

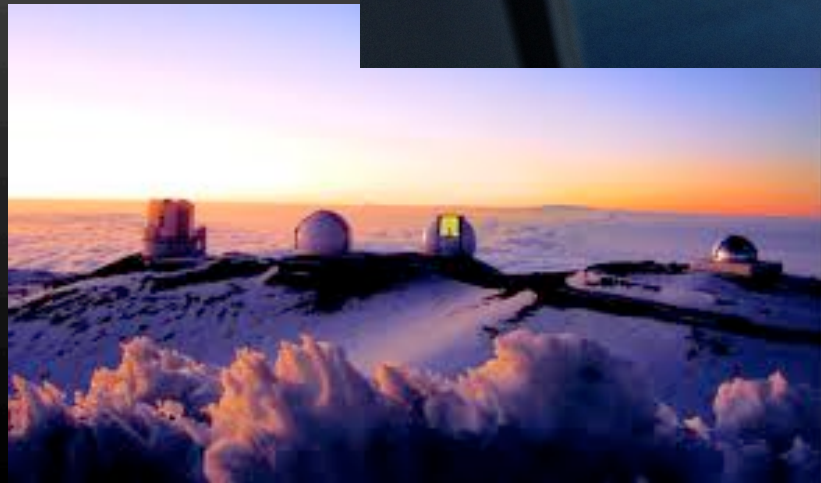
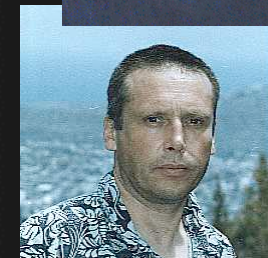
Gamma Ray Bursts and the Birth of Black Holes



Neil Gehrels
NASA-GSFC

UH Institute of Astronomy
May 16, 2013





Outline

- **GRB discovery**
- *Swift* mission
- **Long GRBs**
 - Probes of distant universe
 - New window on supernovae
 - Black hole birth
- **Enigmatic short GRBs**
 - Stellar mergers & collisions
 - Black hole birth
- **Non-GRB astrophysics**
 - Tidal-disruption events
 - Hard X-ray sky survey
- **The future**

Swift



TNT – 10^{17} erg



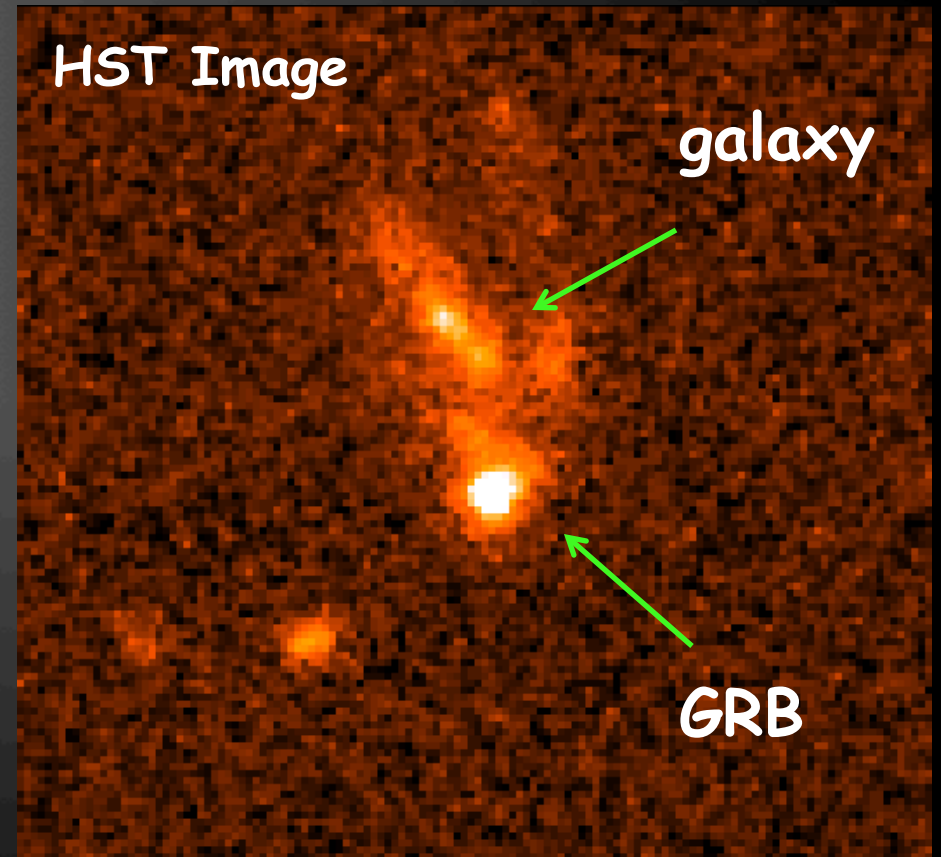
H bomb – 10^{21} erg



Supernova (electromagnetic) – 10^{49} erg



Gamma Ray Burst – 10^{51} erg

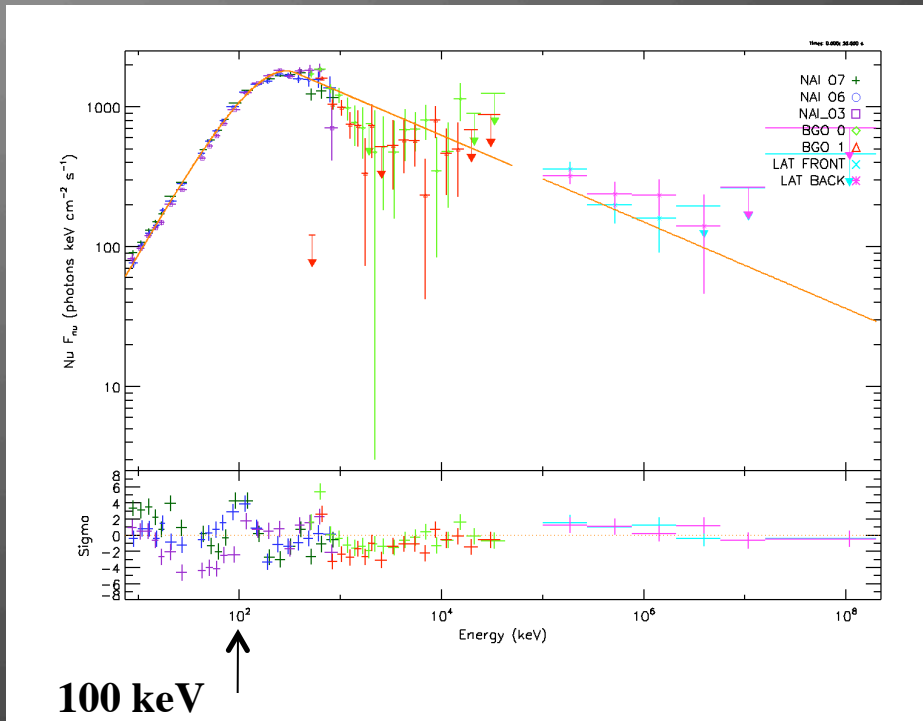


Occur in distant galaxies

~1000 per year all sky

Durations of 0.1 – 100 sec

Emission in ~5 degree beams

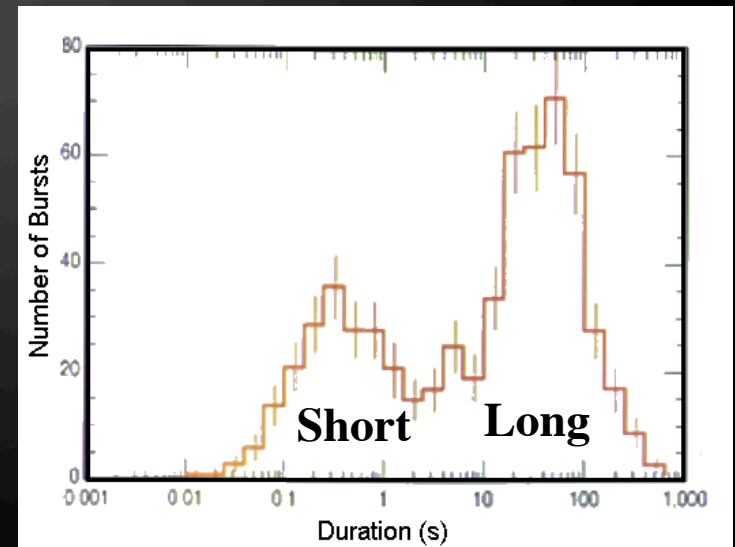


100 keV

Guiriec+ 12

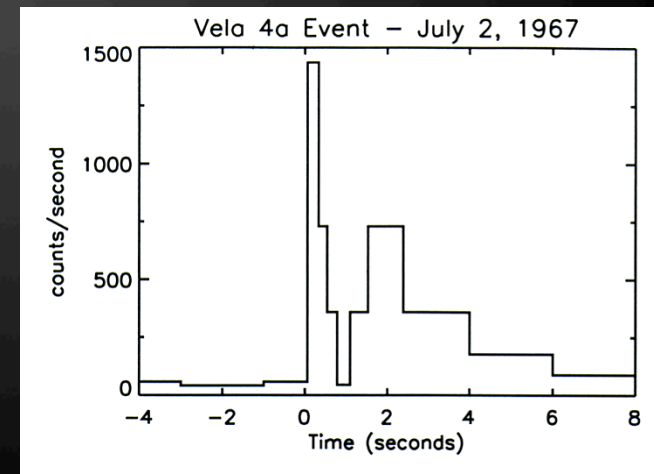
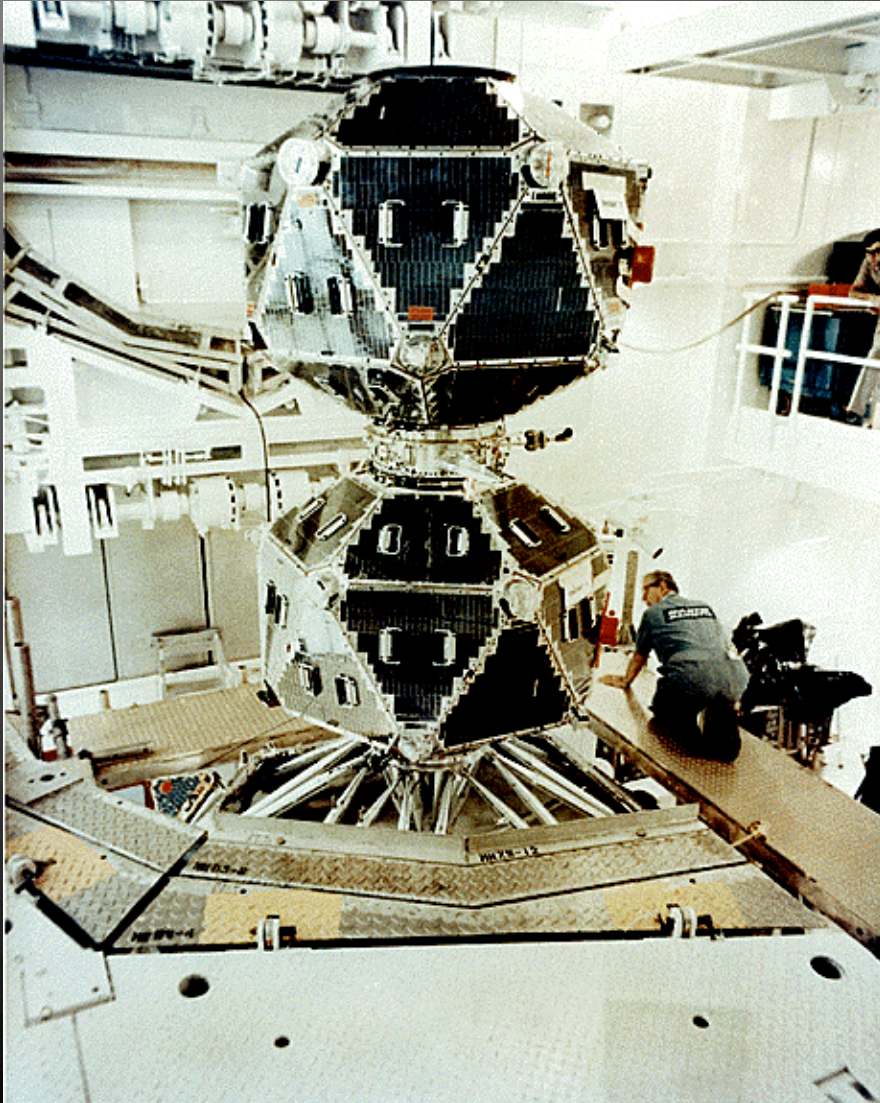
Non-thermal Spectra

2 Duration Classes



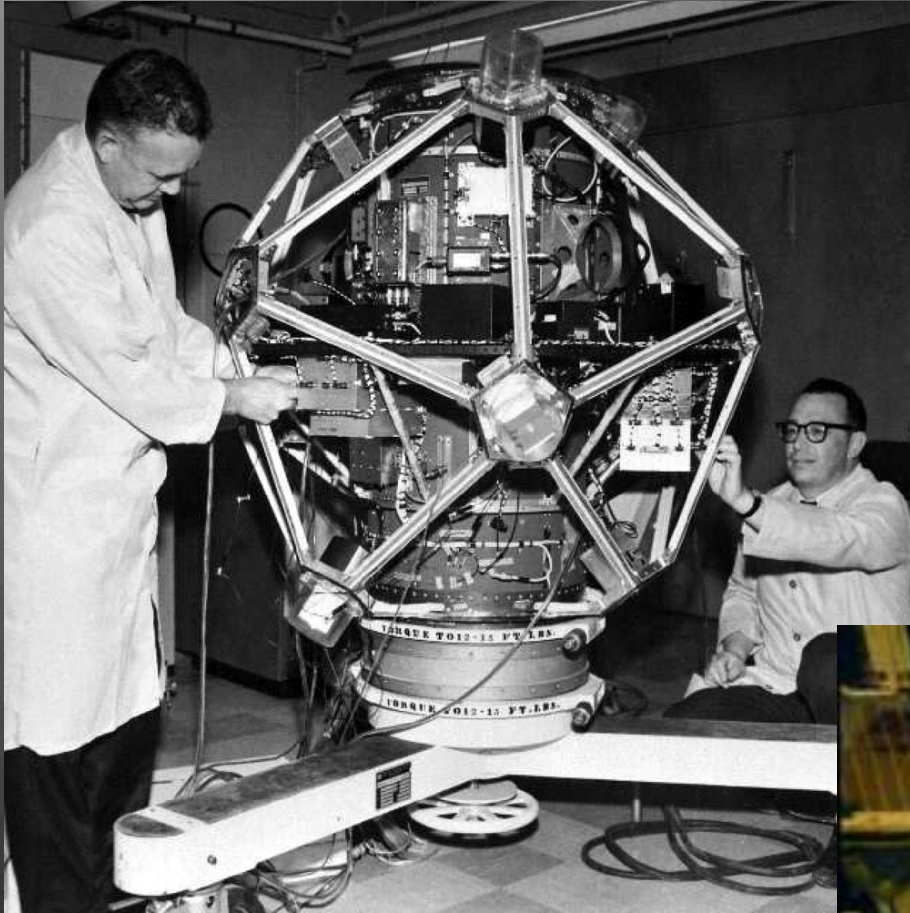
Kouveliotou+ 93

First GRB Detection



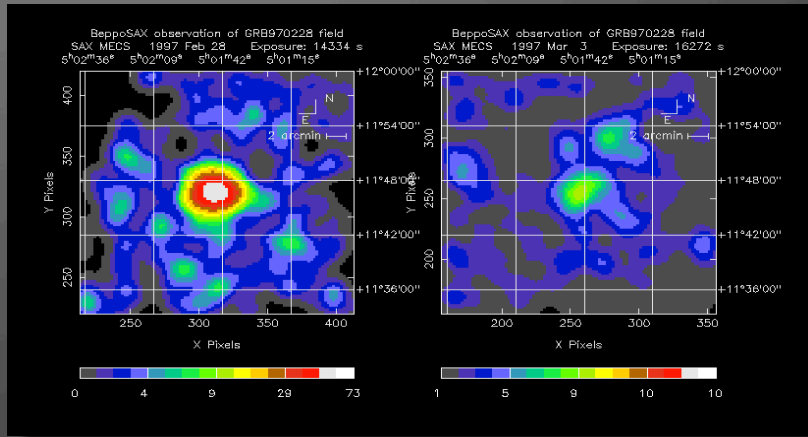
Vela Satellites - Los Alamos

(Klebesadel, Strong & Olson 1973)

