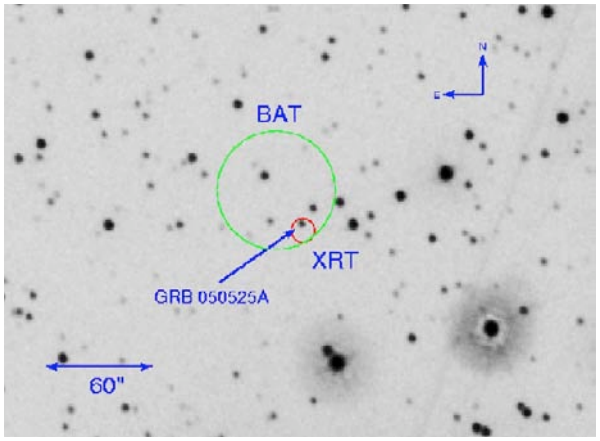
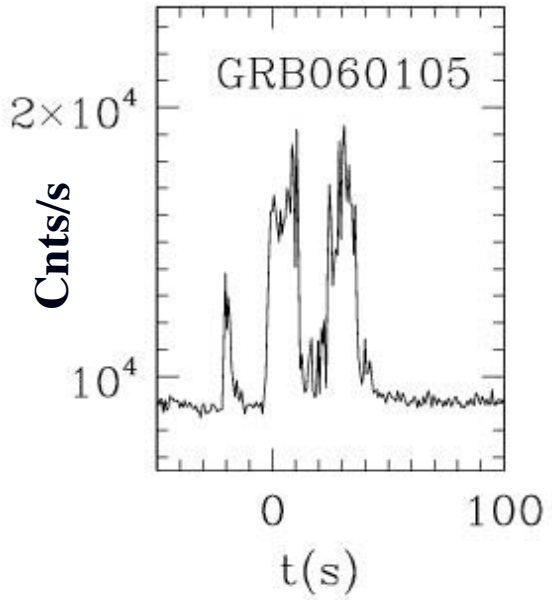
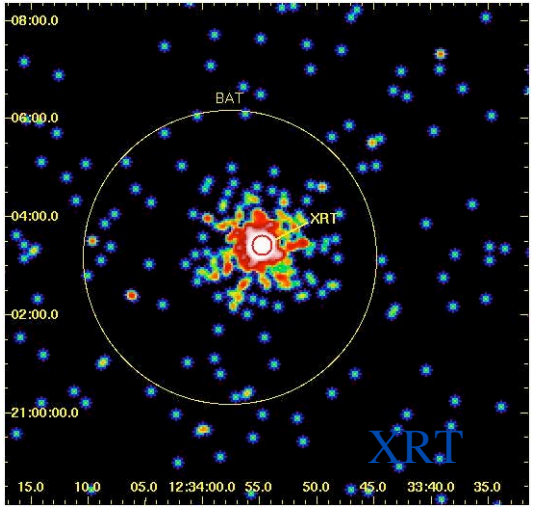




Gamma Ray Bursts



Neil Gehrels

NASA-GSFC

NAM - Leicester

April 5, 2006

Outline

GRB current understanding

Swift observatory

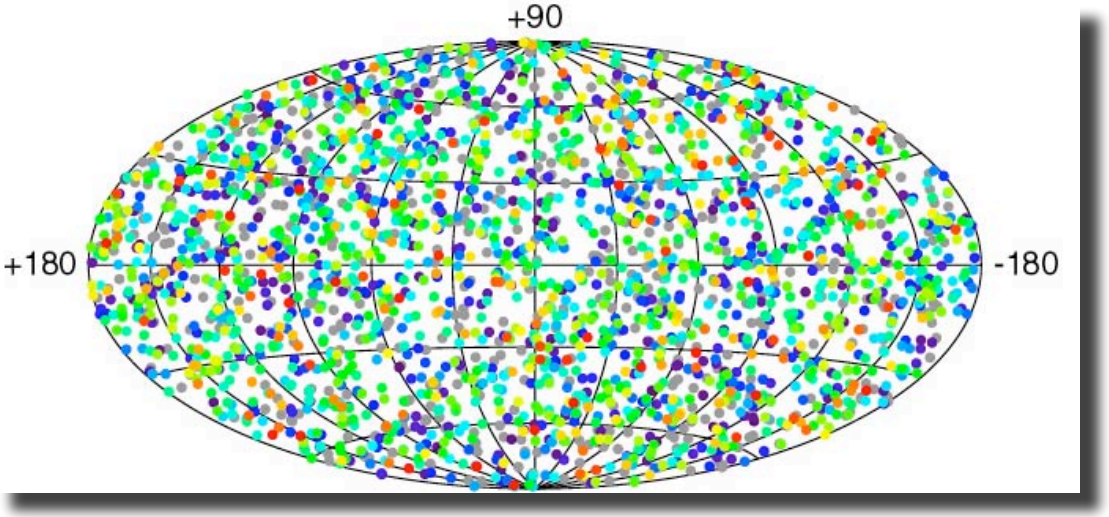
Short GRBs

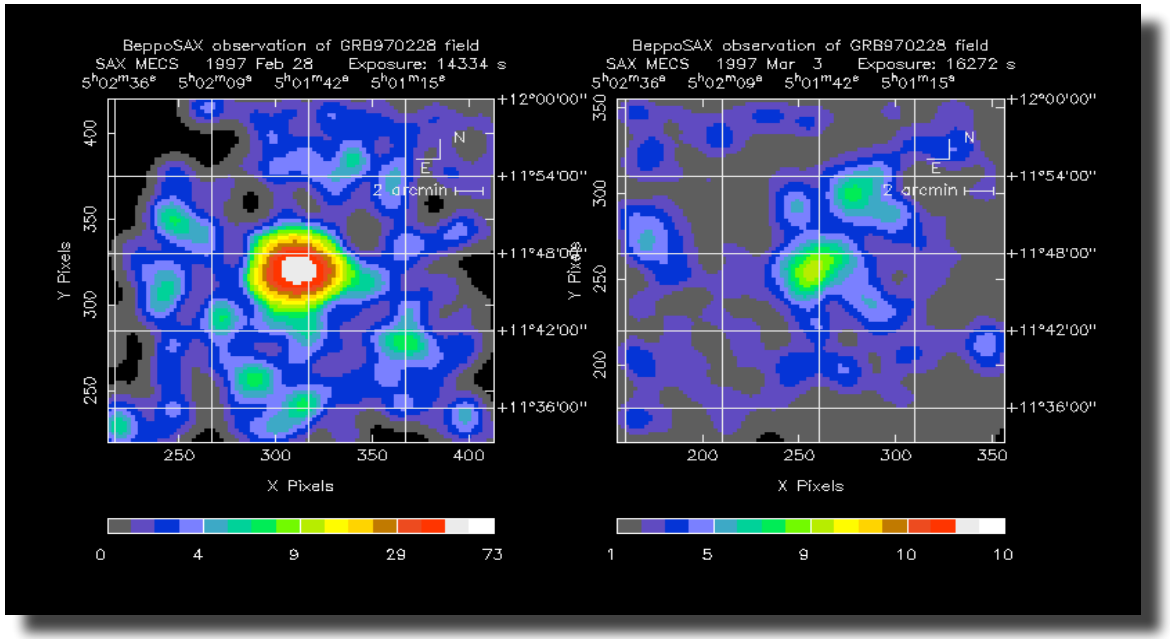
Afterglow

Redshifts

GRB Background

CGRO BATSE
Sky distribution
1991-2000





BeppoSAX
X-ray afterglow
discovery
1997

GRB Background cont.

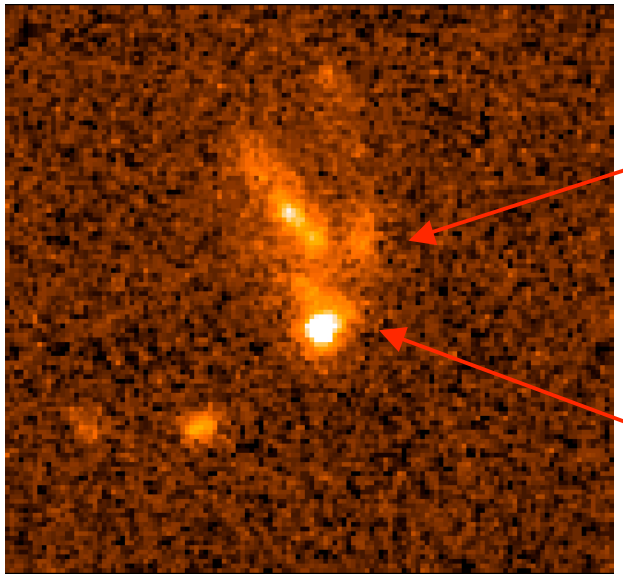
Typical distance (pre-Swift) z ~ 1

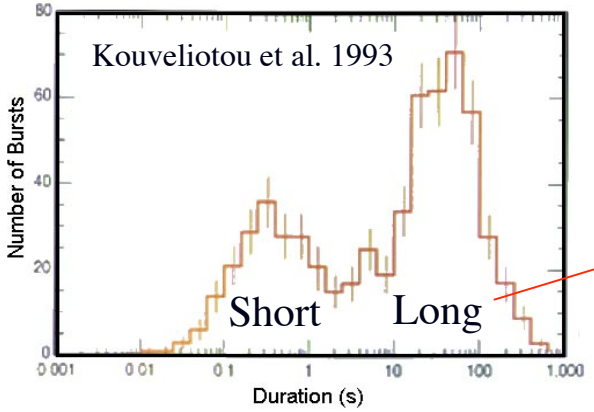
Huge explosions E ~ 10^{51} ergs

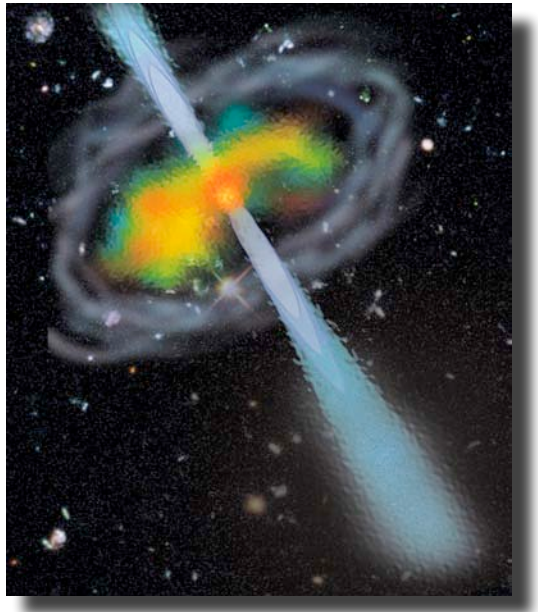
Signatures of black hole birth

Ultra-relativistic outflows (Γ ~ 100)

GRB 990123 - HST







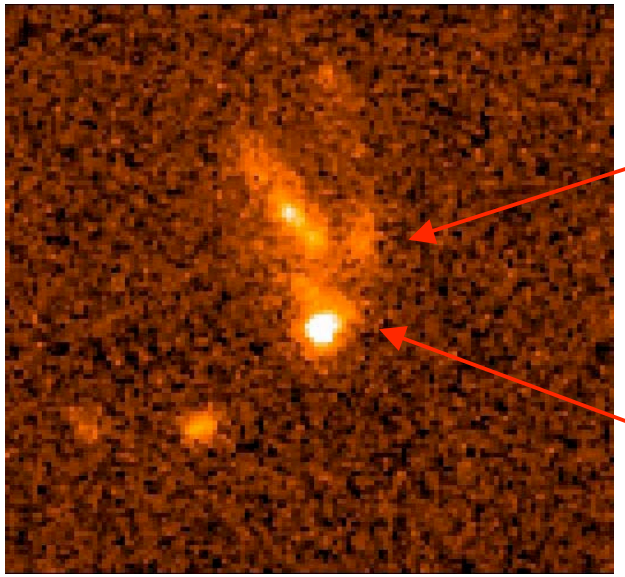
GRB Background cont.

