GRB Observations and Follow-up by Swift

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NASA-GSFC

June 5, 2013

Fermi Summer School

Lenape or Delaware Indians

1632 – Zwaanendael
1664 – Hoernkills
1673 – New Deale
1831 – Lewes

Outline

→ Gamma ray burst background

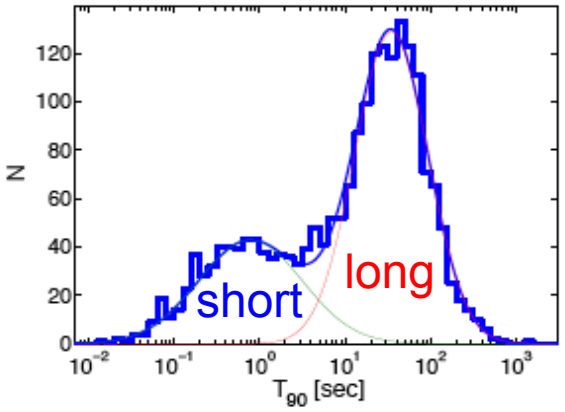
→ The Swift mission

→ Swift GRB results

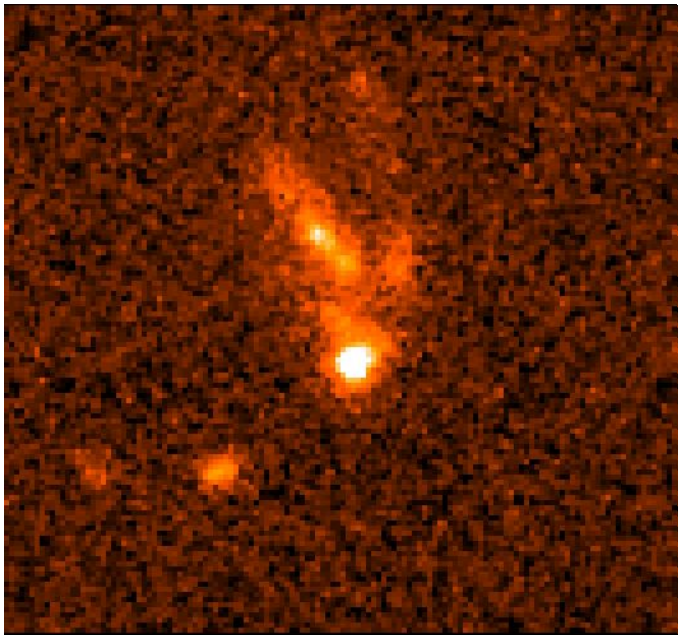
→ Swift follow-up of Fermi GRBs

GRB Properties

Durations – CGRO / BATSE



GRB 990123 - HST image



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

Origin:
NS-NS mergers SGRBs
Massive star collapse LGRBs

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

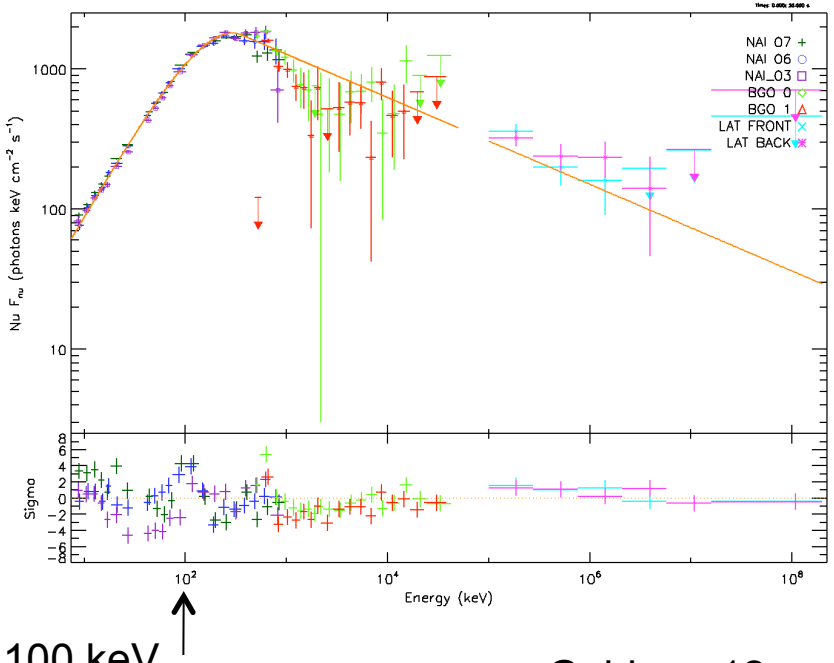
Energy release in γ-rays:
10^{49}-10^{50} ergs SGRBs
10^{50}-10^{51} ergs LGRBs

Jet opening angle:
? (5-20) deg SGRBs
~5 deg LGRBs

Both types have delayed & extended high-E emission

GRB Spectra

Prompt

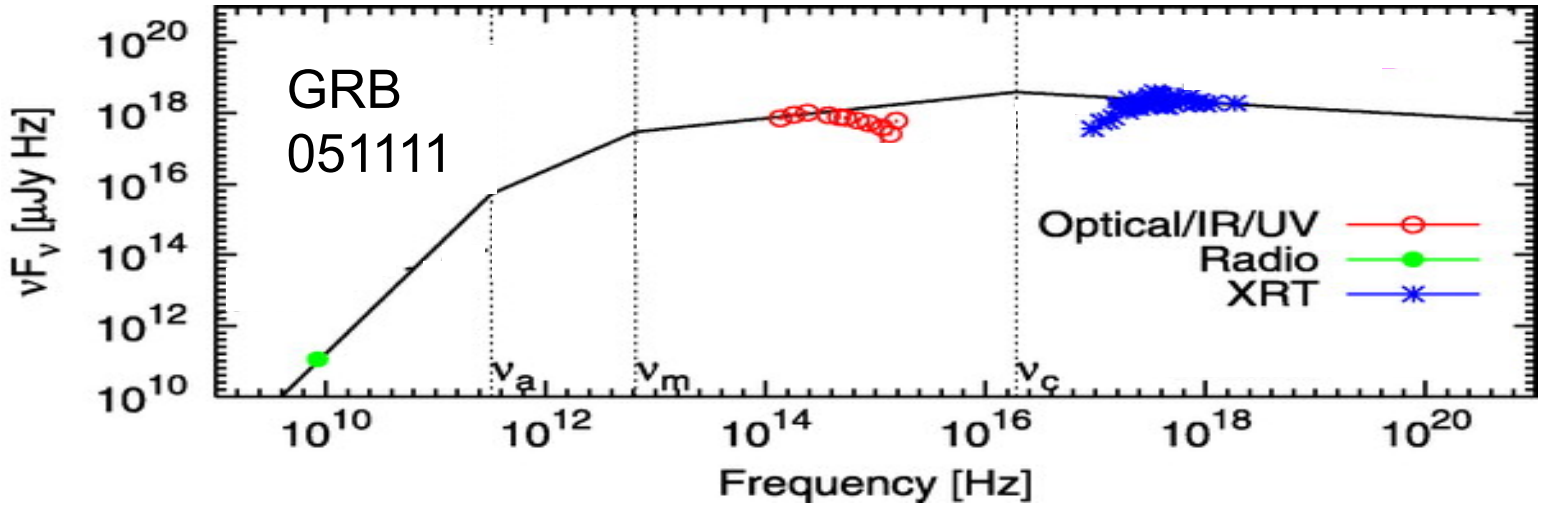


100 keV

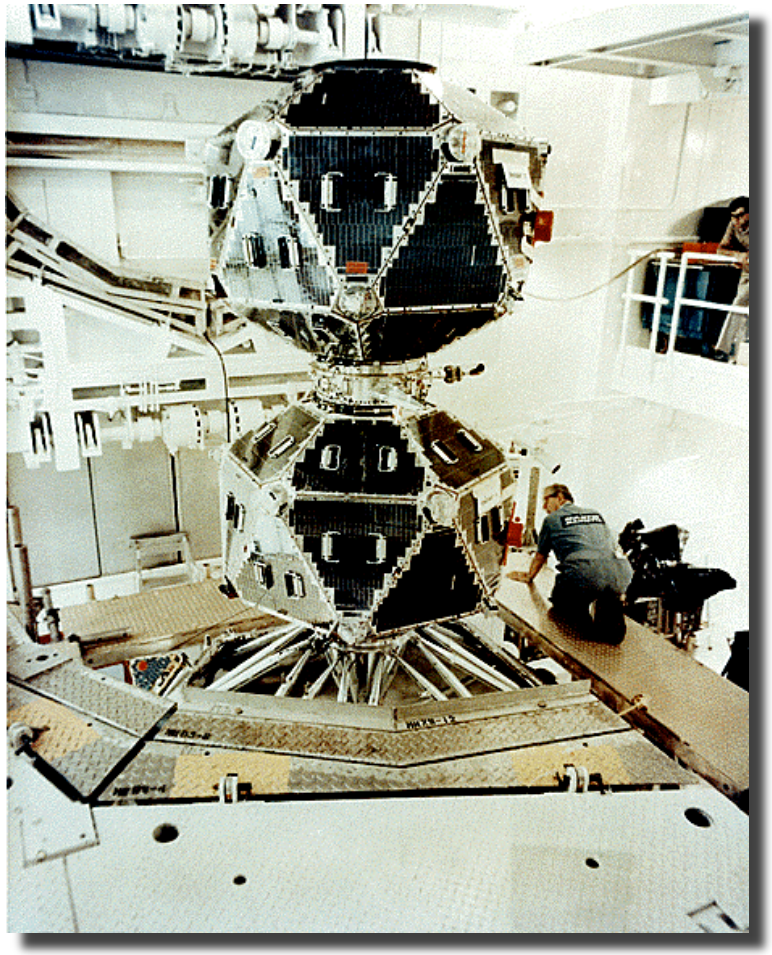
Guiriec+ 12

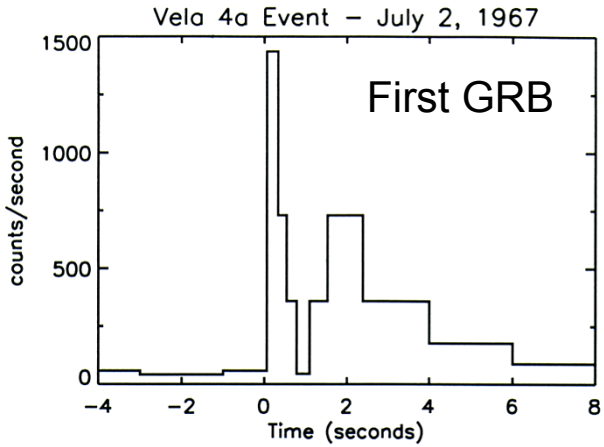
Afterglow

Butler+ 06



VELA Discovers GRBs





Klebesadel, Strong & Olson 1973

Ray Klebesadel 2009

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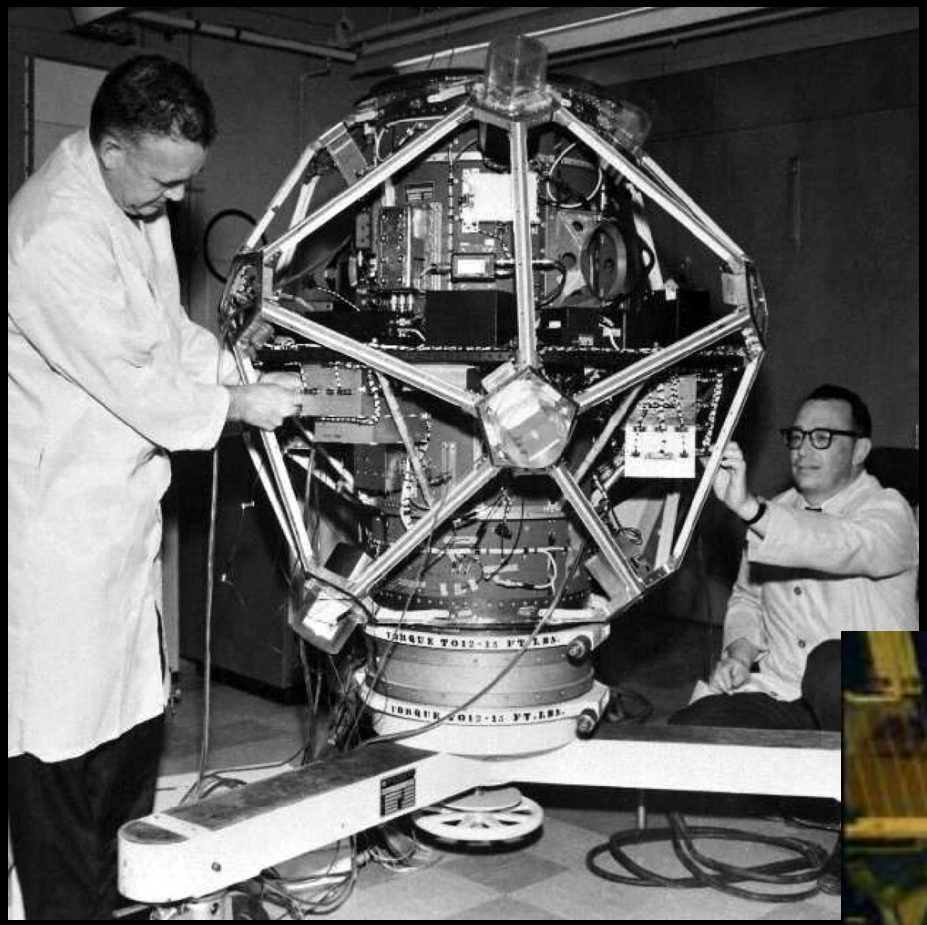
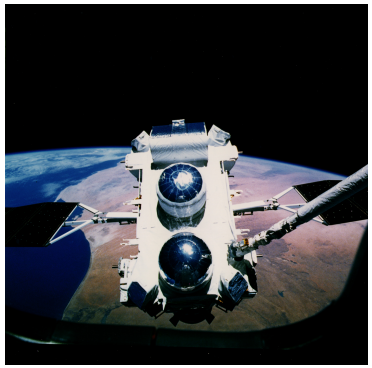
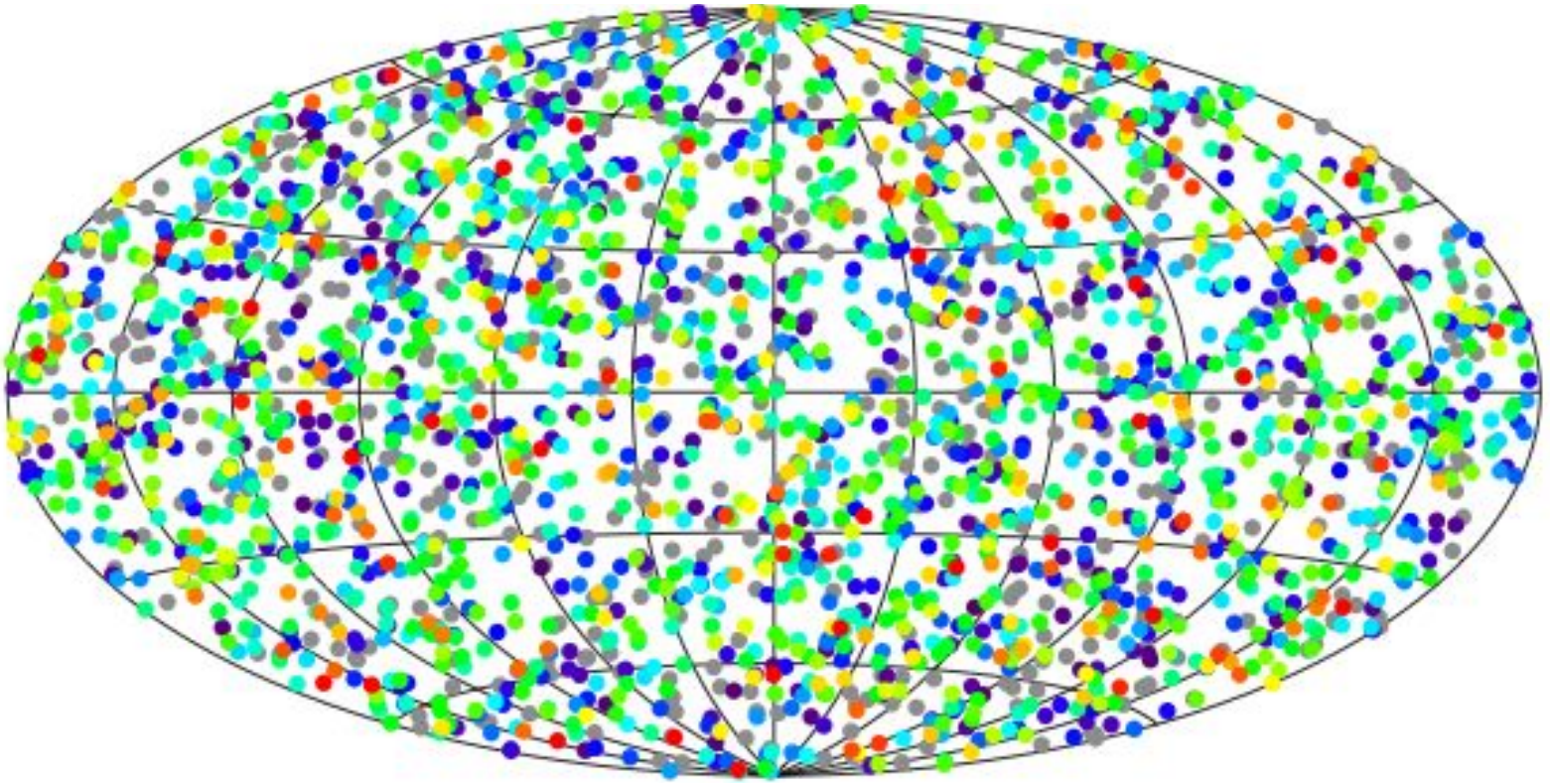


Compton Observatory Era

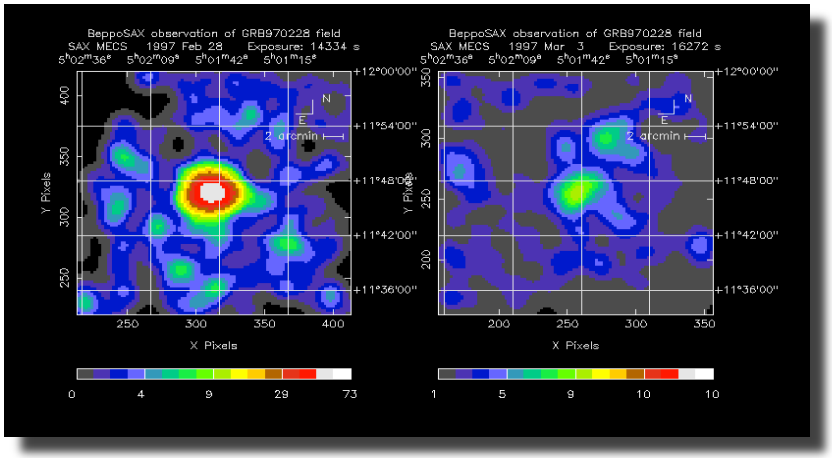


Sky Distribution of BATSE GRBs

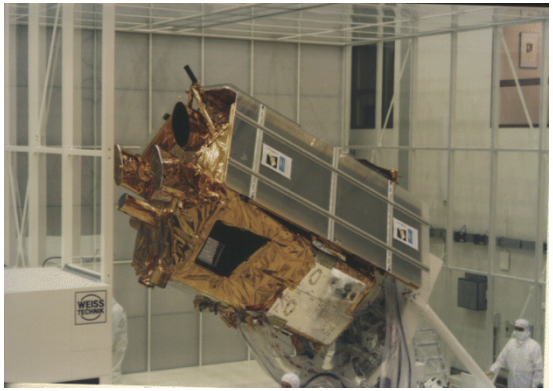


The Fireball !

