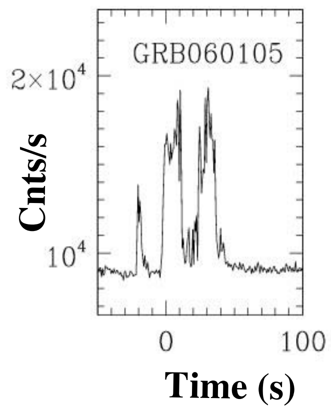
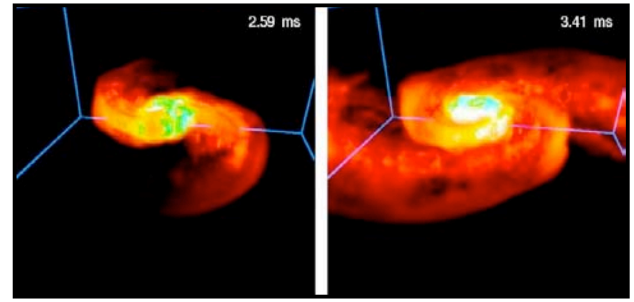


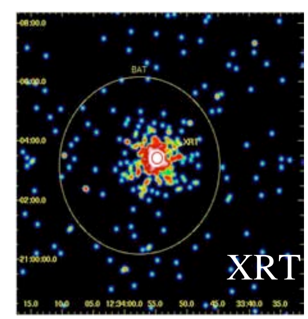


Gamma Ray Bursts
Physics and *Swift* Observations

Neil Gehrels

NASA-GSFC

February 10, 2010



Outline

→ GRB history

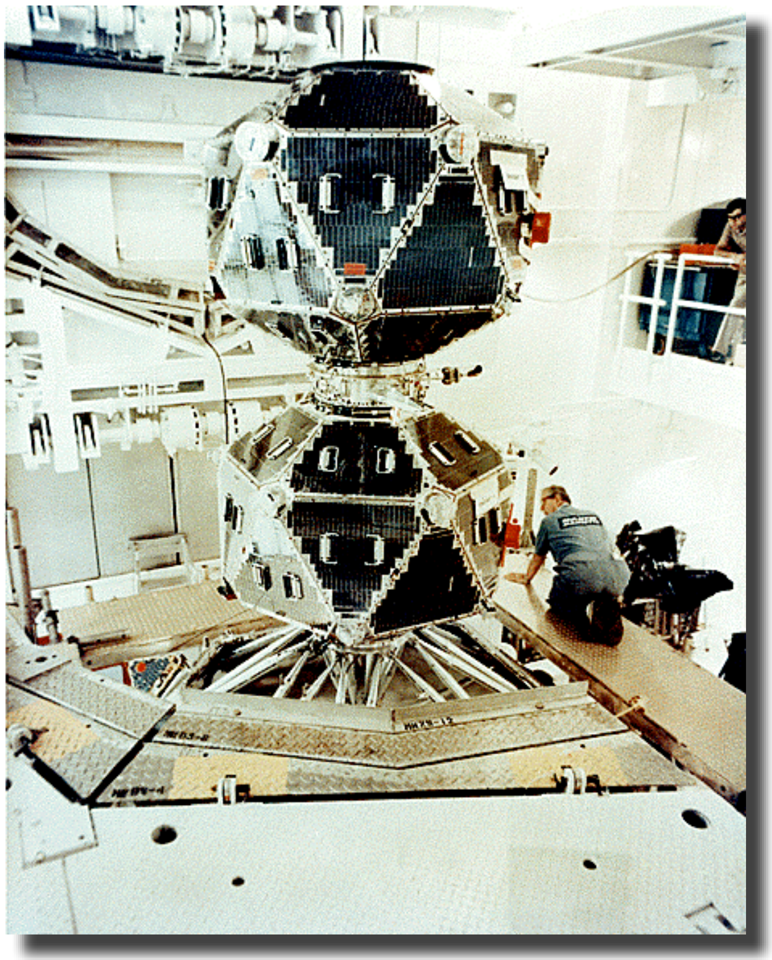
→ GRB physics

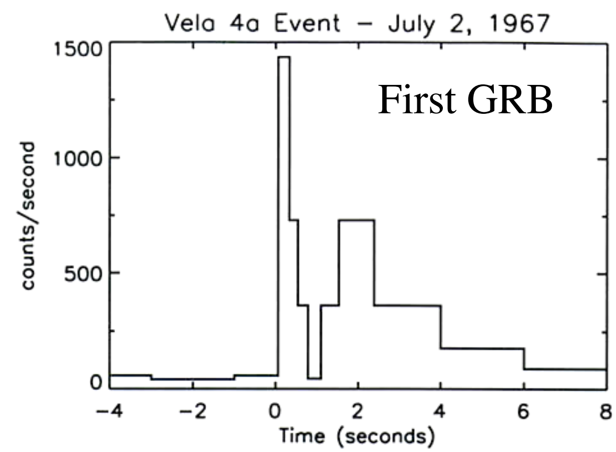
→ Swift development & launch

→ Swift findings
  - Long & short bursts
  - Host galaxies
  - Energetics

ARAA Annual Reviews 2009 Gehrels, Ramirez-Ruiz and Fox

VELA Discovers GRBs



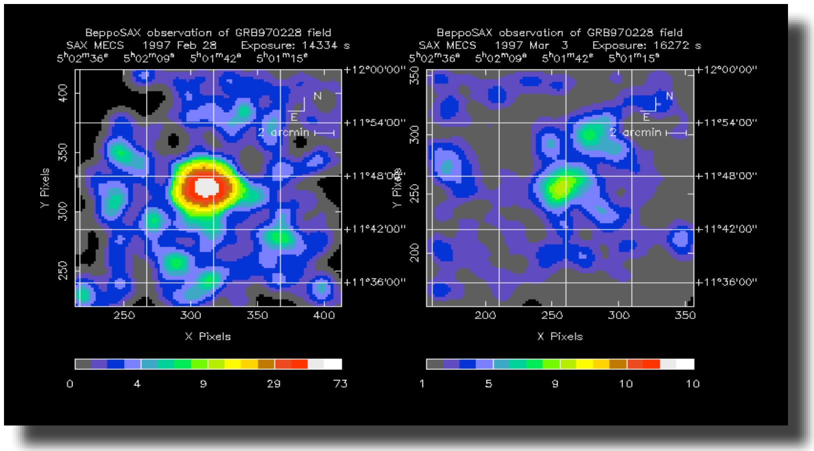


Klebesadel, Strong & Olson 1973

Ray
Klebesadel
2009

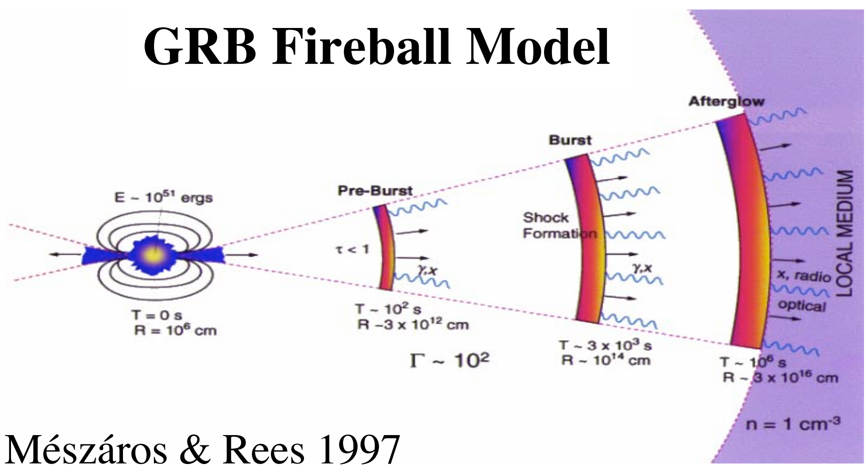
The Fireball !

X-ray afterglow discovery
GRB 970228

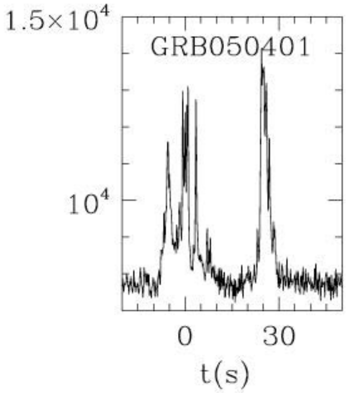


BeppoSAX 1996 - 2003

GRB Fireball Model



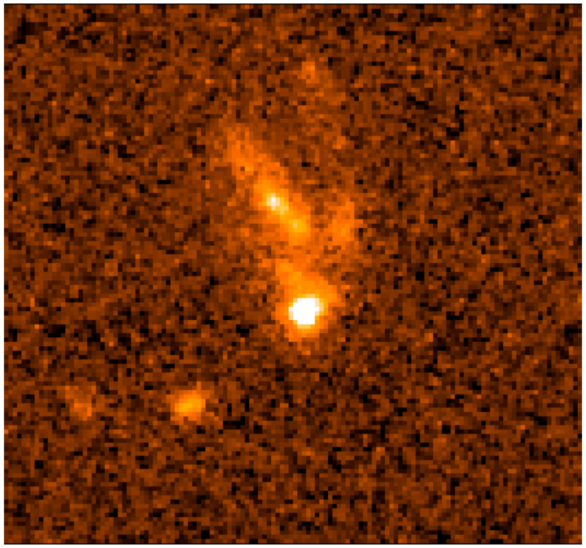
Mészáros & Rees 1997



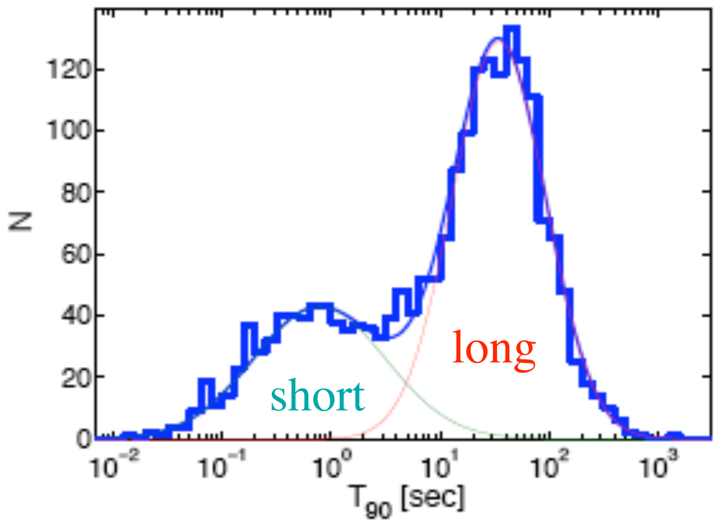
The GRB Phenomenon

Energy:	~ 10^{51} ergs in ~30s flash of γ-rays
	$\lesssim 10^{51}$ ergs in afterglow
	~ 10^{52} ergs in outflow
Distance:	$< z > = 2.3$ (*Swift* long GRBs)
	11 Gyr light travel time
Jet Outflow:	highly relativistic ($\Gamma > 500$)
	~5° beams
Variability:	msec time structure in prompt burst
Power source:	gravitational infall on new-born BHs