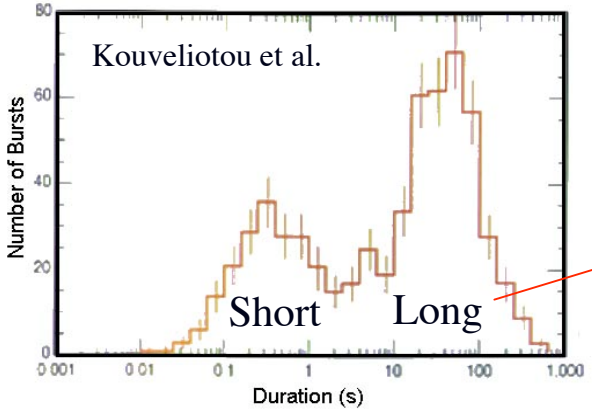
Typical distance (pre-Swift) z ~ 1

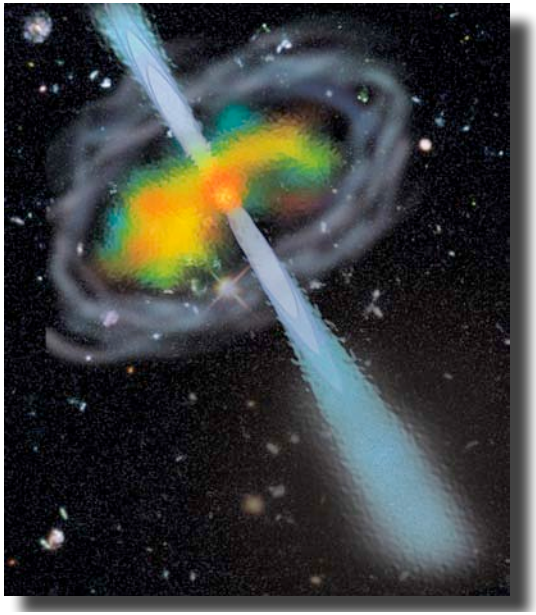
Huge explosions E ~ 10^{51} ergs

Signatures of black hole birth

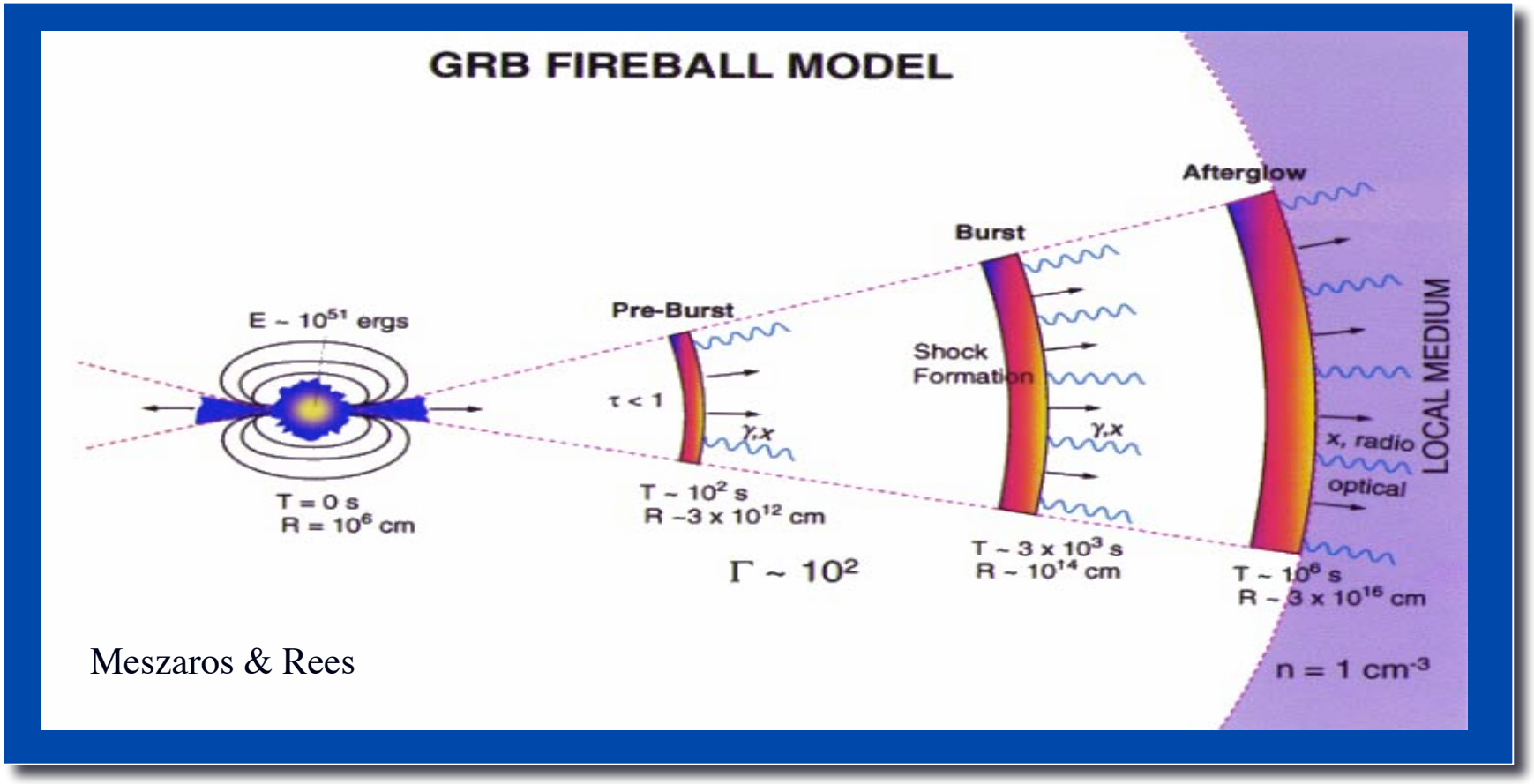
Ultra-relativistic outflows (Γ ~ 100)







Fireball Model of GRBs



Shocks also accelerate protons

Interactions with photons ⇒ pions, muons, neutrinos

Neutrinos expected 10^{14} - 10^{19} eV range

Swift Observatory

Burst Alert Telescope (BAT)
- 32,000 CdZnTe detectors
- 2 sr field of view

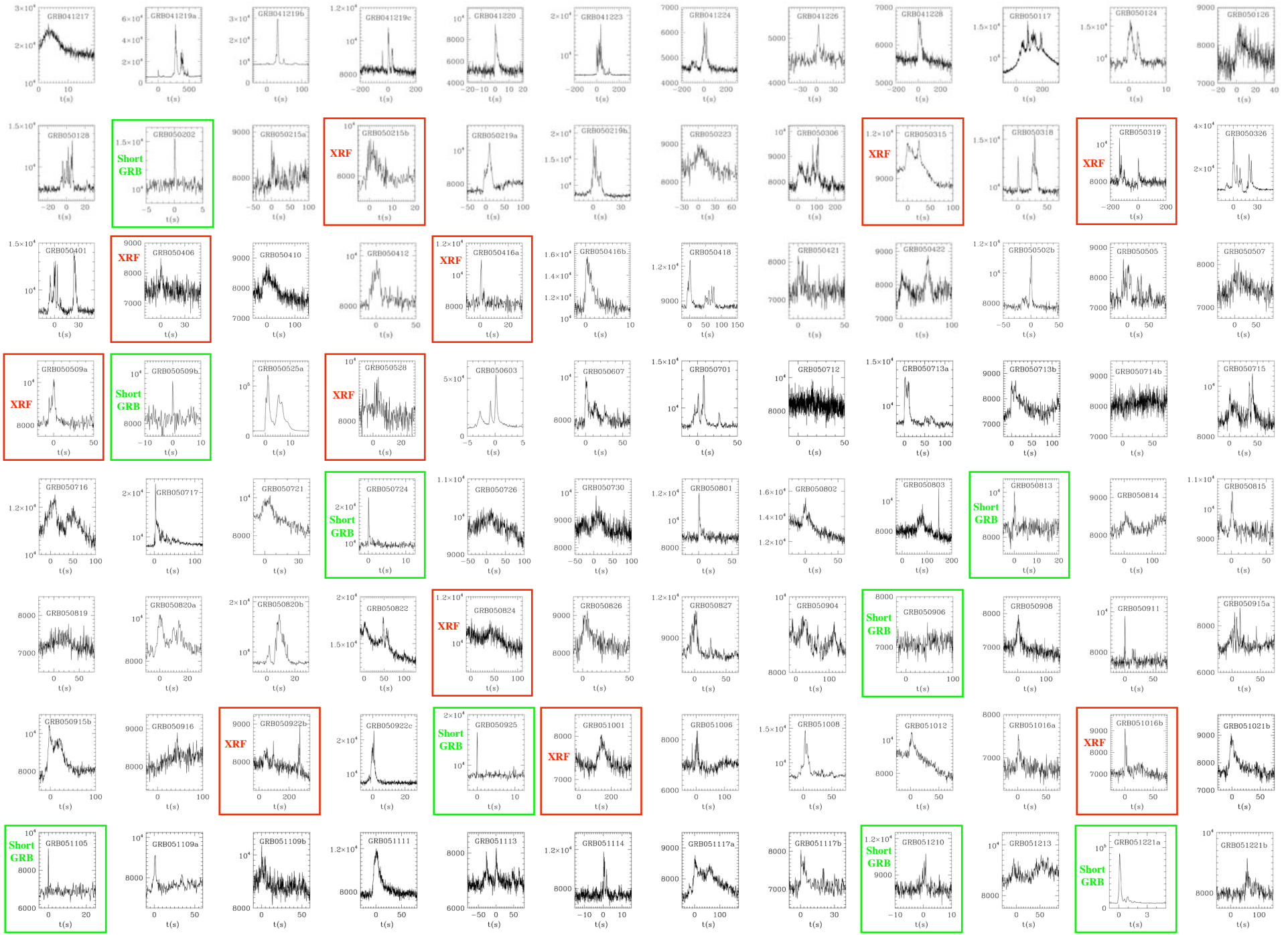
X-Ray Telescope (XRT)
- CCD spectroscopy
- Arcsec GRB positions

UV-Optical Telescope (UVOT)
- Sub-arcsec position
- 22 mag sensitivity

Spacecraft slews XRT & UVOT to GRB in <100 s


Swift on
rocket


November 20, 2004
USAF
BOEING
DELTA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GRB041219c
GRB041220
GRB041223
GRB041224
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GRB041228
GRB050117
GRB050124
GRB050126
GRB050128
Short GRB
GRB050202
GRB050215a
XRF
GRB050215b
GRB050219a
GRB050219b
GRB050223
GRB050306
XRF
GRB050315
GRB050318
XRF
GRB050319
GRB050326
GRB050401
XRF
GRB050406
GRB050410
GRB050412
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GRB050416a
GRB050416b
GRB050418
GRB050421
GRB050422
GRB050502b
GRB050505
GRB050507
XRF
GRB050509a
Short GRB
GRB050509b
GRB050525a
XRF
GRB050528
GRB050603
GRB050607
GRB050701
GRB050712
GRB050713a
GRB050713b
GRB050714b
GRB050715
GRB050716
GRB050717
GRB050721
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GRB050724
GRB050726
GRB050730
GRB050801
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GRB050803
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GRB050814
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GRB050819
GRB050820a
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GRB050824
GRB050826
GRB050827
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GRB050915b
GRB050916
XRF
GRB050922b
GRB050922c
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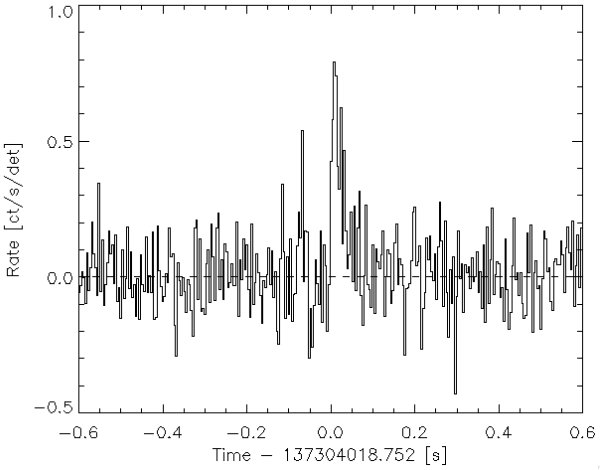
GRB051008
GRB051012
GRB051016a
XRF
GRB051016b
GRB051021b
Short GRB
GRB051105
GRB051109a
GRB051109b
GRB051111
GRB051113
GRB051114
GRB051117a
GRB051117b
Short GRB
GRB051210
GRB051213
Short GRB
GRB051221a
GRB051221b
t(s)