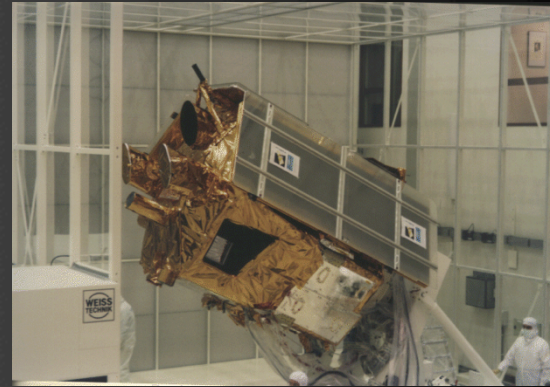


The Fireball !

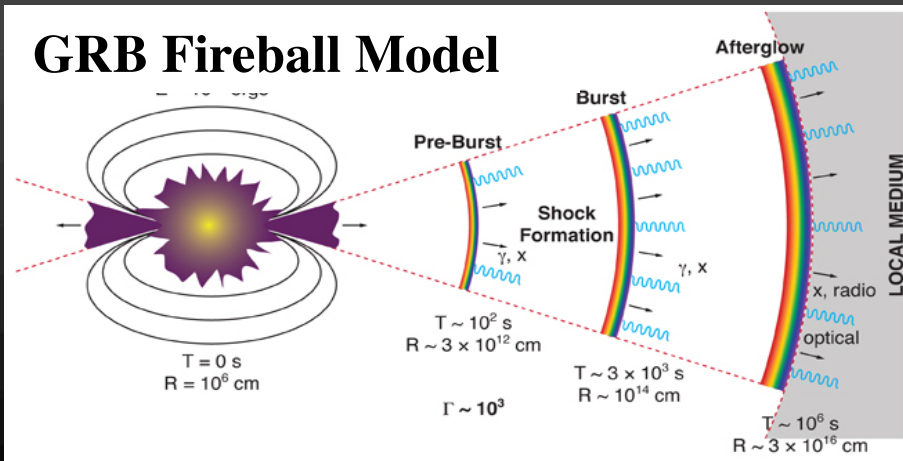
X-ray afterglow GRB 970228



BeppoSAX satellite



GRB Fireball Model



Mészáros & Rees 1997

Swift

Developments ~2000

**Scientific urgency
for new GRB mission**

**New CdZnTe detectors enable
advanced γ -ray camera**

Recognized:

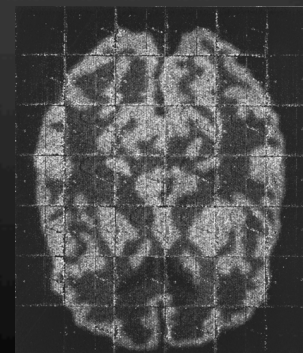
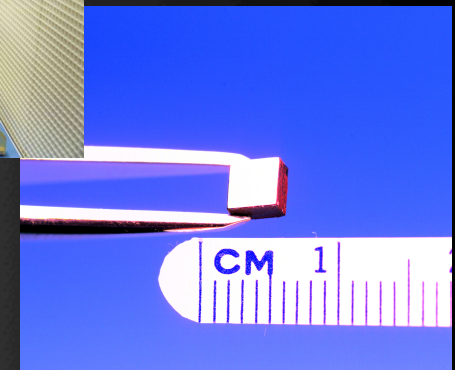
- * **GRBs are new tools for**
 - **high-z universe**
 - **SN physics**
 - **jet physics**

However:

- * **Long GRBs poorly understood**
- * **Short GRBs not understood**

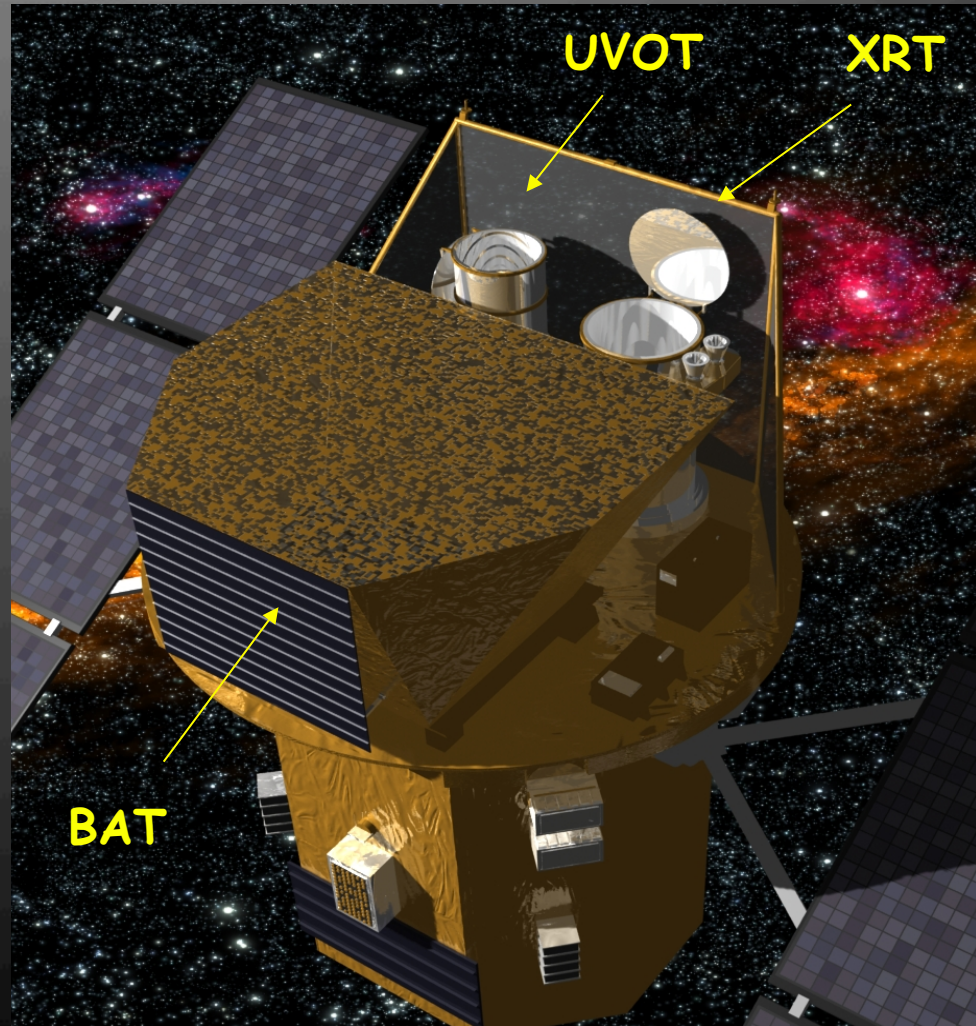
Needed:

- * **Rapid response & multi-wavelength observatory**



**medical imaging
brain scan**

Swift Mission



3 instruments:

- gamma-rays
- X-rays
- optical

32,000 CdZnTe detectors

Rapid slewing spacecraft

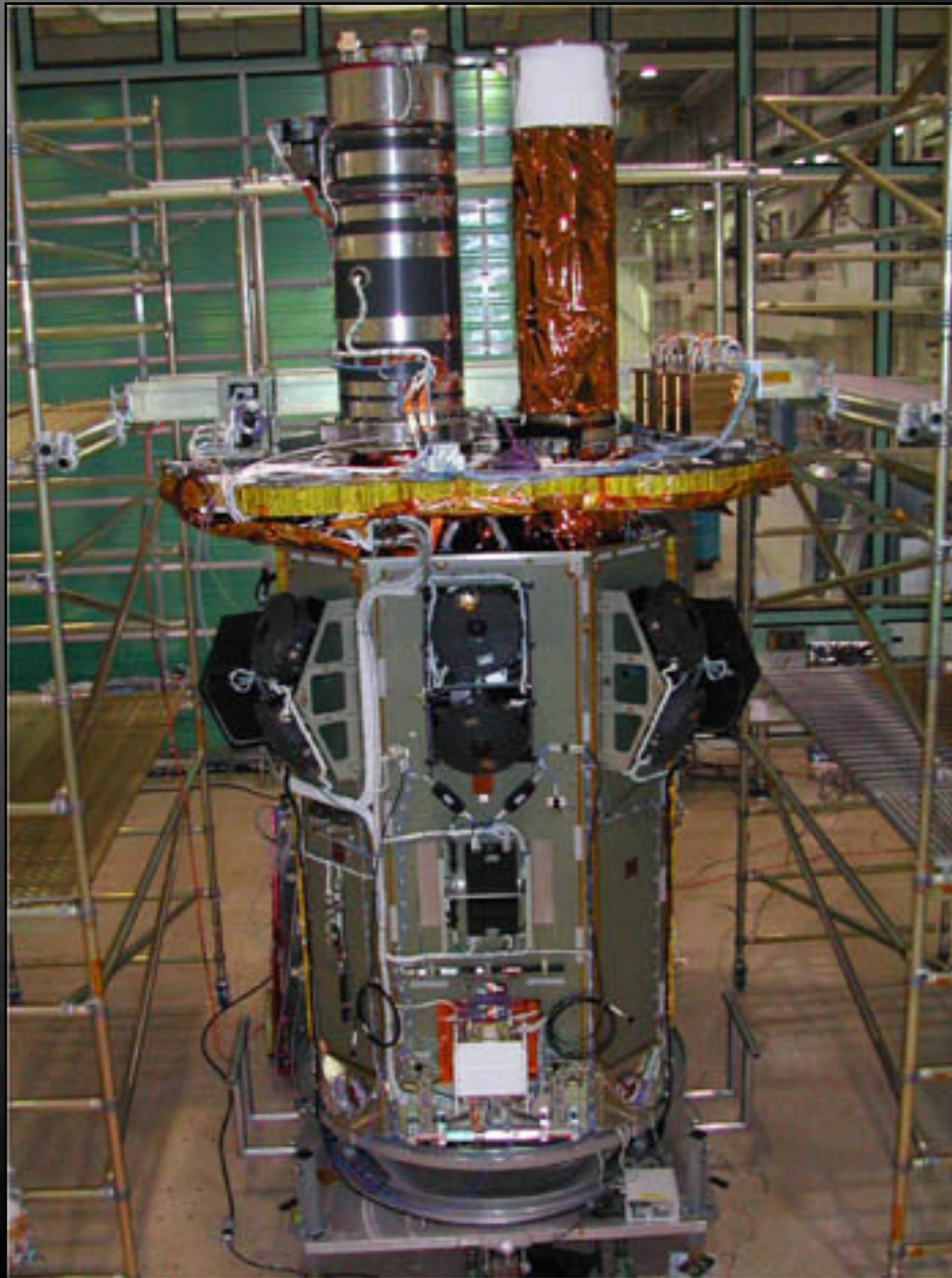


Swift Trucking



Swift Trucking









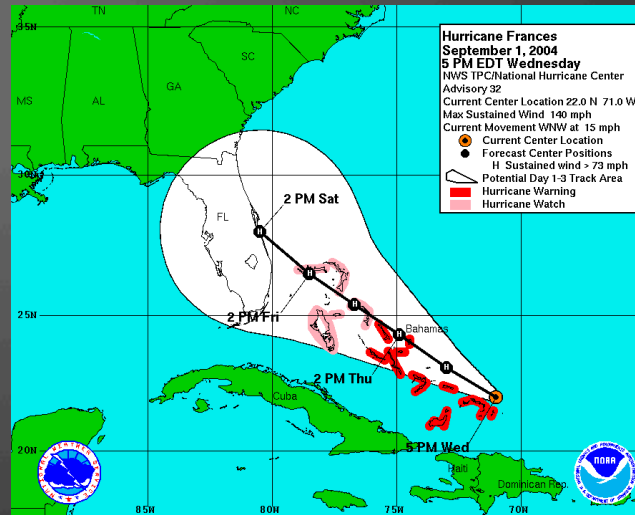


Florida 2004 - Hurricane Alley

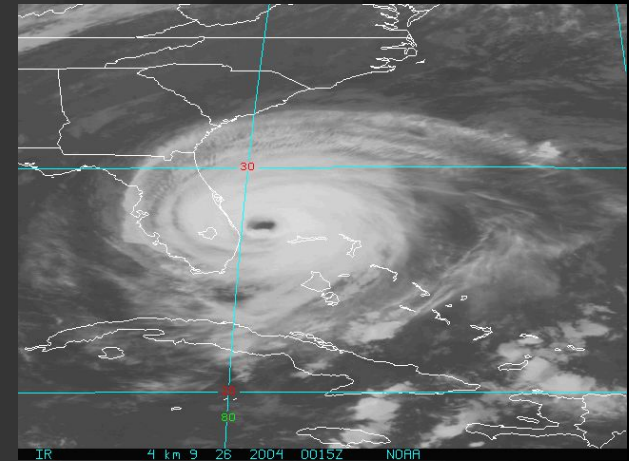
Hurricanes:

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

Frances

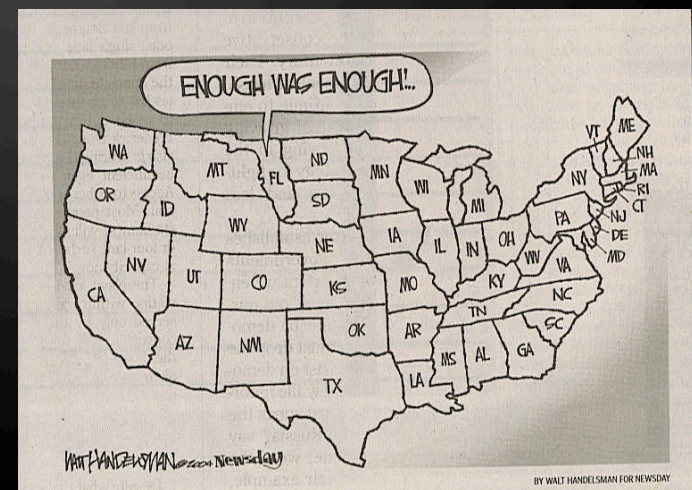


Jeanne

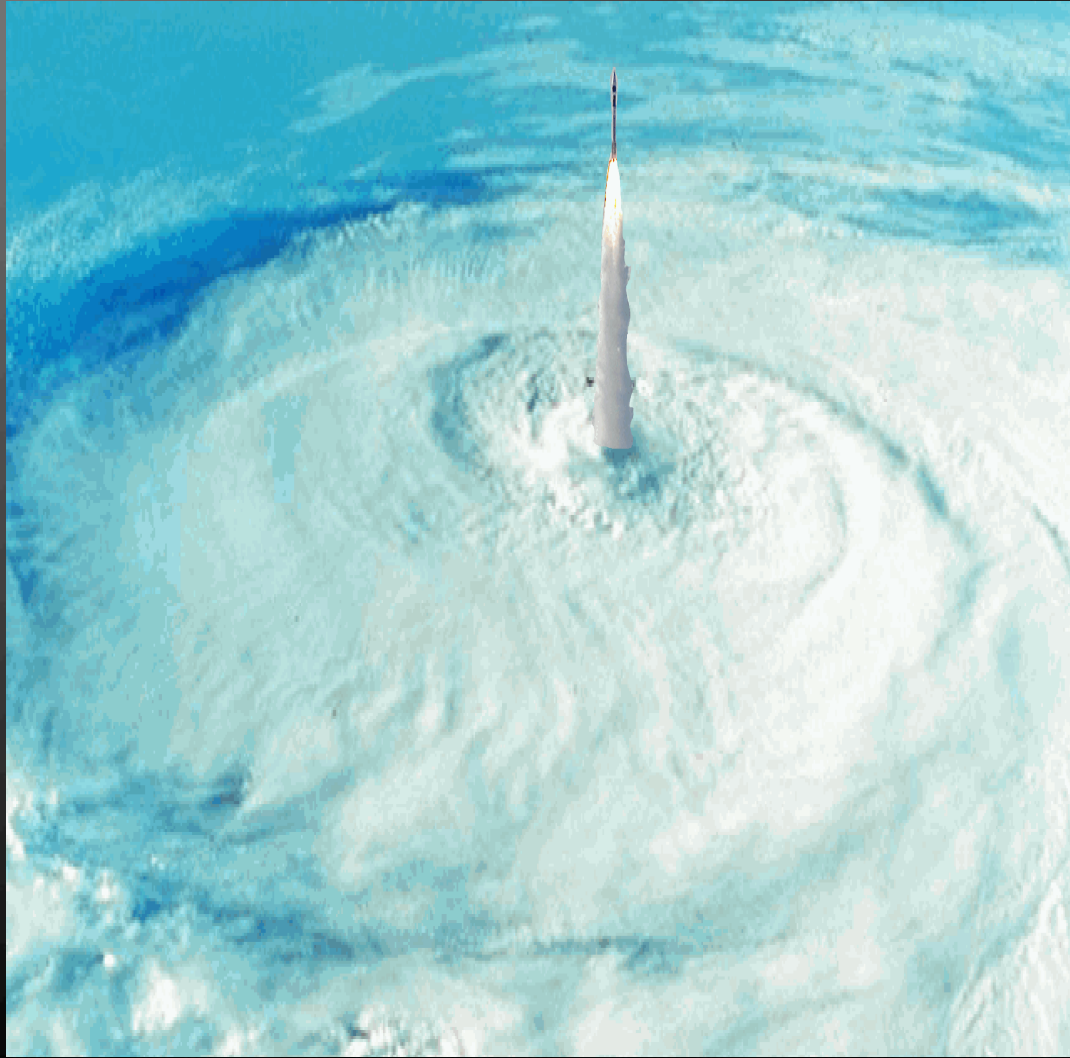


Jeanne

Vehicle
Assembly
Building
damage



Let's Launch Anyway !!!

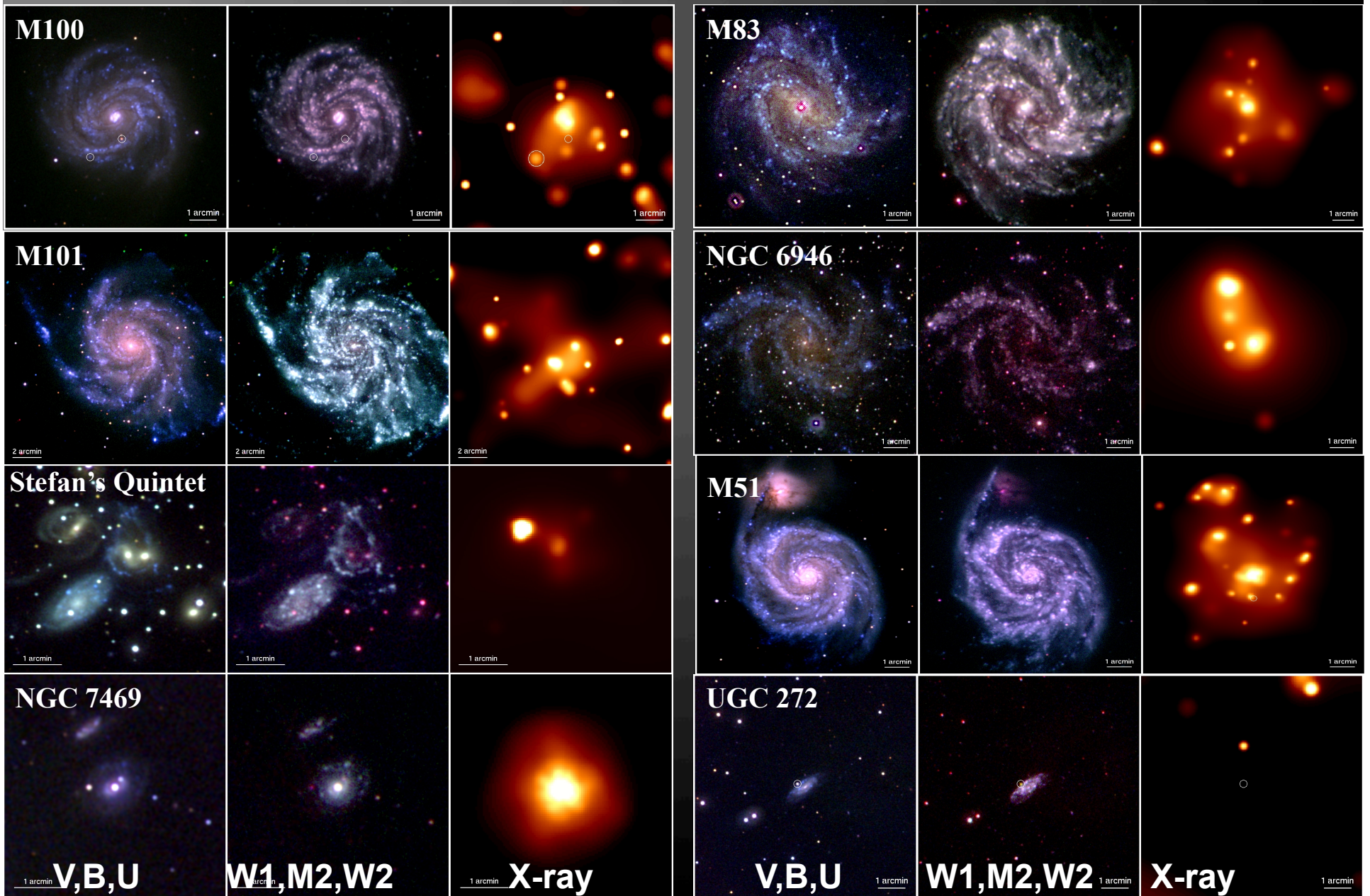






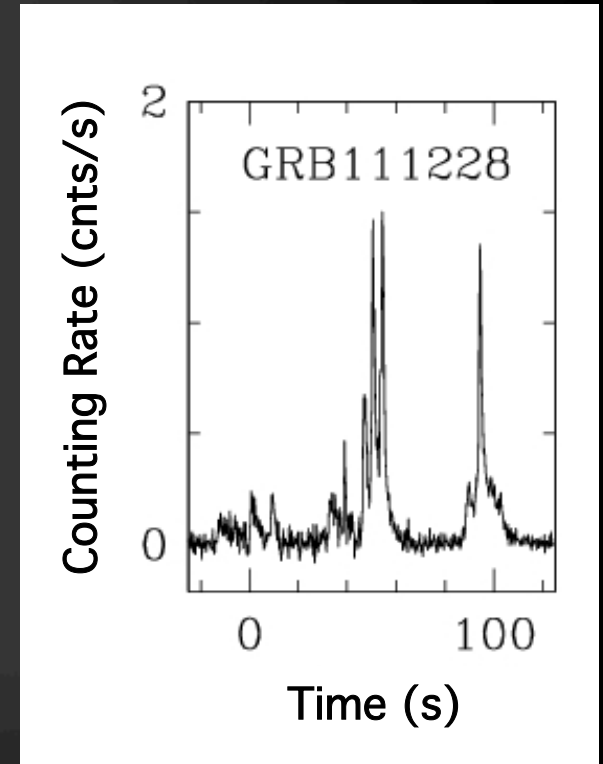
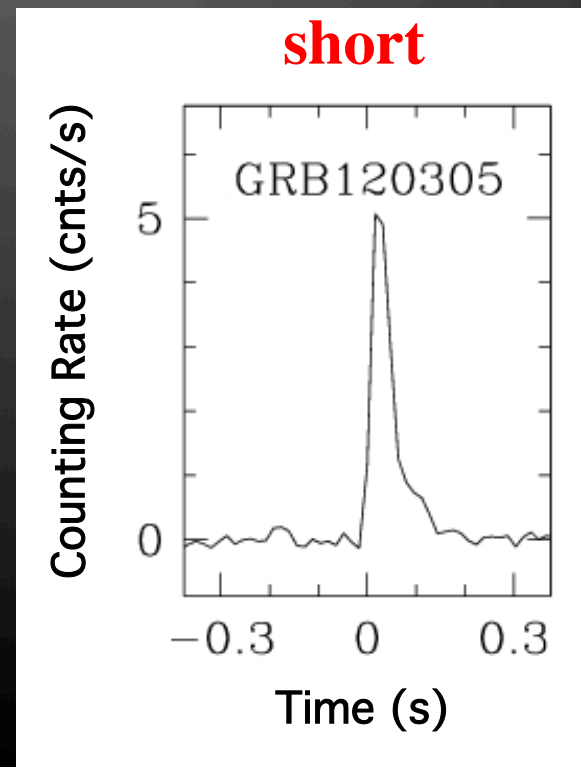
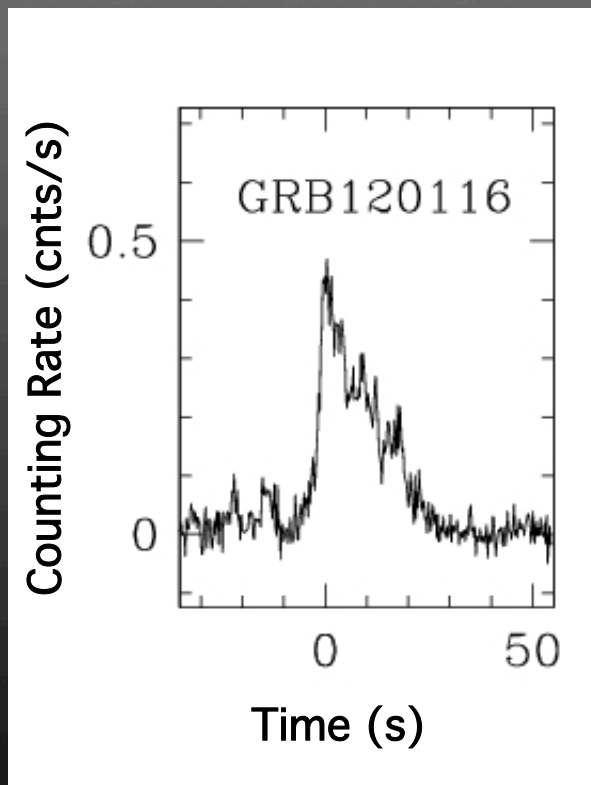
XRT & UVOT Galaxy Mugshots

S. In



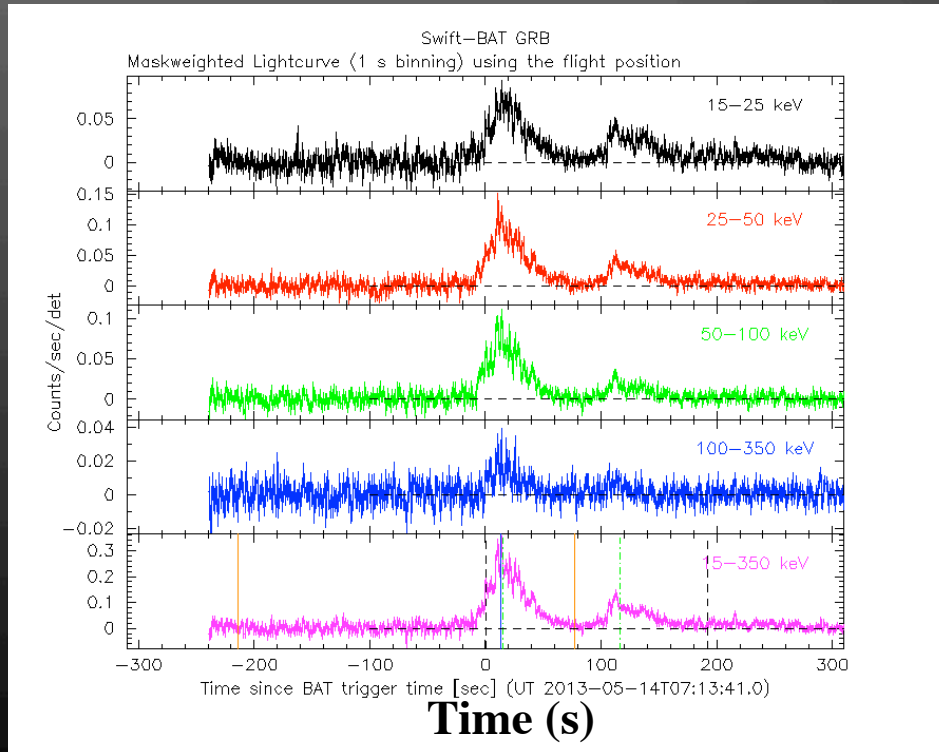
Swift Statistics

764 GRBs as of last night
85% with X-ray detections
60% with optical detection
247 with redshift (41 prior to Swift)
71 short GRBs localized (0 prior to Swift)