GRB 990123 - HST



Short vs Long GRBs



Kouveliotou et al. 1993

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

Redshift range:
0.2 - ~2 SGRBs
0.009 - 8.3 LGRBs

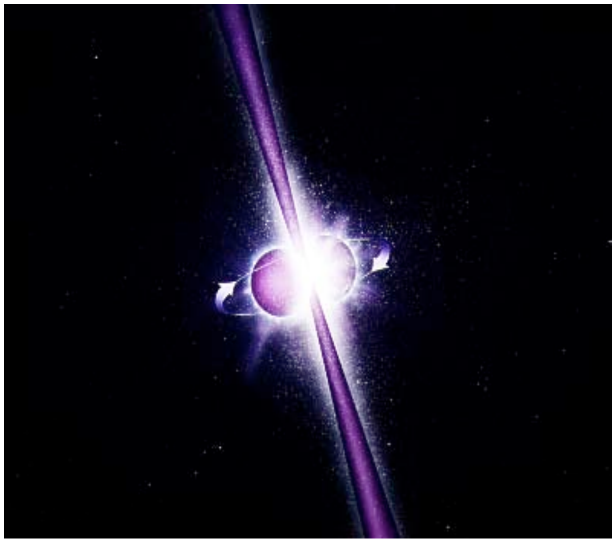
Energy release in γ-rays:
10^{49}-10^{50} ergs SGRBs
10^{50}-10^{51} ergs LGRBs

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

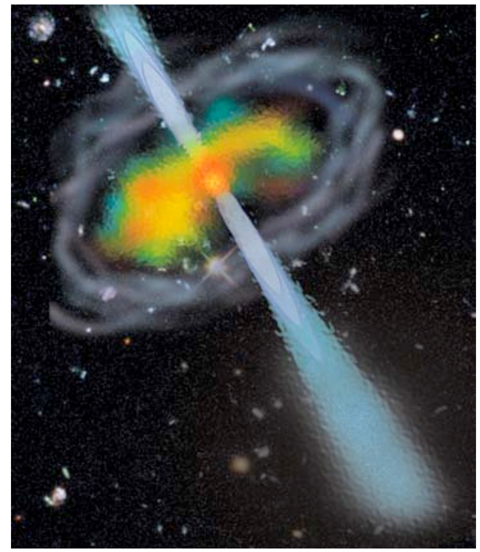
Both types have delayed & extended high-E emission

GRBs and Black Hole Birth

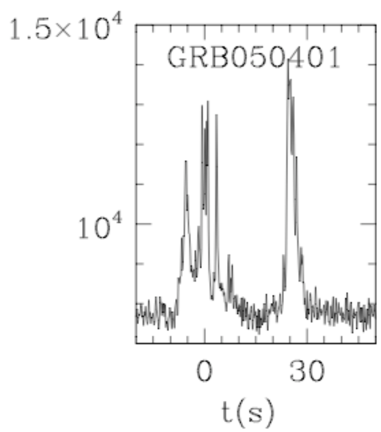
Short Bursts
Neutron Star Merger



Long Bursts
Collapsar - Massive Star Explosion



short time
structure
⇒ small size



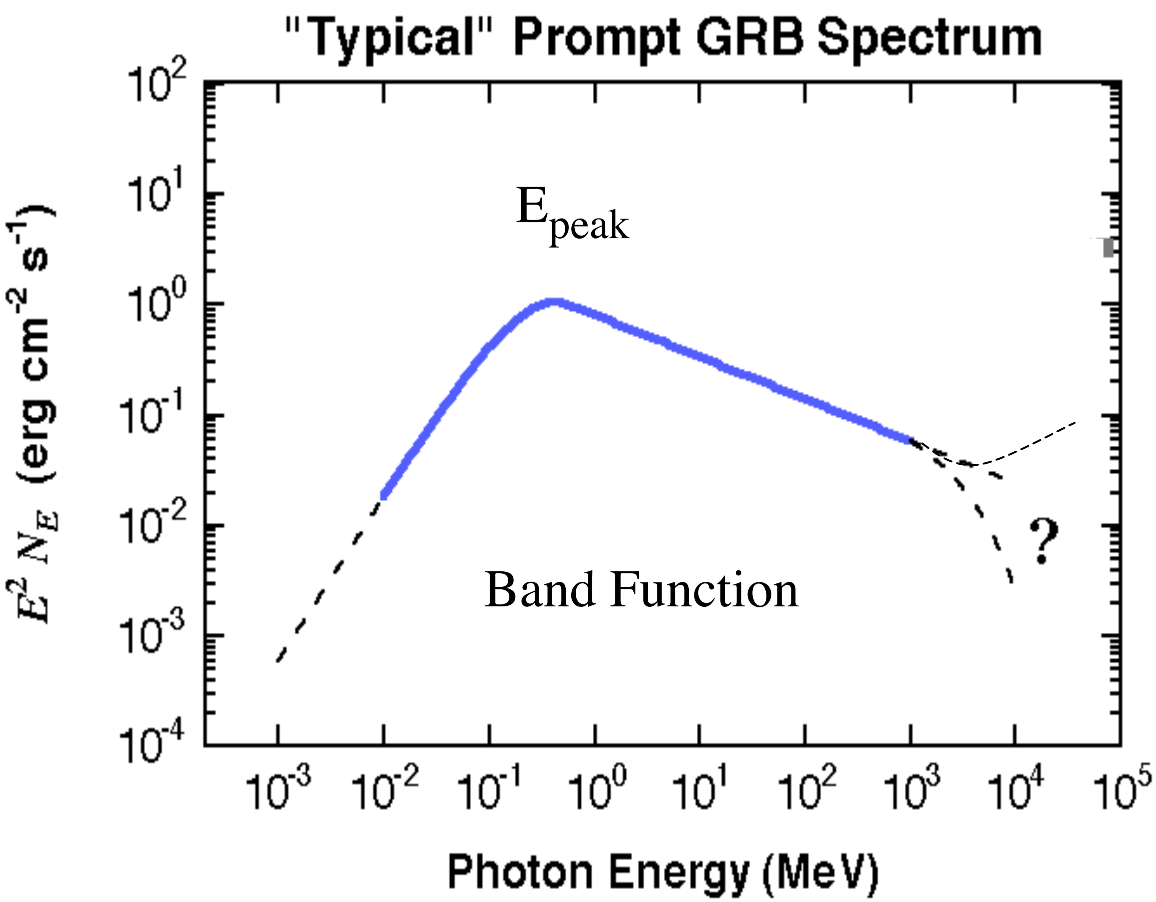
Black Hole Energetics

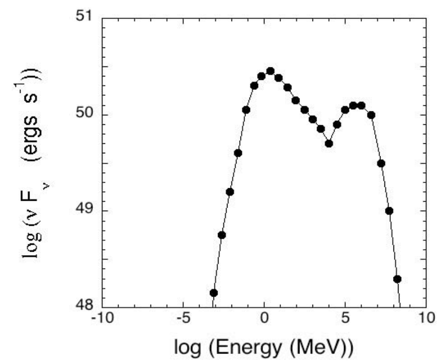
$$\textbf{Energy} = \frac{\textbf{GMm}}{\textbf{r}}$$

$$\approx \mathbf{mc^2} \qquad \textbf{for } \mathbf{r = R_{BH}} = \frac{\mathbf{2\,GM}}{\mathbf{c^2}}$$