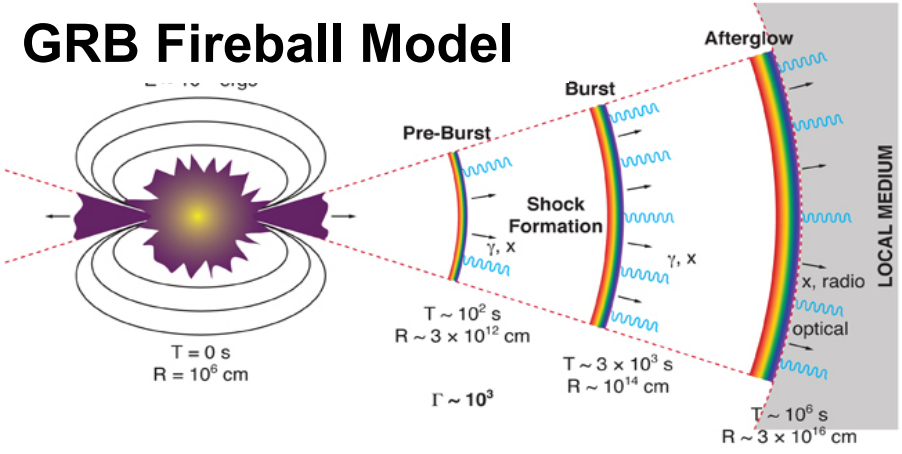
X-ray afterglow GRB 970228



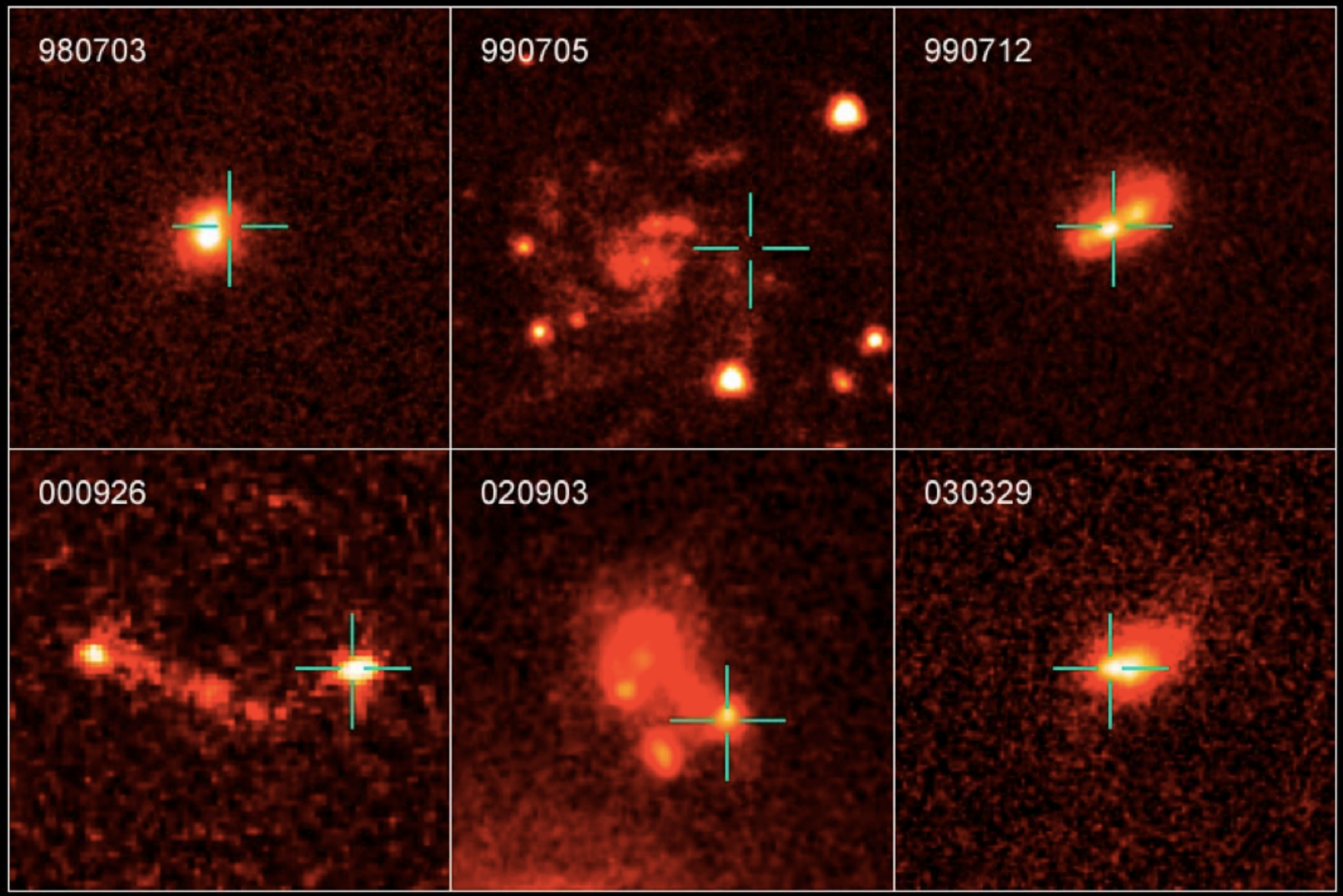
BeppoSAX satellite



GRB Fireball Model



Mészáros & Rees 1997



NASA, ESA, A. Fruchter (STScI), and the GOSH Collaboration

STScI-PRC06-20

Developments ~2000

Scientific urgency
for new GRB mission

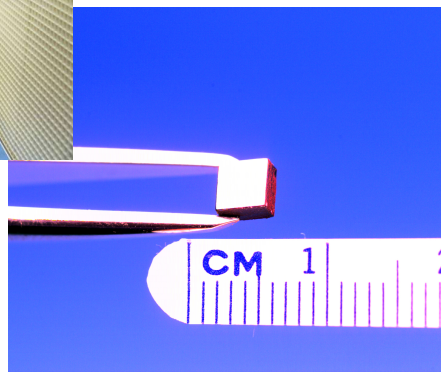
New CdZnTe detectors enable
advanced γ-ray camera

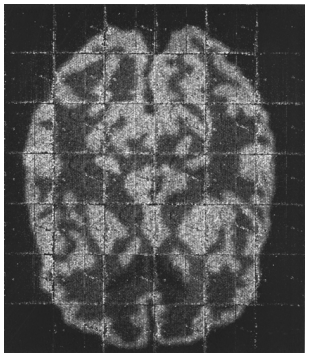
Recognized:
* GRBs are new tools for
  - high-z universe
  - SN physics
  - jet physics

However:
* Long GRBs poorly understood

* Short GRBs not understood

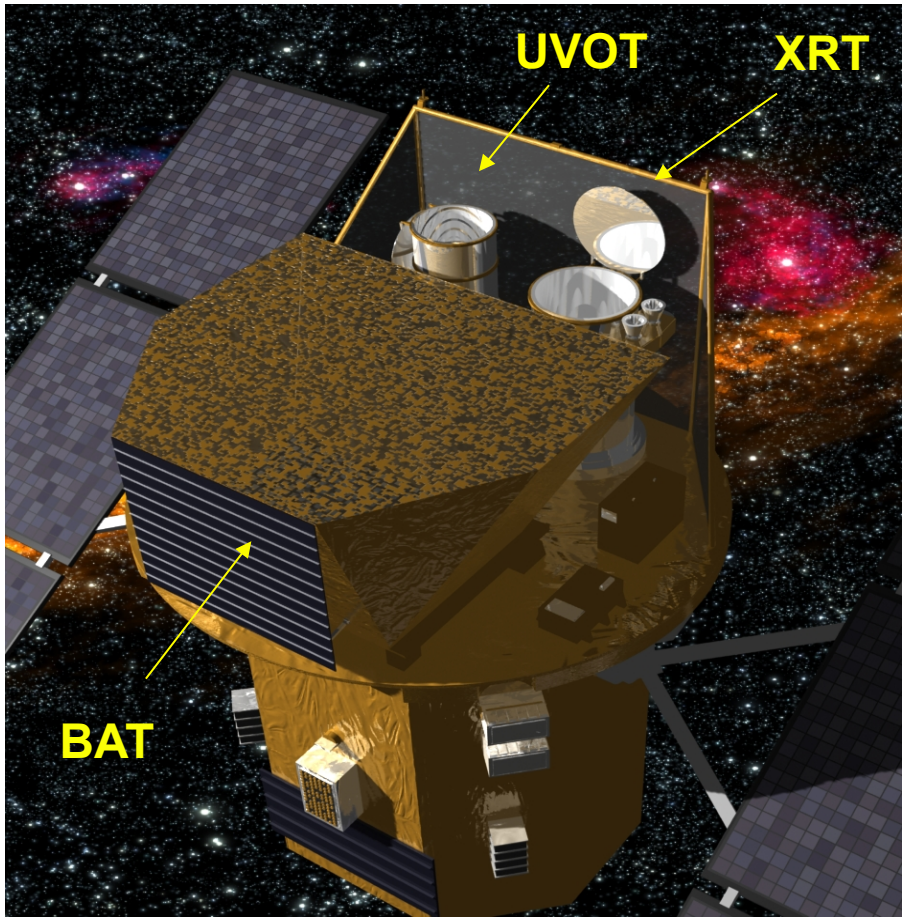
Needed:
* Rapid response & multi-wavelength observatory





medical imaging
brain scan

The Swift Mission



Swift Mission

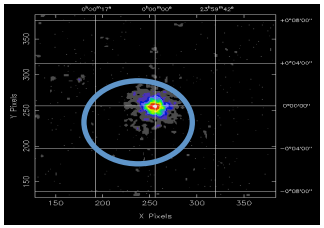
3 instruments, each with:
- lightcurves
- images
- spectra