Short GRBs

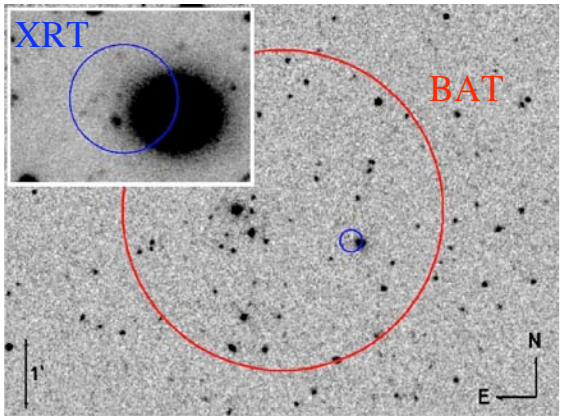
8 short GRBs with rapid arcsec positions

2 Short GRBs - 2 Elliptical Hosts

GRB 050509B

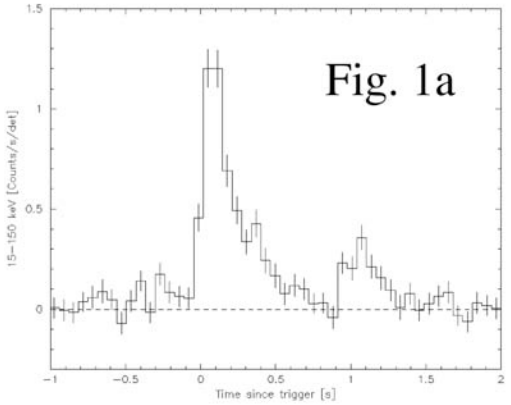


35 kpc offset



Gehrels et al. 2005

GRB 050724

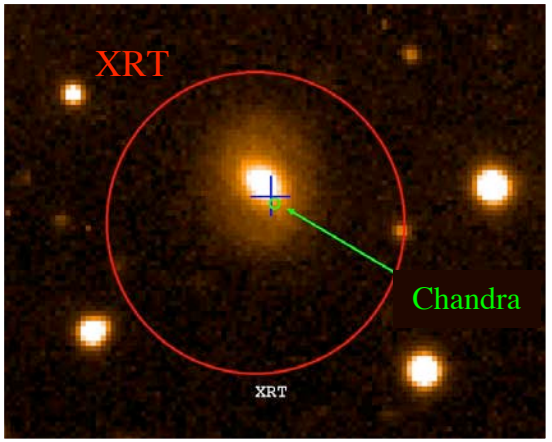


- **elliptical hosts**
- **low SF rates**
- **offset positions**
- **redshifts z ~ 0.2**

>> inconsistent with collapsar model

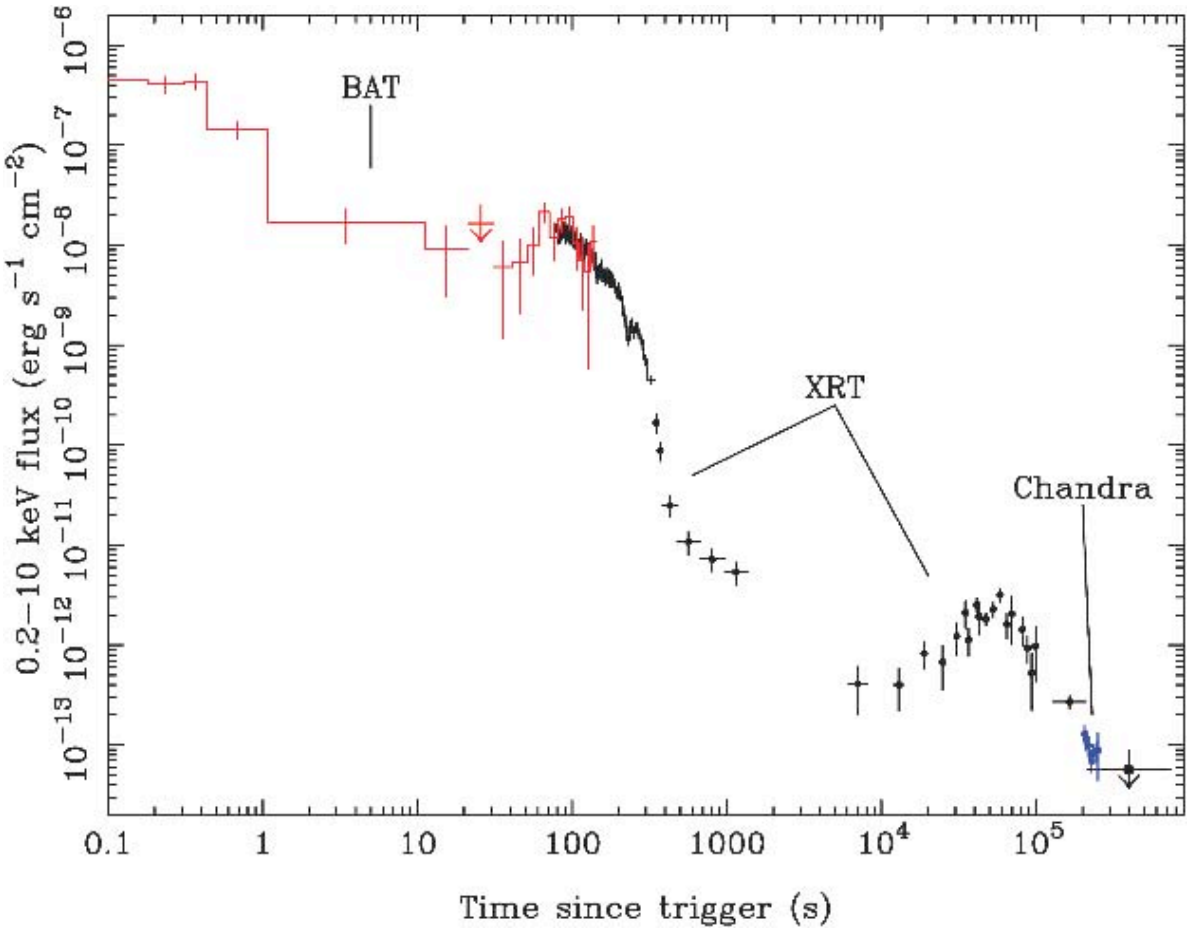
>> supportive of NS-NS model

4 kpc offset



Barthelmy et al. 2005

GRB 050724



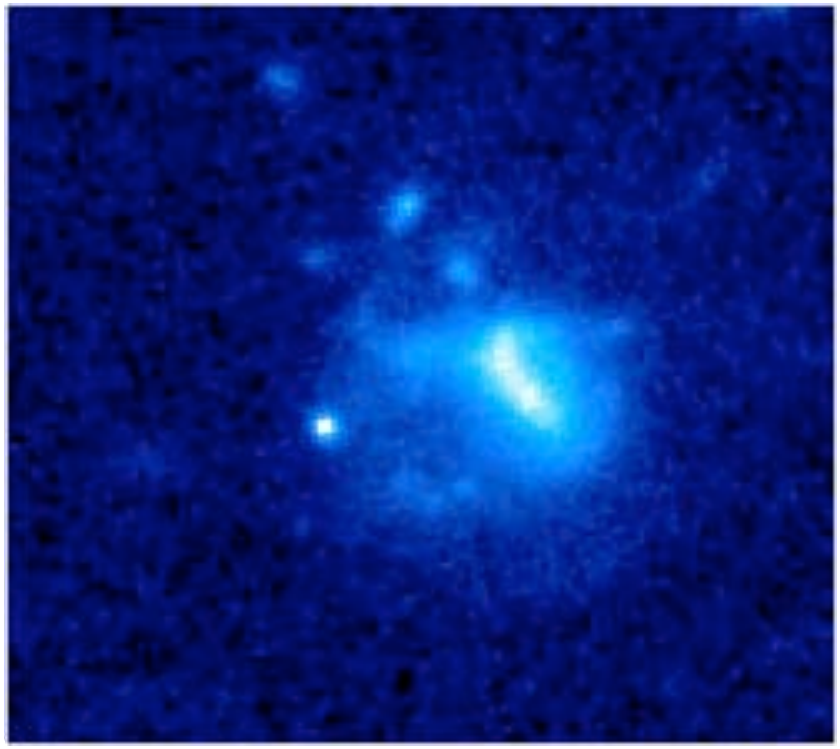
BAT
- 250 ms hard spike
- 6×10^{-7} erg/cm^2 fluence

Afterglow
- bright afterglow with flares
- detected by Chandra
- optical & radio

Host:
- Elliptical
- L = 1.7 L*
- z = 0.258
- SFR < 0.02 M_O yr^{-1}

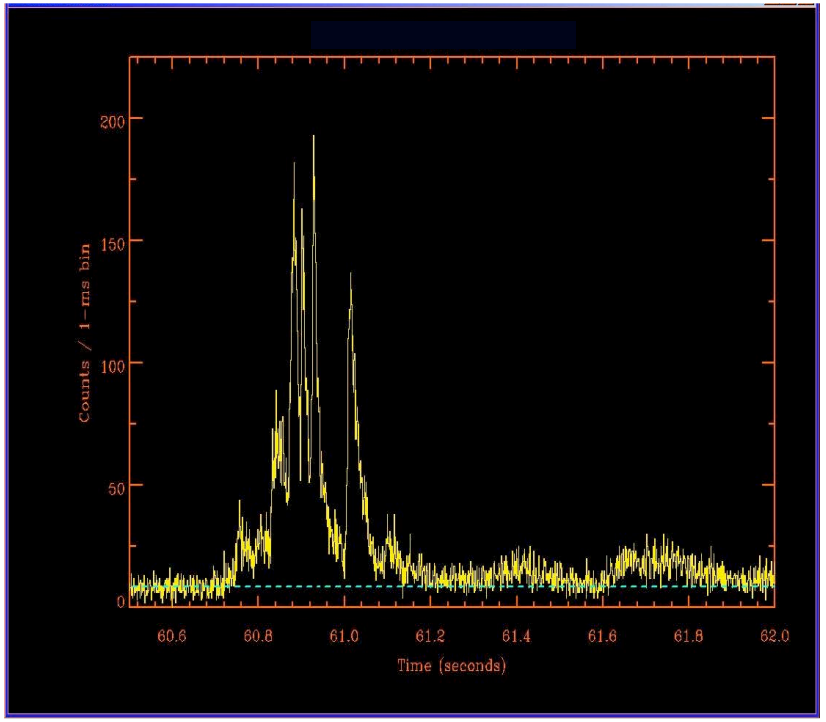
Barthelmy et al. 2005

HETE-2 GRB 050709
HST Image



Fox et al. 2005

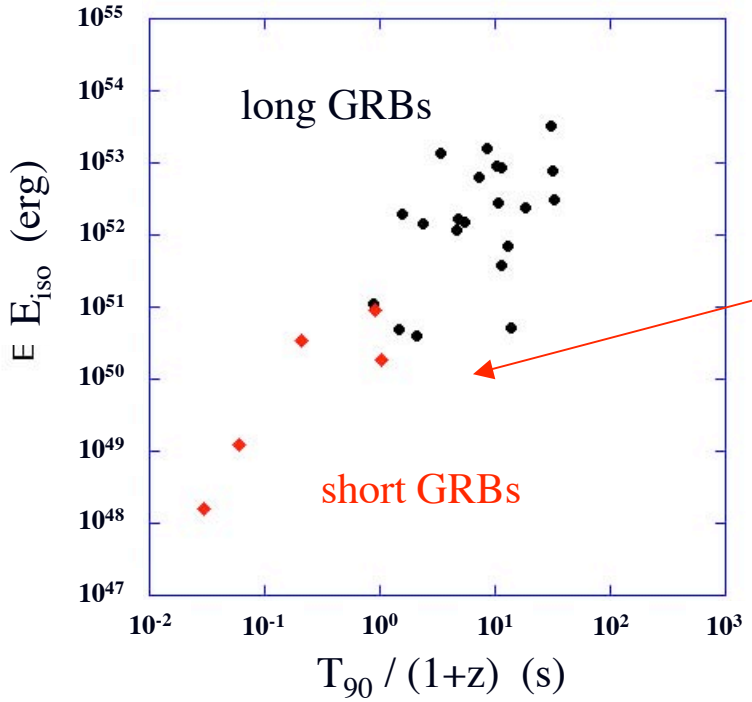
Swift GRB 051221
BAT Lightcurve



Parsons et al. 2005

Short GRB Observations

Swift GRBs



Name	Redshift	Afteglow	Host	E_{iso}(15-150keV) (erg)	What might it be?
				-	-
			Elliptical@	$1x10^{48}$	NS-NS merger
			SF galaxy	$6x10^{49}$	NS-NS merger
			Elliptical	$3x10^{50}$	NS-NS / NS-BH merger
			galaxy@	? $2x10^{51}$	? NS-NS merger
			galaxy	-	? minimal afterglow
			n gal. plane	-	? possible new SGR
				-	? minimal afterglow
			cluster@	? $2x10^{48}$	? NS-NS merger
			SF galaxy	$9x10^{50}$	-
				-	-
			cluster@	-	? NS-NS merger