$$= \mathbf{3x10^{54}}\ \textbf{ergs for } \mathbf{m=3M_{\odot}}$$

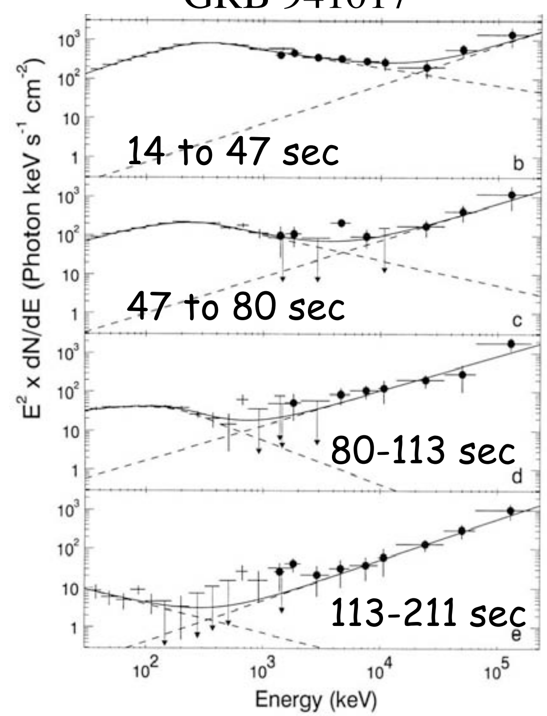
GRB Prompt Spectra





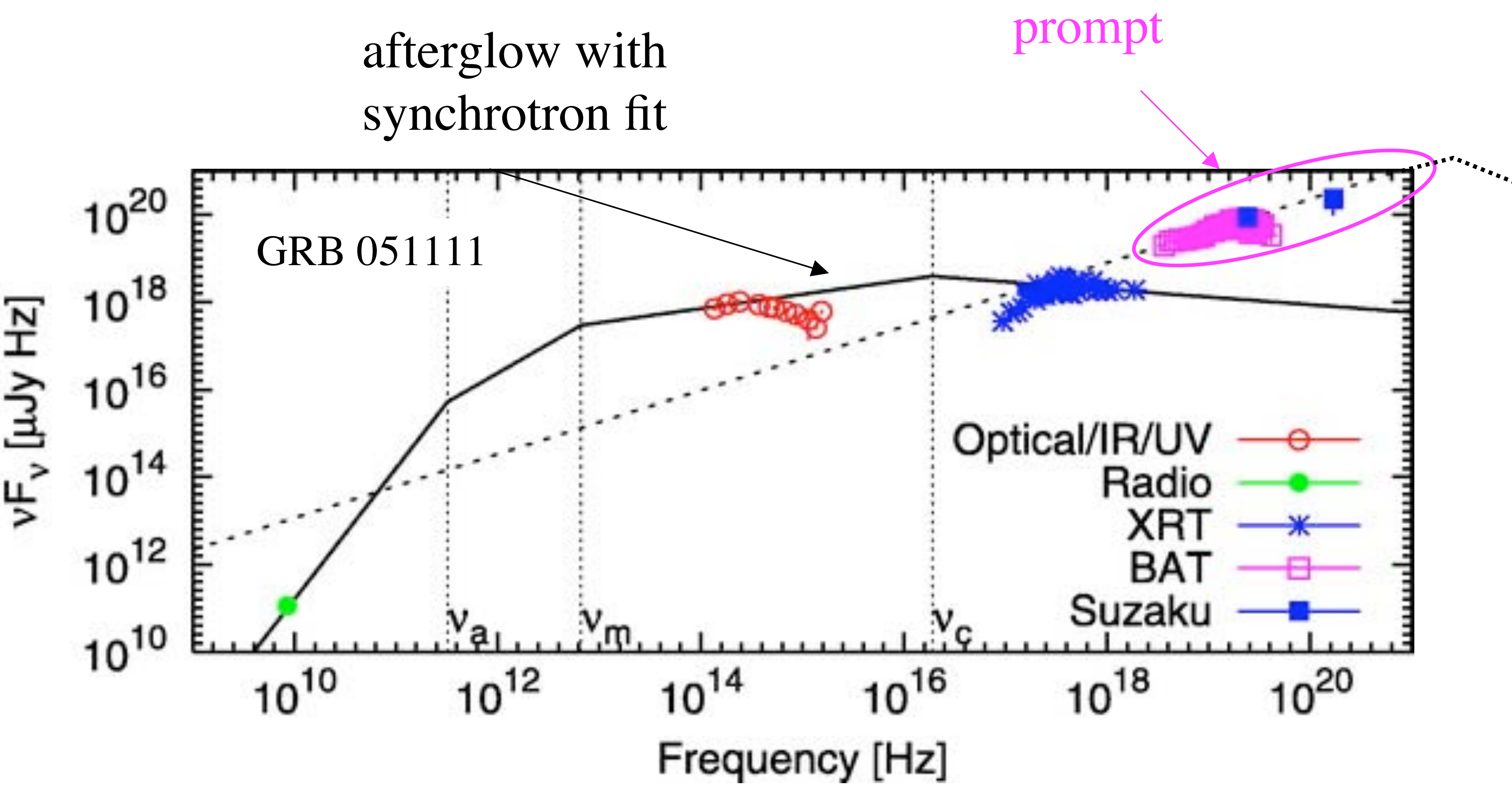
Dermer et al. 2000

GRB 941017



Gonzalez et al. 2003

GRB Afterglow Spectrum



Butler et al. 2006

Swift GRB Opportunities - 2000

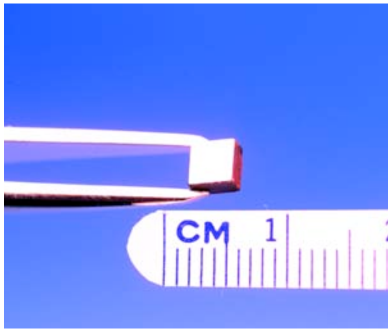
Scientific need
new capabilities

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

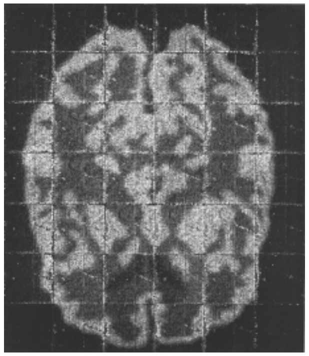
However:
* Long GRBs poorly understood
* Short GRBs not understood
* High energy emission barely sampled

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

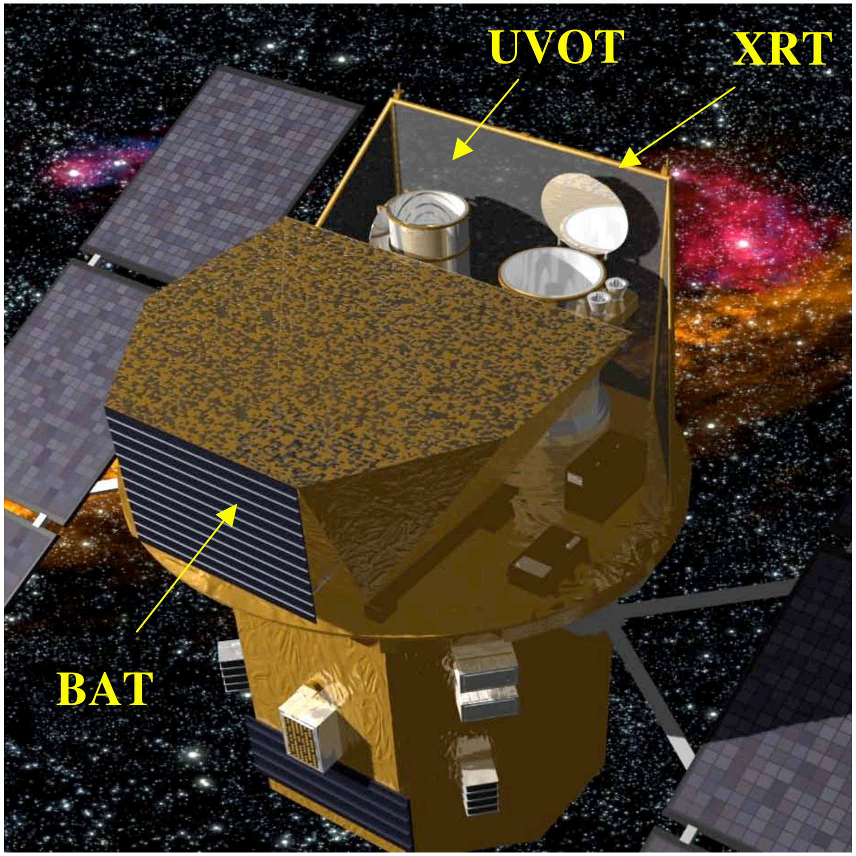
New CdZnTe detectors and
pair tracking technology



CdZnTe detector


medical imaging

Swift Mission



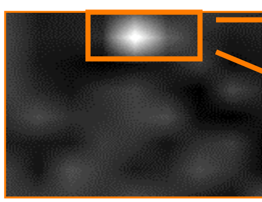
3 instruments, each with:

- lightcurves
- images
- spectra

Rapid slewing spacecraft

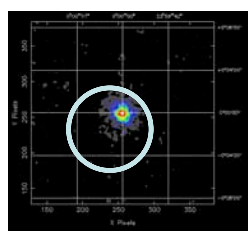
Rapid telemetry to ground

BAT Position - 2 arcmin



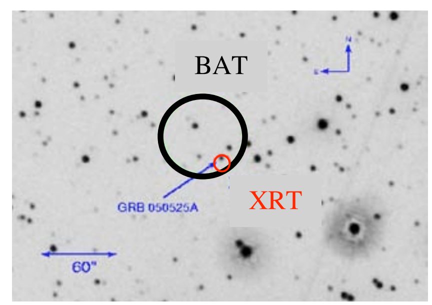
T<10 sec

XRT Position - 5 arcsec



T<90 sec

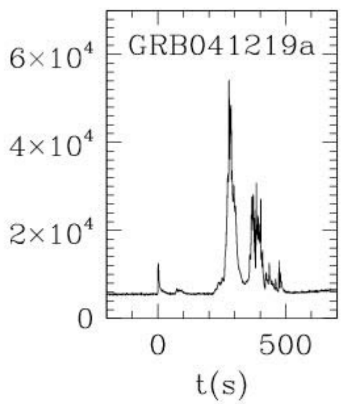
UVOT Position - < 1 arcsec

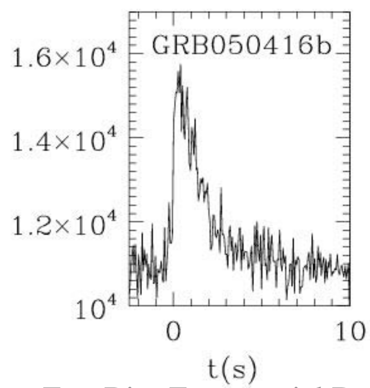


T<2 min

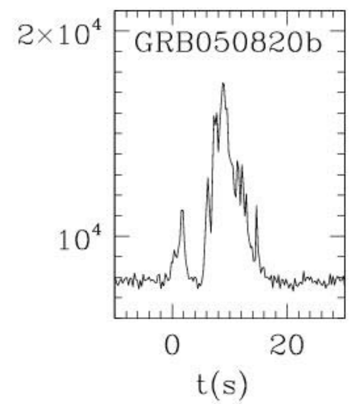
Swift Statistics

494 GRB as of this week
- 85% with X-ray detections
- ~60% with optical detection
- 158 with redshift (41 prior to Swift)
- **50 short GRBs** localized (0 prior to Swift)

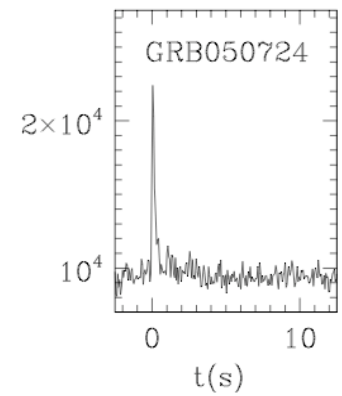


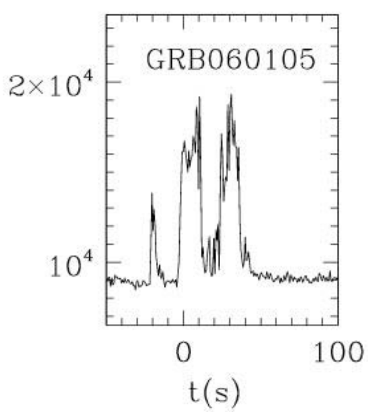


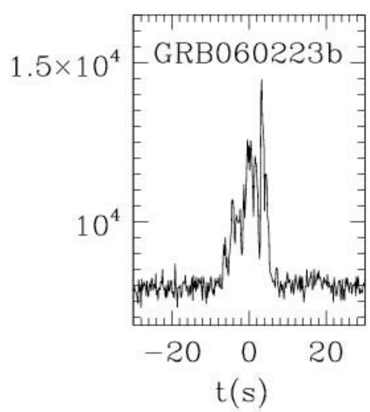
Fast Rise Exponential Decay



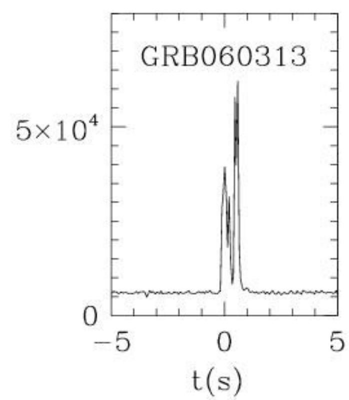
Short GRB

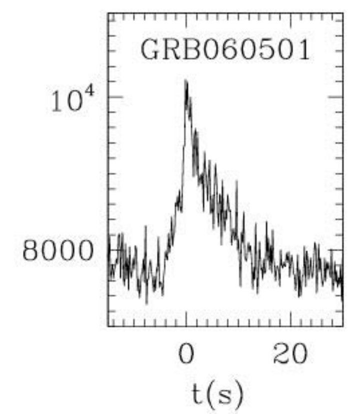






Short GRB

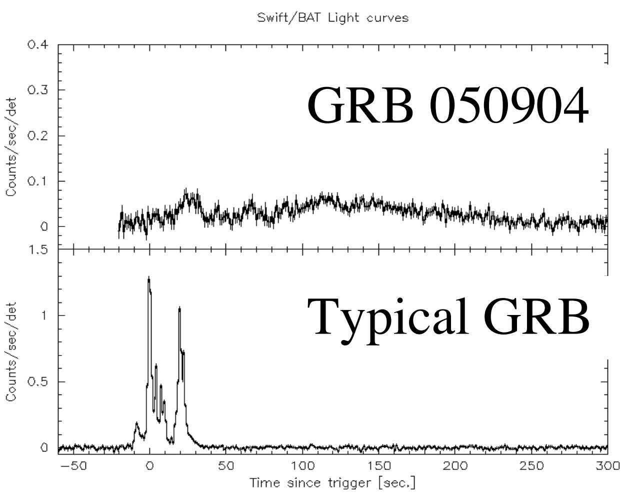


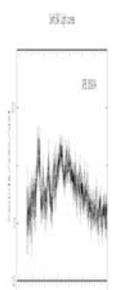


"The Year of High-z GRBs"