Rapid slewing spacecraft

BAT Position - 2 arcmin

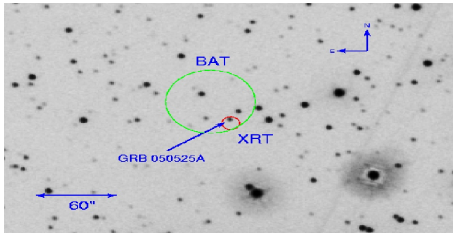
T<10 sec

XRT Position - 5 arcsec



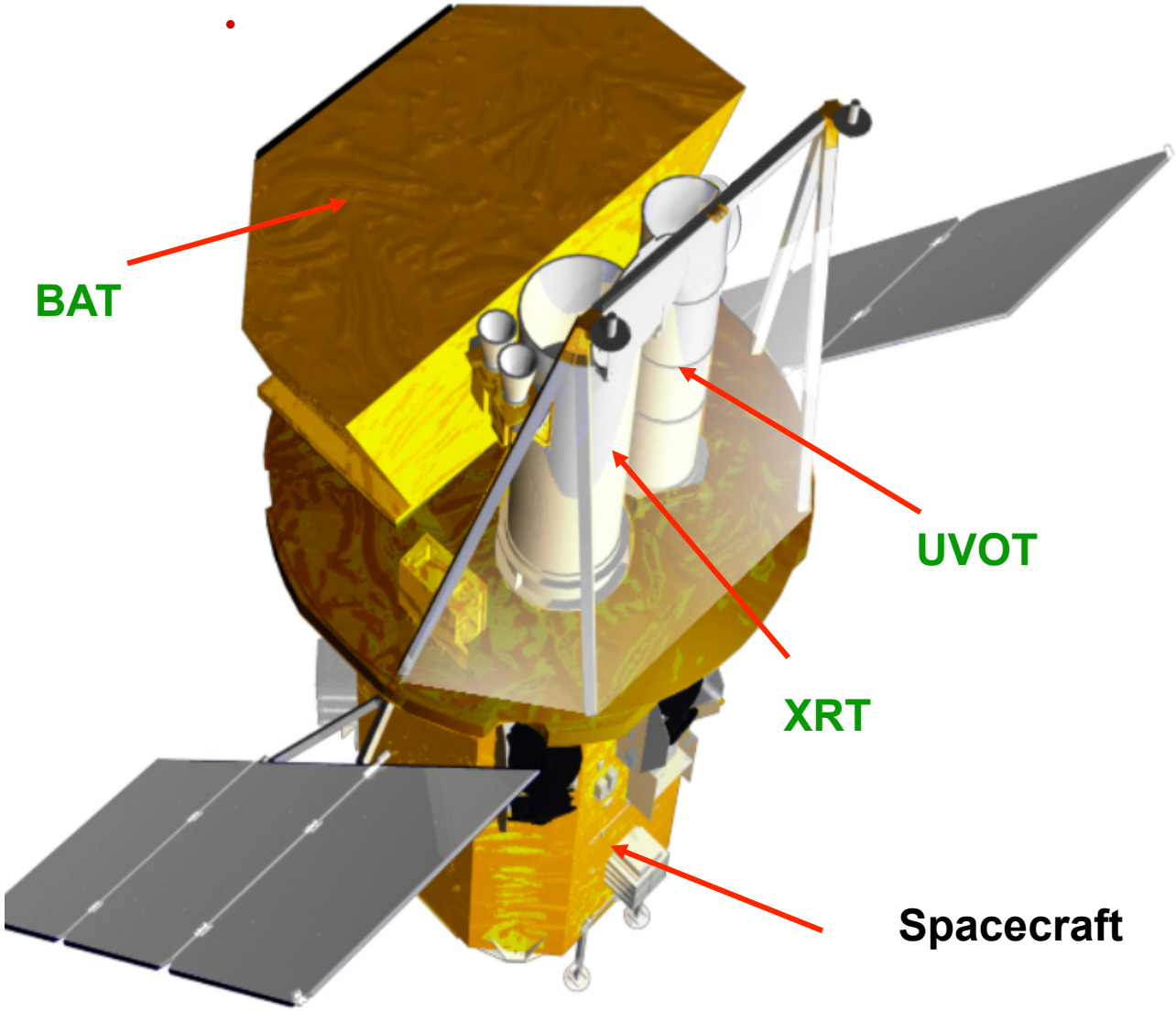
T<90 sec

UVOT Position - < 1 arcsec



T<2 min

Observatory Properties



Orbit

600 km x 28˚ inclination

BAT

New CdZnTe detector

2 sr FoV

13 – 150 keV

XRT

Arcsec GRB positions

24' x 24' FoV

0.2- 10 keV

CCD spectroscopy

UVOT

Sub-arcsec positions

17' x17' FoV

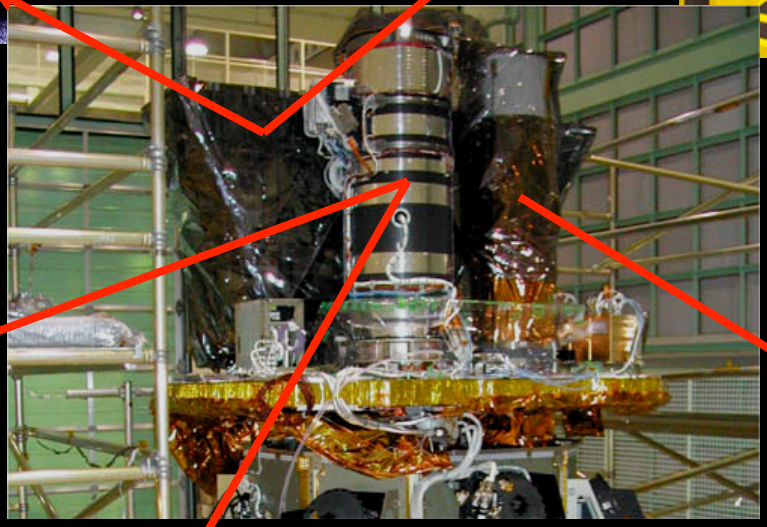
170 – 650 nm

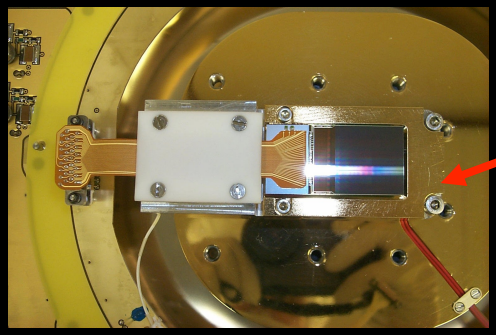
filters = grism

Spacecraft

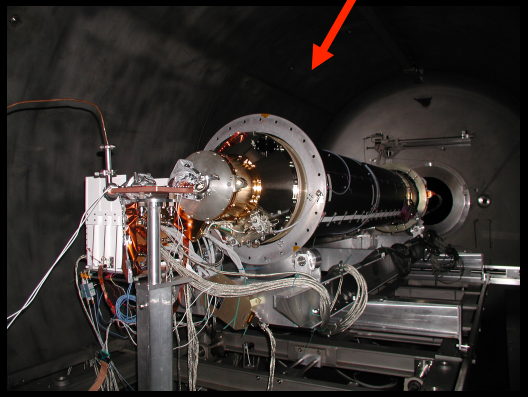
Autonomous slews 20-75s

BAT



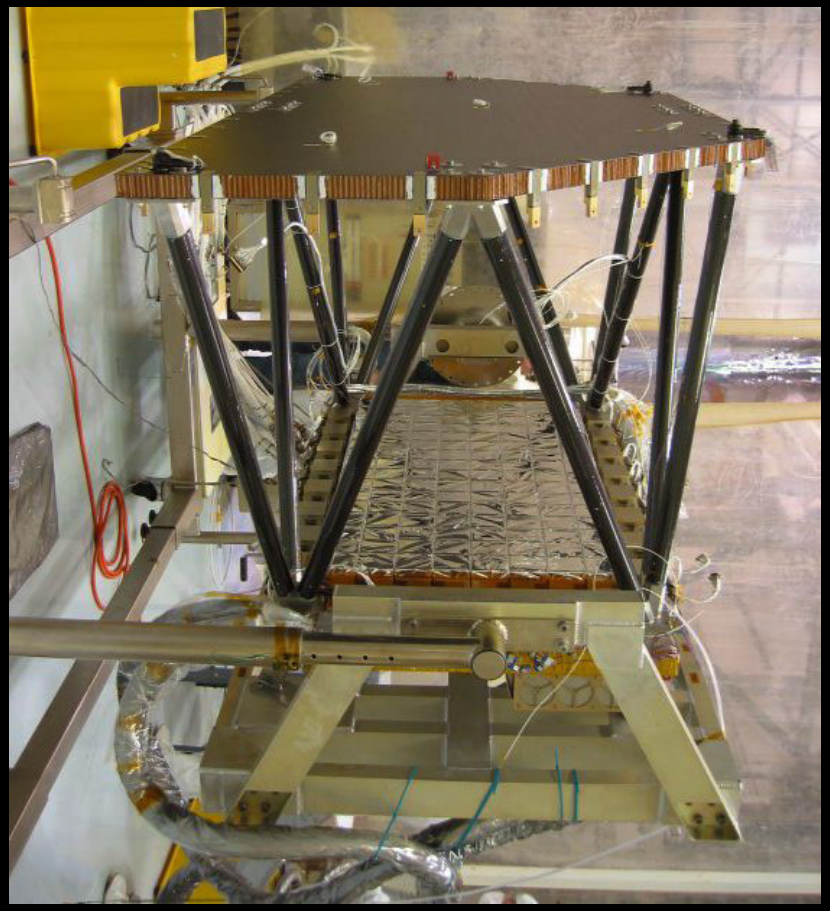


XRT

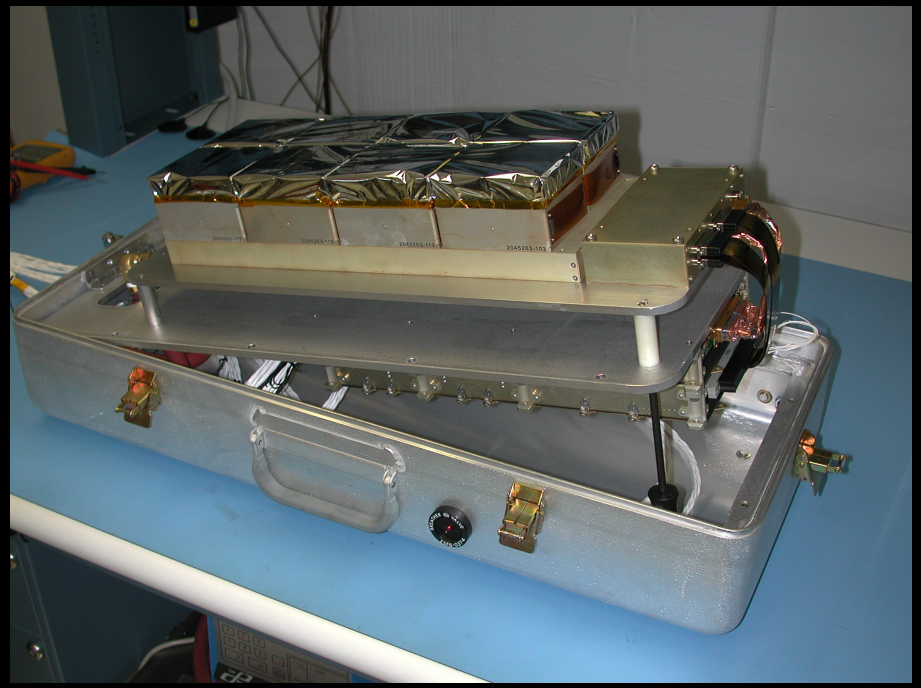


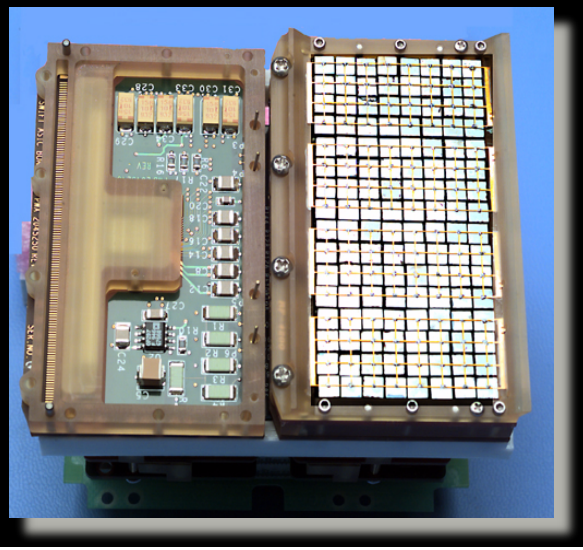
UVOT

BAT CdZnTe Detectors



13 – 300 keV





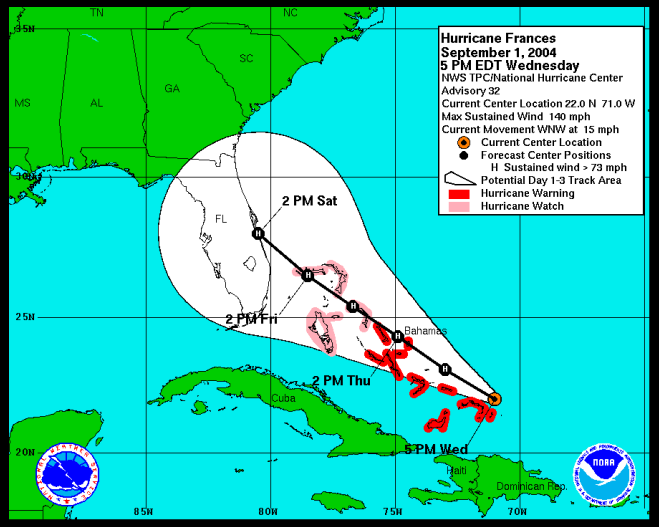
32,000 CZT detectors

Florida 2004 - Hurricane Alley

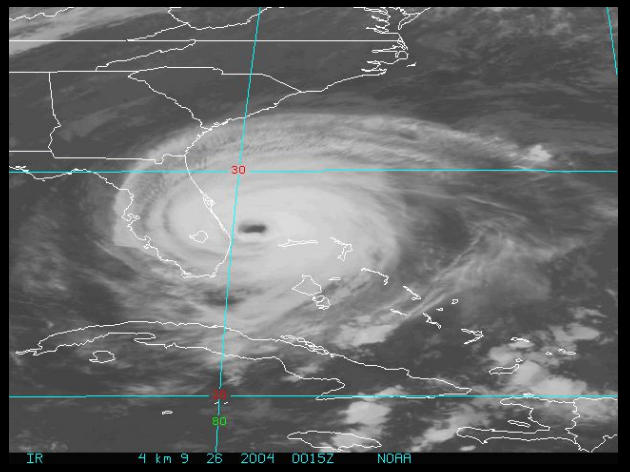
Hurricanes:

- Charley Aug 13
- Frances Sept 4
- Ivan Sept 10
- Jeanne Sept 25

Frances

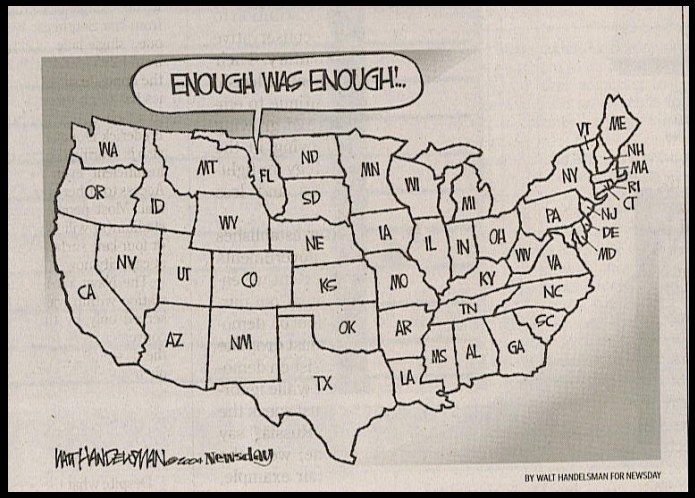


Jeanne

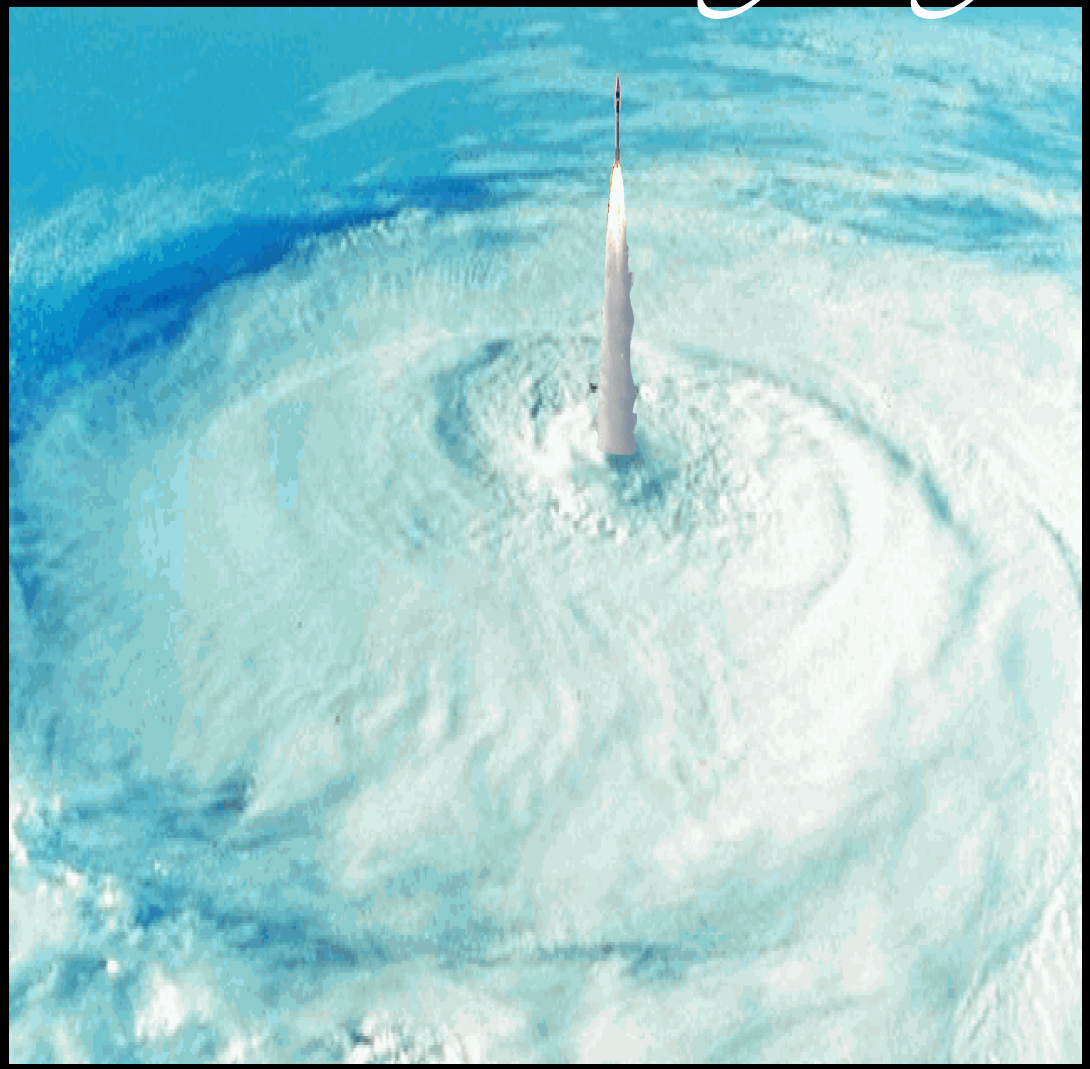


Jeanne

Vehicle Assembly Building damage

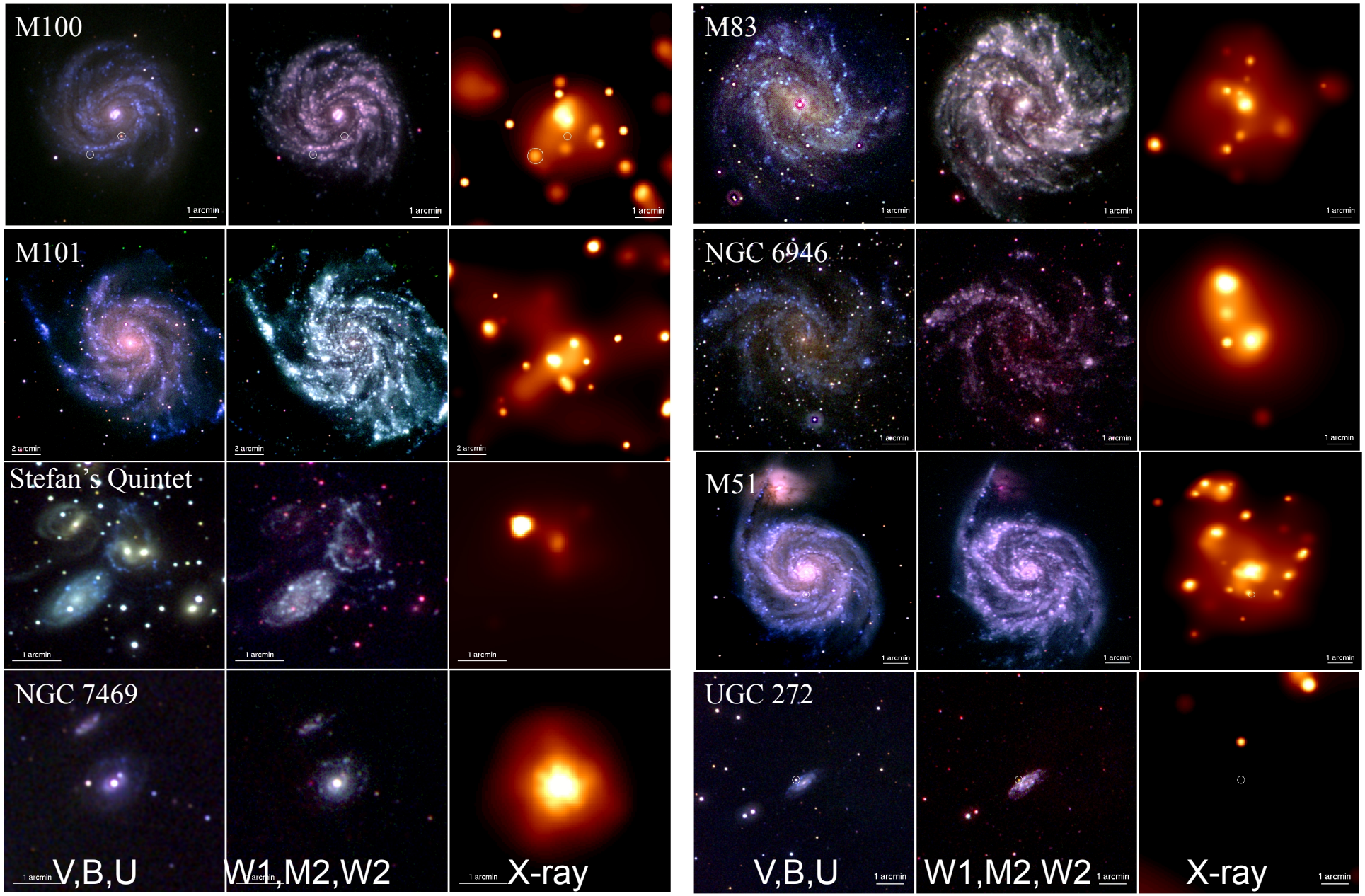


Let's Launch Anyway !!!