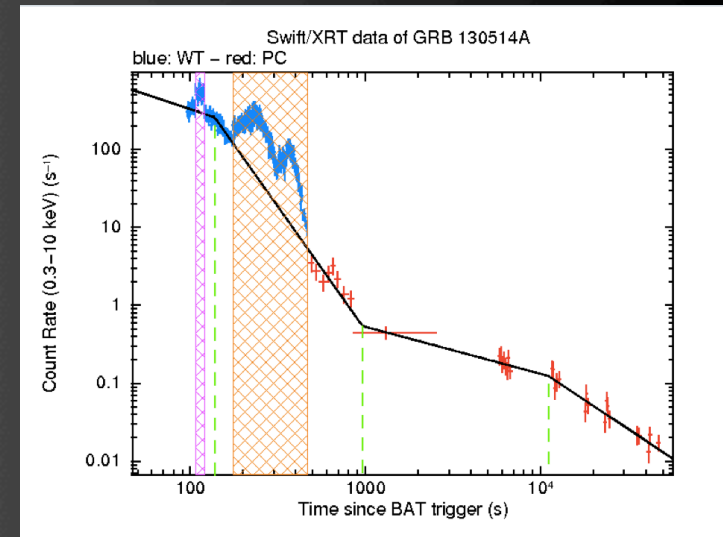


Swift Data GRB 130524A $z = 3.6$

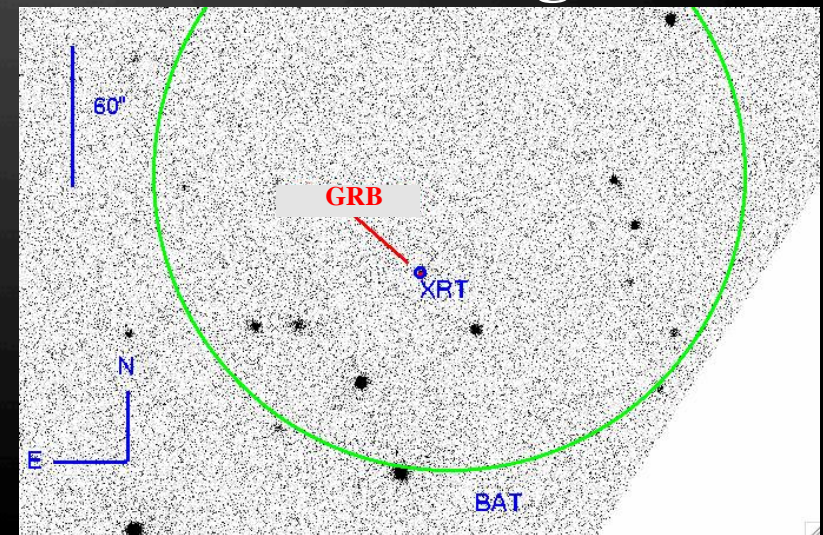
BAT lightcurves



XRT lightcurve



UVOT image

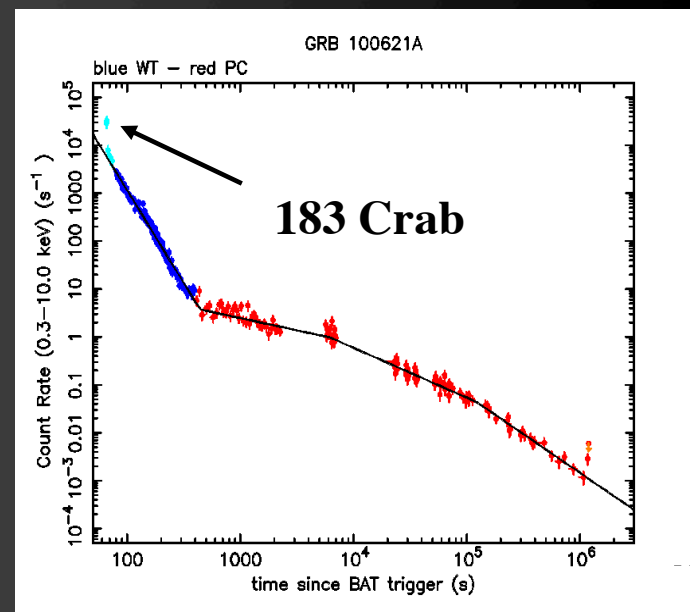


Long GRBs

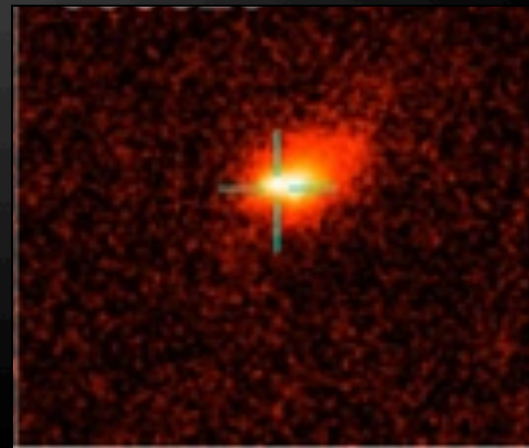
GRB Bright Afterglows

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	H ~ 22
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

XRT Lightcurve

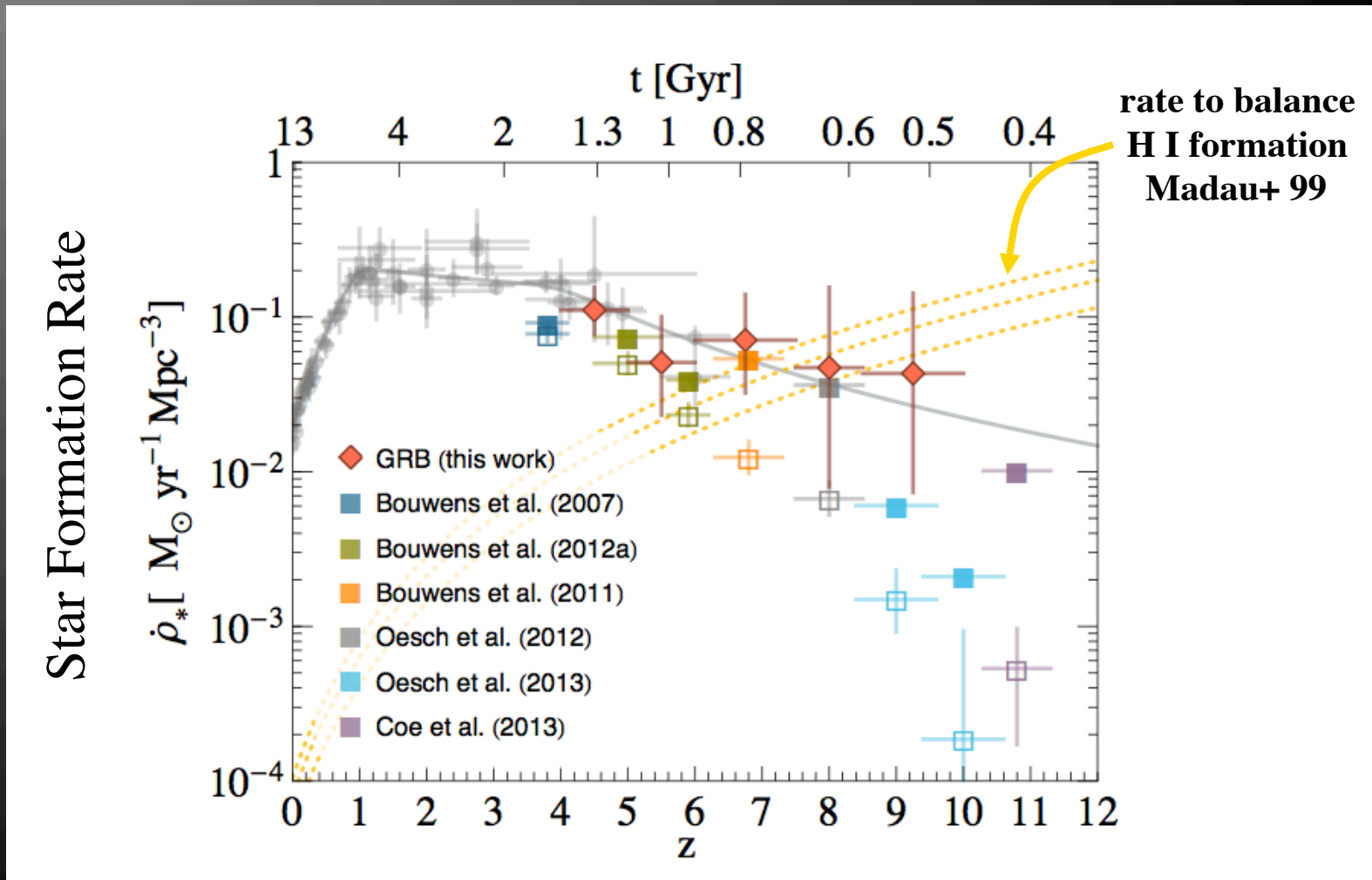


HST image

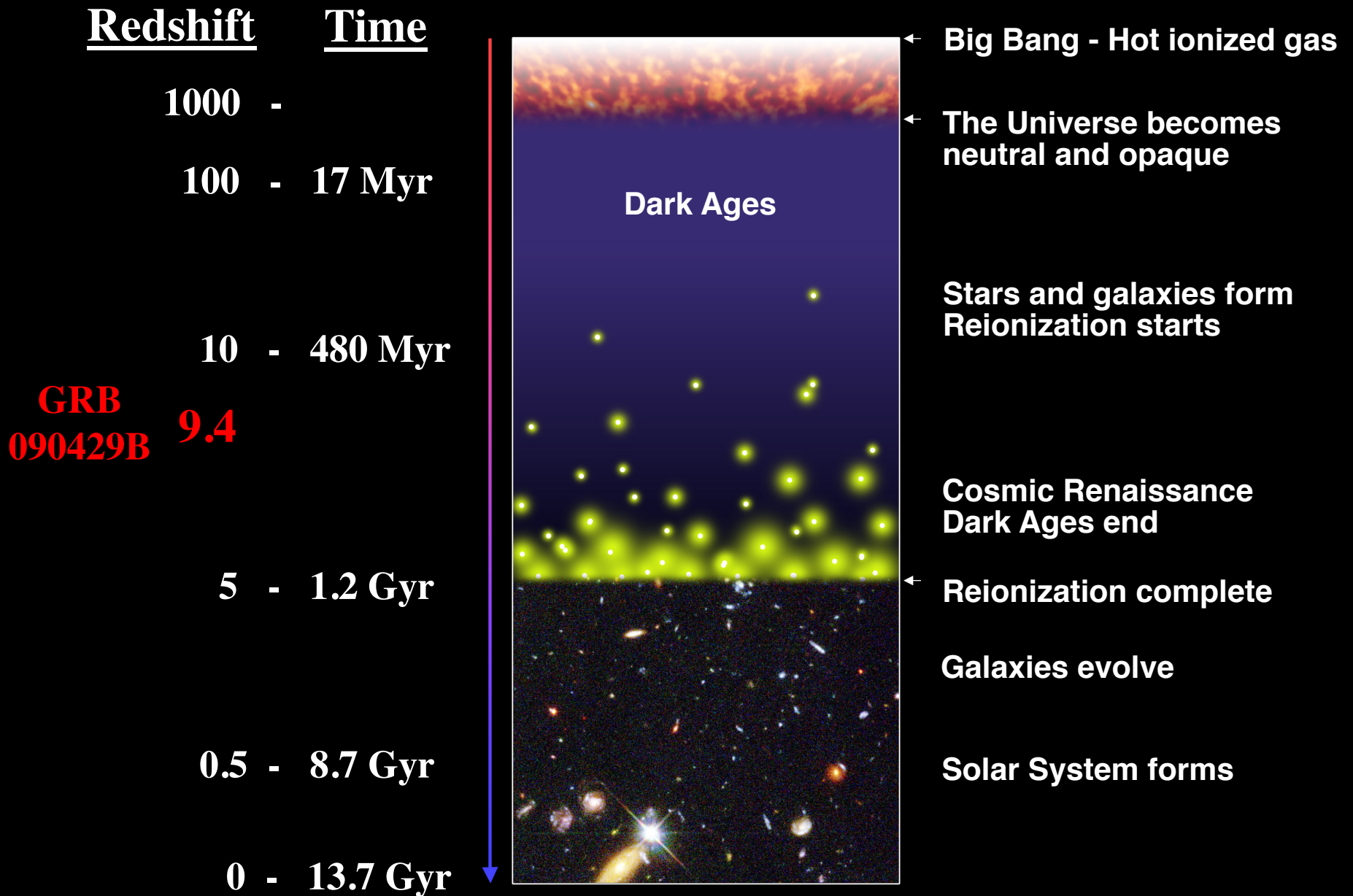


**GRBs: brightest
high-z sources**

Star Formation Rate

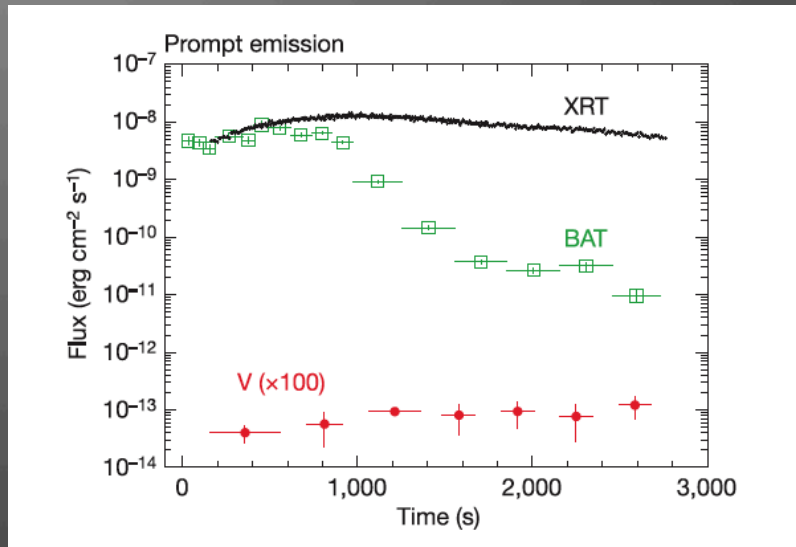


History of the Universe



Djorgovski et al.