GRBs: brightest high redshift sources

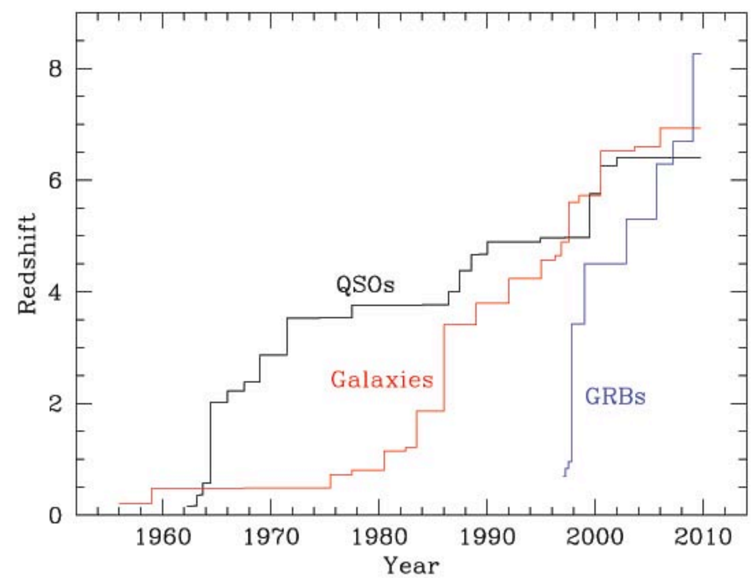
z	Time (10^9 years)	GRB	Optical Brightness
8.3	13.0	090423	K = 20 @ 20 min
6.7	12.8	080813	K = 19 @ 10 min
6.29	12.8	050904	J = 18 @ 3 hrs
5.6	12.6	060927	I = 16 @ 2 min
5.3	12.6	050814	K = 18 @ 23 hrs
5.11	12.5	060522	R = 21 @ 1.5 hrs





GRB 050904
undilated by z+1

Cusumano et al. 2005

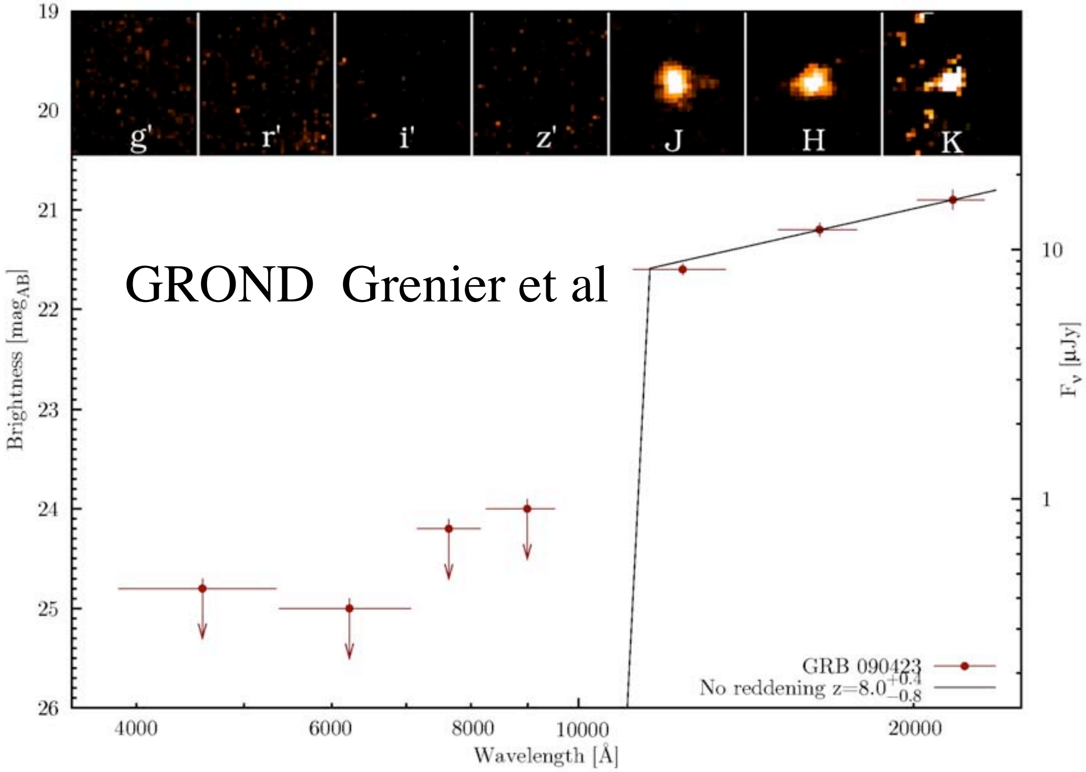


McMahon & Tanvir

Blast from the past!
GRB 090423

z = 8.29 look back time = 13.0 billion light years

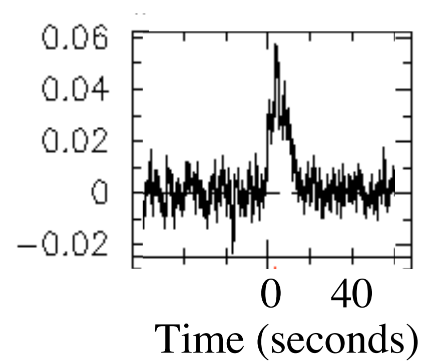
Lyman break redshifted from UV to IR



Tanvir et al. 2009; Salvaterra et al.

Duration = 10.3 s
= 1.2 s in source frame

γ-ray Lightcurve



GRB Host Spectroscopy

$z = 4.275$ (12.2 G yrs)

