
# The Swift Gamma-Ray Burst Explorer: Early Views into Black Hole Creation

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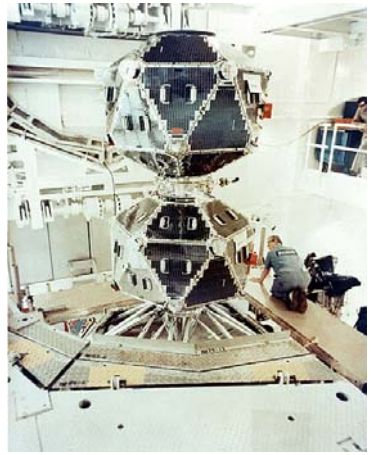
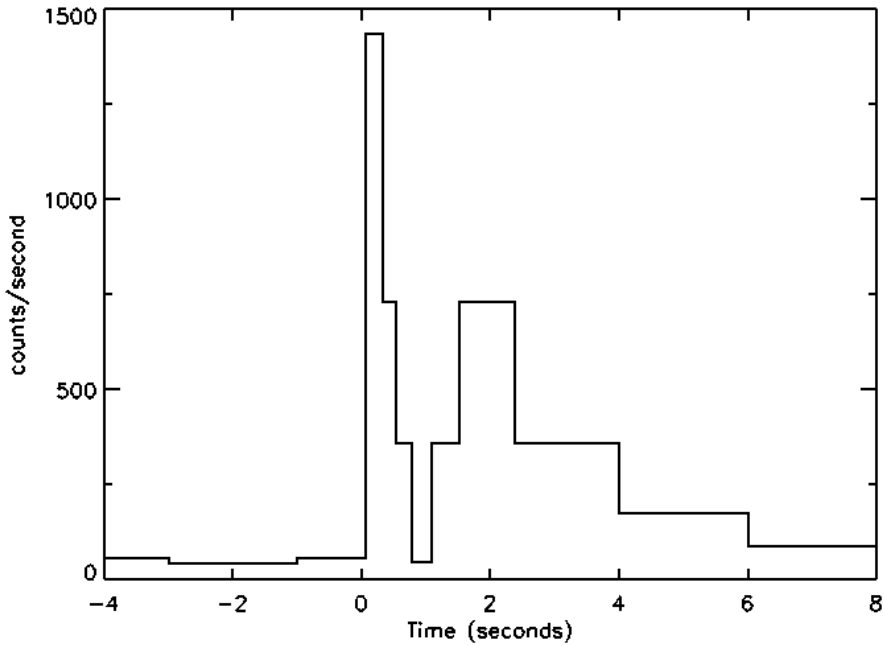
and the Swift team

Rev 7/28/05

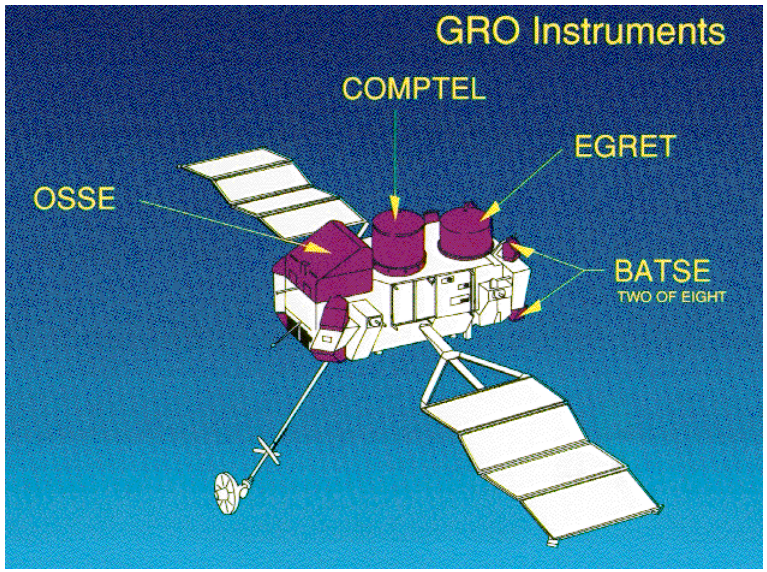
# *Setting the Stage: 1967*

- Vela satellites launched in mid-1960s to monitor the Atmospheric Test Ban Treaty
  - Strange pulses discovered in 1969 by Ray Klebesadel of LANL
    - Data classified until 1973

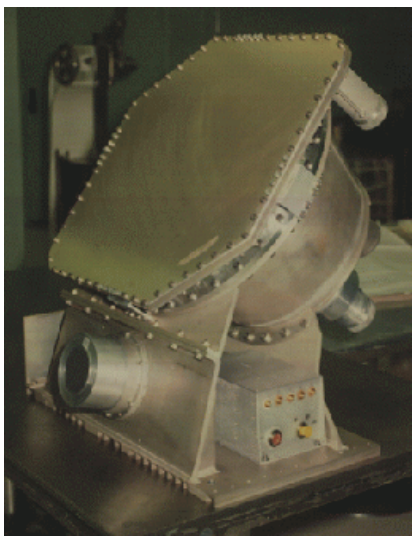


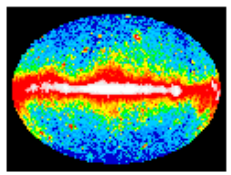


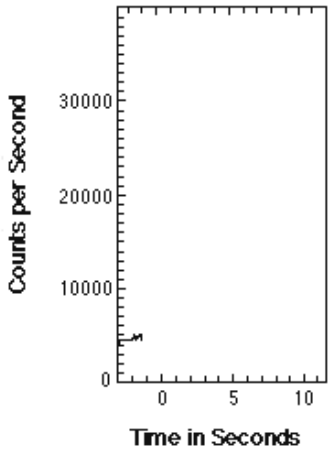
# *30 Years Later: 1997*



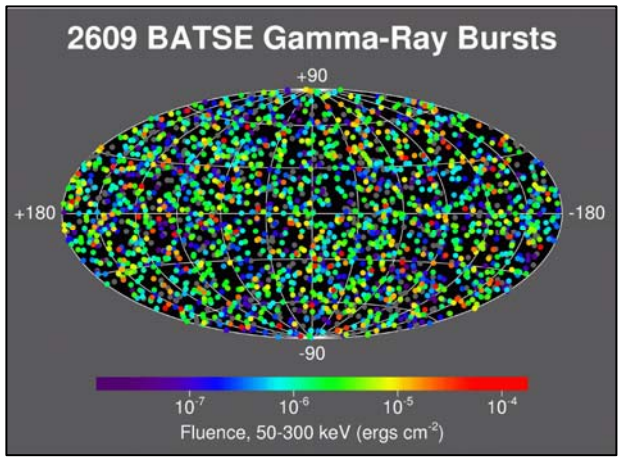

- Compton Gamma-Ray Observatory launched in April 1991
- BATSE: 2609 bursts in 8.5 years
  - Bursts are isotropic
  - Frequency ~ 1 burst per day
  - Not clear whether they are nearby or distant

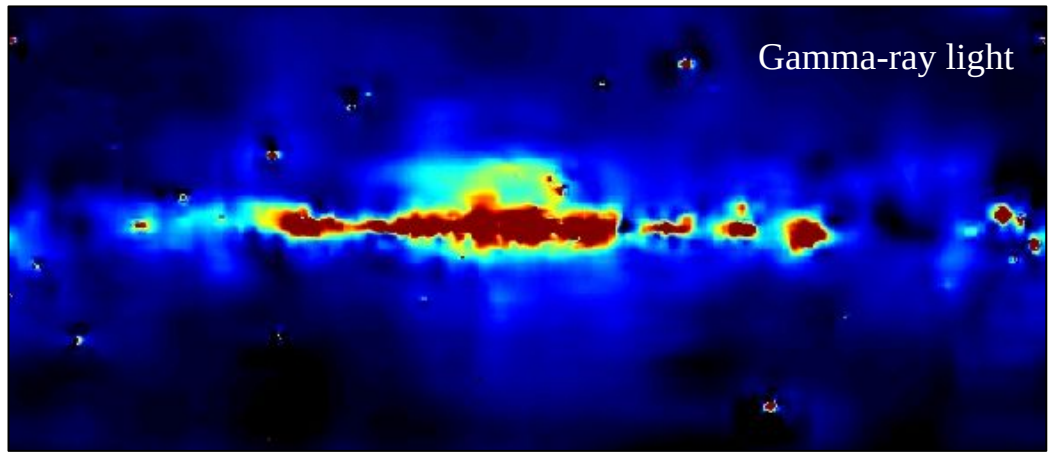


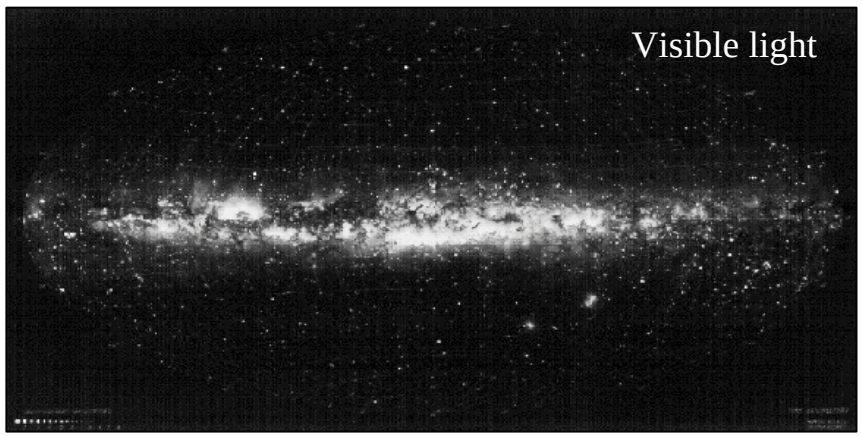


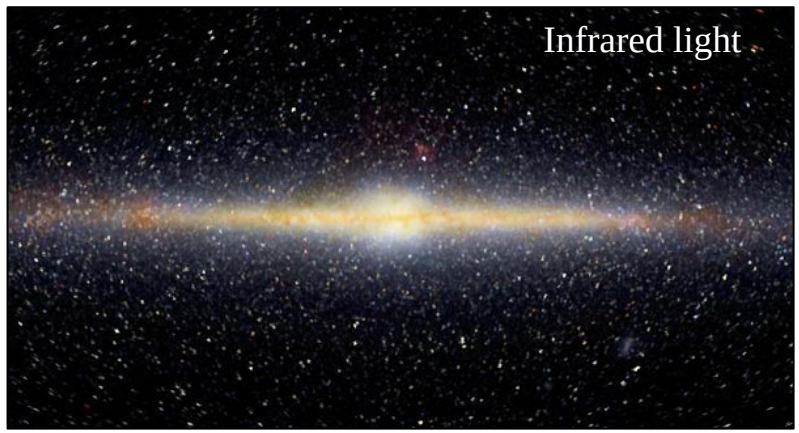


# *The celestial sky*



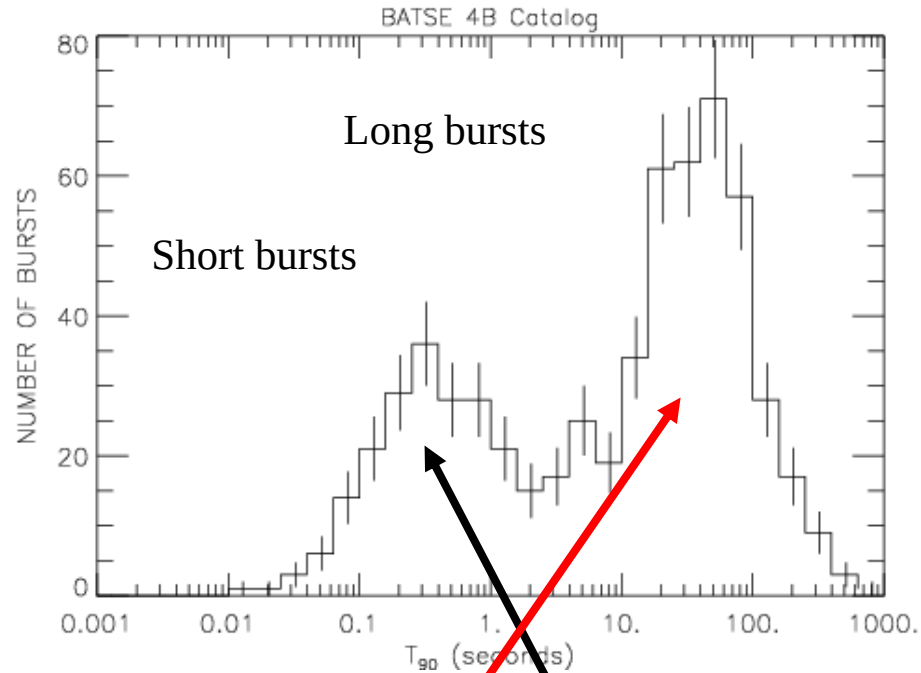



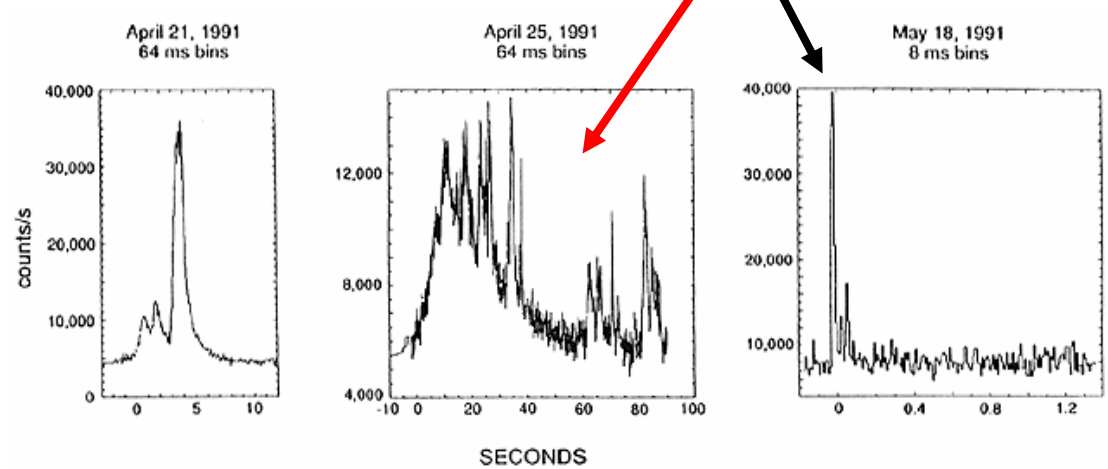




GRBs are distributed isotropically on the sky.

# GRB Characteristics (BATSE)

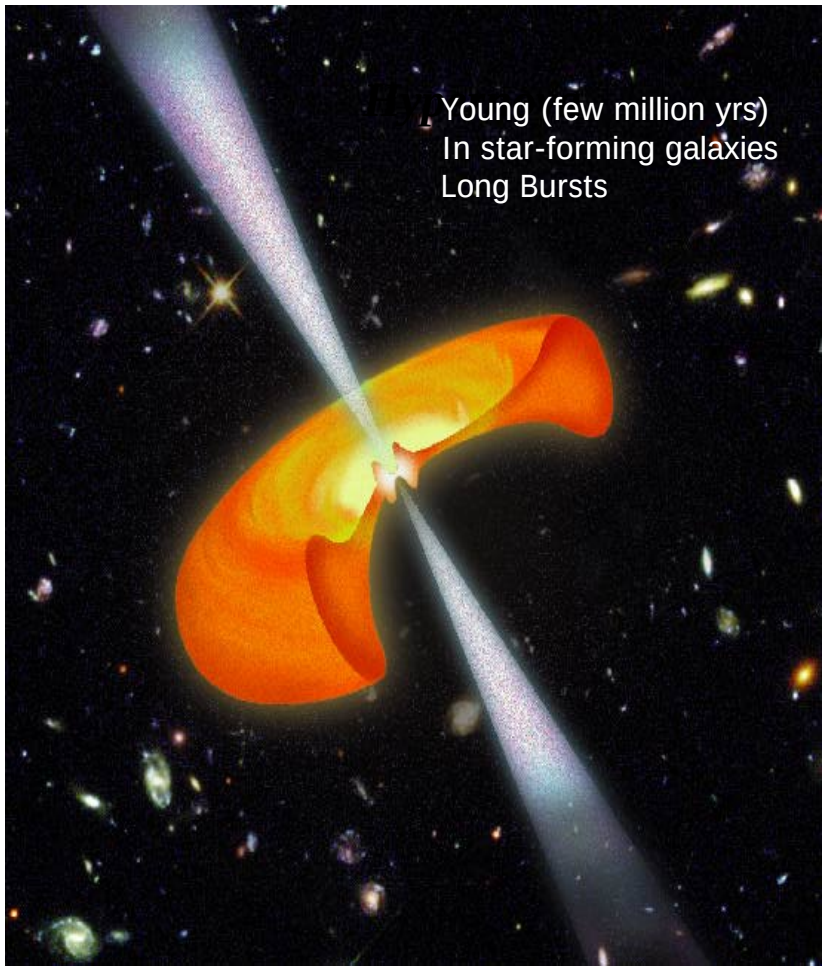
- Characteristics:
  - About 1 per day
  - Powerful: brightest γ-ray object in sky
    - Typically $10^{51}$ ergs
  - Isotropic distribution
  - Finite Extent
  - Unique lightcurves
  - Bimodel distribution of durations