* HETE GRB
\# soft spectrum
@ galaxy in cluster

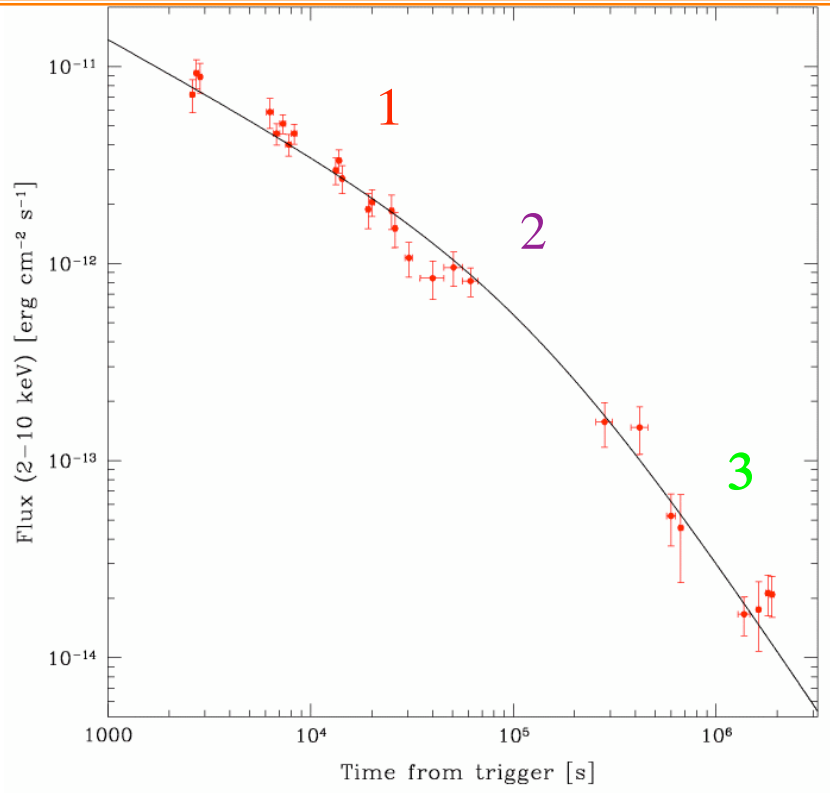
Sari et al. 1999; Frail et al 2001

$\theta = 3.3\ (t_{break}/1day)^{3/8}\ ((1+z)/2)^{-3/8}\ (E_{iso\text{-}\gamma}/10^{53}\ ergs)^{-1/8}\ (\eta_\gamma/0.2)\ (n/0.1\ cm^{-3})^{1/8}$

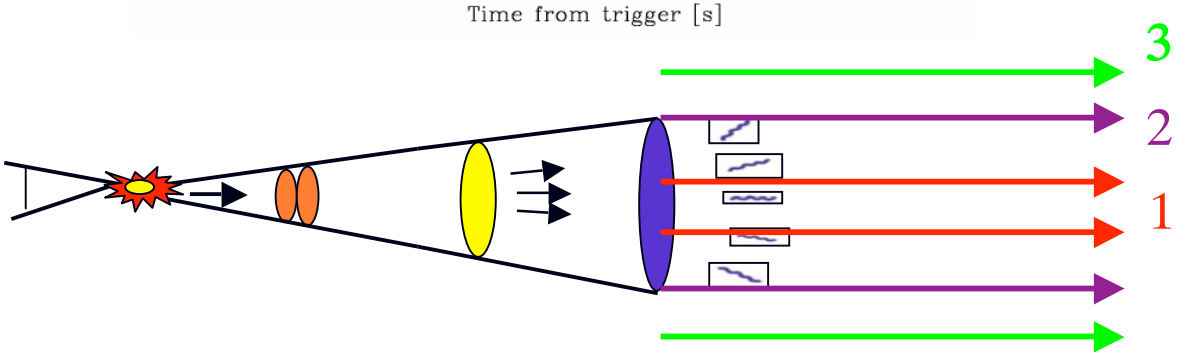
$z = 1.24$ $E_{iso} = 1.3 \times 10^{52}$ erg $t_{break} = 8 \times 10^4$ sec = 0.9 day

$\theta = 3.9$ degrees

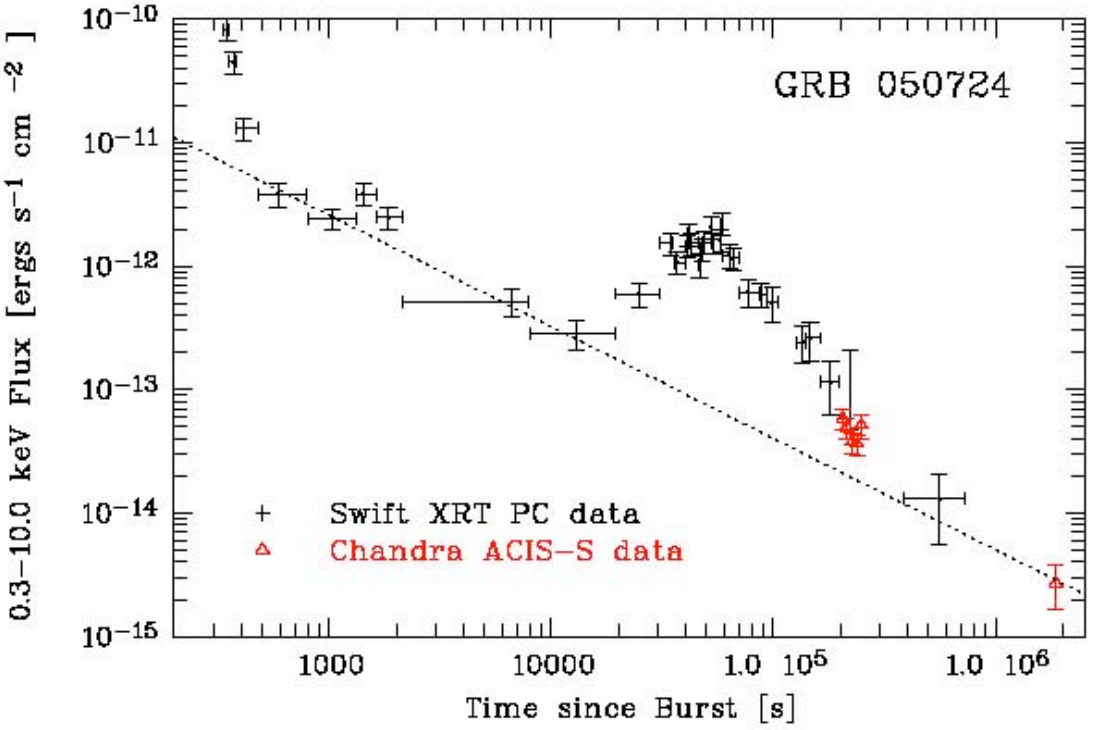
GRB 050408
HETE-2



$\theta \sim \Gamma^{-1}$



Beaming for Short GRBs



Grupe, Burrows, et al.

Lack of jet break implies $\theta > 25^{\circ}$

Other hints of jet breaks give $\theta \sim 10^{\circ}$ - 20°

Long bursts have $\theta \sim 5^{\circ}$

Conclusion:

$\theta_{short} > \theta_{long}$

Short GRB Summary

Strong evidence that short GRBs associated with old stellar populations

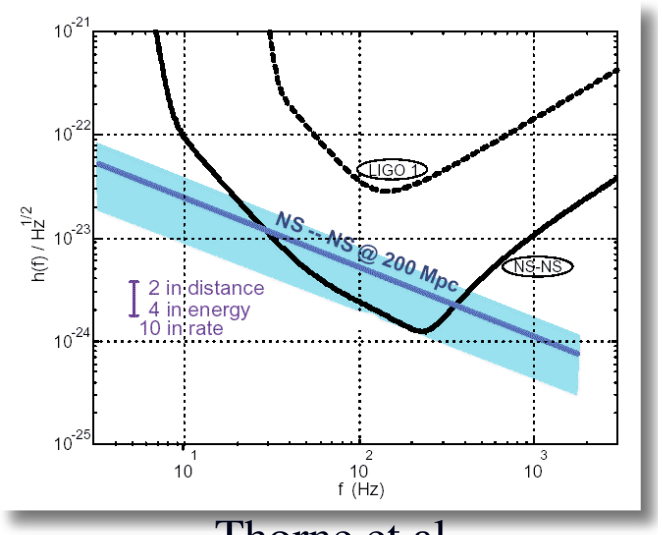
Rapid fluctuations imply compact source origin.
Energetics suggest collapse to BH

Could be NS-NS mergers. Could be accretion-induced collapse of NS.

If NS-NS, some systems may be exchange captures in globular clusters

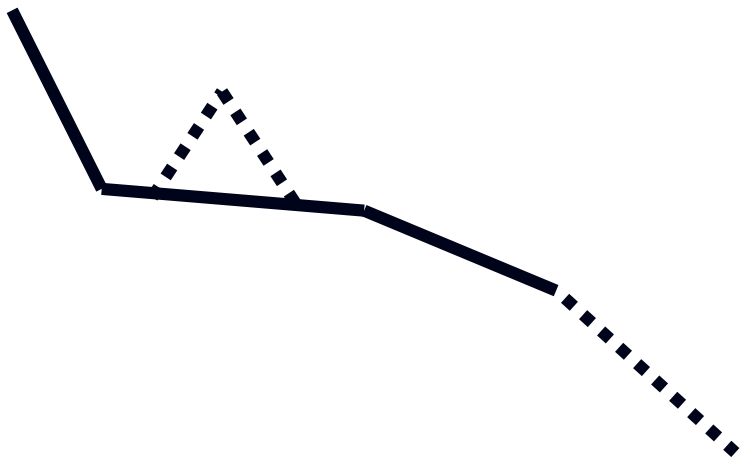
Gravitational Waves:

Assuming short GRBs are NS-NS mergers
Assuming 30° beaming
⇒ A-LIGO detection rate of ~100 yr^{-1}

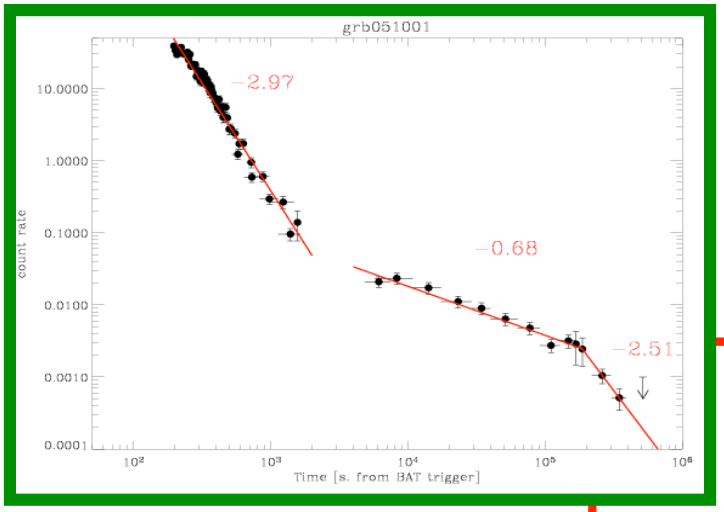


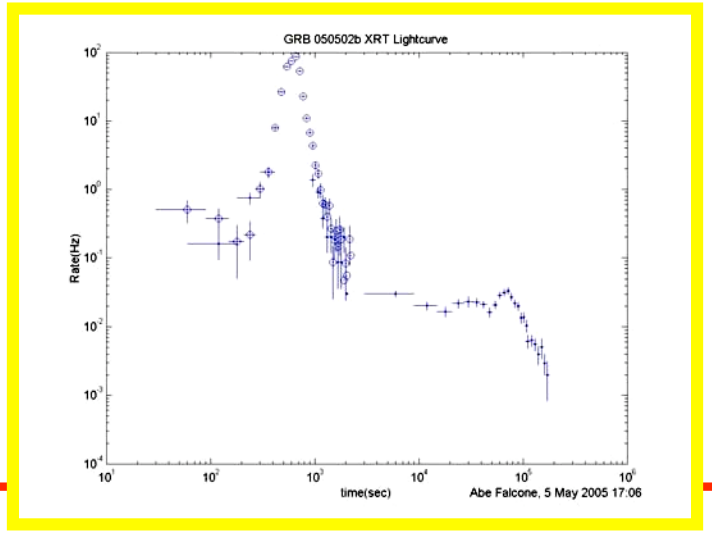
Thorne et al.

