The Swift GRB Observatory

- The Mission
- The Science
- The Analysis

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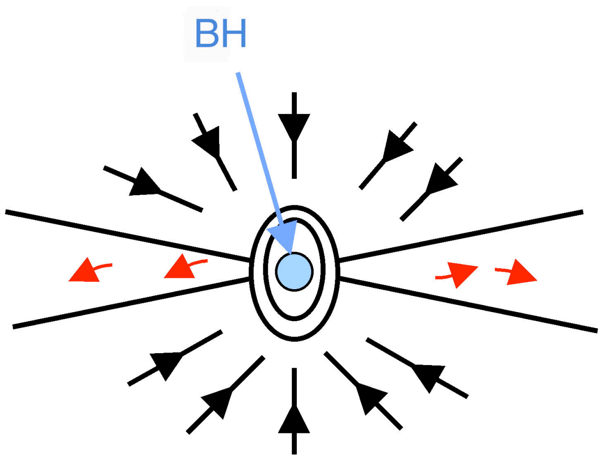
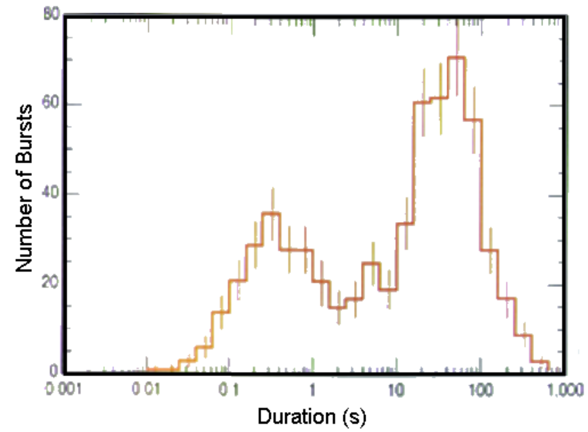
http://swift.gsfc.nasa.gov/

Key Questions

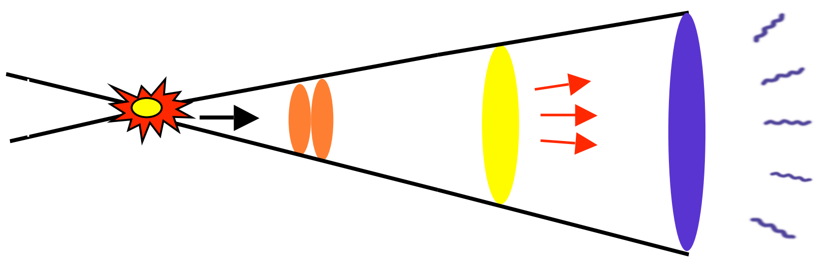
What causes GRBs?



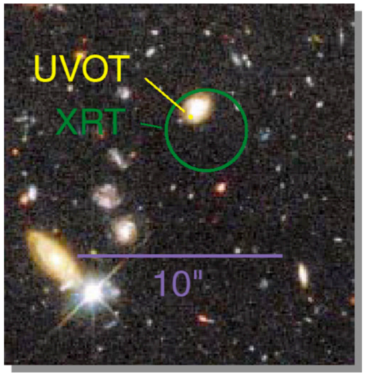
What is the nature of subclasses?



What physics can be learned about BH formation and ultra-relativistic outflows?



What can GRBs tell us about the early universe?



Outline

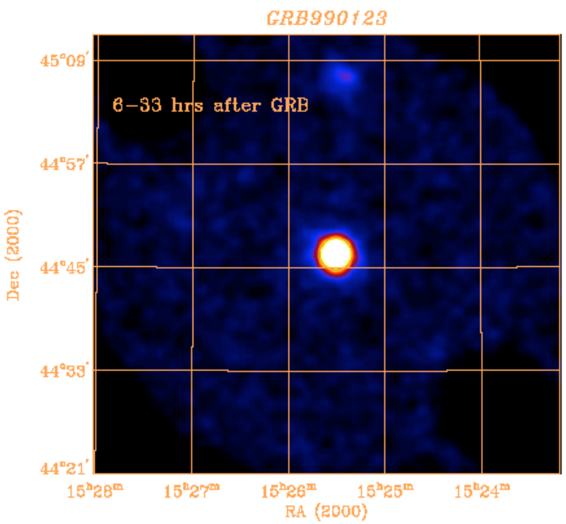
- GRB Summary - the main science questions
- How we built Swift and its instruments
- Some science results
- What *you* can do?
- Some crucial lore to help you along when analyzing Swift data

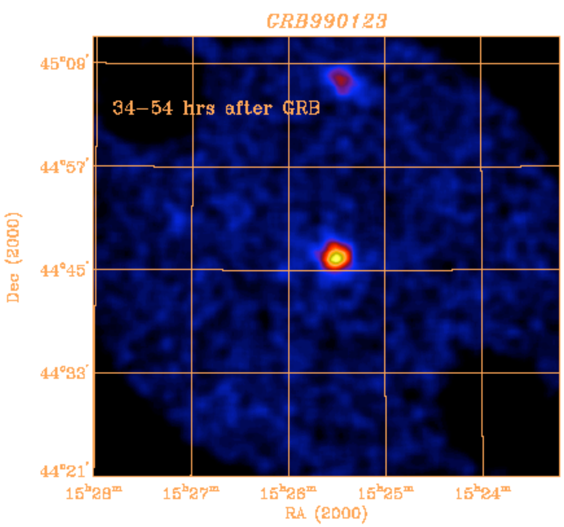
Summary of Gamma-Ray Bursts

- Gamma-ray transients lasting 0.05 - 1000 seconds first detected in the 1960s
- Completely unpredictable in time and space
- Energy release:
  - $\sim 10^{51}$ erg (if beamed)
  - $\sim 10^{53}$ - 10^{54} erg (if isotropic)
  - Most luminous explosions in the universe!
- Distance: cosmological ($z \geq 0.5$)
- Morphology:
  - Simple "short" bursts
  - Complex "long" bursts
- Afterglows - have been detected since 1997 in optical and X-ray

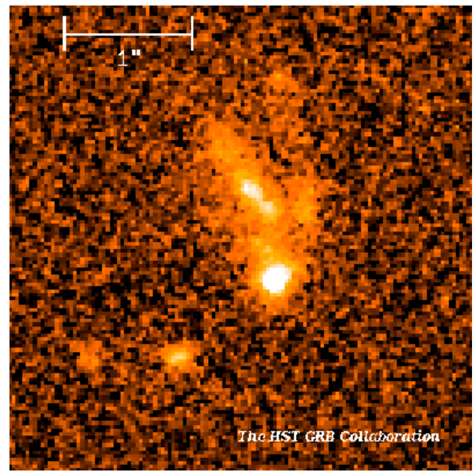
The Problem Before Swift: Follow-ups Usually Hours Later