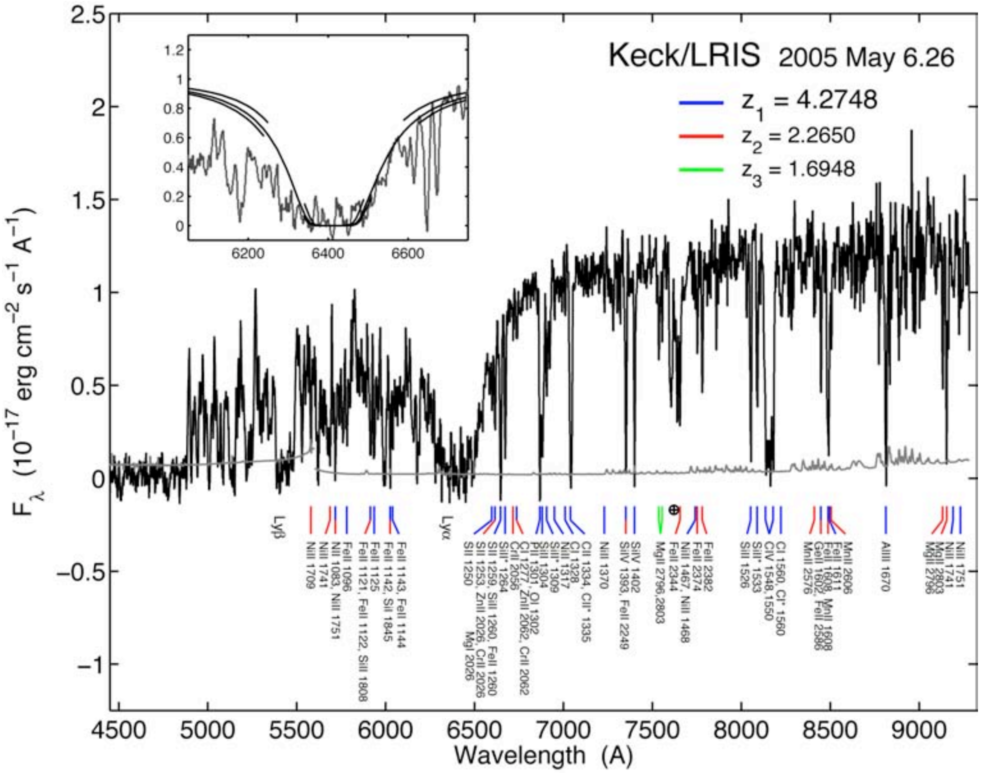
Damped Lyα

density ~ 10^2 cm^{-3}

metallicity = 0.06 Z_O

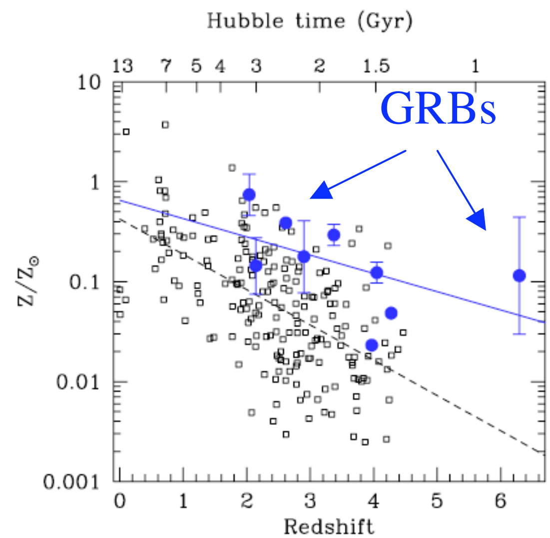
$M_{progenitor} < 25\ M_O$

GRB 050505



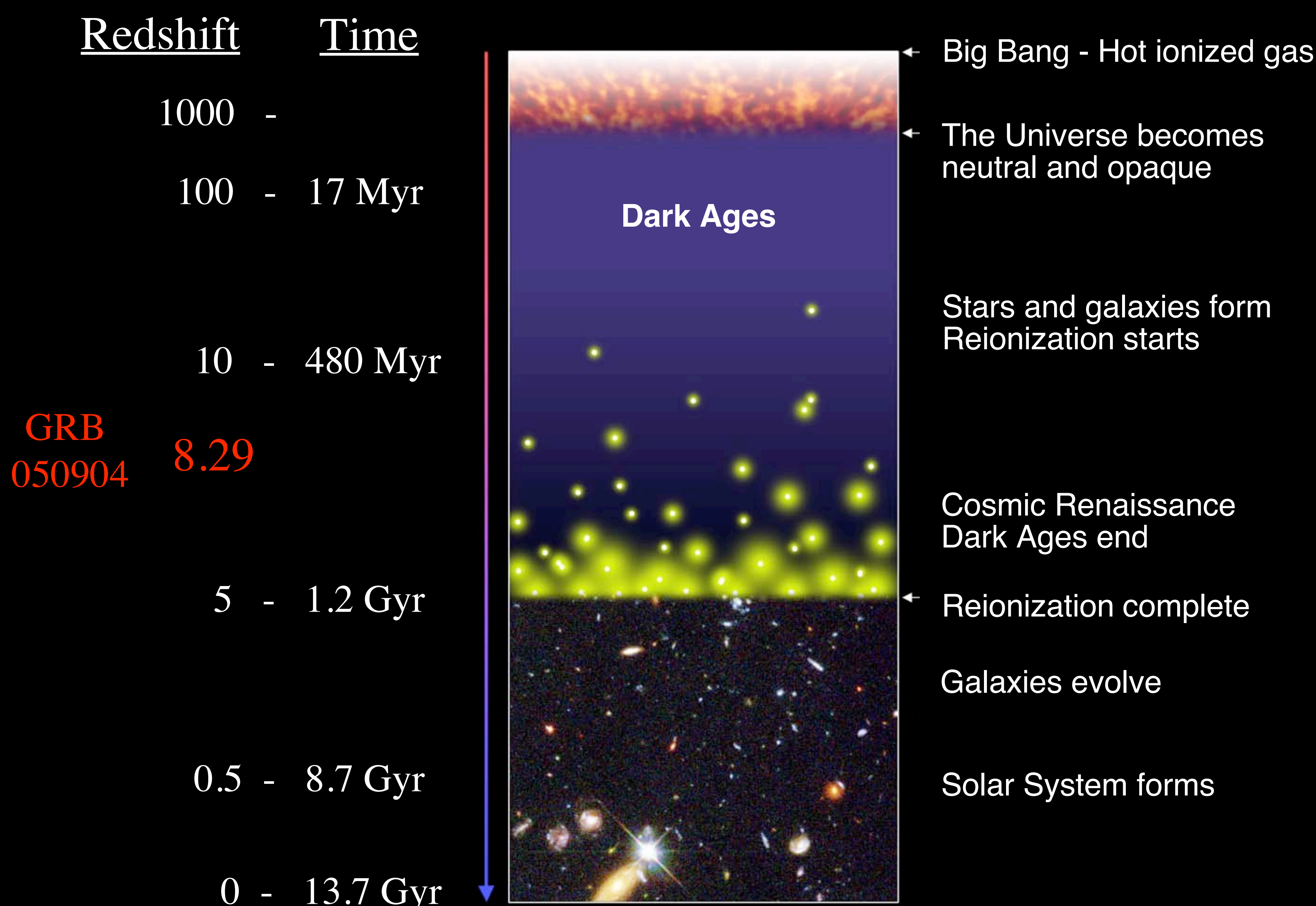
Berger et al. 2005

Metallicity vs Redshift



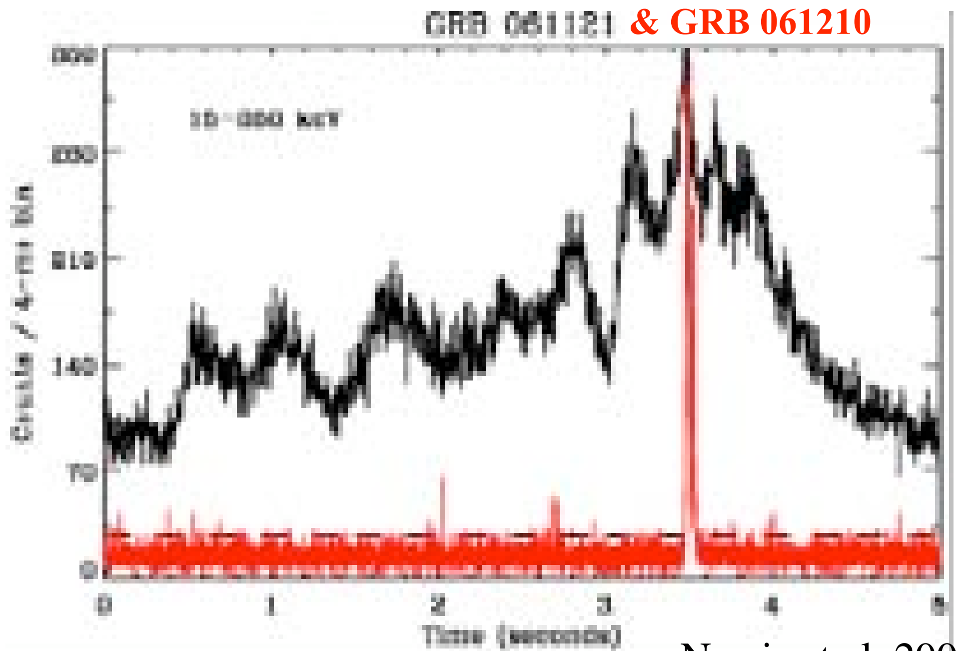
Savaglio 2006

History of the Universe



Djorgovski et al.