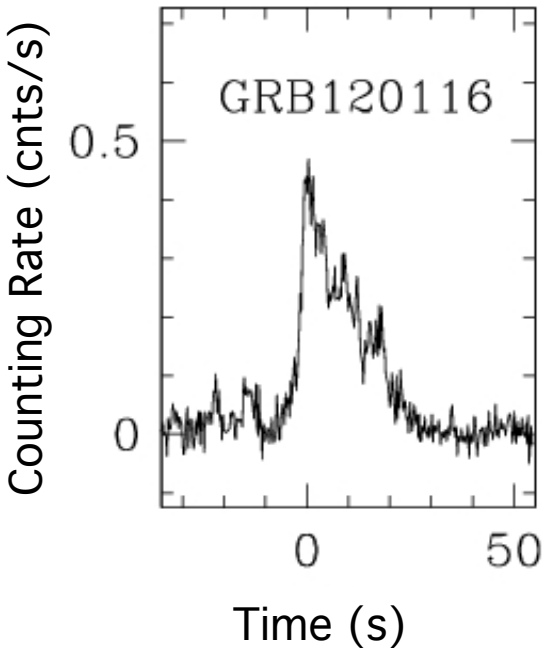
XRT & UVOT Galaxy Mugshots

S. Immler

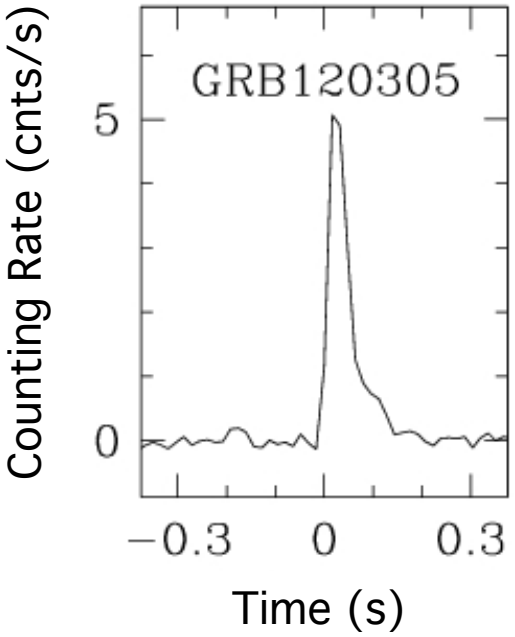


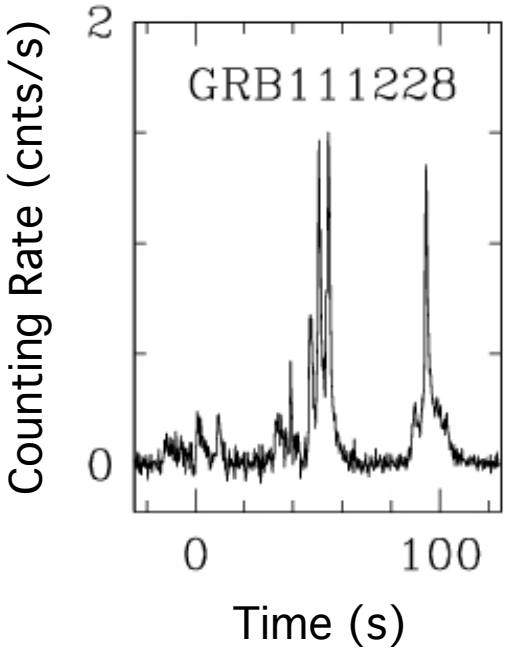
Swift Statistics

773	GRBs as of yesterday
85%	with X-ray detections
60%	with optical detection
250	with redshift (41 prior to Swift)
72	**short GRBs** localized (0 prior to Swift)



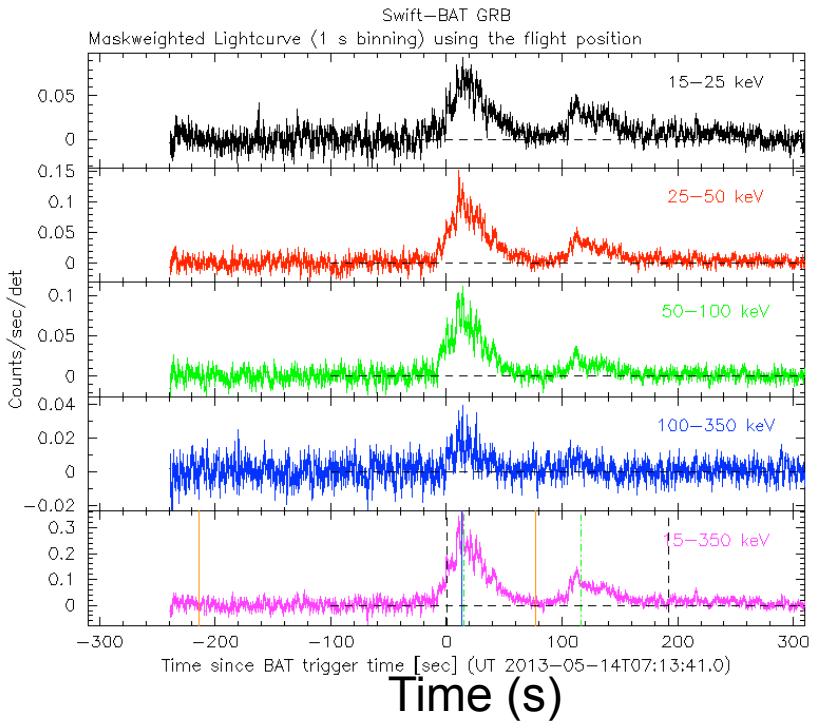
short





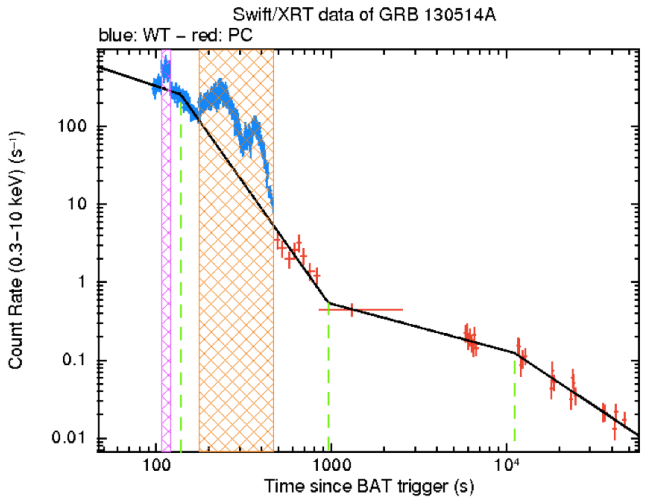
Swift Data
GRB 130524A

BAT lightcurves

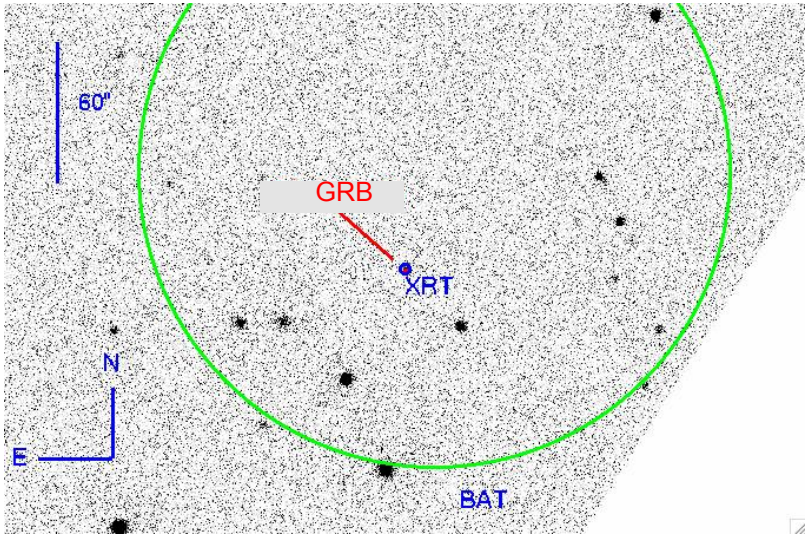


Time (s)

XRT lightcurve



UVOT image



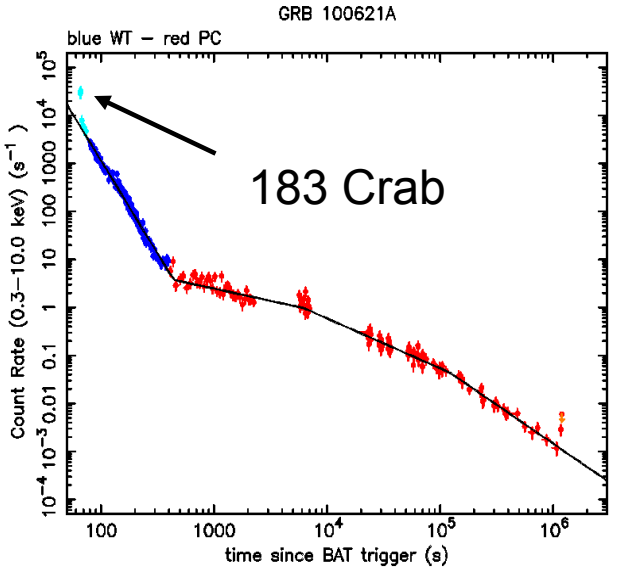
Long GRBs

High Redshift GRBs

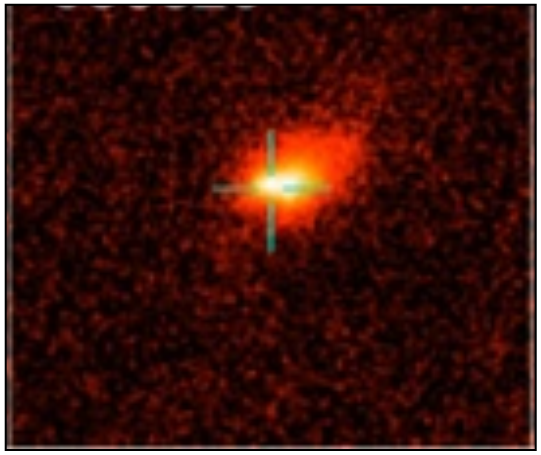
z	Look-Back Time (Gyr)	GRB	Optical Brightness
9.4	13.1	090429B	K = 19
8.2	13.0	090423	K = 20
~8	13.0	120923A	
7.5	13.0	100905A	H ~ 19
6.7	12.8	080813	K = 19
6.3	12.8	050904	J = 18
6.2	12.8	120521C	
5.6	12.6	060927	I = 16
5.3	12.6	050814	K = 18
5.11	12.5	060522	R = 21

GRBs: brightest high-z sources

XRT Lightcurve

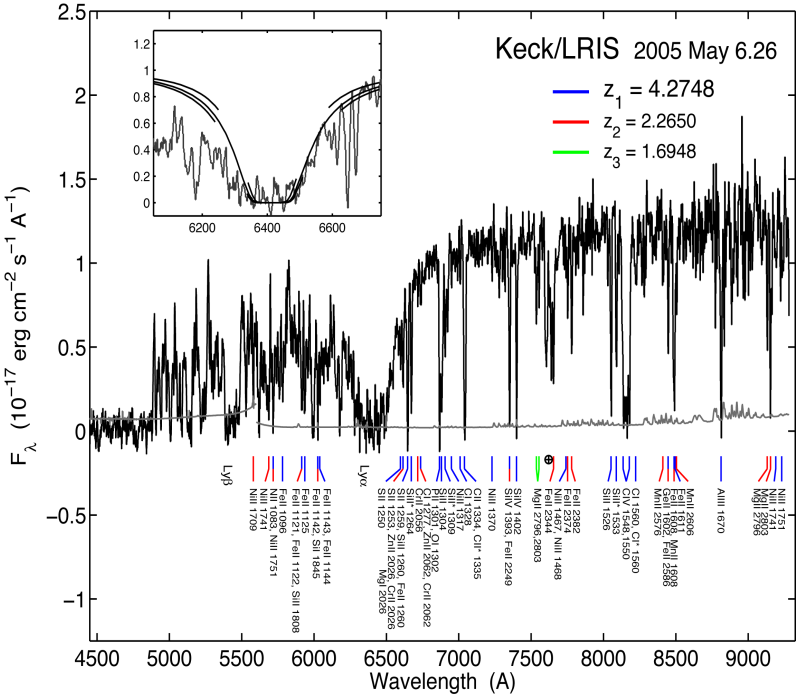


HST image



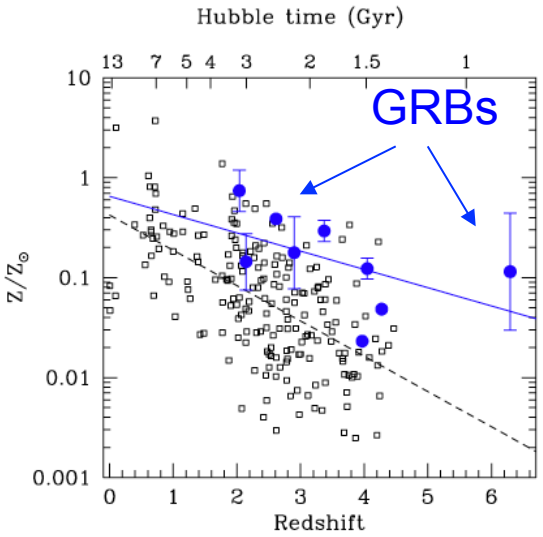
GRB Host Spectroscopy

GRB 050505 z=4.2 12.2 Gyr



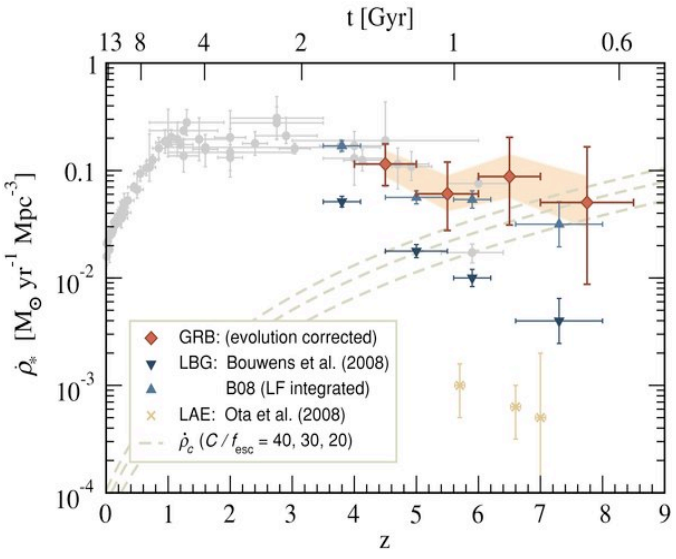
Berger+06

Metallicity



Savaglio 06

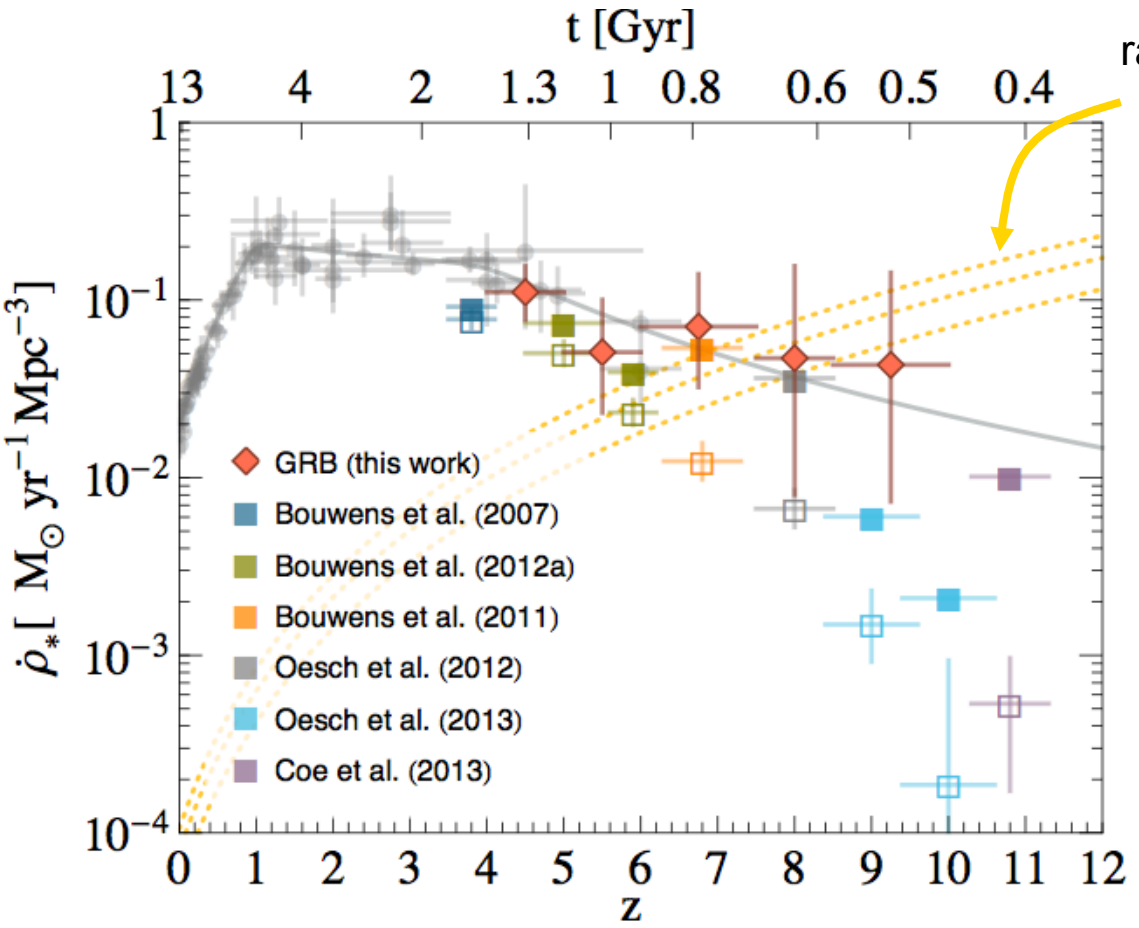
Star Formation Rate



Kistler+ 09
Robertson & Ellis 11

Star Formation Rate

Star Formation Rate

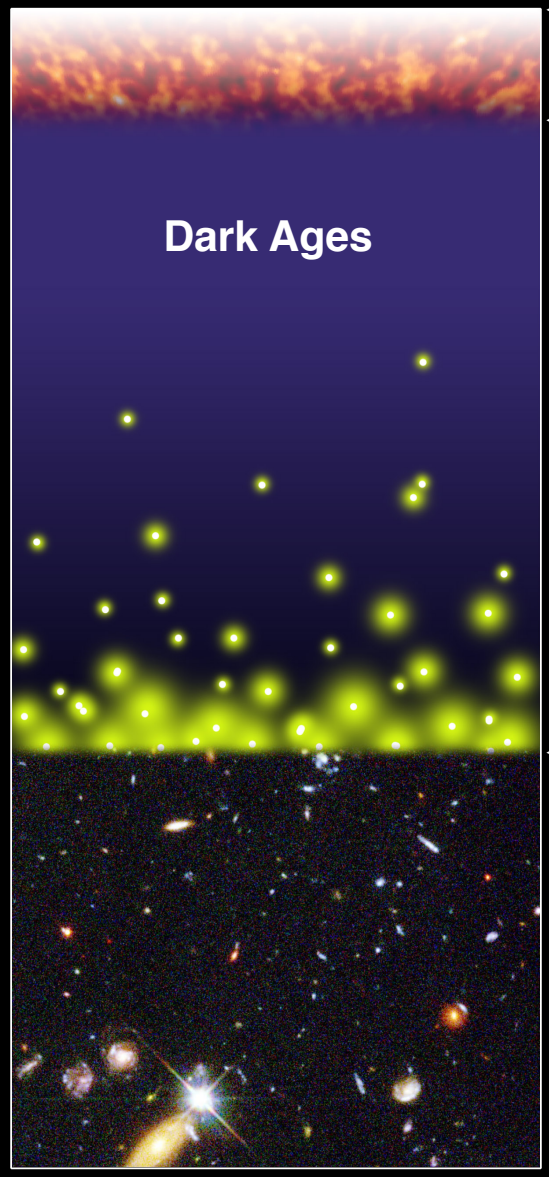


rate to balance
H I formation
Madau+ 99

Kistler+ 13

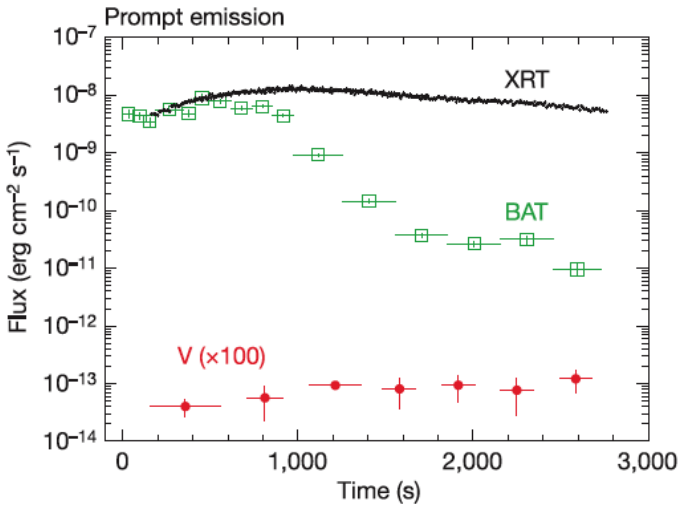
History of the Universe

Redshift	Time	
1000	-	Big Bang - Hot ionized gas
		The Universe becomes neutral and opaque
100	- 17 Myr	
		Stars and galaxies form Reionization starts
10	- 480 Myr	
GRB 090429B 9.4		
		Cosmic Renaissance Dark Ages end
5	- 1.2 Gyr	Reionization complete
		Galaxies evolve
0.5	- 8.7 Gyr	Solar System forms
0	- 13.7 Gyr	



Djorgovski et al.

