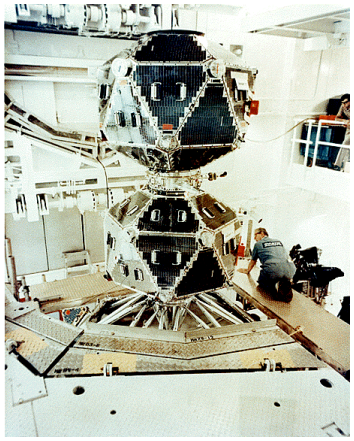
Both types have delayed & extended high-E emission

GRB Spectra

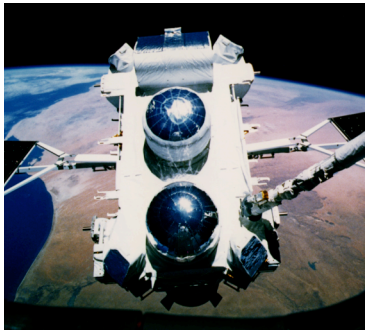


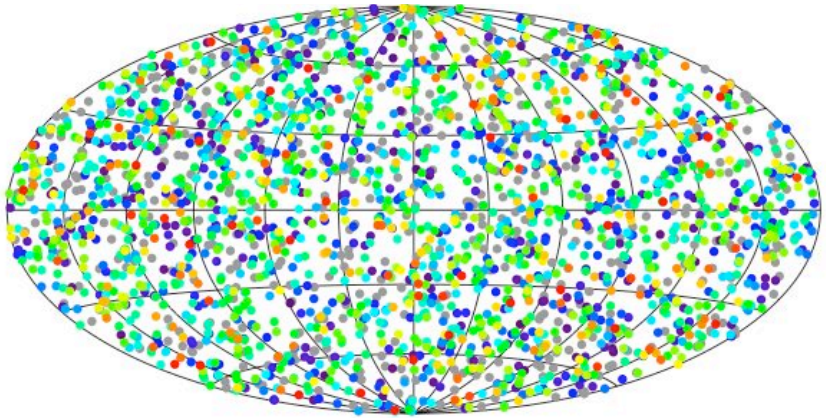
Butler et al. 2006

VELA
GRB discovery
1973

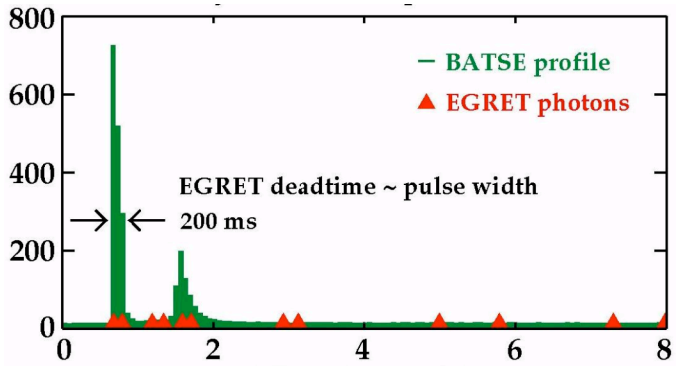


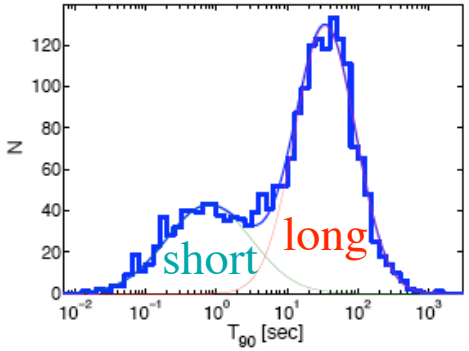
Compton / BATSE
isotropy &
inhomogeneity
2 duration classes
1991



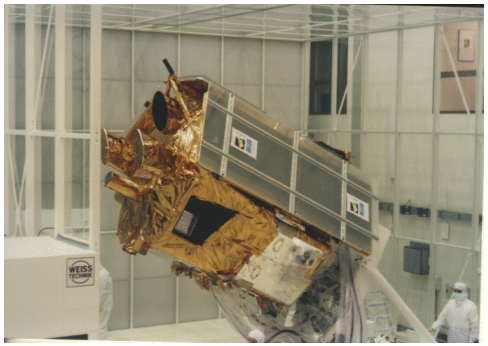


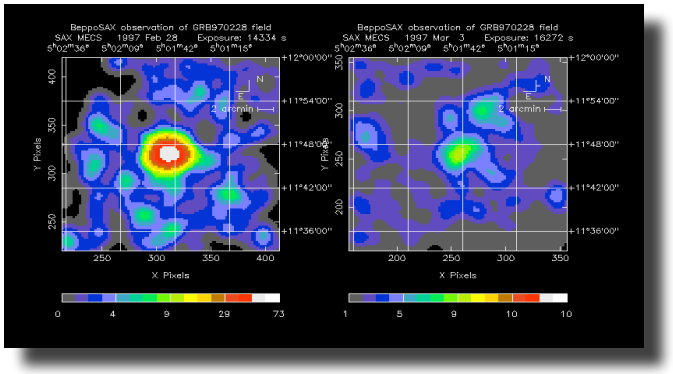
Compton / EGRET
GeV extended emission
1994



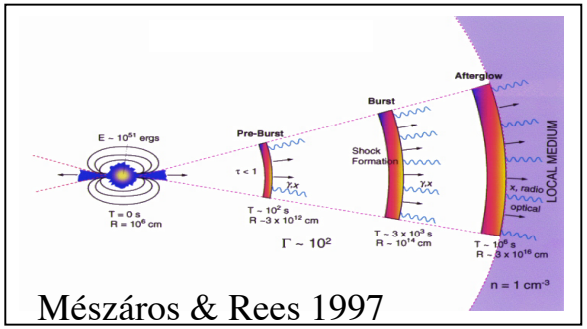


BeppoSAX
afterglow & distance
1997

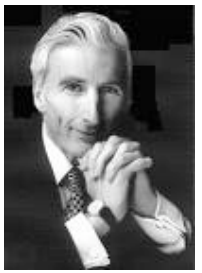




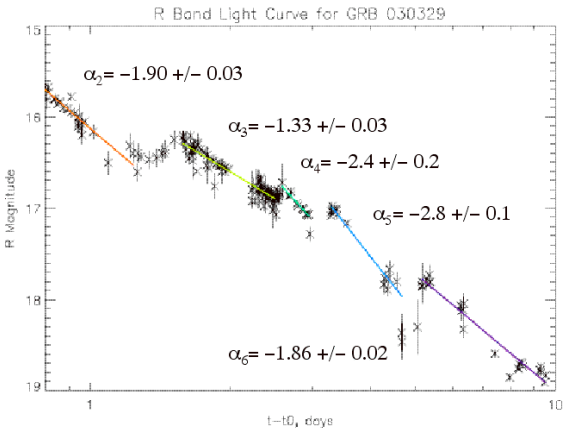
Fireball Model
1997



Mészáros & Rees 1997



HETE-II
GBR030329 / SN2003dh
XRFs
~ 2003



Swift / Fermi Opportunities - 2000

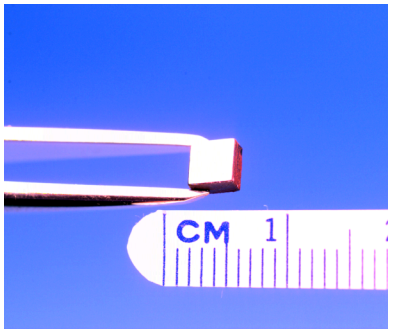
Scientific need
new capabilities

Recognized:
* GRBs are new tools for
  - high-z universe
  - SN physics
  - jet physics

However:
* Long GRBs poorly understood
* Short GRBs not understood
* High energy emission barely sampled

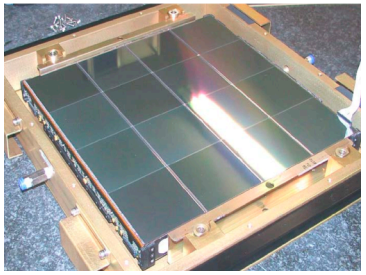
Needed:
* Rapid response & multi-wavelength observatory
* Sensitive high-E instrument with low event deadtime

New CdZnTe detectors and
pair tracking technology



CdZnTe detector

medical imaging

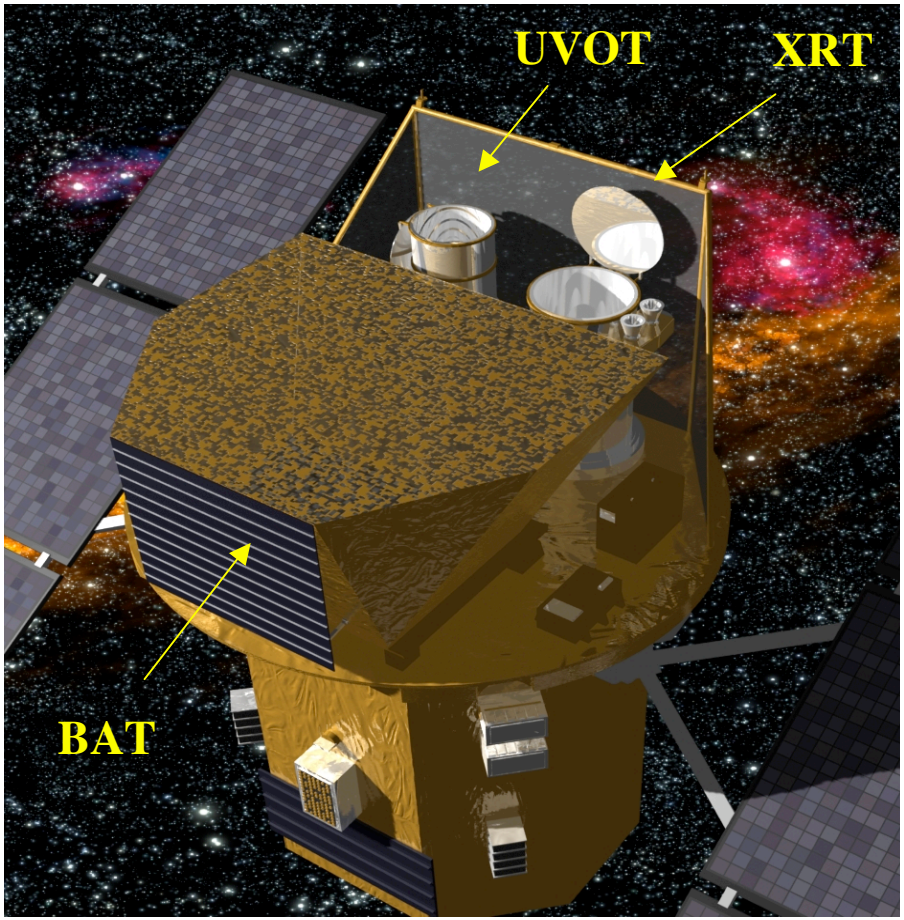


Si strip detector

accelerator physics

Swift GRBs

Swift Mission

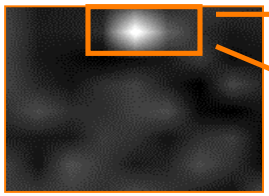


3 instruments, each with:
- lightcurves
- images
- spectra

Rapid slewing spacecraft

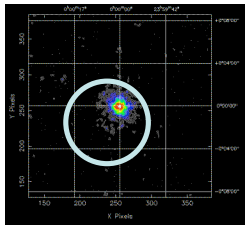
Rapid telemetry to ground

BAT Position - 2 arcmin



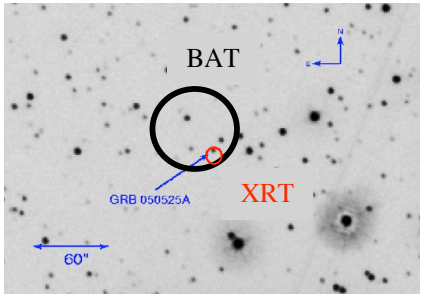
T<10 sec

XRT Position - 5 arcsec



T<90 sec

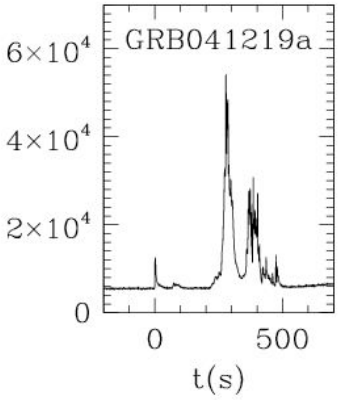
UVOT Position - < 1 arcsec

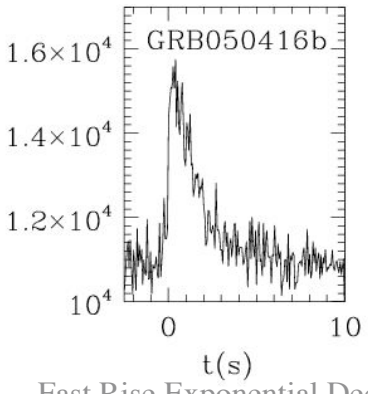


T<2 min

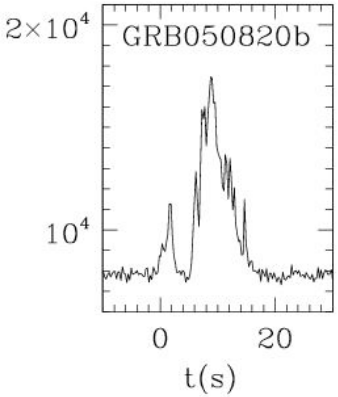
475 GRB as of this week
85% with X-ray detections
~60% with optical detection
155 with redshift (41 prior to Swift)
46 short GRBs localized (0 prior to Swift)

