The First 100 Gamma-Ray Bursts

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Space Part ‘06

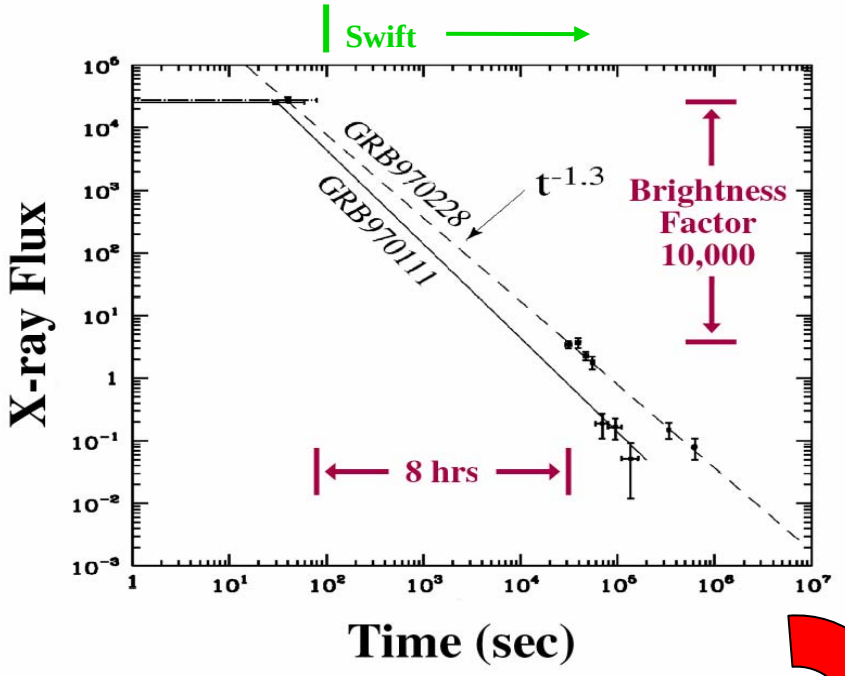
Motivation for Swift

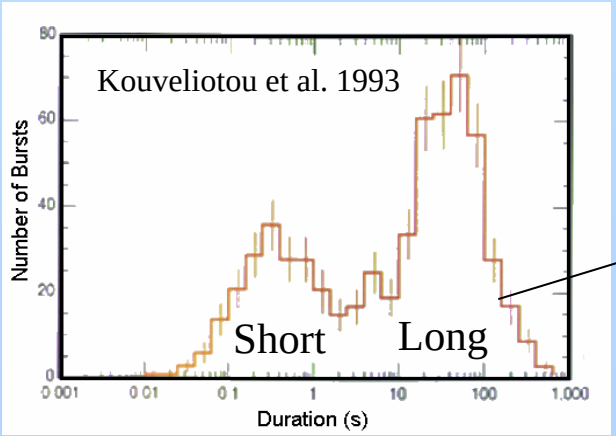
Brightest explosions in Universe
- standard candles?

Black hole birth
- progenitors?
- sub-classes?

Ultra-relativistic outflows ($\Gamma \sim 100$)
- particles vs Poynting flux?
- internal vs external shocks?

Early universe probes
- GRBs from Pop III stars?
- metallicity effects?
- usable for cosmology?





Requires:
- **fast-response**
- **multiwavelength coverage**
- **high sensitivity**

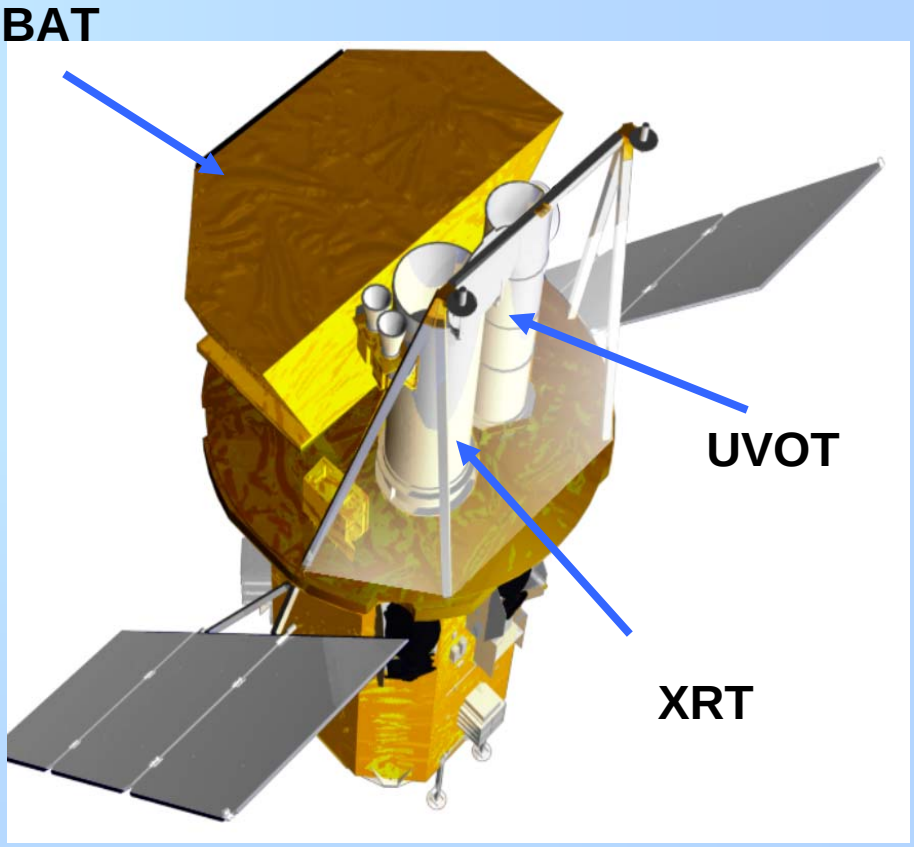
Major Swift Components

Instruments

- **Burst Alert Telescope (BAT)**
  - New CdZnTe Detectors
  - Arcminute GRB Positions (20 sec)
- **X-Ray Telescope (XRT)**
  - Arcsecond GRB Positions (100 sec)
  - CCD Spectroscopy
- **UV/Optical Telescope (UVOT)**
  - Sub-arcsec Imaging
  - Spectroscopy with Filters
  - 22nd Mag Sensitivity

Spacecraft Bus

- Autonomous re-pointing, 20 - 75 sec
- Onboard and ground triggers



Observatory Performance

All instruments performing to specifications

BAT GRB rate close to 100 yr^{-1} predicted

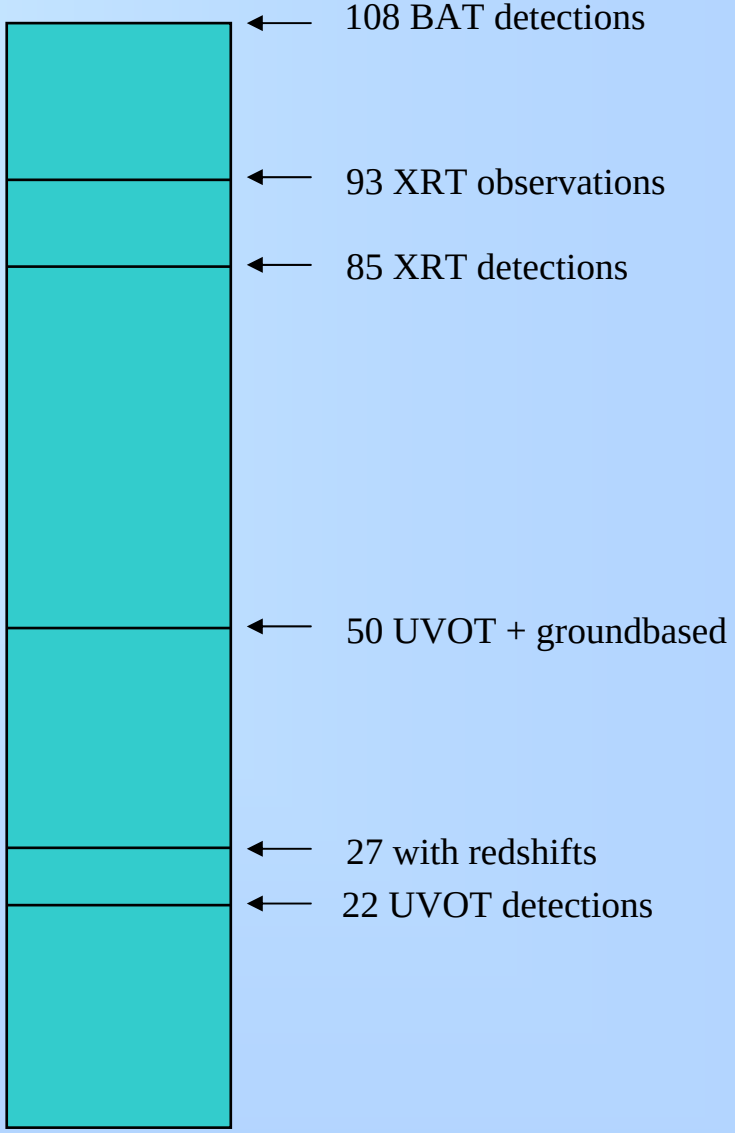
BAT:
- **2.5x more sensitive than BATSE**

XRT:
- **Sensitivity 5x better than BeppoSAX**
- **Imaging 4x better than BeppoSAX**