GRB 060218: GRB + Supernova



Campana+ 006

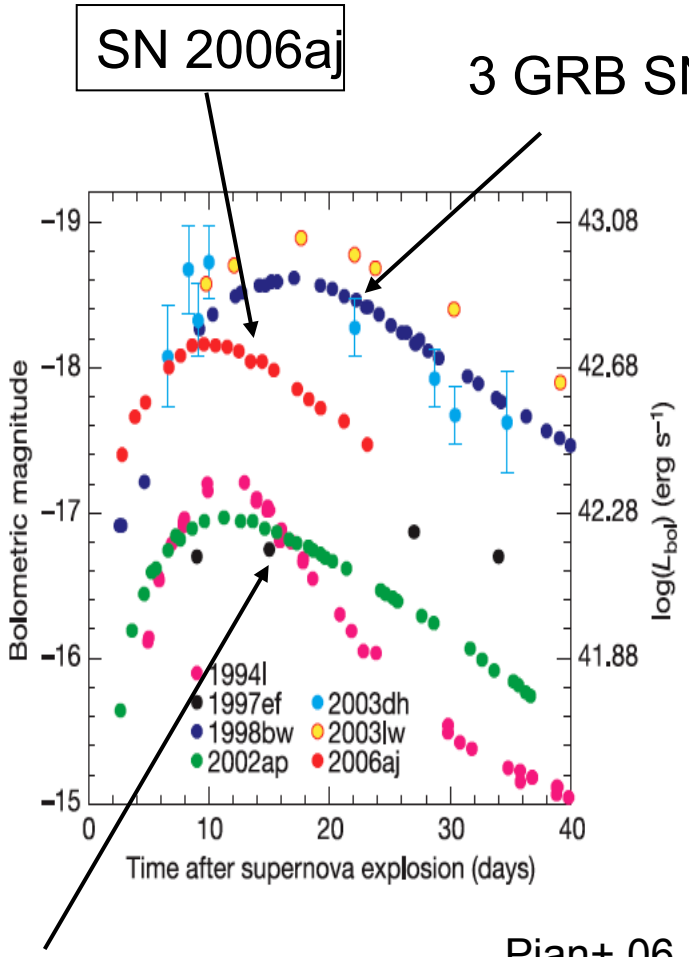
Super-long GRB - ~35 minutes

BAT, XRT, UVOT during GRB

z = 0.033 d = 145 Mpc

SN 2006aj SN Ib/c

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

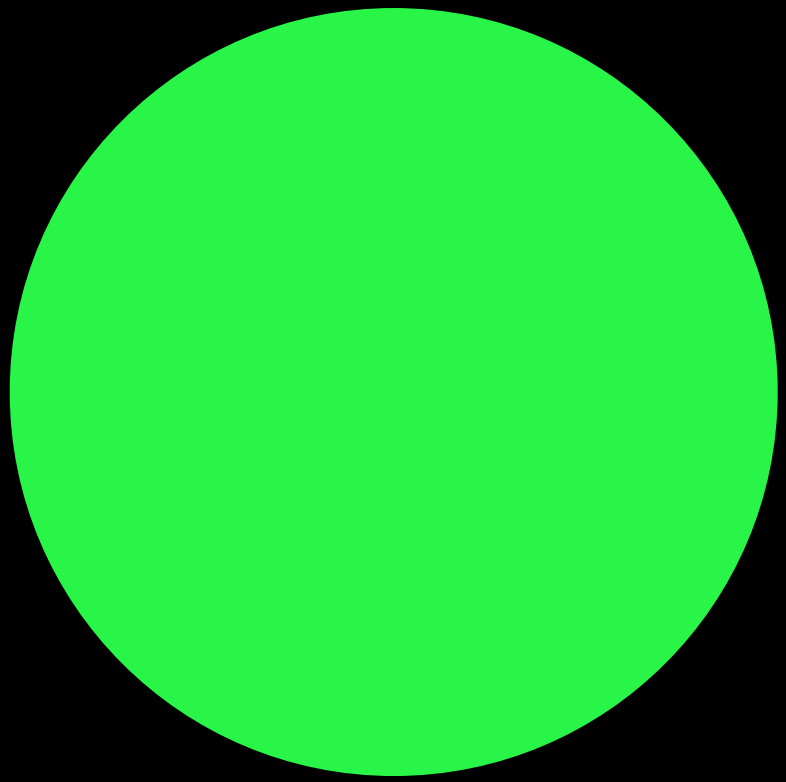


Pian+ 06

SNe Ic

Campana+ Mazzali+, Pian+, Soderberg+ 06

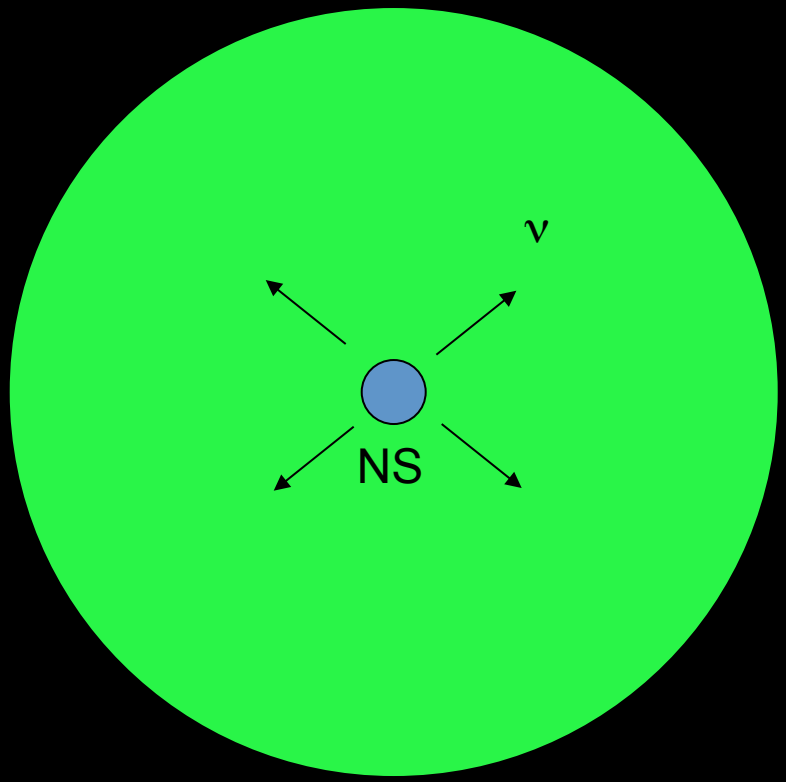
Long GRB Scenario



Massive star with H & He envelope stripped

Rapidly rotating

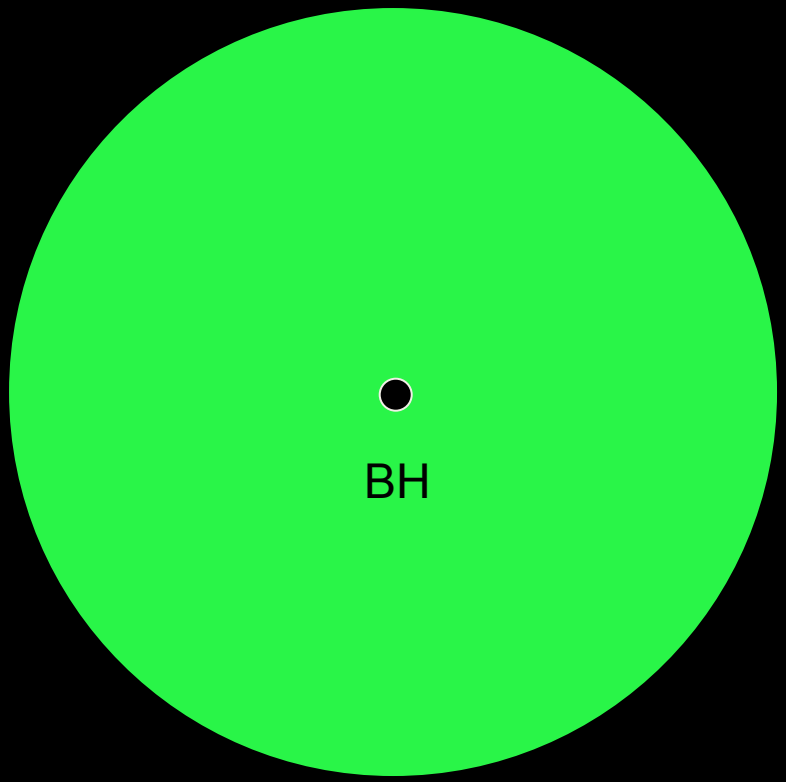
Long GRB Scenario



Massive star
Rapid rotation

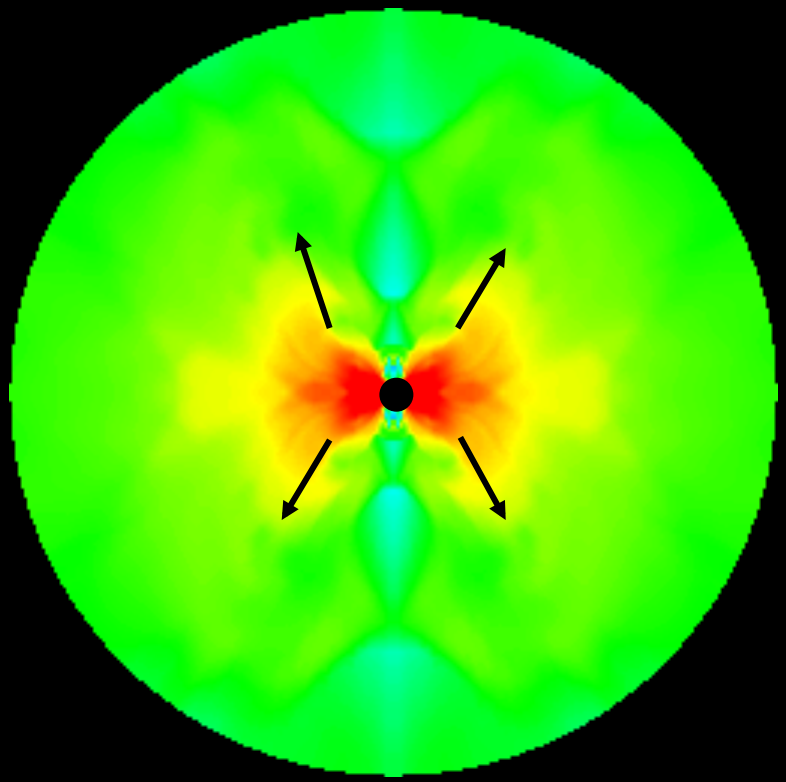
Proto-NS
Neutrino emission
Collapse τ < 1 sec

Collapsar Model



Collapse to BH

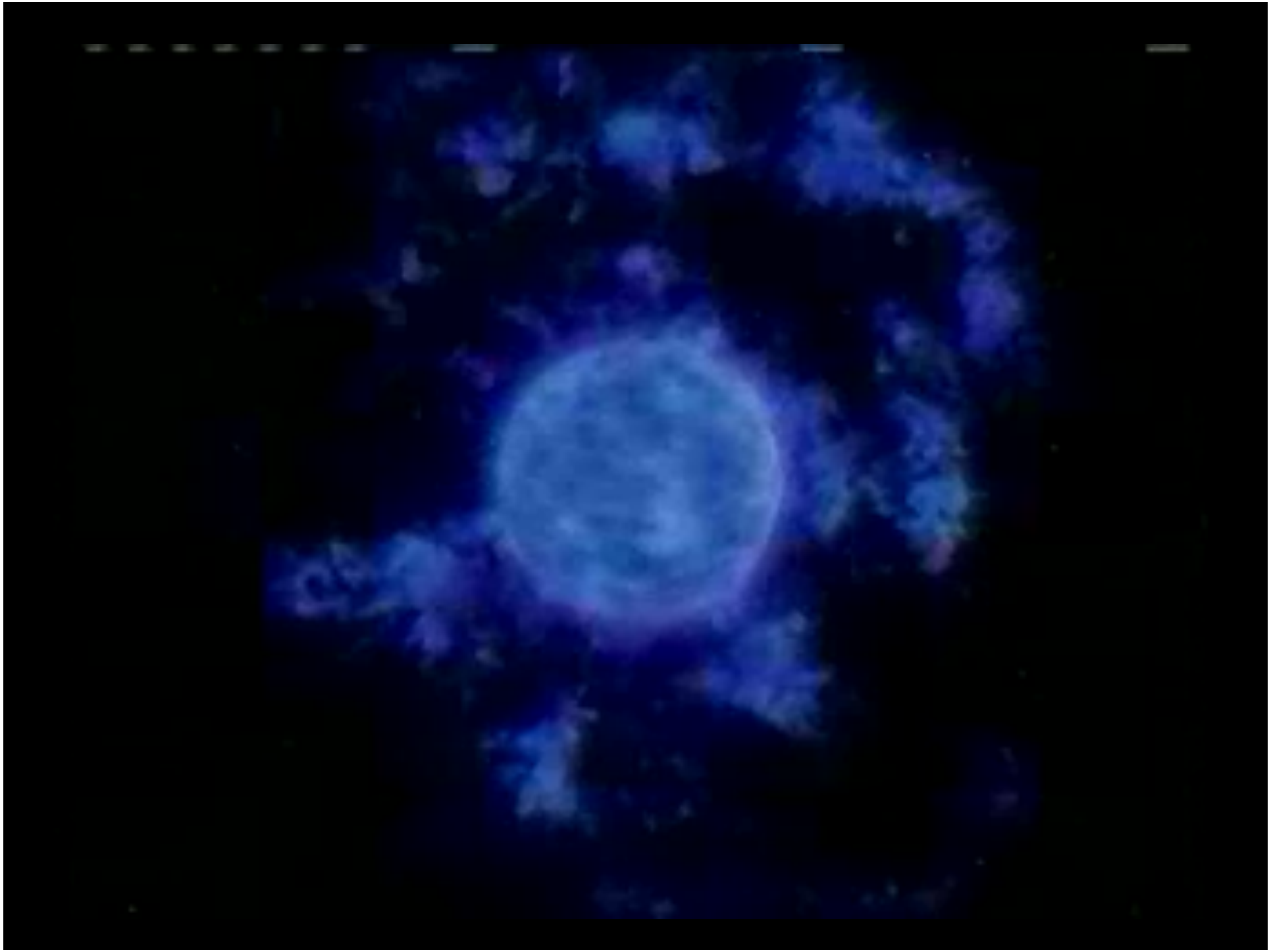
Long GRB Scenario



Accretion onto BH
τ ~ 10's sec

Jet emergence
τ ~ 10 sec

MacFadyen & Woosley




6 October 2005 | www.nature.com/nature | $10
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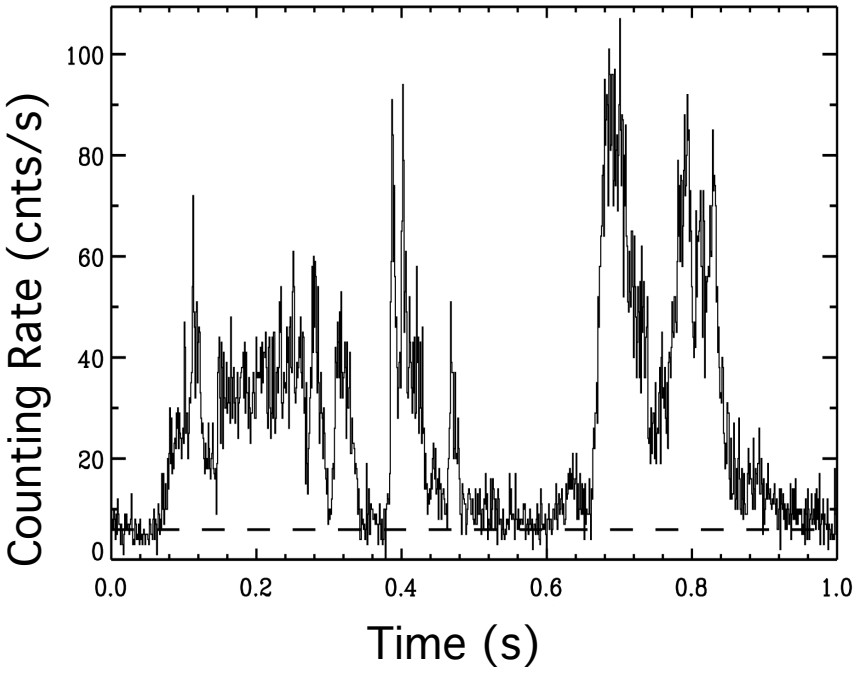
nature
SHORT GAMMA-RAY BURSTS
The birth of a black hole seen in the stars
INFLUENZA PANDEMIC
Genome sequence of the 1918 virus
SEX PHEROMONES
A glint in the eye
EARTHQUAKES
Pulling the trigger
NATUREJOBS
Project management