Swift Statistics

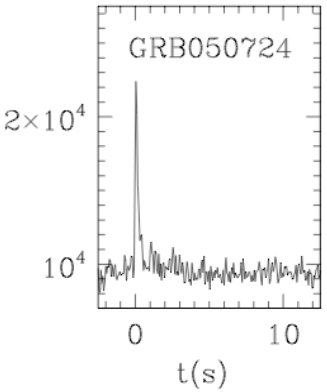


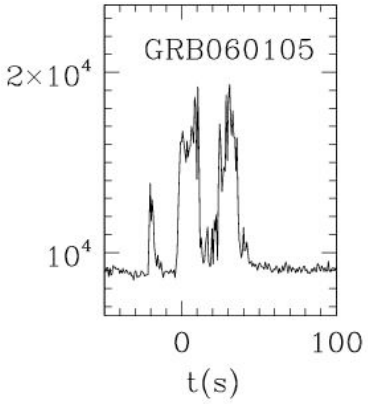


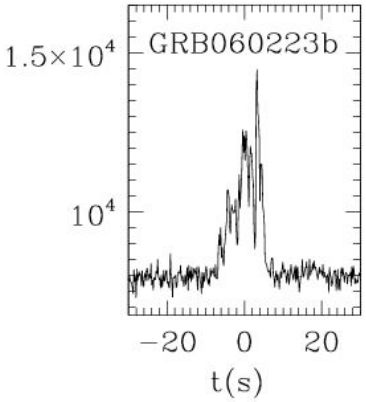
Fast Rise Exponential Decay



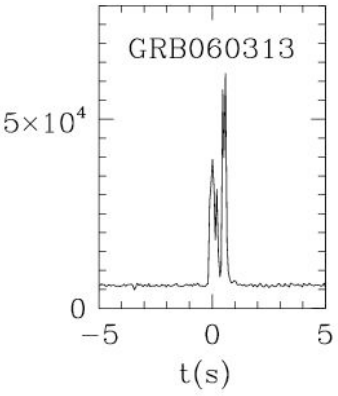
Short GRB

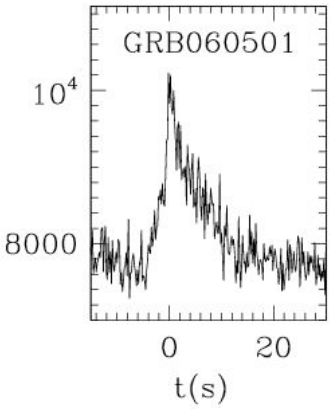






Short GRB



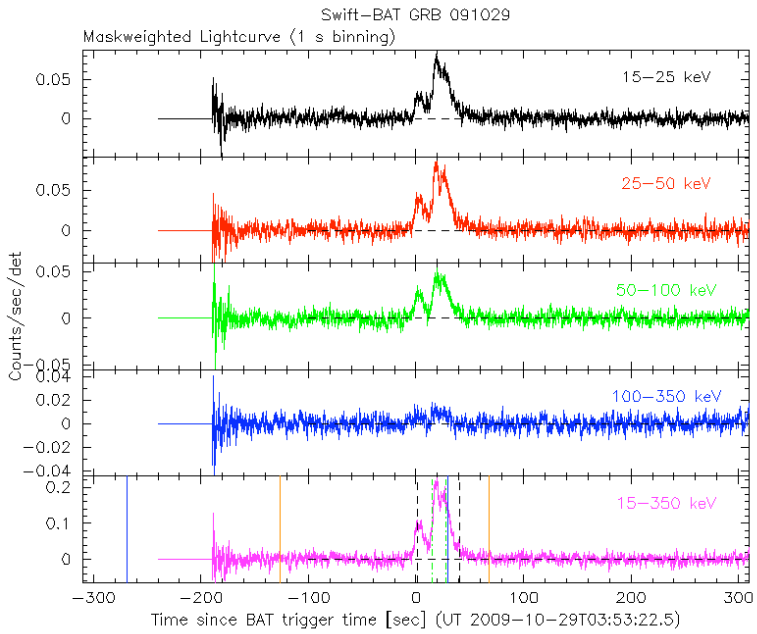


Swift GRB Data

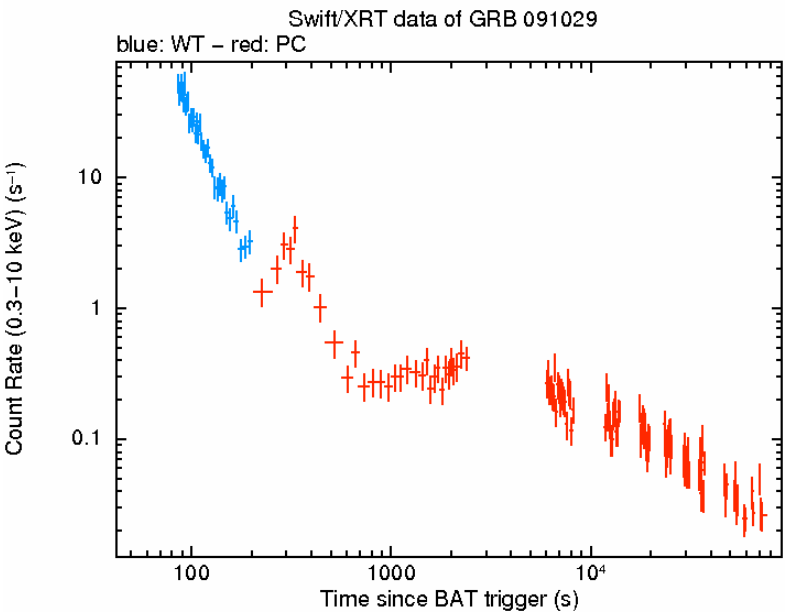
GRB 091029

Yesterday's burst

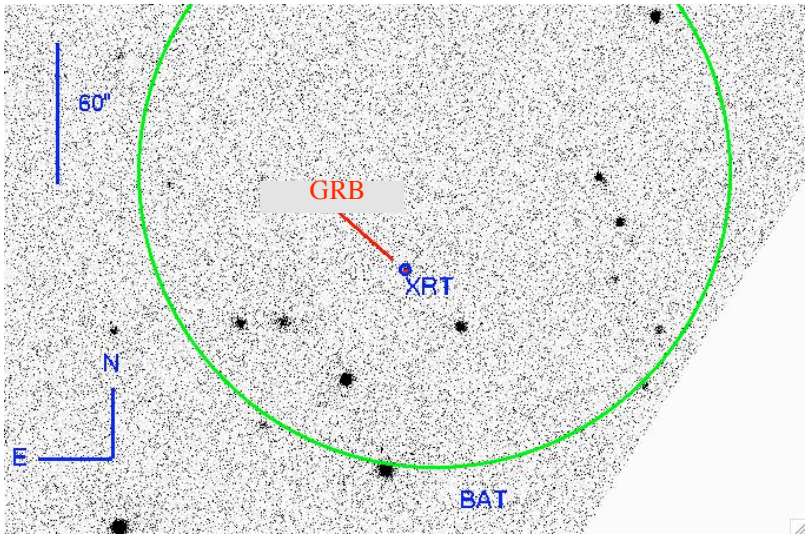
BAT lightcurve



XRT lightcurve



UVOT image

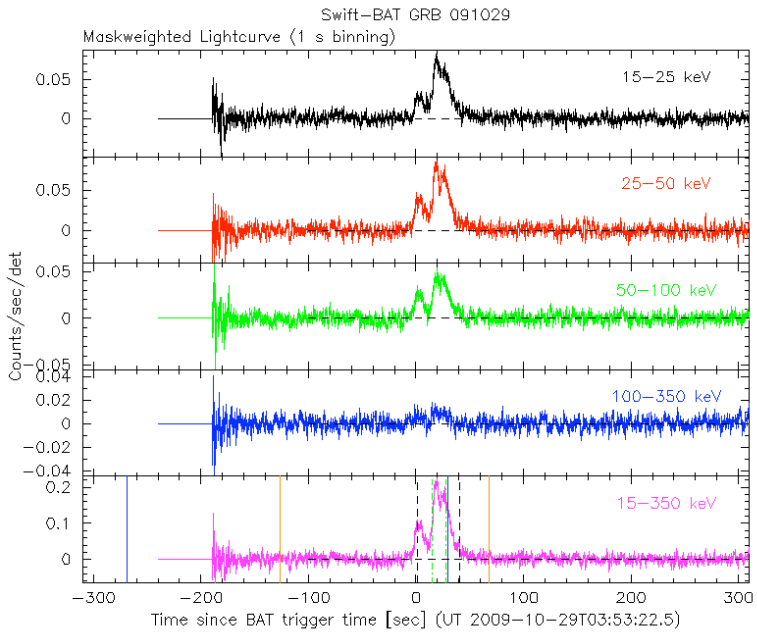


Swift GRB Data

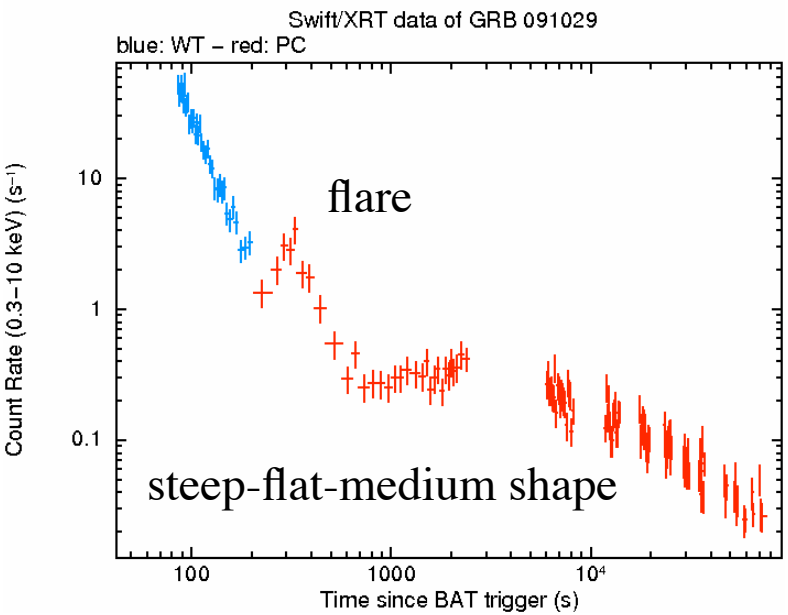
GRB 091029

Yesterday's burst

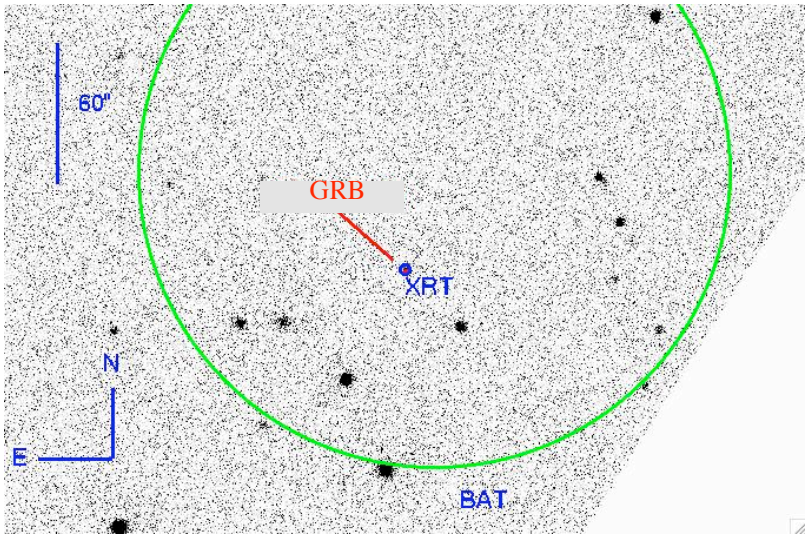
BAT lightcurve

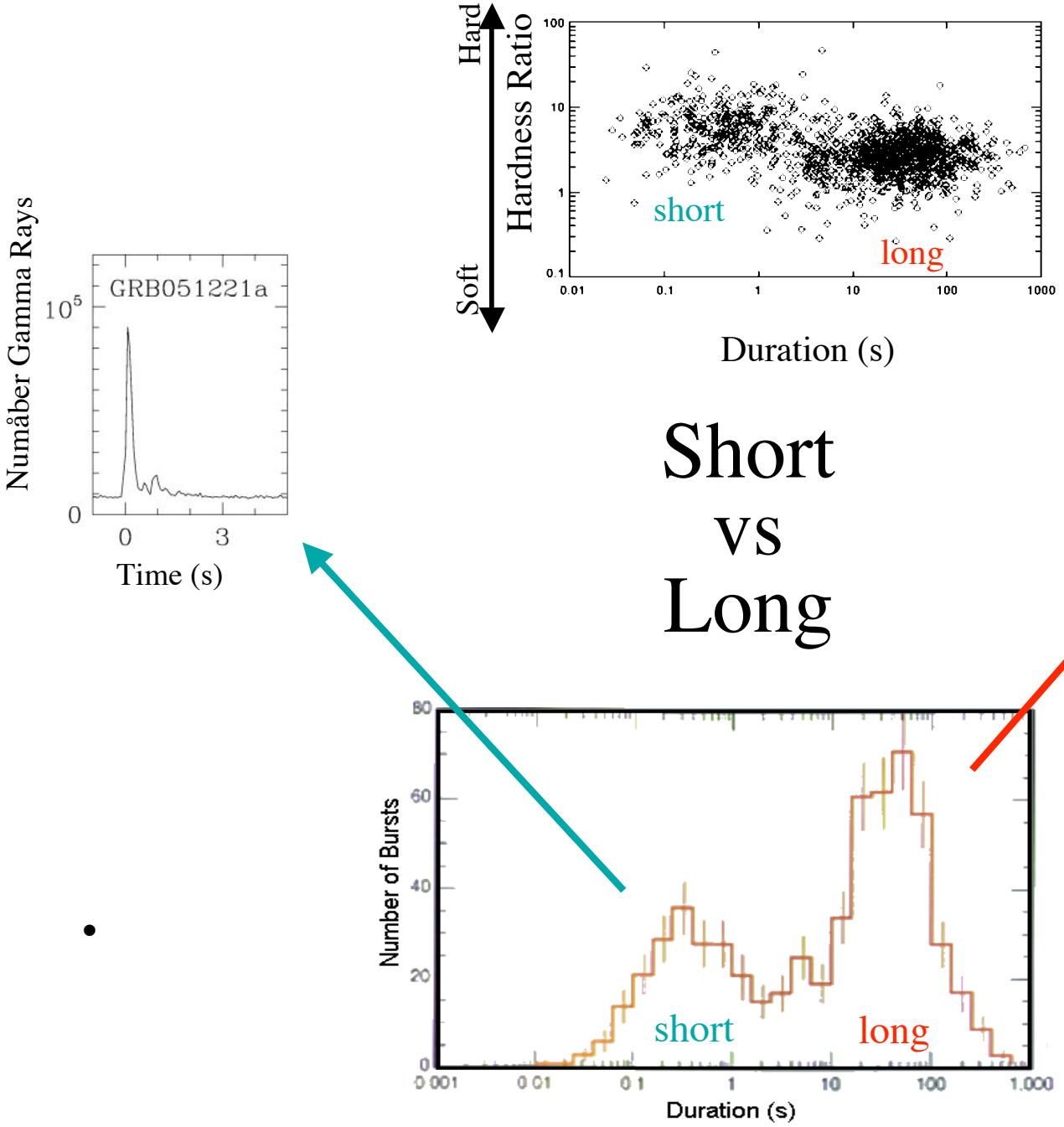


XRT lightcurve



UVOT image

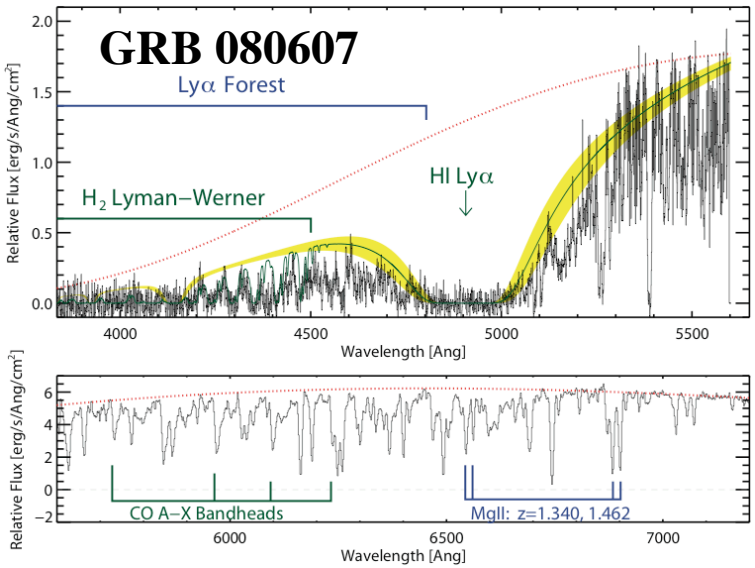




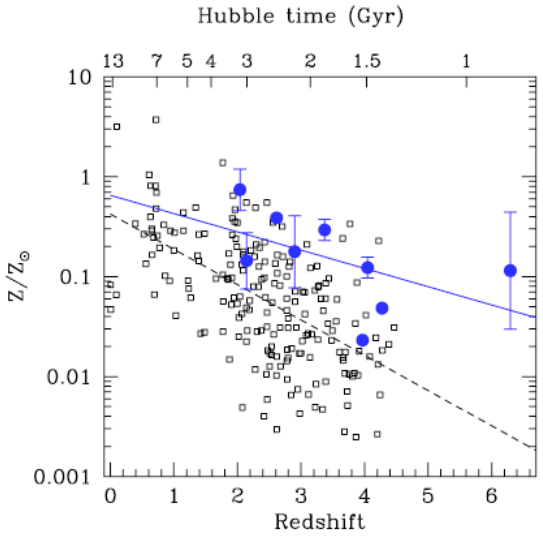
Kouveliotou et al. 2003

GRB Spectroscopy

z	Time (10^9 years)	GRB	Optical Brightness
8.3	13.0	090423	K = 20 @ 20 min
6.7	12.8	080813	K = 19 @ 10 min
6.29	12.8	050904	J = 18 @ 3 hrs
5.6	12.6	060927	I = 16 @ 2 min
5.3	12.6	050814	K = 18 @ 23 hrs
5.11	12.5	060522	R = 21 @ 1.5 hrs