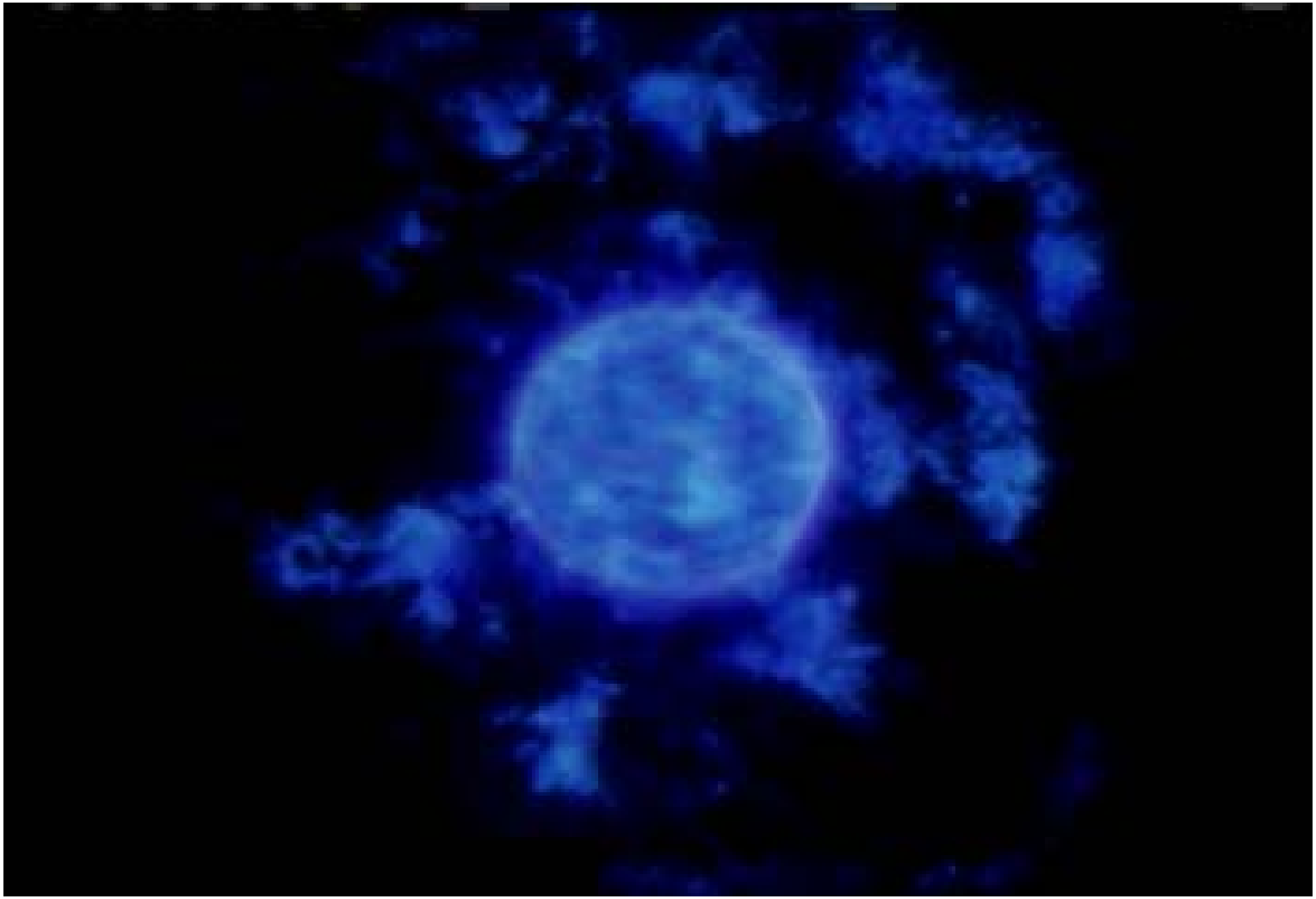



# *GRB Models*

Hypernova

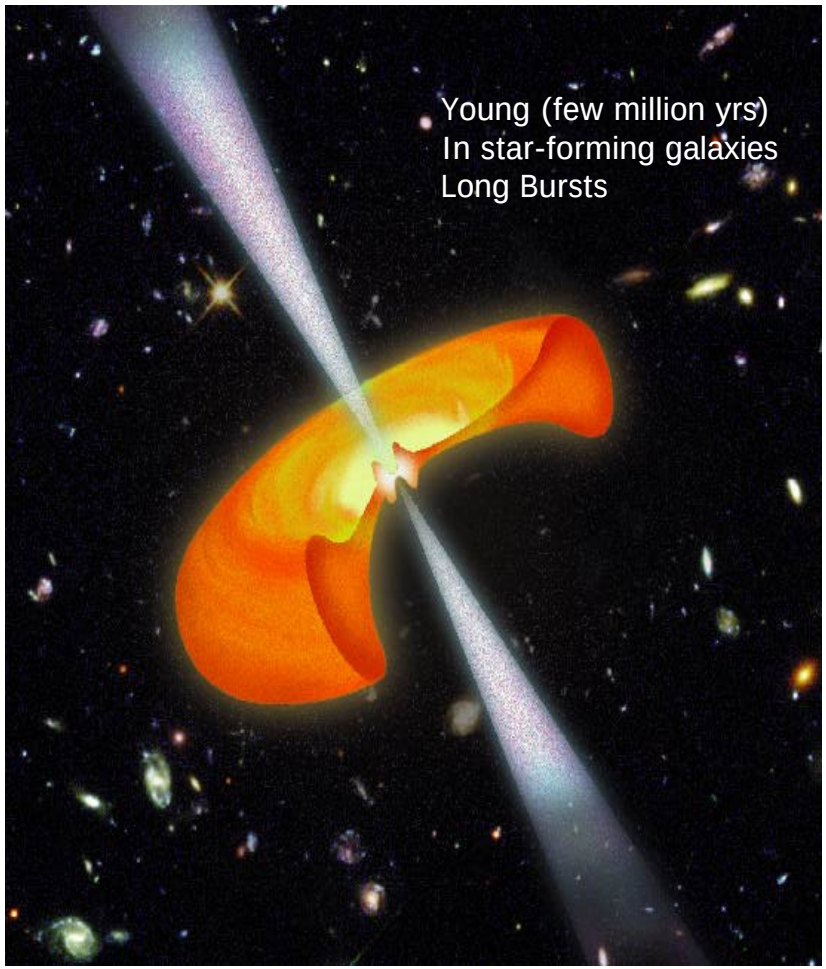


# *Hypernova*

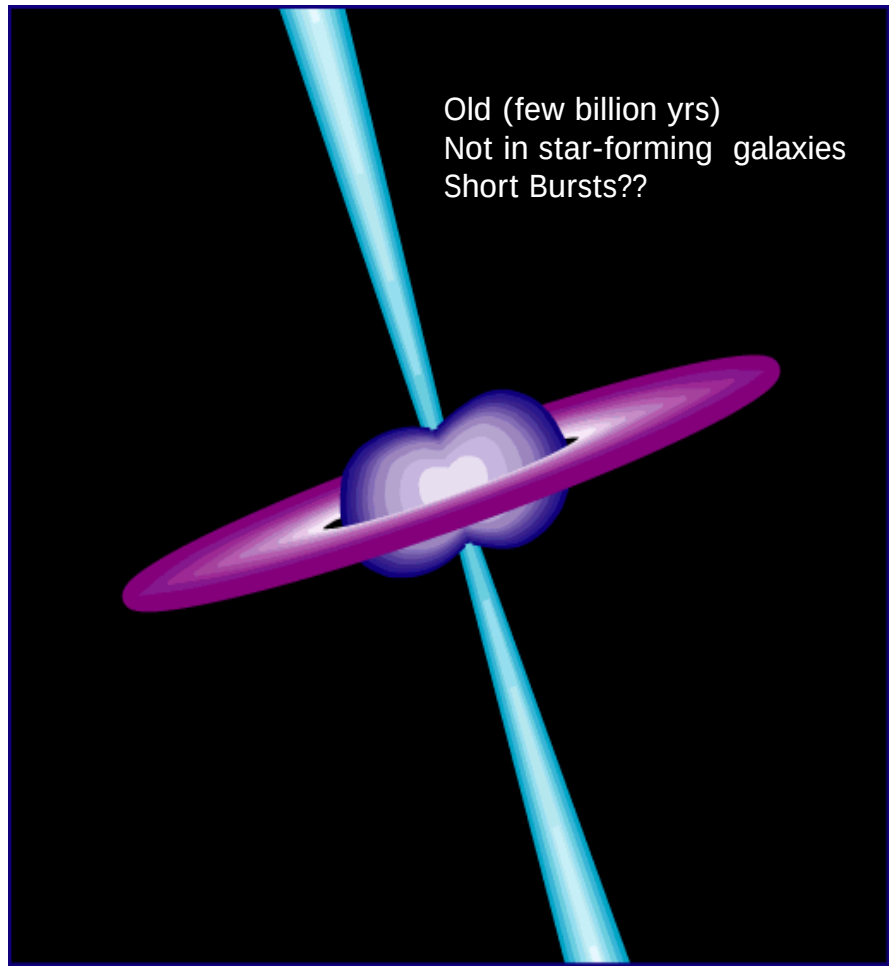


# GRB Models

Hypernova



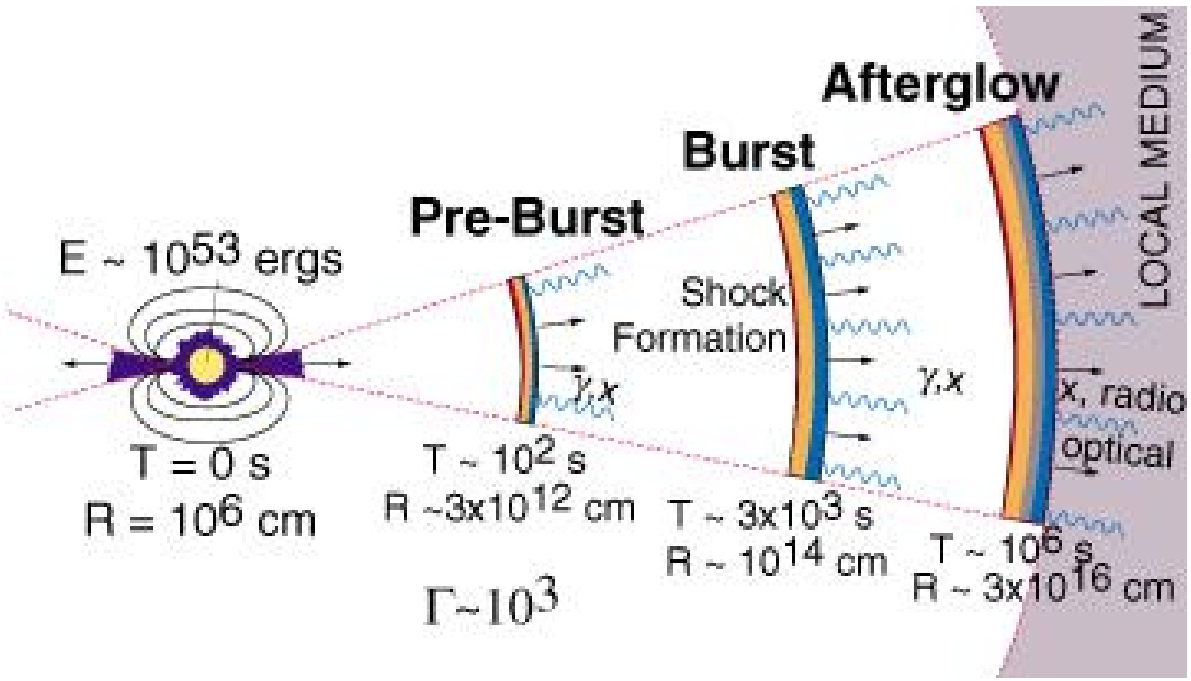

Merging Neutron Stars



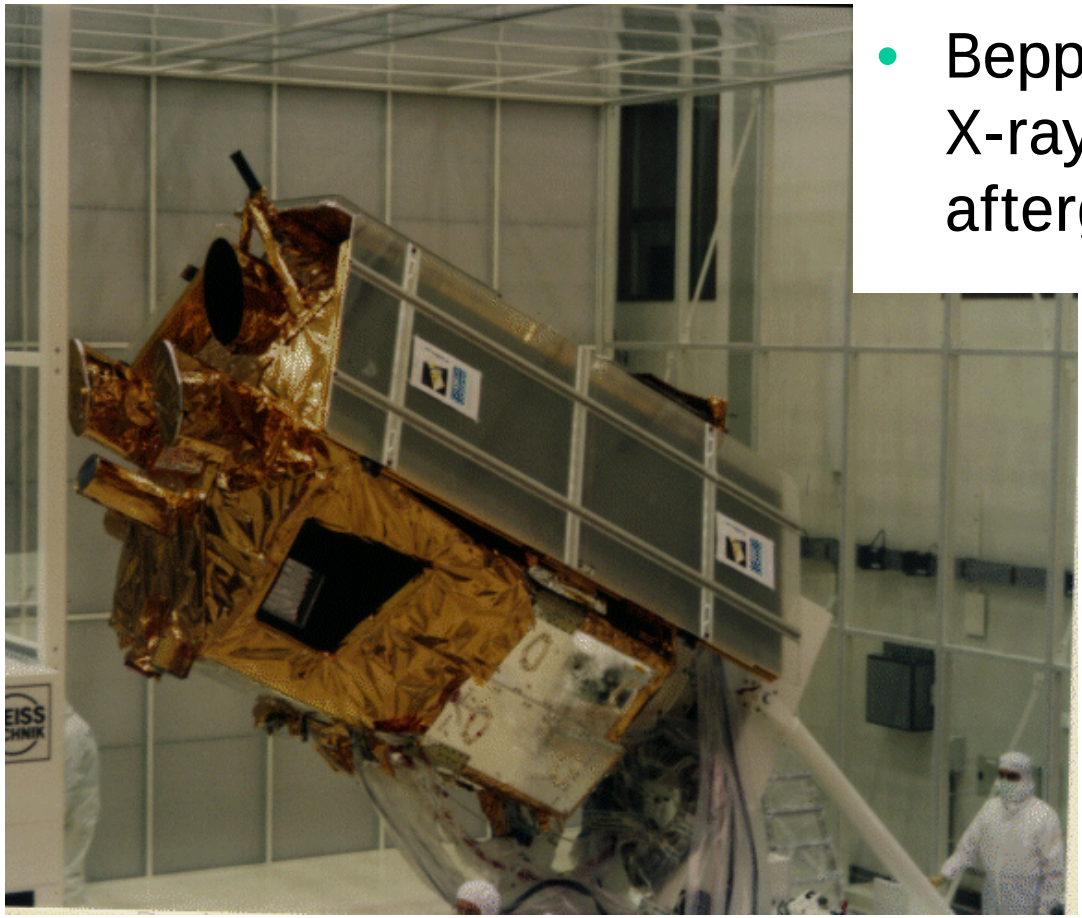
# *1997 Theoretical Breakthrough*

2/10/97: Meszaros and Rees GRB relativistic fireball model published in ApJ; predicted broadband afterglows

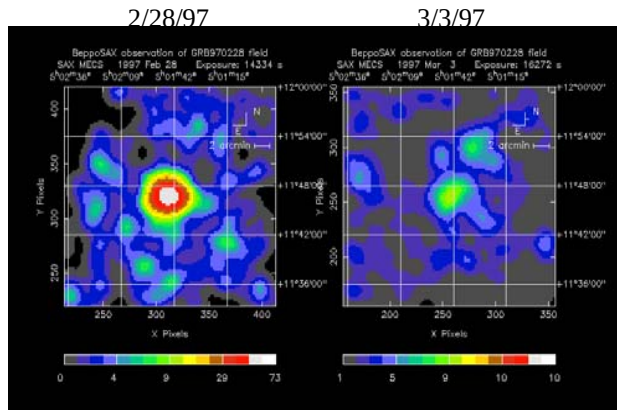
Emission mechanism: synchrotron emission from power-law distribution of electrons in highly relativistic outflows



# *Observational Breakthrough: 1997*



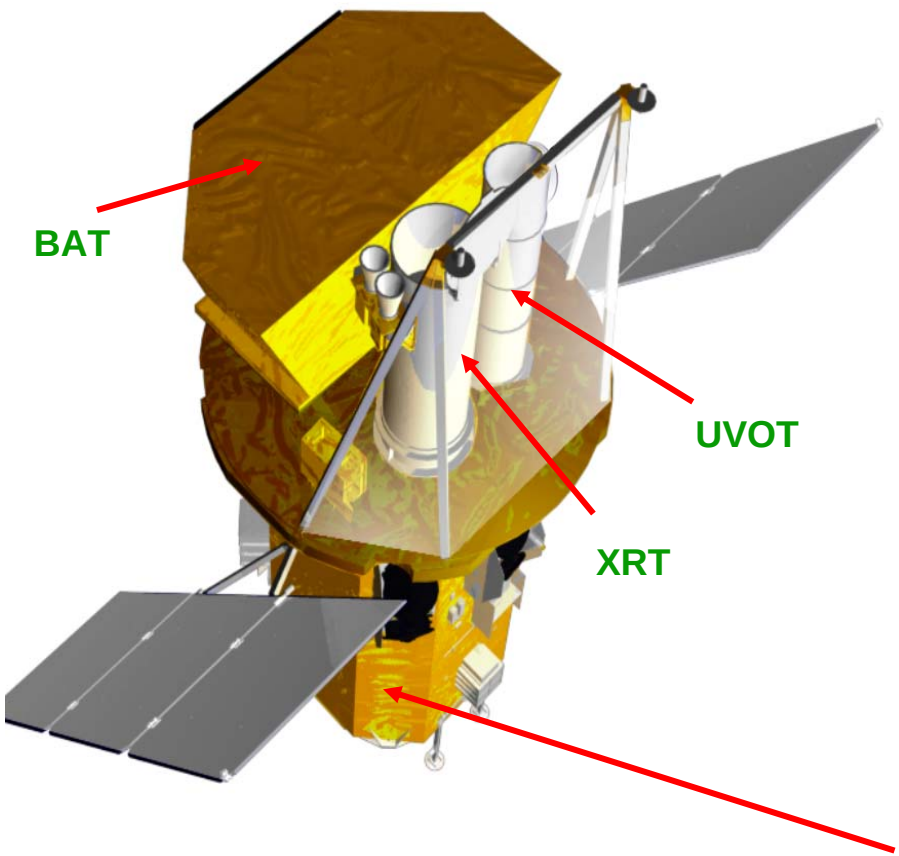
- Beppo-SAX makes the first X-ray image of a GRB afterglow.



# *The Beppo-SAX/HETE-II era*

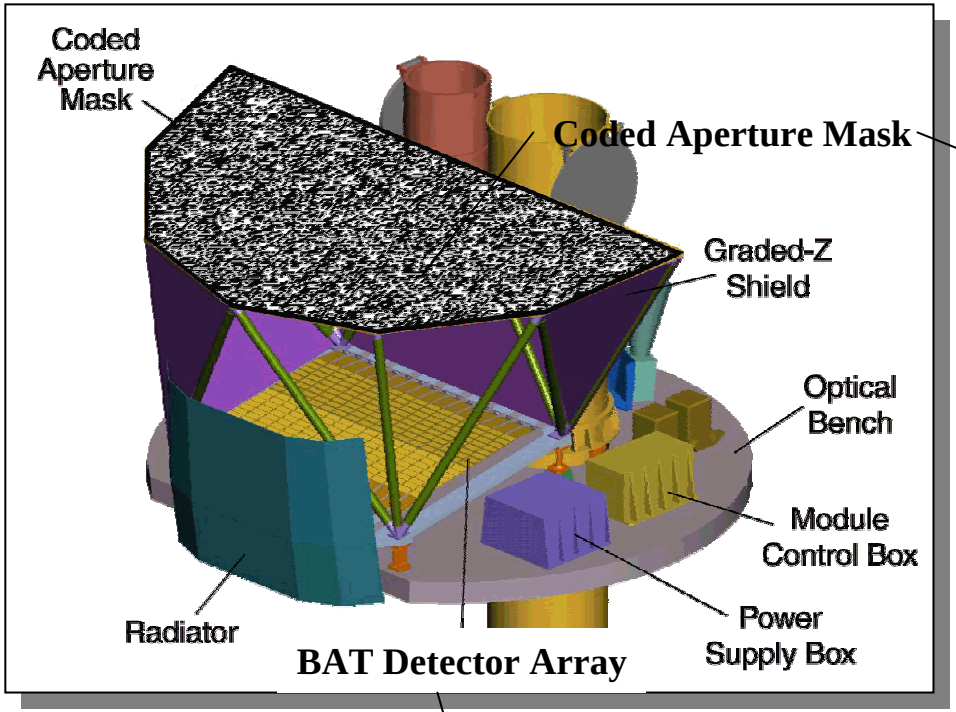
- GRB 970228: first detection of X-ray and optical afterglows
- GRB 970508:
  - First redshift of GRB afterglow (Keck)
  - Also first radio detection of afterglow (VLA – scintillation)
    - Scintillation demonstrated that central source was compact => BH
    - Scintillation also proved superluminal expansion => fireball shock model
- GRB 990123: first optical observation of GRB (ROTSE)
  - "Biggest explosion since Big Bang"
- 55 afterglows discovered by Beppo-SAX and HETE-2
  - Typical delay of 6-8 hours in position determination

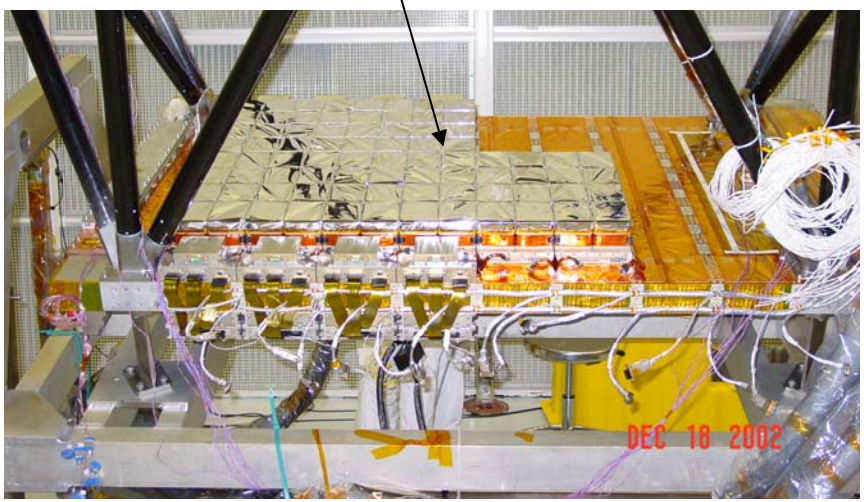
# *Swift Instruments*




- **Burst Alert Telescope (BAT)**
  - New CdZnTe detectors
  - Detect ~100 GRBs per year depending on logN-logS
  - Most sensitive gamma-ray imager ever
- **X-Ray Telescope (XRT)**
  - Arcsecond GRB positions
  - CCD spectroscopy
- **UV/Optical Telescope (UVOT)**
  - Sub-arcsec imaging
  - Grism spectroscopy
  - 24$^{th}$ mag sensitivity (1000 sec)
  - Finding chart for other observers
- **Spacecraft**
  - **Autonomous re-pointing, 20 - 75 sec**
  - **Onboard and ground triggers**

# *Burst Alert Telescope (BAT)*



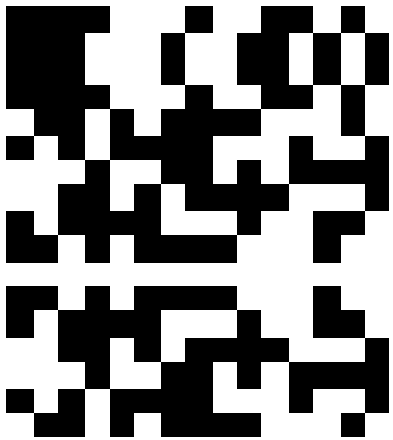




## BAT Characteristics

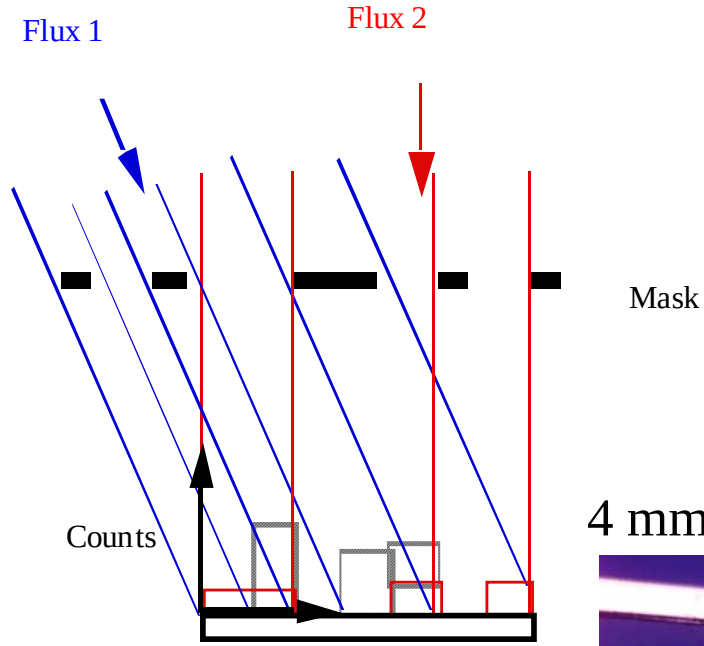
- E Range: 15 - 150 keV (12-300)
- E Resoln: 7 kev (5)
- Loc Resoln: 1-4 arcmin (1-4)
- PSF: 22 arcmin (21.8)
- 2 steradian field of view
- 32K CZT dets, 5200 cm2
- Autonomous operations

# *Coded-Aperture Imaging*

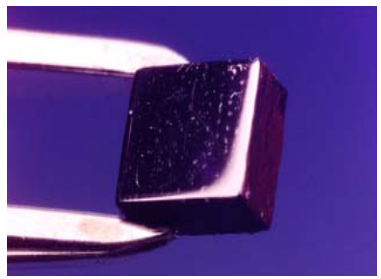
Coded Aperture
Mask Pattern



5 mm square Pb tiles

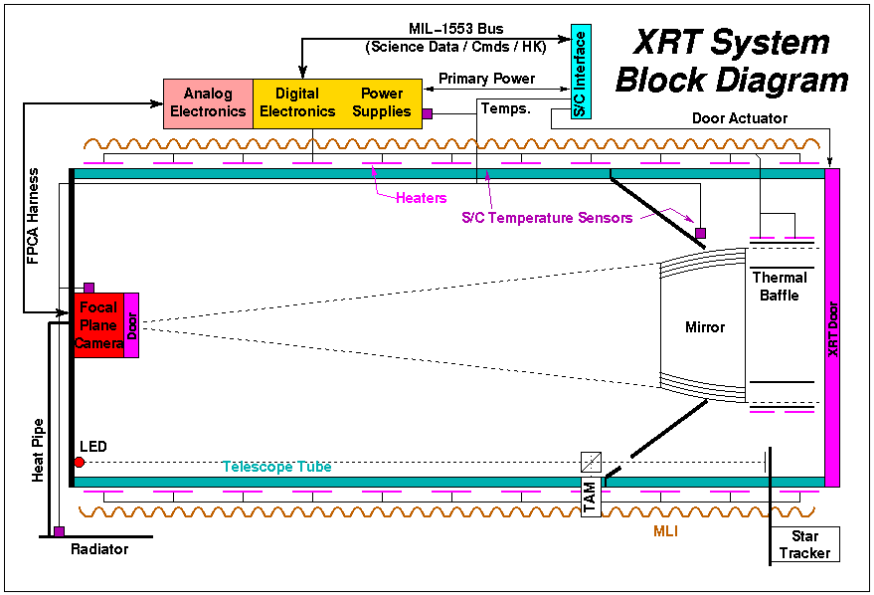


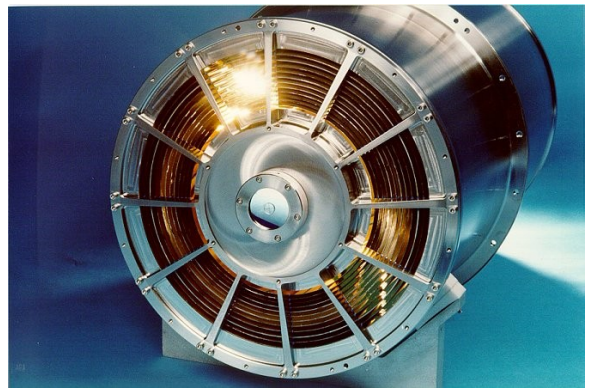

4 mm square CZT

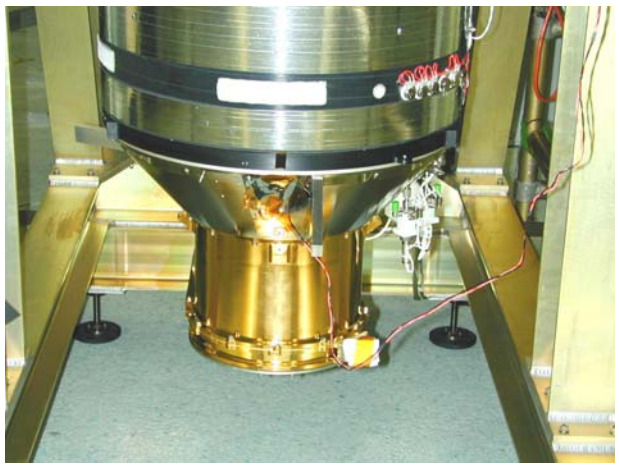


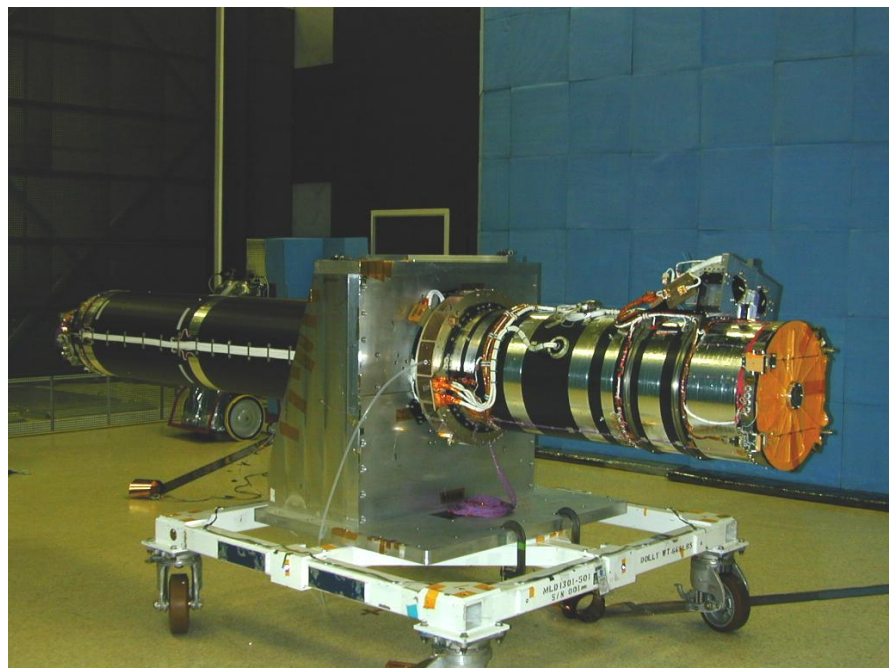
- Source Photons “Encoded” by Partially Blocked Aperture
- Can be Decoded in Data Analysis to Determine Source Position
- Missing Pixels = Graceful Degradation in Sensitivity