Short vs Long GRBs

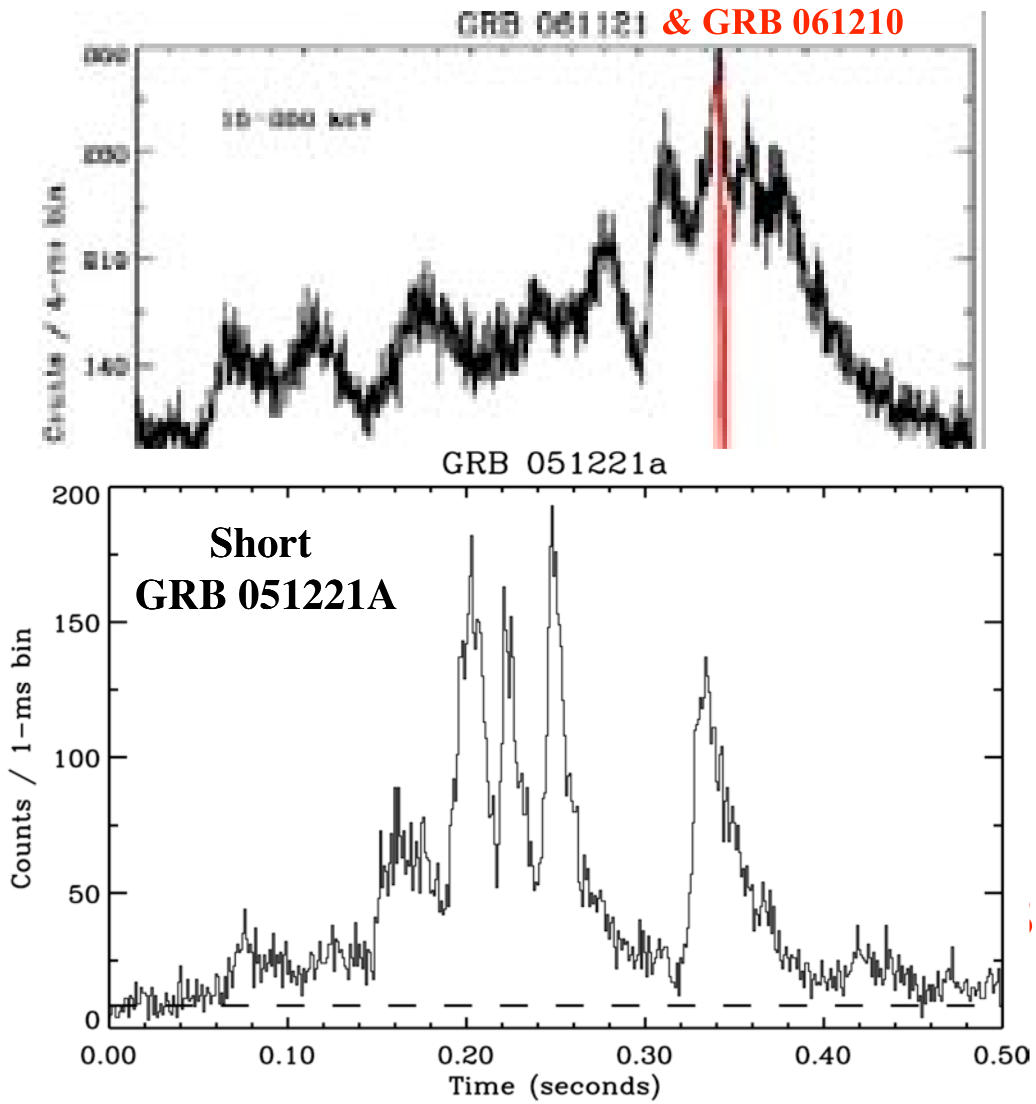


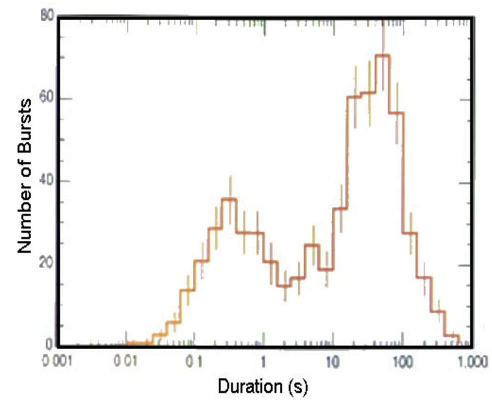
Norris et al. 2006

GRB 061121 = brightest long GRB

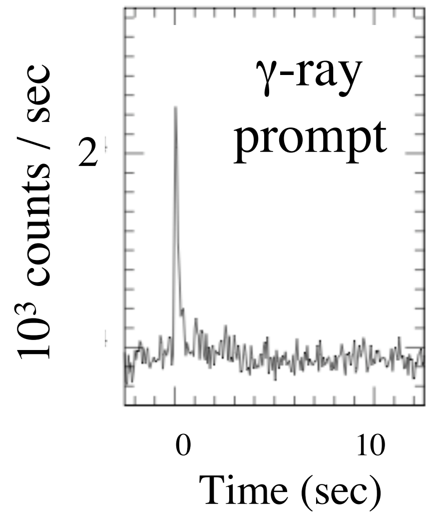
GRB 061210 = brightest short GRB

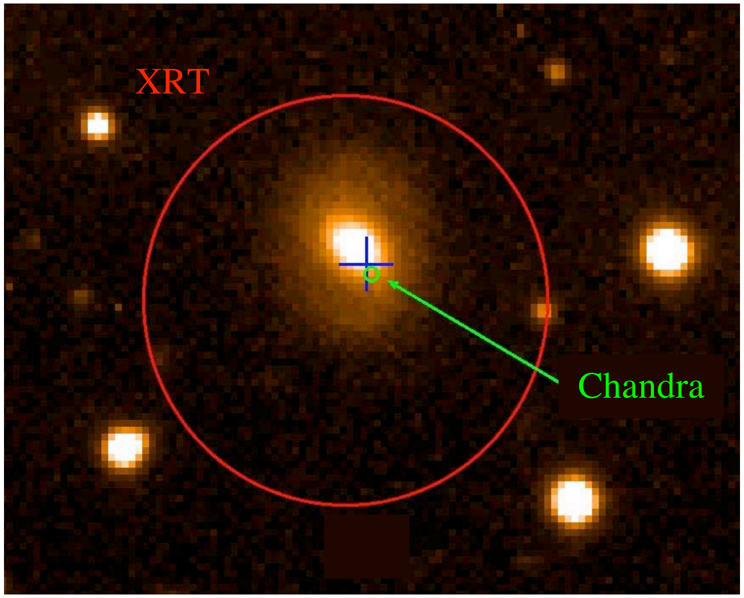
Short vs Long GRBs

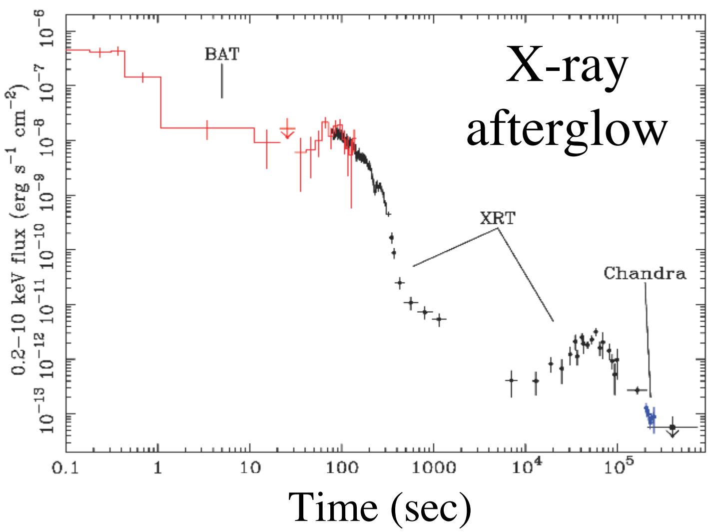




Short GRB 050724







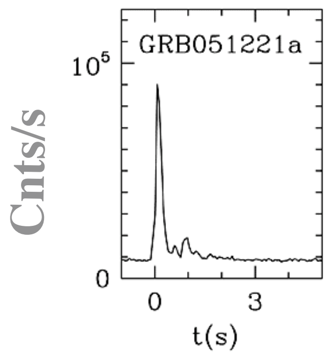
Host:

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

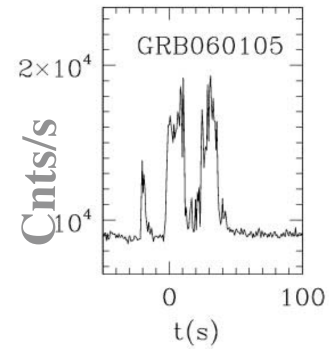
Barthelmy et al. 2005

Short vs Long GRBs

Short GRB

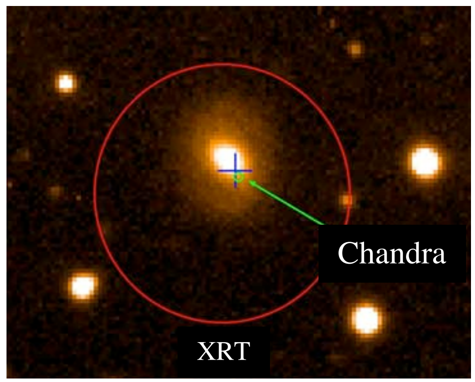


Long GRB

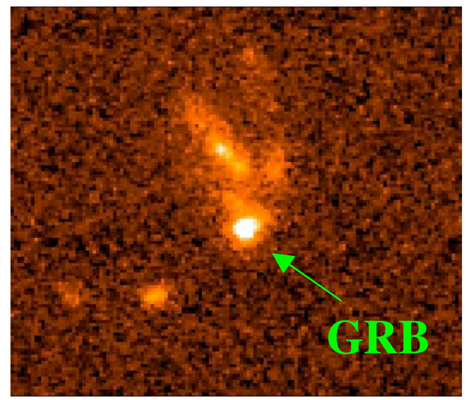


GRB 090916

GRB 050724 - *Swift*
elliptical host



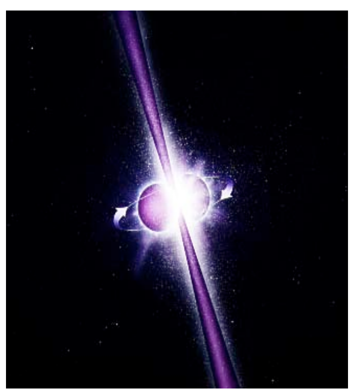
GRB 990123 - *SAX*
SF dwarf host

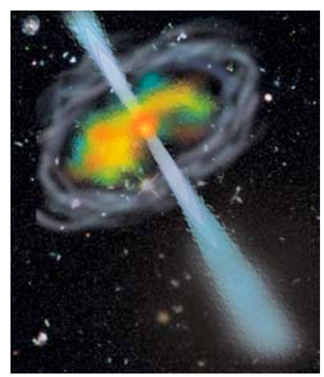


In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model





BH

In SF
galaxies

Accompanied by SNe

Collapsar model
well supported

Short vs Long GRBs

50 short GRBs detected by Swift/BAT

Lower Redshifts

$< z > = 0.4$ short

$< z > = 2.3$ long

Weaker Afterglows

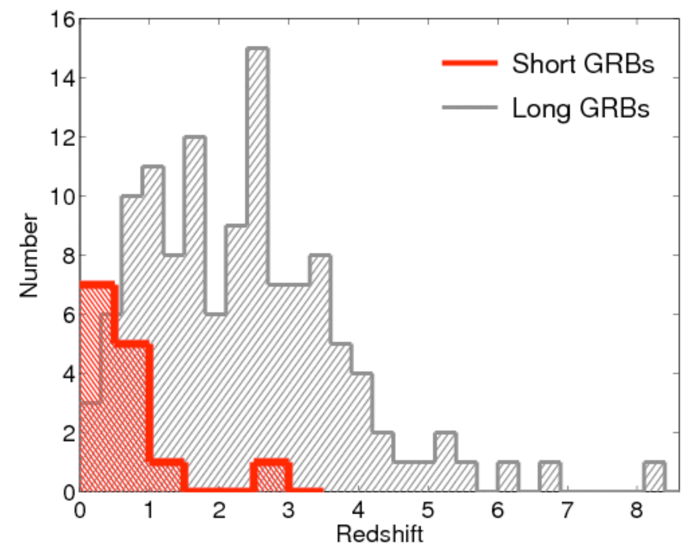
$< F_X > = 7x10^{-10}$ erg cm^{-2} s^{-1} short

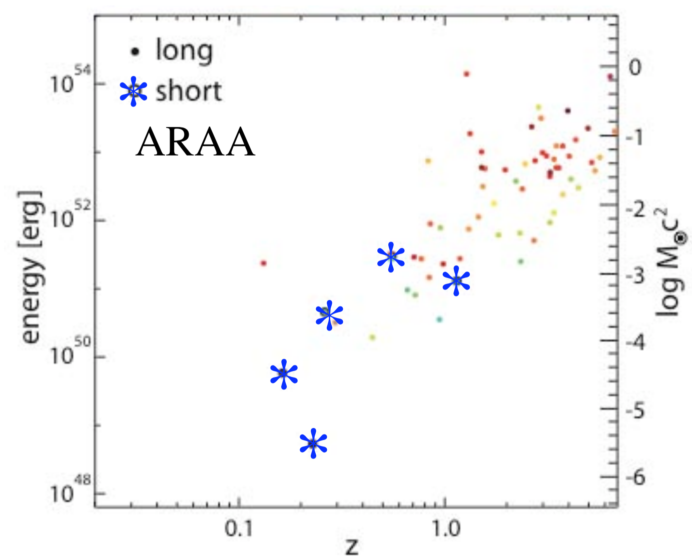
$< F_X > = 3x10^{-9}$ erg cm^{-2} s^{-1} long

Lower Energy release

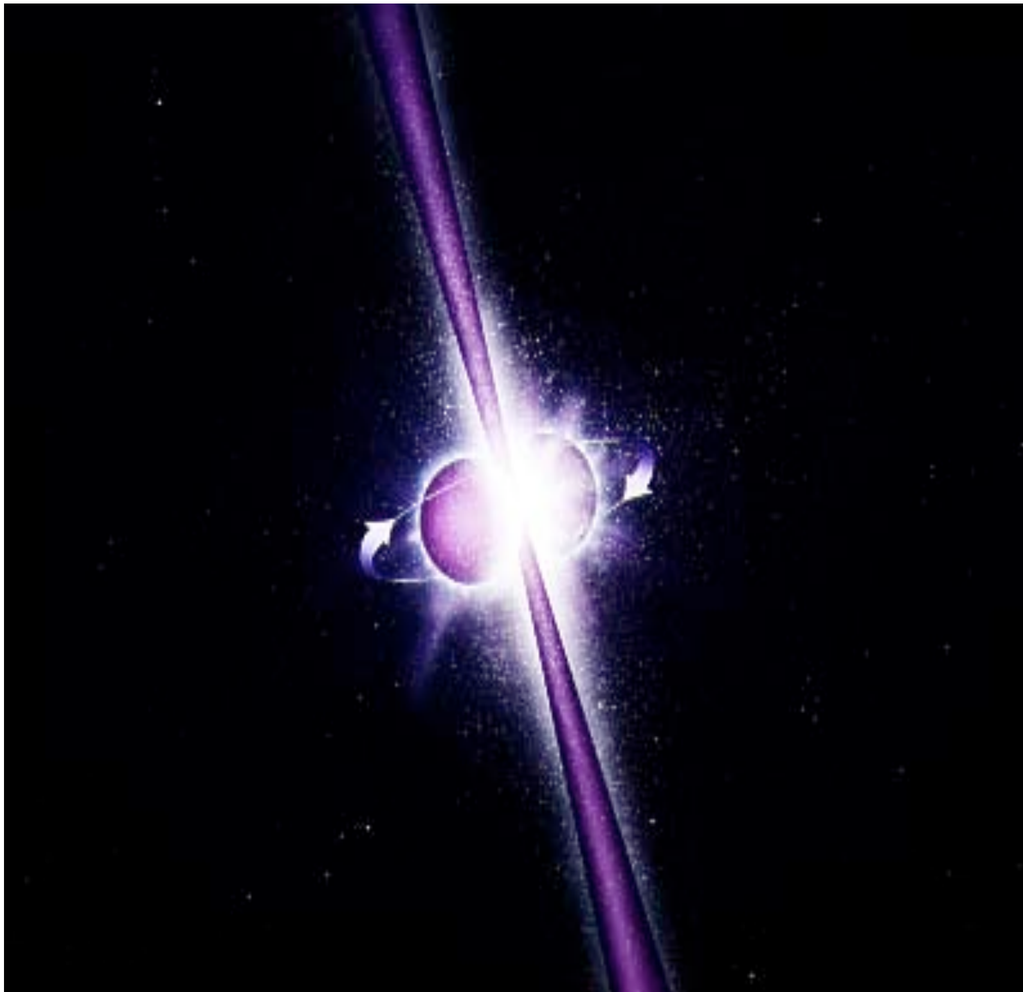
$E_{iso} \sim 10^{50}$ $E_\gamma \sim 10^{49}$ short