GRB 060218: GRB + Supernova



Campana+ 006

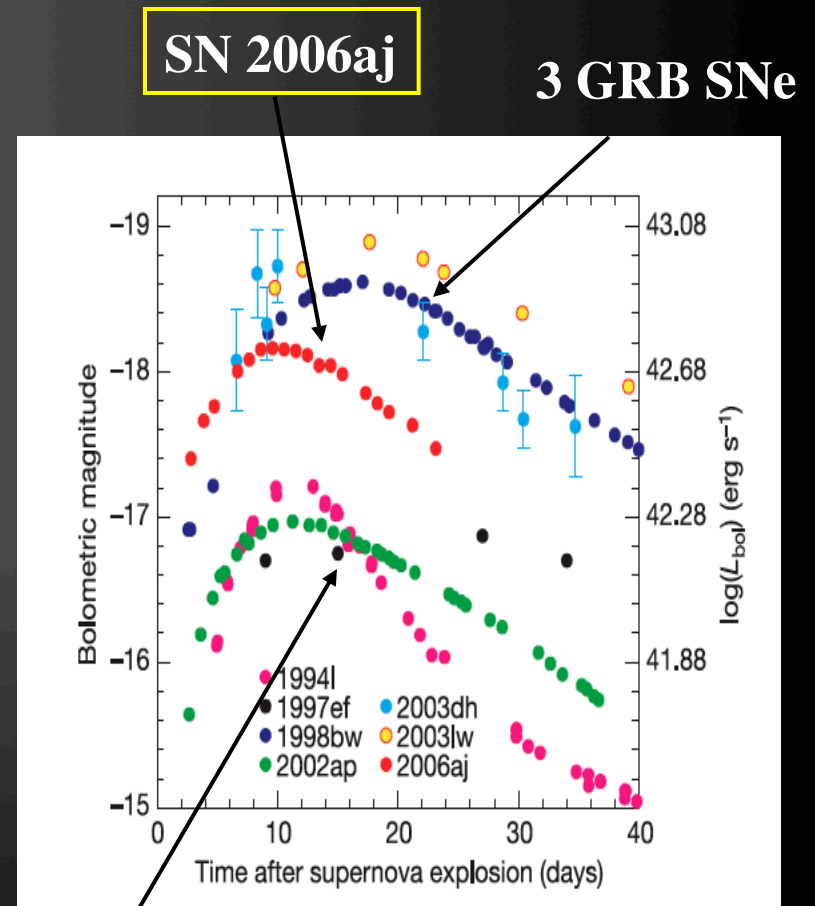
Super-long GRB - ~ 35 minutes

BAT, XRT, UVOT during GRB

$z = 0.033$ $d = 145$ Mpc

SN 2006aj SN Ib/c

$E_{\text{iso}} = \text{few} \times 10^{49}$ erg - underluminous

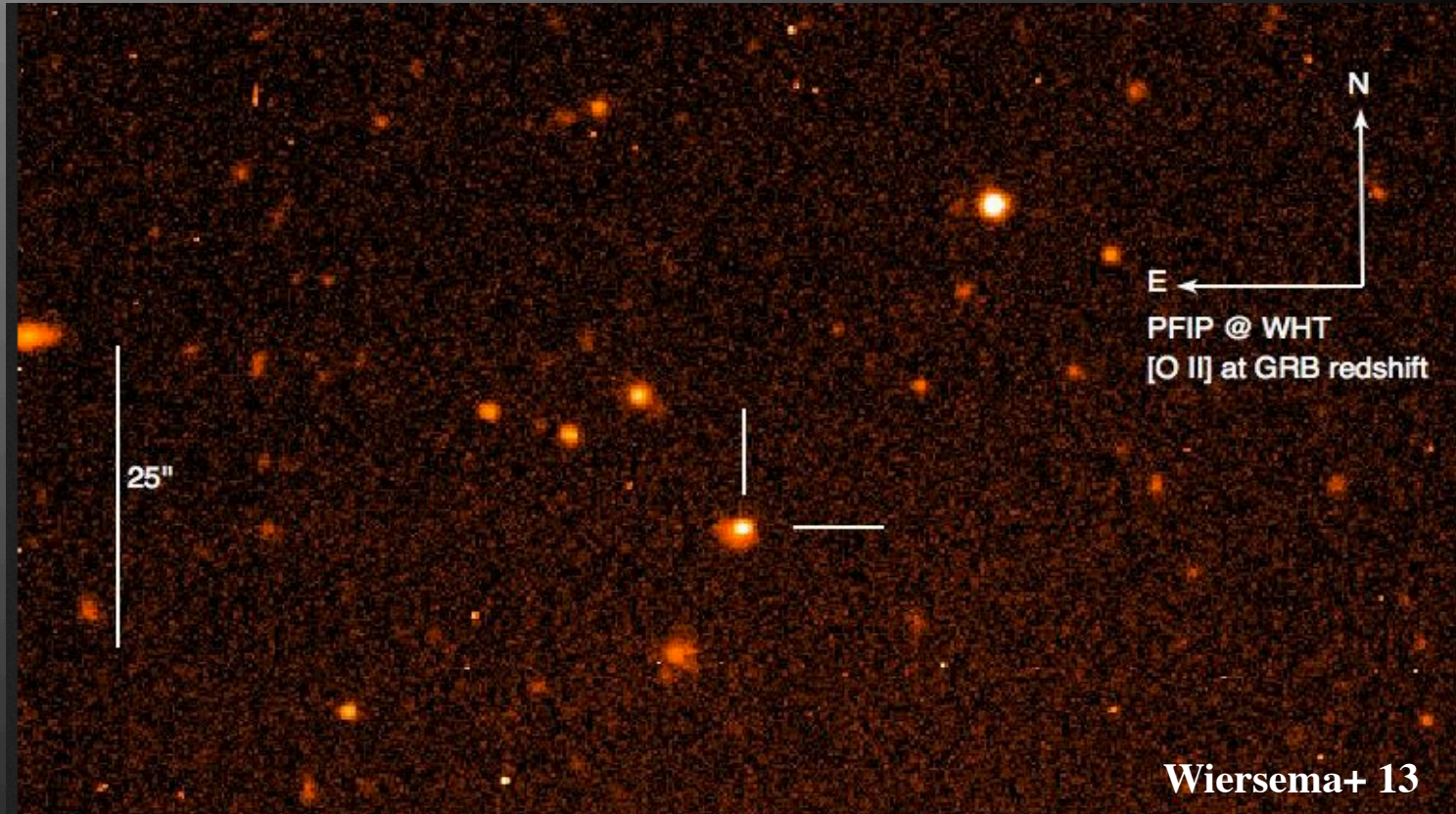


Pian+ 06

SNe Ic

Campana+ Mazzali+, Pian+, Soderberg+ 06

GRB 130427A



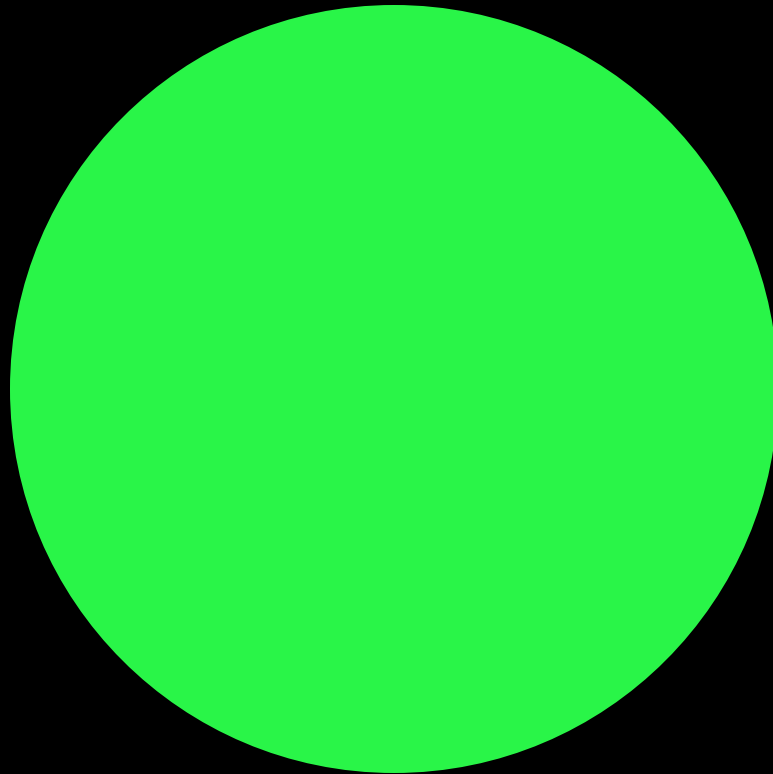
Bright burst in 5 years

$z = 0.34$

Afterglow observations: PanSTARRS, Gemini, Keck, +20 others

Supernova searches underway

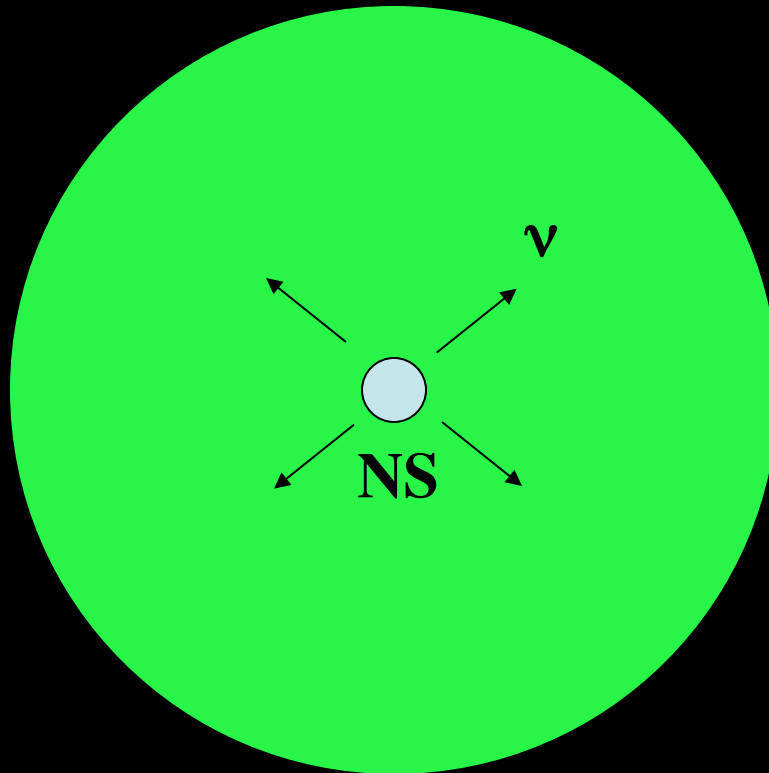
Long GRB Scenario



**Massive star with
H & He envelope
stripped**

Rapidly rotating

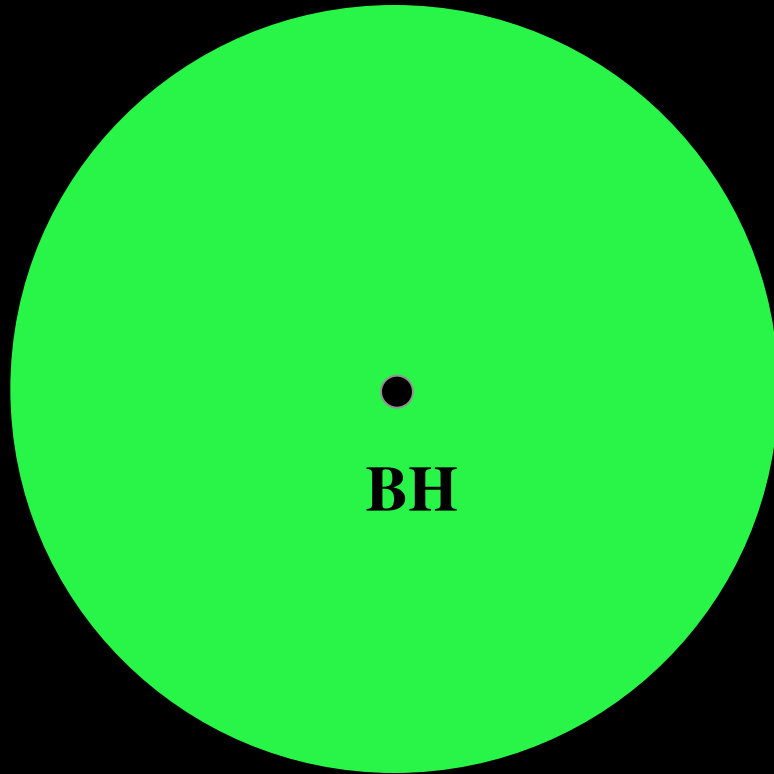
Long GRB Scenario



Massive star
Rapid rotation

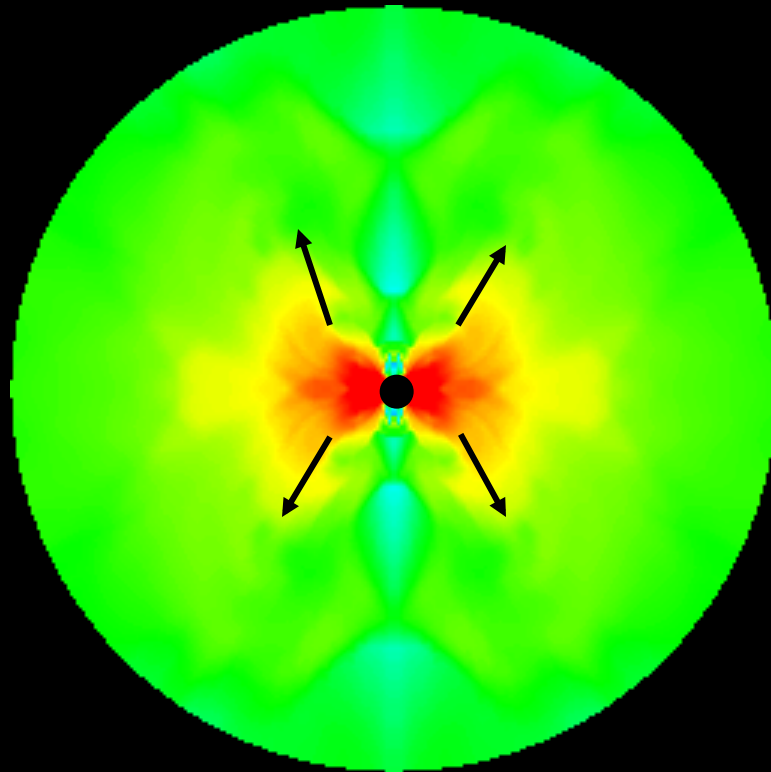
Proto-NS
Neutrino emission
Collapse $\tau < 1$ sec