# The X-Ray Telescope

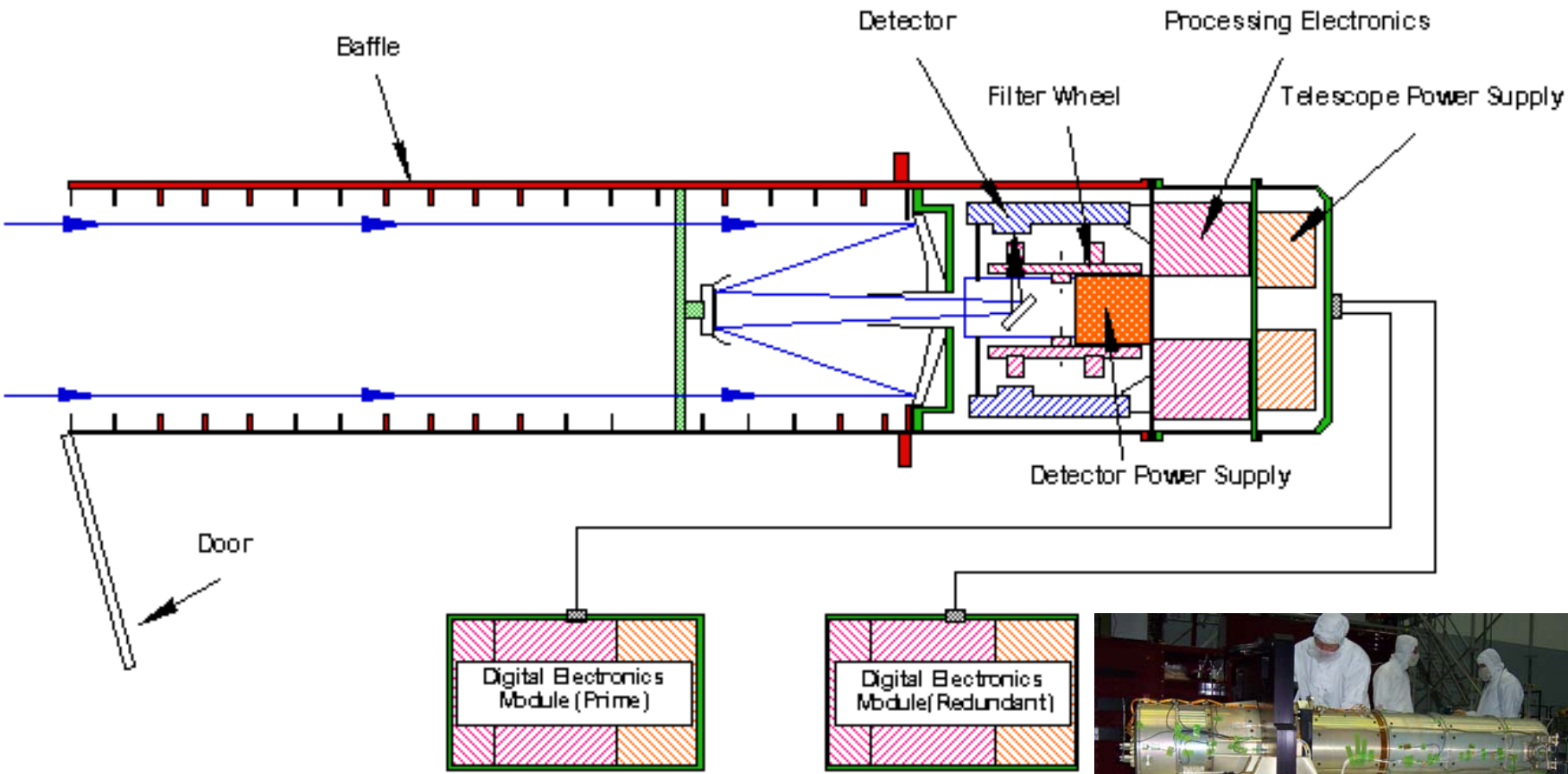






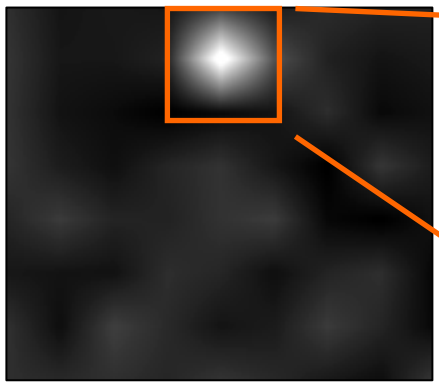
# *The UV/Optical Telescope*




# *Observing Scenario*

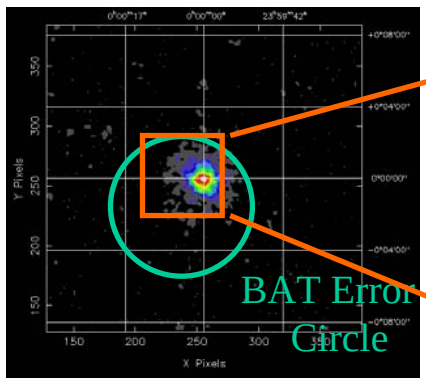
1. Burst Alert Telescope triggers on GRB, calculates position to ~ 1 arcmin
2. Spacecraft autonomously slews to GRB position in 20-70 s
3. X-ray Telescope determines position to ~ 3 arcseconds
4. UV/Optical Telescope images field, transmits finding chart to ground

**BAT Burst Image**



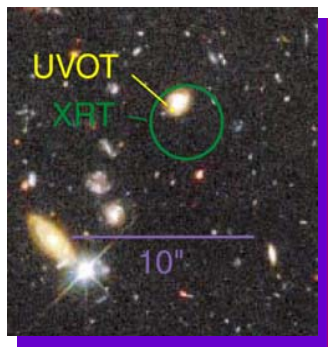
***T~10 sec***

**XRT Image**




***T~100 sec***

**UVOT Image**




***T~300 sec***

# *The Swift Observatory*

- Launched: 20 November 2004
- BAT First Light: 3 December 2004
- XRT First Light: 11 December 2004

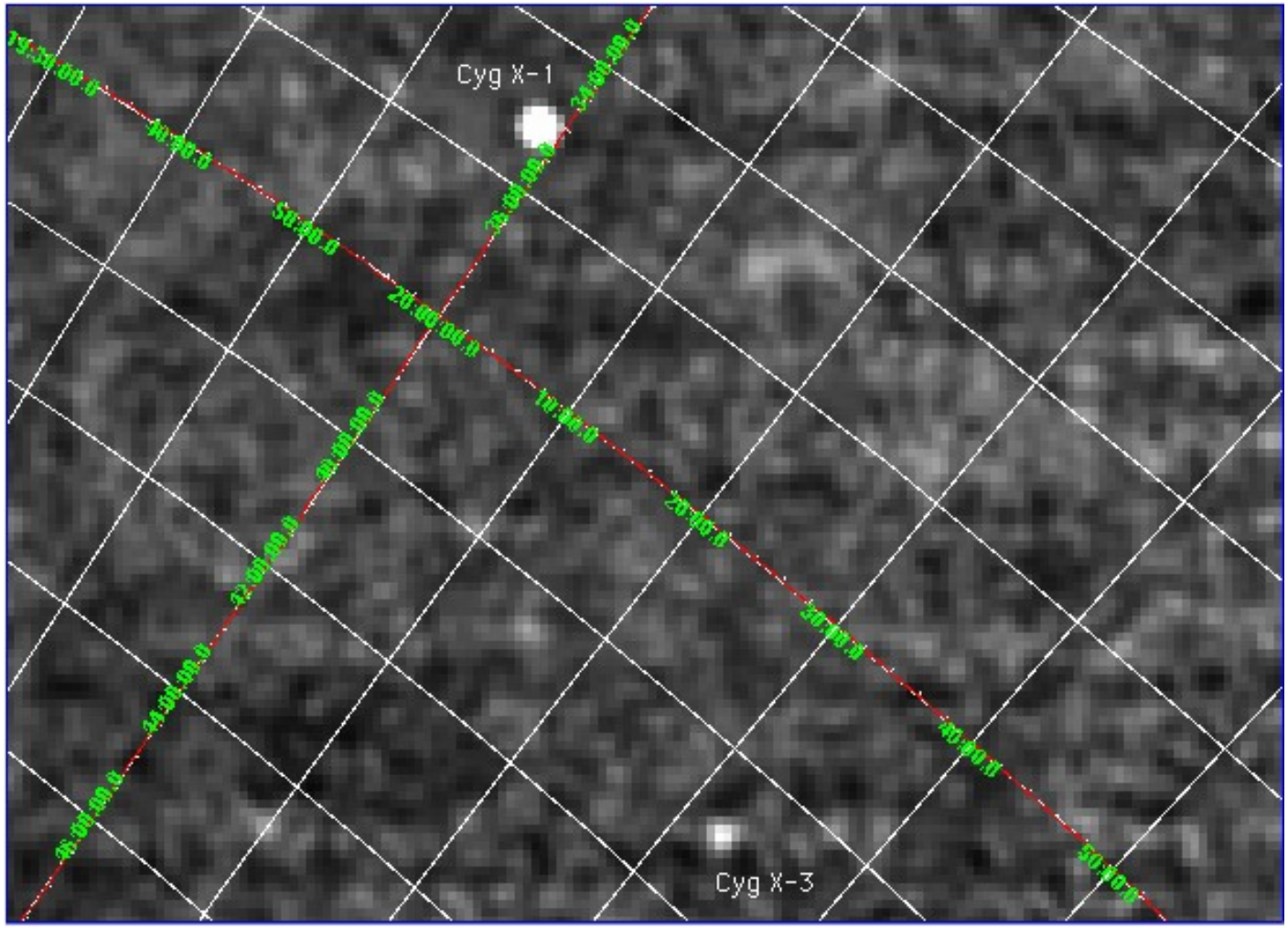

- First BAT Burst: 17 December 2004
- First XRT Afterglow: 23 December 2004
- UVOT First Light: 12 January 2005
- Data public since 5 April 2005

# *BAT First Light*

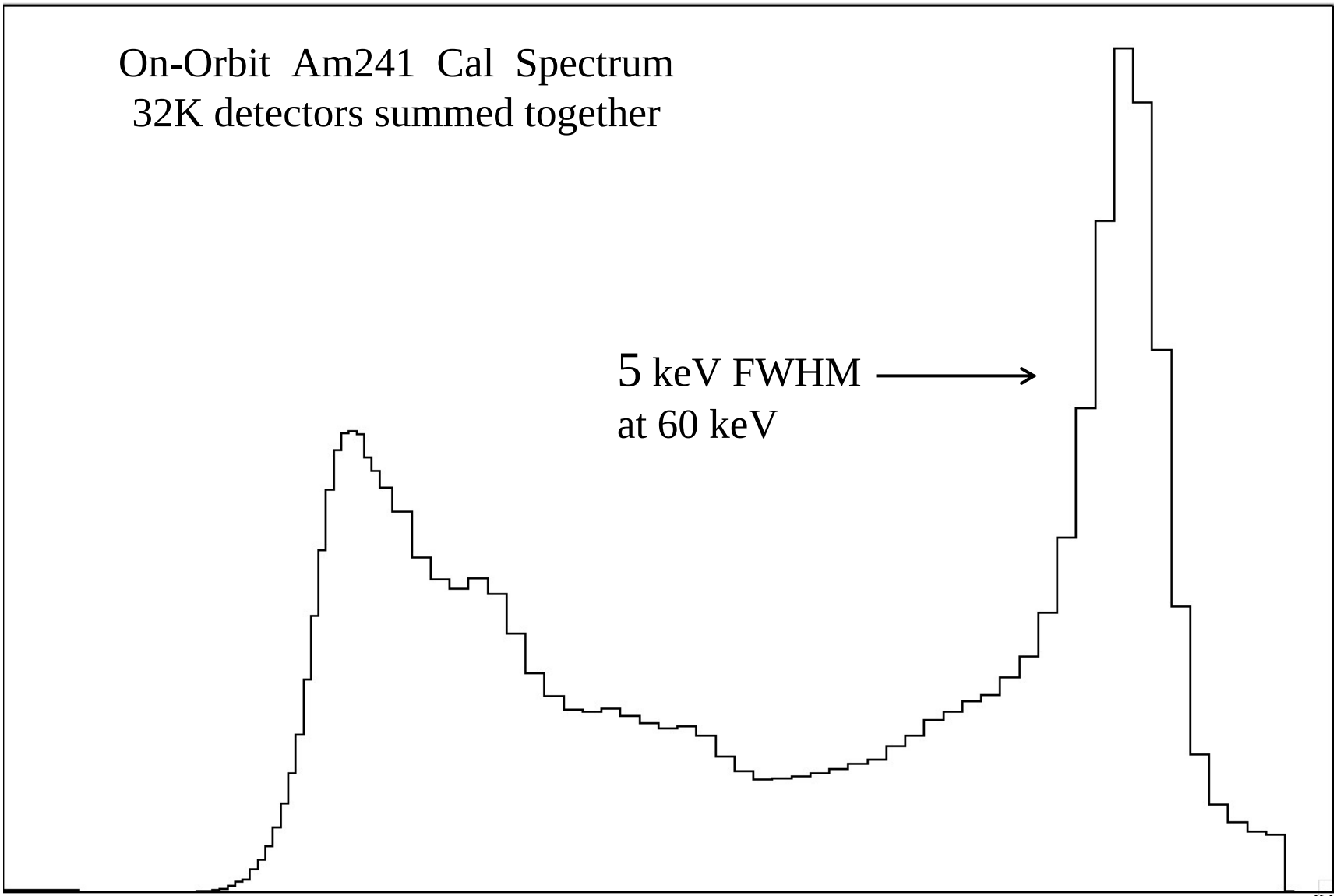
Pixel = 17'

FWHM = 22'

Position < 4'



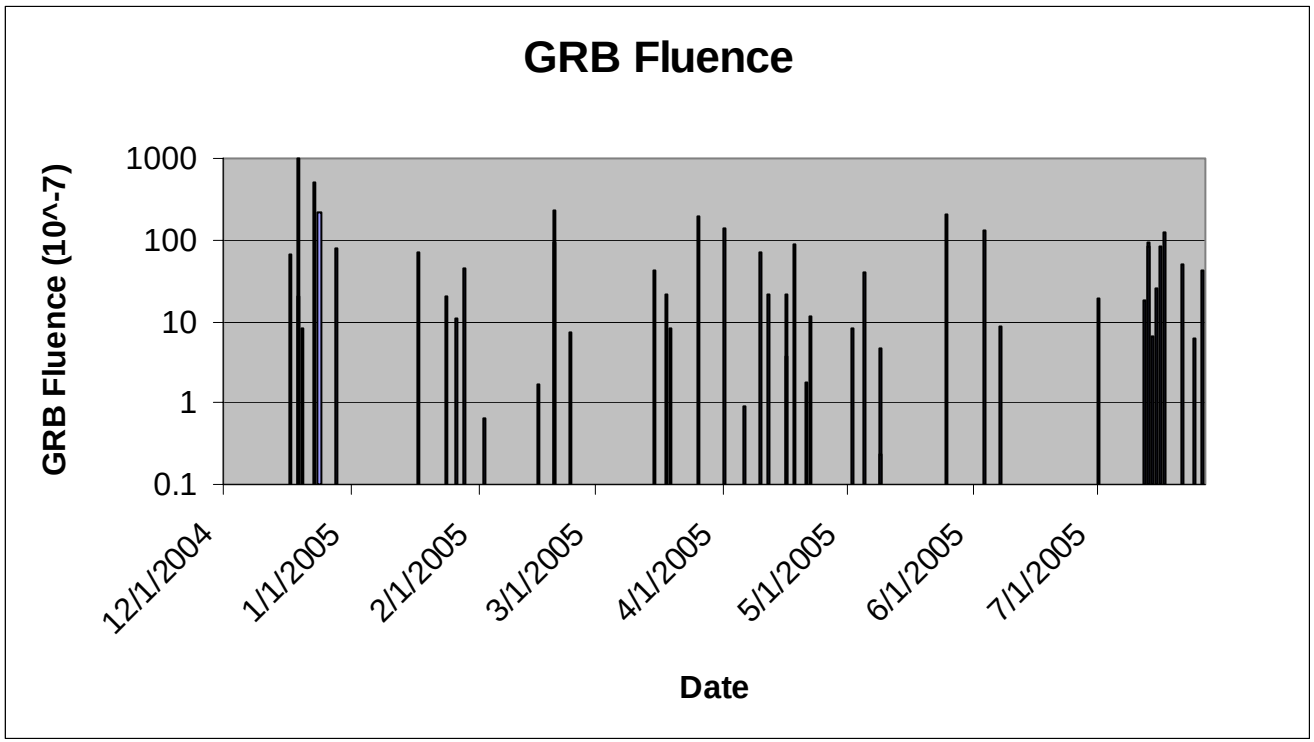
# *BAT Energy Resolution*



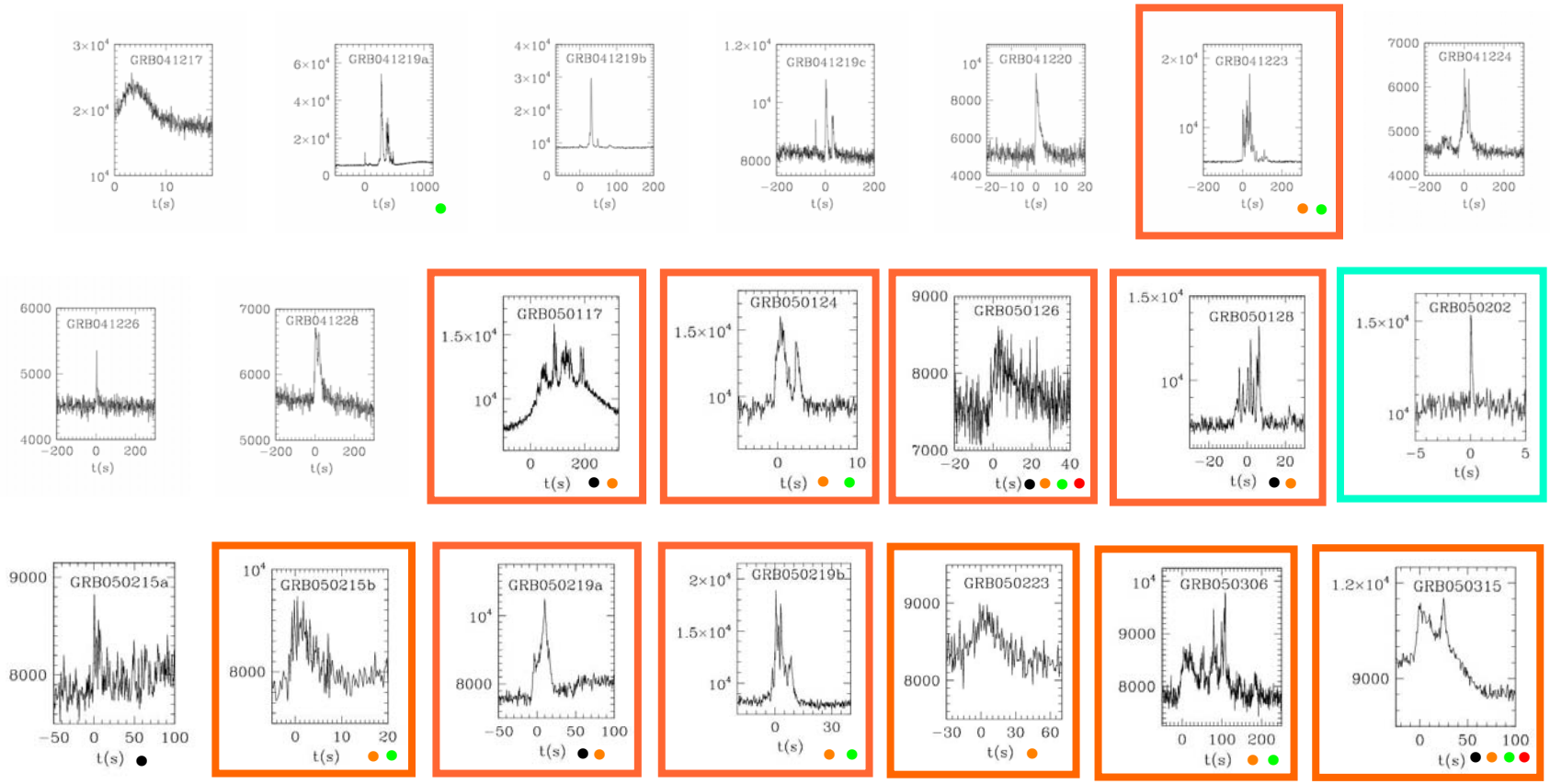
# BAT Bursts

- **53 GRBs detected/imaged since Dec. 17 (29.5 weeks as of 7/26/05)**

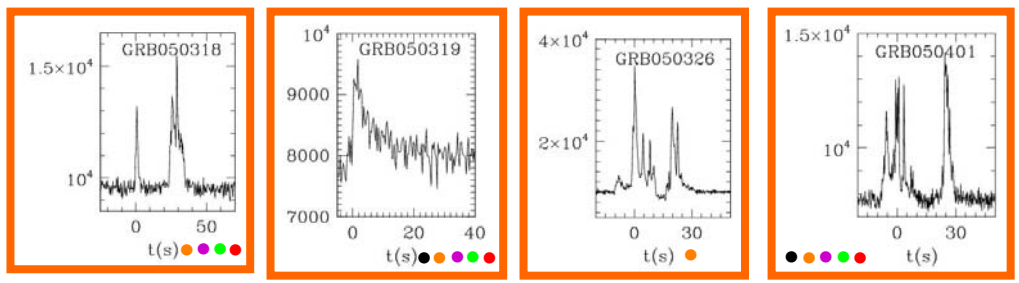
| | | | | | |
|---|---|---|---|---|---|
| 041217 | 050315 | 050410 | 050502B | 050603 | 050715 |
| 041219A,B,C | 050318 | 050412 | 050505 | 050607 | 050716 |
| 041220 | 050319 | 050416A,B | 050507 | 050701 | 050716 |
| 041223 | 050326 | 050418 | 050509A,B | 050712 | 050721 |
| 041224 | 050401 | 050421 | 050525 | 050713A,B | 050724 |
| 041226 | 050406 | 050422 | 050528 | 050714B | 050726 |
| 041228 | | | | | |
| 050117 | | | | | |
| 050124 | | | | | |
| 050126 | | | | | |
| 050128 | | | | | |
| 050202 | | | | | |
| 050215A | | | | | |
| 050215B | | | | | |
| 050219A,B | | | | | |
| 050223 | | | | | |
| 050306 | | | | | |



# *Light Curves of First 25 BAT GRBs*




- = prompt slew
- = detected by XRT
- = detected by UVOT
- = detected by ground-based optical/IR
- = redshift measurement



# *UVOT Detections of BAT GRBs*

- Detected 8/38 with UVOT
  - Why so few?? Big mystery!
  - UVOT upper limits are quite faint and very early for many of these
  - However, 21 have ground-based detections (typically R, I, J, or K)
    - High z? (perhaps in some cases)
    - Dust extinction? (some evidence supporting this)
    - Magnetic suppression?