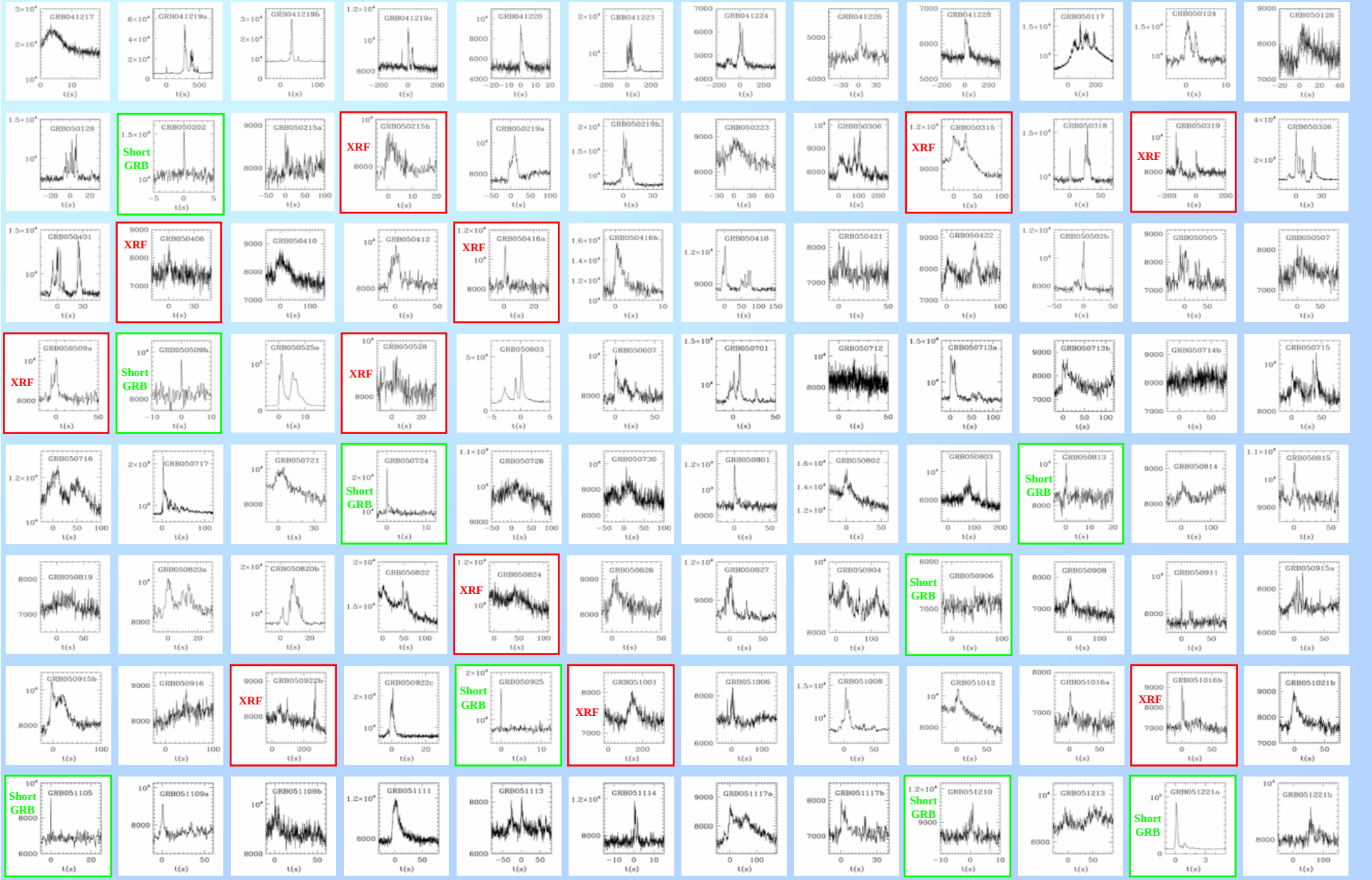
Source positioning:
- **BAT = 3’ prompt (90% confidence)**
  = 1’ ground analysis
- **XRT = 5" prompt**
  = 3.7" ground analysis
- **UVOT = 0.56" (average star centroid)**

62 non-GRB Targets of Opportunity performed

GRB Detections as of 01/23/2006



Swift's Bursts



Outline of the Talk

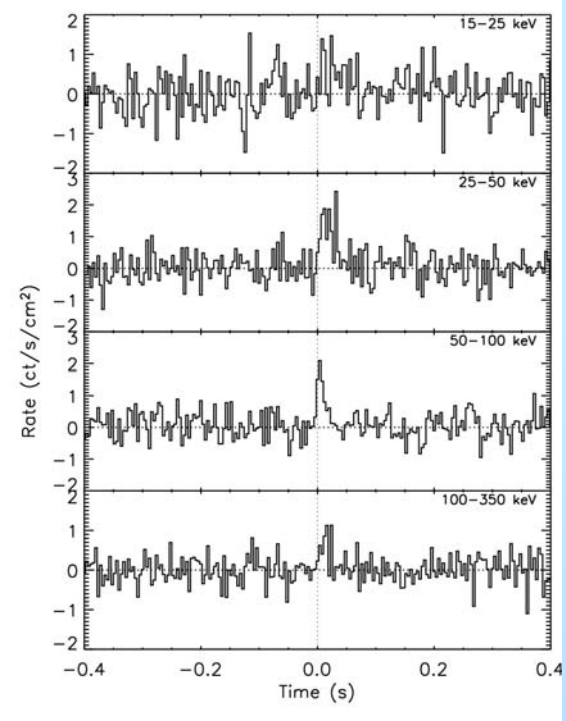
- The Swift Observatory
- Major Science Results
  - Short GRBs
  - GRBs at high redshift
  - Afterglows of GRBs
  - Supernovae & GRBs
- Expectations for the Future

Short GRBs

2005 Was A Remarkable year!!

7 short GRBs with rapid arcsec positions

GRB 050509b - Flash & Gone



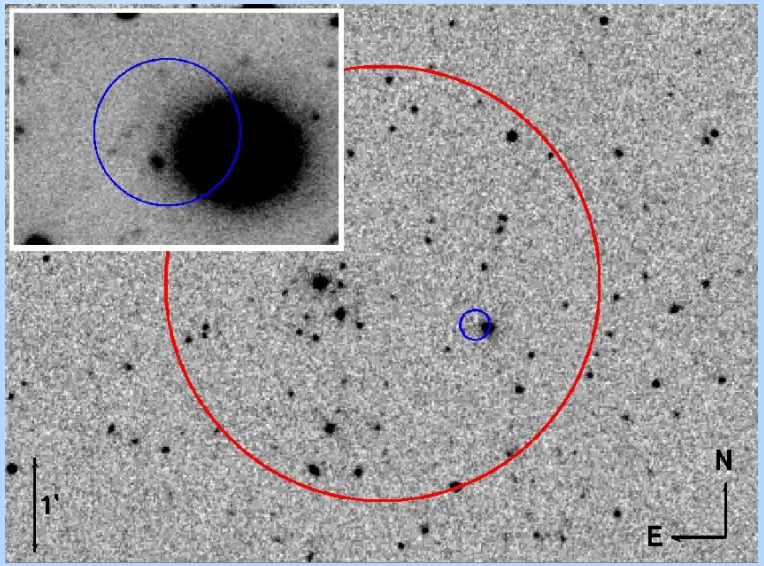
BAT
- 30 ms duration
- very weak, 2×10^{-8} erg/cm^2

Spacecraft slew in 52 sec

XRT
- faint source, fading
- 11 cnts = 1×10^{-12} erg/cm^2/s

Host:
- cD Elliptical
- L = 3 L*
- z = 0.225

VLT image
Hjorth et al.