Prochaska et al. 2008

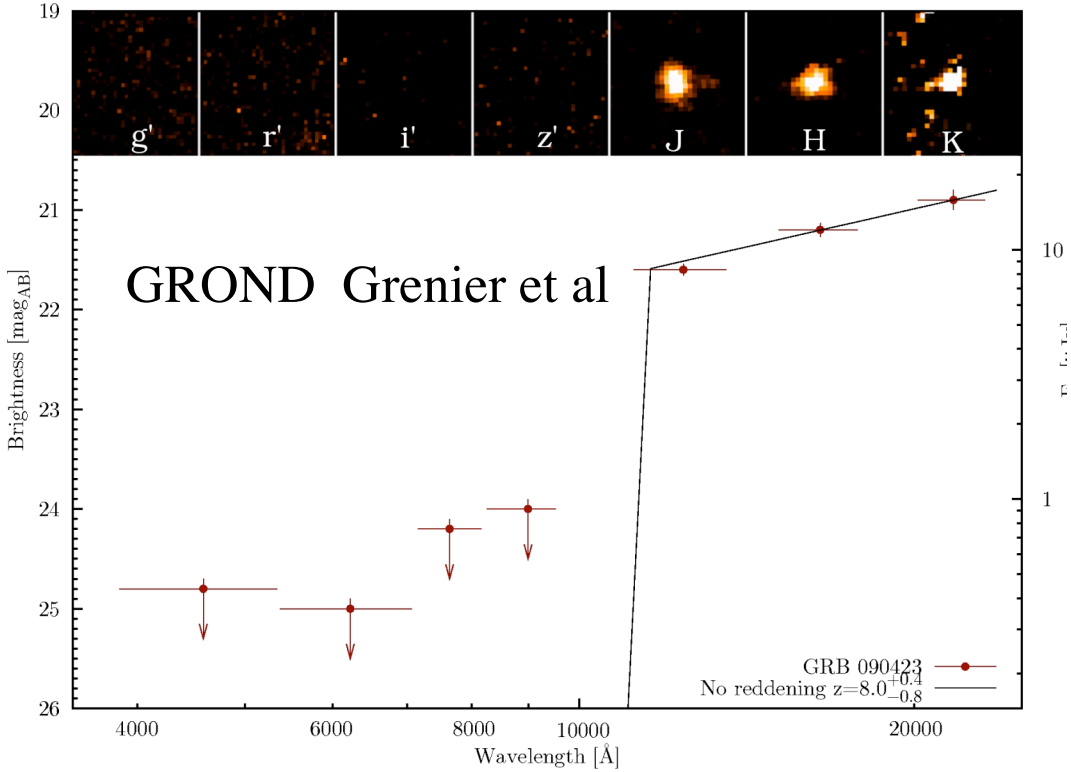


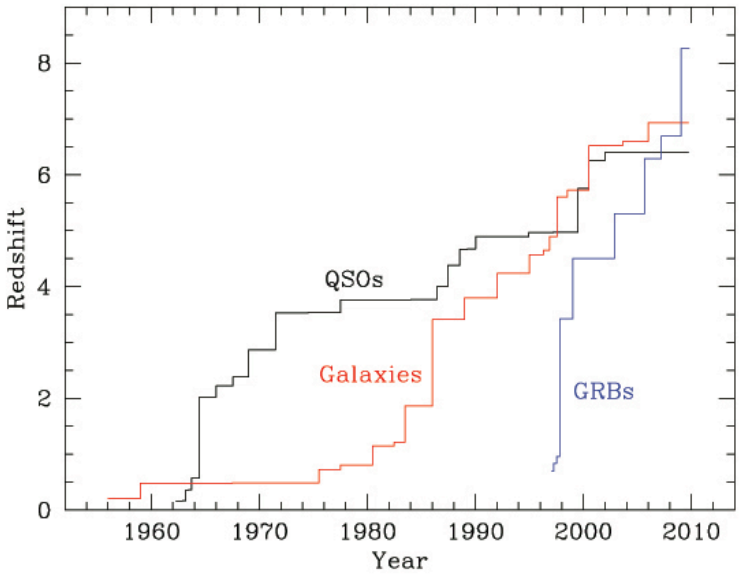
Savaglio 2006

Blast from the past!
GRB 090423

z = 8.29 look back time = 13.0 billion light years

Lyman break redshifted from UV to IR

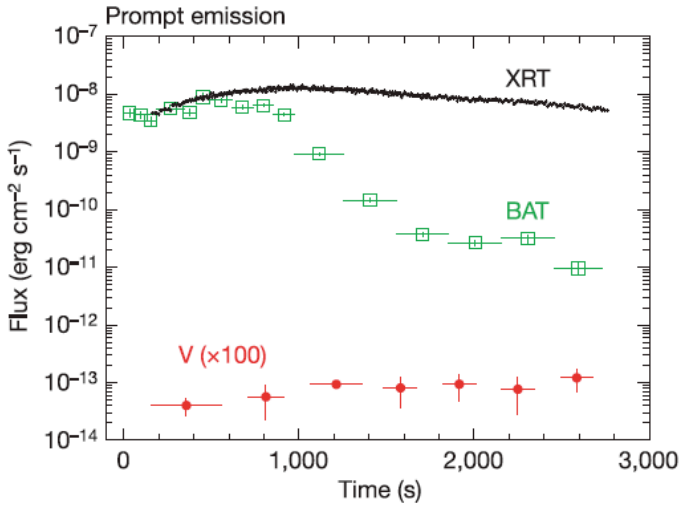


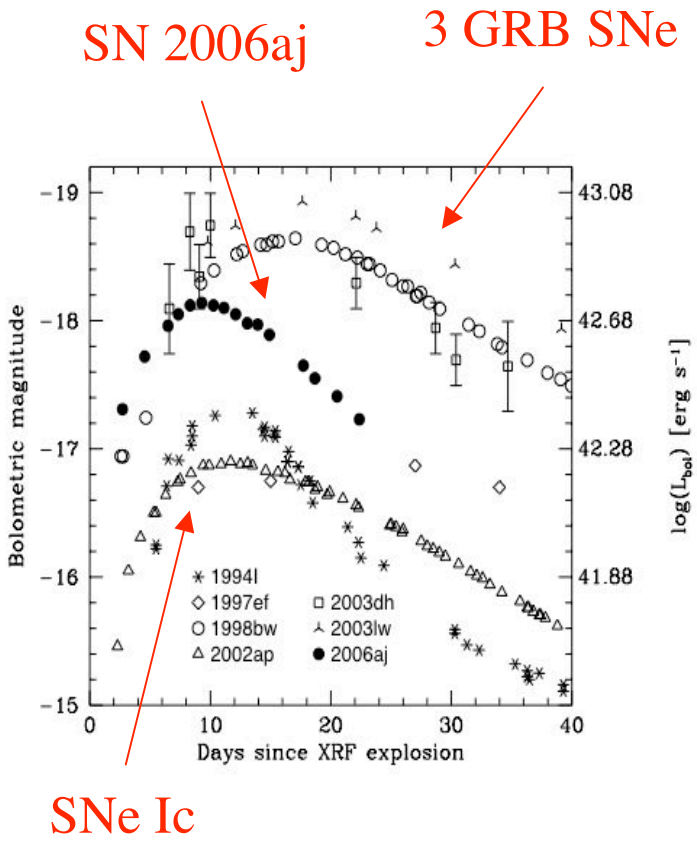


Tanvir et al. 2009; Salvaterra et al.

McMahon & Tanvir

GRB 060218: GRB + Hypernova





Super-long GRB - ~35 minutes

BAT, XRT, UVOT during GRB

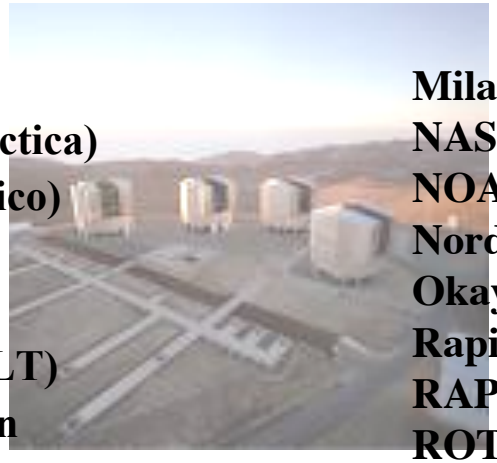
z = 0.033 (450 M yrs)

SN 2006aj SN Ib/c

E_{iso} = few x 10^{49} erg - **underluminous**

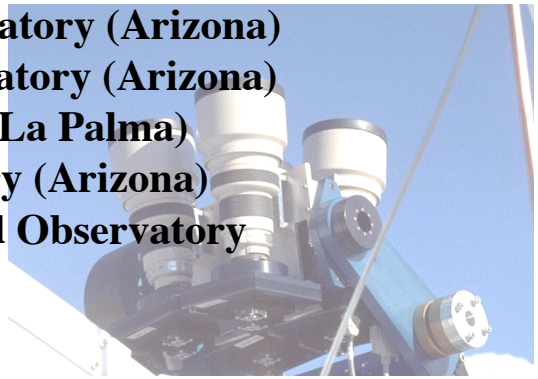
Campana et al., Mazzali et al., Pian et al., Soderberg et al.

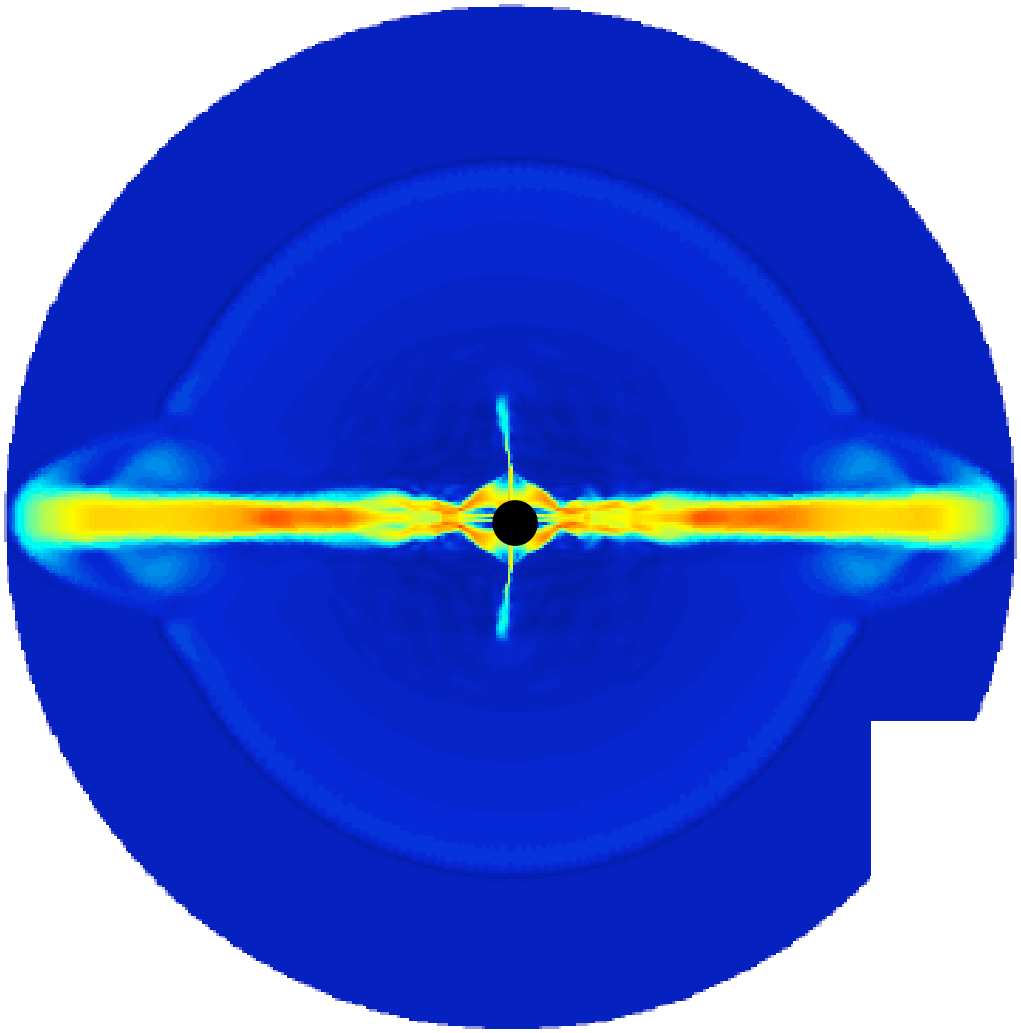
Swift Partner Observatories



AEOS Telescope (Hawaii)
ARAGO Telescope (Antarctica)
ARC Telescope (New Mexico)
Brera Observatory (Italy)
Chandra
ESO (La Silla, Paranal, VLT)
ESA's INTEGRAL mission
Faulkes Telescopes (Hawaii & Australia)
Galileo National Telescope (La Palma)
Gemini Telescopes (north and south)
Hubble Space Telescope
Hobby-Eberly Telescope (Texas)
INTEGRAL
Isaac Newton Telescopes (La Palma)
KAIT (California)
Keck Observatory (Hawaii)
Large Binocular Telescope (Arizona)
LIGO (Louisiana and Washington)
Liverpool Telescope (La Palma)
McDonald Observatory (Texas)

Milagro Gamma-ray Obs. (New Mexico)
NASA (IRTF, Hubble & Spitzer)
NOAO (CTIO, KPNO)
Nordic Optic Telescope (La Palma)
Okayama Observatory (Japan)
Rapid Eye Mount Telescope (Chile)
RAPTOR (New Mexico
ROTSE-III (New Mexico)
SARA Observatory (Arizona)
SIRTF
South African Large Telescope
Super-LOTIS (Arizona)
TAOS Telescope (Taiwan)
TAROT Telescope (France)
Tenerife Observatory
U.S. Naval Observatory (Arizona)
VERITAS Observatory (Arizona)
WASP Telescope (La Palma)
WIYN Observatory (Arizona)
Wyoming Infrared Observatory
XMM Newton