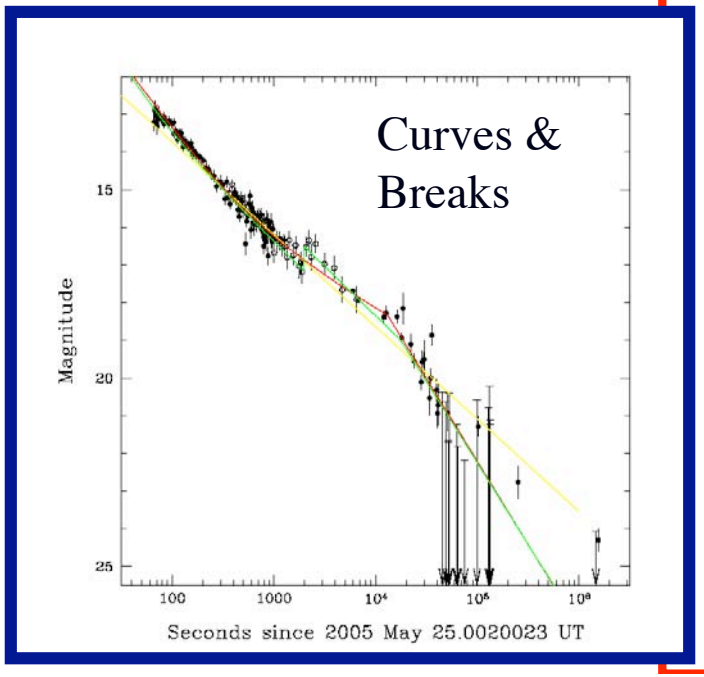
GRB Afterglow

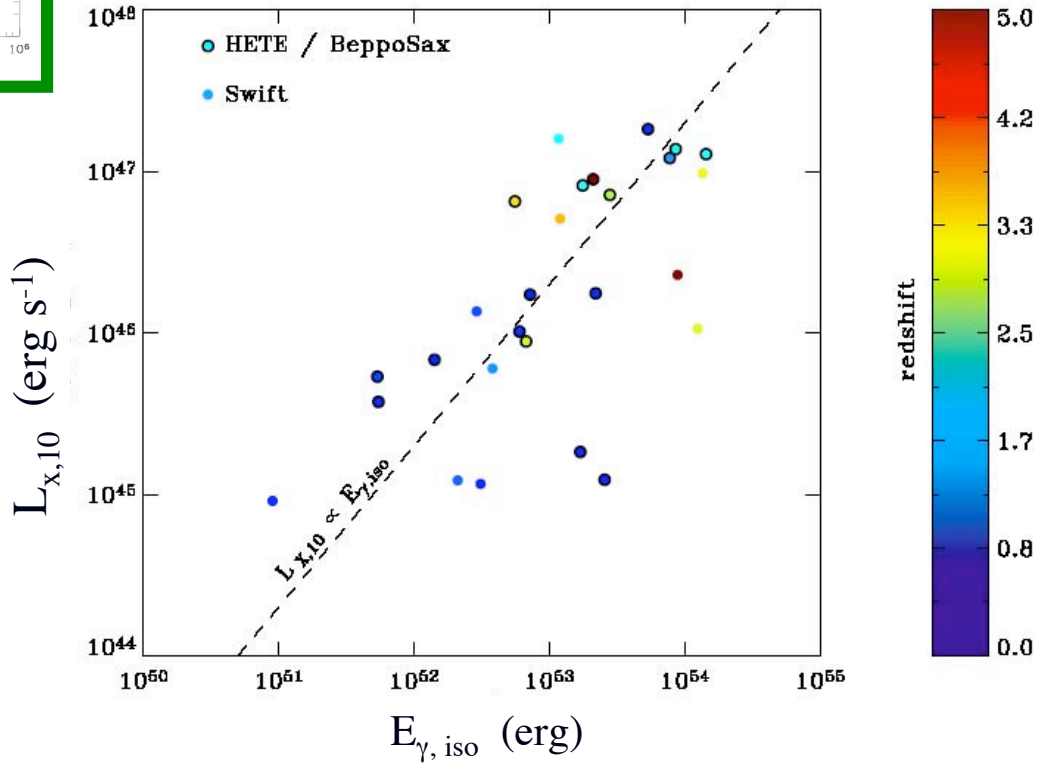


Afterglow Discoveries

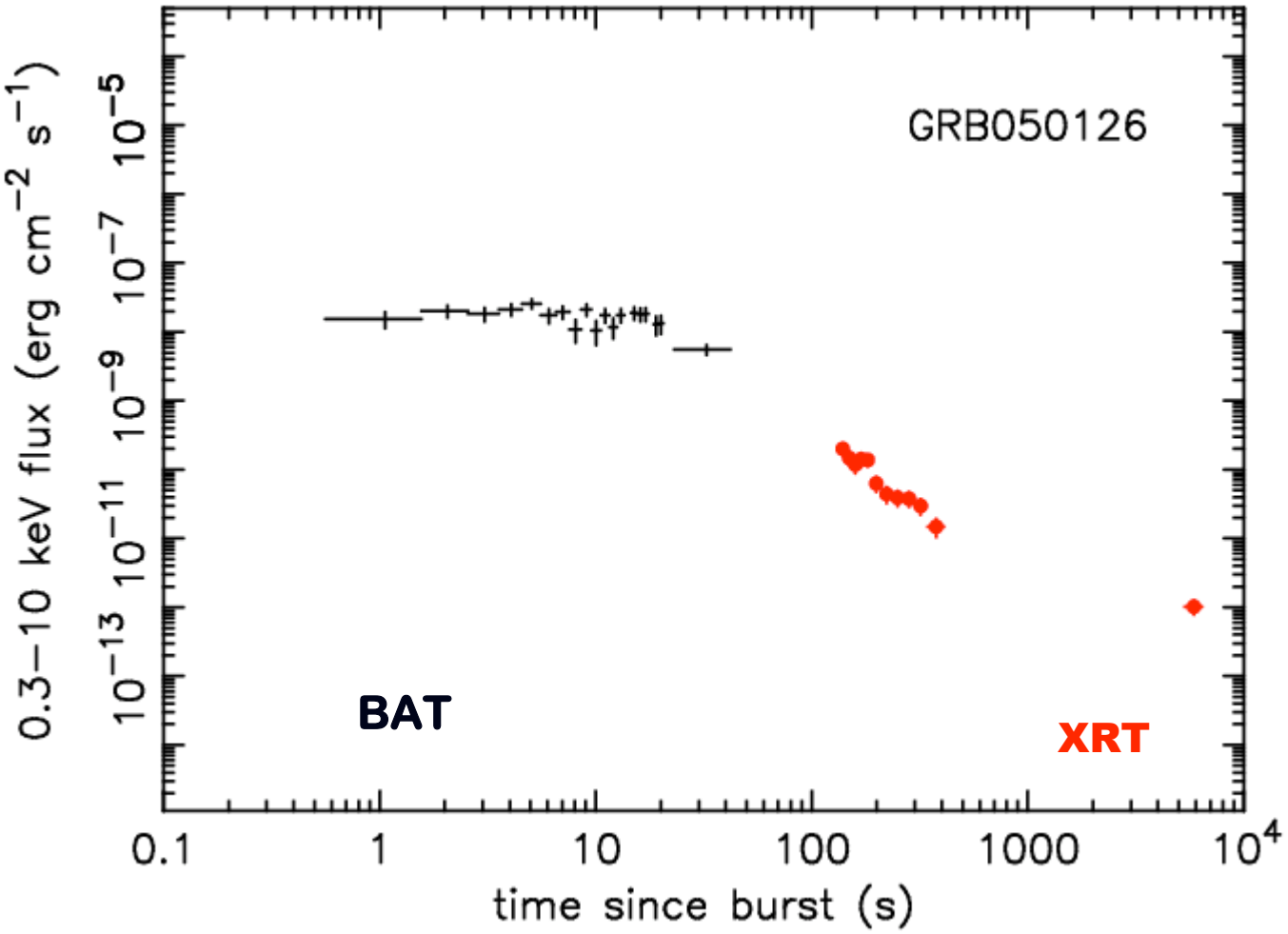






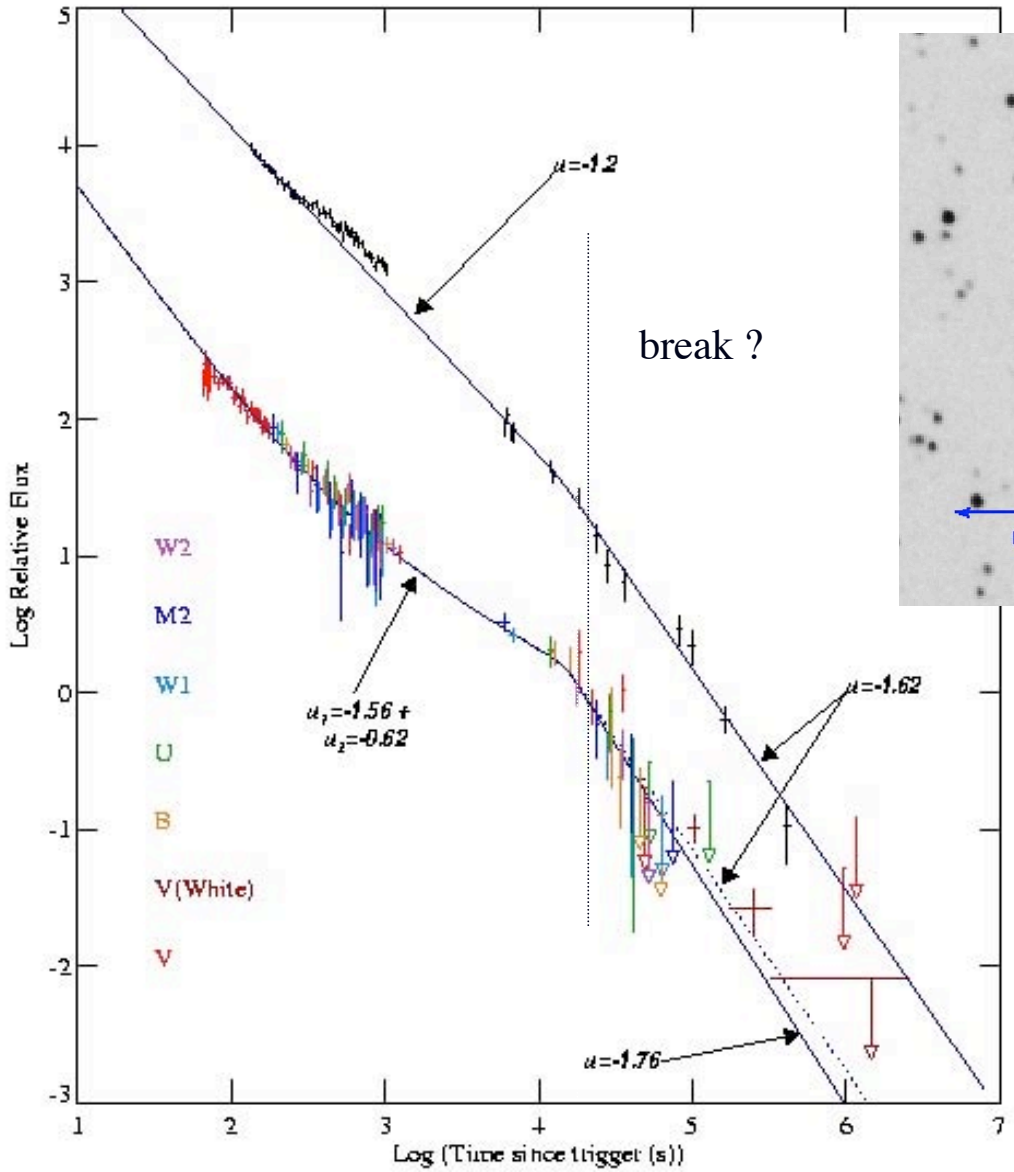


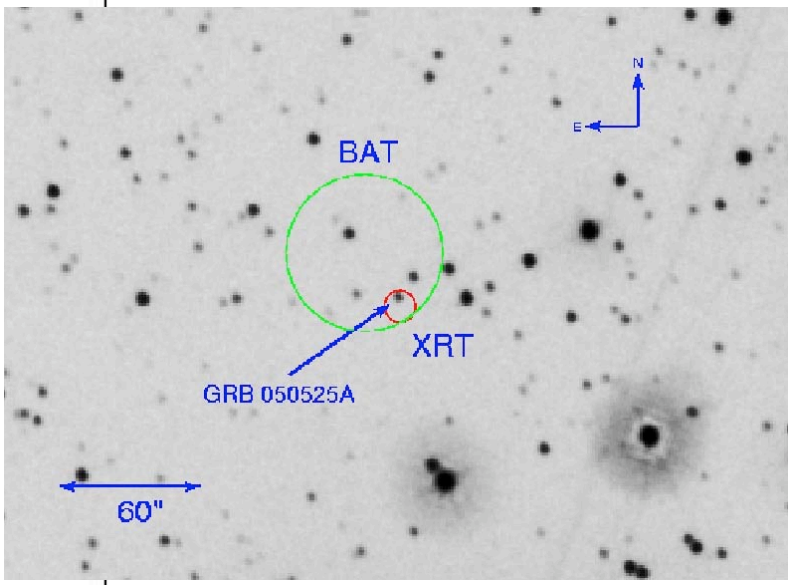
Swift Lightcurves - The Movie



Paul O'Brien / UL

GRB 050525a Afterglow





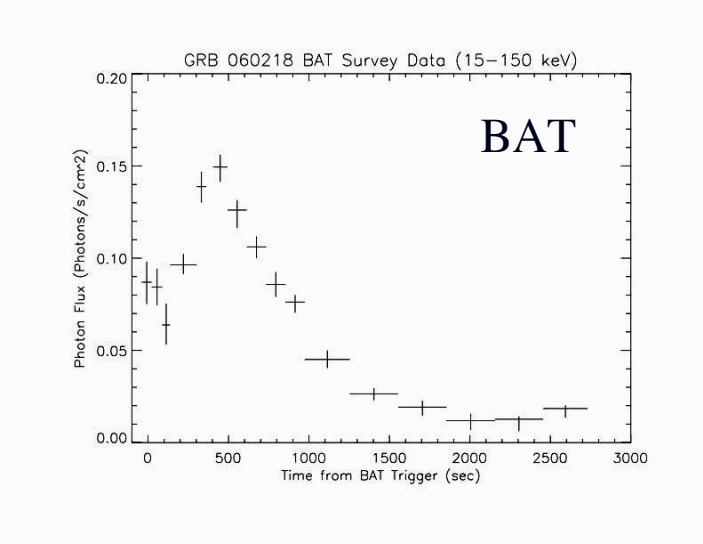
Blustin et al.

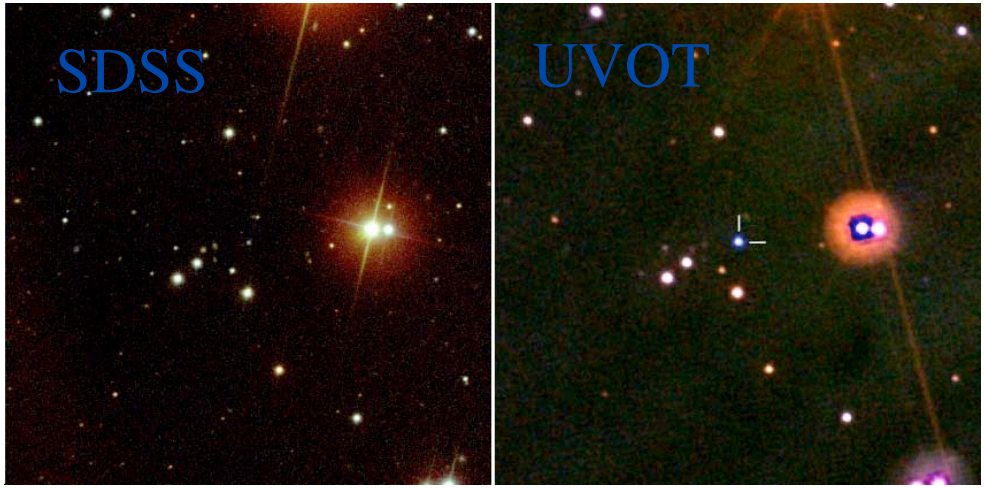
GRBs Without XRT Detection

Name	BAT Fluence (erg cm^{-2})	GRB Type	Time to Observation	Comments
060102	2.4	long	2 days	No prompt slew (moon constraint)
051114	1.32	long	1.5 days	Did not trigger BAT (found in ground processing)
051105A	0.2	short	68 sec	
050925	0.75	short	100 sec	
050911	3.01	long	3.6 hours	No prompt slew (Earth limb constraint)
050906	0.0721	short	79 s	
050528	4.40	long	14 hours	XRT in engineering mode at trigger time