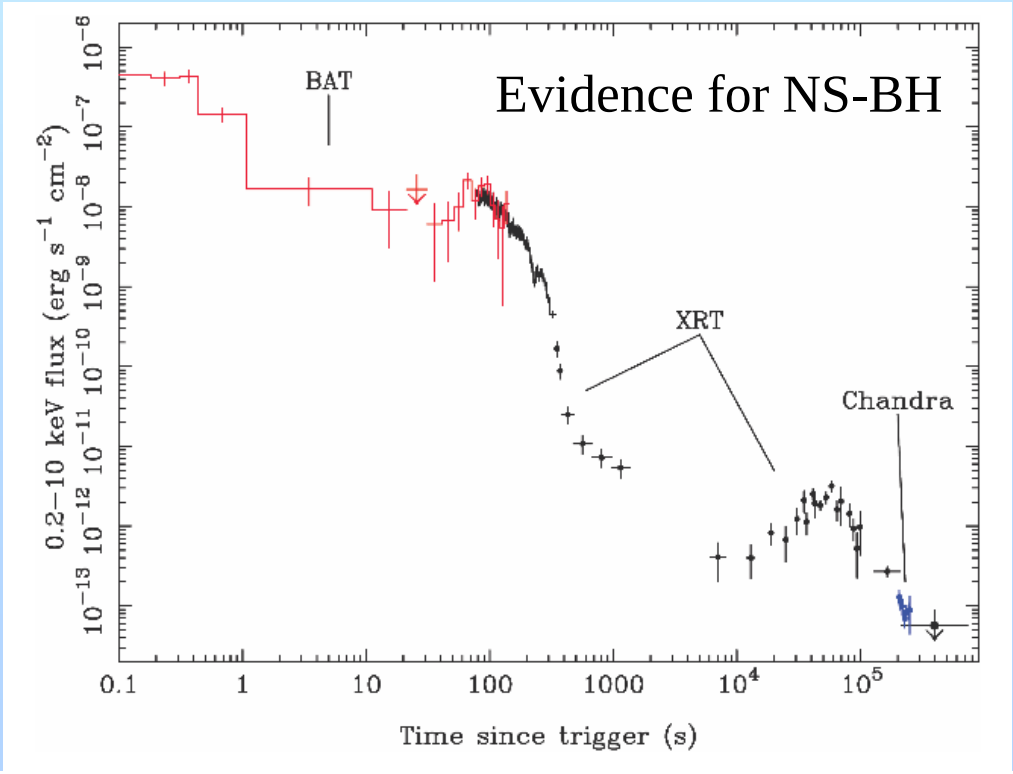


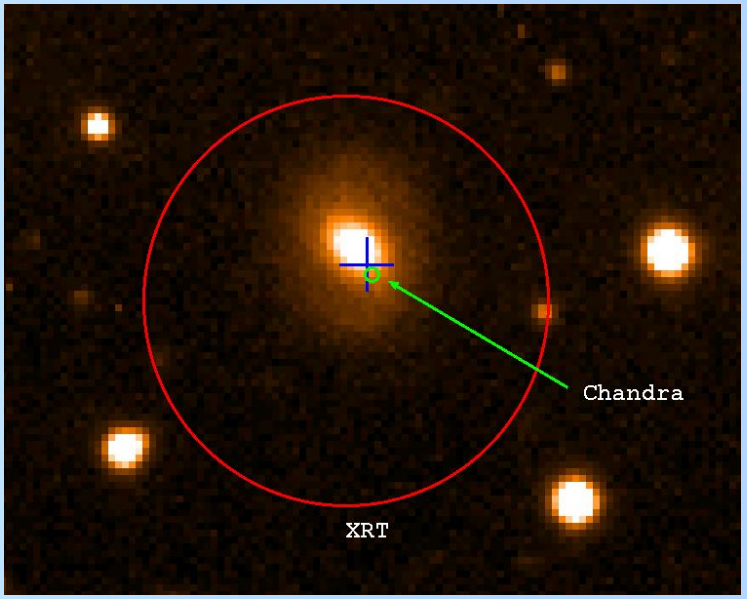
Gehrels et al. 2005

GRB 050724

BAT
- 250 ms hard spike (T_{90} = 3 s)
- 6×10^{-7} erg/cm^2 fluence

Afterglow
- bright fading x-ray afterglow with flares
- detected by Chandra days after GRB
- optical & radio



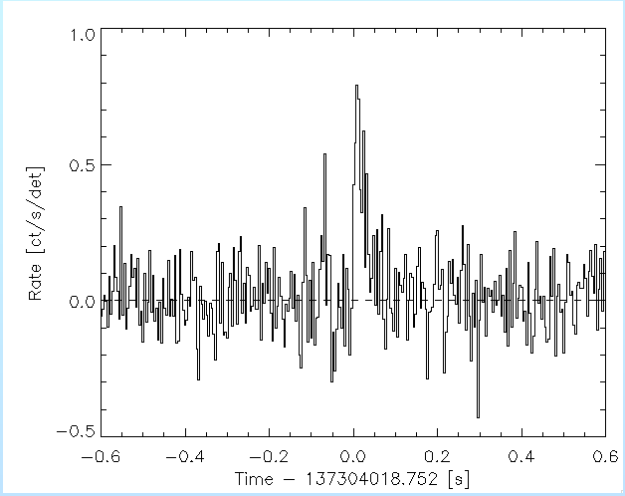


Host:
- Elliptical
- L = 1.7 L*
- z = 0.258
- SFR < 0.02 M_O yr^{-1}

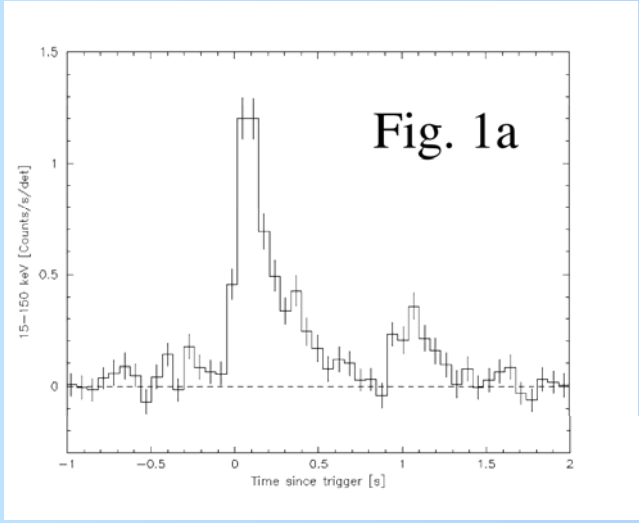
Barthelmy et al. 2005

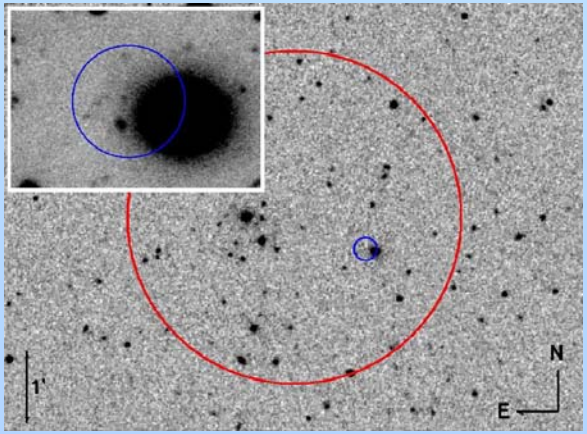
2 Short GRBs - 2 Elliptical Hosts

GRB 050509B



GRB 050724

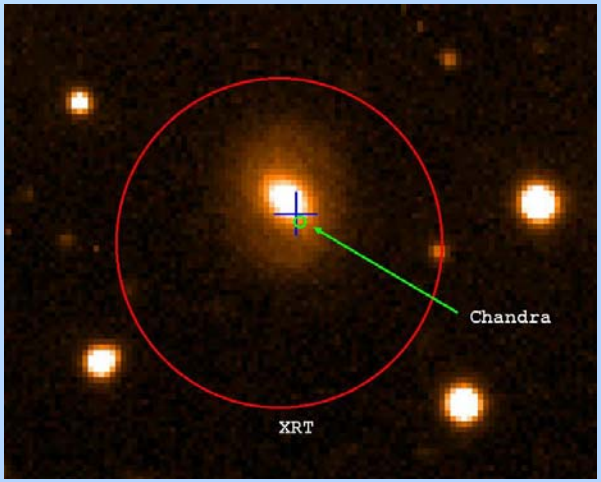




- **elliptical hosts**
- **low SF rates**
- **offset positions**
- **redshifts z ~ 0.2**

>> inconsistent with collapsar model

>> supportive of NS-NS model



Short GRB Summary

Name	Redshift	Afteglow	Host	E_{iso}(15-150keV) (erg)	What might it be?
050202	-	no slew (near the Sun)		-	-
050509B	0.225	X	Elliptical	$1x10^{48}$	NS-NS merger
050709*	0.161	X, O	SF galaxy	$6x10^{49}$	NS-NS merger
050724	0.258	X, O, R	Elliptical	$3x10^{50}$	NS-NS / NS-BH merger
050813	? 1.8	X	galaxy	? $2x10^{51}$	? NS-NS merger
050906	? 0.03	-	? galaxy	-	? minimal afterglow
050925#	-	-	in gal. plane	-	? possible new SGR
051105A	-	-	-	-	? minimal afterglow
051210	? 0.11	X	? cluster	? $2x10^{48}$	? NS-NS merger
051221	0.547	X, O, R	SF galaxy	$9x10^{50}$	? NS-NS merger
060121*	? high	X, O	? galaxy	-	? NS-NS merger
060313	-	X, O			

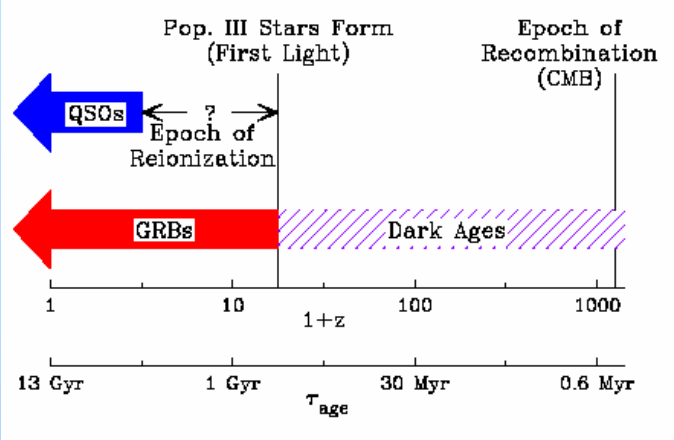
possibly short
051211*, 051227, *SGR 1820-06*

* HETE GRB
\# soft spectrum

High Redshift GRBs

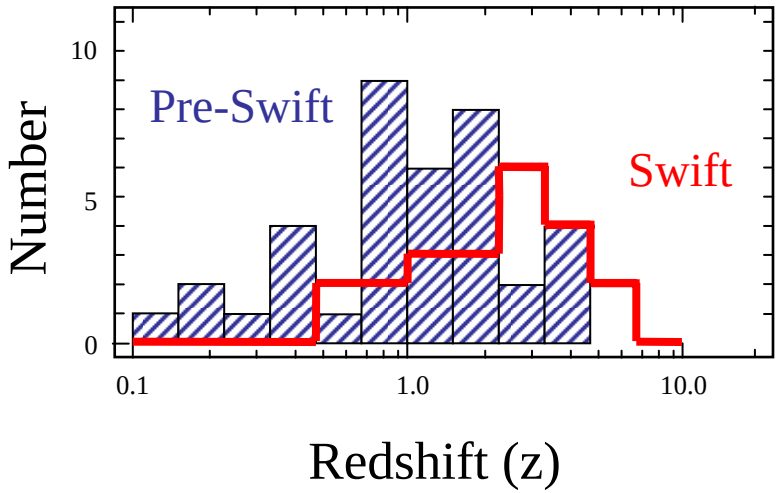
What Can We Learn?