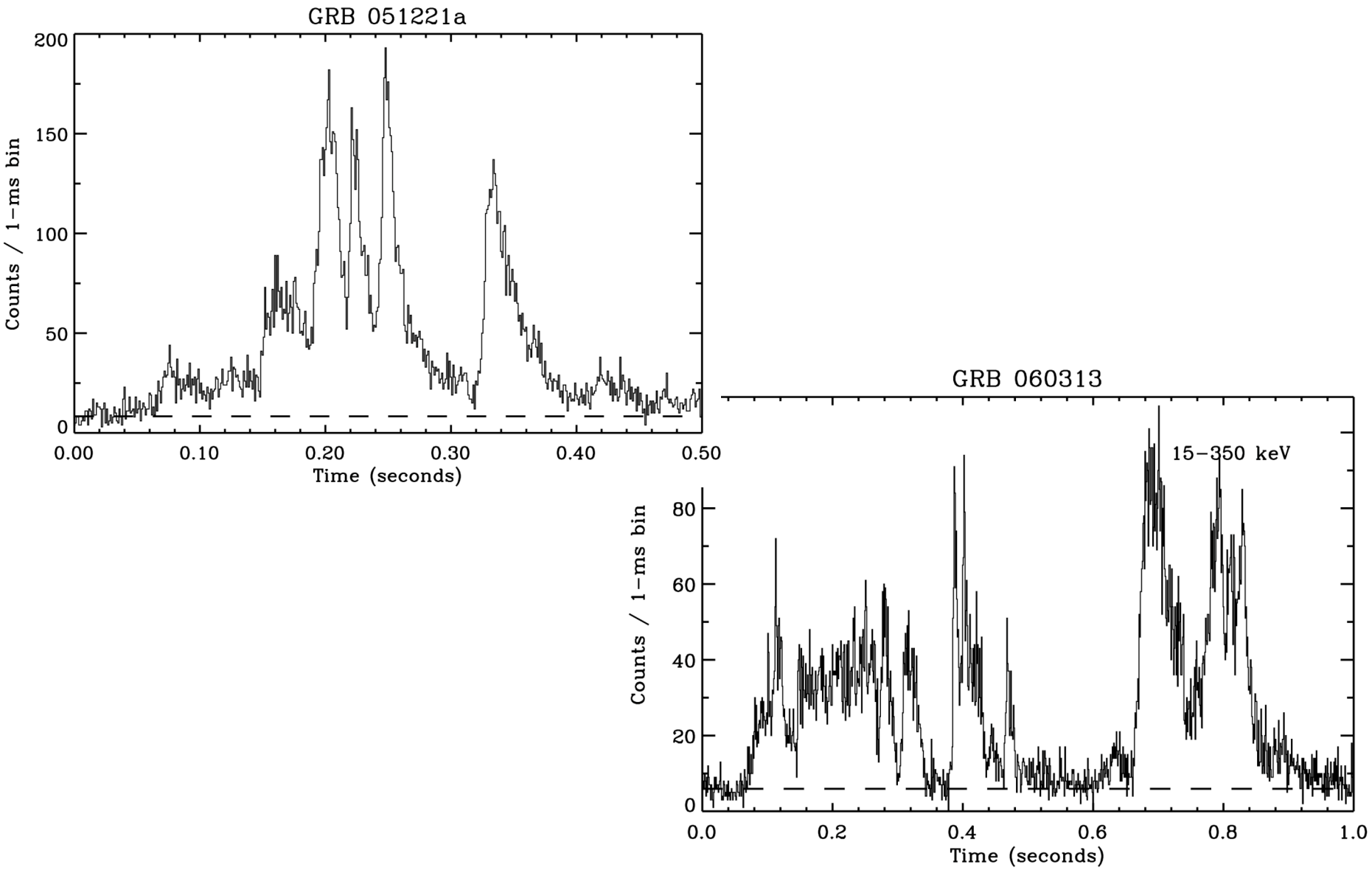
Long GRBs
Collapsar Model

star forming
regions of hosts

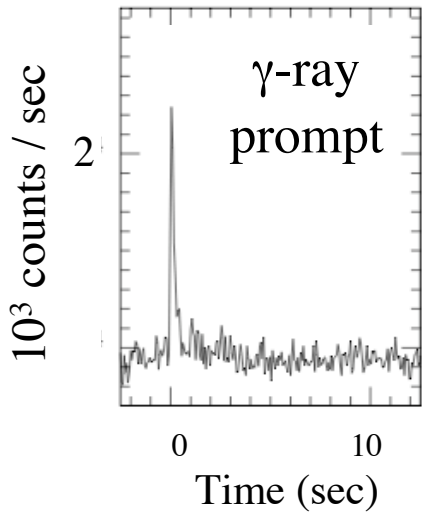
Barkov & Komissarov

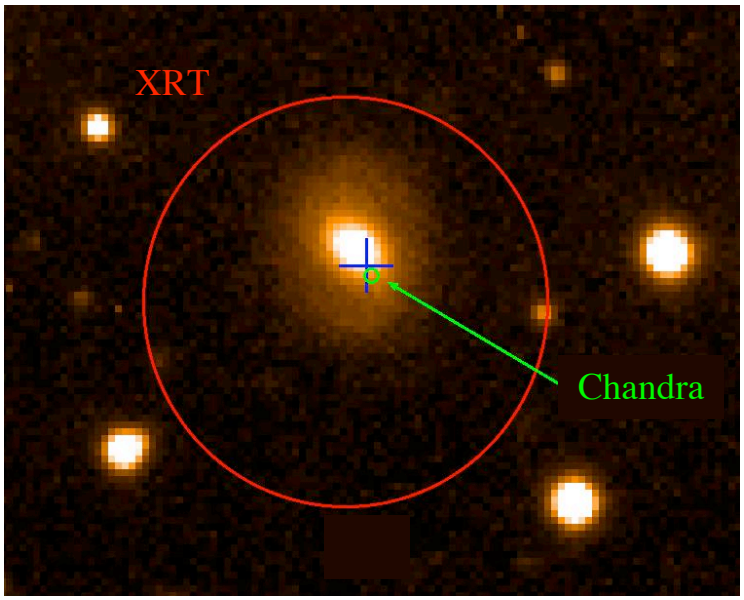
Zhang, Woosley & Heger

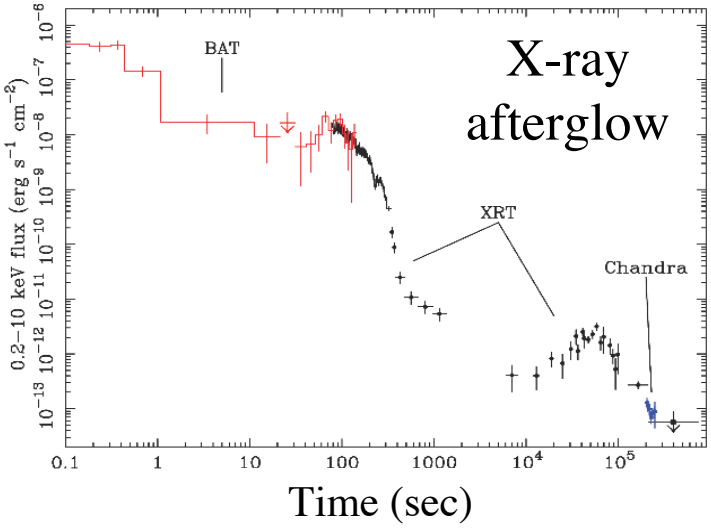
Short Burst Variability



GRB 050724







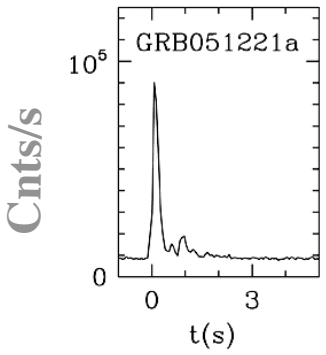
Host:

- Elliptical
- $z = 0.258$
- no coincident supernova
- SFR $< 0.02\ M_O\ yr^{-1}$

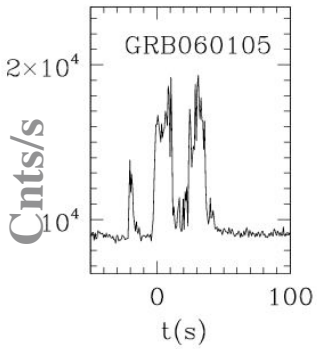
Barthelmy et al. 2005

Short vs Long GRBs

Short GRB

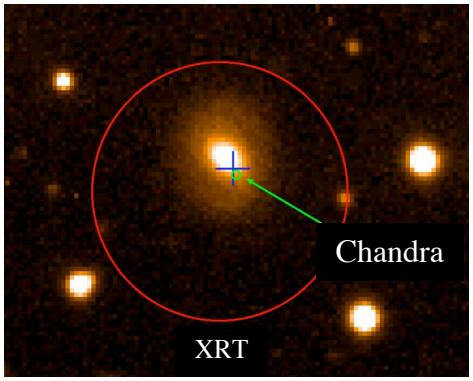


Long GRB

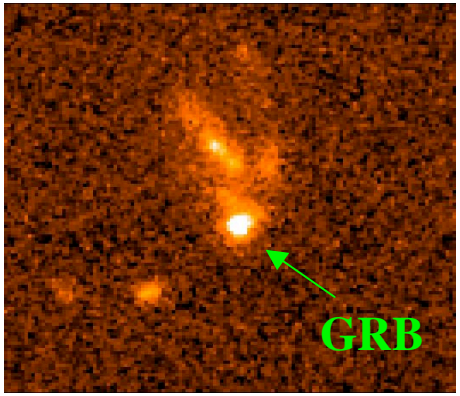


GRB 090916

GRB 050724 - *Swift*
elliptical host



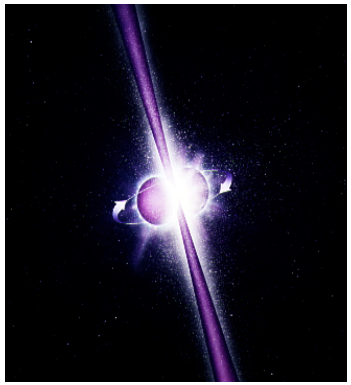
GRB 990123 - *SAX*
SF dwarf host

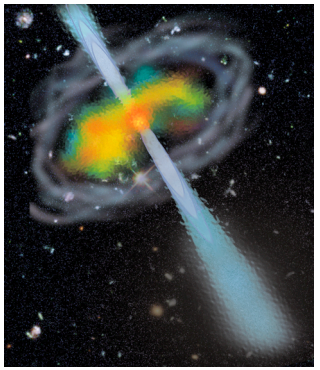


In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model





BH

In SF
galaxies

Accompanied by SNe

Collapsar model
well supported

Short GRBs Compared to Long GRB

46 short GRBs detected by Swift/BAT

Lower Redshifts

$< z > = 0.4$ short

$< z > = 2.3$ long

Weaker Afterglows

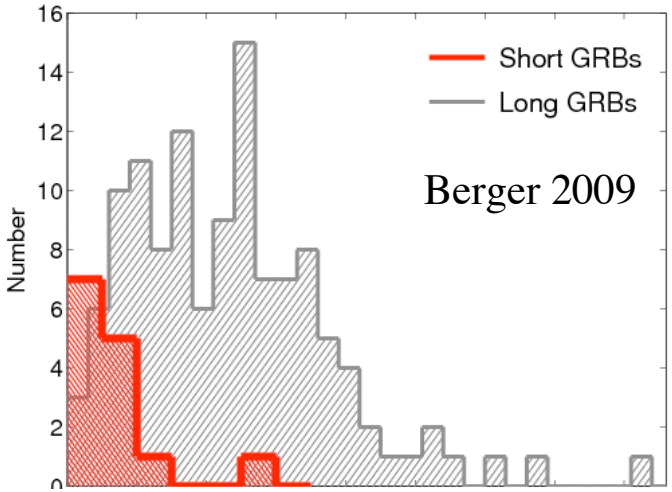
$< F_X > = 7 \times 10^{-10}$ erg cm^{-2} s^{-1} short

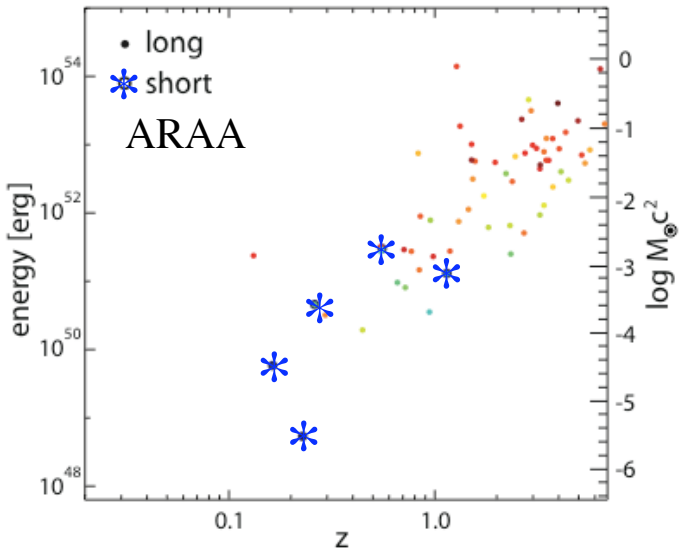
$< F_X > = 3 \times 10^{-9}$ erg cm^{-2} s^{-1} long

Lower Energy release

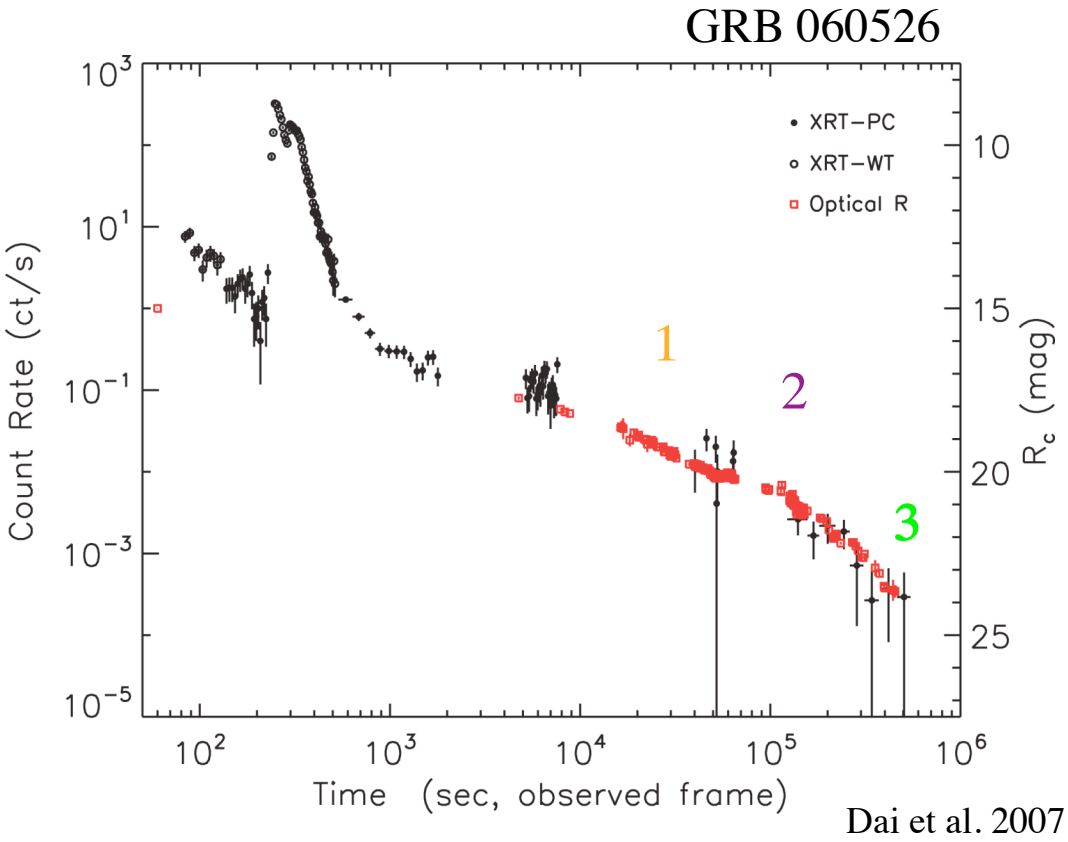
$E_{iso} \sim 10^{50}$ $E_\gamma \sim 10^{49}$ short