# *GRB 050318: the first UVOT afterglow*

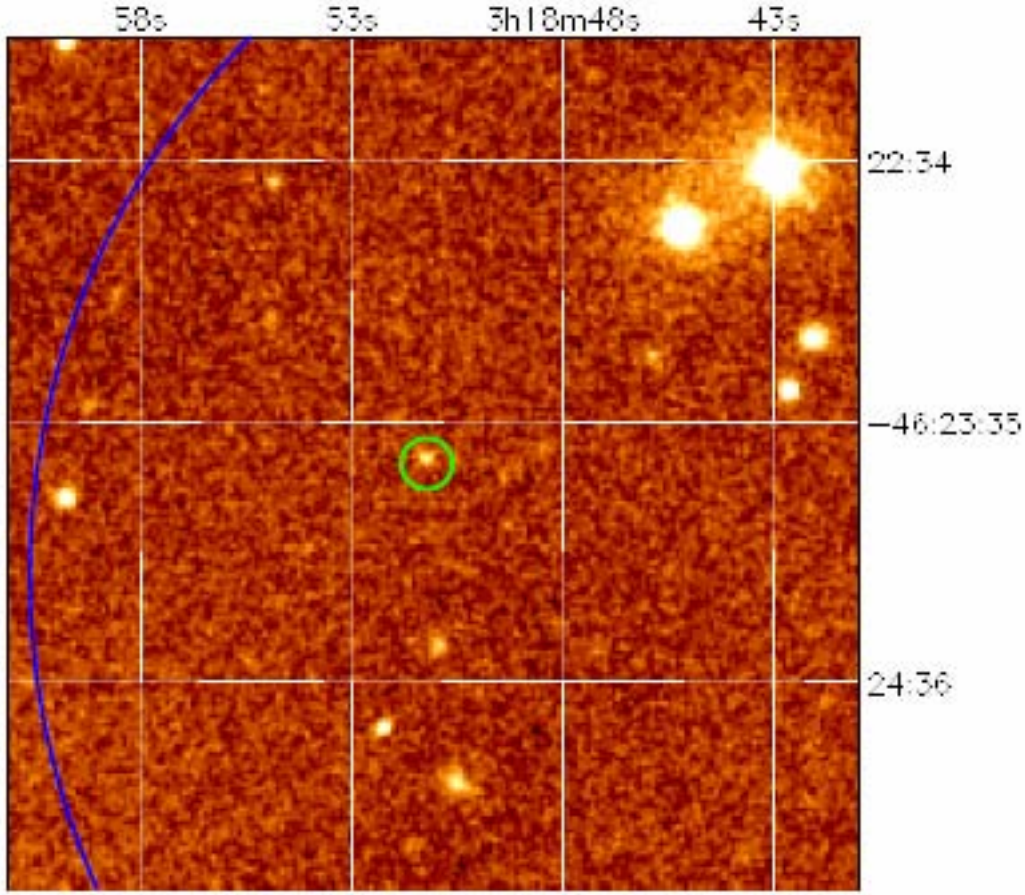
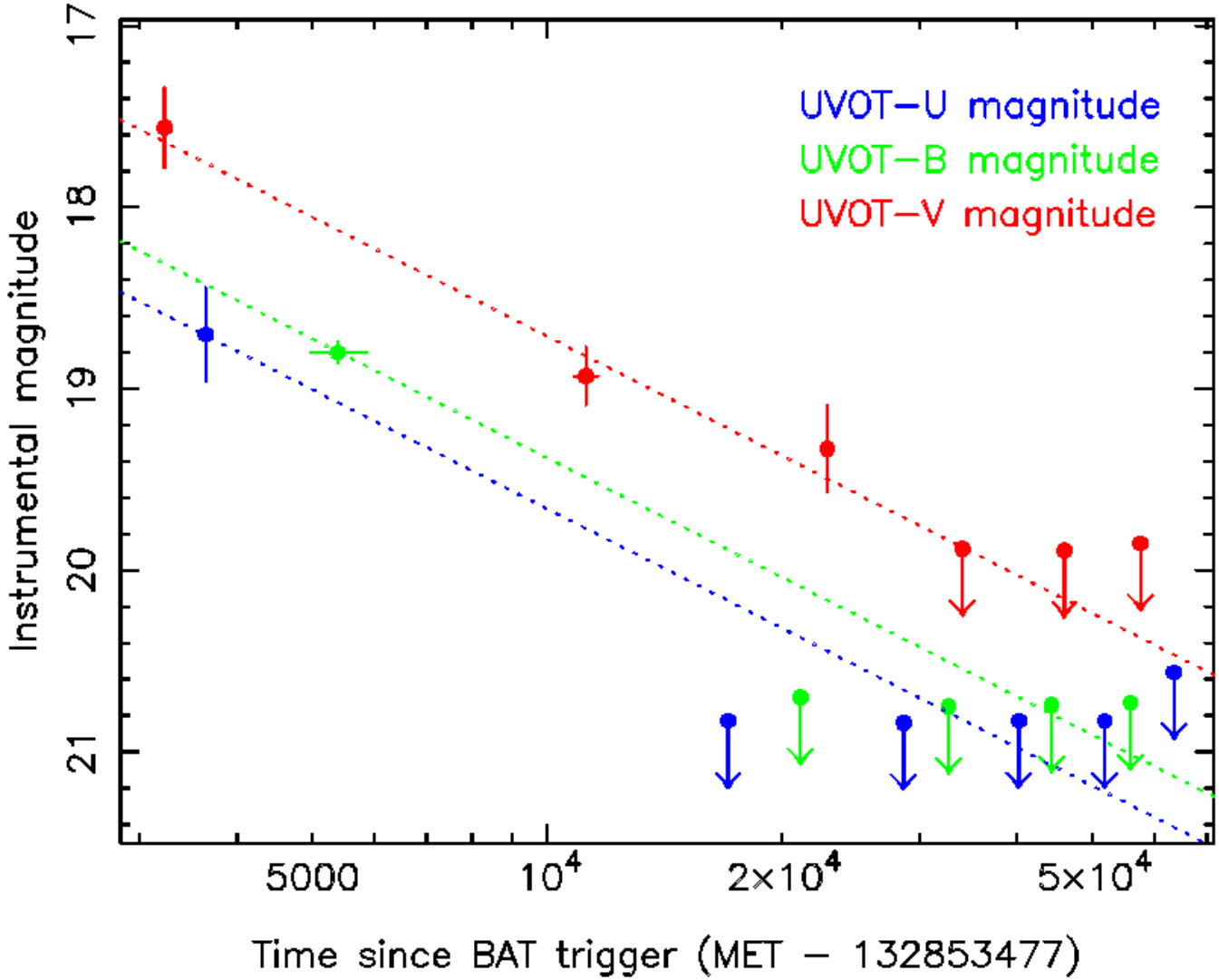
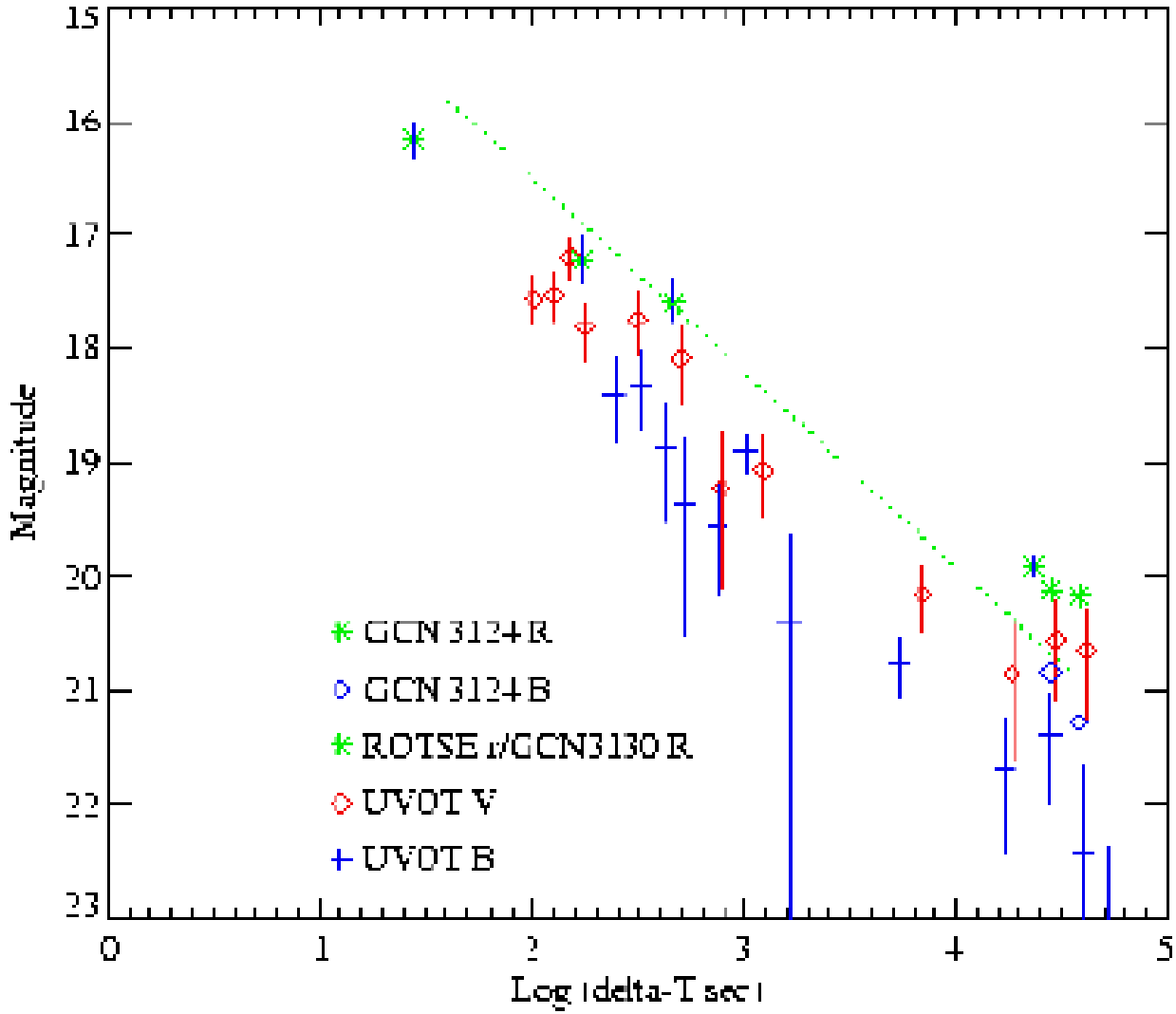



FIG. 1.— Stacked UVOT-V filter image of the field with the transient source at RA = $03^h\ 18^m\ 51^s.15$, Dec = $-46°\ 23'\ 43''.7$ (J2000) and a $3'$ BAT error circle and $6''$ XRT error circle overlaid. Total exposure time for the stacked image is 3,732s.

# *GRB 050318: the first UVOT afterglow*



# GRB 050319: UVOT Lightcurve

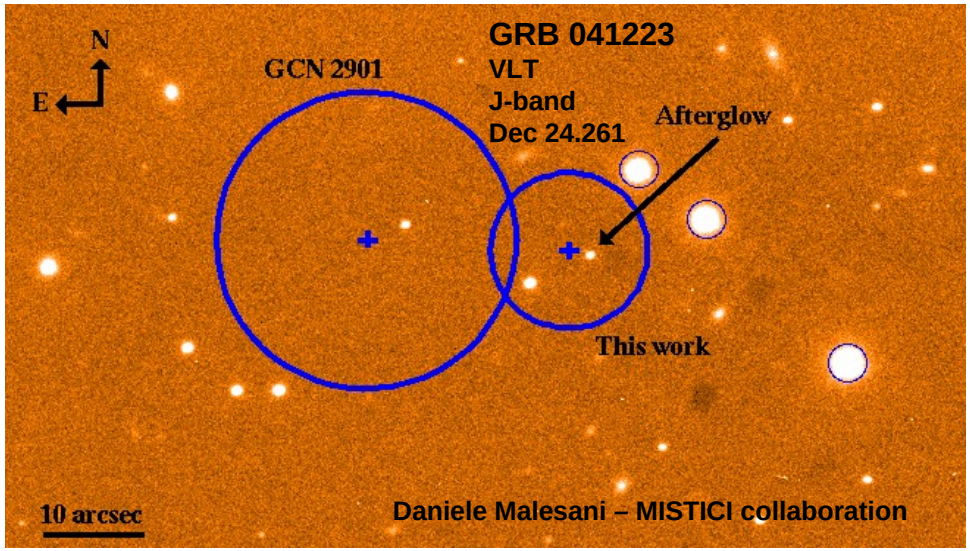


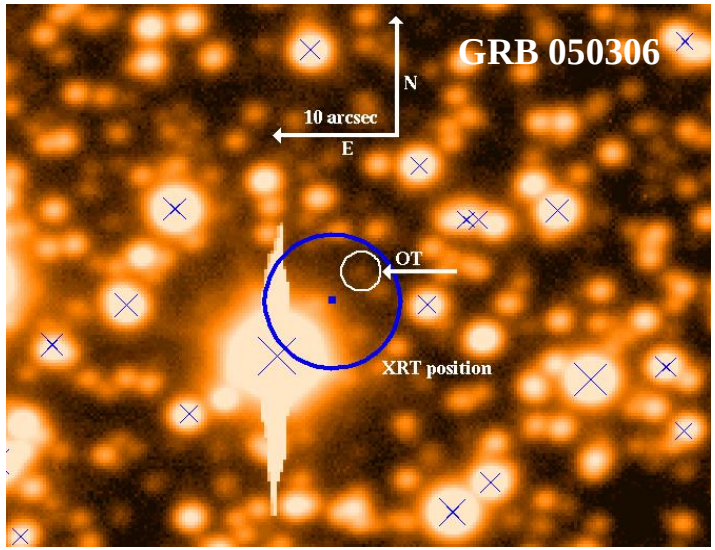
# *XRT Detections of BAT GRBs*

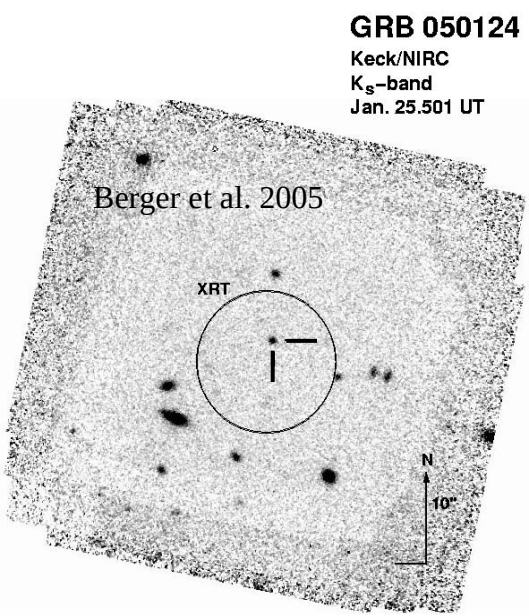
- Detected 39/40 with XRT (observed @ T < 200 ks)
  - Observed two during burst
  - 27/39 Swift detections were prompt observations (< 300 s)
    - 24/27 have fast decline or flare within first ~5 minutes
  - 11 have redshift measurements:
    - Average redshift: 1.8 (compared with about 1 for Beppo-SAX bursts)
    - Highest redshift: 4.27 (2$^{nd}$ highest on record)

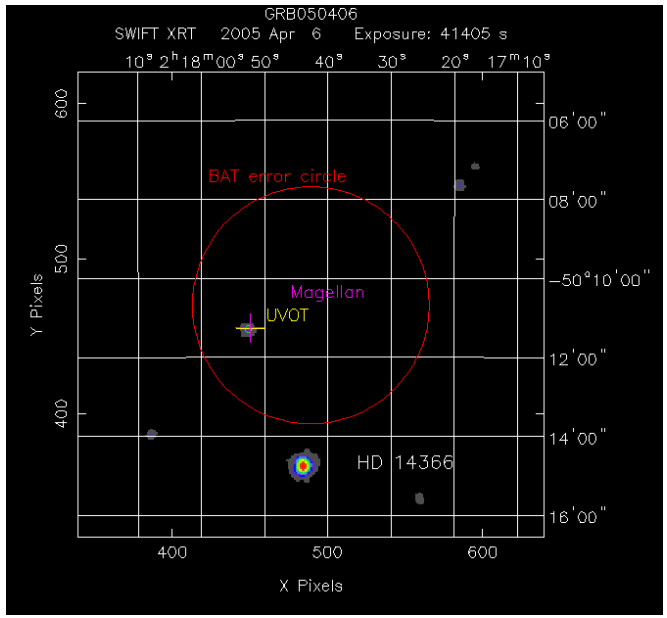
- Detected 1/2 HETE burst with XRT
- Detected 4/7 Integral bursts with XRT

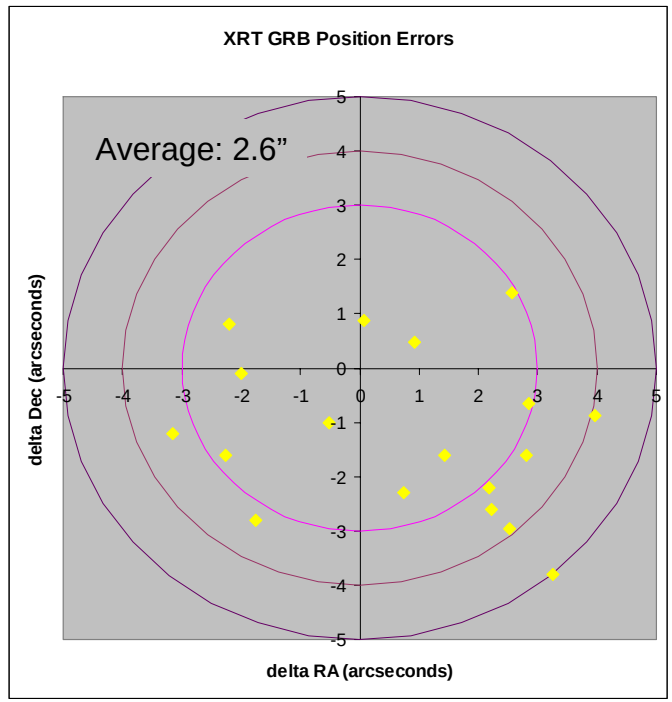
# *XRT Positional Accuracy*



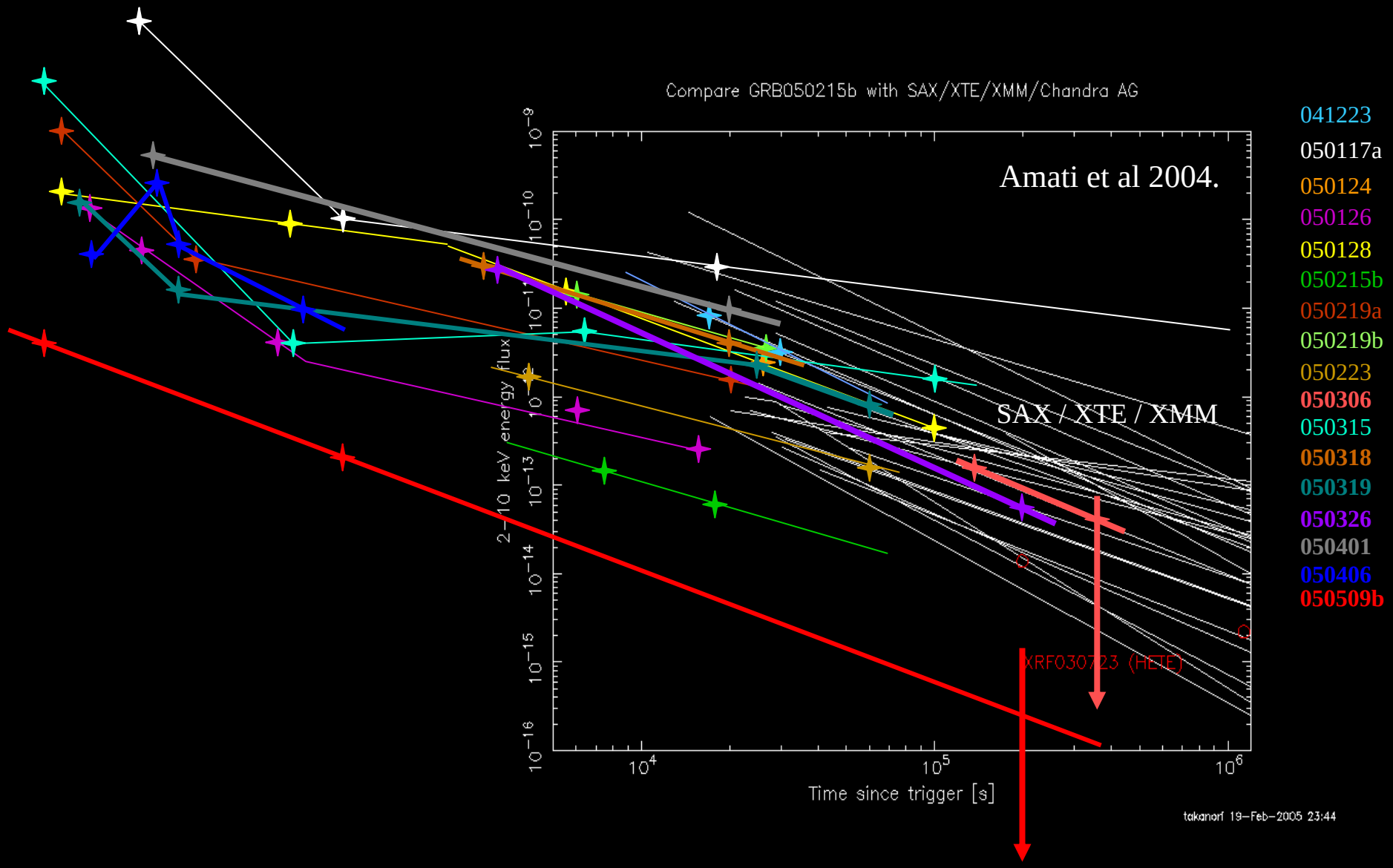



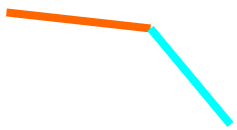
# *XRT Afterglow Summary*



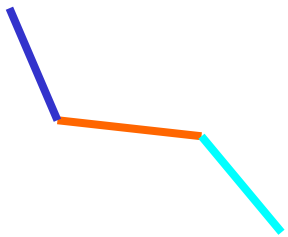
# *XRT Afterglow Types*

At least 3 shapes of afterglows. Out of 24 prompt observations, we have:

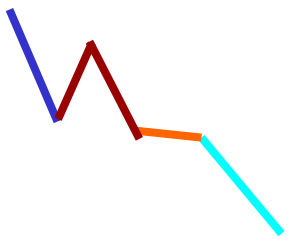
- Type A (3)



- Type B (10)

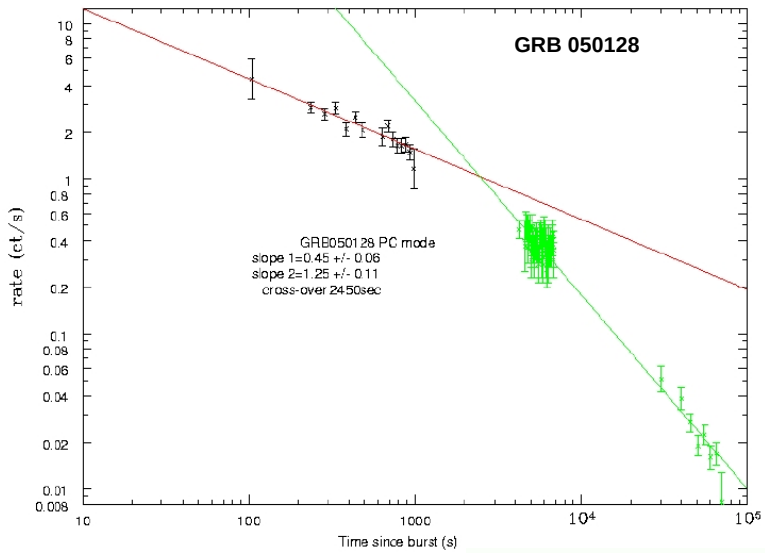


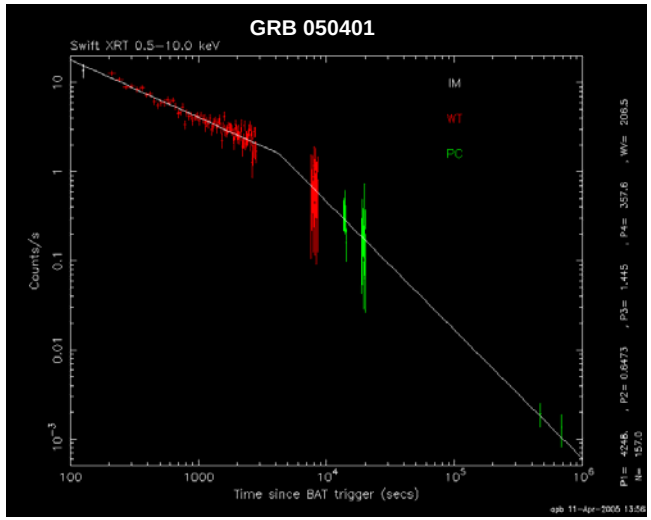
- Type C (11)