050416B	11.3	long	3.6 days	No prompt slew (tmoon constraint)

GRB 060218
Really Nearby GRB
(z = 0.0331)

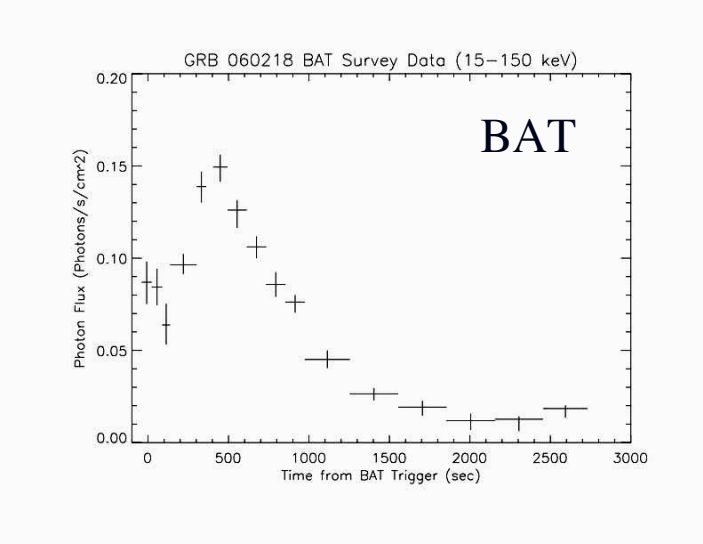
GRB 060218

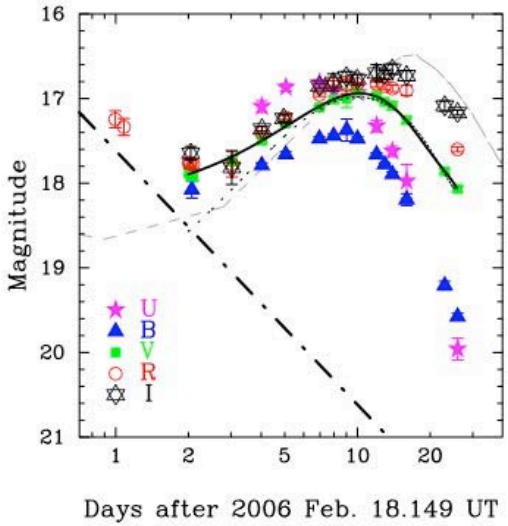


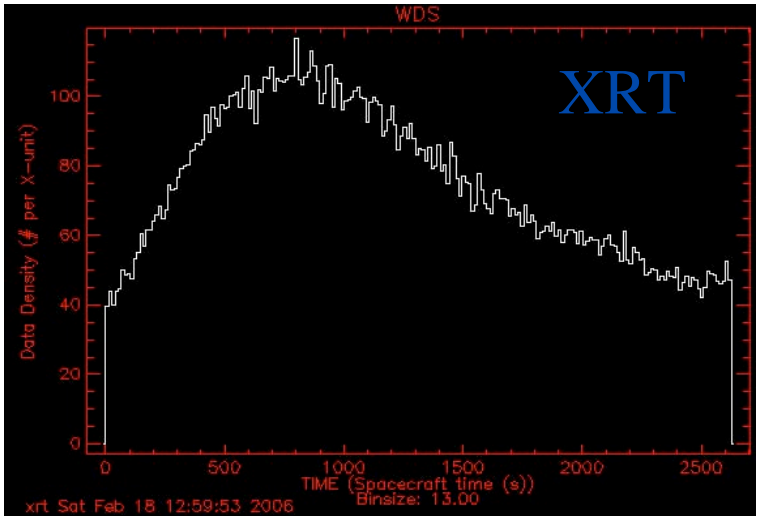


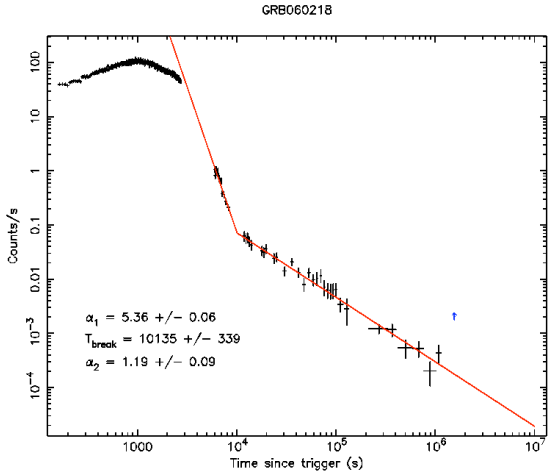
Super-long GRB - ~35 minutes
BAT, XRT, UVOT during GRB
VLA detection at 0.5 mJy
$z = 0.033$
E_{iso} = few x 10^{49} erg cm^{-2}
Supernova currently at peak
SN Ib/c

GRB 060218 cont.









GRB 060218 Summary

Wolf-Rayet star progenitor

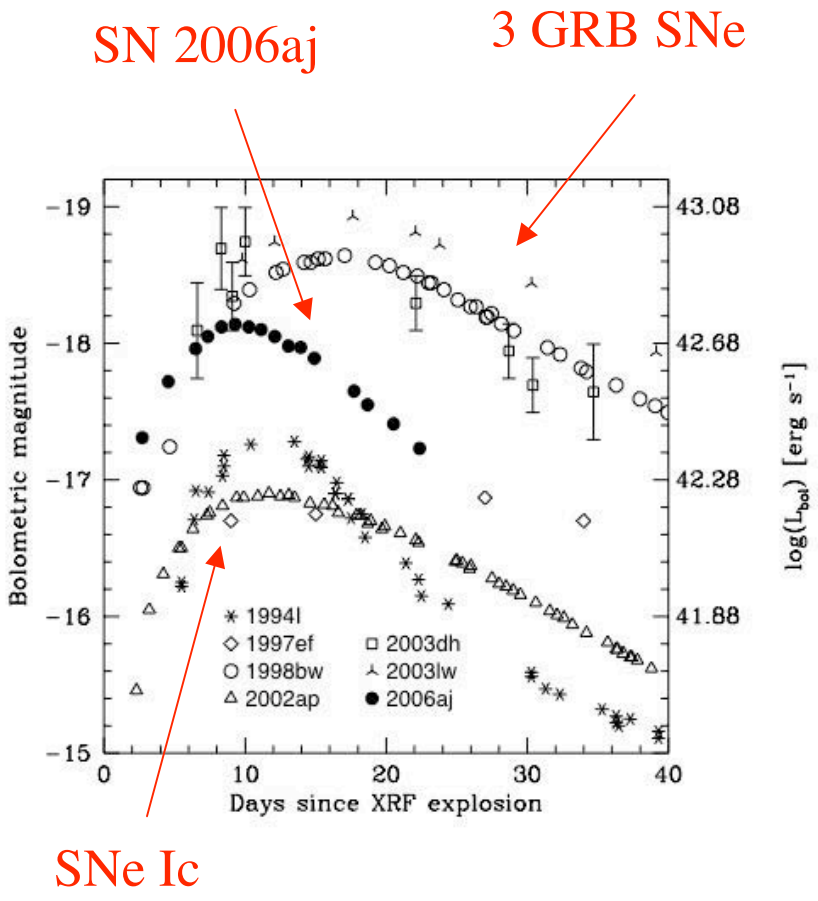
Low metallicity dwarf host

Soft spectrum (E_{peak} ~ 5 keV) with thermal component

Shock break-out from dense W-R wind region may explain thermal emission

2 components
- broad outflow disrupts star (SN)
- narrow jet produces GRB

Do all GRBs have SNe or just nearby underluminous ones?