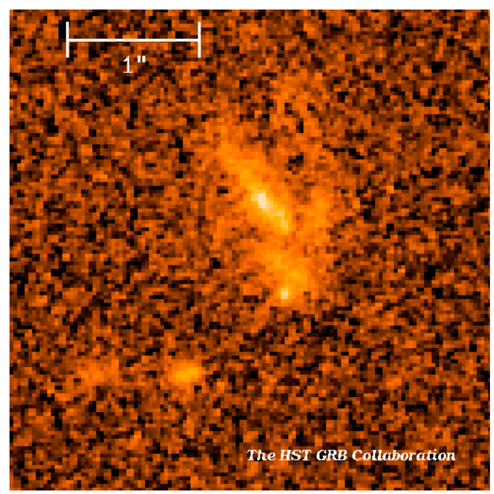
BeppoSAX & HETE-2 X-ray



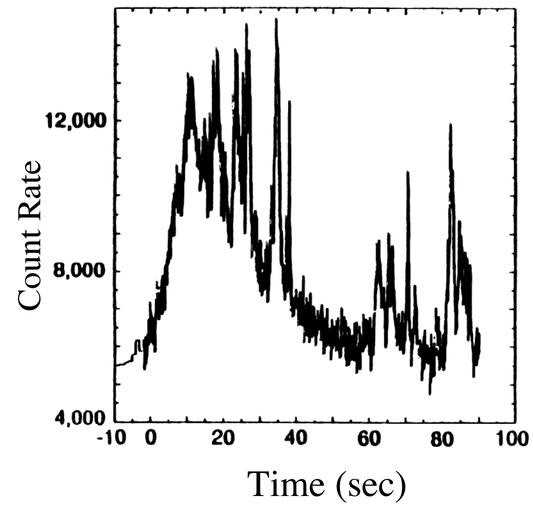


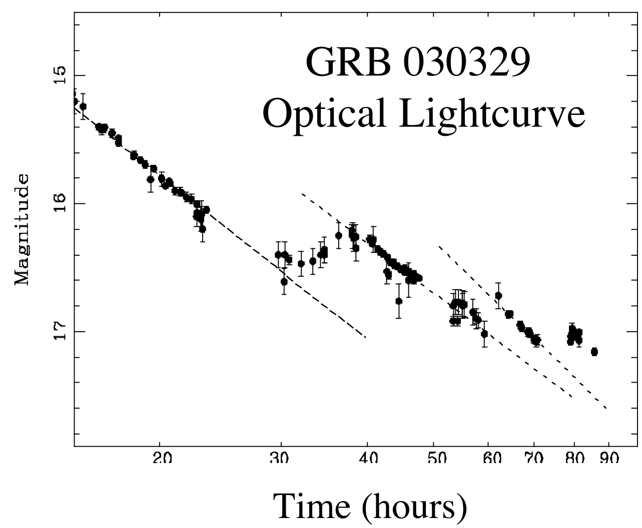
HST & Ground Optical



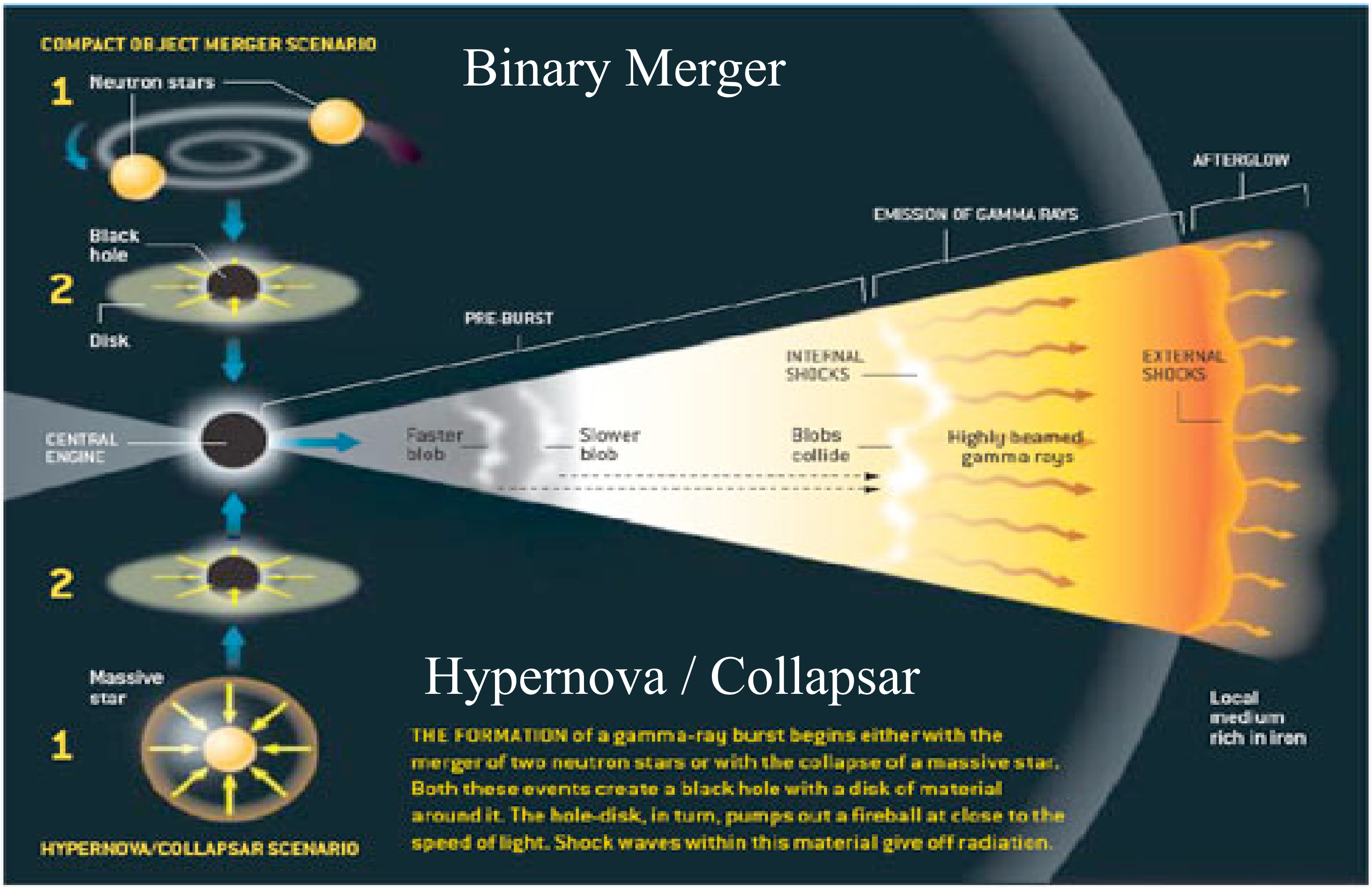


BATSE Gamma Ray





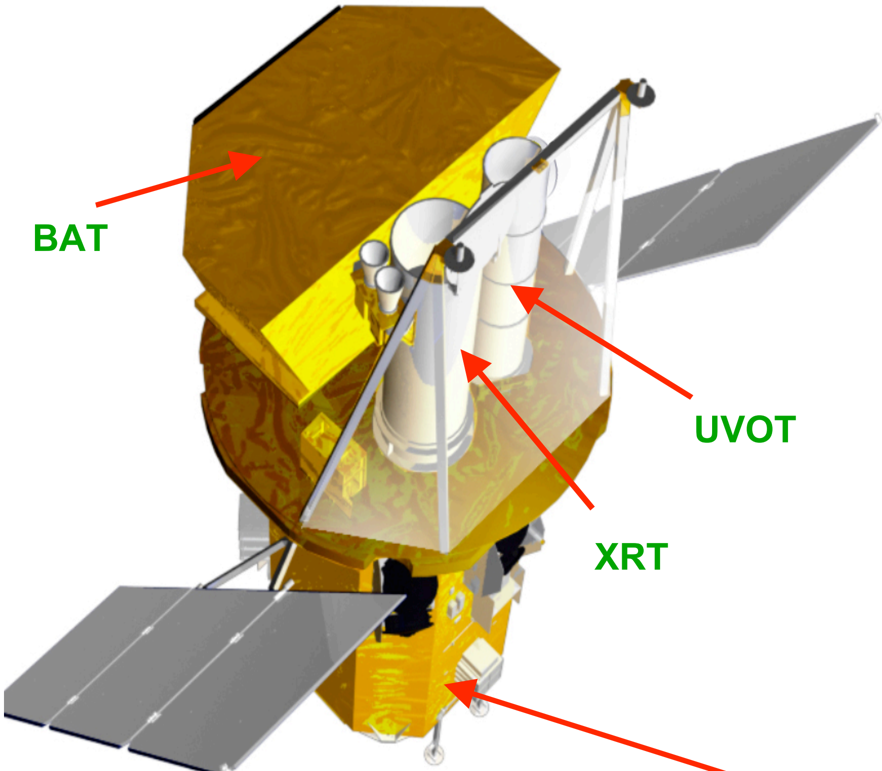
Theory Motivation: Relativistic Fireball Model



Swift Mission Concept

- Wide field gamma-ray imager detects gamma-ray bursts
- On-board decision making
  - Spacecraft slews autonomously
- Rapid slewing capability
  - Get to gamma-ray burst locations quickly, sometimes while the prompt GRB emission is still occurring
- Complement of sensitive narrow field X-ray and UV-Optical instruments to follow the afterglow
- Rapid ground notification of GRB
- Extensive follow-up network on the ground