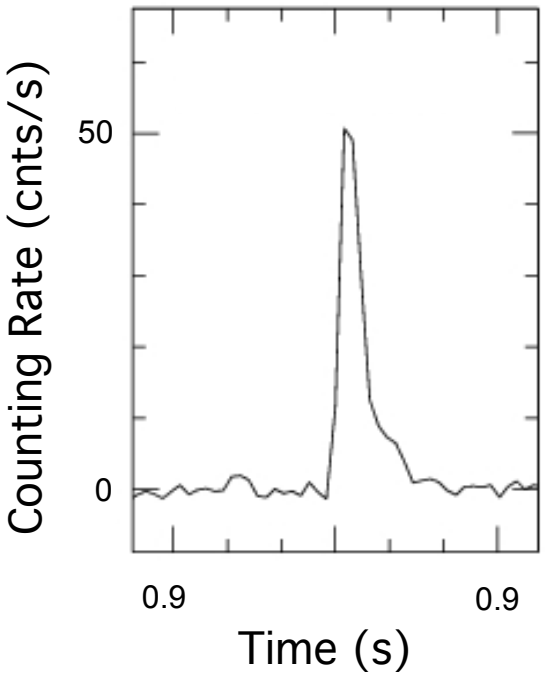
Short GRBs

Short Burst Variety

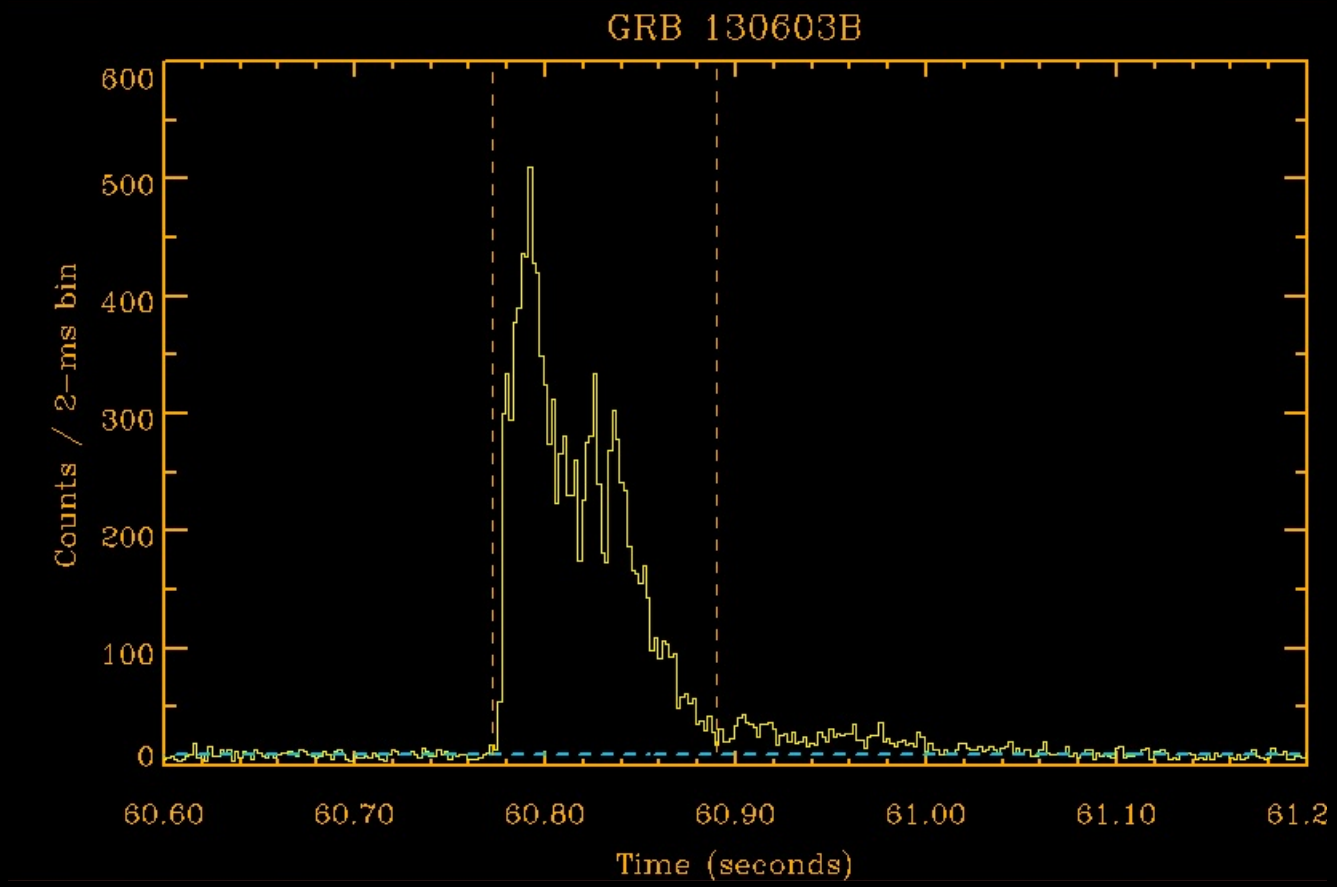
GRB 060313



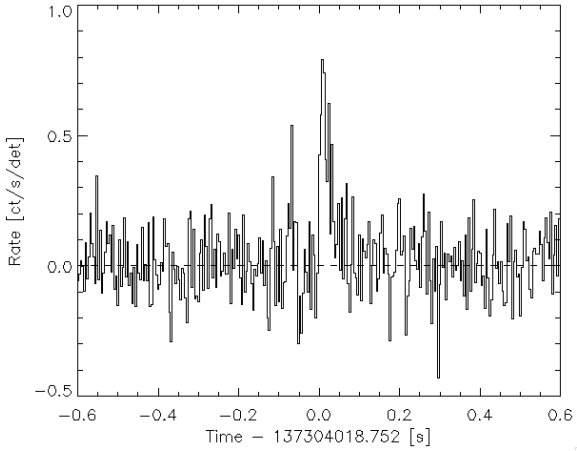
GRB 130515



GRB 130603B


GRB 130603B
Counts / 2-ms bin
600
500
400
300
200
100
0
60.60
60.70
60.80
60.90
61.00
61.10
61.2
Time (seconds)

Cracking the Short Burst Problem



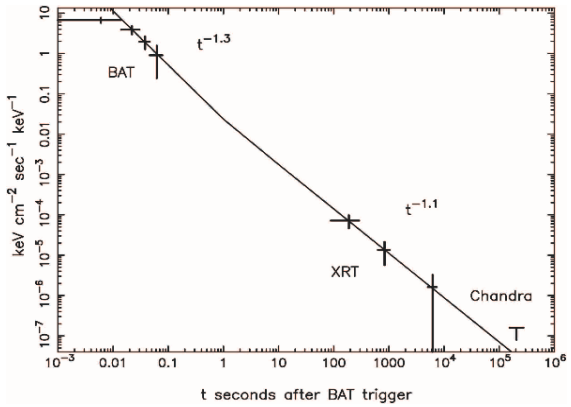
GRB 050509B

BAT
- 30 ms duration

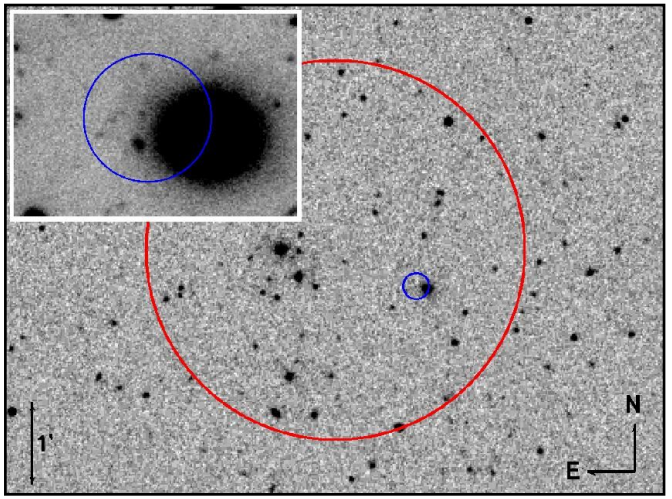
XRT
- faint source, fading

Host
- cD elliptical (L = 3 L*)
- low star formation rate
- **z = 0.225** (817 M yrs)