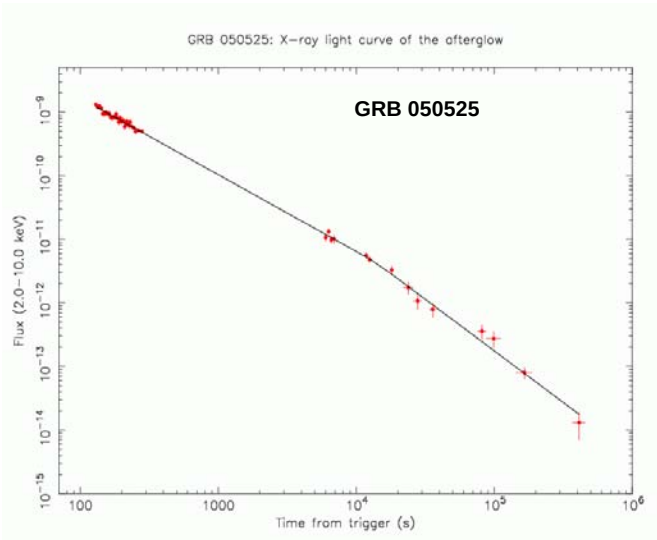


# *Type A Afterglows*

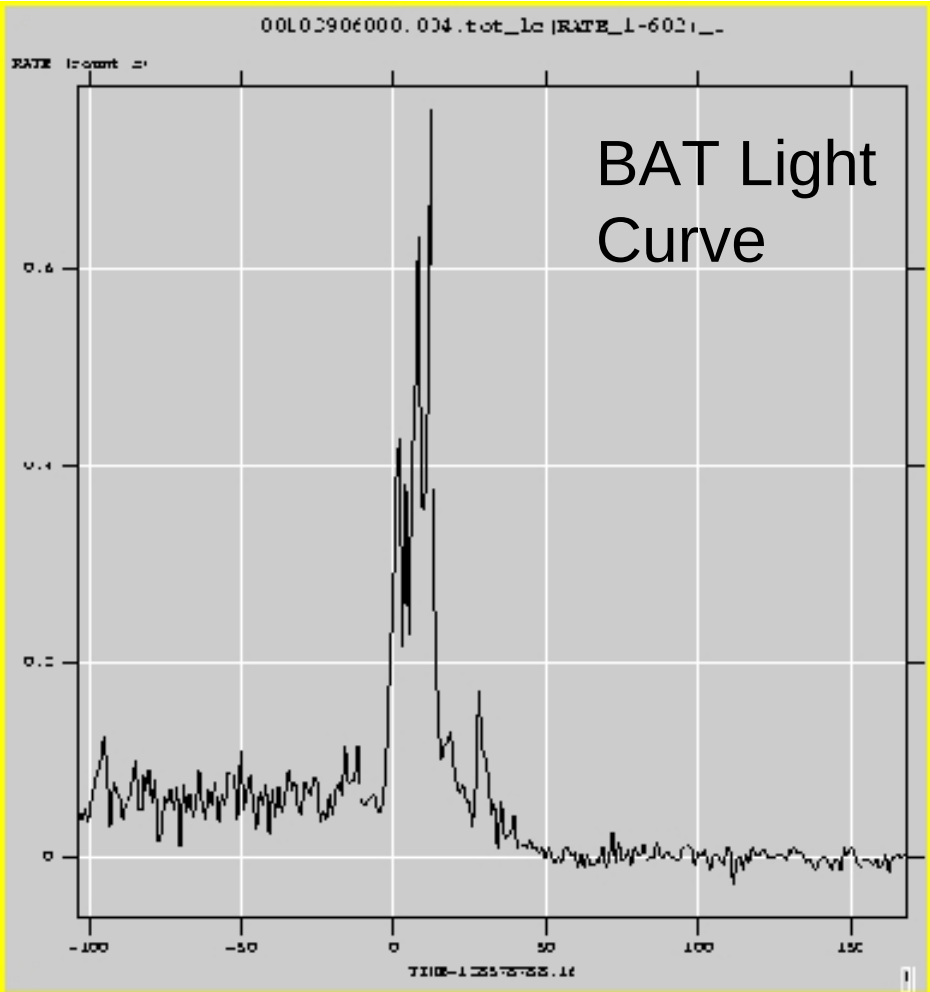
**050128**
**050401**
**050525A?**



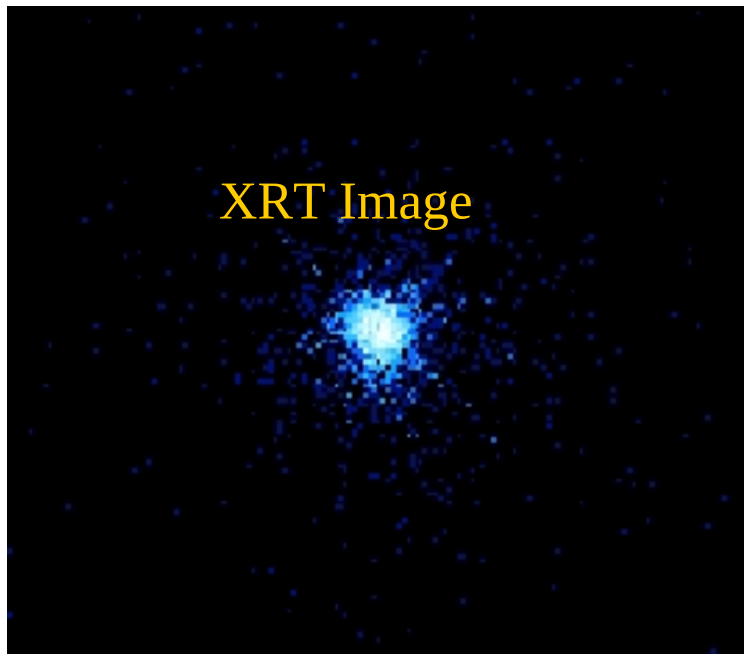



# *GRB 050128*

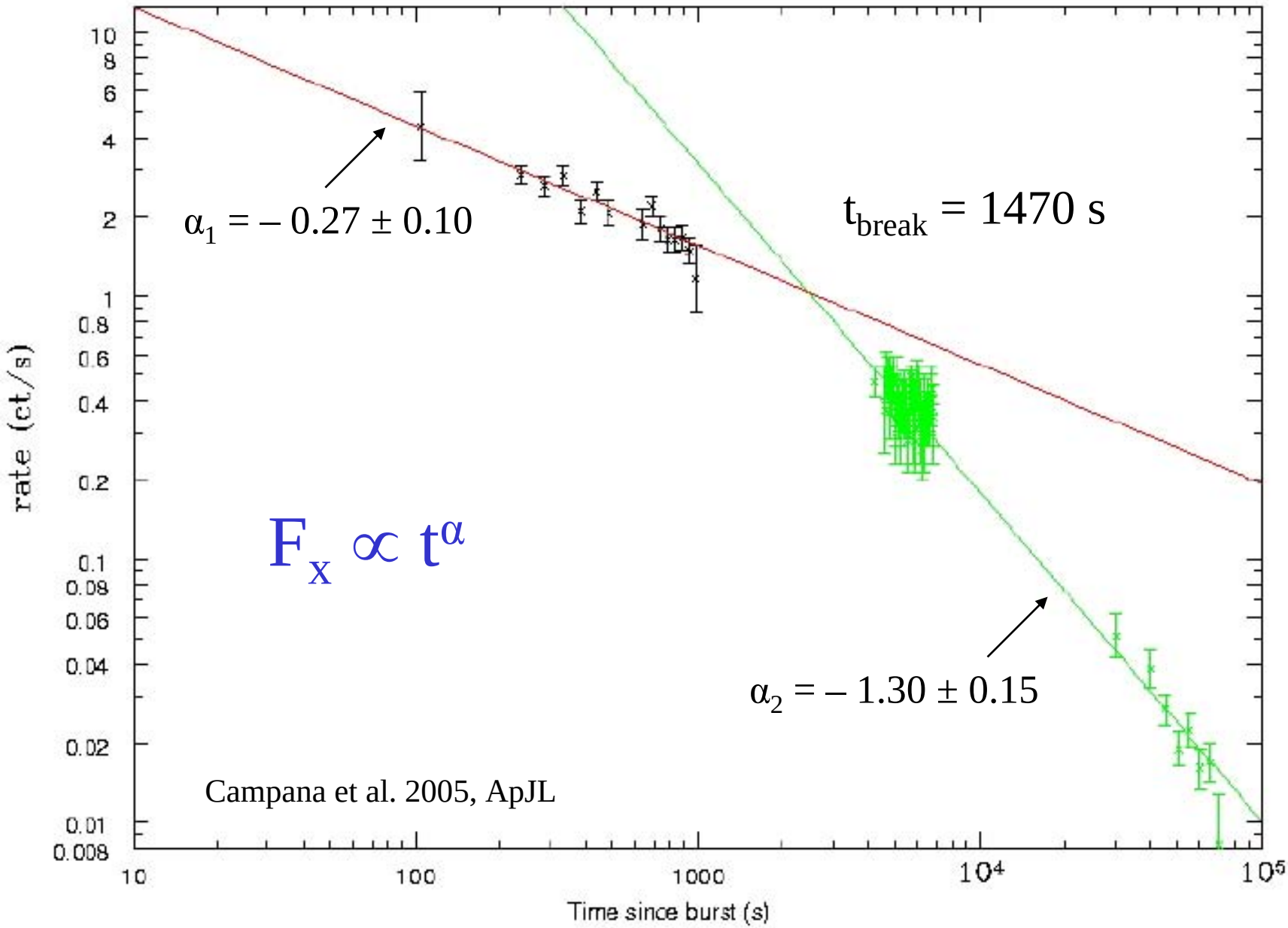



XRT in Manual State, PC Mode

- **108 s after burst trigger**
- Bright, piled-up X-ray source
- Very shallow decay index in first orbit

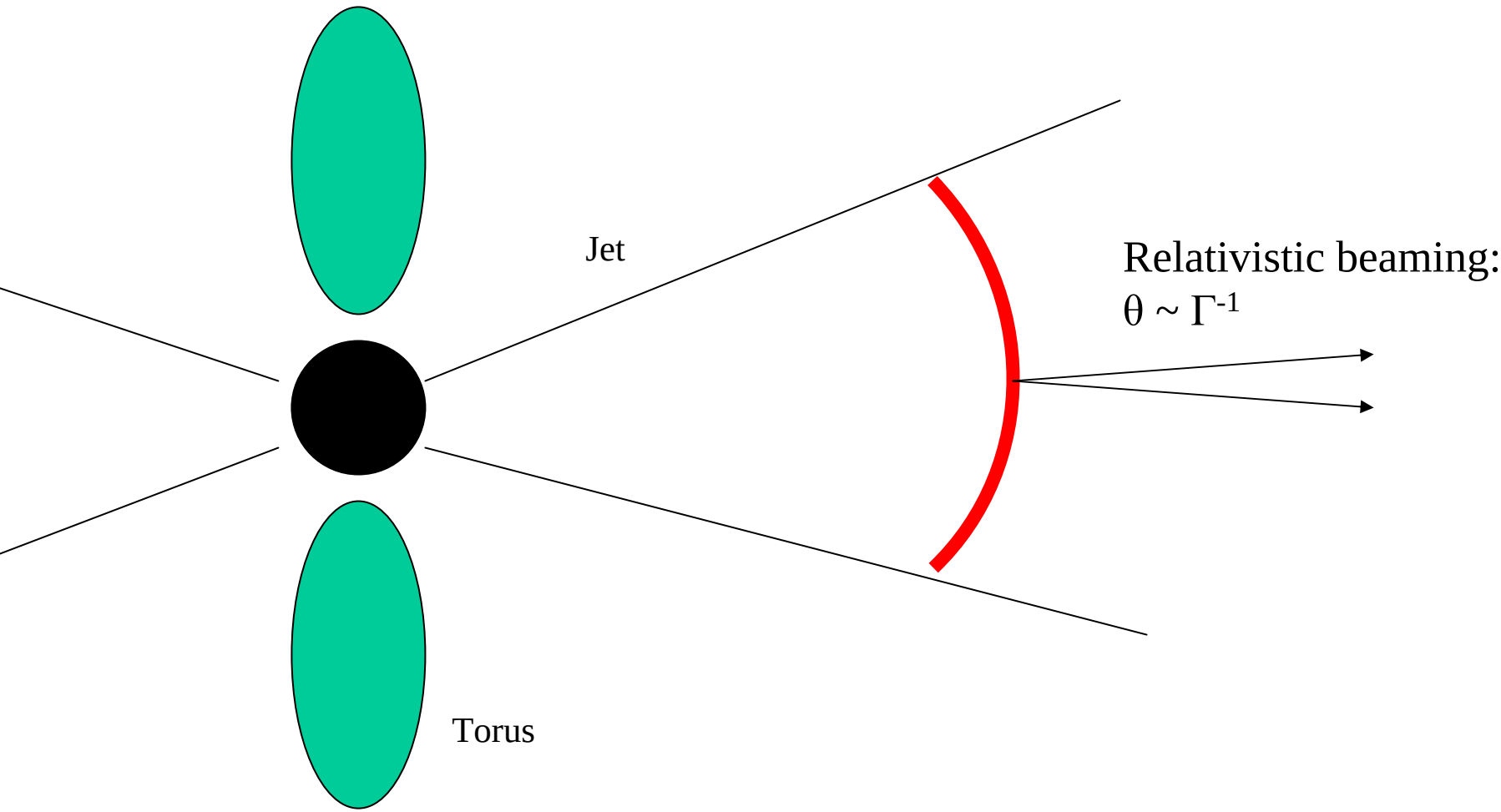


# *GRB 050128 XRT Lightcurve*

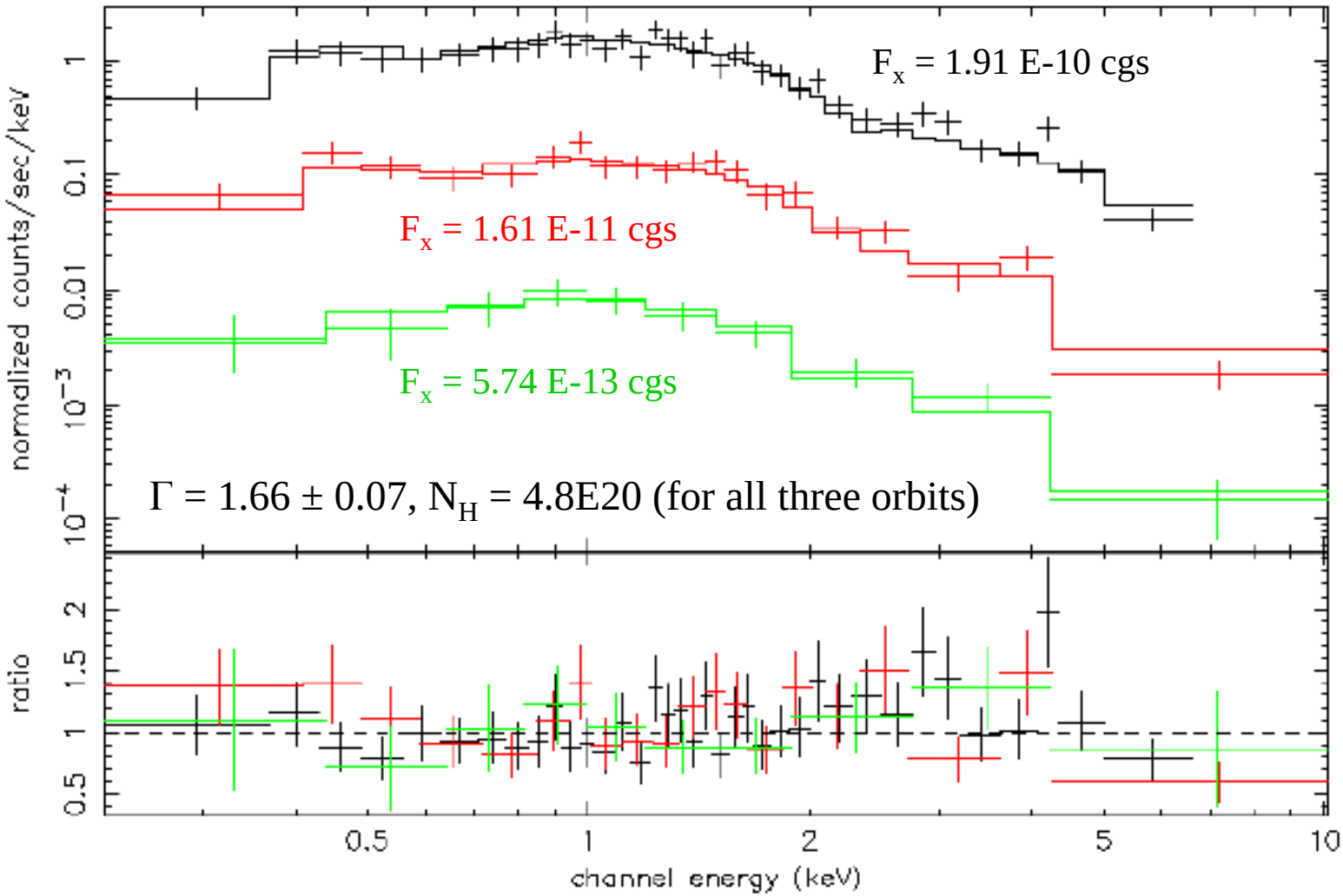



Campana et al. 2005, ApJL

# Jet Break



# *GRB 050128 spectrum*

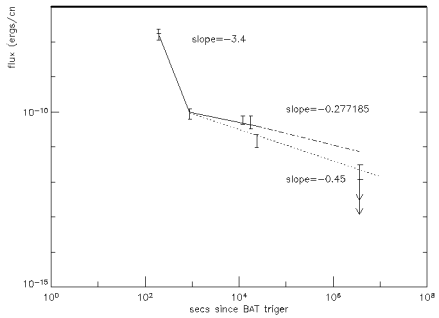



Campana et al. 2005, ApJL

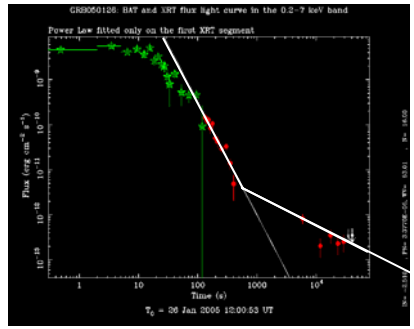
# *Type B Afterglows*

**050117**
**050126**
**050219A**
**050315**
**050319**
**050412?**
**050416A**
**050422**
**050713B**
**050721**

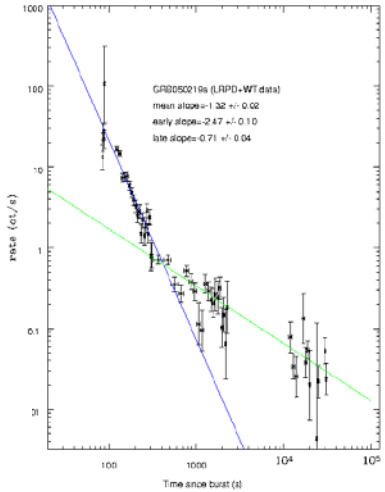
**GRB050117a**



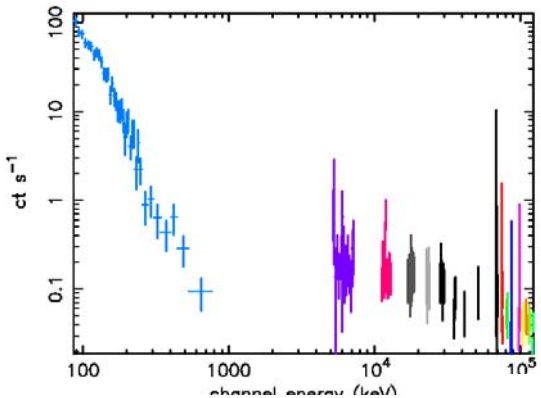

**GRB050126**



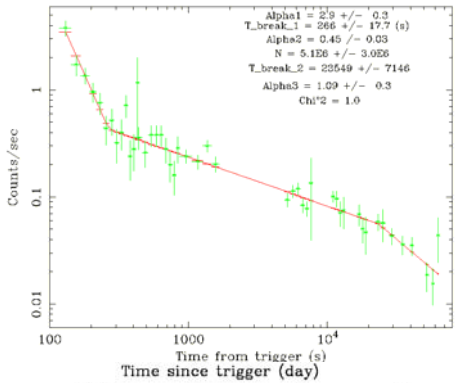

**GRB050219a**

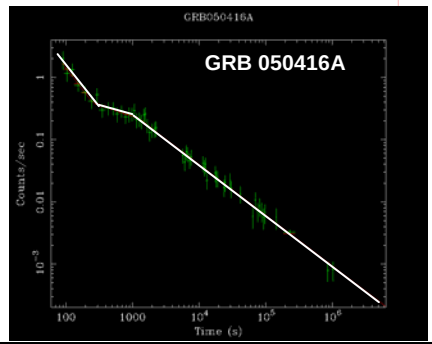



GRB050315 PC mode only

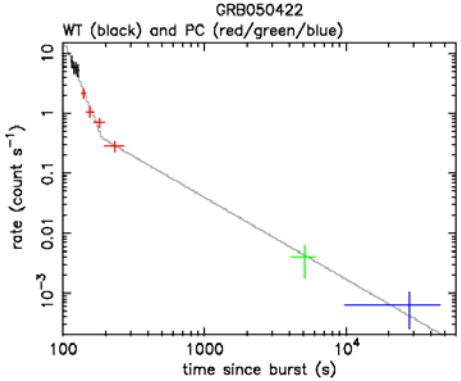


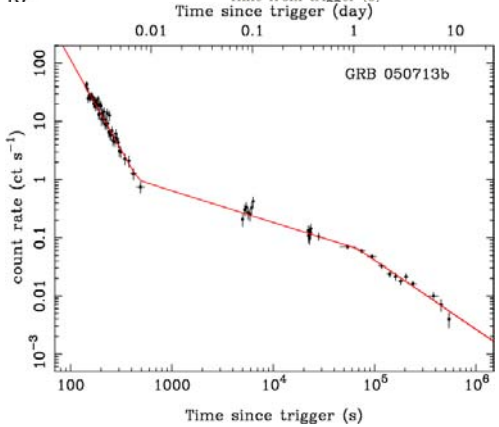

**GRB050319**

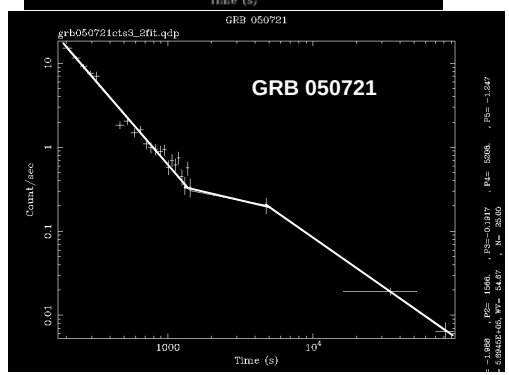


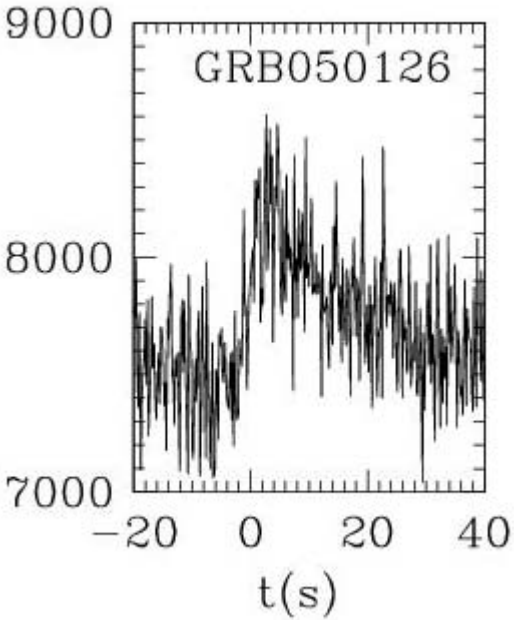

GRB050422
WT (black) and PC (red/green/blue)

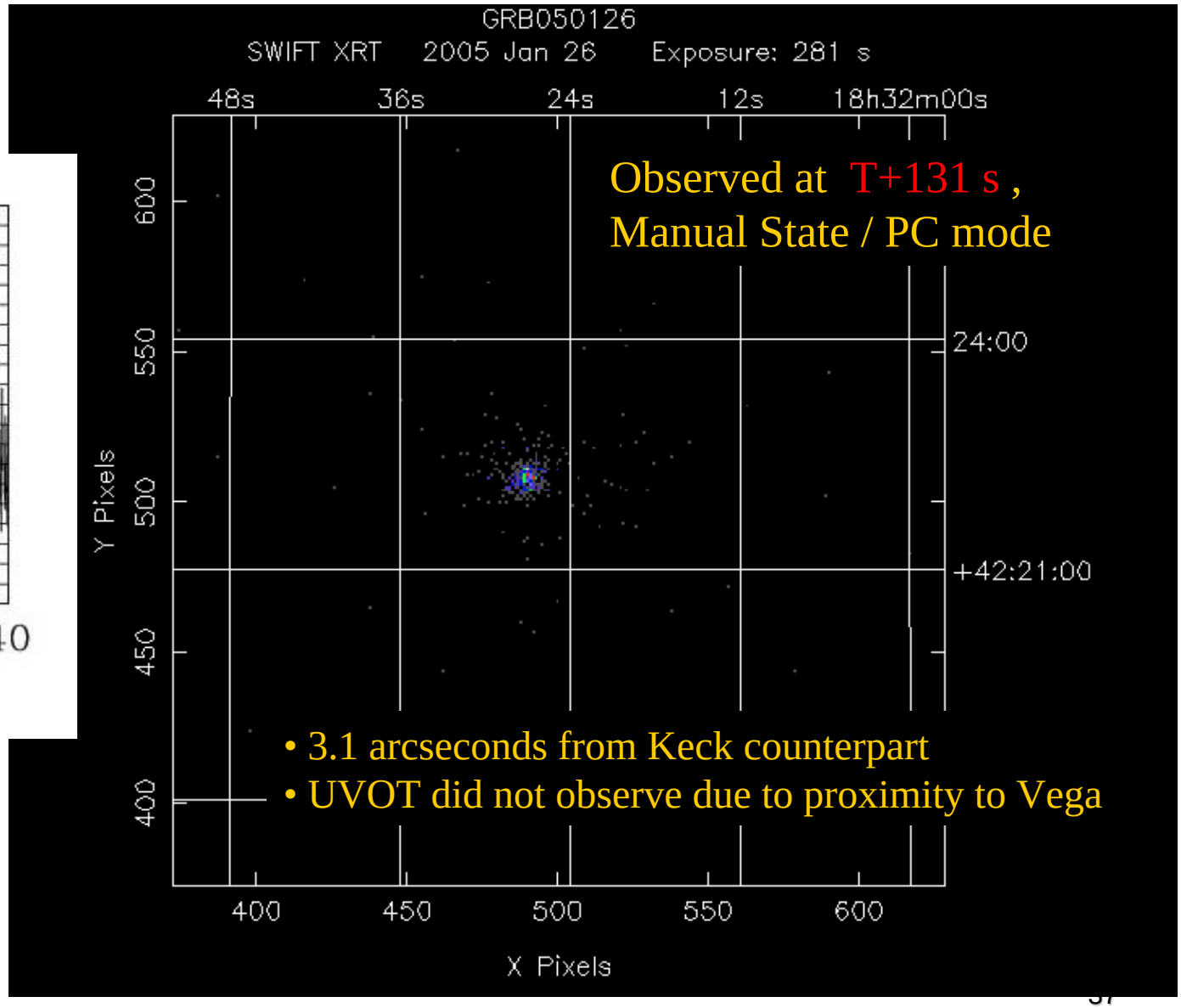


# *GRB 050126*

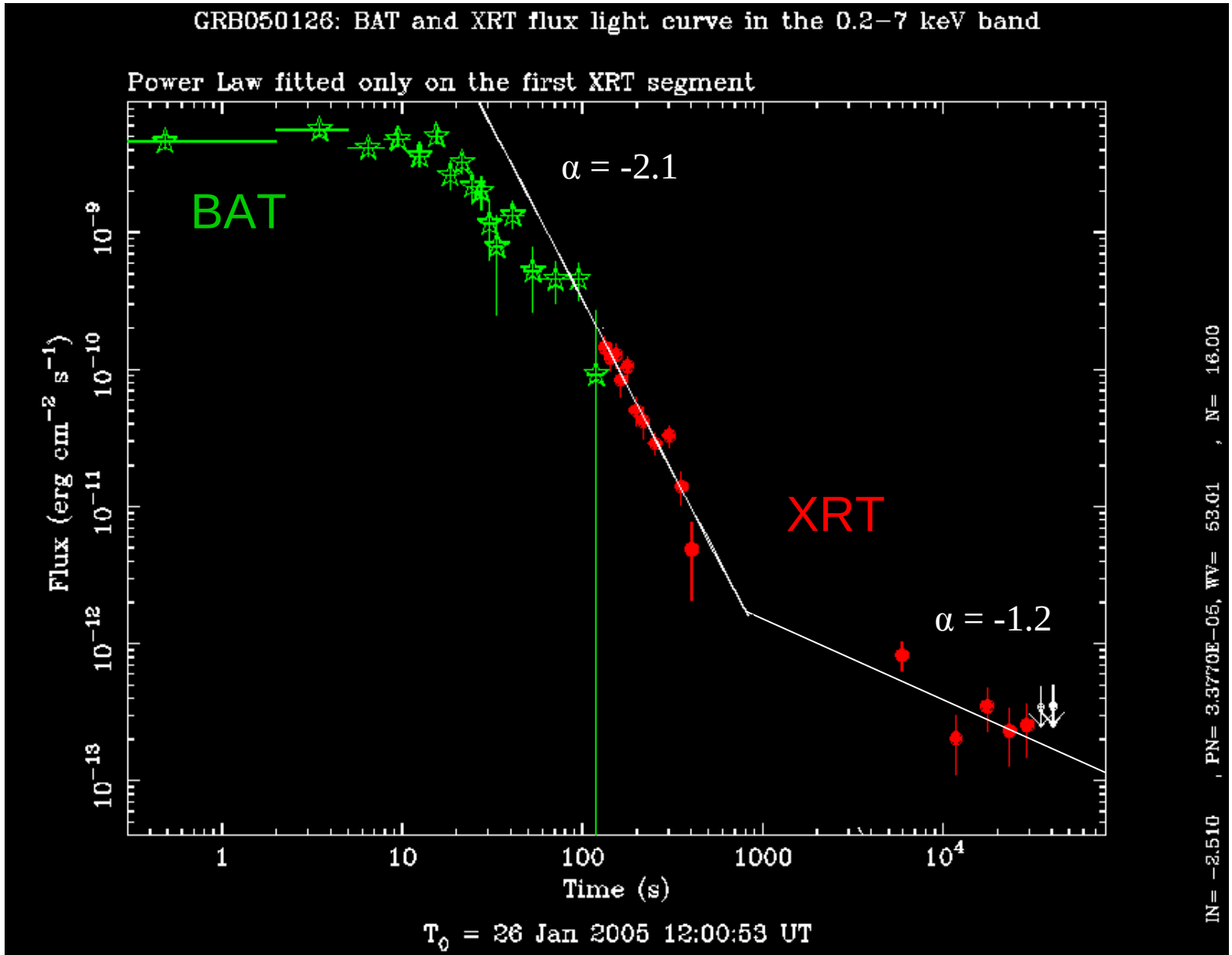



Observed at T+131 s ,
Manual State / PC mode

- 3.1 arcseconds from Keck counterpart
- UVOT did not observe due to proximity to Vega