- Automated science data processing within 2 hours

Swift Instruments



Instruments

Wide Field

- Burst Alert Telescope (BAT)
  - **New CdZnTe detectors**
  - **Detect >100 GRBs per year depending on logN-logS**
  - **Most sensitive gamma-ray wide-field imager ever (> 2 sr on sky)**

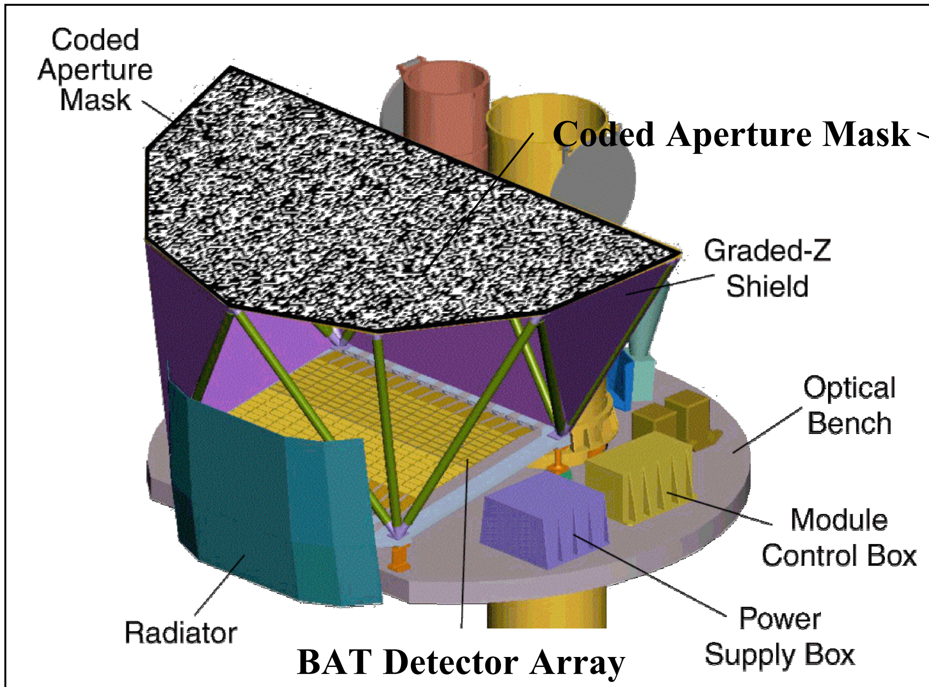
Narrow Field

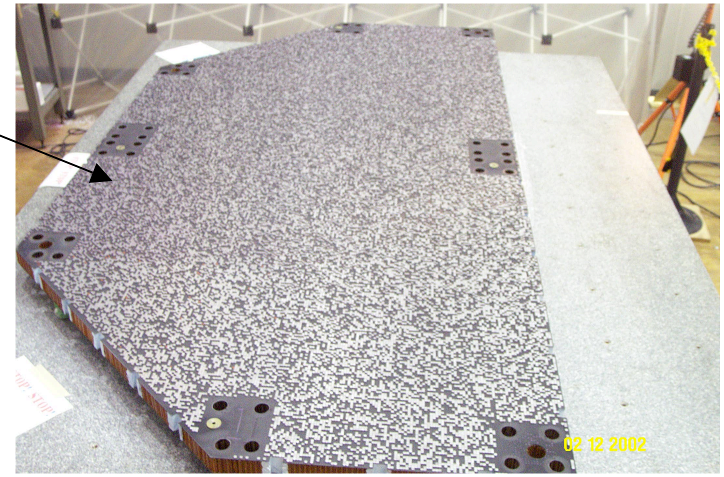
- X-Ray Telescope (XRT)
  - **Arcsecond GRB positions**
  - **CCD spectroscopy**
- (UVOT) UV/Optical Telescope
  - **Sub-arcsec imaging**
  - **Grism spectroscopy**
  - **24^{th} mag sensitivity (1000 sec)**
  - **Finding chart for other observers**

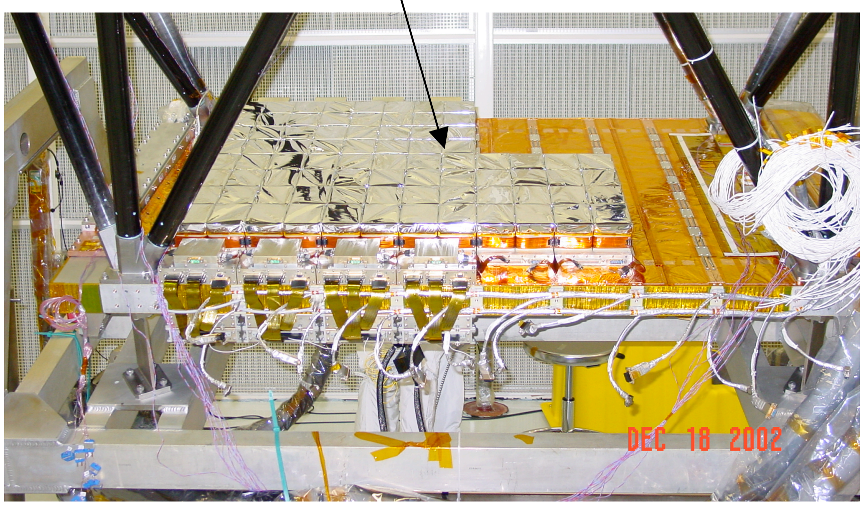
Spacecraft

- "Smart" spacecraft autonomously decides to slew
- Rapid slewing to new burst
- Onboard and ground triggers