Pian et al. 2006

High Redshift GRBs

GRB 050904

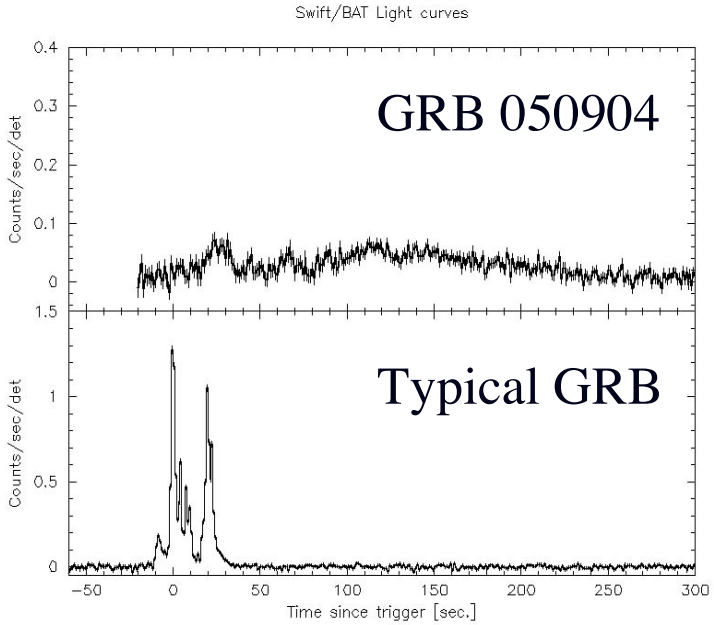
Prompt

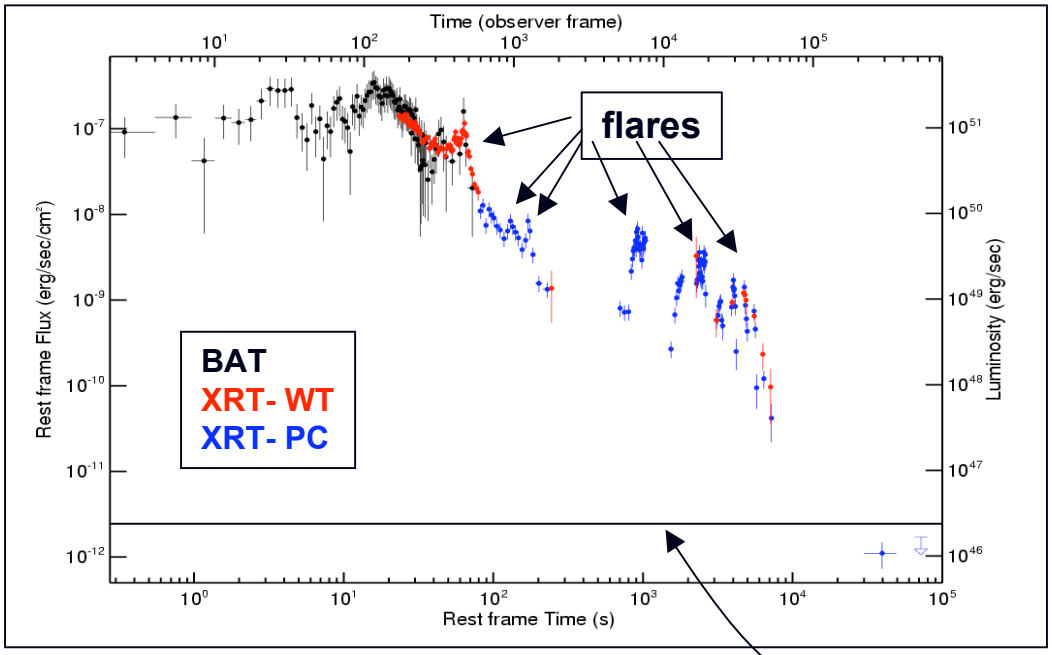
Redshift **z= 6.29**

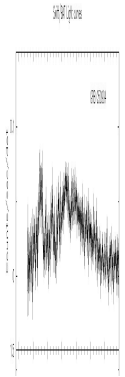
T_{90} = 225 sec

S (15-150 keV) = 5.4×10^{-6} erg cm^{-2}

E_{iso} = 3.8×10^{53} erg







undilated by

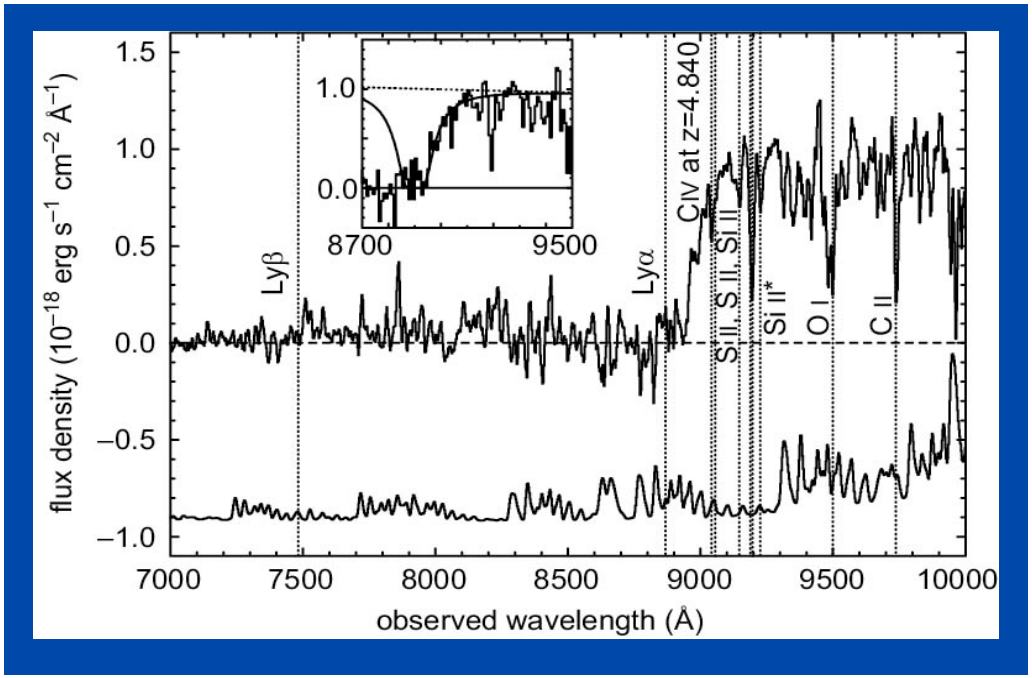
Flux x100 of high-z luminous X-ray AGN

Cusumano et

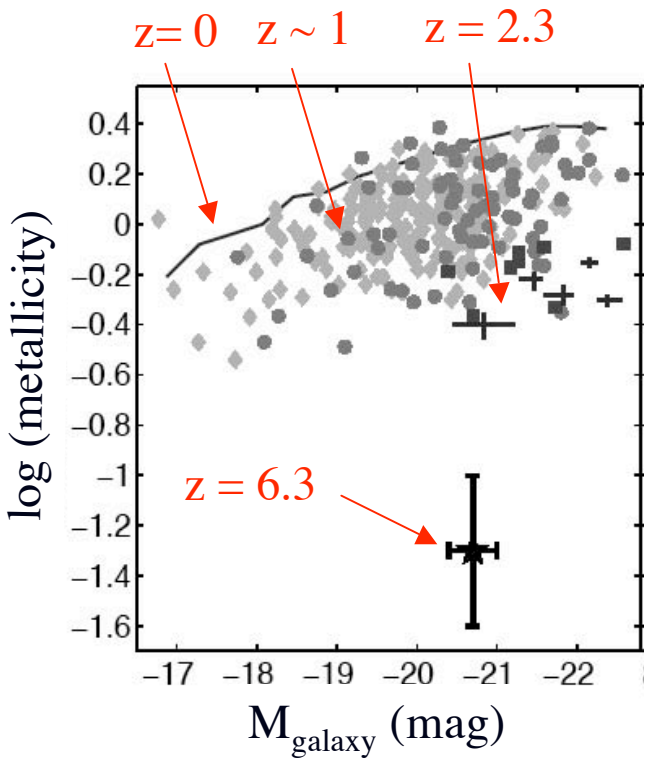
GRB 050904 Optical Spectroscopy

Ly break in the IR
J=17.6 at 3.5 hours

Subaru Spectroscopy



Kawai et al. 2006



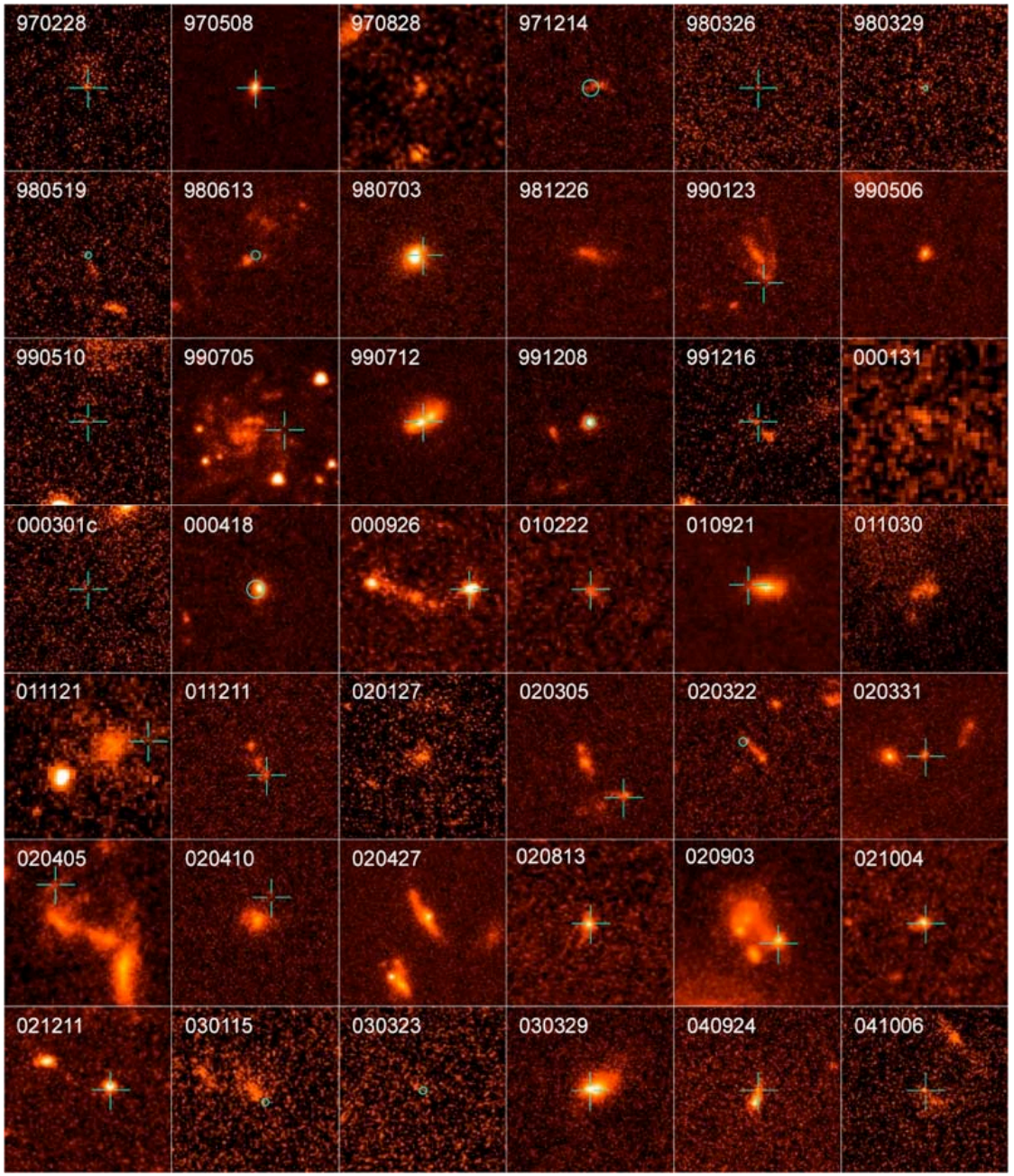
Berger et al. 2006
HST & SIRTF

GRB Hosts

- GRBs trace brightest regions in hosts
- Hosts are sub-luminous irregular galaxies