- GRBs are very luminous, detectable to z>10
- X-ray and optical afterglows are the brightest objects at high z
- GRBs are tools to study:
  - Star formation history
  - First light and re-ionization of IGM
  - Metallicity history
  - Dust and gas content of early galaxies
  - Cosmology



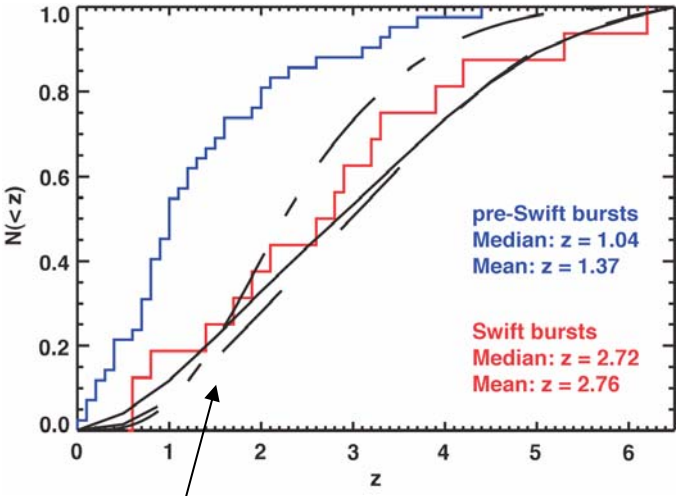
High Redshift GRBs

GRB Redshift Distributions



Average Redshift
- Pre-Swift: z = 1.2
- Swift: z = 2.5

Swift GRBs Tracing SFR



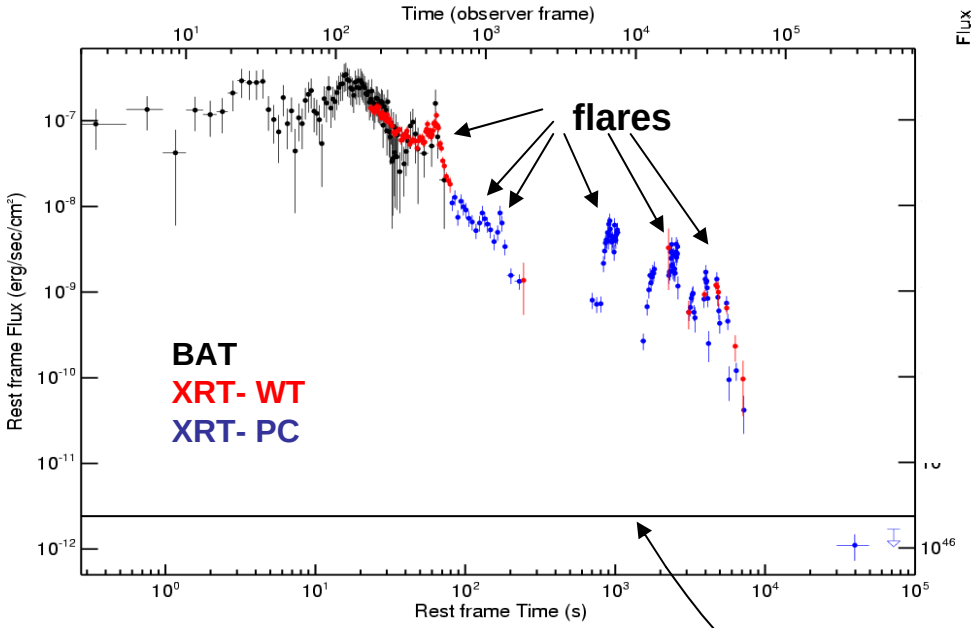
Jakobsson et al. 2006

Lines are models with GRBs proportional to SFR

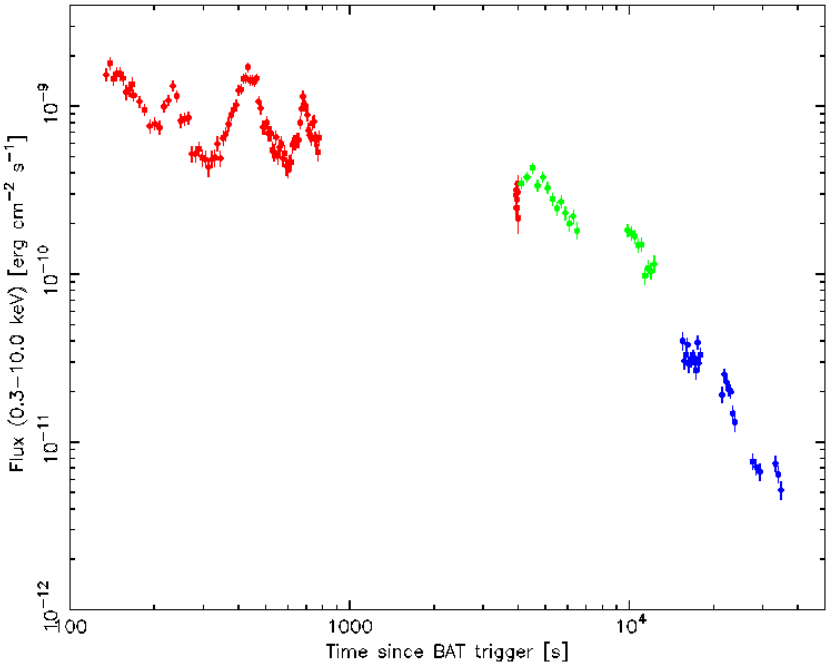
GRB 050904

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

X-ray Afterglow



GRB 050730
z=4.0



Flux 100x that of high-z luminous X-ray AGN

Cusumano et al. 2006

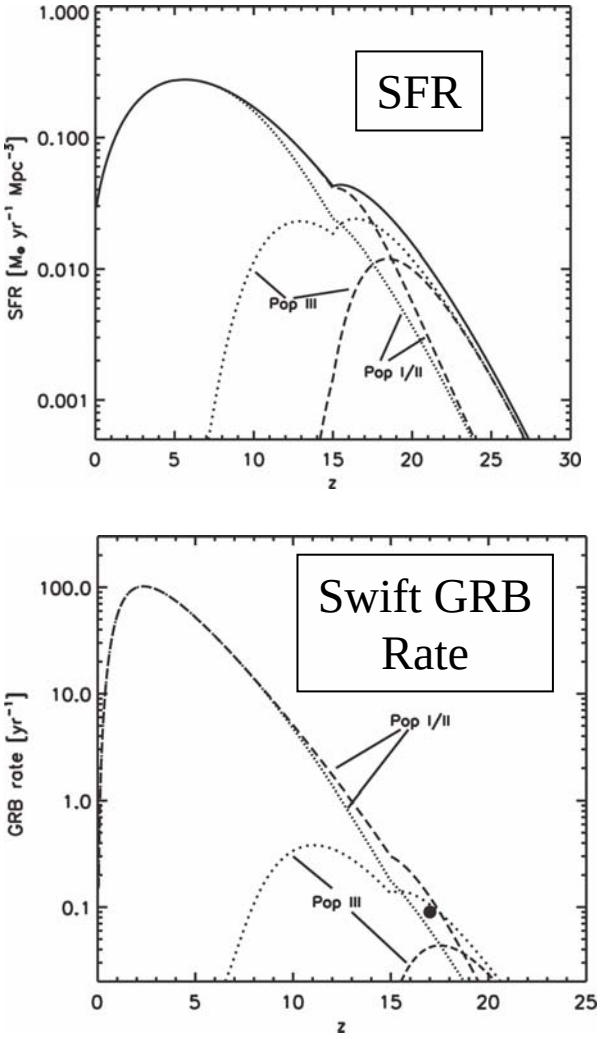
Predictions for High-z Rates

Studies of Swift detection rates at high-z
- Lamb and Reichart 2000
- Ciardi and Loeb 2002
- Bromm & Loeb 2005 (astro-ph 0509303)