Burst Alert Telescope (BAT)



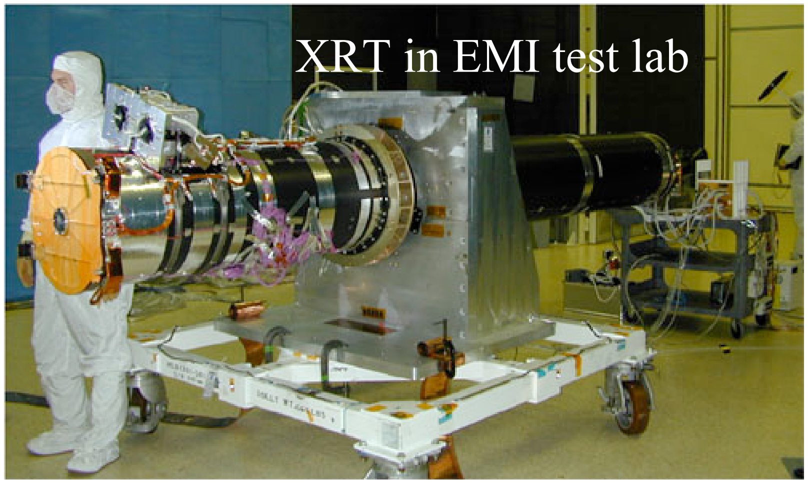


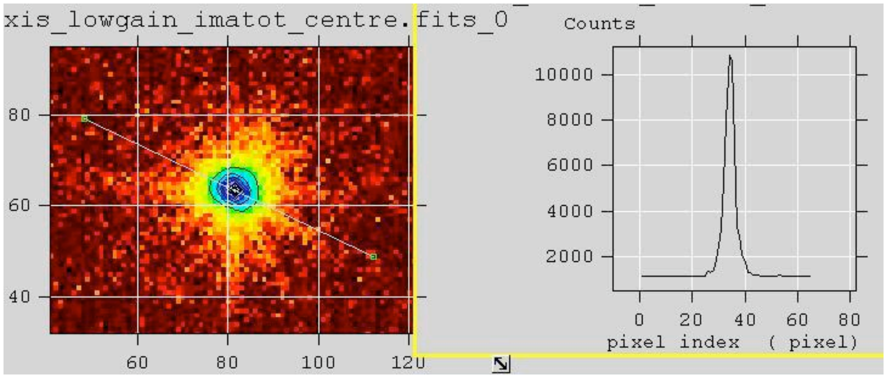


BAT Characteristics

Telescope	Coded Aperture
Telescope PSF	17 arcmin FWHM
Position Accuracy	1-4 arcminutes
Detector	CZT
Detector Format	32768 pixels
Energy Resolution	7 keV FWHM (ave.)
Timing Resolution	100 microseconds
Field of View	2 Steradians, partially-coded
Energy Range	15 – 150 keV
Detector Area	5200 cm^2
Sensitivity	0.2 $photons/cm^2/s$
Max Flux	195,000 cps (entire array)
Operation	Autonomous

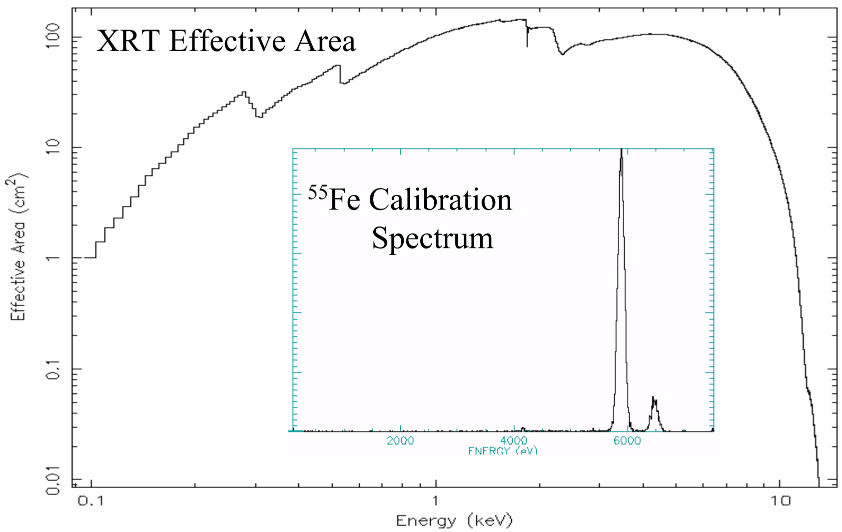
X-ray Telescope (XRT)





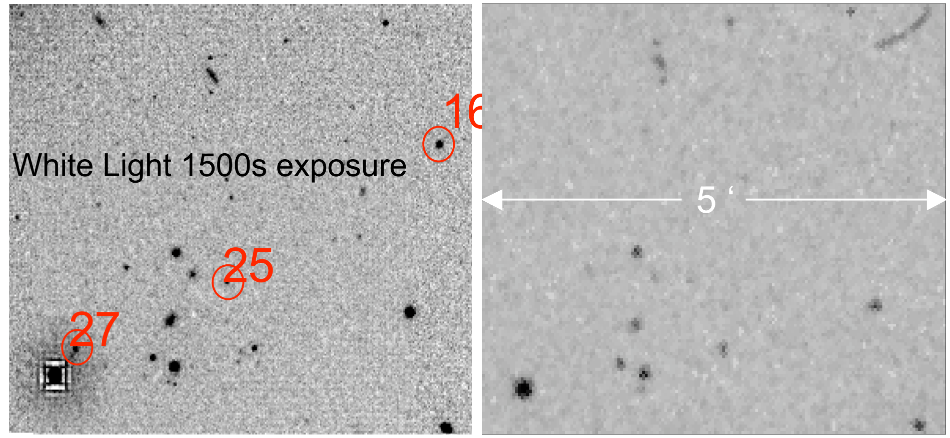
XRT Characteristics

Telescope	3.5 m Wolter I, 12 shells
Telescope PSF	18 arcsec HPD @ 1.5 keV
Position Accuracy	2.5 arcsec (2 sigma)
Detector	E2V CCD-22
Detector Format	600 x 600 pixels
Energy Resolution	140 eV @ 5.9 keV
Timing Resolution	0.14 / 1.1 milliseconds
Field of View	23.6 x 23.6 arcmin
Pixel Scale	2.36 arcsec / pixel
Energy Range	0.2 - 10 keV
Effective Area	110 cm^2 @ 1.5 keV
Sensitivity	$2x10^{-14}$ erg $cm^{-2} s^{-1}$ in $2x10^4$ s
Max Flux	> 45 Crabs (45,000 cps)
Operation	Autonomous



UV/Optical Telescope (UVOT)