Long GRB Scenario



Collapse to BH

Long GRB Scenario



Accretion onto BH
 $\tau \sim 10$'s sec

Jet emergence
 $\tau \sim 10$ sec

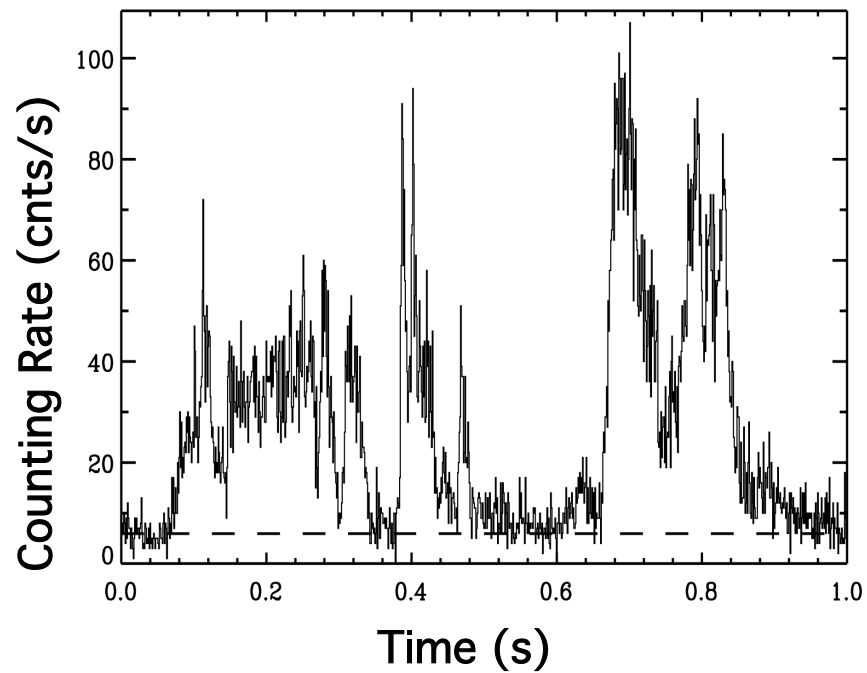
MacFadyen & Woosley



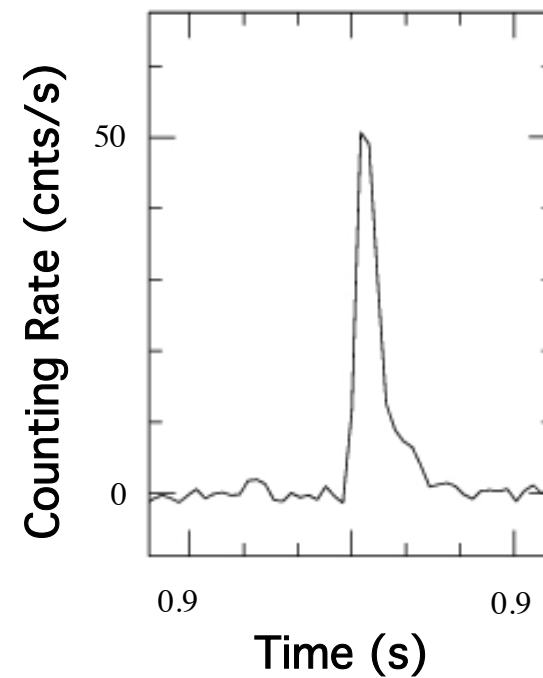
*Short
GRBs*

Short Burst Variety

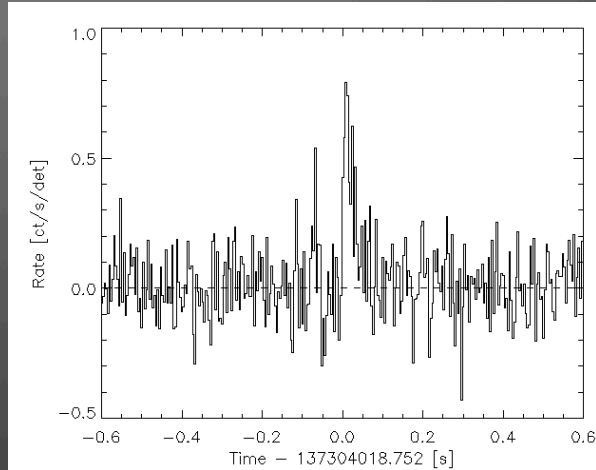
GRB 060313



GRB 130515



Cracking the Short Burst Problem



**GRB
050509B**

BAT

- 30 ms duration

XRT

- faint source, fading

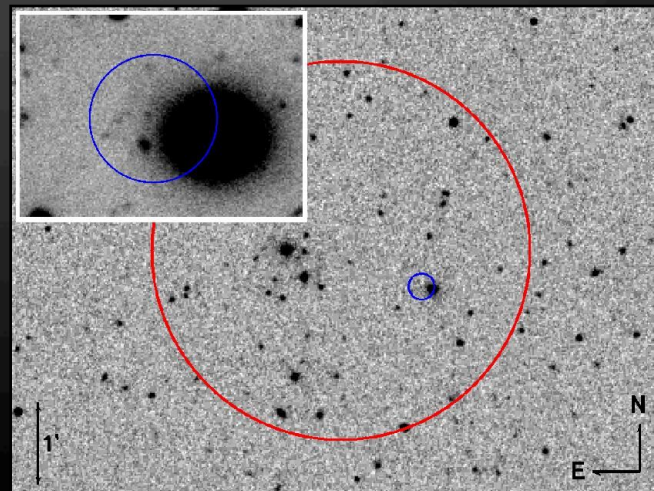
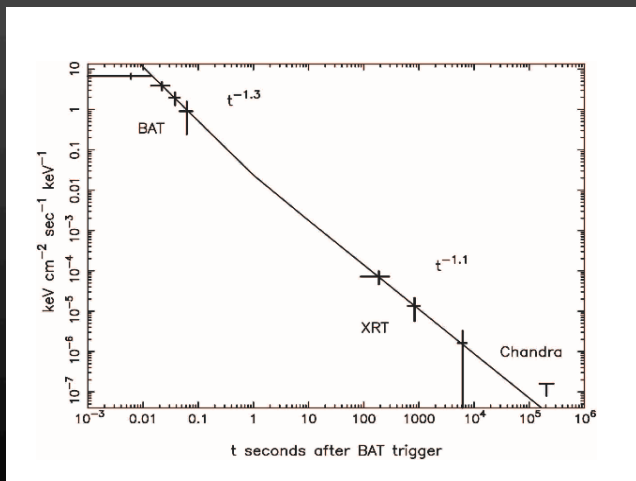
Host

- cD elliptical ($L = 3 L^*$)

- low star formation rate

- $z = 0.225$

No supernova to deep limits

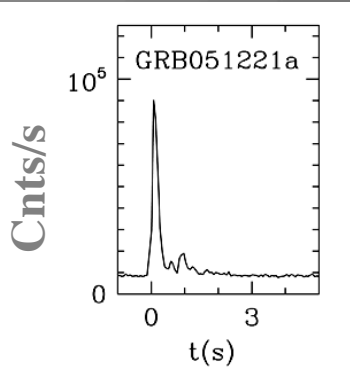


**VLT image
Hjorth+ 05**

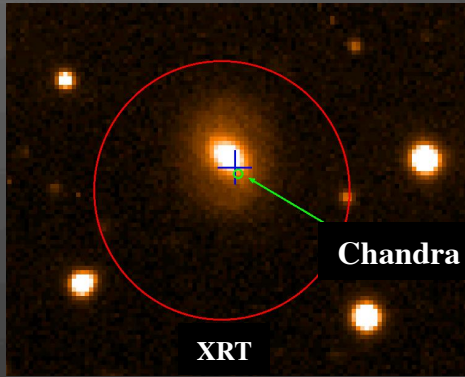
Gehrels+ 05; Bloom+ 06

Short vs Long GRBs

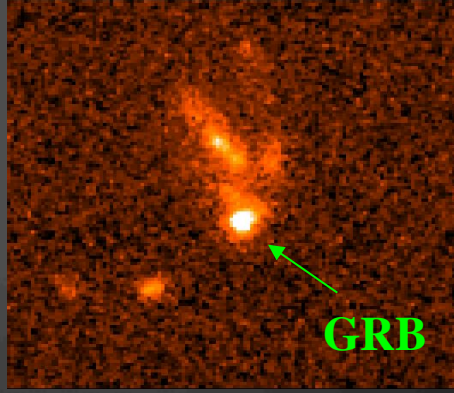
Short GRB



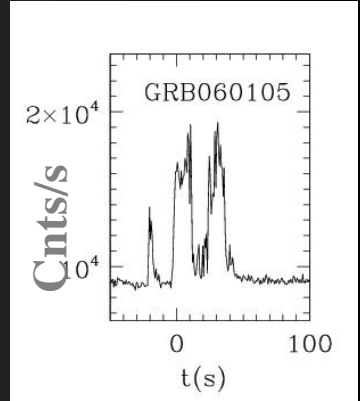
GRB 050724 - *Swift*
elliptical host



GRB 990123 - *SAX*
SF dwarf host



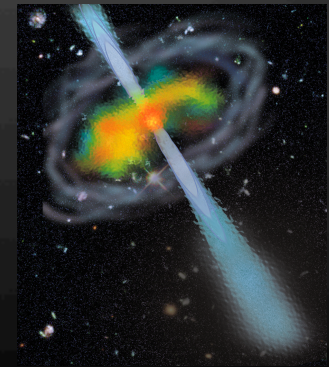
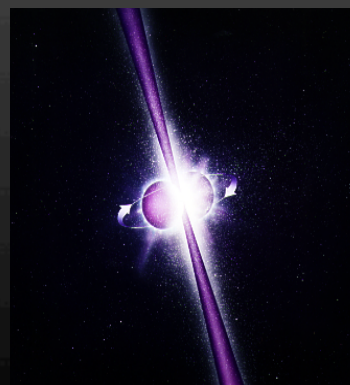
Long GRB



**In non-SF
and SF galaxies**

No SNe detected

**Possible merger
model**

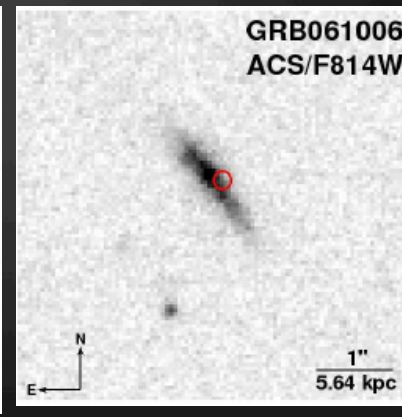
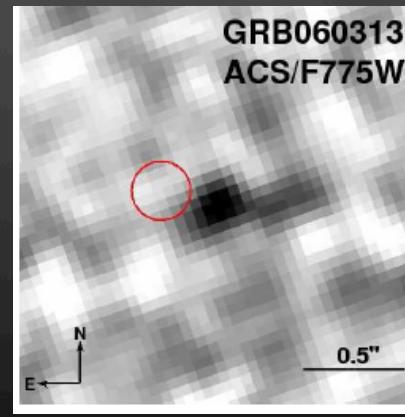
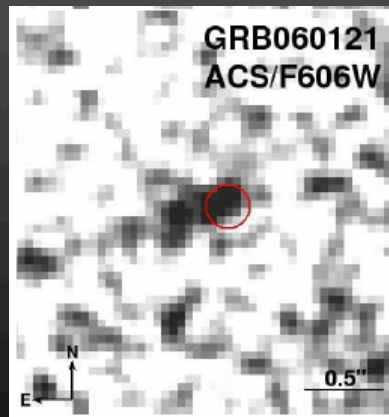
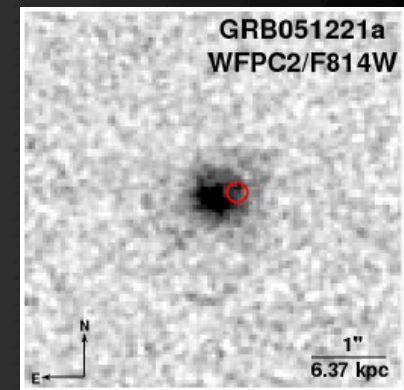
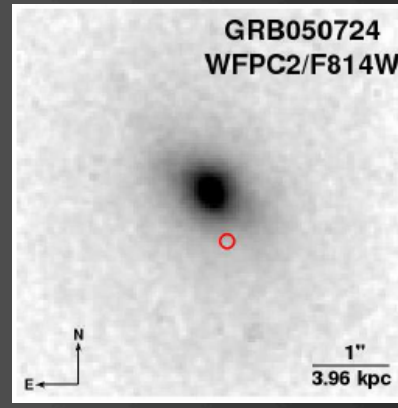
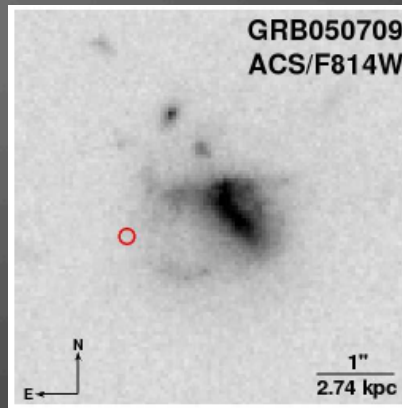
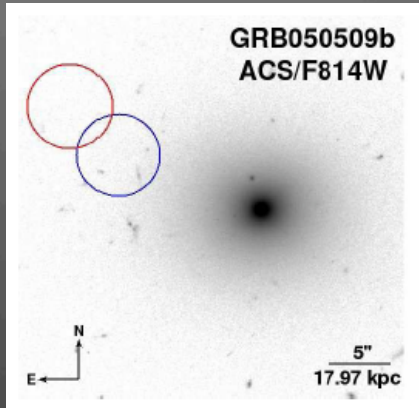