# GRB 050126



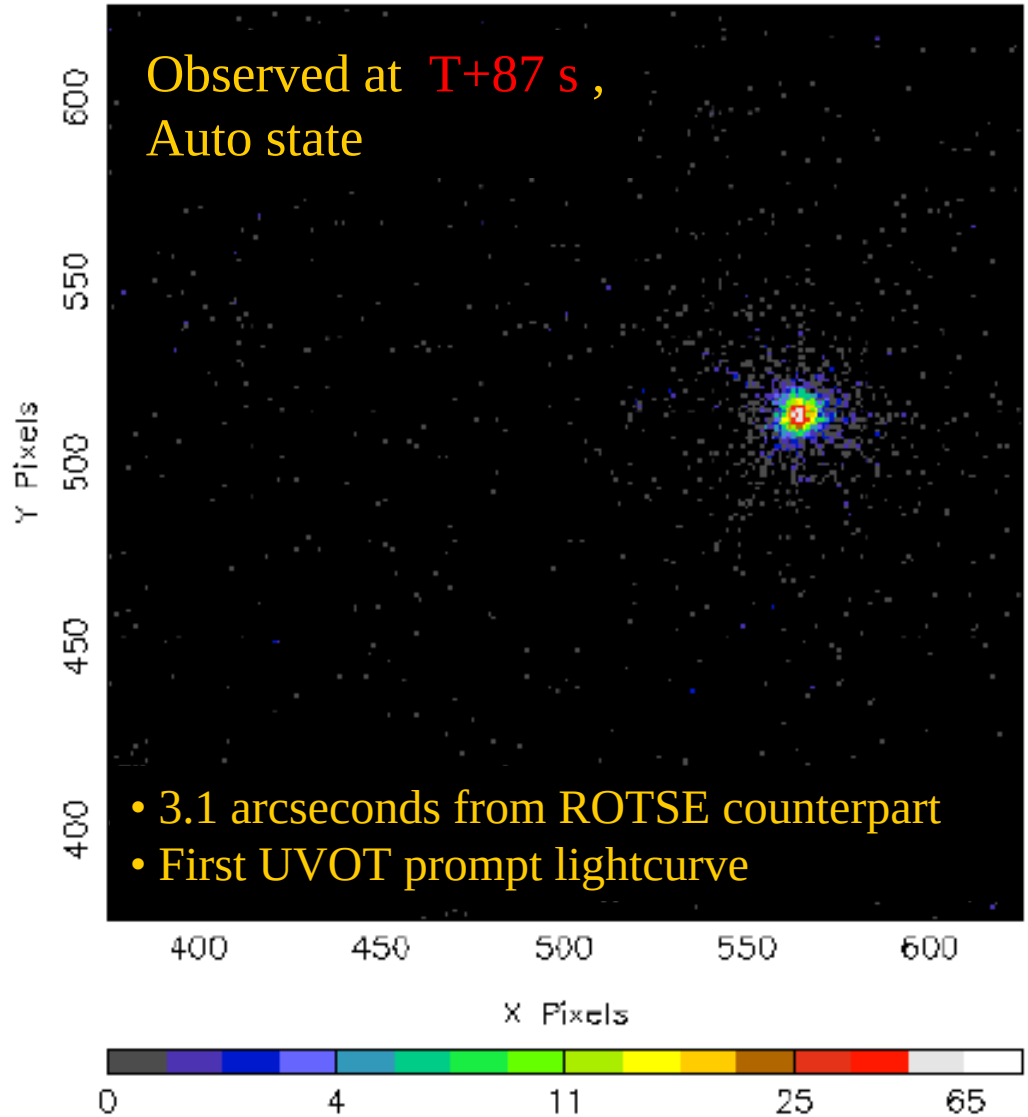

Tagliaferri et al. 2005, Nature

# GRB 050319

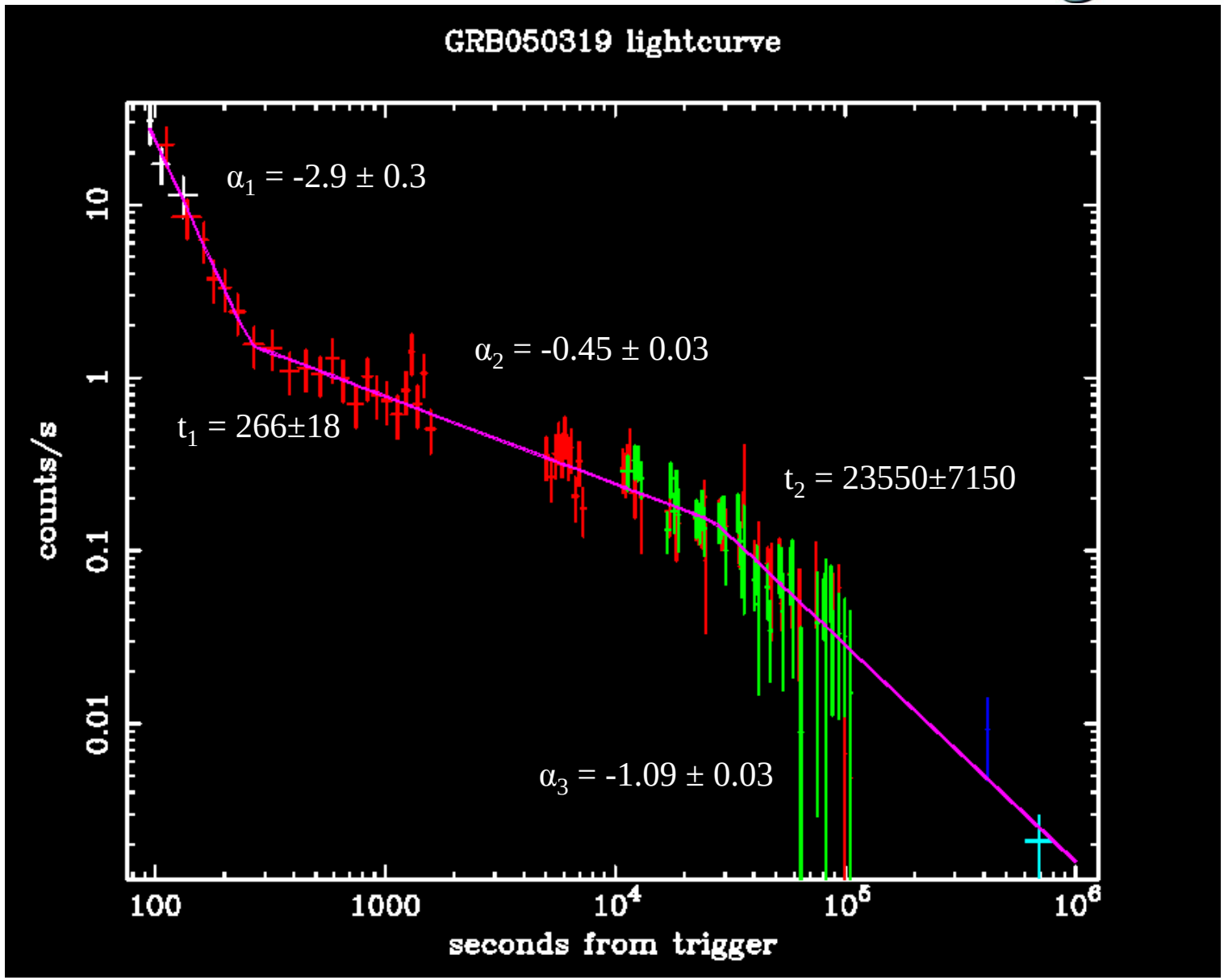
Detected at 09:31:18 UT
(T+ 87s)

Source is at:
RA(J2000) = 10h 16m 48.1s,
Dec(J2000) = +43d 32' 52.3“

Detected by ROTSE telescope and by UVOT

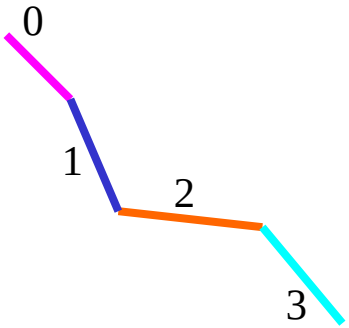


# GRB 050319: XRT Lightcurve




Cusumano et al. 2005, ApJ

# *Possible models for initial decay*



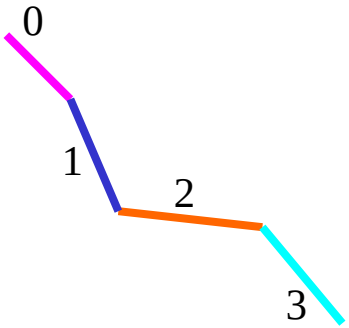

1. t0 offset: expect single power-law, $\beta_1 = \beta_2$
2. Prompt shock stops: expect $\beta_0 = \beta_1$
3. Photospheric emission: expect $\beta_0 < \beta_1$ (steeper)
5. Jet cocoon: thermal emission
6. Multiple collimated mini-jets

Observationally:

$\beta_0 > \beta_1 = \beta_2$ for GRB 050219a

$\beta_1 < \beta_2$ for GRB 050315

# *Possible models for initial decay*




1. t0 offset:

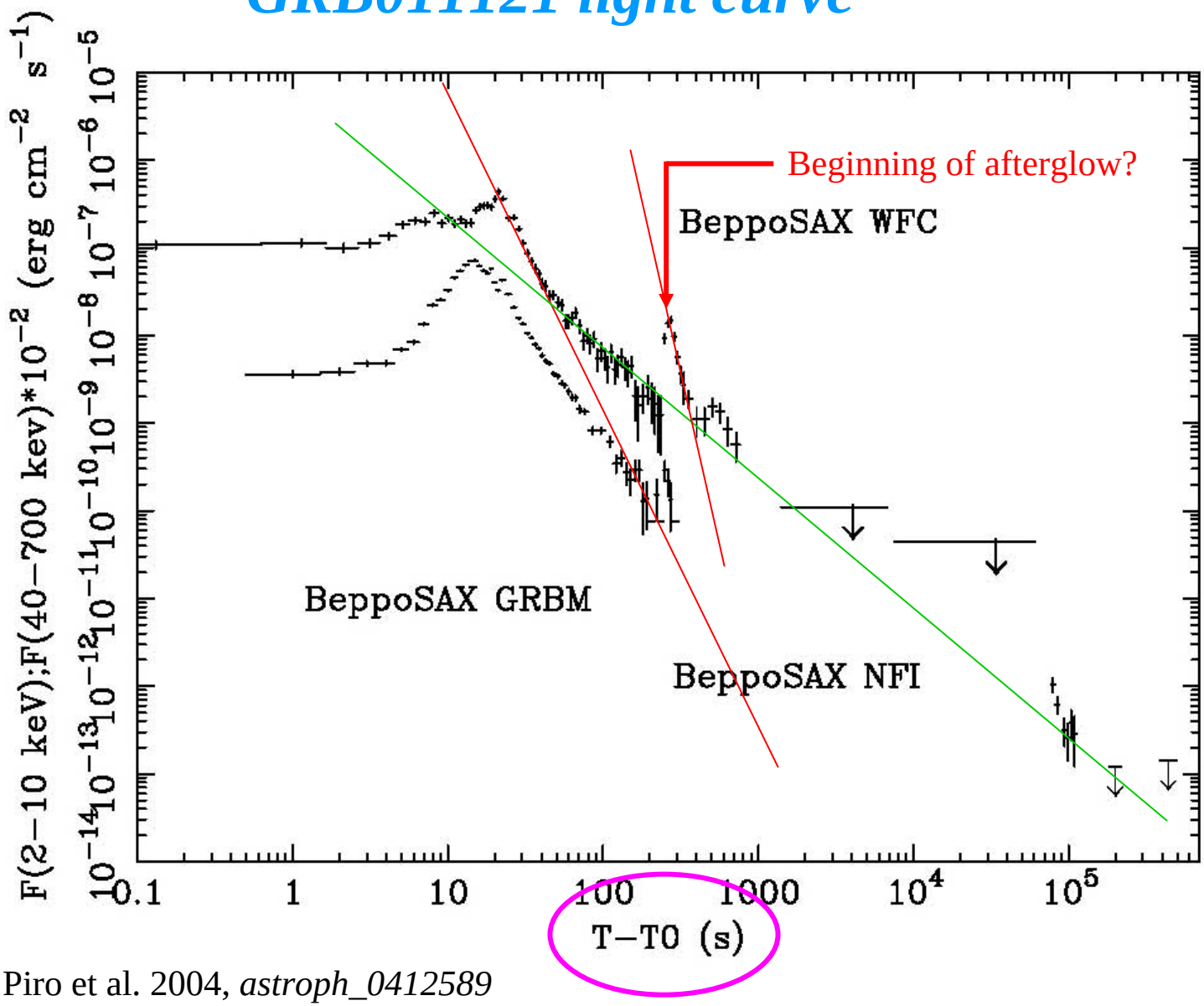
   Q: when does the afterglow begin fading as a power-law?

   a) when burst occurs? Or

   b) when shocks hit external medium?

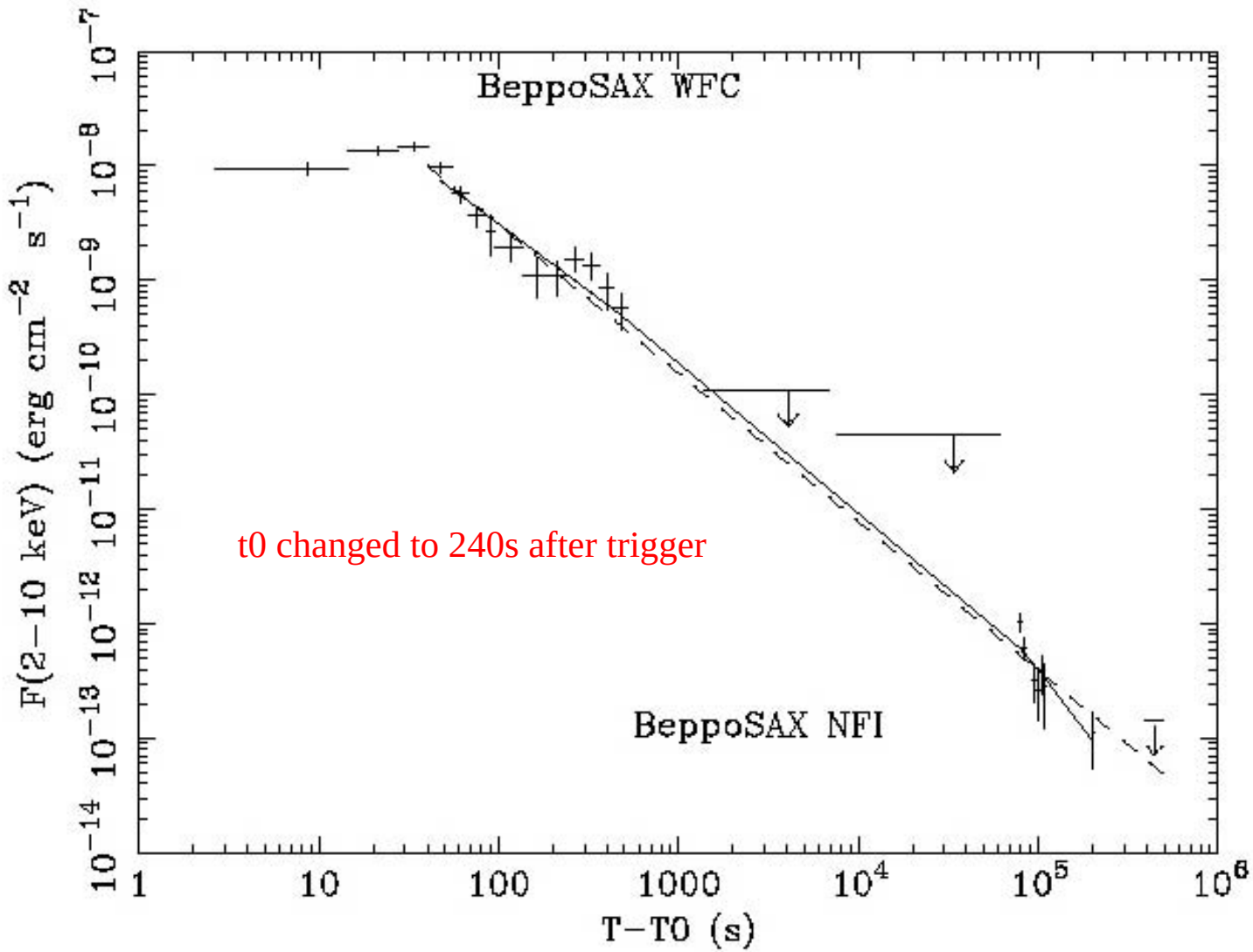
   Perhaps we are using the wrong t0 and these bursts are really a single power-law decline, beginning when the afterglow (external shock) begins

# *Compare with GRB011121 light curve*



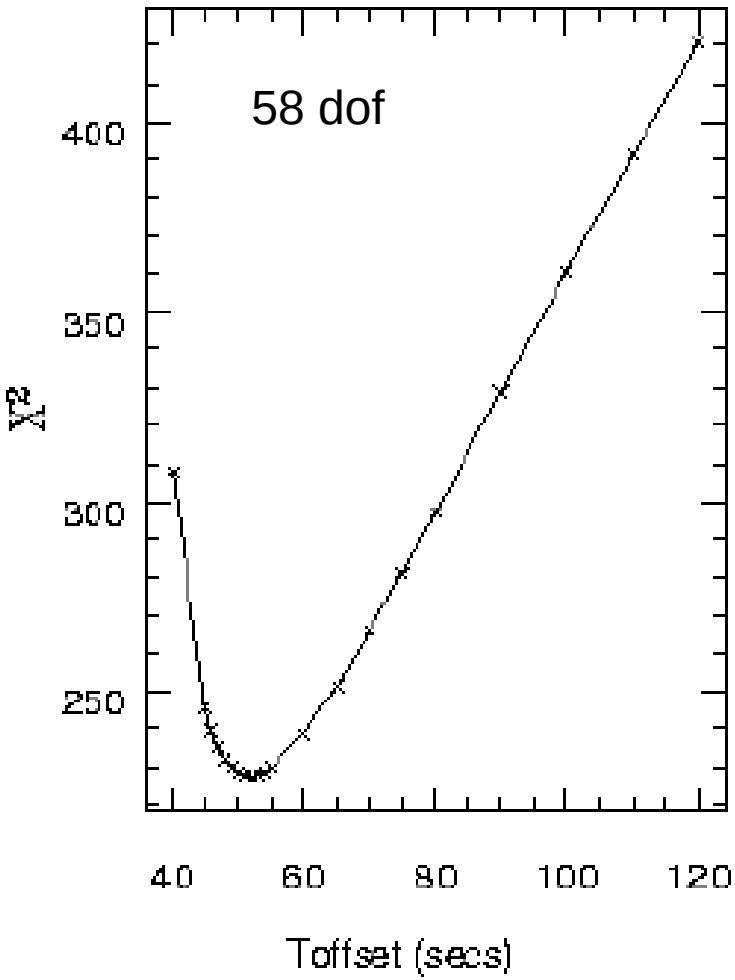

L. Piro et al. 2004, *astroph_0412589*

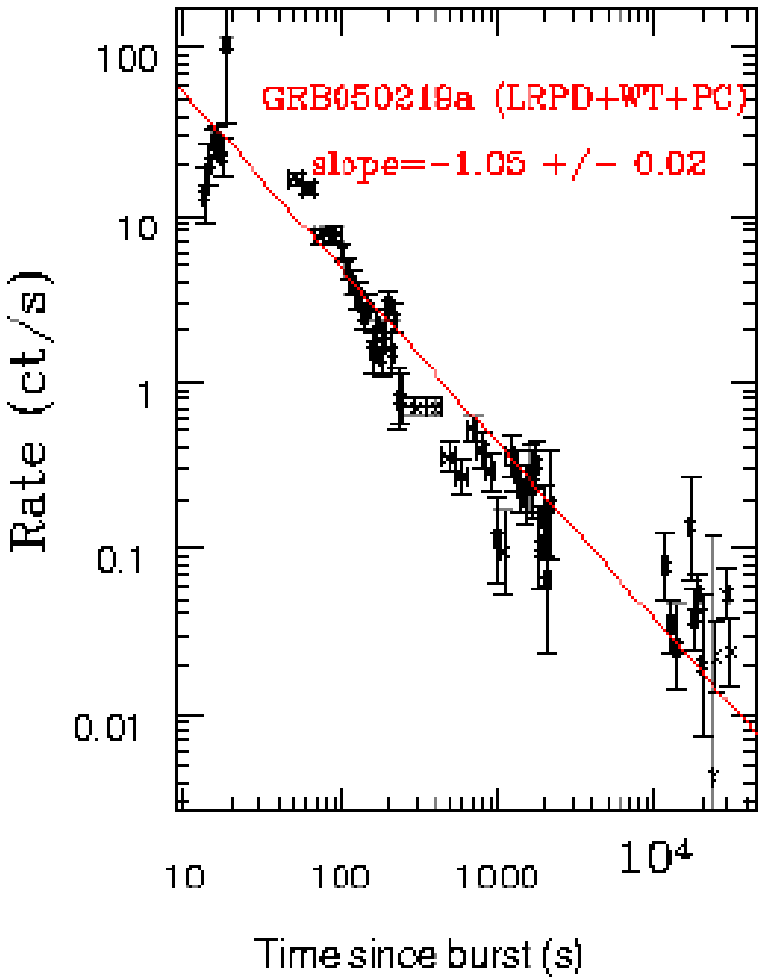
# *t0 error*



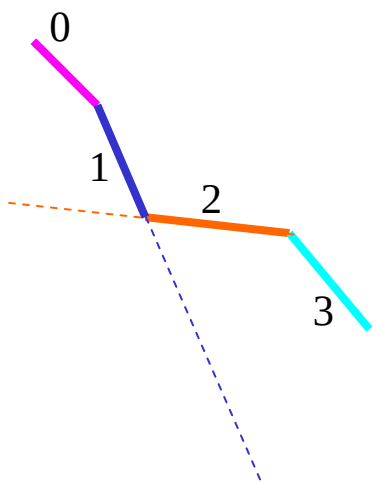

L. Piro et al. 2004, *astroph_0412589*

# *t0 error*


58 dof
400
350
300
250
$\chi^2$
40
60
80
100
120
Toffset (secs)


GRB050219a (LRPD+WT+PC)
slope=-1.05 +/- 0.02
100
10
1
0.1
0.01
Rate (ct/s)
10
100
1000
$10^4$
Time since burst (s)

# *Possible models for initial decay*




2. Unified mechanism:

Q: Are we seeing a single mechanism that is responsible segments 0 and 1?