⇒ Concentrated in regions of most massive stars

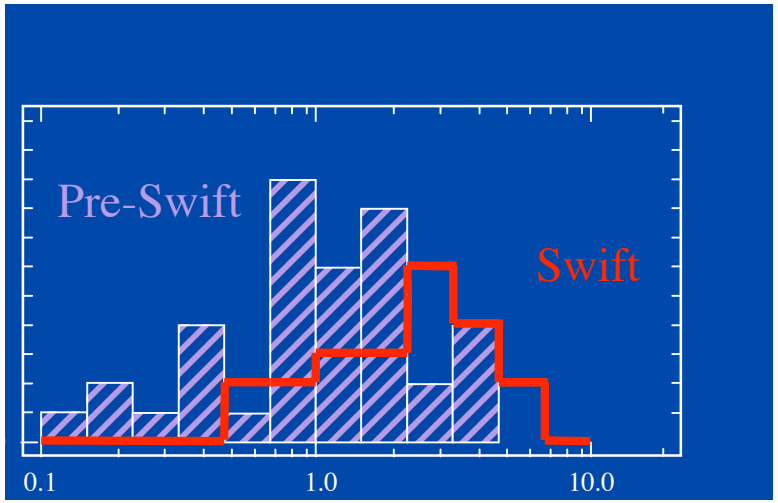
⇒ Restricted to low metallicity galaxies



Fruchter 2005

High Redshift GRBs

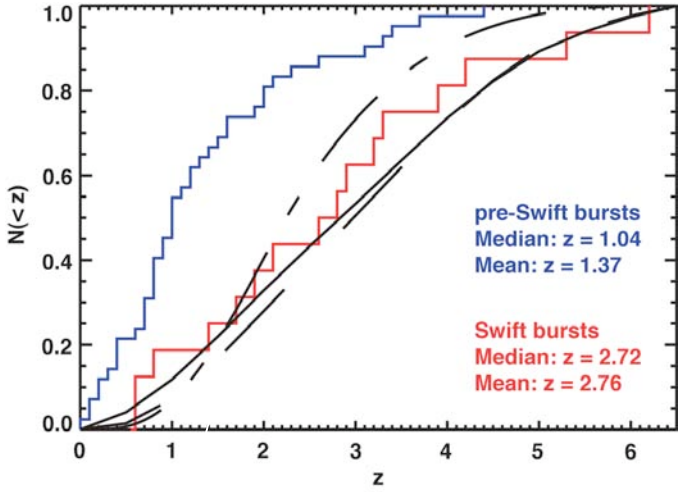
GRB Redshift Distributions



Redshift (z)

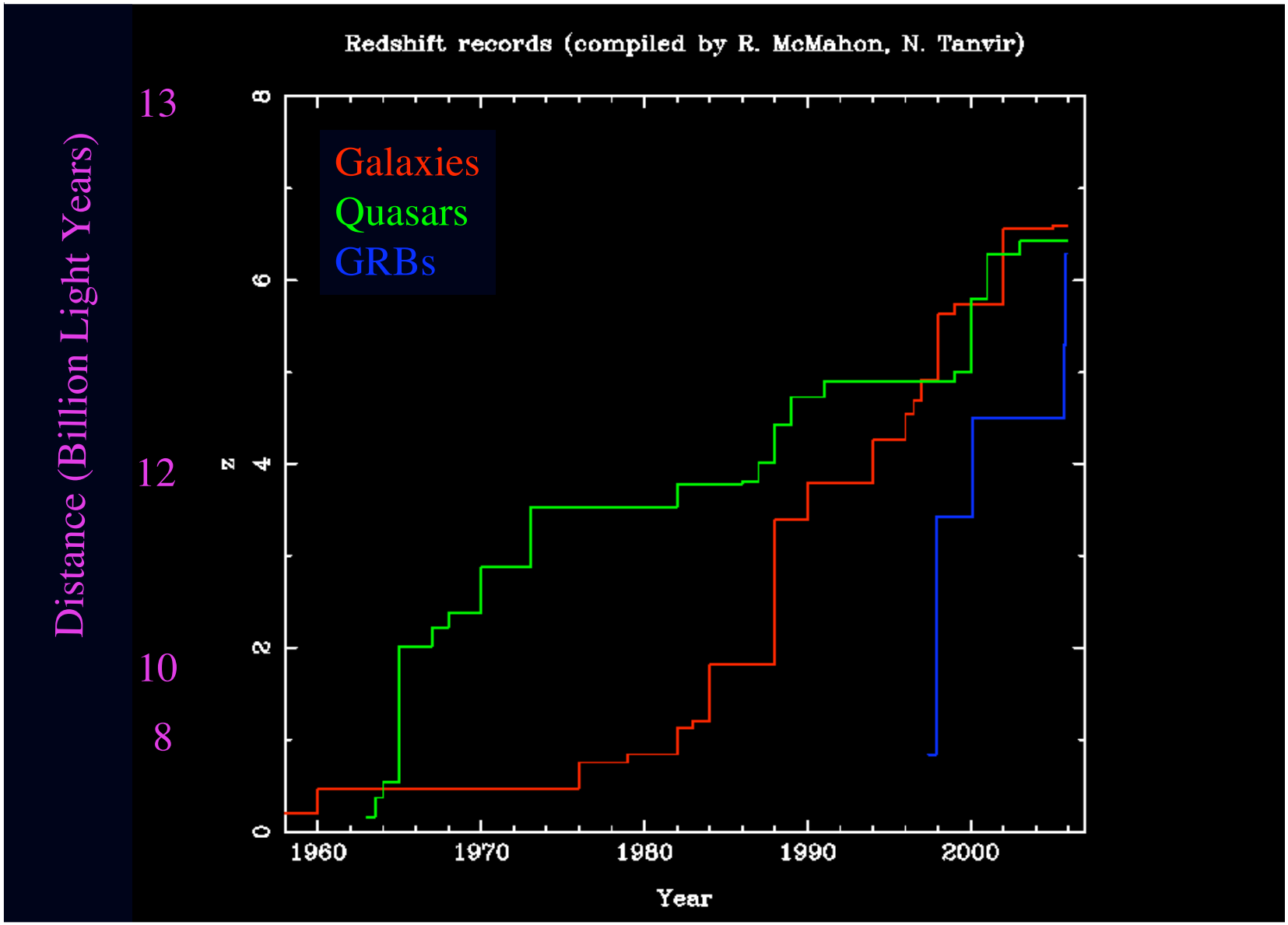
Average Redshift
- **Pre-Swift: z = 1.2**
- **Swift: z = 2.7**

Swift GRBs Tracing SFR



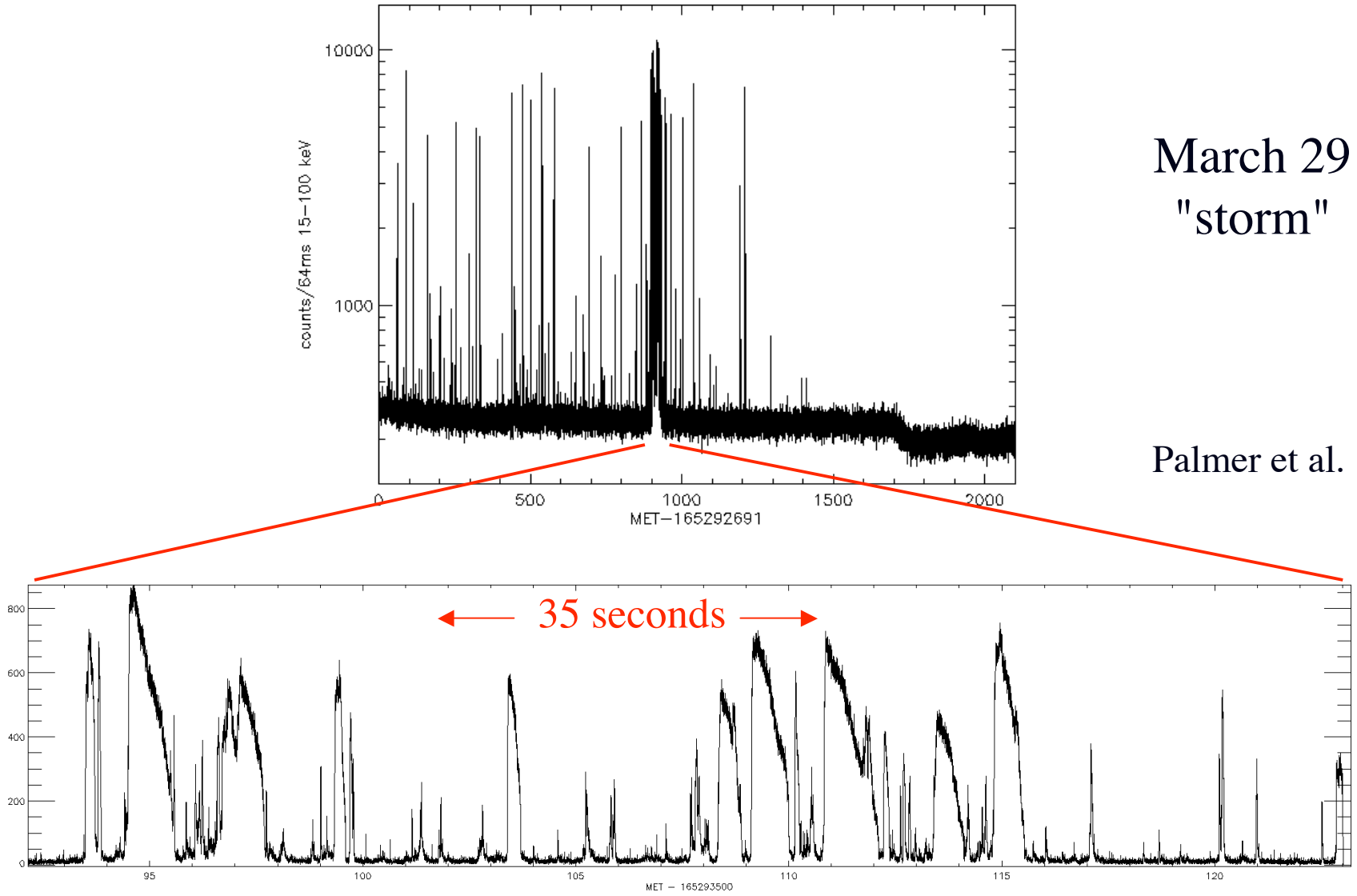
Jacobsson et al. 2005

Lines are models with GRBs proportional to SFR


Redshift records (compiled by R. McMahon, N. Tanvir)
Distance (Billion Light Years)
13
12
10
8
z
0
2
4
6
8
Galaxies
Quasars
GRBs
1960
1970
1980
1990
2000
Year

Tanvir (2005)

SGR 1900+14 Outburst

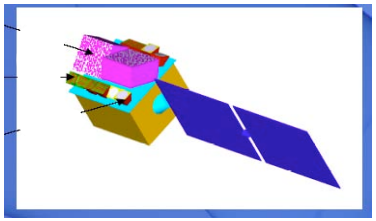


March 29
"storm"

Palmer et al.

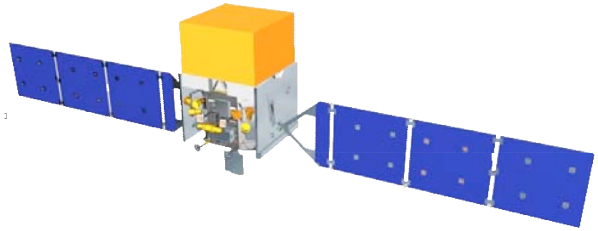
The Future

Swift will be in orbit until >2012



ECLAIRS - Smal French-Chinese GRB mission (~2010?)

GLAST & AGILE - High energy (>100 MeV) gamma-ray missions



Gravitational wave, neutrino & TeV gamma-ray observatories all searching for GRB signals

Swift Team

University of Leicester

NASA

GSFC

PENNSTATE 1855

UCL MSSL

asi agenzia spaziale italiana

OSSERVATORIO ASTRONOMICO DI BRERA

SPECTRUMASTRO

eV PRODUCTS

MPE

SONOMA STATE UNIVERSITY LUX MENTIS • LUX ORBIS • 1960

THE UNIVERSITY OF CALIFORNIA 1868

SwRI

SWALES AEROSPACE

Los Alamos NATIONAL LABORATORY

OMITRON inc.