Assumption: long GRBs track SFR

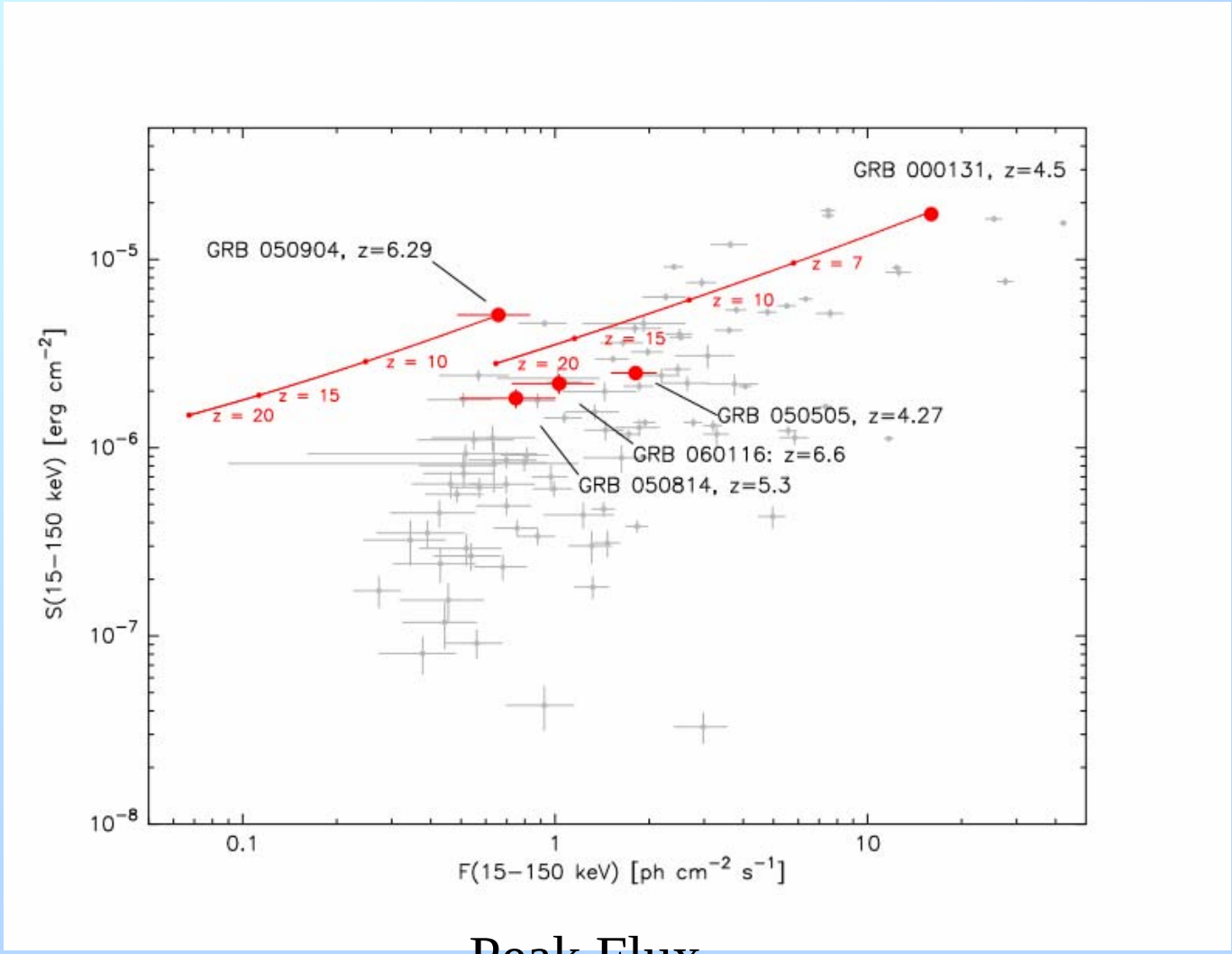
Prediction:
- 7% - 10% of Swift GRBs at z>5
  (Bromm & Loeb 10%, Jakobbson et al. 7%)
- ~0.5% at z>10

$$d N_{GRB} / d \ln(1+z)$$



Bromm & Loeb (astro-ph 0509303)