No supernova to deep limits



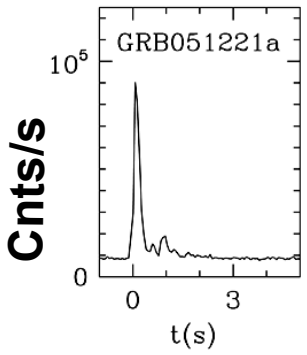
Gehrels+ 05; Bloom+ 06



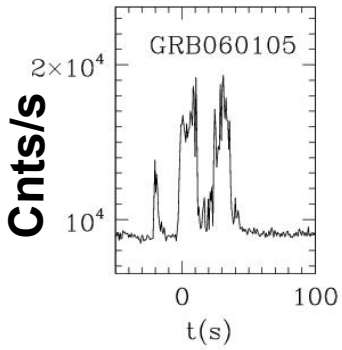
VLT image
Hjorth+ 05

Short vs Long GRBs

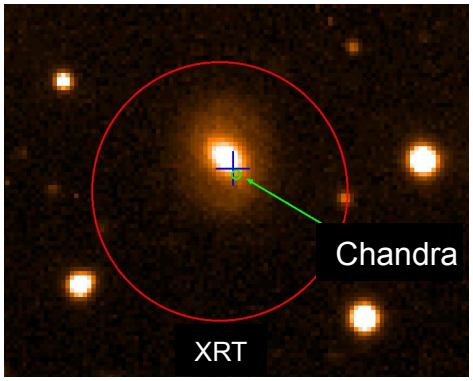
Short GRB



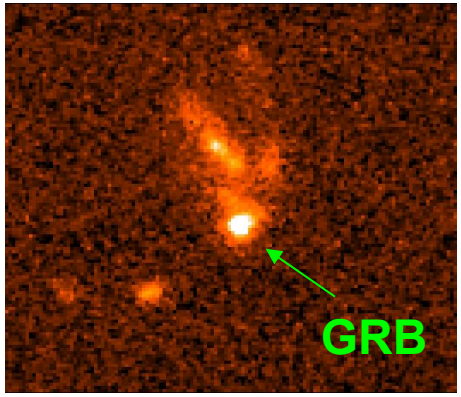
Long GRB



GRB 050724 - *Swift*
elliptical host



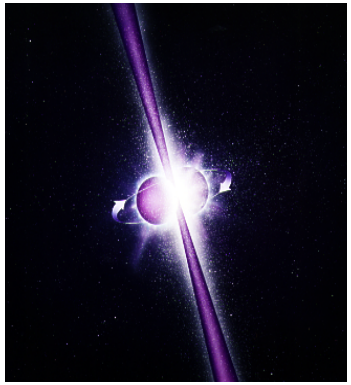
GRB 990123 - *SAX*
SF dwarf host

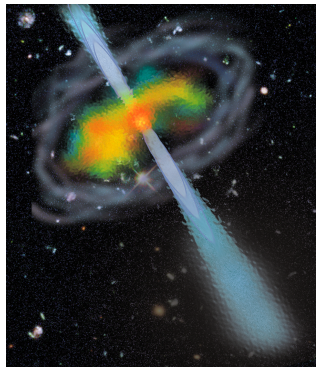


In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model





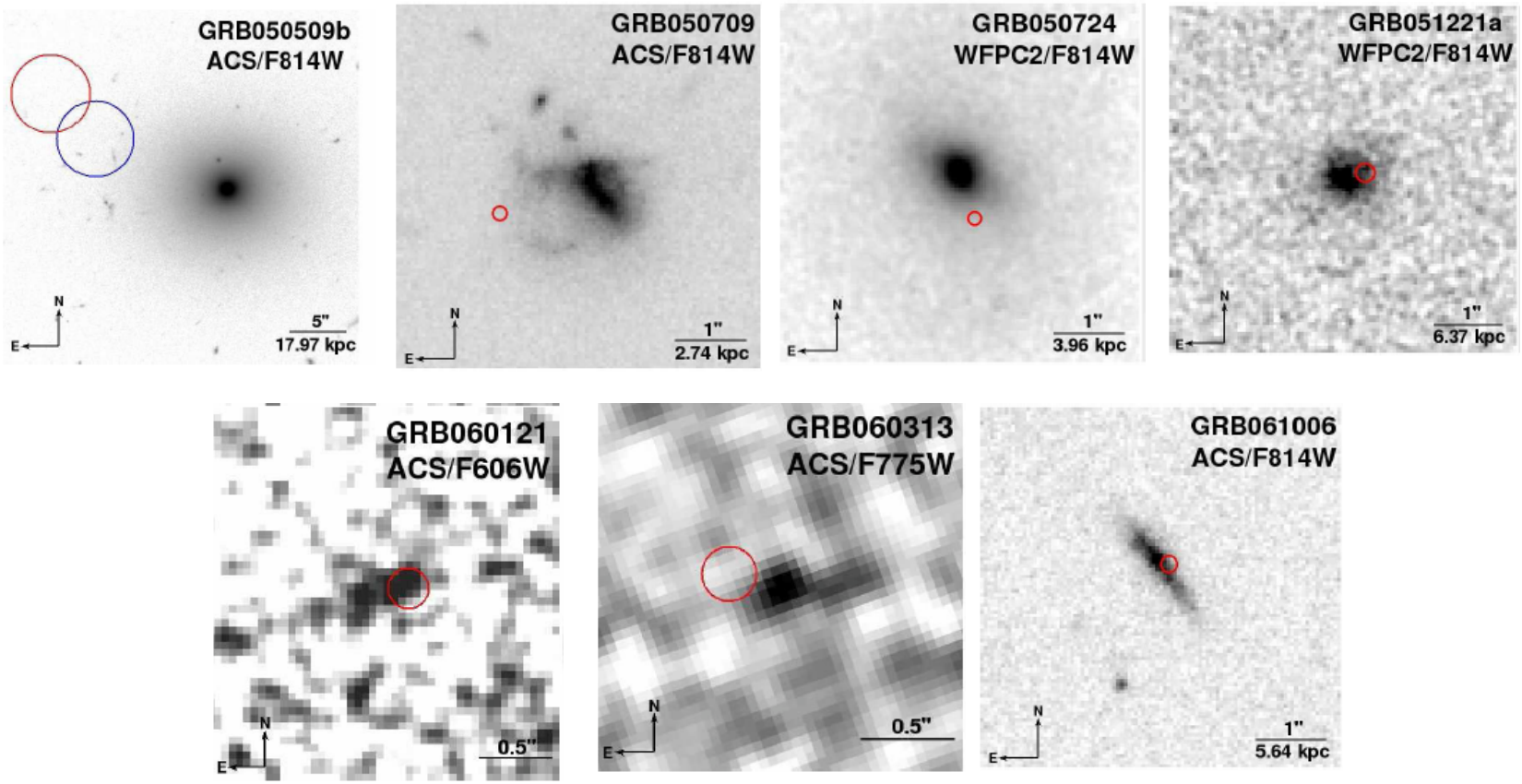
BH

In SF
galaxies

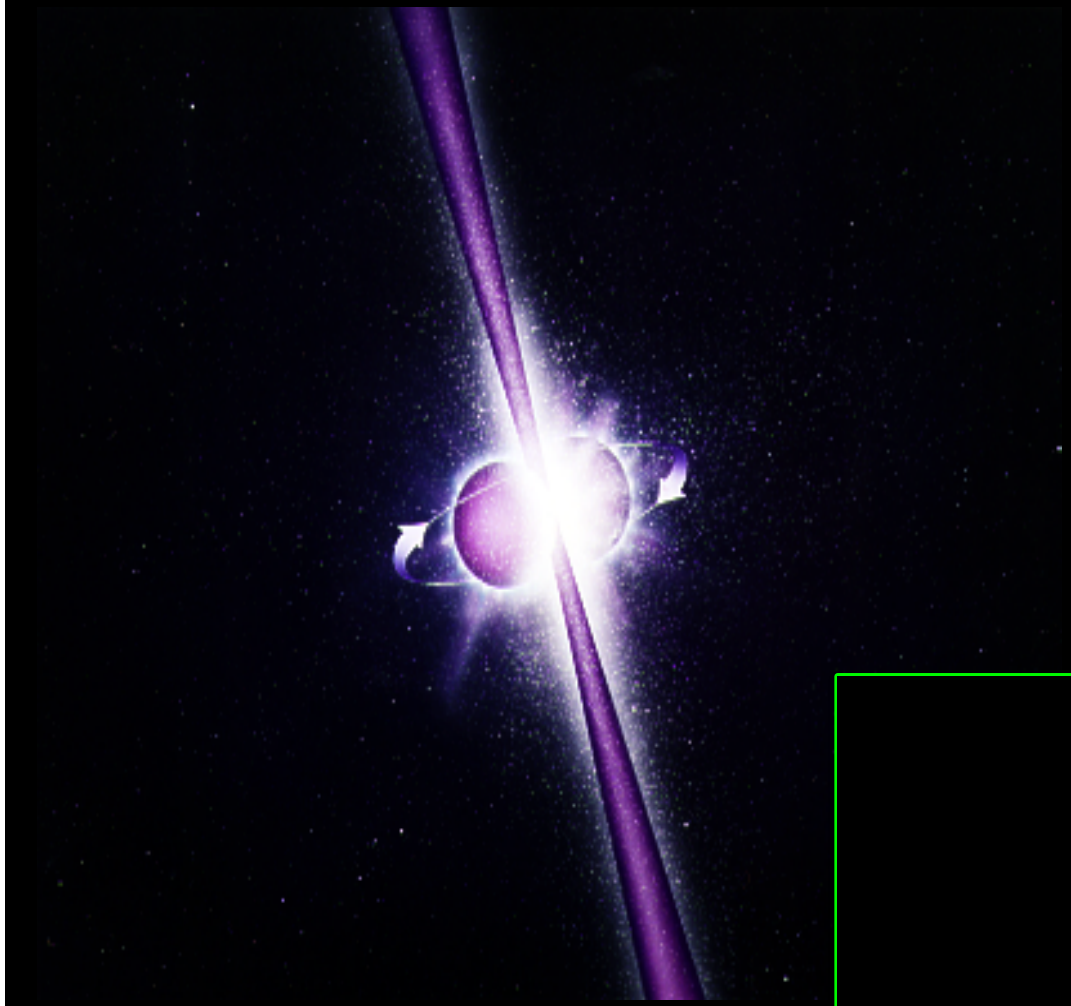
Accompanied by SNe

Collapsar model
well supported

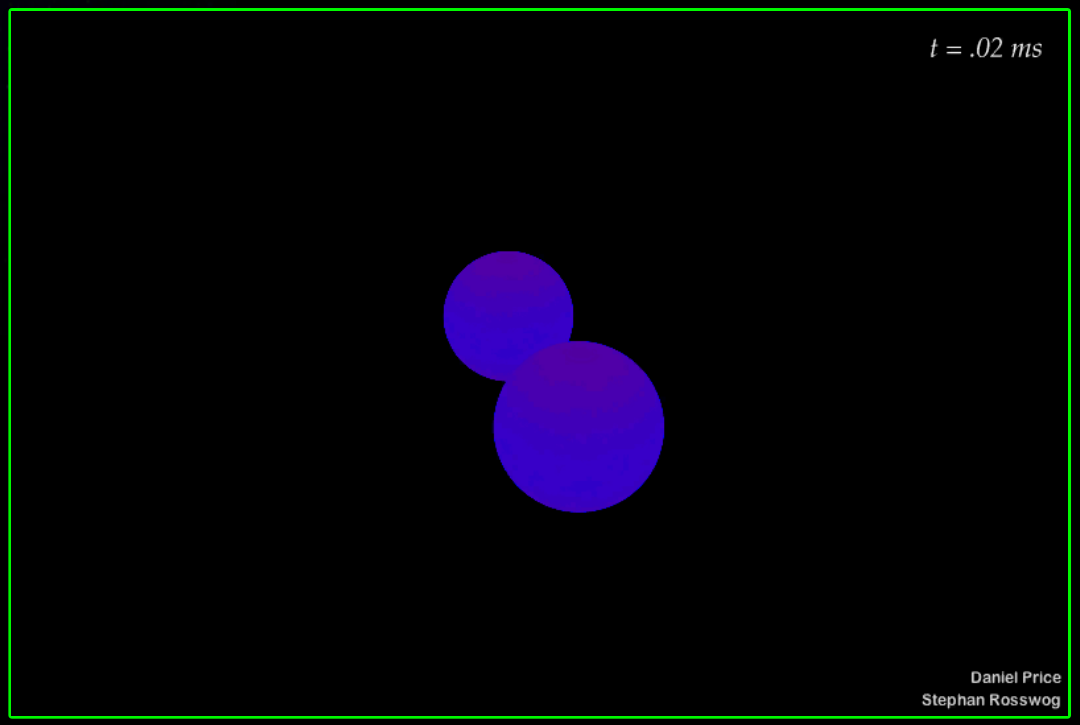
Short Burst HST Images



Fong, Berger & Fox 10



Short GRBs
Merger Model



Credit: Daniel Price and Stephan Rosswog

Short GRB Info

Swift localized 72 short GRBs

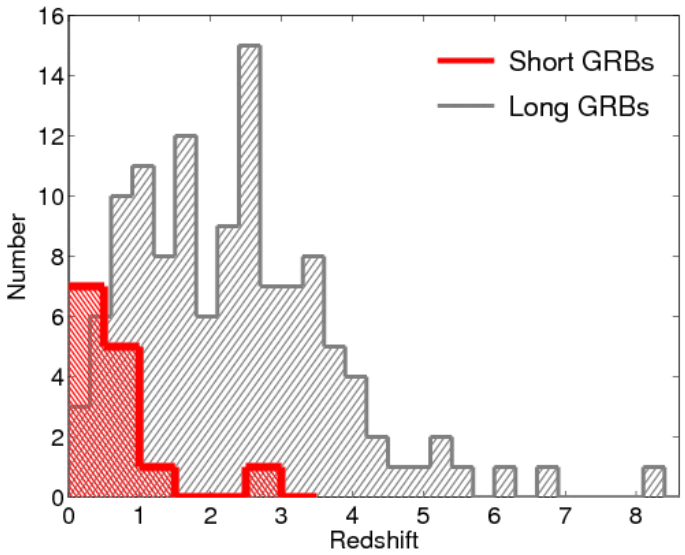
Weak afterglow

Low average redshift

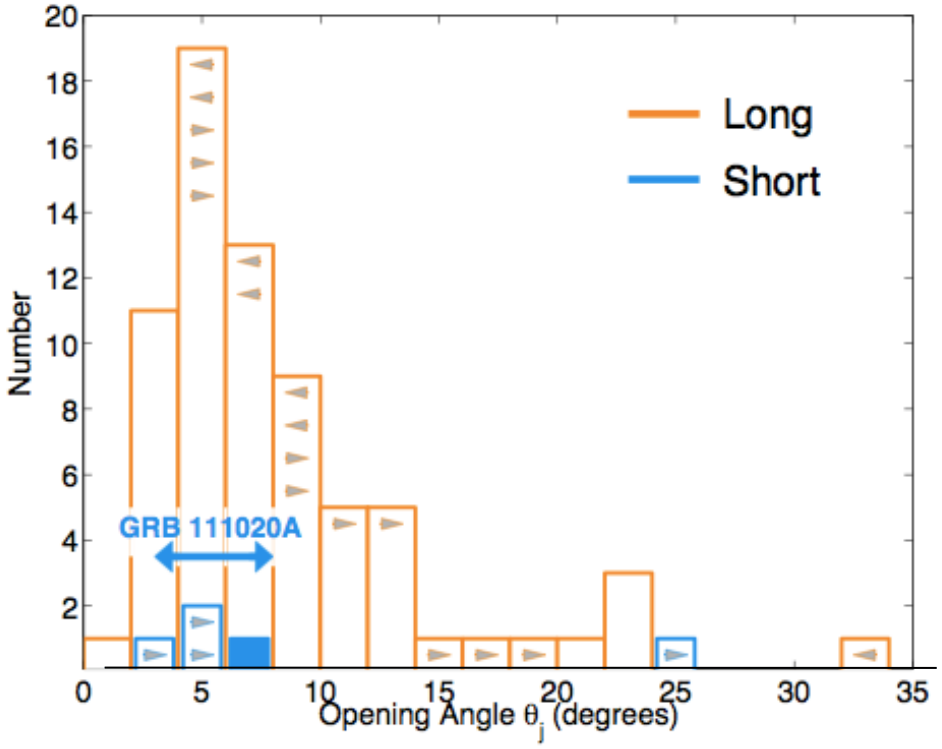
Jet opening angle

$\theta_{jet} \sim 5 - 20^{\circ}$ short

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



Berger+ 09



Fong+ 12

Why Black Holes?

- Energetics

Both BH & NS
have enough energy

- Time variability

ms variability
$\Rightarrow$ 300 km

- Jets

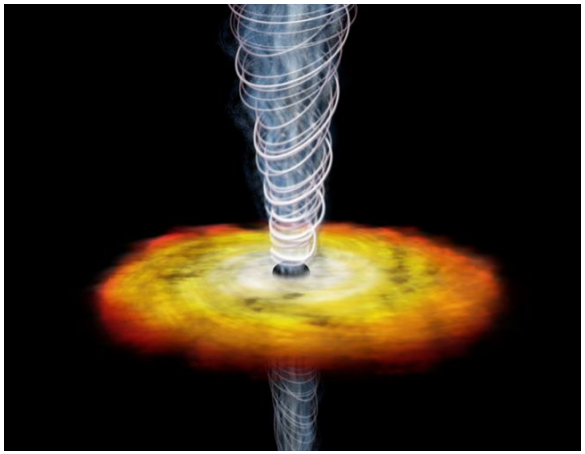
May be best BH
discriminator

Black Hole Energetics

$$\text{Energy} = \frac{G M m}{r}$$

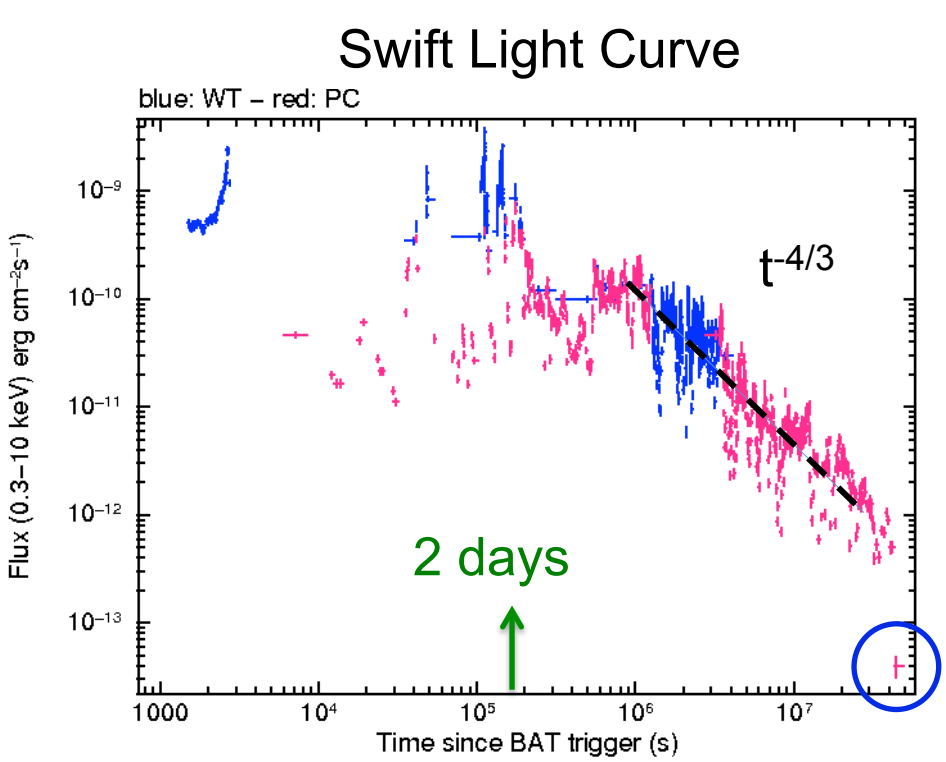
$$= \frac{1}{2} mc^2 \quad \text{for } r = R_{Sch} = \frac{2GM}{c^2}$$

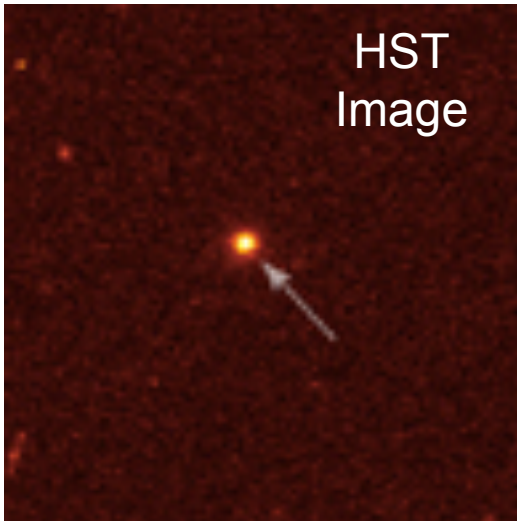
$$= 3 \times 10^{54} \text{ ergs} \quad \text{for } m = 3M_O$$



Swift Transient - Sw J1644+57

- Highly erratic γ-ray and X-ray light curve, March 28, 2011
- Like a GRB, but lasting 2 days instead of 20 second
- Tidal disruption event beamed at us



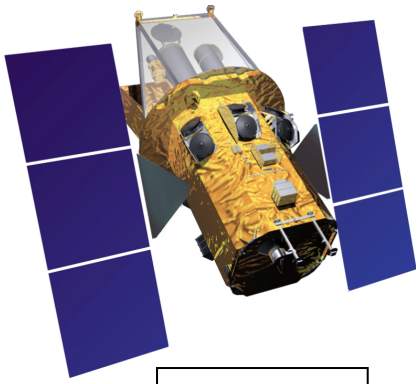


Center of galaxy at z=0.35

Bloom+, Burrows+ ... 11

Fermi GRB Follow-up

Swift Data & Comm

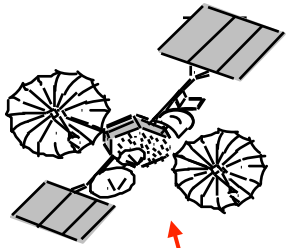


Spacecraft

Spectrum Astro
Rapid Autonomous Slews

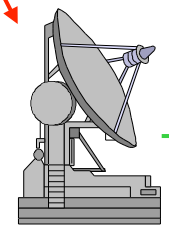
Payload

BAT
XRT
UVOT



TDRSS

Malindi



Mission Operations Center (MOC)

PSU

Science Center

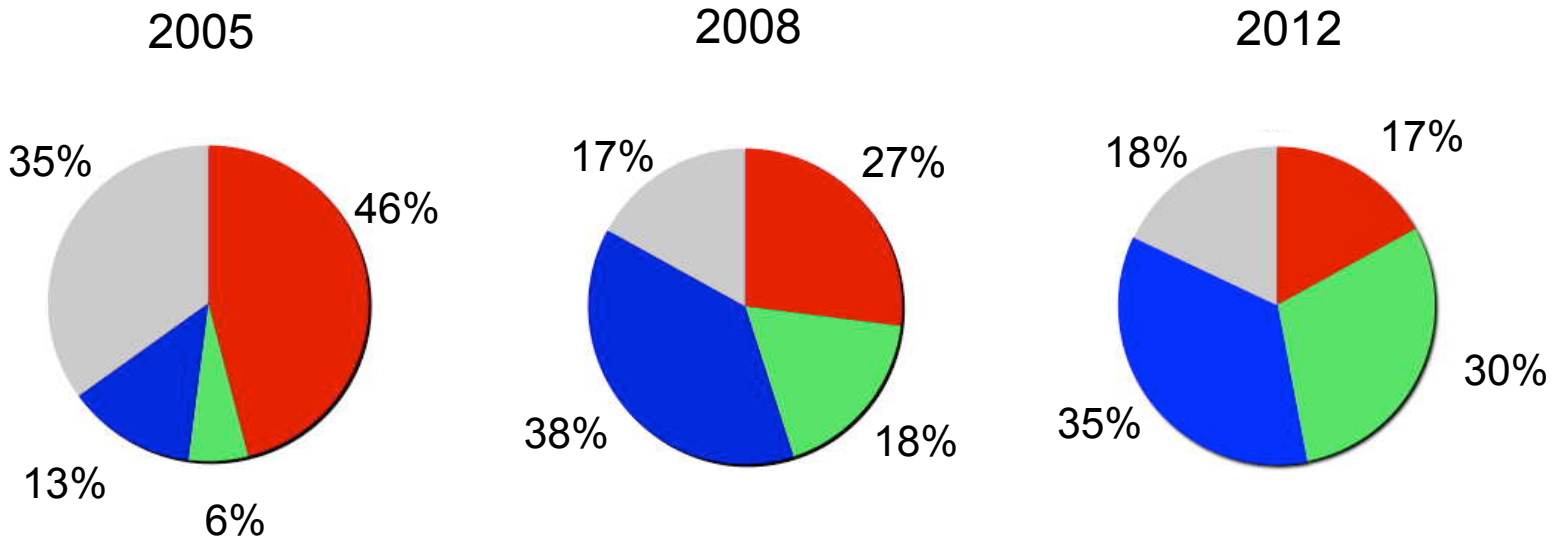
GSFC

GCN & Web

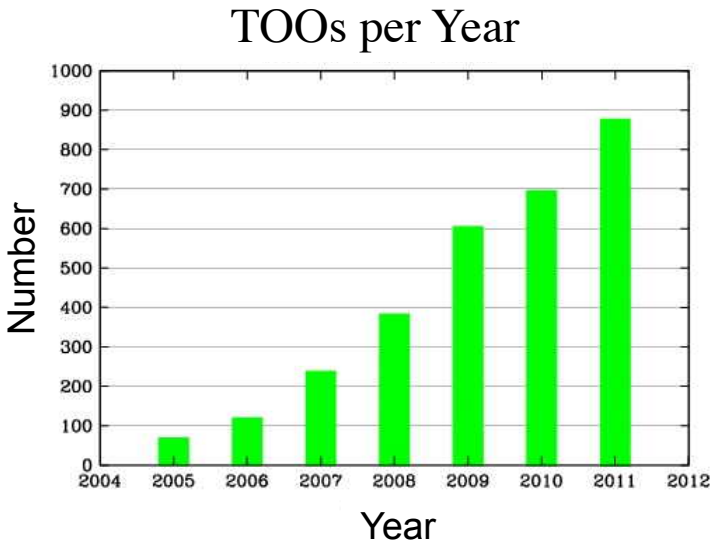
HEASARC
UK
Italian
Archives

User Communit y

Evolving Observing Time



- Swift GRBs
- Target of Opportunities (TOOs)
- GI targets / Fill-ins
- SAA & Calibration