The behavior in segment 1 could be a continuation of the end of the prompt emission under several scenarios:

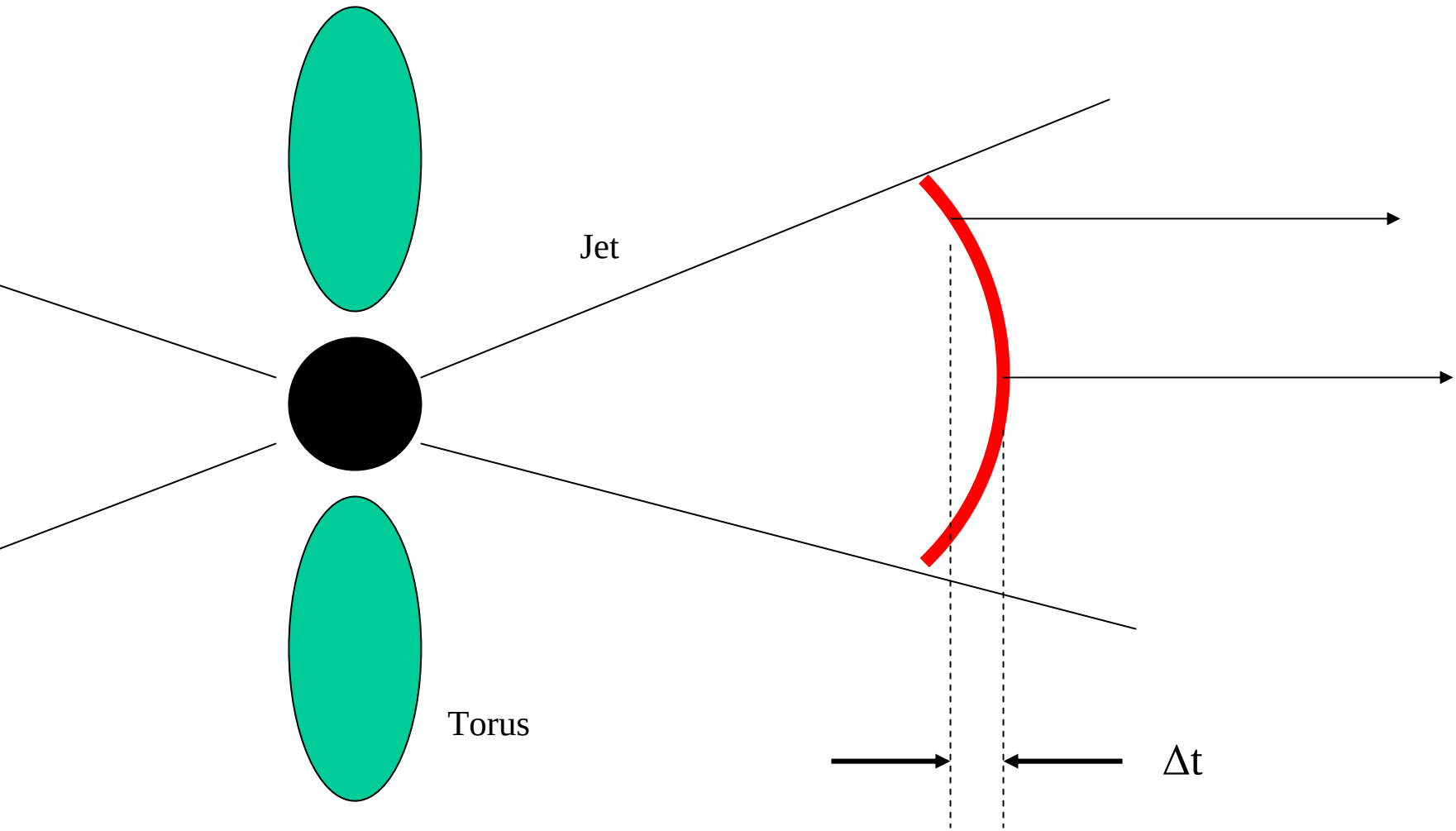
a) Internal shock ends

b) Off-axis emission and light delay effects

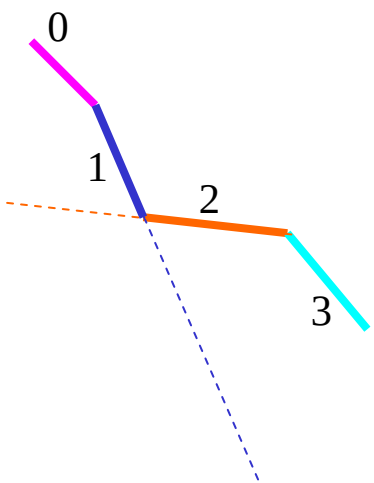
In these cases, expect smooth transition from segment 0 to segment 1.

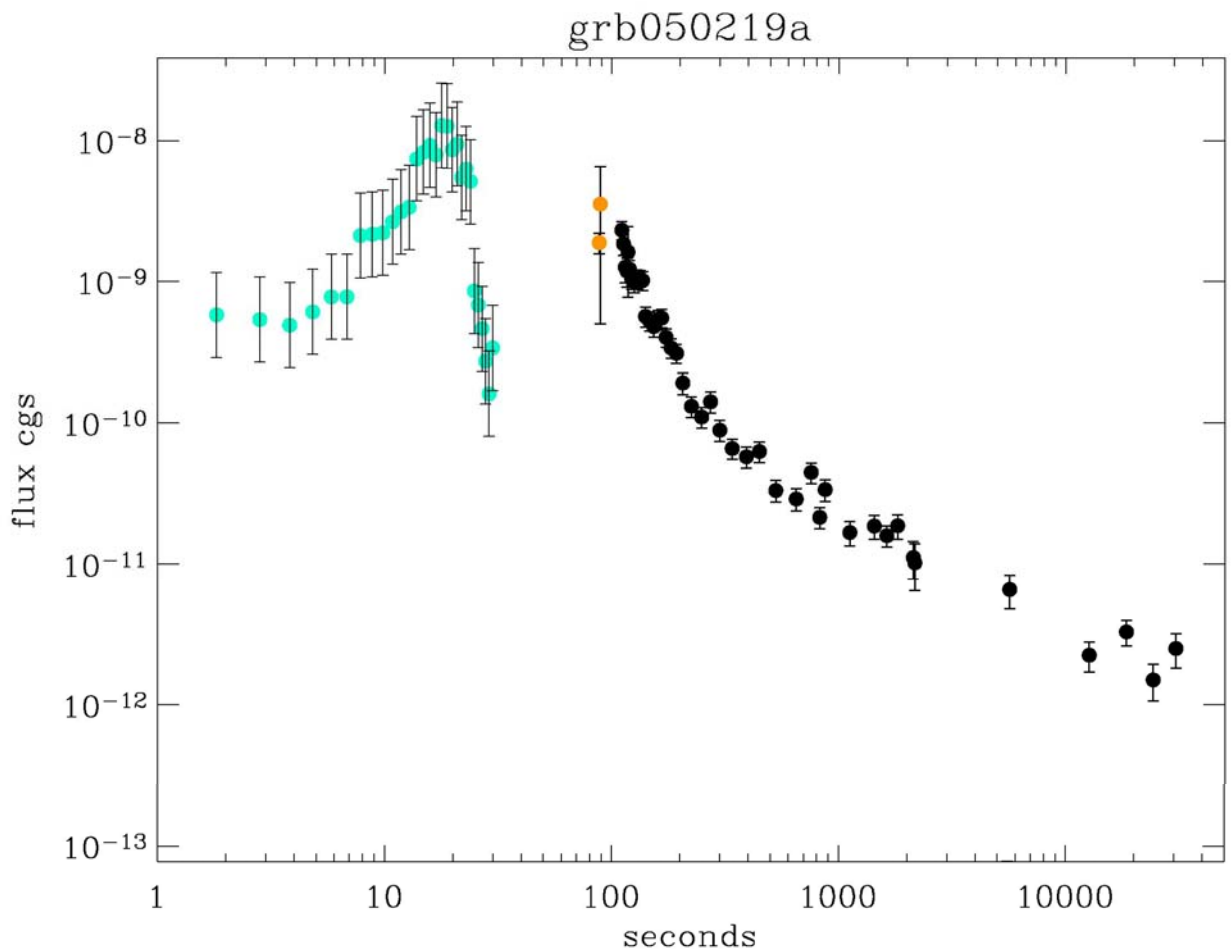
No relationship between segment 1 and segment 2 (as shown).

# Jet Break



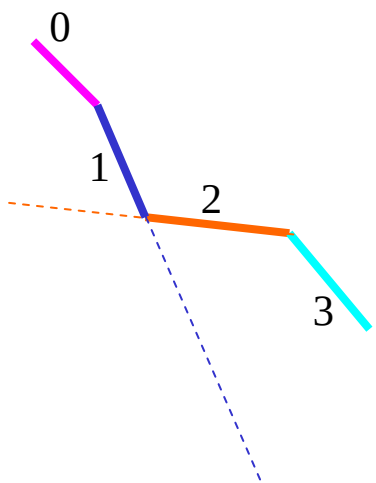
# *Possible models for initial decay*




Tagliaferri et al. 2005, Nature; Goad et al. 2005, ApJ

# *Possible models for initial decay*



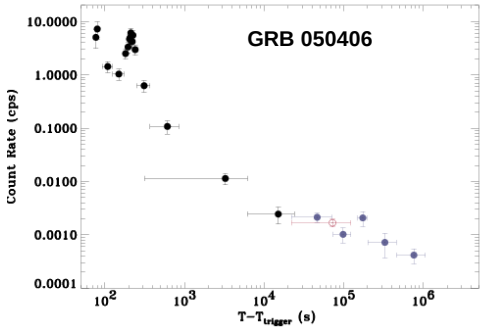

3. Unrelated to prompt emission. Possible “exotic” models for segment 1:
   a) Photospheric emission
   b) Jet cocoon: thermal emission
   c) Multiple collimated mini-jets

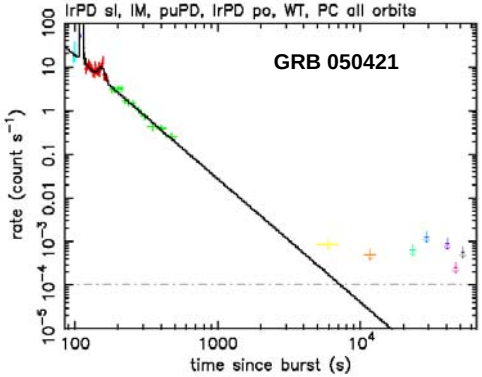
In these cases, expect no relationship between segment 0 to segment 1.

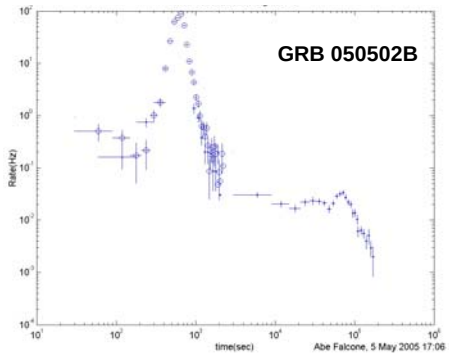
No relationship between segment 1 and segment 2 (as shown).

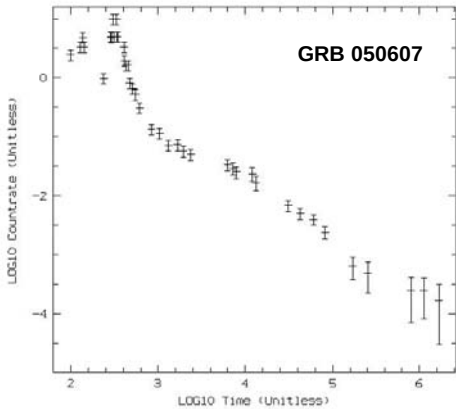
# *Type C Afterglows*

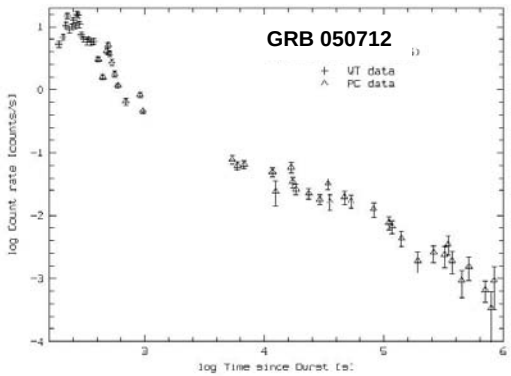
**050406**
**050421**
**050502B**
**050607**
**050712**
**050713A**
**050714B**
**050716**
**050724?**
**050726**

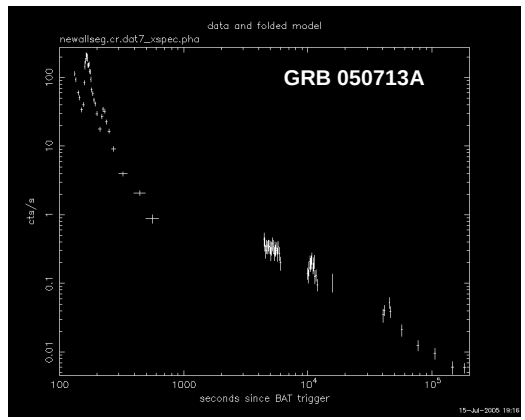


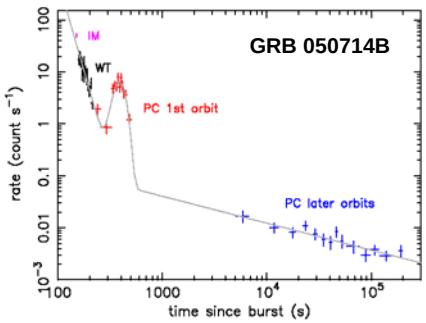



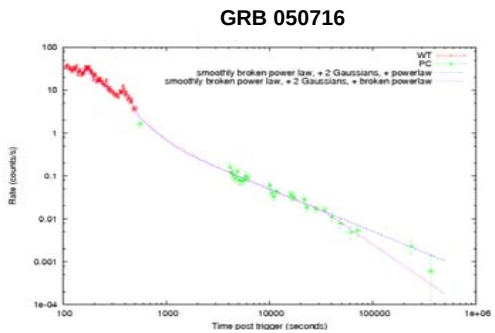



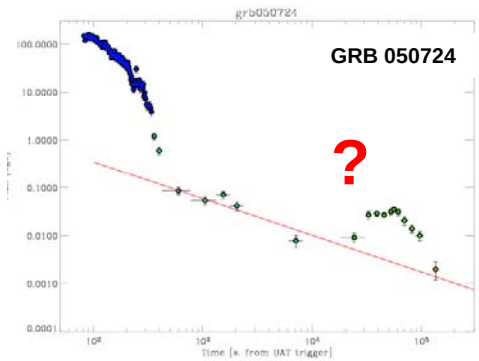



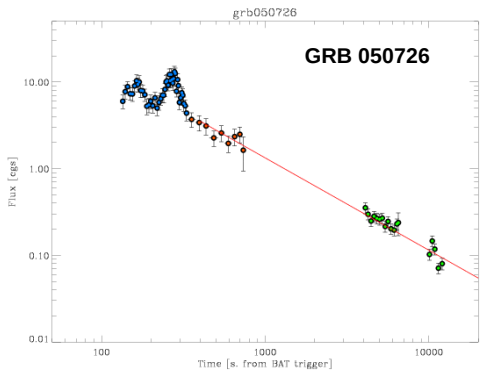



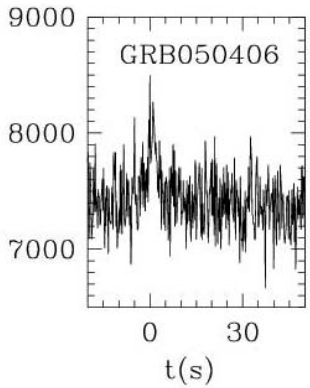
# GRB 050406

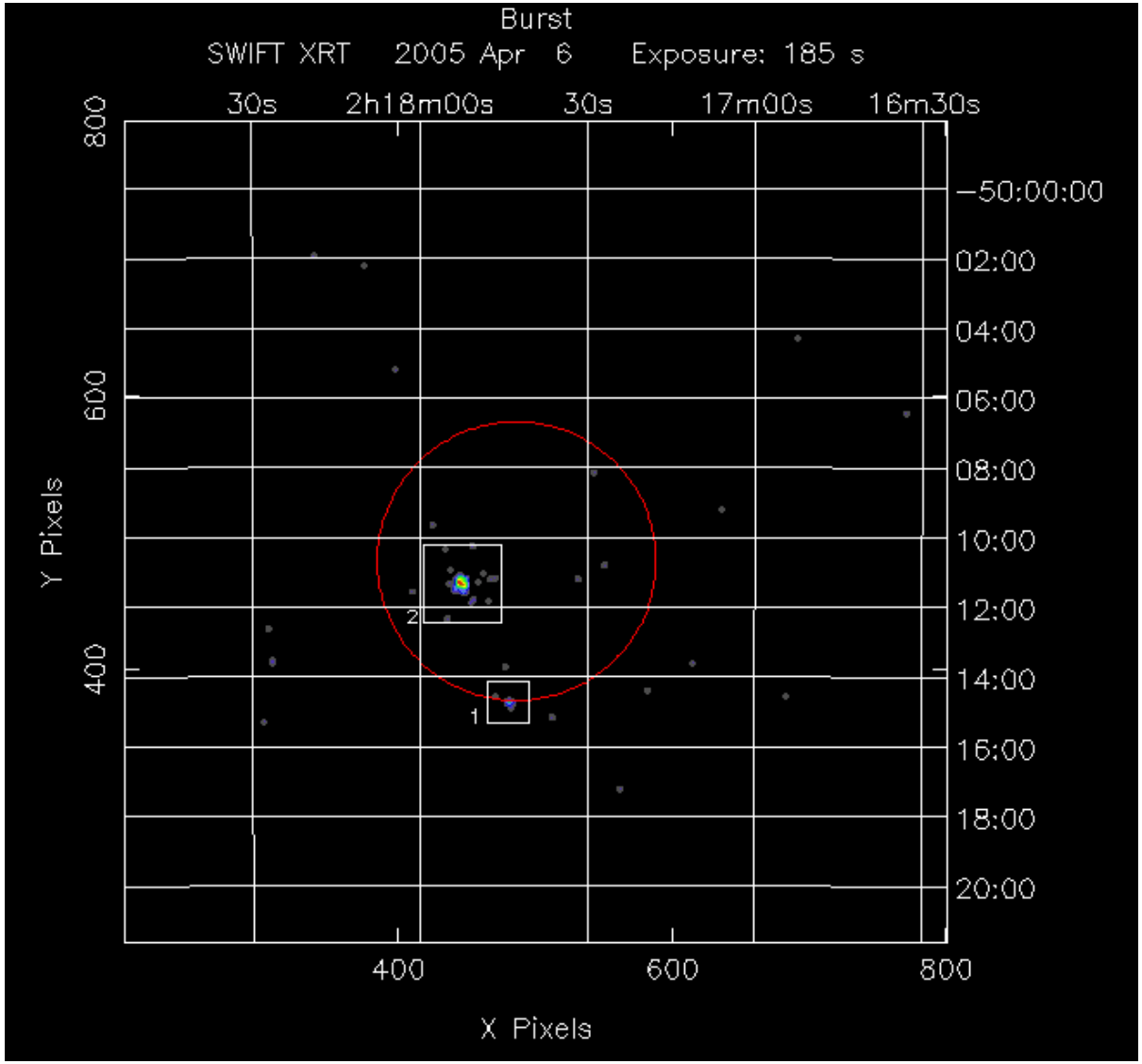
Detected at 15:58:48.4 UT

Displaced observation of South Galactic Pole (BAT calibration target)

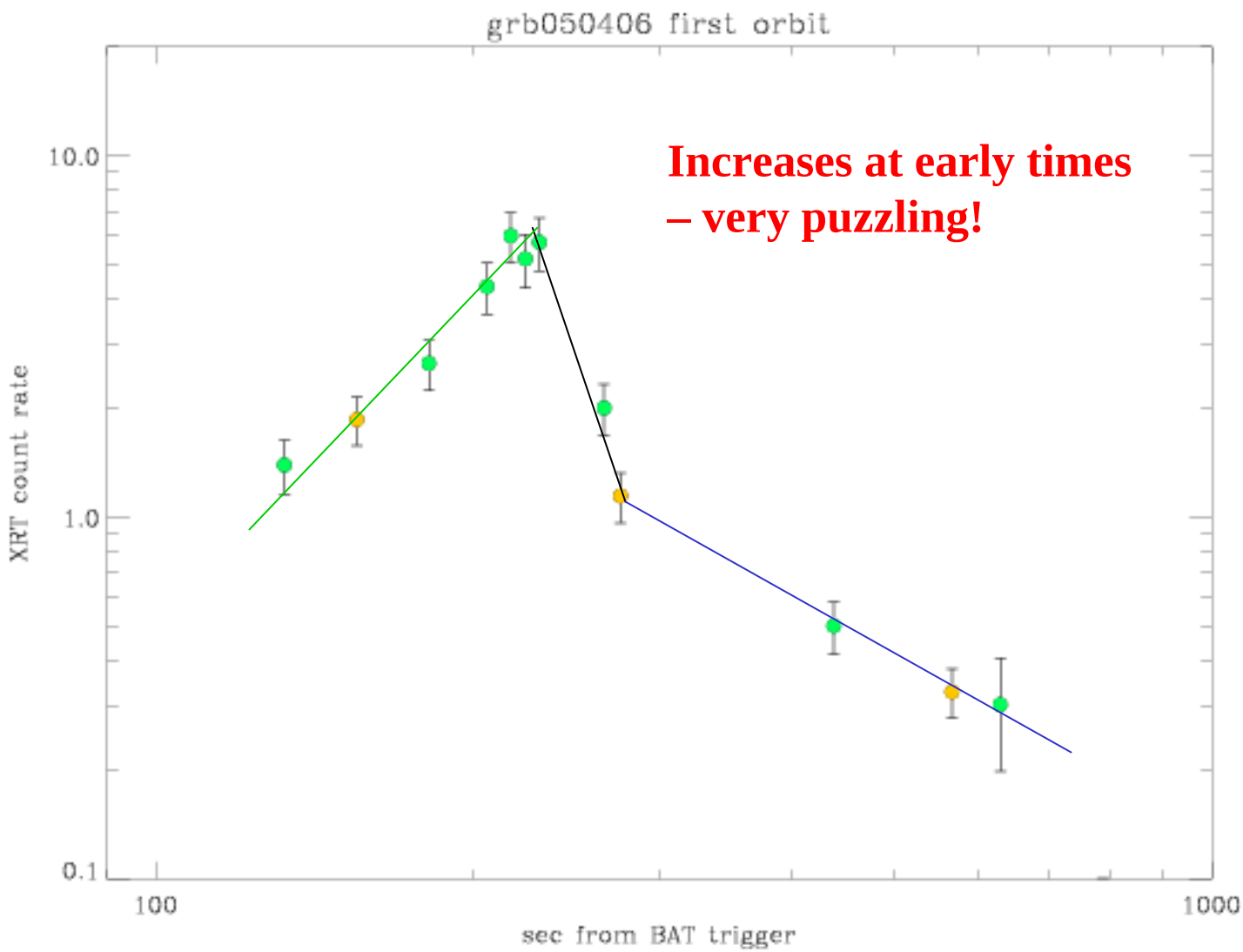
Source is at:
RA(J2000) = 02h 17m 52.6s,
Dec(J2000) = -50d 11' 18.8“