Extrapolating to z>10

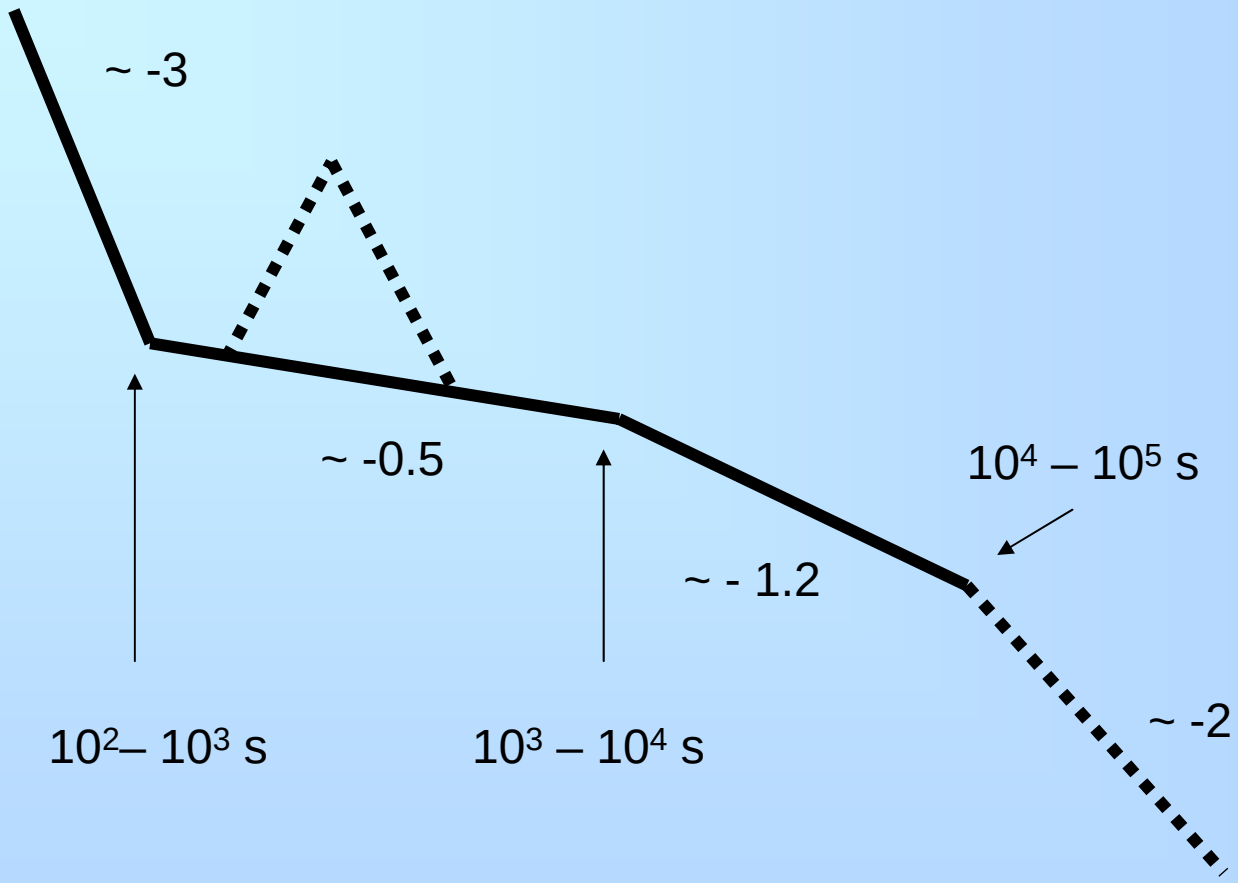


Fluence

Peak Flux

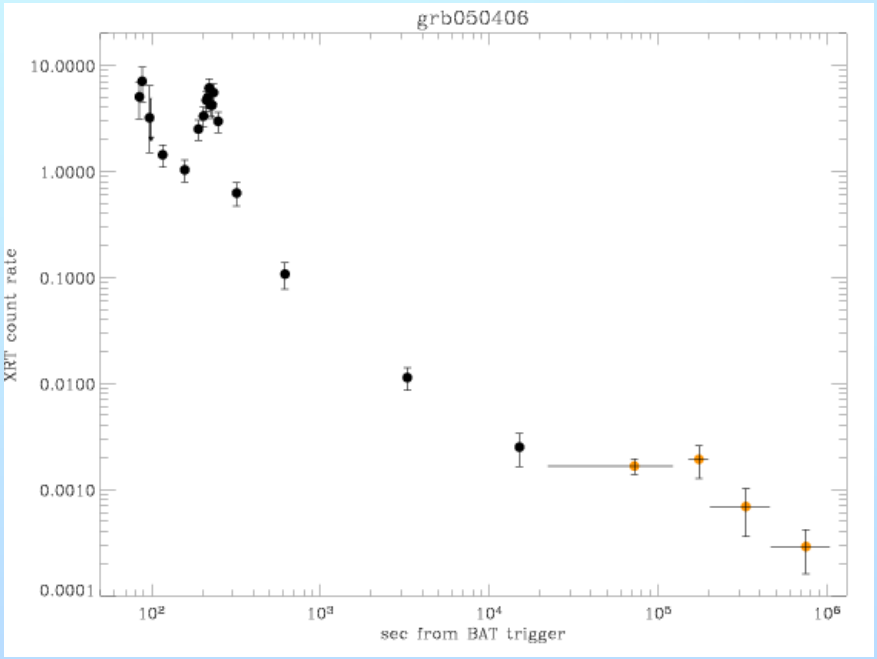
Afterglows & Flares

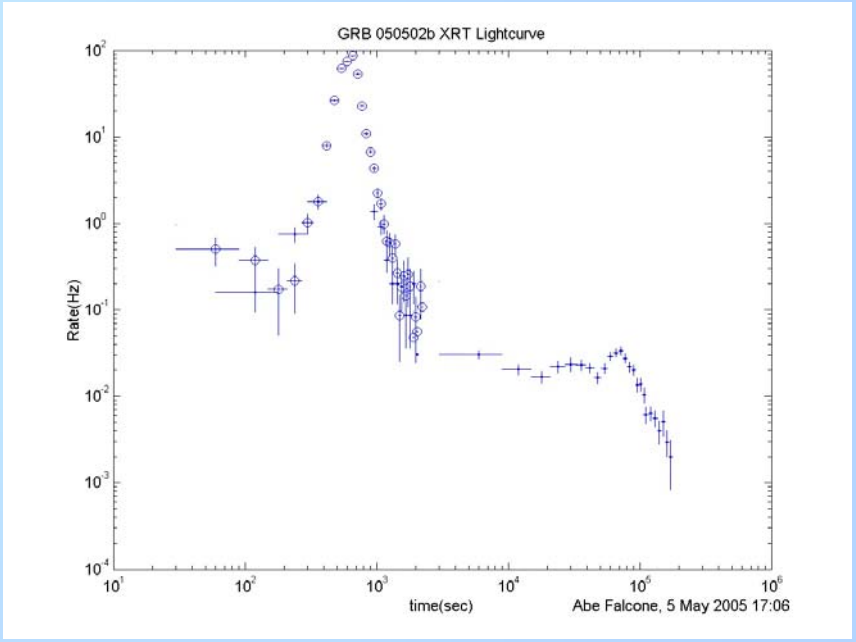
Generic X-ray Lightcurve



Zhang et al.; Nousek et al. 2005

Afterglow Flares

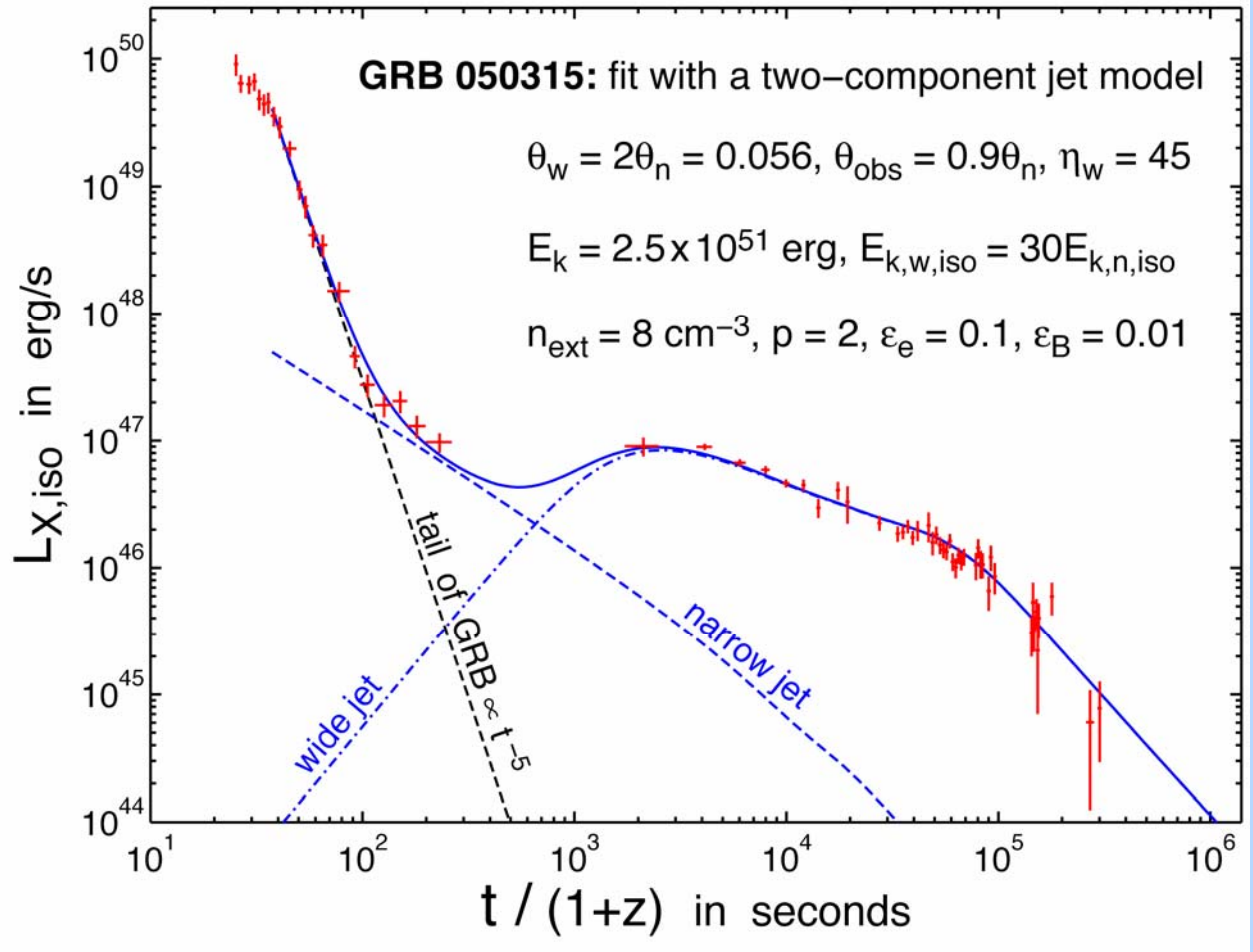




Flares are common in the unexplored early time domain.

Burrows et al. 2005

Two Component Jet Model



Granot, Königl & Piran 2006

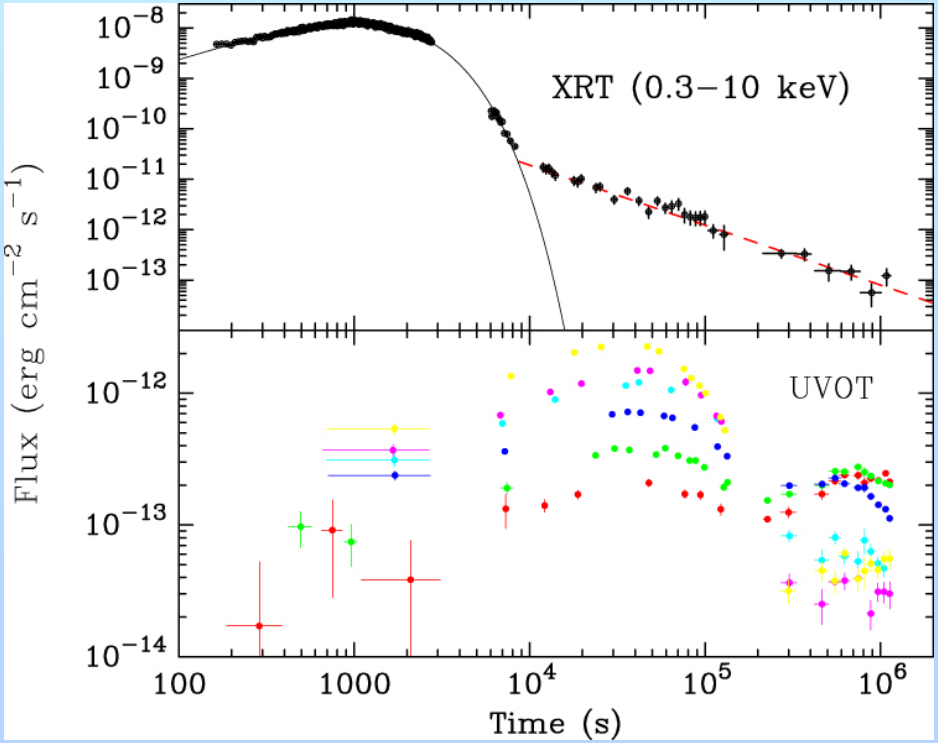
Afterglow Summary

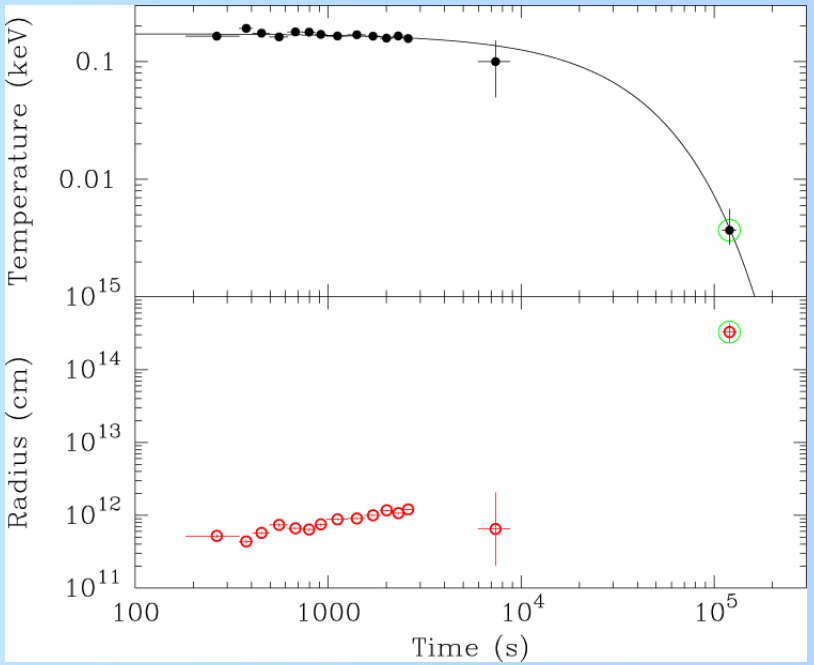
- Swift has discovered an unexpectedly rich set of phenomena in the first few hours of the GRB afterglow.
- A new “standard” light curve.
- Large flares a common occurrence.
- Jet breaks are rarely seen.