Swift Follow-up of LAT GRBs

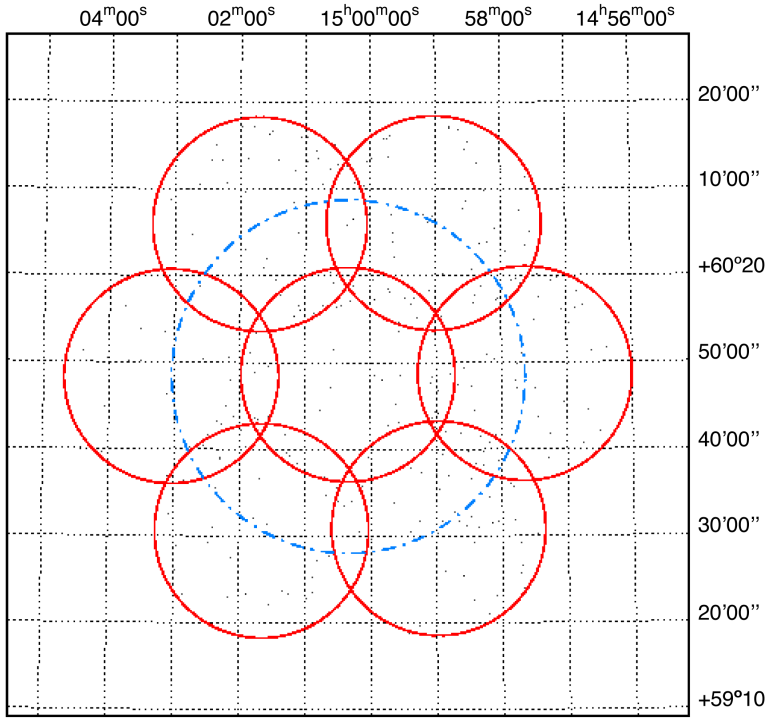
GRB 080825C	22 s		extended emission	Swift
GRB 080916C	66 s	z = 4.35	extended emission	Swift
GRB 081024B	0.8 s		extended emission	Swift
GRB 081215A	7.7 s			Swift
GRB 090217	33 s			Swift
GRB 090228			found by Akerlof group (10-10)	
GRB 090323	150 s	z = 3.57	AG dominant, ext emm	Swift
GRB 090328	100 s	z = 0.736	AG dominant, ext emm	Swift
GRB 090510	2.1 s	z = 0.903	extended emission	BAT/XRT
GRB 090626	70 s		extended emission	
GRB 090902B	21 s	z=1.822	34 GeV photon	Swift
GRB 090926A	20 s	z=2.1062	extended emission	Swift
GRB 091003	21s		extended emission	Swift
GRB 091031	35s			
GRB 100116A	110s			sun cnstrnt
GRB 100225A	13s			
GRB 100414A	26s	z=1.468		Swift
GRB 100708A				
GRB 100728A	198s (BAT)	z=1.567	during late flares (found 10-10)	BAT/XRT
GRB 100826A	150s (Konus)			
GRB 110120A				
GRB 110328B	~40s		soft LLE only, large error circle	
GRB 110428A	~200s		high energy emission	Swift
GRB 110625A	~30s			BAT/XRT
GRB 110721A	24s	z=0.382		BAT/XRT
GRB 120226A	57s		>20 MeV only	
GRB 120328B	31s		ground analysis	
GRB 120624B	271s		bright GBM, ground optical	BAT/XRT
GRB 120709A	30s			XRT
GRB 120711A	135s	z=1.405	INTEGRAL GRB	XRT
GRB 120830A	1.3s			
GRB 120911B	30s		IPN burst	sun constraint
GRB 120916A	53s		IPN burs	
GRB 121011A	66 s		LLE	Swift
GRB 130305A	29s			Swift
GRB 130310A	2.4s		ARR, very hard BATSE	Swift
GRB 130325A	8s (Konus)		not in prompt, only in afterglow	Swift
GRB 130327B	62s		with AGILE	Swift
GRB 130427A	162s (BAT)	z=0.340	with Swift, brightest burst to date	Swift
GRB 130502B	24s		called in FOT for Swift TOO	Swift
GRB 130504C	74s		XRT detection at 18 hours	Swift
GRB 130518A	48s	z=2.49	BAT untriggered at edge of FoV	Swift

Auto Sky Tiling

LAT GRB position accuracy <1 deg

GRB GRB position accuracy ~5 deg

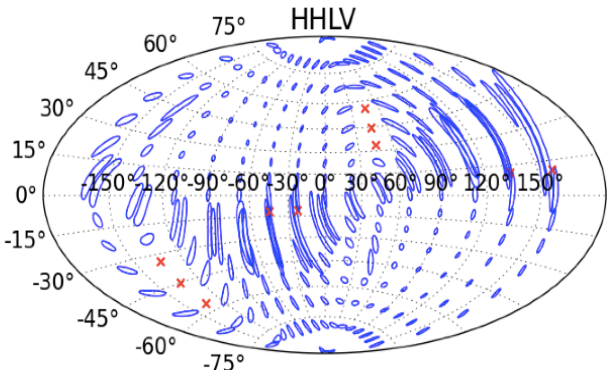
XRT 7 Tile Pattern



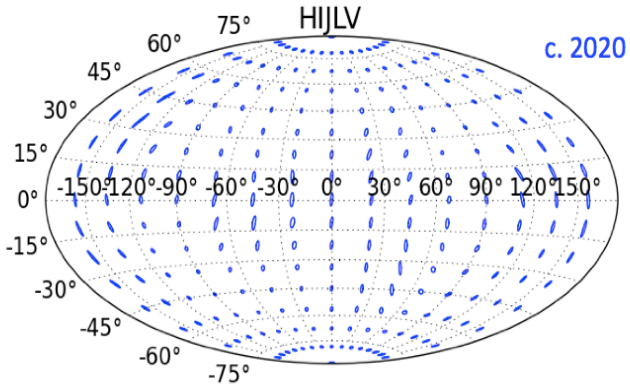
Covering Large Error Boxes

- Large error boxes from GBM, IPN, & grav. waves
- Tiling & coordination with wide-field telescopes
- In preparation of ALIGO/Virgo, goal is to detect a GBM afterglow with PTF + *Swift*

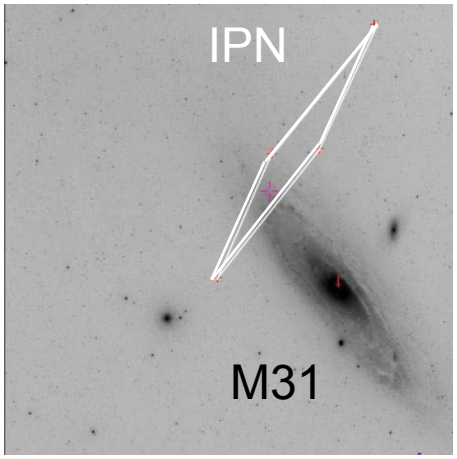
Sky localization with 3 sites ...



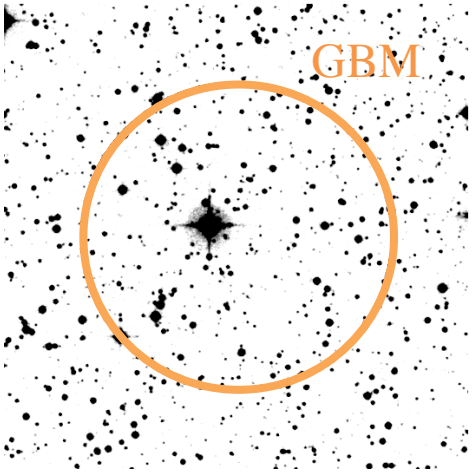
... and with 5 sites



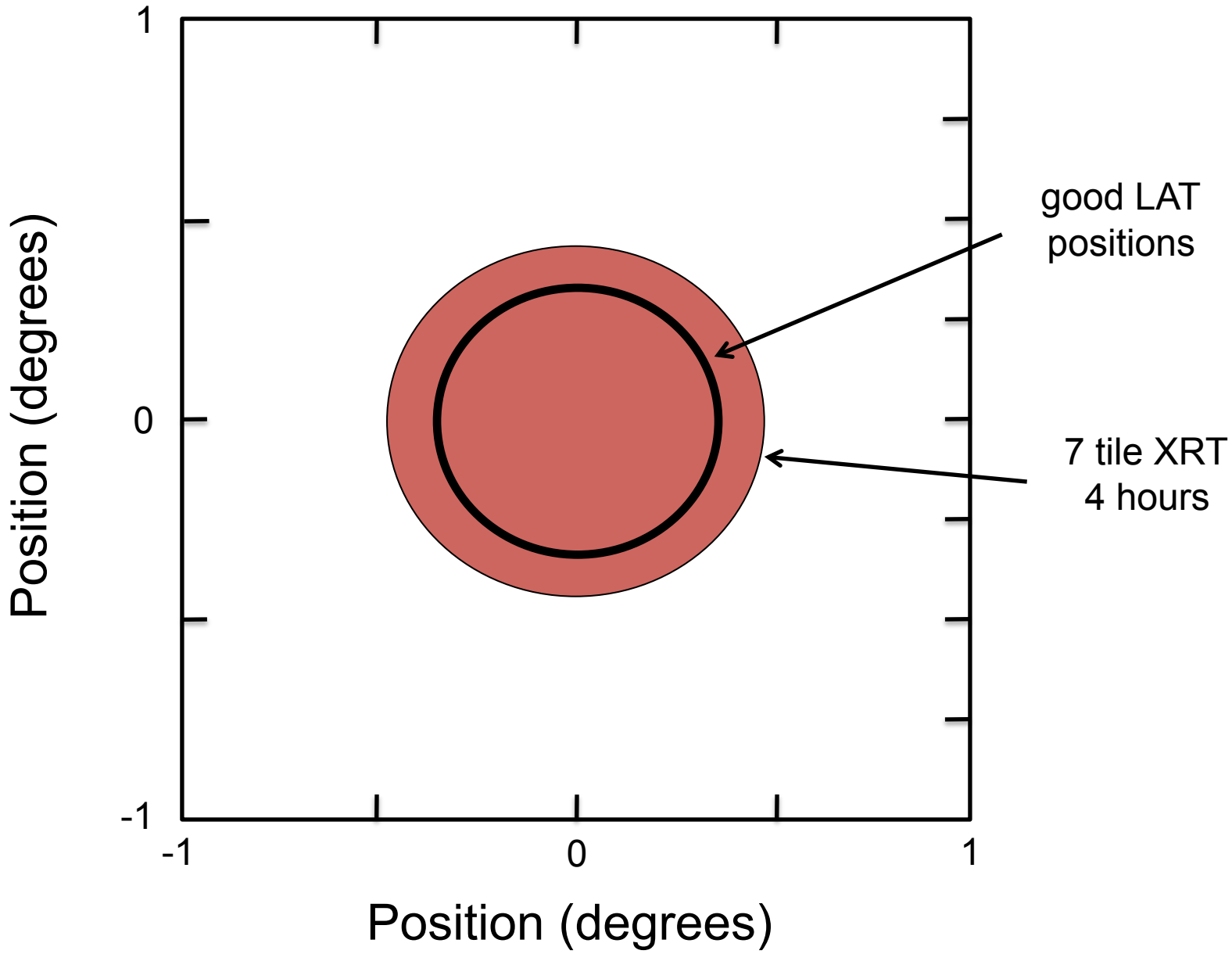
Fairhurst (2011)



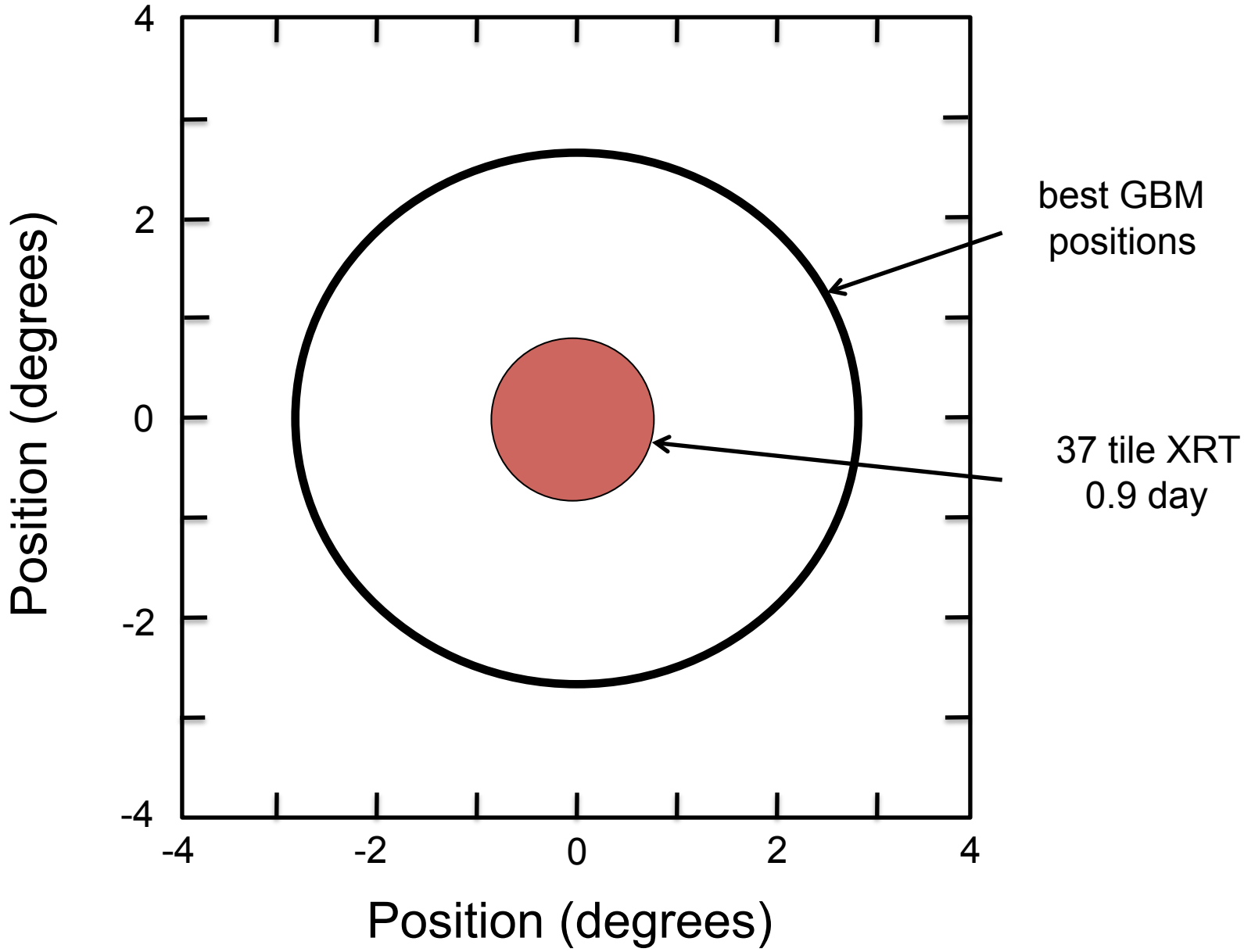
GRB 081024



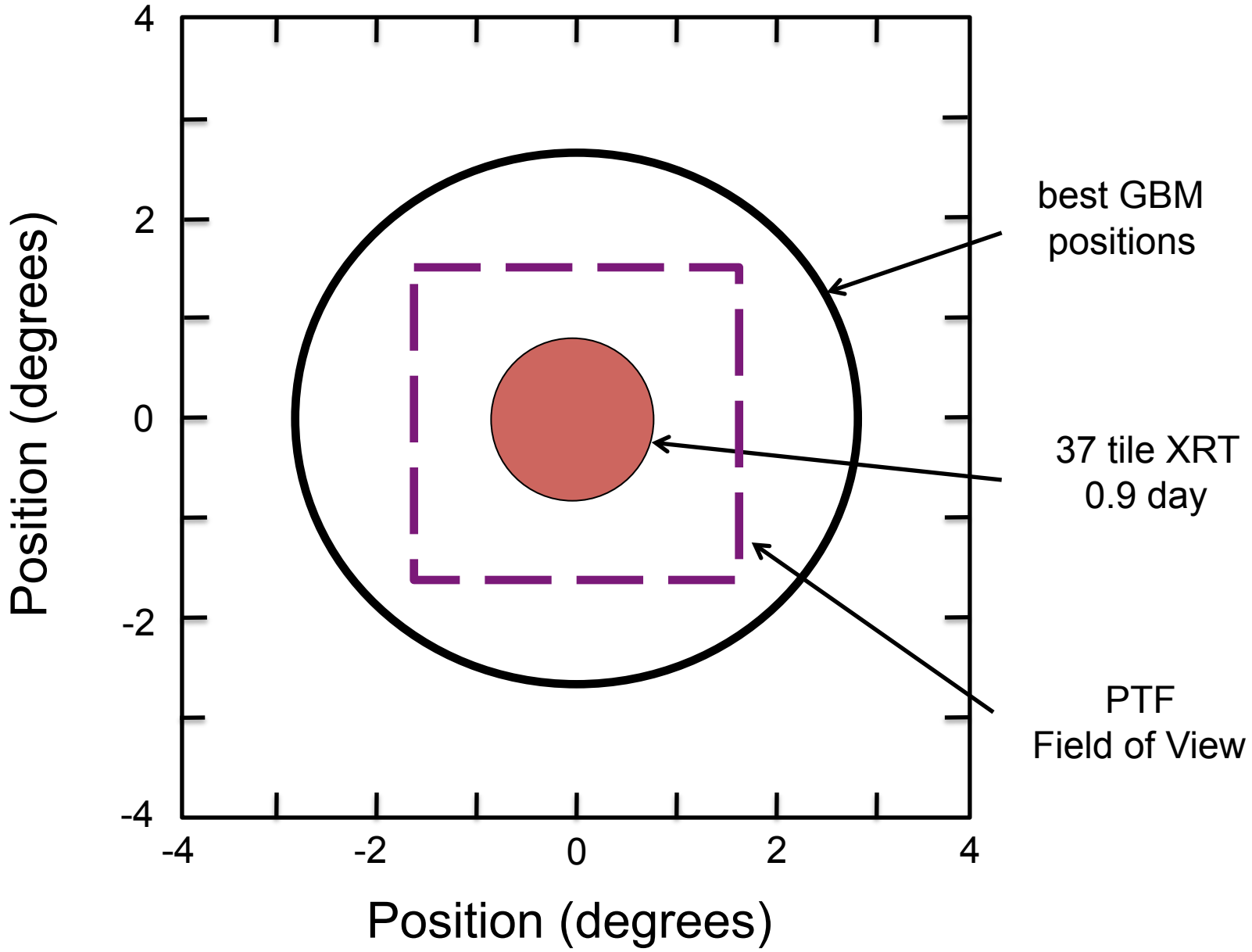
Swift XRT Tiling LAT Error Box



Swift XRT Tiling GBM Error Box



Swift XRT Tiling GBM Error Box



Summary

GRBs are powerful explosions
- most luminous sources at all wavelengths
- afterglow lasts for days

Long GRBs
- due to core collapse to black hole of massive star
- new probe of high redshift universe
- produce energetic, high-velocity supernovae

Short GRBs
- associated with old stellar populations
- likely caused by NS-NS mergers
- exciting sources for gravitational wave observations

Long & short GRBs are likely signatures of BH birth

Swift & Fermi are working together to learn the nature of GRBs and use them to study the universe