**In SF
galaxies**

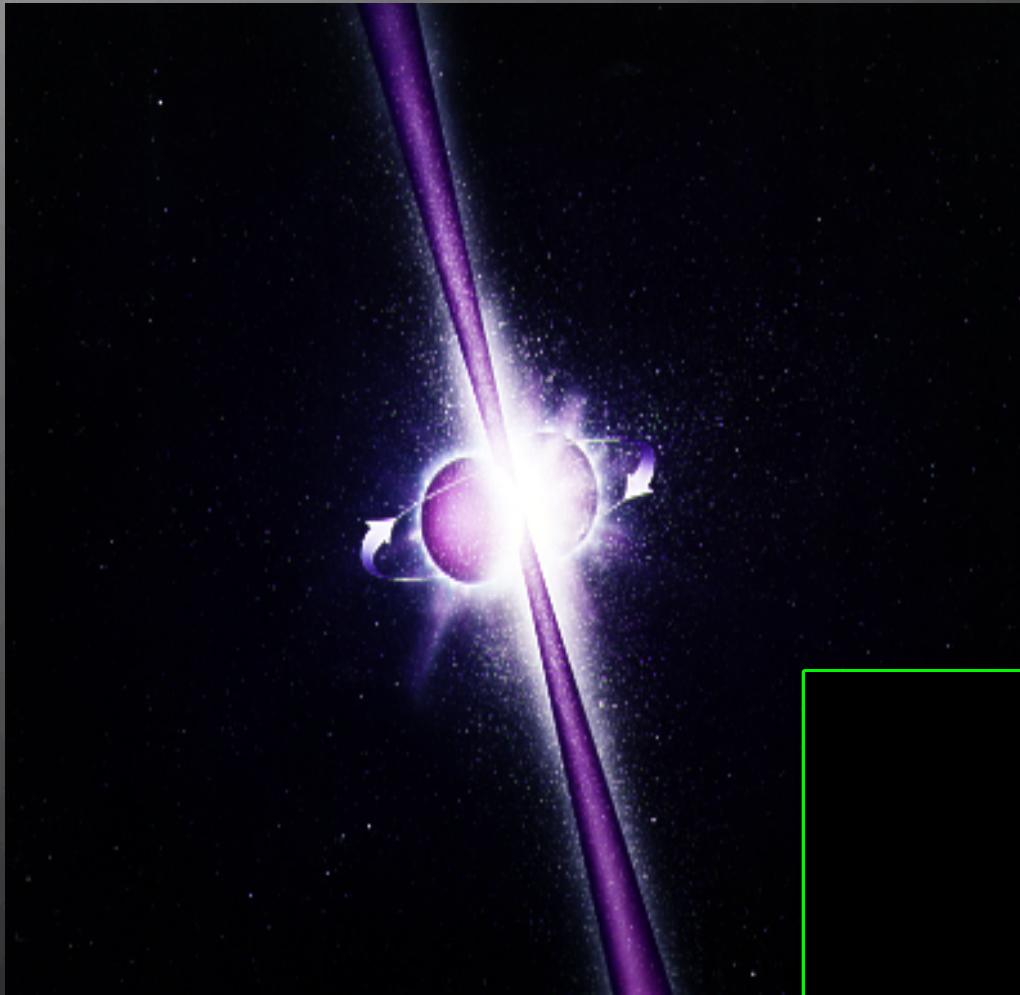
**Accompanied by
SNe**

**Collapsar model
well supported**

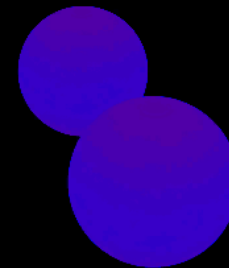
Short Burst HST Images



Short GRBs Merger Model



$t = .02 \text{ ms}$



Credit: Daniel Price and Stephan Rosswog

Daniel Price
Stephan Rosswog

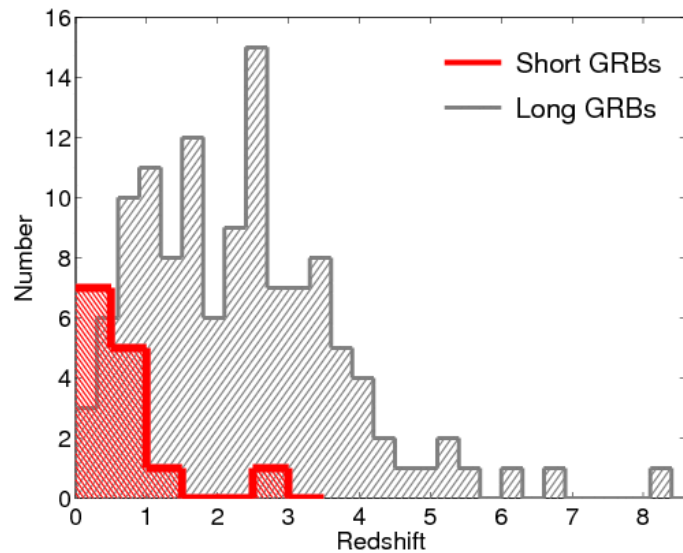
Swift localized 69 short GRBs

Weak afterglow

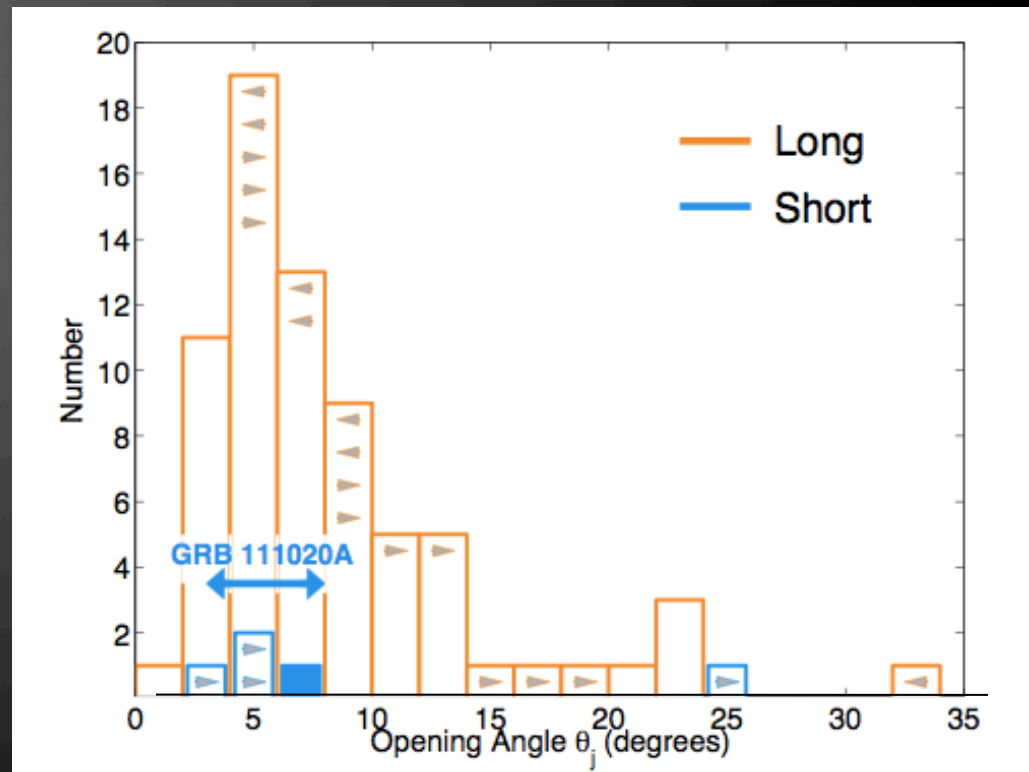
Low average redshift

Jet opening angle

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



Short GRB Info



Fong+ 12

Berger+ 09

Implications for GW Detections

Short GRB rate is $\sim 10 \text{ Gpc}^{-3} \text{ yr}^{-1}$

If all short GRBs due to NS-NS mergers
& beaming angle is 5 – 20 deg

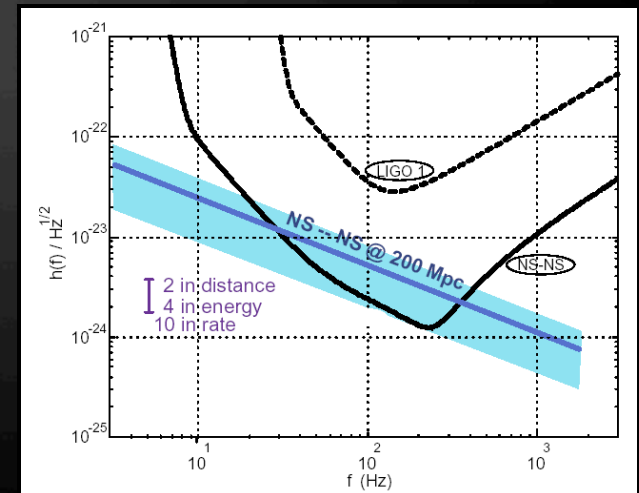
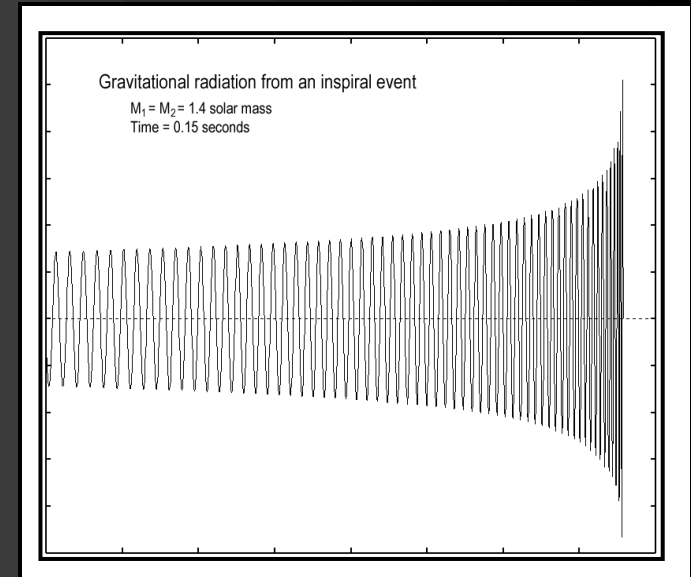
\Rightarrow NS-NS merger rate is 150 - 2500 $\text{Gpc}^{-3} \text{ yr}^{-1}$

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

For ALIGO/Virgo NS-NS merger sensitivity
distance is $\sim 200 \text{ Mpc}$:

aLIGO detection rate is 3 - 50 yr^{-1}

(plus BH-BH and gamma-ray quiet mergers)

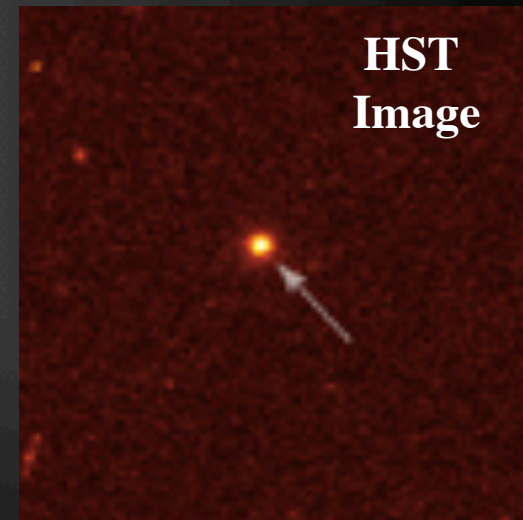
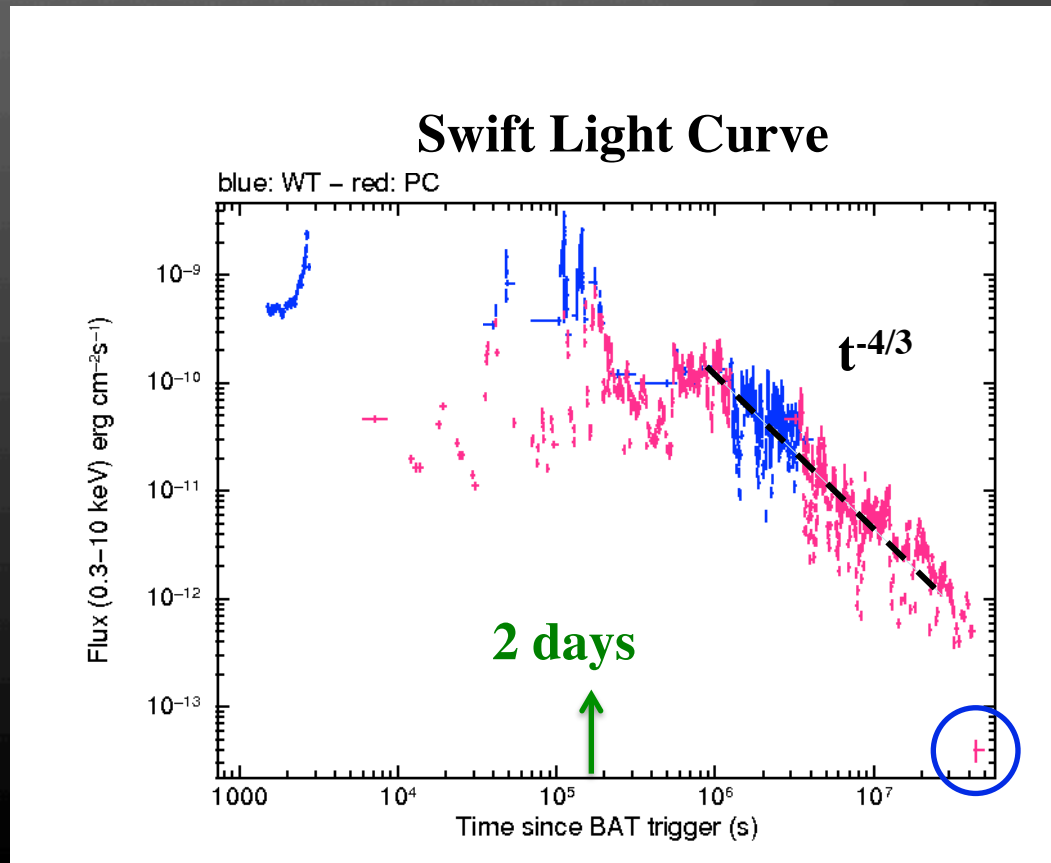