Supernovae & GRBs

GRB 060218/SN 2006aj

Swift:
- Unique light curve at all wavelengths
- First observation of shock breakout from SN
- Soft thermal component with
- falling Temperature & increasing Radius



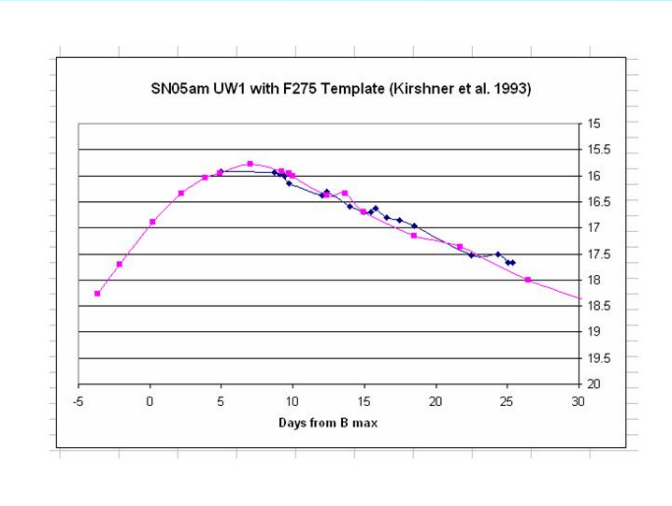


SN:
- Type Ic
- z = 0.0331
- 4th SN associated with GRB

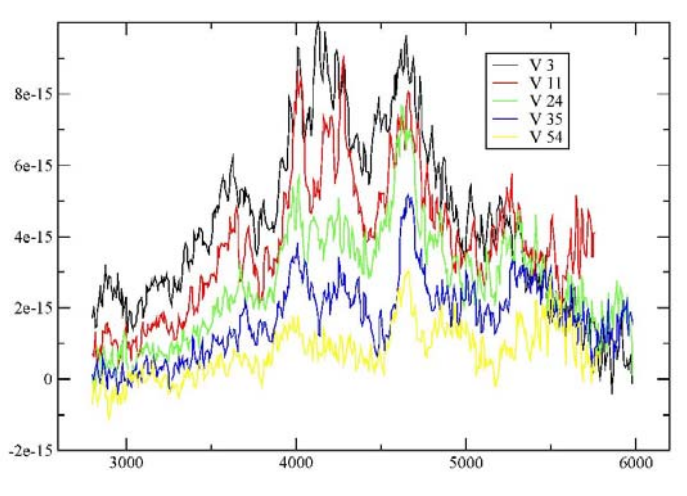
Campana et al. 2006

UVOT – SN 2005am

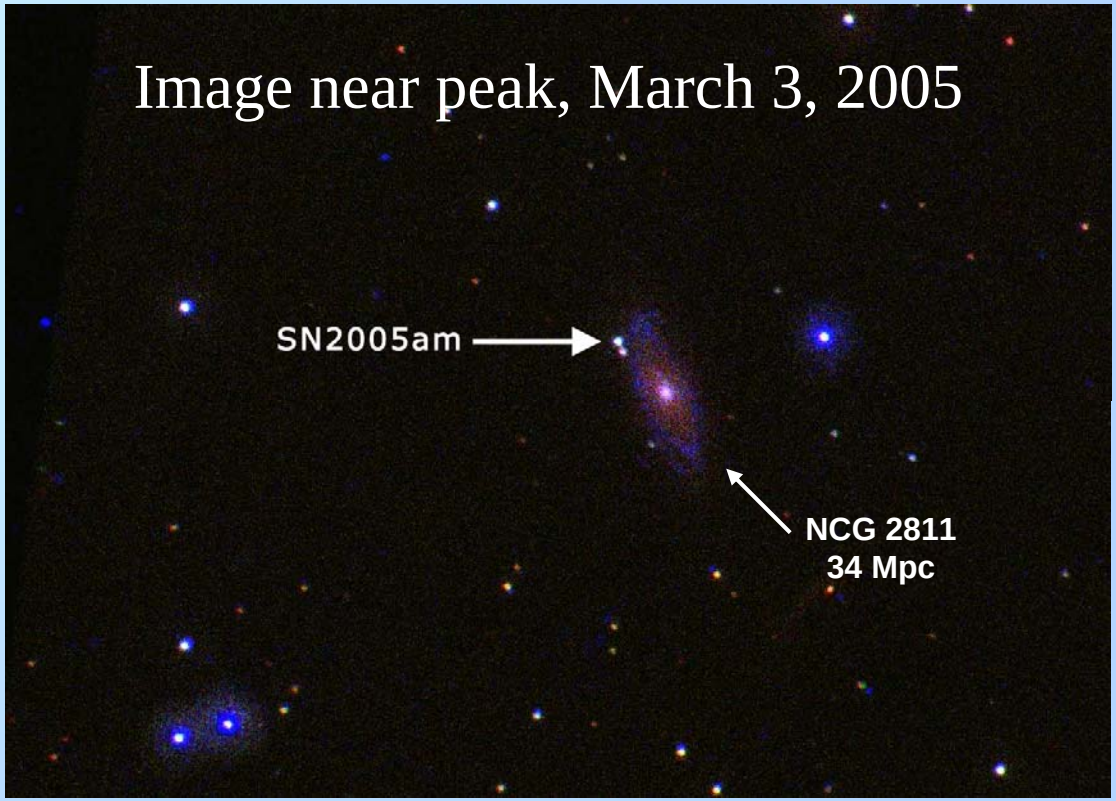
Lightcurve



Spectra

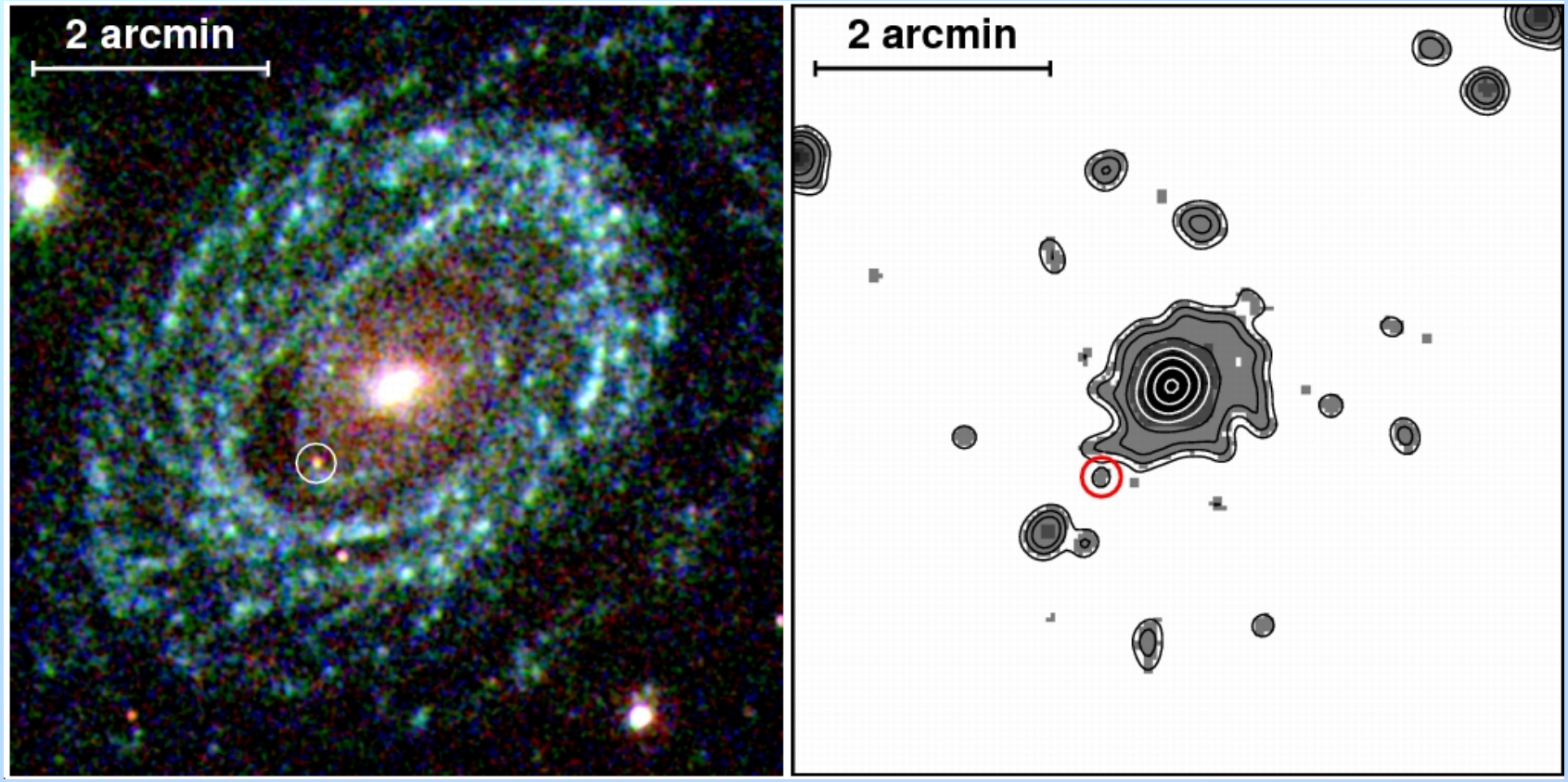


Brown et al. 2005



SN 2005am (Ia)	SN 2005az (Ib)
SN 2005cf (Ia)	SN 2005cs (II)
SN 2005da (Ic)	SN 2005df (Ia)
SN 2005ek (Ic)	SN 2005ke (Ia)
SN 2005gj (Ia)	SN 2005bf (Ib/c)
SN 2006E (Ia)	SN 2005ek (Ic)