$E_{iso} \sim 10^{53}$ $E_\gamma \sim 10^{51}$ long





Jet Breaks & Beaming

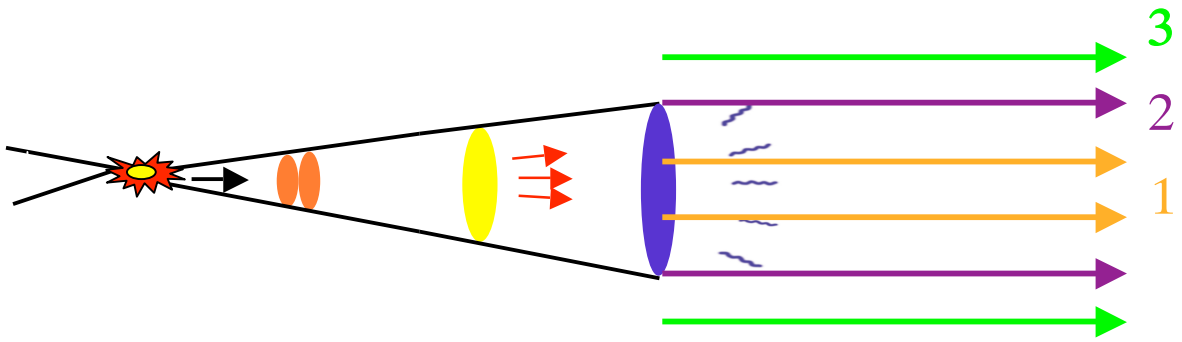


Dai et al. 2007

z=3.21
jet angle = 7°

With beaming:
$E_\gamma \sim 10^{51}$ ergs

Without beaming
$E_\gamma \sim 10^{53}$ ergs



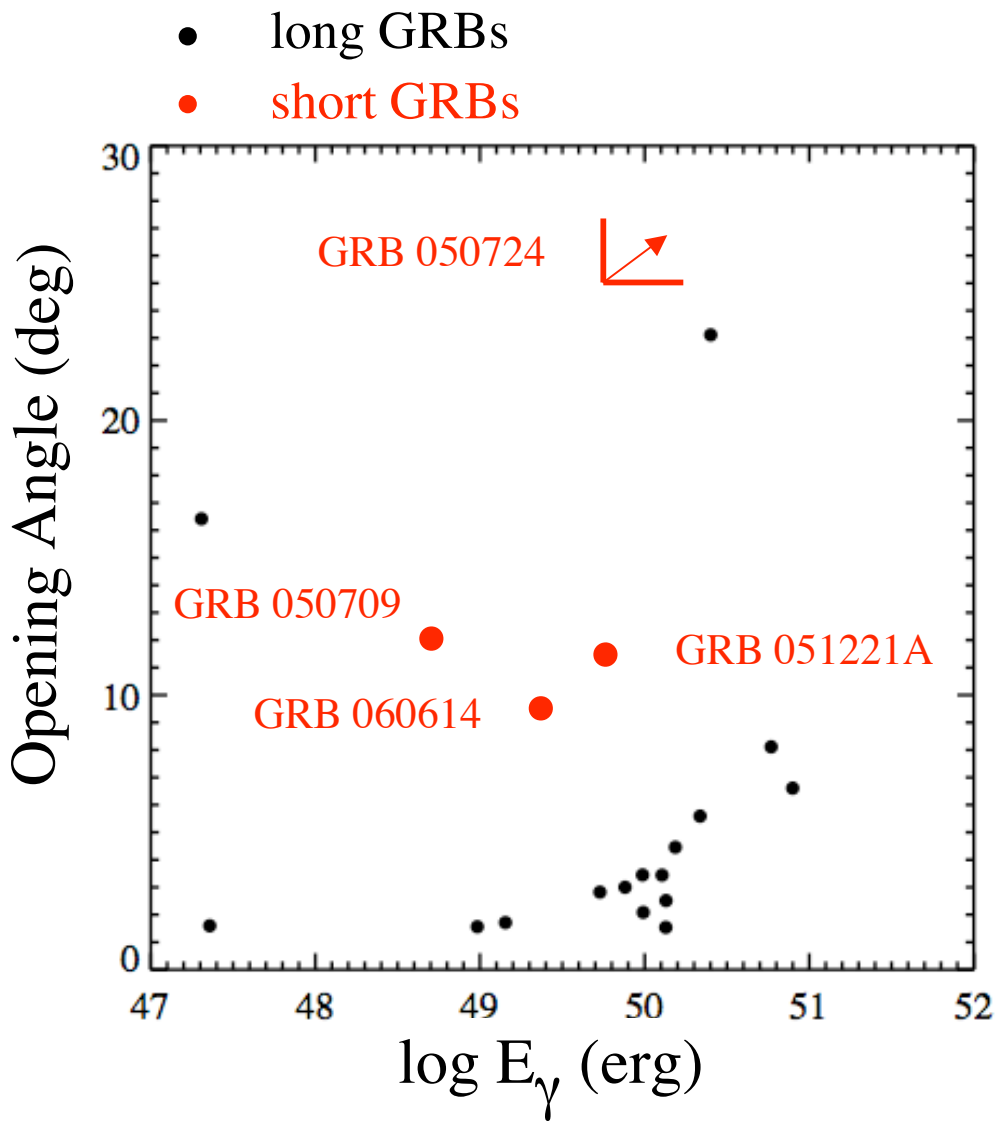
Jet Breaks & Beaming

Data on beaming opening angles are poor and confusing

Typical values:

$\theta_{jet} \sim 15^{\circ}$ short

$\theta_{jet} \sim 5^{\circ}$ long

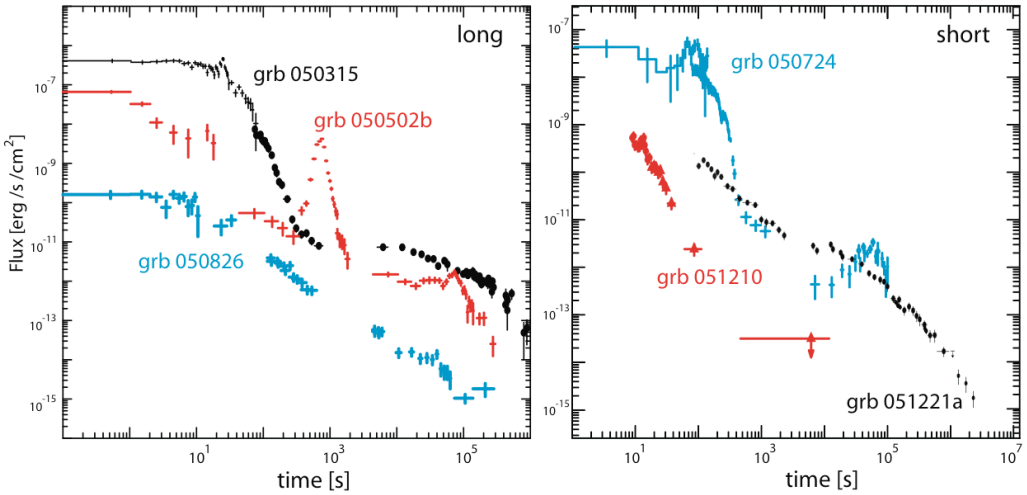


Racusin et al. 2009

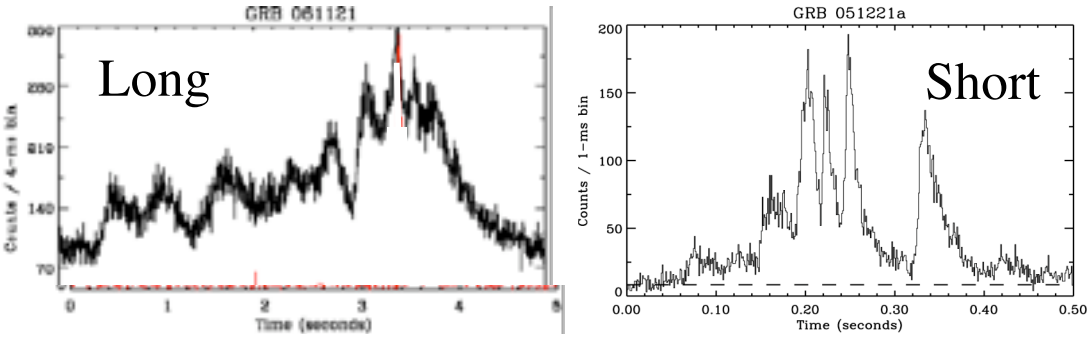
Similarities of Short & Long GRBs

Similar LC shapes

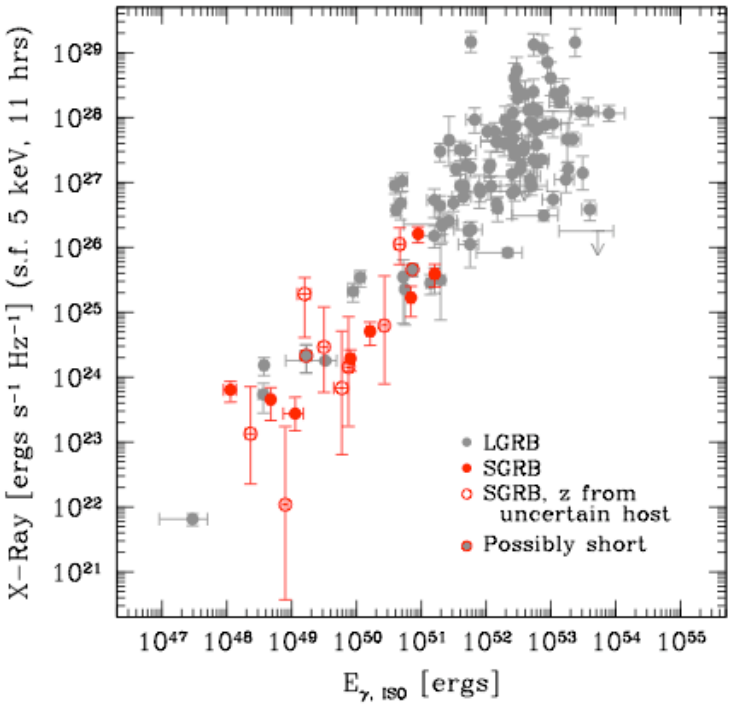
ARAA paper



Similar Variability

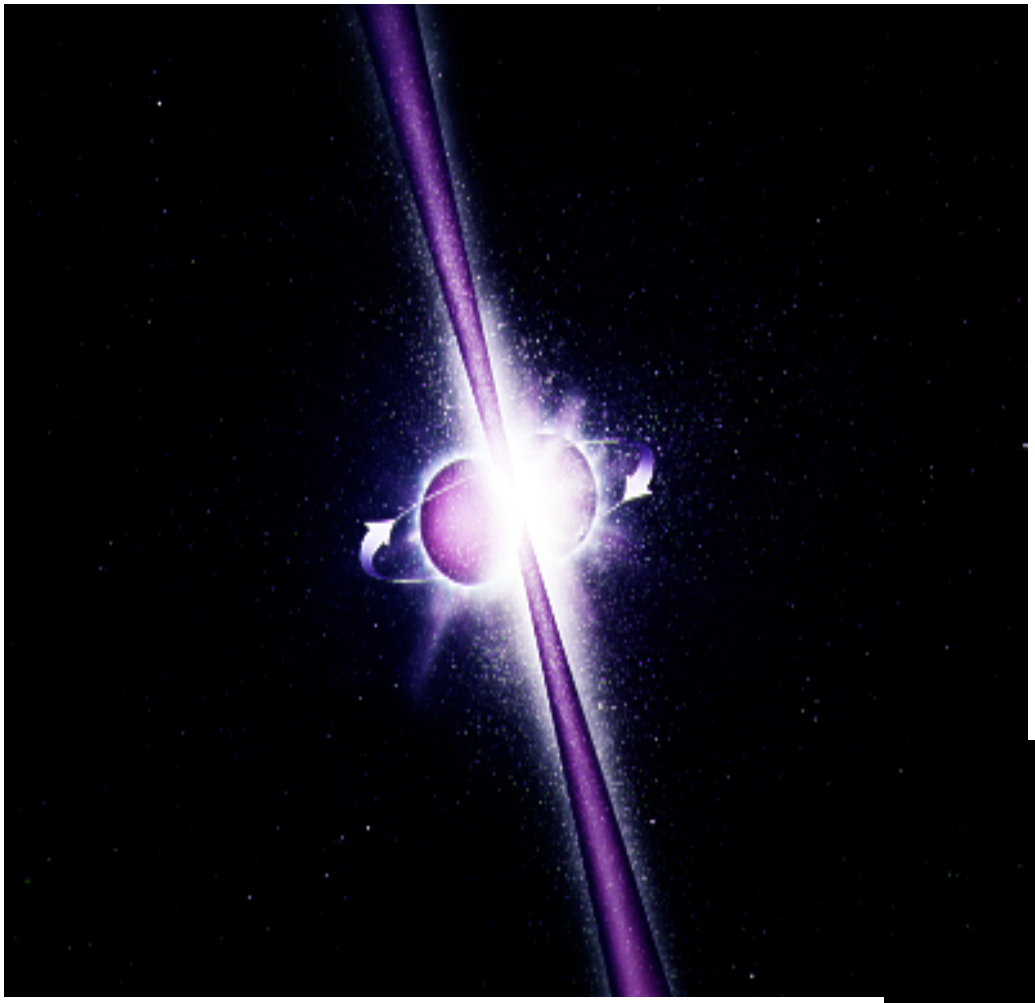


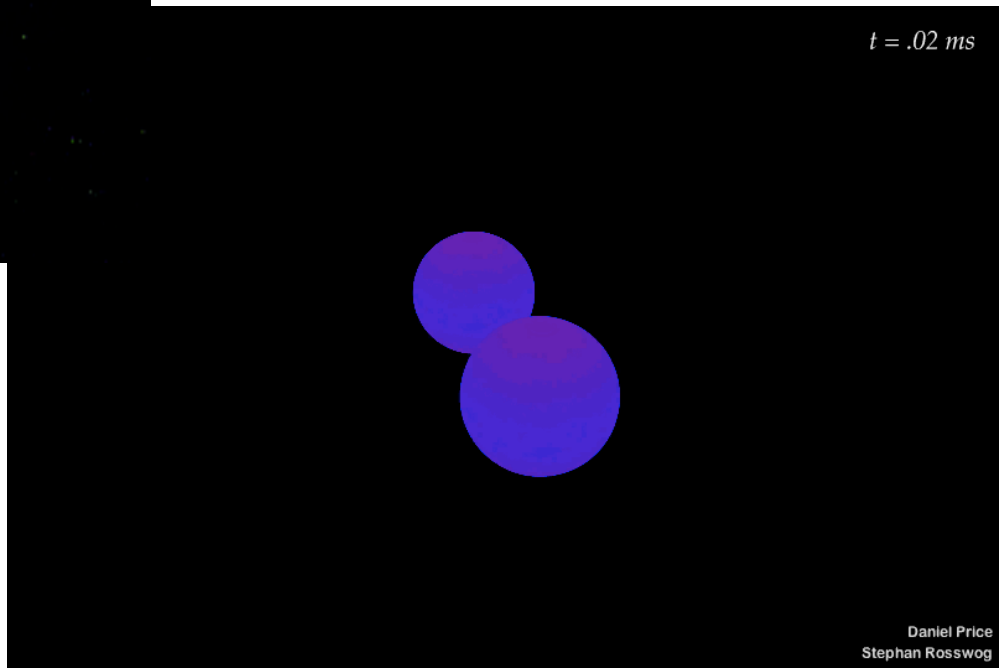
Similar L_X / $E_{\gamma\text{-iso}}$



Nysewander, Fruchter & Pe'er 2009

Short GRBs
Merger Model

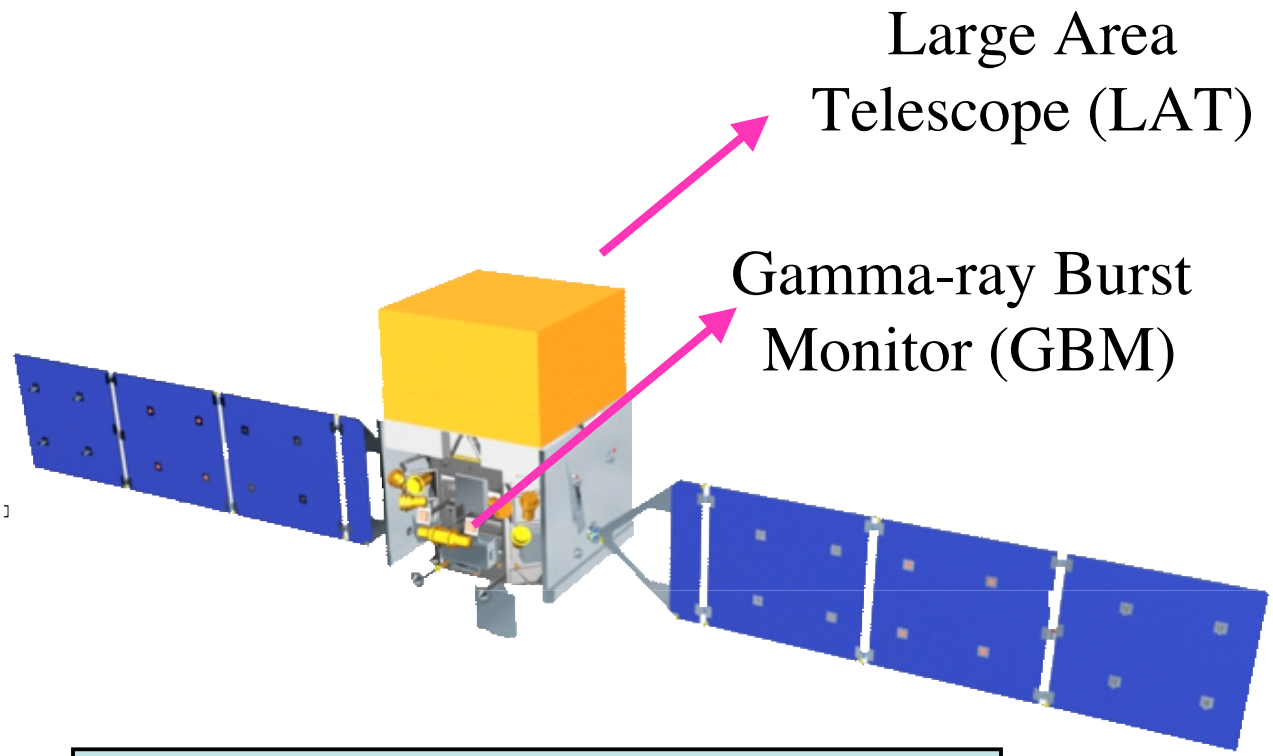




Credit: Daniel Price and Stephan Rosswog

Fermi GRBs

Fermi Gamma Ray Mission

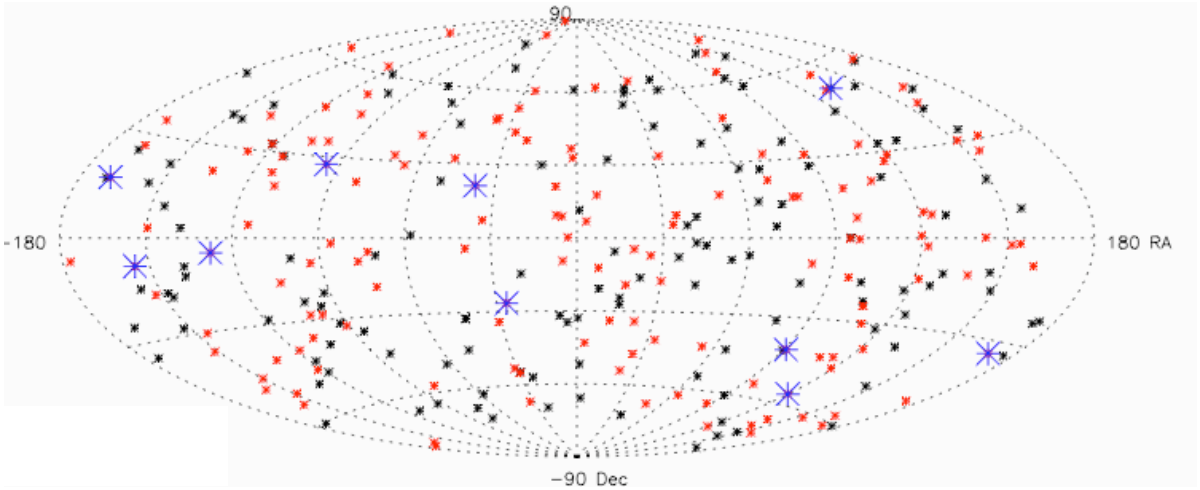


LAT - 20 MeV - >300 GeV