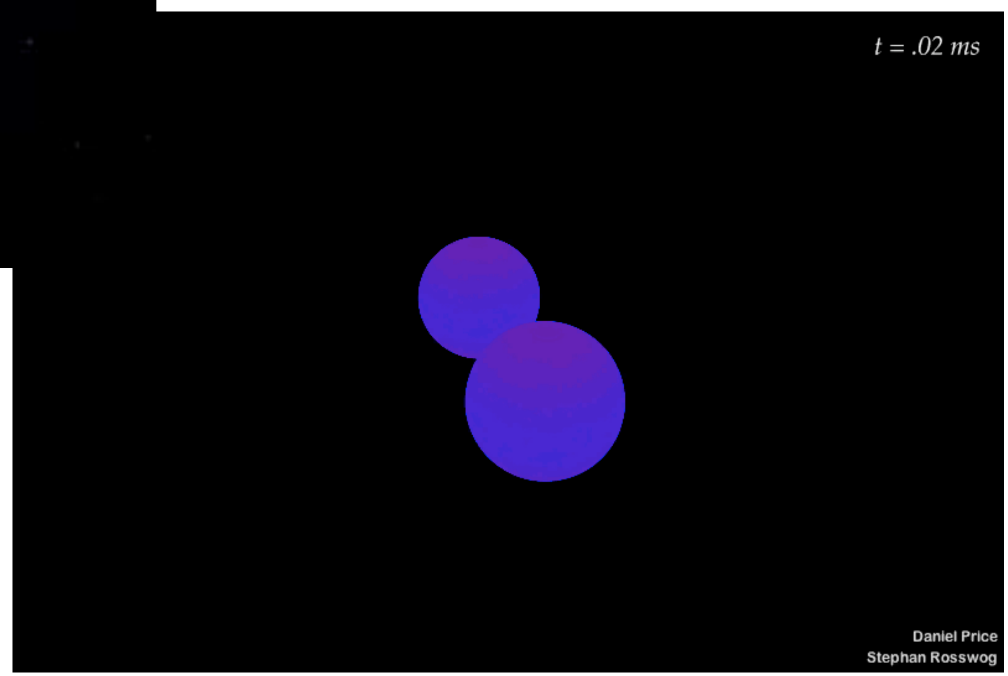
$E_{iso} \sim 10^{53}$ $E_\gamma \sim 10^{51}$ long





Short GRBs Merger Model





Credit: Daniel Price and Stephan Rosswog

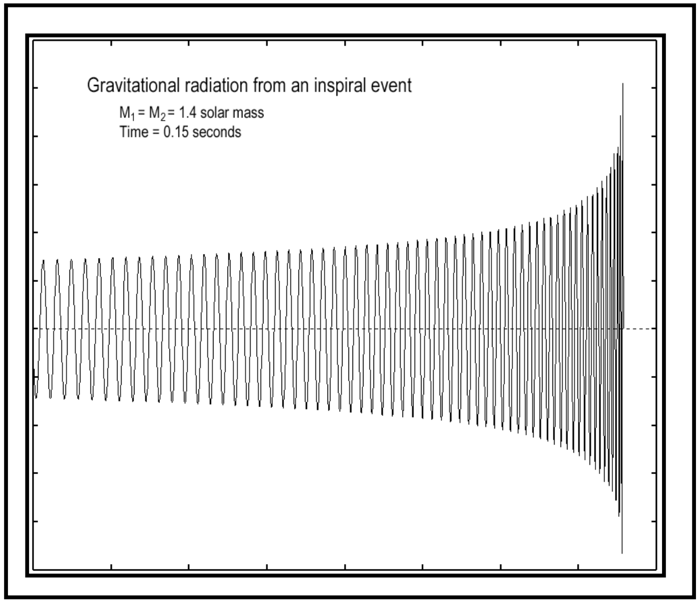
Implications for GW Detections

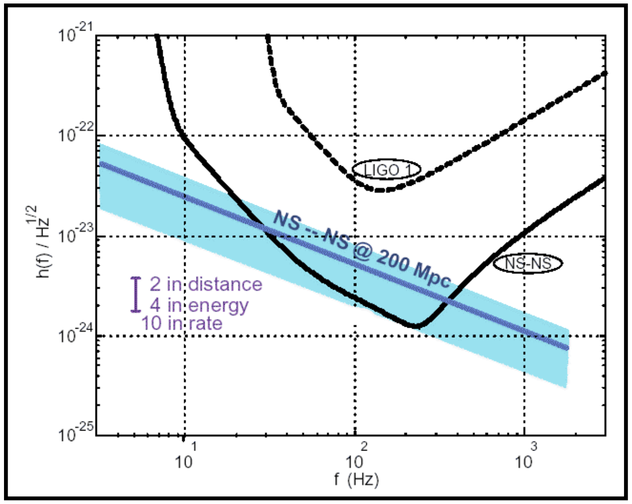
If all short GRBs due to NS-NS mergers
$\Rightarrow$ NS-NS merger rate is >300 Gpc^{-3} yr^{-1}

[Consistent with NS-NS population synthesis modeling O'Shaughnessy et al. (2005)]

For aLIGO NS-NS merger sensitivity distance is 170 - 300 Mpc:

aLIGO detection rate is 6 - 30 yr^{-1}





(K. Thorne)

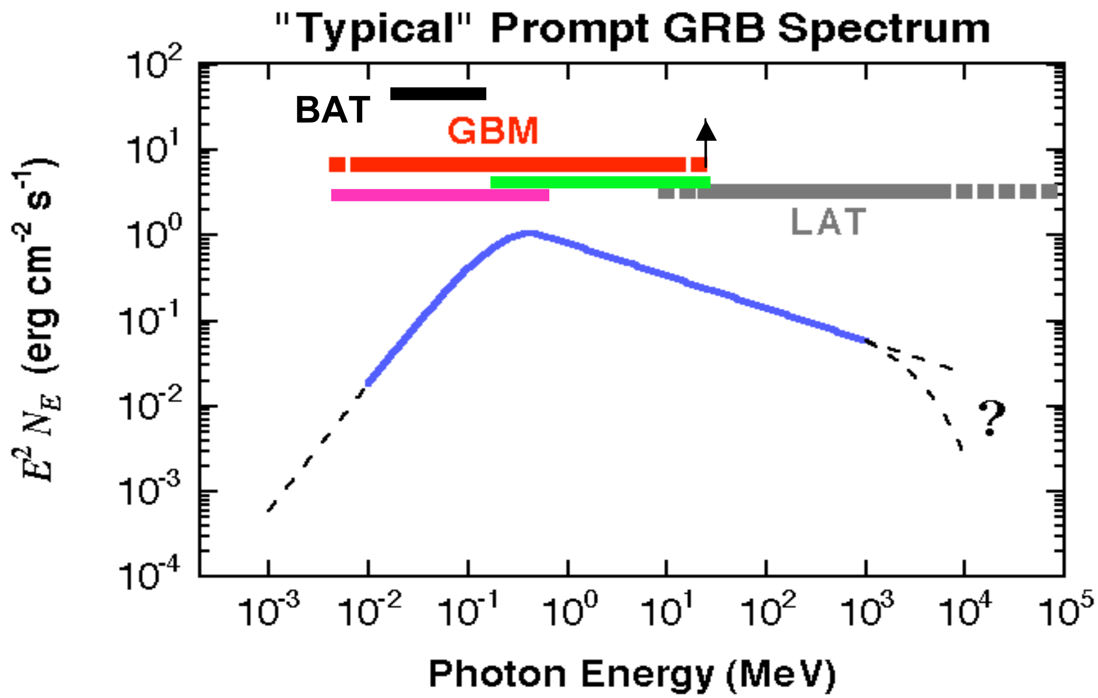
aLIGO on line in ~2014

Swift will be in orbit until > 2020

Joint Swift-Fermi GRB Observations

Several joint science areas:

- ~50% of BAT bursts are observed by GBM giving high energy coverage
- ~10% of LAT bursts are detected by BAT giving **rapid** follow-up
- ~80% of LAT bursts have XRT and UVOT follow-up giving hosts and redshifts