XMM-OM **Digital Sky Survey**



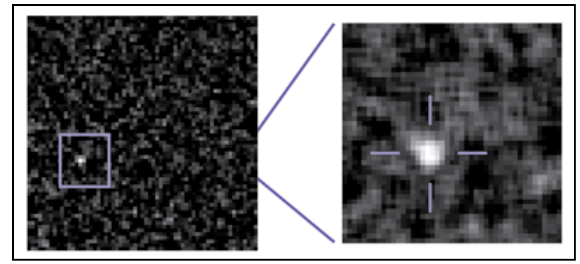
UVOT Characteristics

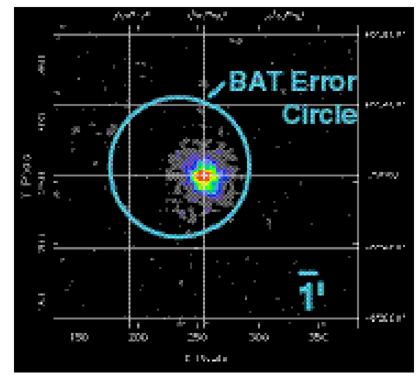
Telescope	30 cm Ritchie-Cretien
Telescope PSF	0.9 arcsec FWHM @ 350 nm
Position Accuracy	0.3 arcseconds (2 sigma)
Detector	Microchannel-intensified CCD
Detector Format	2048 x 2048 pixels
Spectral Resolutn	>300 @ 300 nm for $M_v < 17$
Timing Resolution	11 milliseconds
Field of View	17 x 17 arcminutes
Pixel Scale	0.5 arcsec / pixel
Spectral Range	170 – 600 nm
Sensitivity	24th magnitude in 1000 s
Max source	8th magnitude
Operation	Autonomous

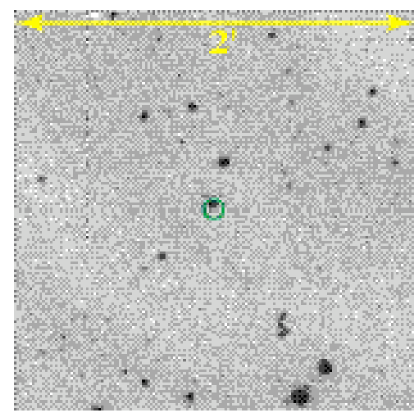
Swift GRB Sequence

Notification	Time (sec)	Event
	0	GRB
Rapid position	15	BAT position Spacecraft slew
Arcsec position	70	XRT position
Spectra, light curves, images	~110	XRT & BAT
UVOT finding chart	240	UVOT image

Cascade of Images





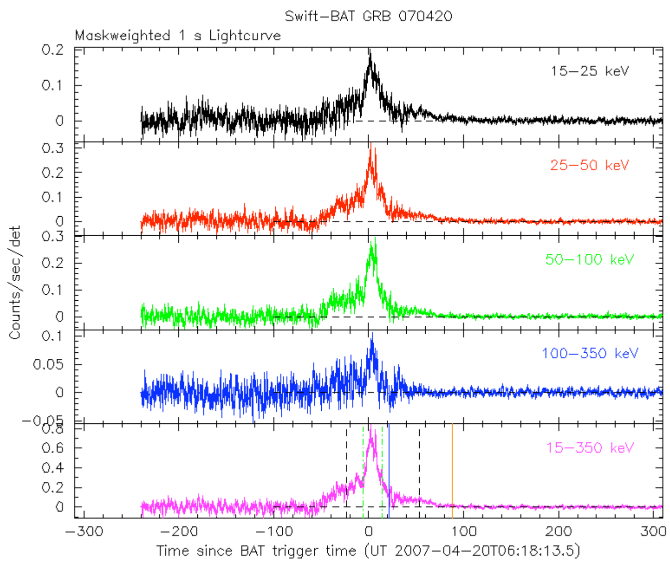


Swift Science Results

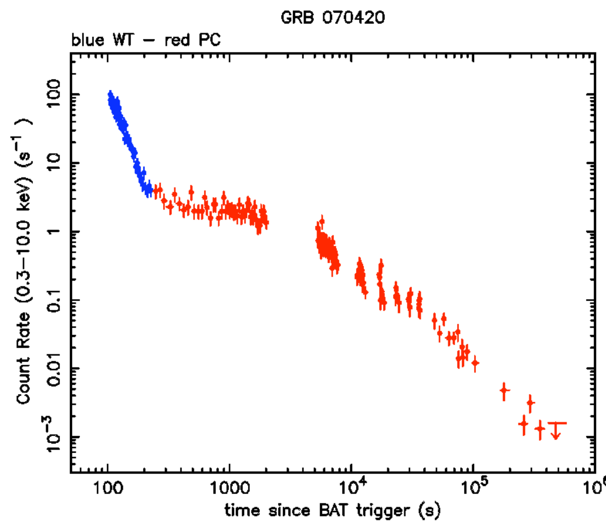
- Example Swift GRB response
- Long bursts vs. short bursts
- Using GRB afterglows as a light house to study the early universe

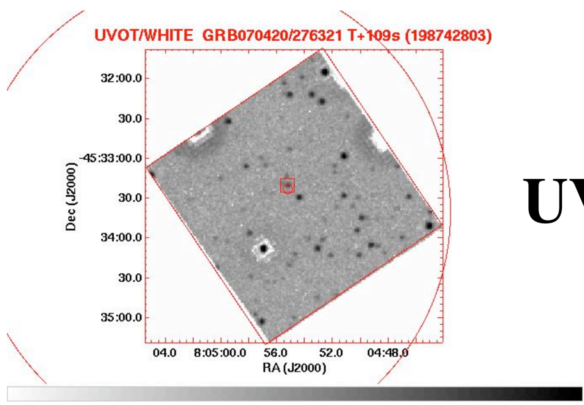
Swift GRB from April 20

BAT prompt emission

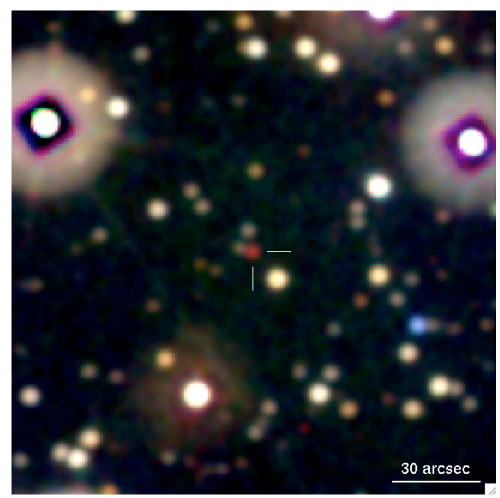


XRT afterglow lightcurve





UVOT images

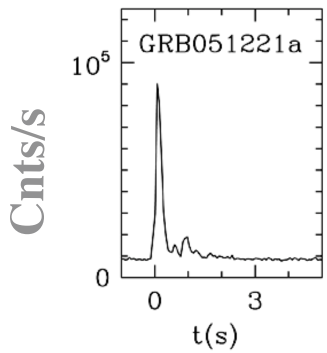


Revelations of Swift

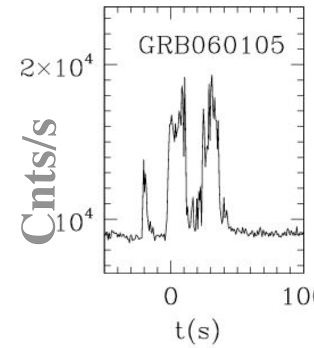
- Rapid, precise positions
  - Allows ground based follow-ups
  - Identification and redshift of host galaxy
- Early-time light curves
  - X-ray “flaring”
  - Prompt X-ray and optical emission (during the burst) constrains fireball models
- Excellent γ-ray background-subtraction
  - We now know that GRBs can last much longer!