UVOT+XRT – SN 2005ke

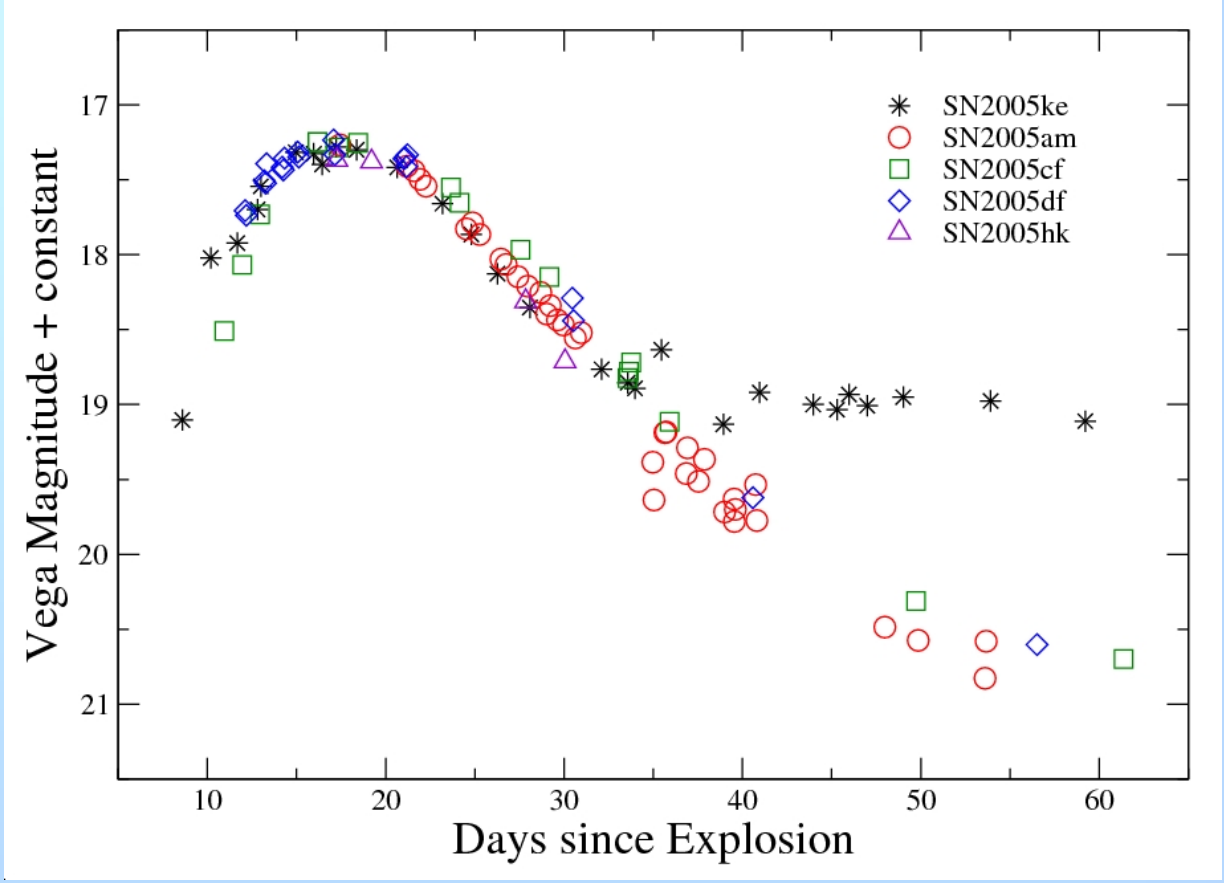


UVOT *UVW1, UVW2, UVM2* XRT (258 ks)

- **First detection of a Type Ia SN in X-rays from CSM interaction**
- **Mass-loss rate of the progenitor's companion $6 \times 10^{-6}\ M_{\odot}\ \mathrm{yr}^{-1}$**
- **CSM density $8 \times 10^{7}\ \mathrm{cm}^{-3}$ at a distance of 3×10^{15} cm**

Immler et al. 2006

UVOT – SN 2005ke



UVOT *UVW1* lightcurves of Type Ia SNe

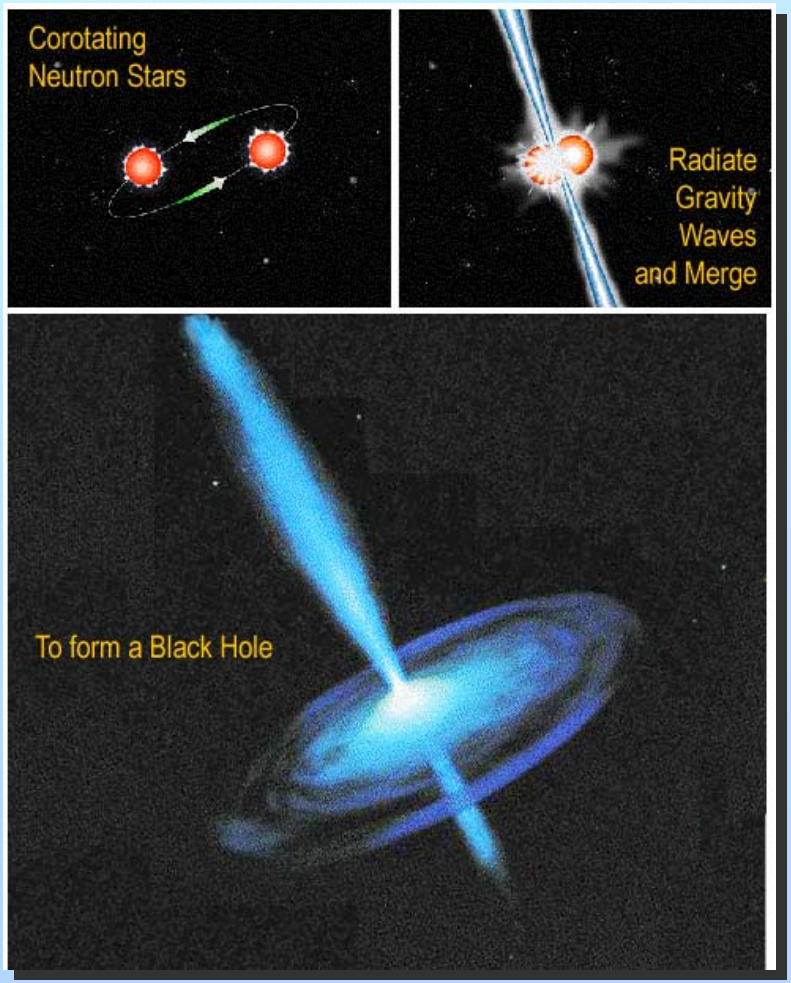
- **The detection of CSM interaction in X-rays is independently confirmed by an excess in the UV past maximum**
- **Are Type Ia SNe standard candles in UV?**

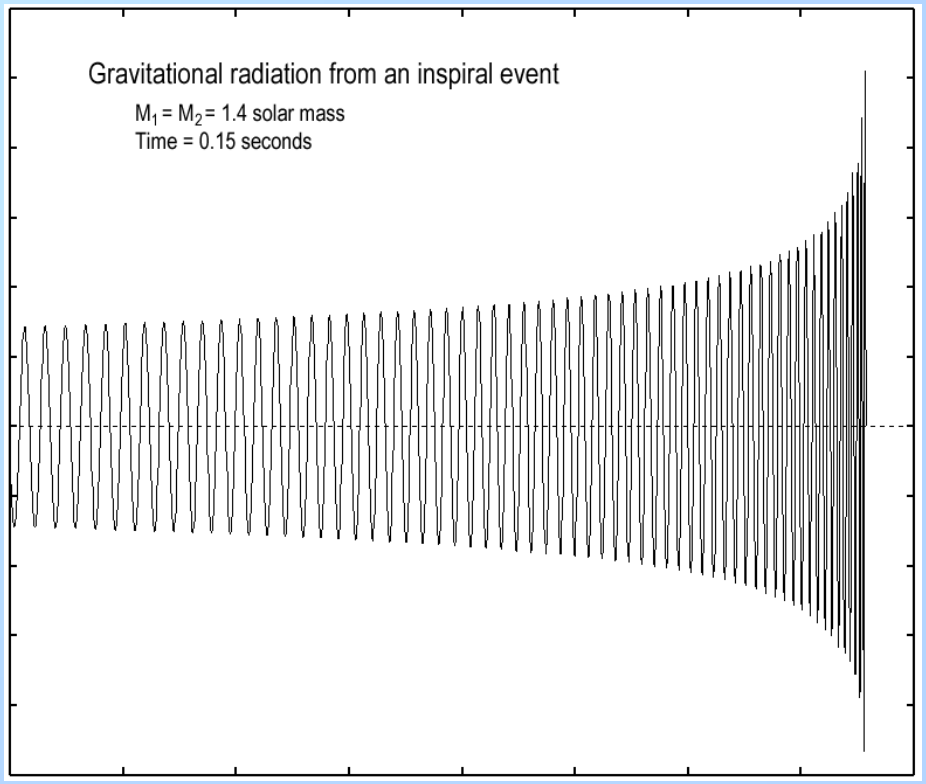
Immler et al. 2006

The Future

- Swift is expected to remain in orbit until at least 2022.
- Possible Discoveries:
  - Most distant object in the Universe
  - First short GRB from a magnetar
  - Understanding the relationship between GRBs and SN
  - Simultaneous gamma-ray, X-ray, optical & UV observations of a GRB (e.g., GRB 060124)
  - Simultaneous detection of GRB and gravitational waves

Short Bursts and Gravitational Waves





Fox 2005

Swift Team

GSFC