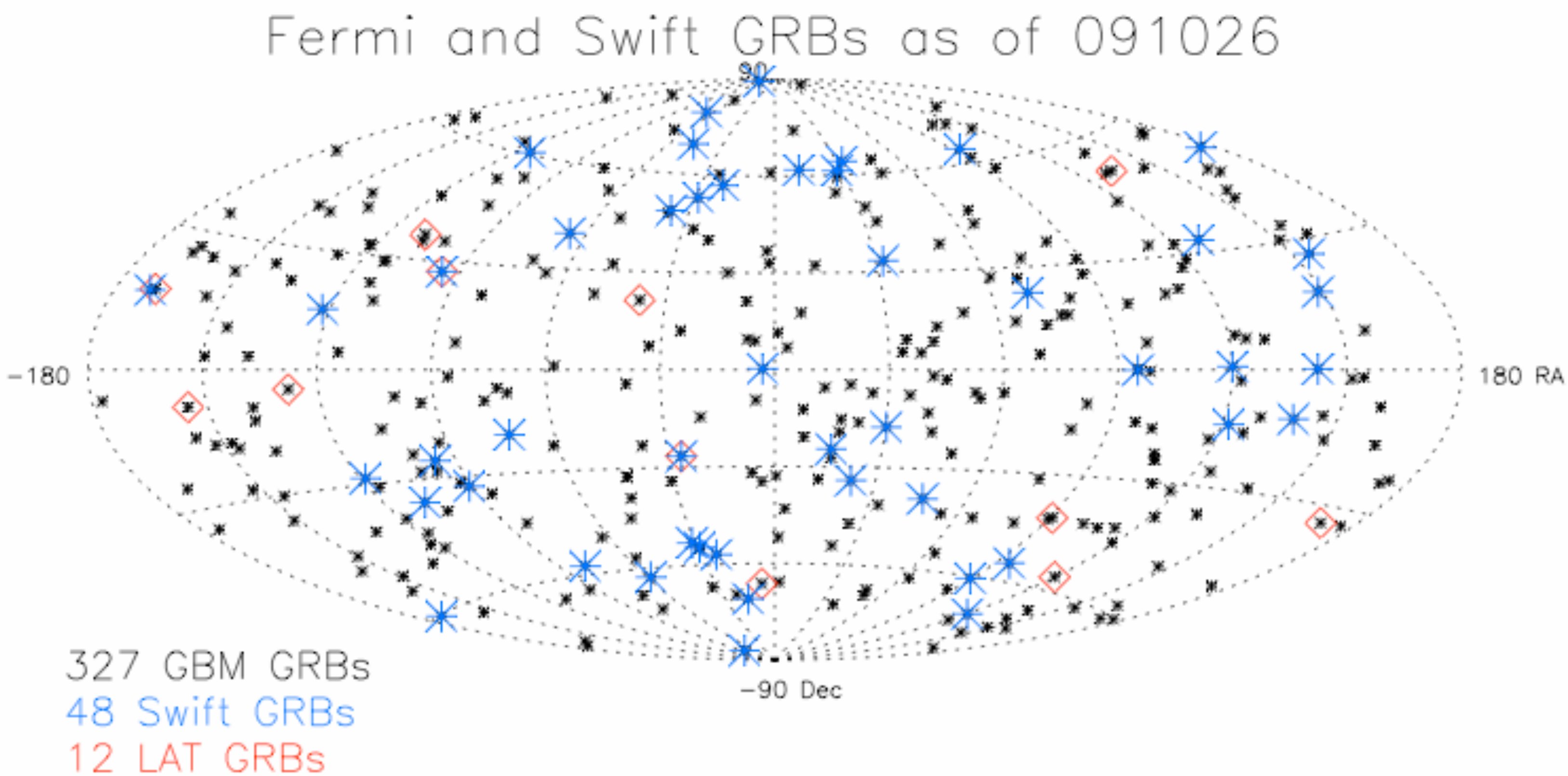


BAT field of view = 2 sr

GRB field of view = 8 sr

LAT field of view = 2.4 sr

GRBs Detected by BAT and GBM

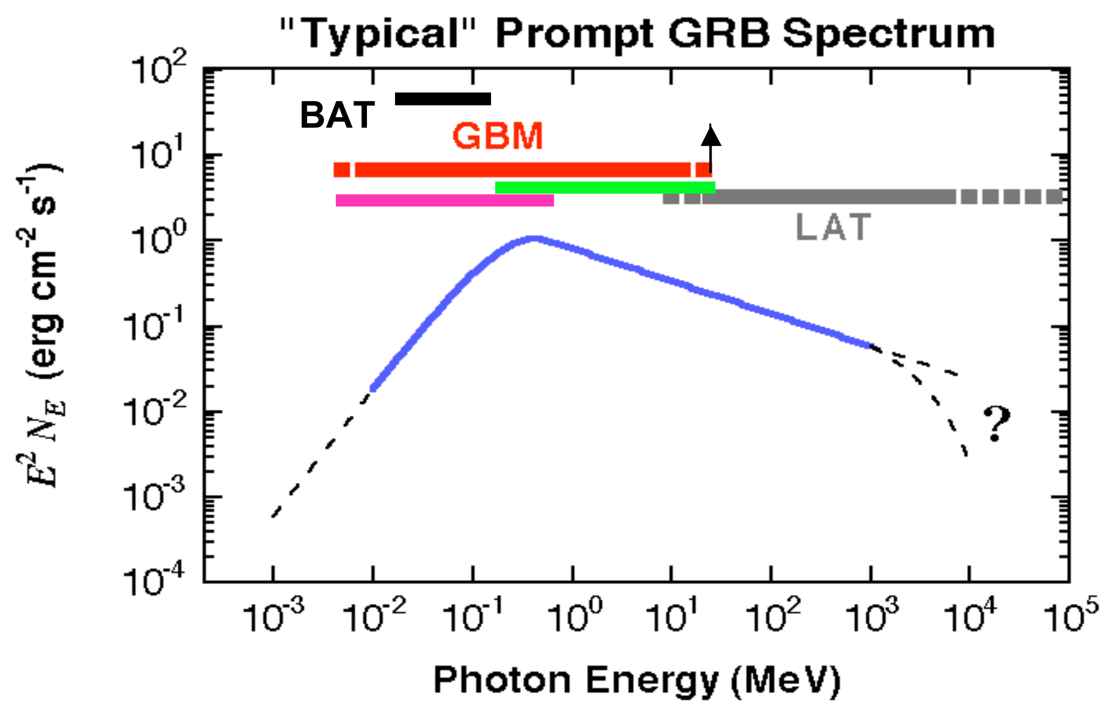


Connaughton

Joint Swift-Fermi GRB Observations

Several joint science areas:

- ~50% of BAT bursts are observed by GBM giving high energy coverage
- ~10% of LAT bursts are detected by BAT giving **rapid** follow-up
- ~80% of LAT bursts have XRT and UVOT follow-up giving hosts and redshifts

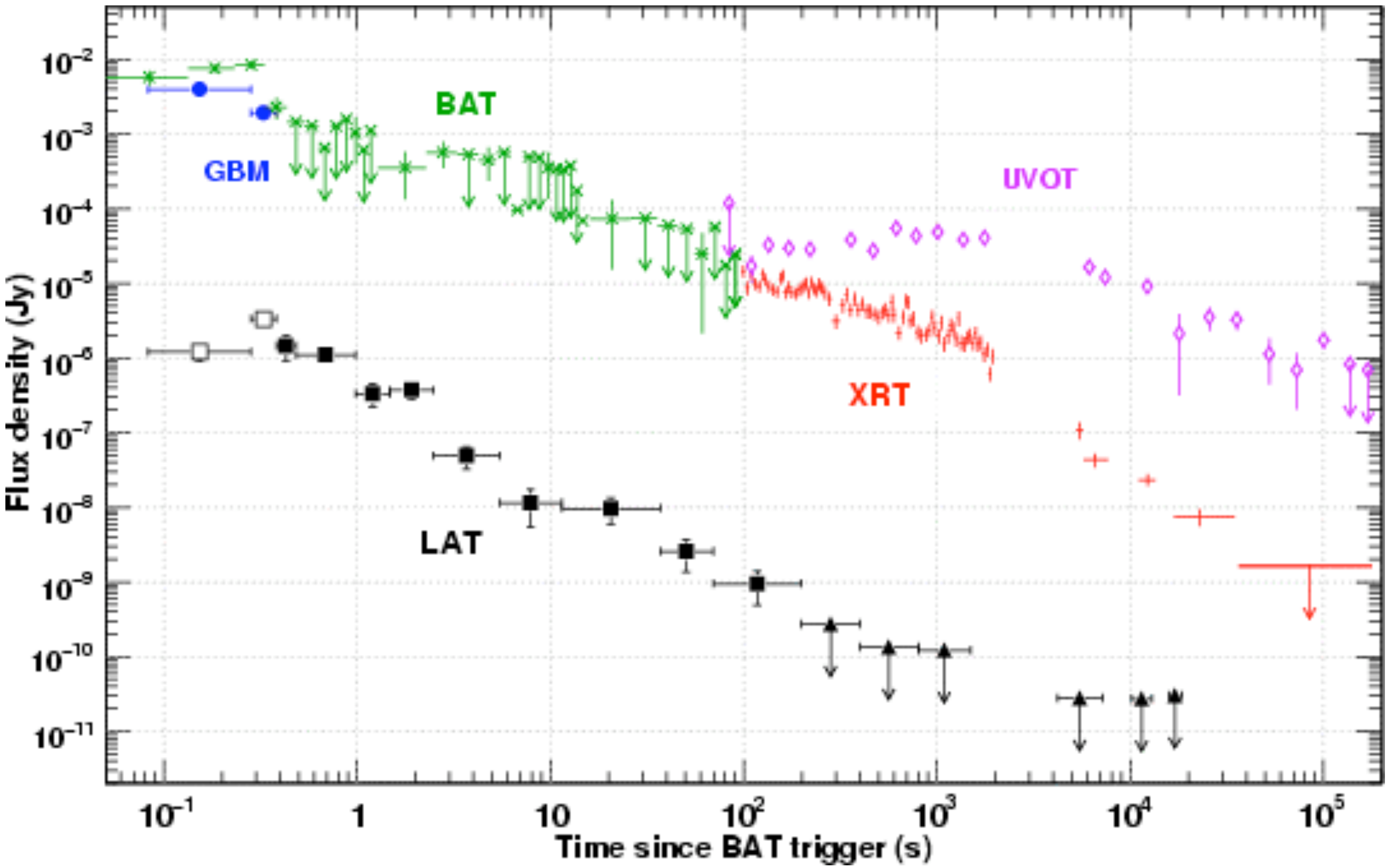


BAT field of view = 2 sr

GRB field of view = 8 sr

LAT field of view = 2.4 sr

GRB 090510 Joint Detection



De Pasquale et al. 2009

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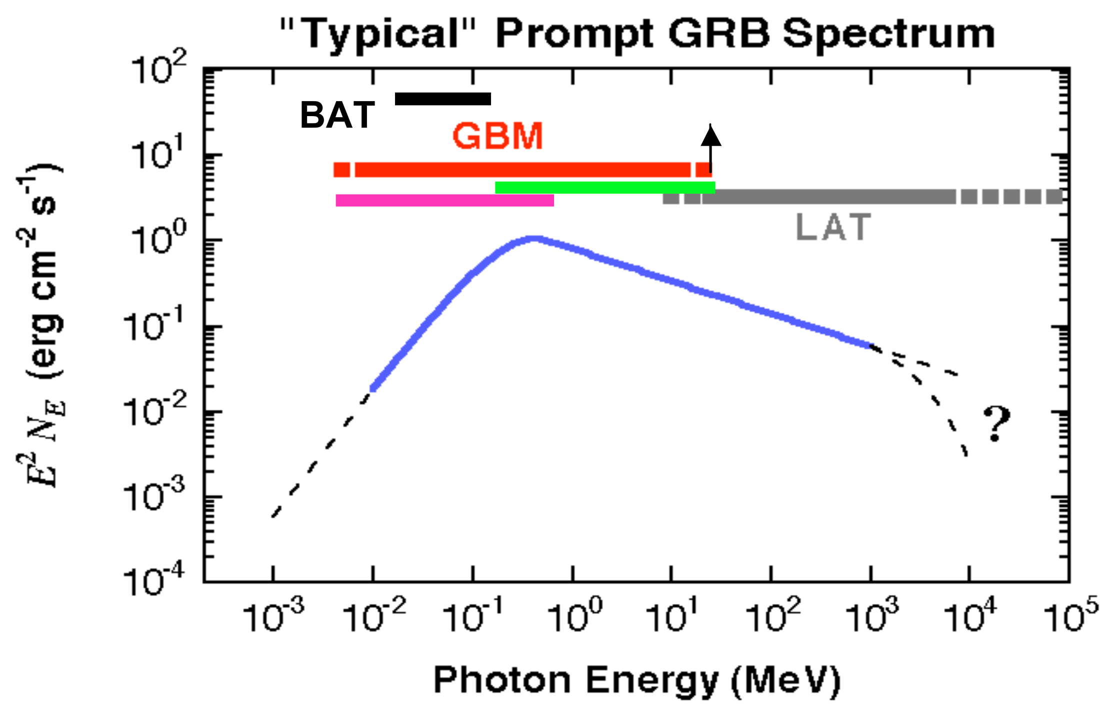

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Swift Observation Log

LAT GRB	T_90	Redshift	Swift Observations
GRB 080825C	22 s		Swift afterglow
GRB 080916C	66 s	z = 4.35	Swift afterglow
GRB 081024B	0.8 s		Swift afterglow
GRB 081215A	7.7 s		Swift afterglow
GRB 090217	33 s		Swift afterglow
GRB 090323	150 s	z = 3.57	Swift afterglow
GRB 090328	100 s	z = 0.736	Swift afterglow
GRB 090510	2.1 s	z = 0.903	Swift prompt & afterglow
GRB 090626	70 s		
GRB 090902B	21 s	z=1.822	Swift afterglow
GRB 090926A	20 s	z=2.1062	Swift afterglow
GRB 091003	21s		Swift afterglow
GRB 091031	35s		
GRB 100116A	110s		sun constrained

Summary of Findings

- *Swift* has detected ~500 GRBs
- Short GRBs are found in different environments than long GRBs and not accompanied by supernovae. Support building for NS-NS merger model.
- GRBs are the most luminous objects in the universe across the electromagnetic spectrum
- High redshift GRBs are elucidating the properties of the high-z universe
- The GRB field is greatly benefiting from joint observations by *Fermi* and *Swift*