GBM - 10 keV - 25 MeV

Fermi GRBs

GRB 080825C	22 s		extended emission
GRB 080916C	66 s	z = 4.35	extended emission
GRB 081024B	0.8 s		
GRB 081215A	7.7 s		
GRB 090217	33 s		
GRB 090323	150 s	z = 3.57	
GRB 090328	100 s	z = 0.736	
GRB 090510	2.1 s	z = 0.903	extended emission
GRB 090626	70 s		
GRB 090902B	21 s	z=1.822	34 GeV photon
GRB 090926A	20 s	z=2.1062	
GRB 091003	21 s		

short GRBs



- GBM out of LAT FoV 120
- GBM in LAT FoV 140
- LAT 10

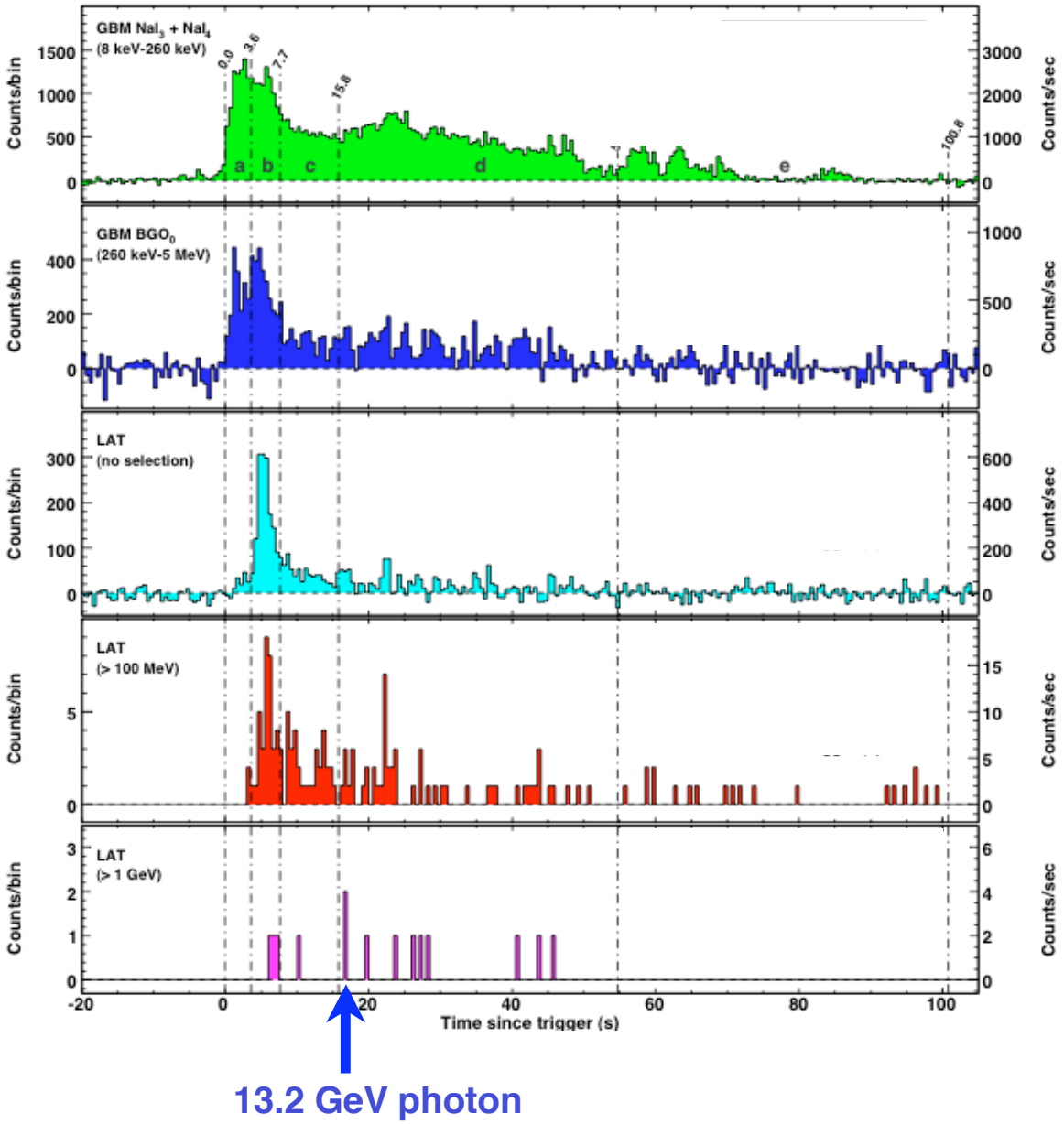
Delayed HE Emission - GRB 090816C

Long GRB

z = 4.35

Extended emission
Lag in MeV/GeV onset
Extended emission (18 min)
Lorentz factor (jet) > 860
($\gamma\gamma$ absorption argument)