Short vs Long GRBs

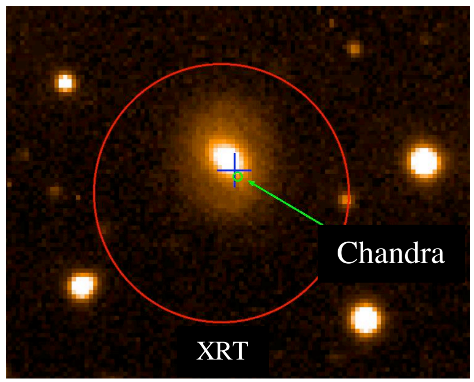
Short GRB



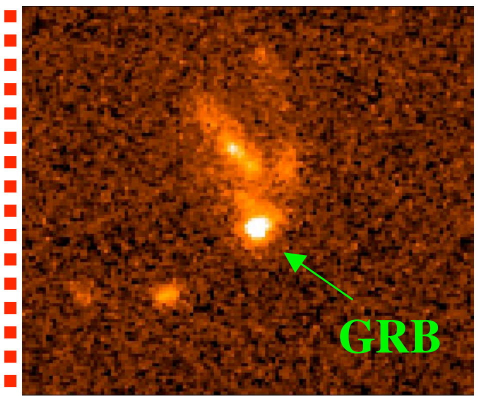
Long GRB



GRB 050724 - Swift
elliptical host



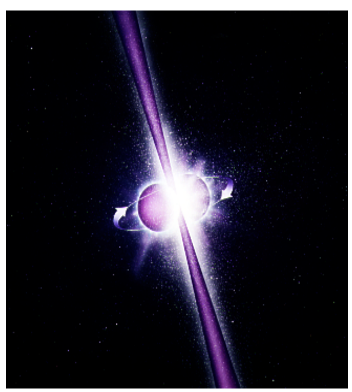
GRB 990123 - SAX
SF dwarf host

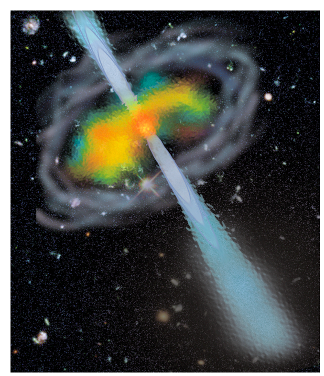


In non-SF
and SF galaxies

No SNe detected

Possible **merger**
model





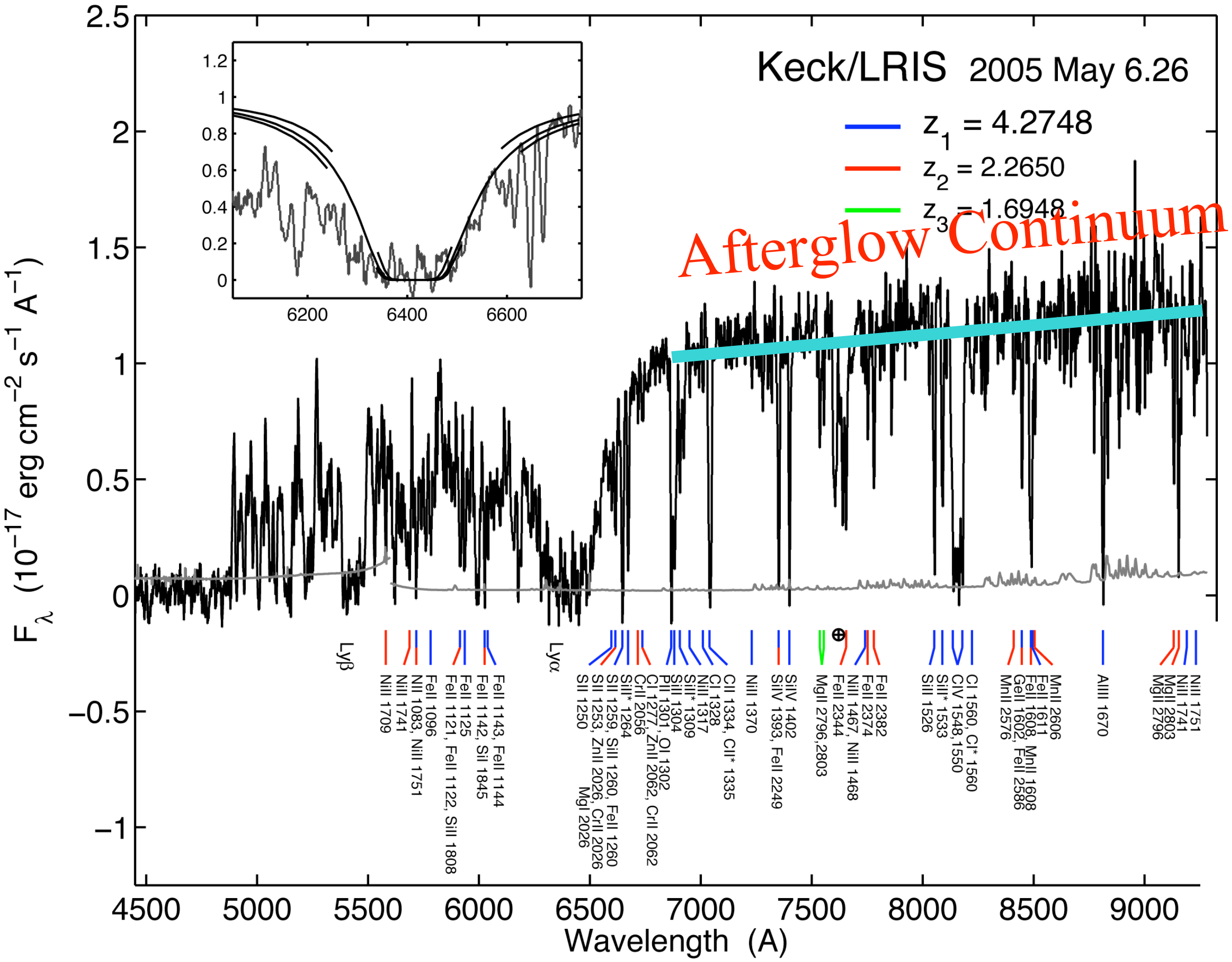
In SF
galaxies

Accompanied by SNe

Collapsar model
well supported

Optical/IR Spectroscopy of a High Redshift Burst

GRB 050505



$z = 4.275$

Damped Lyα

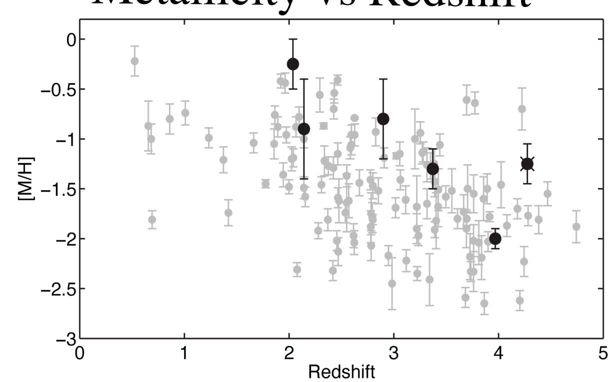
N(HI)=10^{22} cm^{-2}

n ~ 10^2 cm^{-3}

Z = 0.06 Z_O

$M_{progenitor}$ < 25 M_O

Metallicity vs Redshift



Berger et al. 2005

How Does Swift Work?