K. Thorne

*Non-GRB
Astrophysics*

Swift Transient - Swift 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



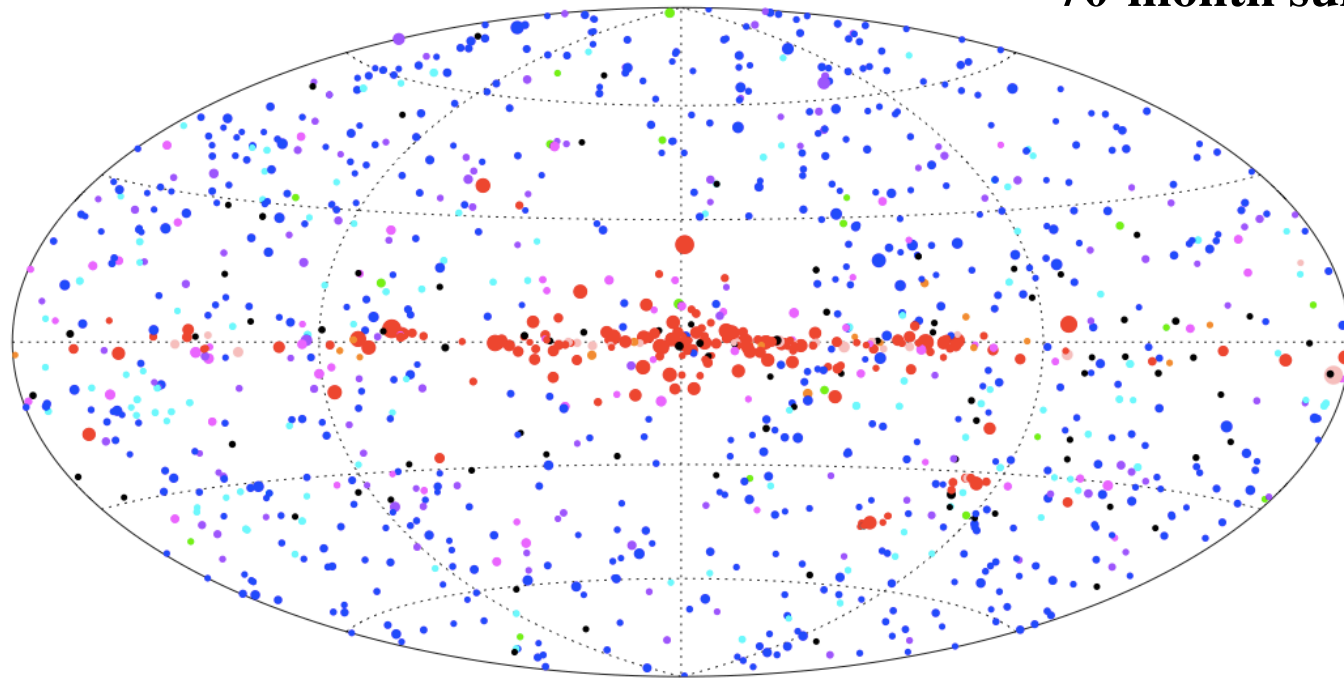
Center of galaxy at $z=0.35$



BAT Hard X-ray Survey

Baumgartner+ 13

14 – 195 keV₇
70-month survey



● Unidentified ● Galaxies ● Seyfert Galaxies ● CVs/Stars ● X-ray Binaries
● Galactic ● Galaxy Clusters ● Beamed AGN ● Pulsars/SNR

1171 sources detected

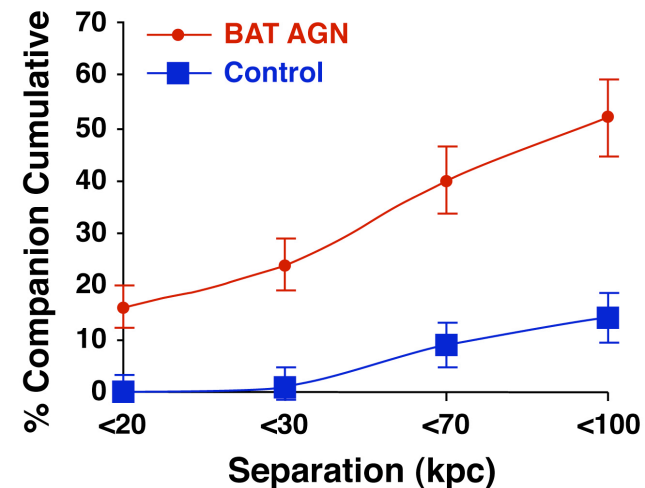
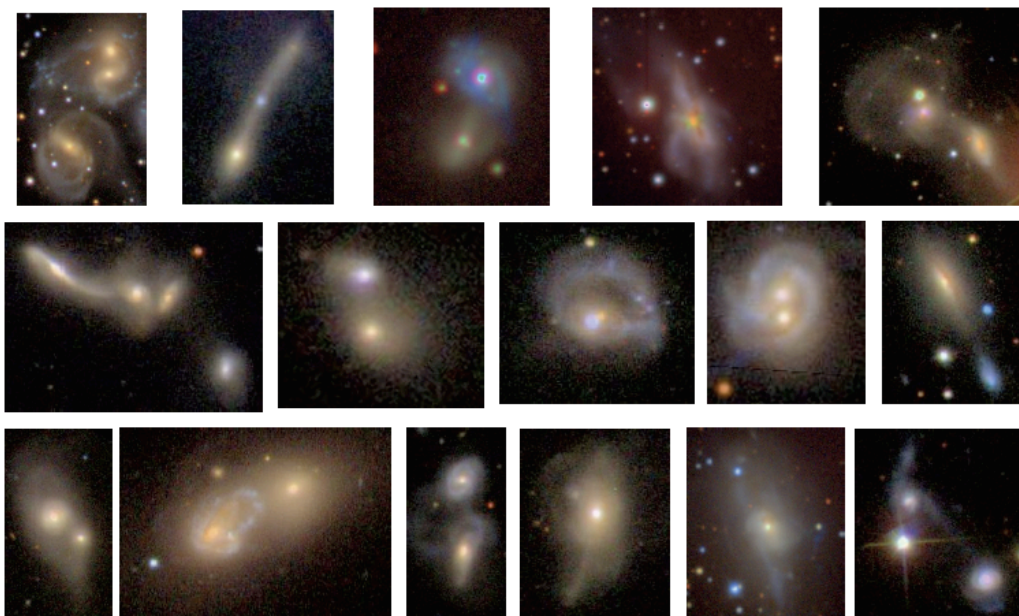
1.3×10^{-11} ergs/cm²-s over 90% of sky (~0.5 mCrab)

50% of sources are AGN (50% AGN absorbed, 10% Compton thick)

Merging Galaxies

Optical follow-up shows larger fraction of merging galaxies for obscured AGN

Conclusion: AGN activity and mergers are critically linked, particularly for AGN with stirred-up obscuration in their cores.



Merging Galaxies

- Flexible scheduling enables fast Targets of Opportunity
- Average ~3 per day
- SNe, novae, AGN, gal. transients, flare stars, comets,

	Target	Requestor	Date
4116	SGR J1645-29 / Sgr A*	Kennea	May 15, 2013
4115	LSQ13aiz	Brown	May 15, 2013
4114	RX J0520.5-6932	Vasilopoulos	May 15, 2013
4113	iPTF13asv	Cenko	May 14, 2013
4112	SwiftJ1910-0546	Jonkers	May 14, 2013
4111	Terzan 5	Heinke	May 14, 2013
4110	GRB 130514B (INTEGRAL)	Marshall	May 14, 2013
4109	NGC 2617	Grupe	May 14, 2013
4108	SN2013cj	Brown	May 14, 2013
4107	V1280 Sco	Schwarz	May 13, 2013
4106	GRB 130513A (INTEGRAL)	Malesani	May 13, 2013

Future Prospects

The Future is Bright

Fermi, HAWC, CTA

high energy γ -rays

JWST (2018)

IR

PTF, PanSTARRS, LSST

optical wide-field

EVLA, LOFAR, ALMA, SKA

radio (m - mm)

ICECUBE

neutrinos

LIGO/Virgo

gravitational wave

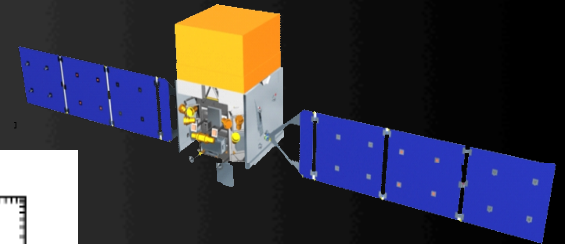
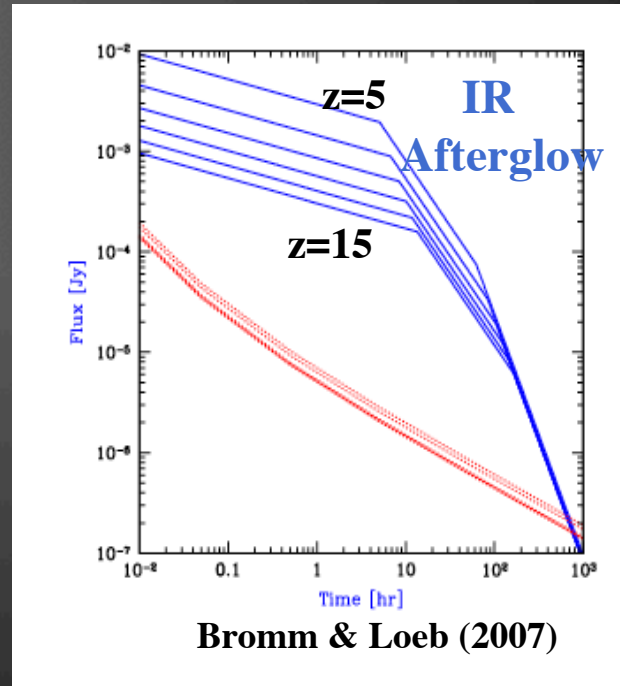
SVOM Chinese-French

GRBs hard X-ray & opt

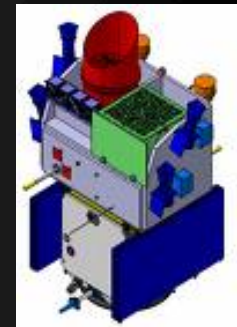
Lobster concept

GRBs

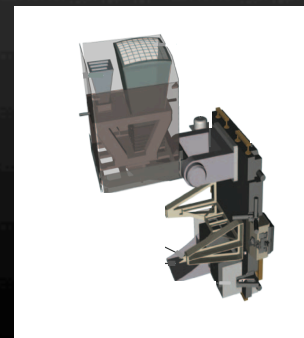
JWST



Fermi



SVOM



Lobster

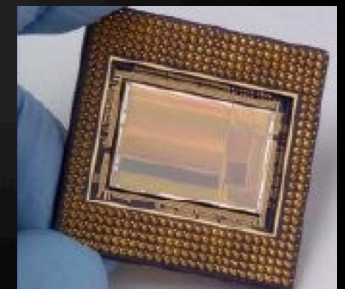
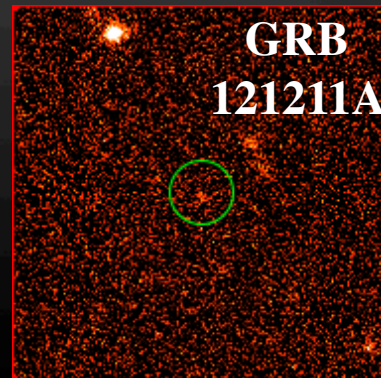
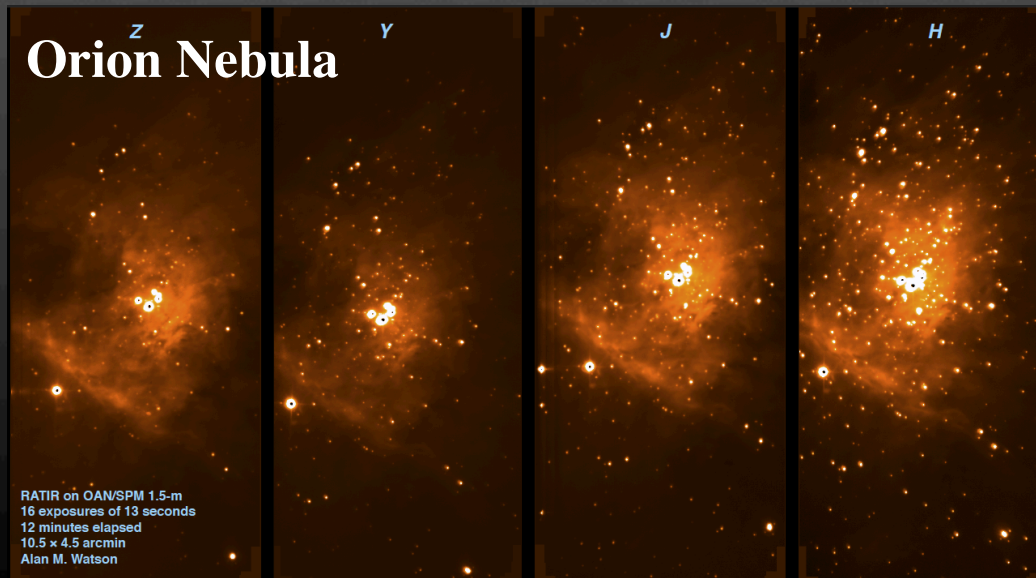
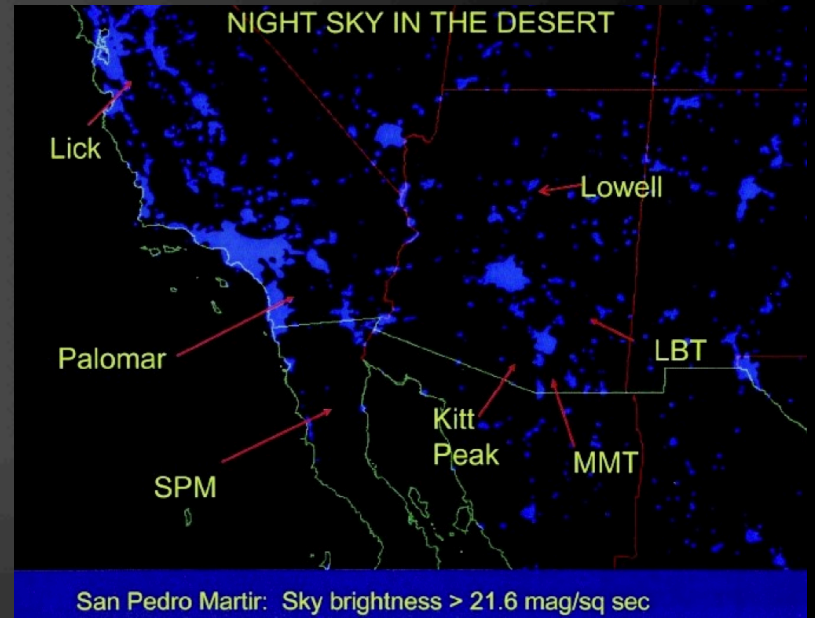


RATIR Instrument on Harold Johnson Telescope (Baja)

UCB, GSFC, UNAM

NIR imager

Photo spectroscopy z, Y, J, H





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