Highly luminous



Abdo et al. Science 2009

Delayed HE Emission - GRB 090816C

Long GRB

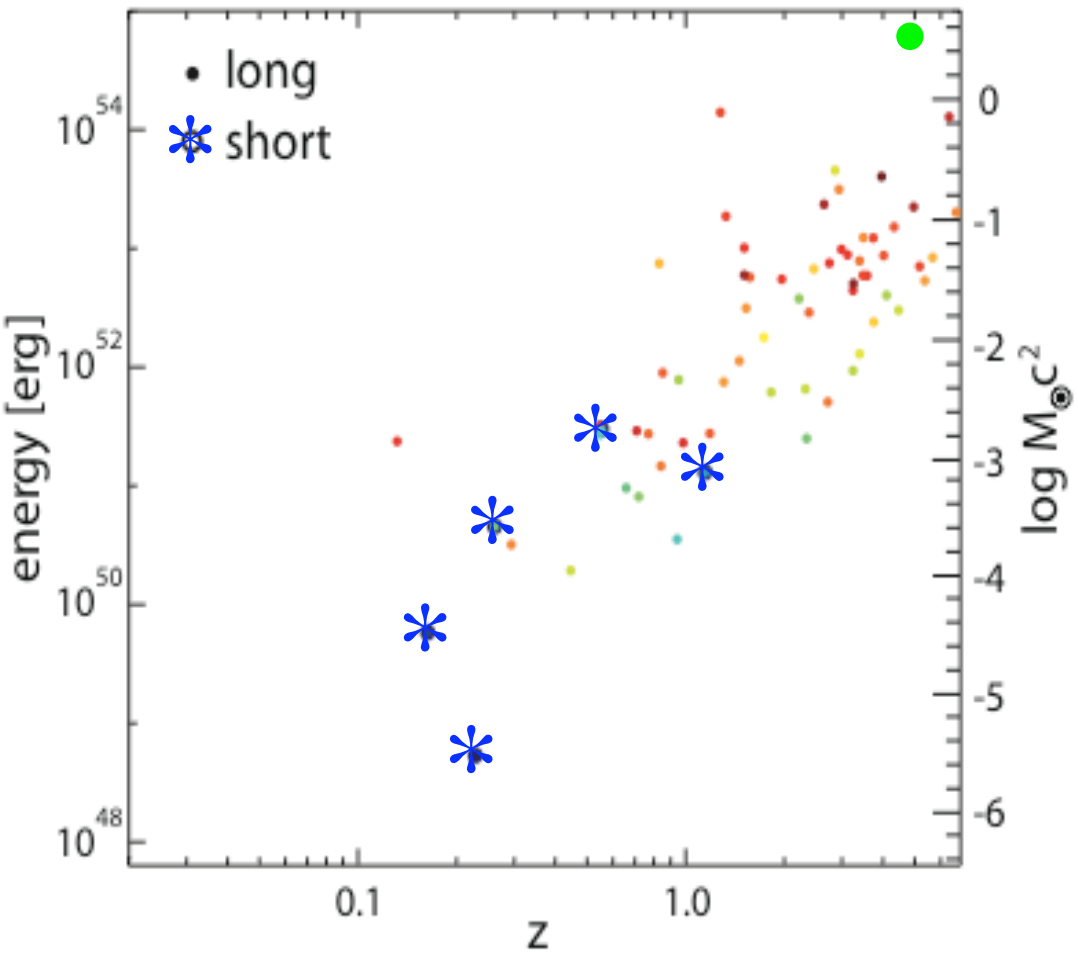
z = 4.35

Extended emissic
Lag in MeV/GeV
Extended emissic
Lorentz factor (je
($\gamma\gamma$ absorption

Highly luminous

E_{iso} vs z

GRB 080916C



LAT high E_{peak} selects high E_{iso}

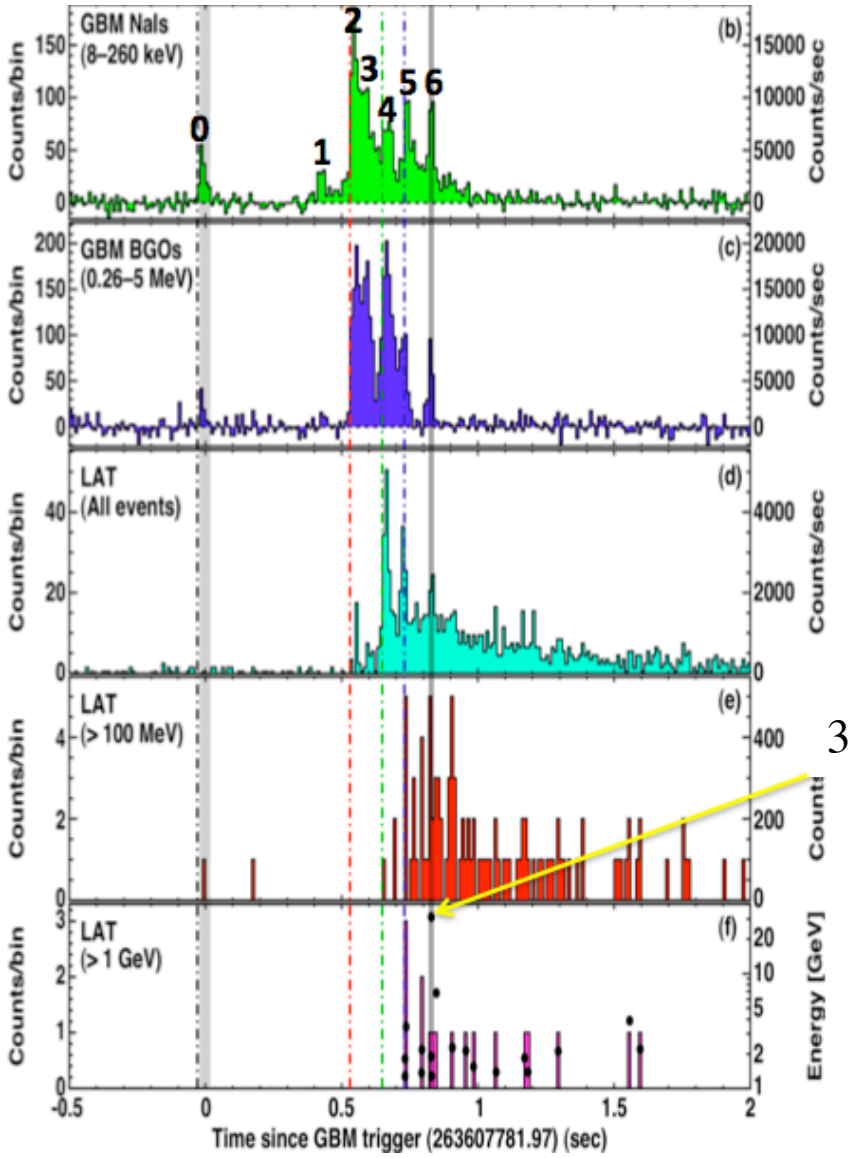
Delayed HE Emission - GRB 090510

Short GRB

z = 0.903

Extended emission
Lag in MeV/GeV onset
Extended emission
Lorentz factor (jet) > 1000
($\gamma\gamma$ absorption argument)

Lorentz invariance violation
limits - no observed dispersion



Abdo et al. Nature 2009

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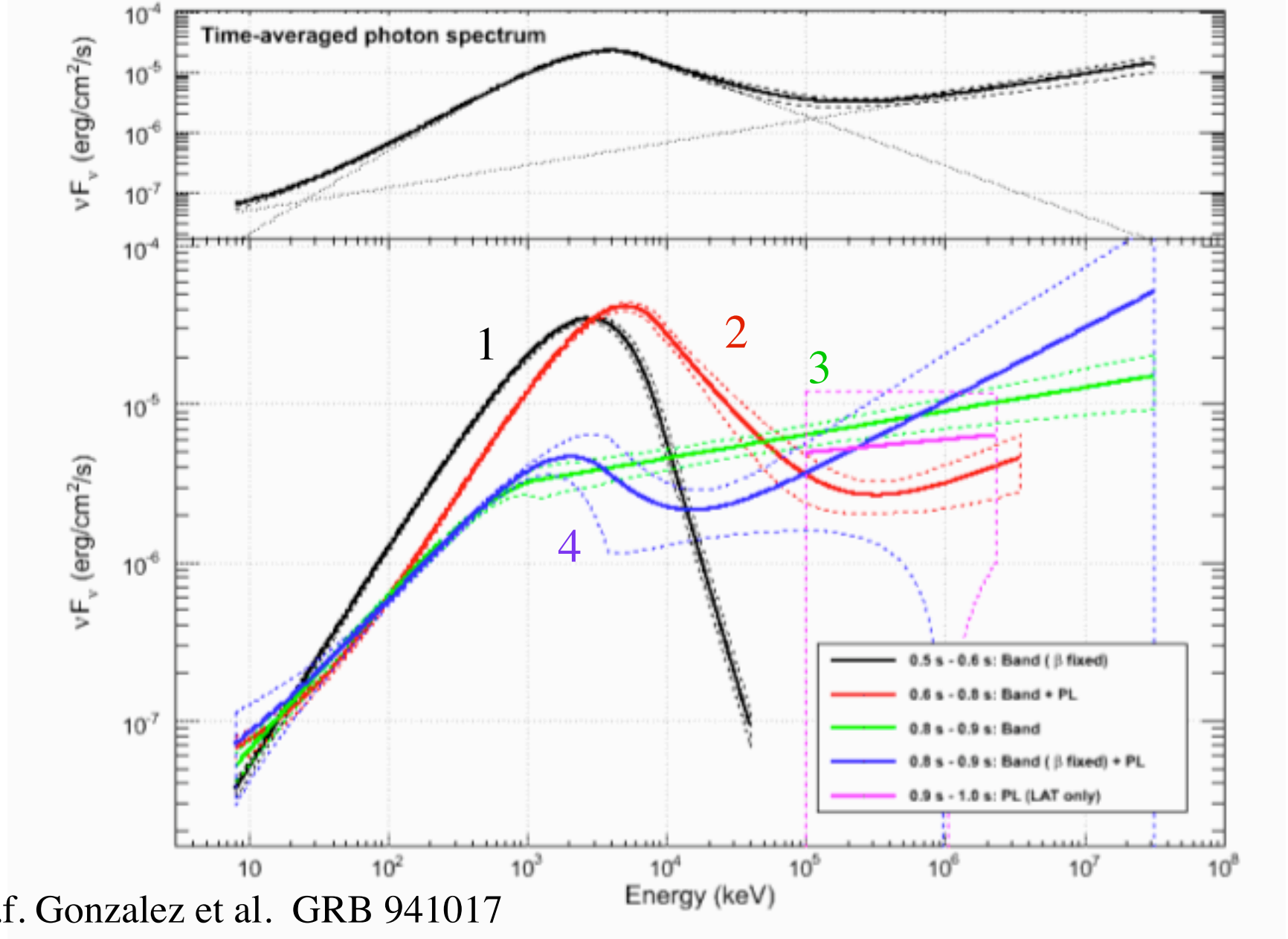
Time Resolved Spectroscopy - 090510



c.f. Gonzalez et al. GRB 941017

Conclusions

- Short and long bursts differ in duration & central engine
- Many other properties are approximately the same
- The physics in the outflow is remarkably independent of the central engine