- Observing with Swift
- Analyzing Swift data
  - BAT
  - XRT
  - UVOT

What Can You Do With Swift?
Answer 1: Observe!

- There are two ways to get observations done:
  - Swift GI peer-reviewed program (due Nov 2007)
  - Can always request a target of opportunity (no advance notice required)
  - See swift.gsfc.nasa.gov for more information
- The best observations take advantage of Swift's co-aligned X-ray and UV/Optical telescopes and the rapid repointing capability

  * X-ray and optical transients!
- Swift pointing constraints limit observations to < 20 minutes
- One possible strategy:
  - Observe with Swift initially for a few snapshots
  - Long follow-up with Chandra or XMM-Newton a week later
- Another strategy:
  - Short observation to confirm X-ray flux of a known source

What Can You Do With Swift?
Answer 2: Analyze!

- Swift analysis software is distributed with HEASoft (aka FTOOLS)
- All of the instruments have canned pipeline scripts which give you a good starting point.
- All of the instruments also have extensive manuals for recipes and reference material. (swift.gsfc.nasa.gov)

Swift Data

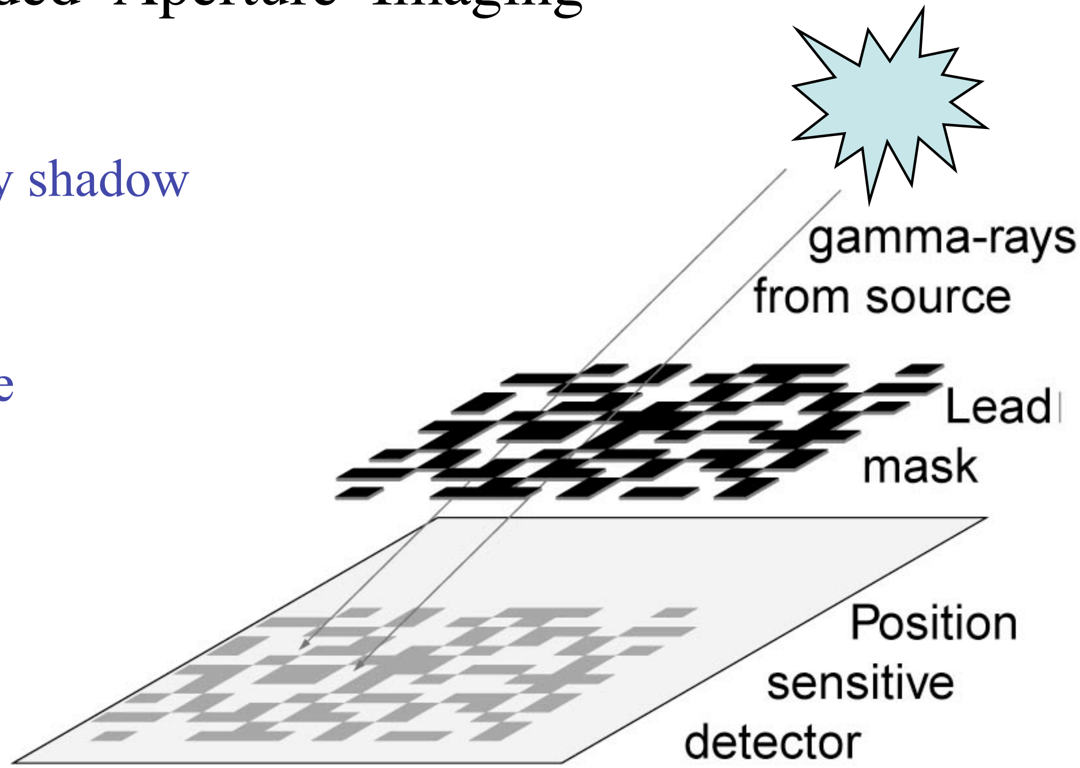
- Organized by observation number and segment
  Example: 00241293 000
  (use on-line GRB / obs. num. converter)
- The gamma-ray burst data is always in segment number 000
- Data is first available in a “quicklook” area at Goddard, and then migrates to the archives within a week or so.

BAT Analysis

- Starting point: `batgrbproduct` script
- This script will make images, light curves and spectra, and response matrices and is semi-intelligent
- You should be able to load these into standard tools like DS9 (images), Xronos (light curves), and XSPEC (spectra)
- Sometimes the script will fail to find the burst time interval, and you will need to specify it by hand (usually short bursts)
- It is possible to make spectra while the spacecraft is slewing; BUT, you must make response matrices if the spacecraft moves more than ~15 degrees

Coded Aperture Imaging

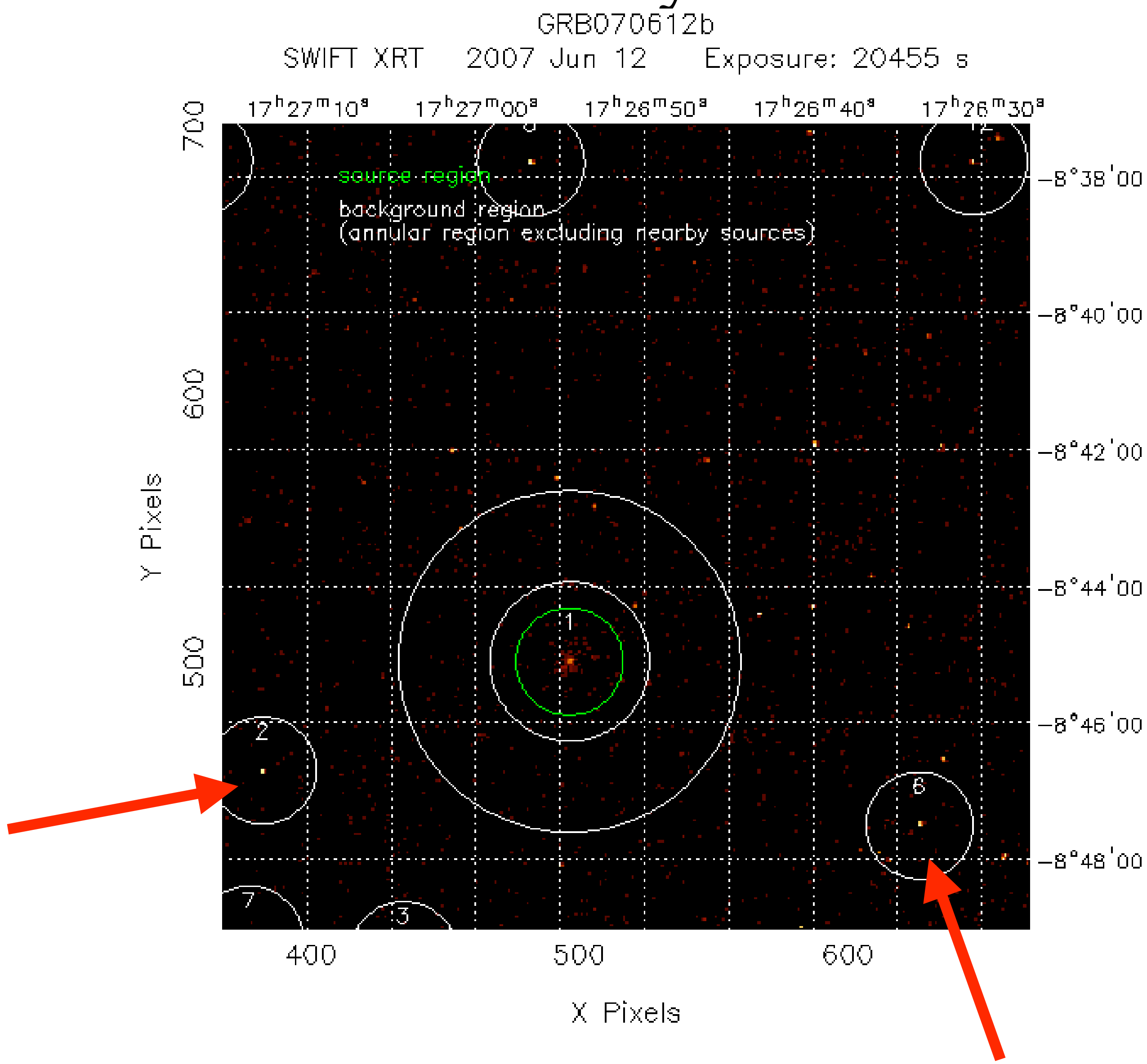
- Source casts gamma-ray shadow on detector
- Location of shadow yields location of source



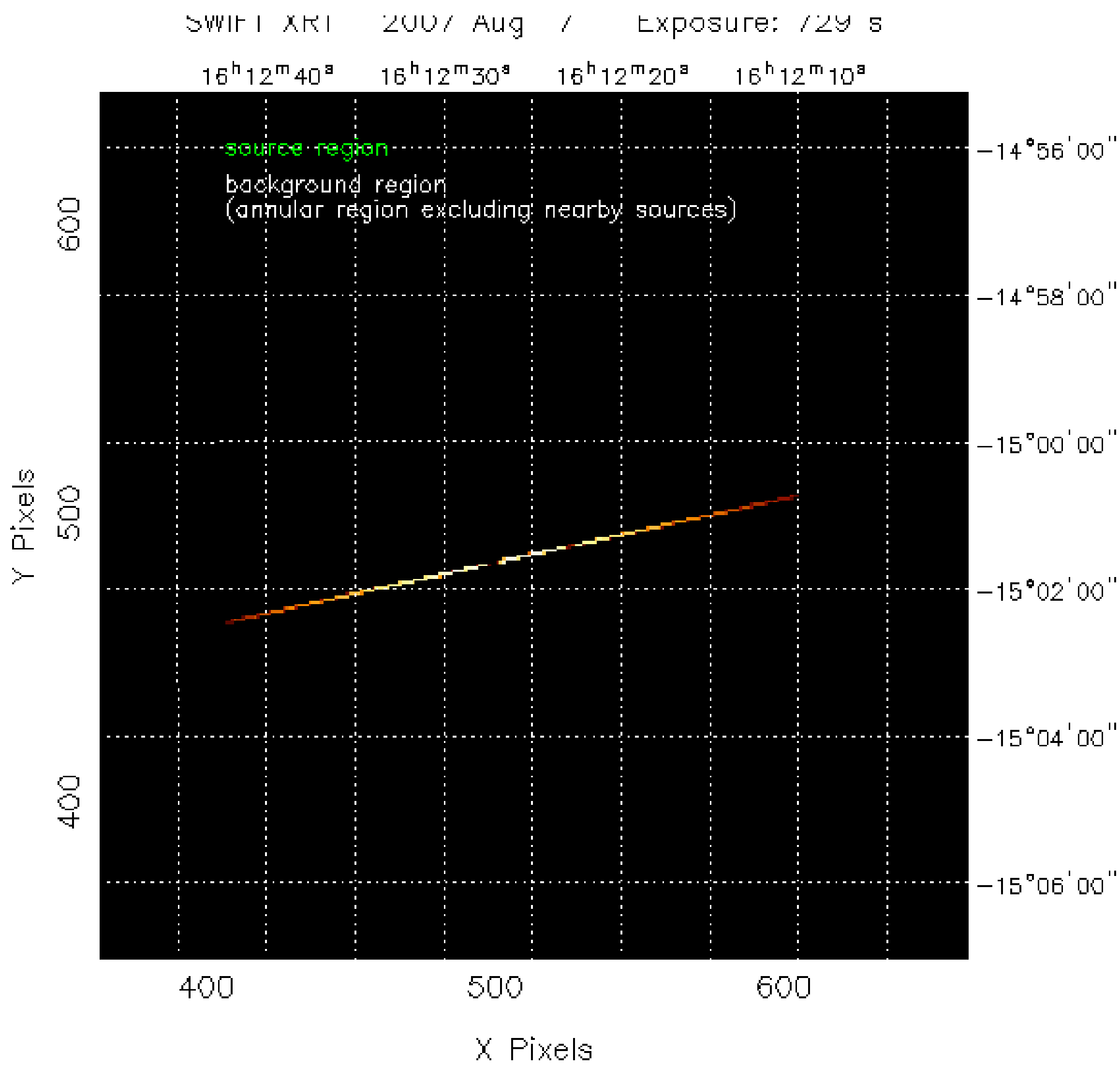
XRT Analysis

- Starting point: `xrtpipeline` script
- Major XRT issues:
  - Cooler failure; more “hot/noisy” pixels
  - Micrometeoroid hit May 2005; created “dead/noisy” columns
- Both of these problems create unusable regions on the CCD, which sometimes overlap with your source
- Compensate with following crucial xrtpipeline parameters
  - `createmkffile=YES createexpomap=YES useexpomap=YES pcbiascorr=YES` (HEASoft 6.3.1)
- Other tips:
  - Exclude dead columns when creating background region
  - Windowed Timing mode must be analyzed one orbit at a time

XRT Hot/Noisy Pixels



XRT Windowed Timing Mode



UVOT Analysis

- Two crucial tools
- `uvotsource` - computes the magnitude of a known source for one image
- `uvotmaghist` - computes a light curve from multiple images
- Requires recent (>Nov 2006) data to work properly
- Other important points
  - UVOT magnitude scale is calibrated for 5" aperture (region)
  - For fainter sources use smaller apertures and uvotapercorr
  - A GRB may not appear in UV/Blue filters if it is at high redshift
  - UVOT generates "image" and "event" data on-board, but it is all convert to images on the ground

Other Kinds of Bursts
(Just to keep things confusing)

- **X-ray bursts** - thermonuclear burning from the surface of an accreting neutron star

- **Accretion “outburst”** - episode of mass transfer lasting days to weeks

- **Soft Gamma Repeater (SGRs)** - probably a highly magnetic neutron star with millisecond bursts

Swift detects all of these too!

Possible Projects

- Mystery: why is BAT trigger 287042 *not* a gamma-ray burst
- High redshift burst GRB 050904
  - What were the spectrum and duration… …*in the rest frame of the burst*?
- Pick a burst
  - Perform joint BAT and XRT analysis

Backup Slides