Detected by Magellan telescope and bv UVOT



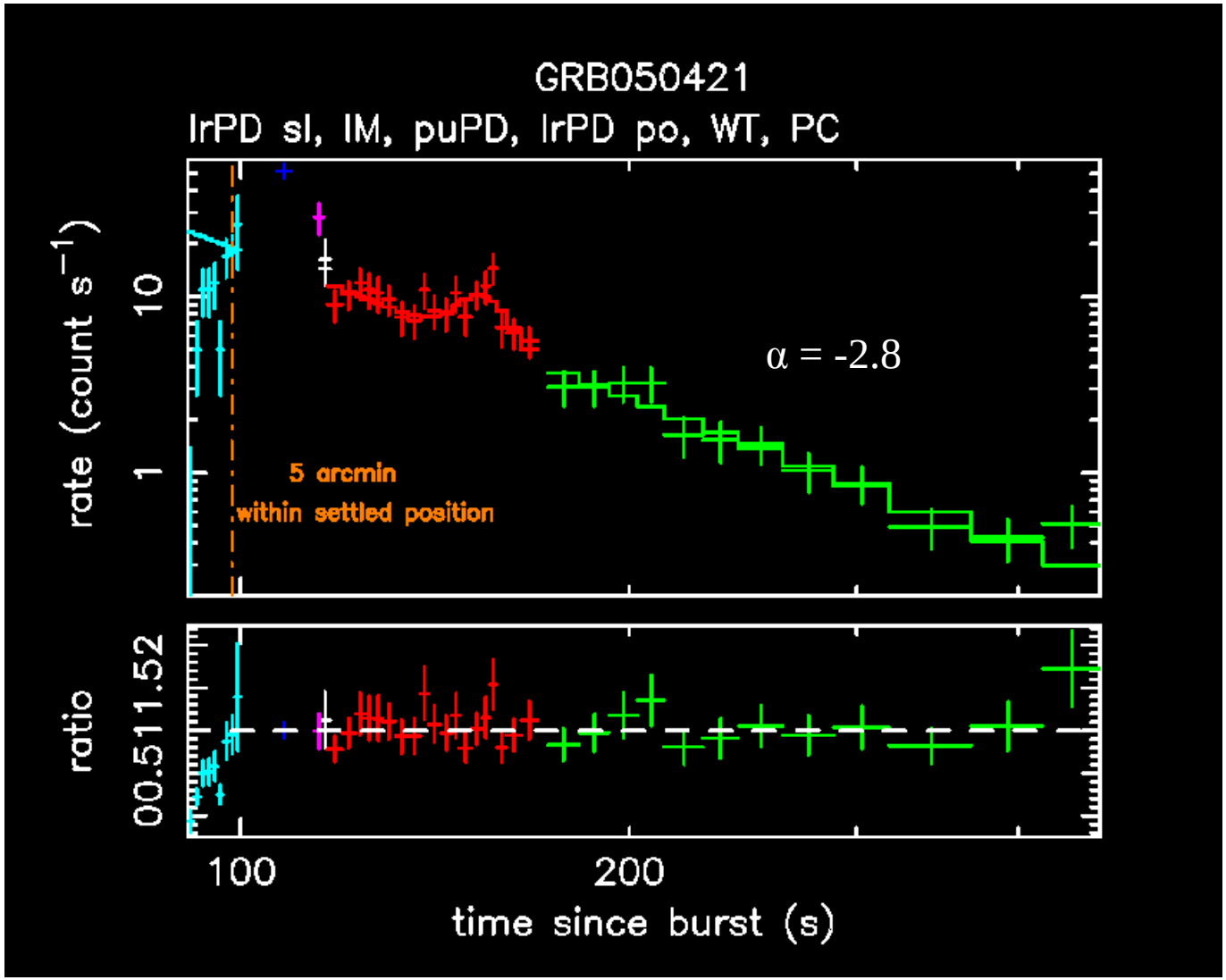



# GRB 050406 XRT Lightcurve

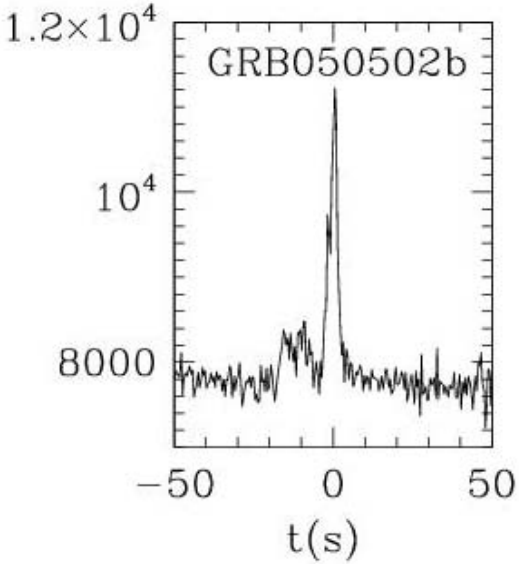


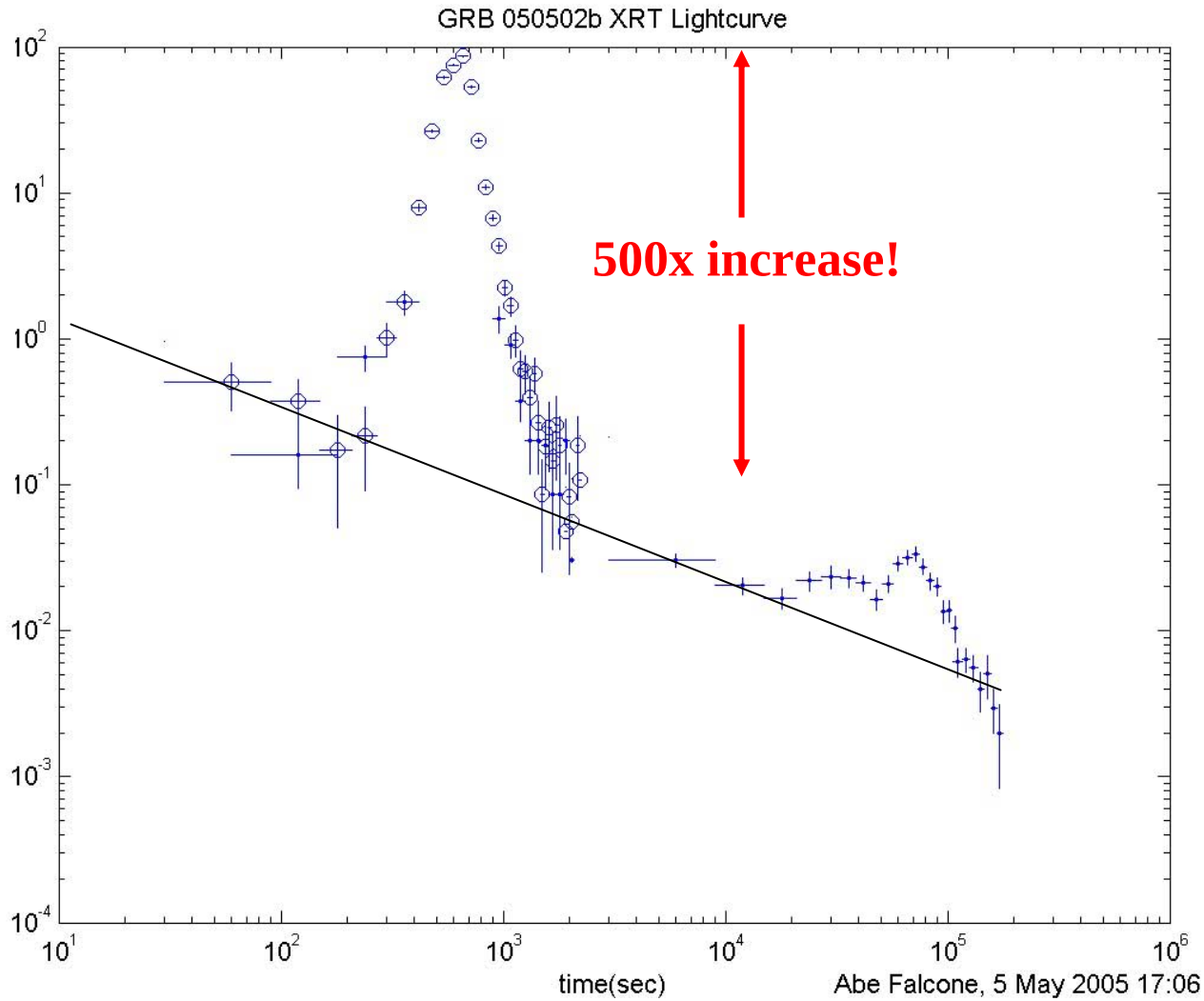

Burrows et al. 2005, Science; Romano et al. 2005, ApJ

# GRB 050421


GRB050421
lrPD sl, lM, puPD, lrPD po, WT, PC
rate (count s$^{-1}$)
10
1
α = -2.8
5 arcmin
within settled position
ratio
0
0.5
1
1.5
2
100
200
time since burst (s)

# *Giant X-ray Flare: GRB050502b*



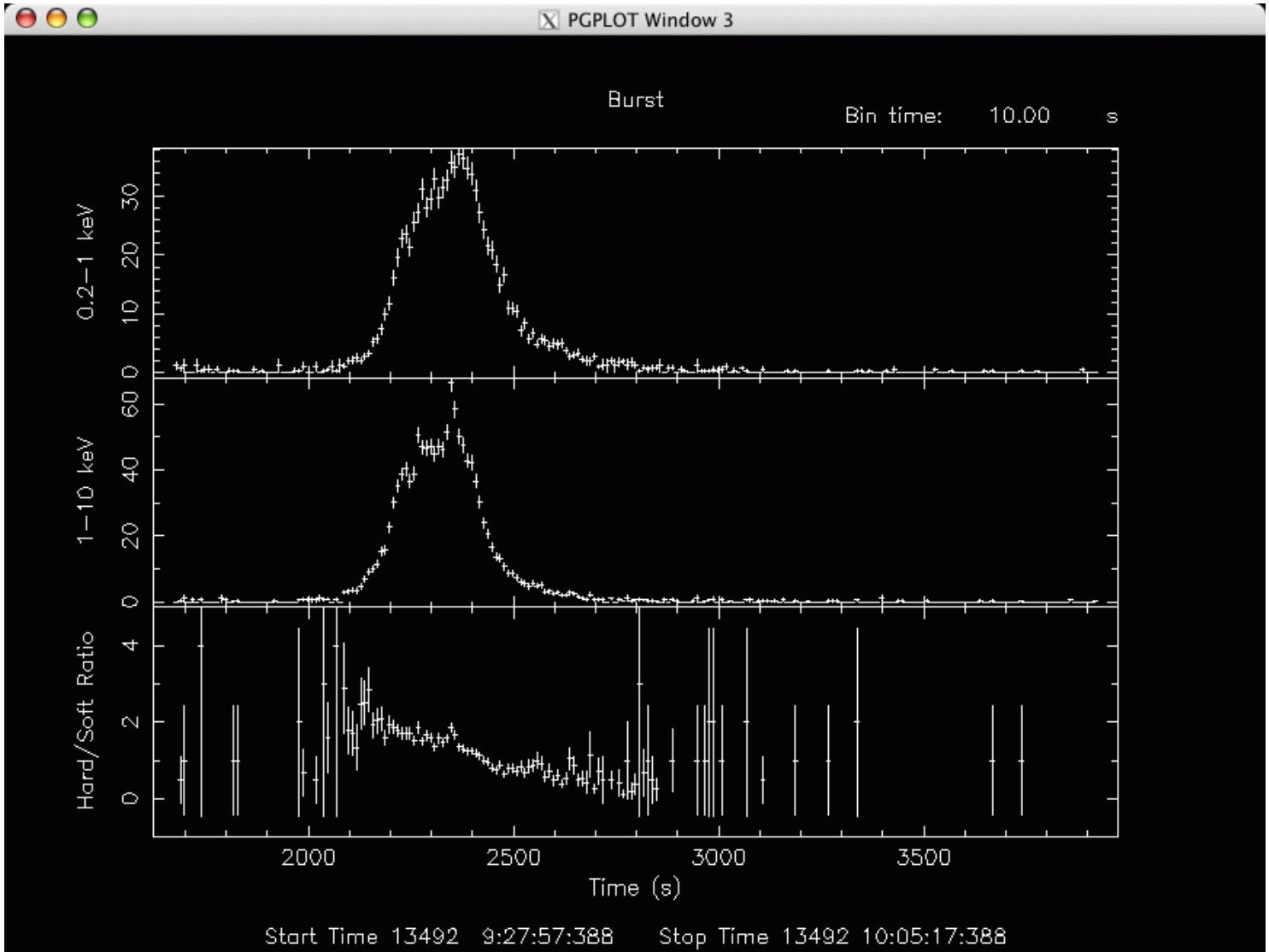




**GRB Fluence:**
**8E-7 ergs/cm$^2$**

**Flare Fluence:**
**9E-7 ergs/cm$^2$**

Burrows et al. 2005, Science; Falcone et al. 2005, ApJ

# *Giant X-ray Flare: GRB050502b*




Burrows et al. 2005, Science; Falcone et al. 2005, ApJ

# Flare Mechanism

- Rapid increase and decrease
  - Inconsistent with external shock
- Enormous increase in GRB 050502B
  - Inconsistent with Inverse Compton mechanism
- Same underlying afterglow before and after
  - Inconsistent with additional energy added to external shock

Most likely explanation is that internal shocks continue at much later times than the prompt $\gamma$-ray emission.

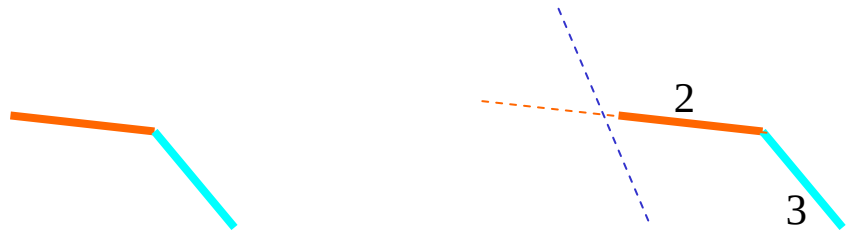
Late-time emission occurs at larger radius, resulting in slower rise/fall and softer energies.

Late emission also has higher Lorentz factor because shocks expand in channel evacuated by earlier shocks.

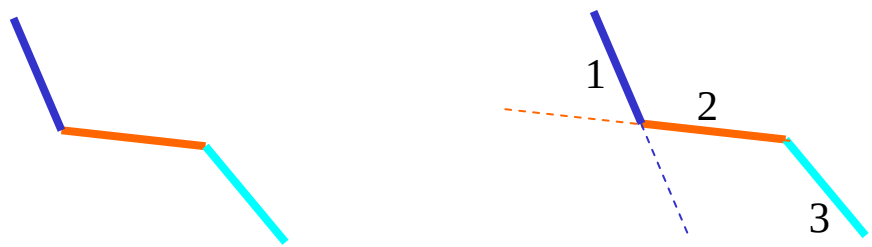
# *XRT Afterglow Types*

At least 3 shapes of afterglows. Out of 24 prompt observations, we have:

- Type A (3)

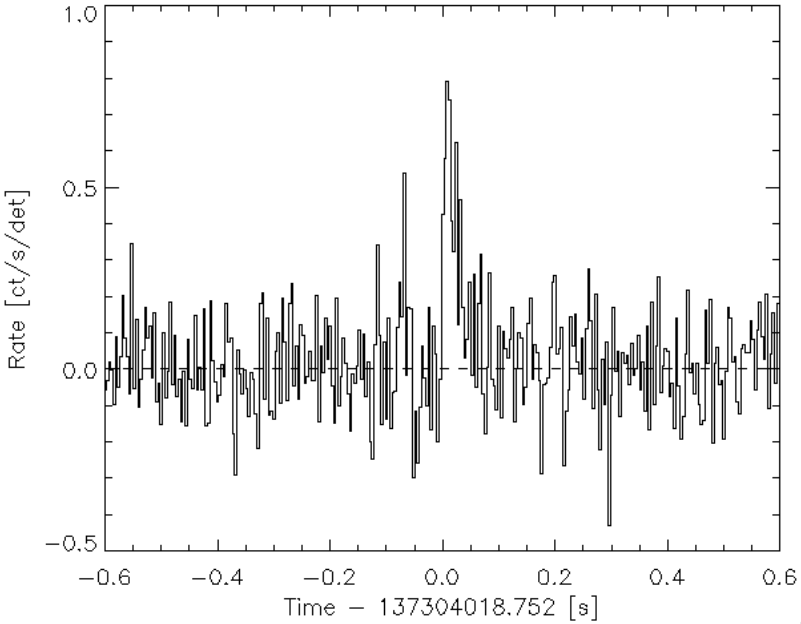


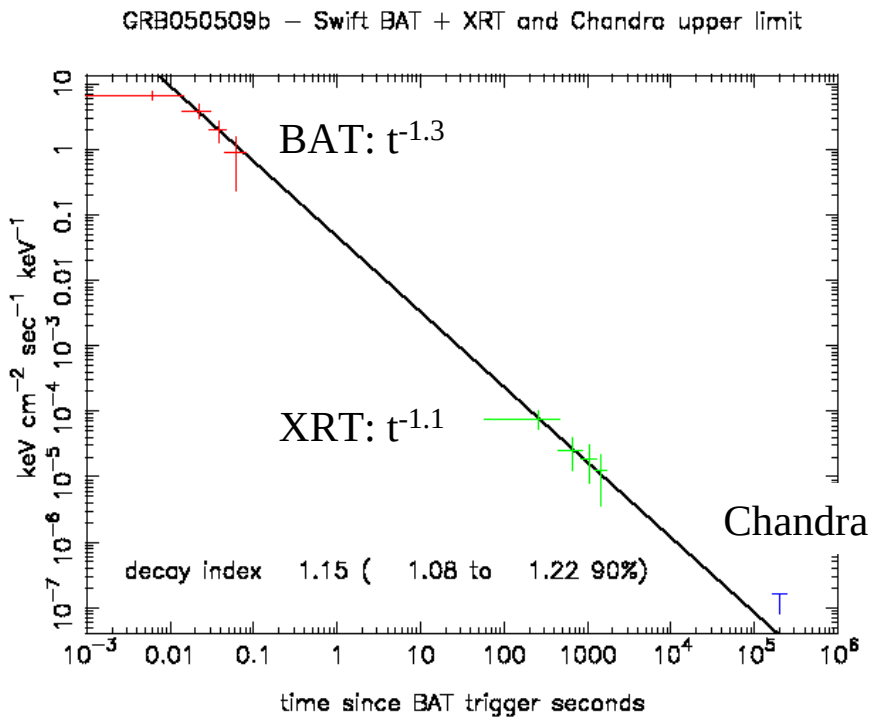

- Type B (10)




- Type C (11)

# GRB050509b: First Short GRB Afterglow



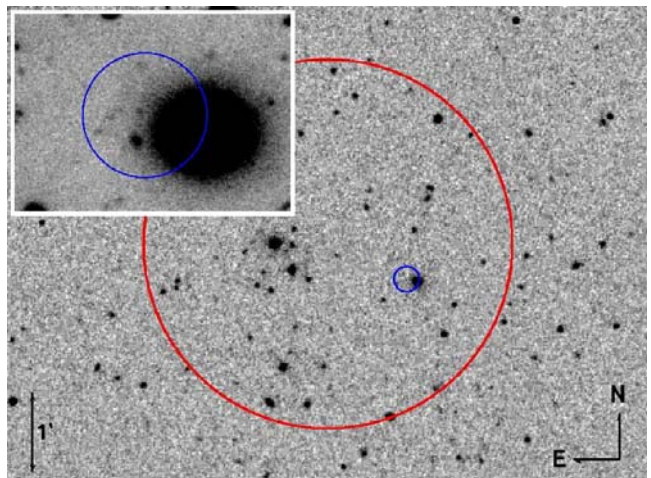

$t_{90}$ = 0.04 s, Fluence = 2E-8 ergs/cm$^2$

XRT counterpart in first 400 s, fades rapidly. 11 photons total.

Location in cluster at z=0.226, near early-type galaxy.

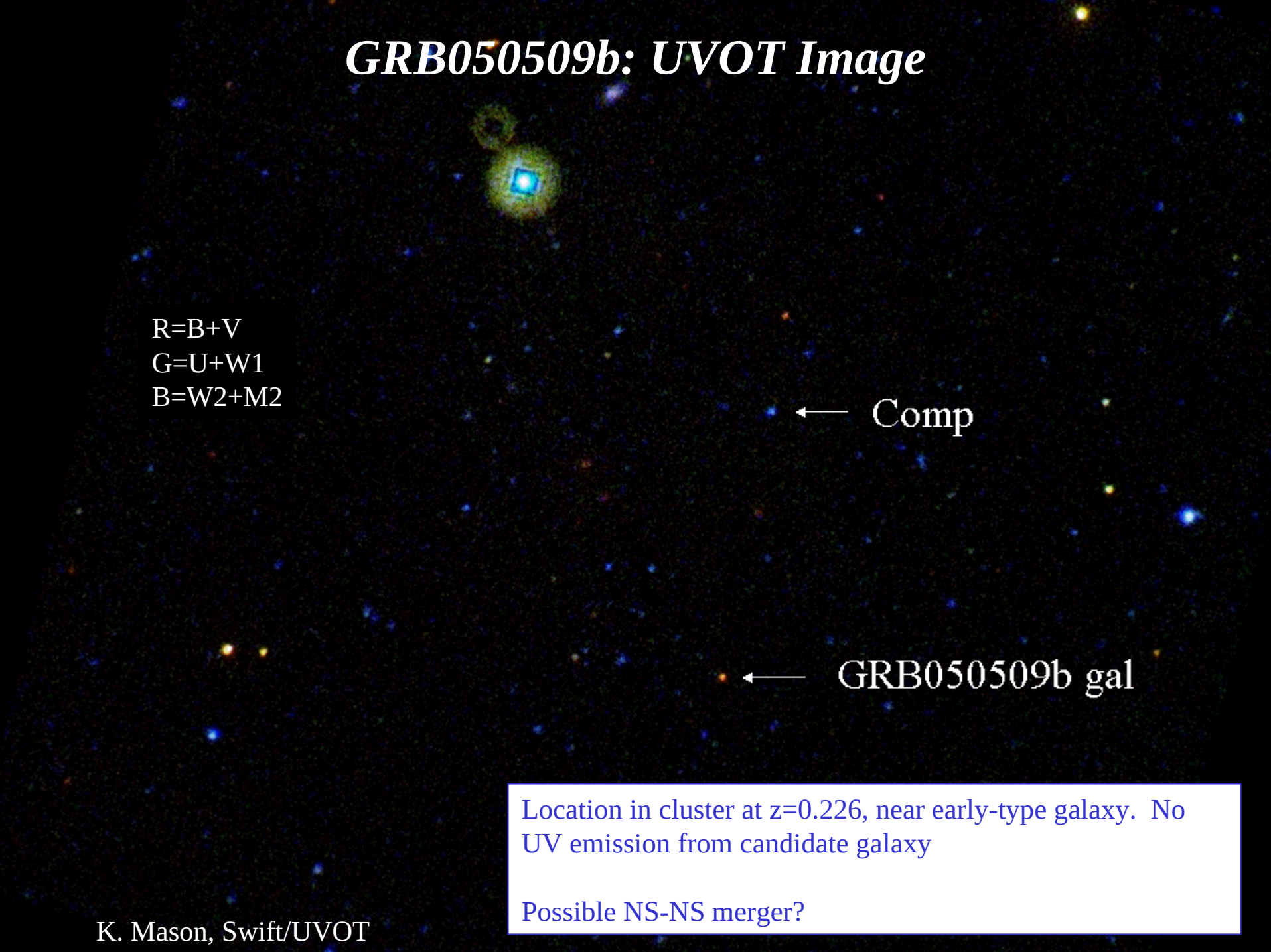
Possible NS-NS merger?

Gehrels et al. 2005, Nature




XRT error circle on VLT image. XRT position is 9.8" from a bright elliptical galaxy at z=0.226

# *GRB050509b: UVOT Image*

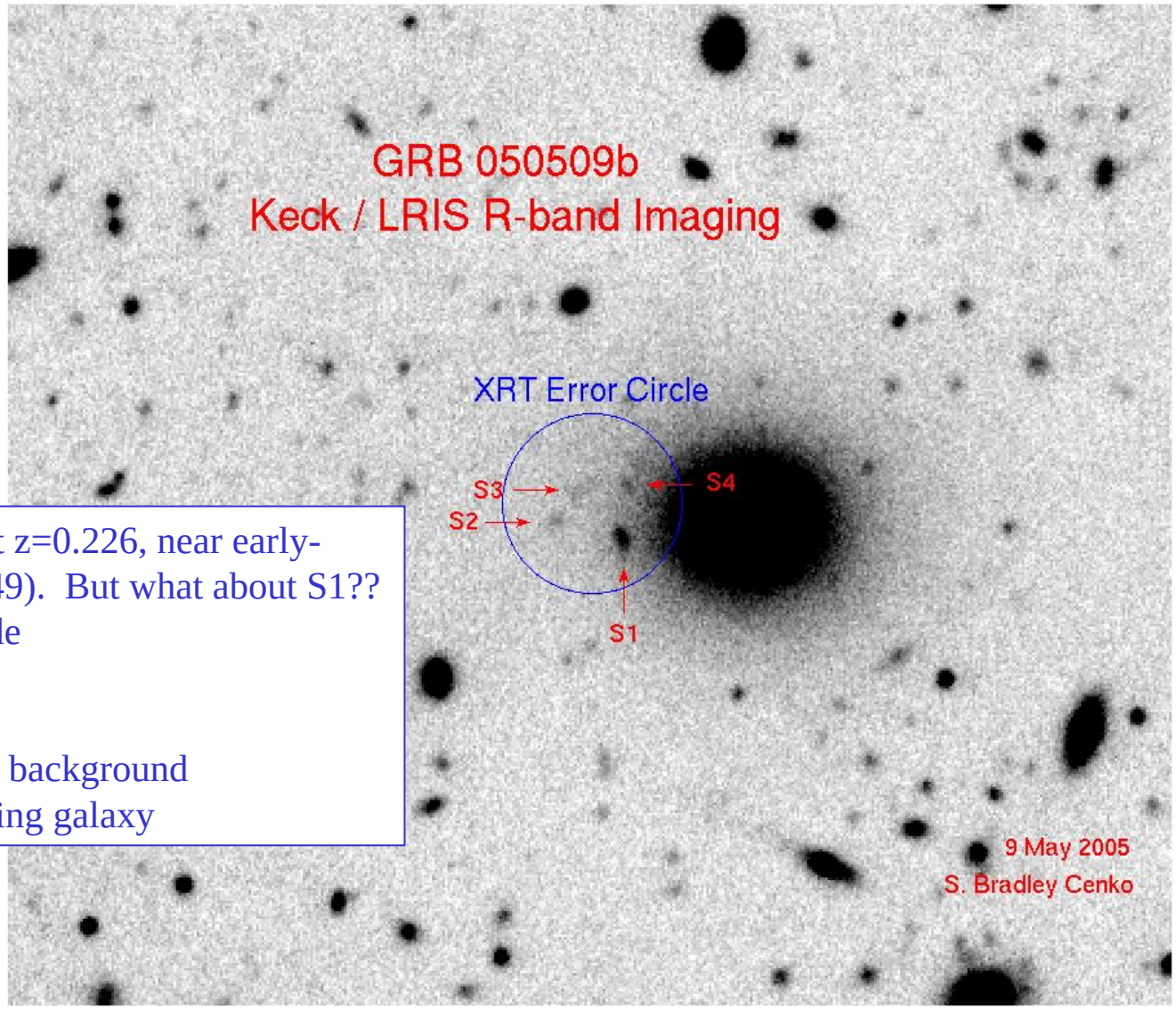



Location in cluster at z=0.226, near early-type galaxy. No UV emission from candidate galaxy

Possible NS-NS merger?

K. Mason, Swift/UVOT

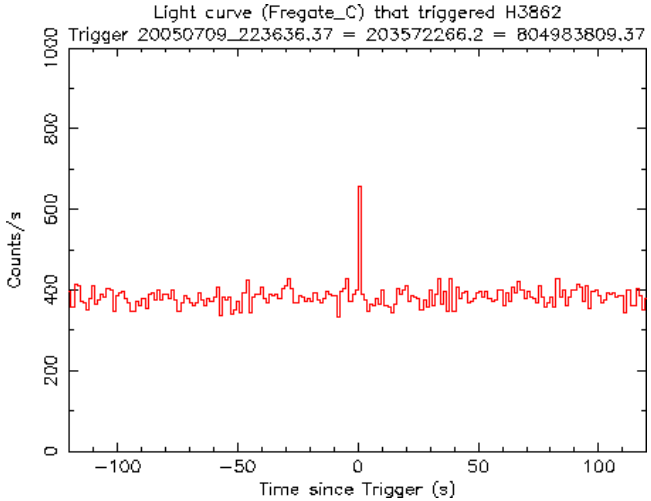
# *GRB050509b: First Short GRB Afterglow*



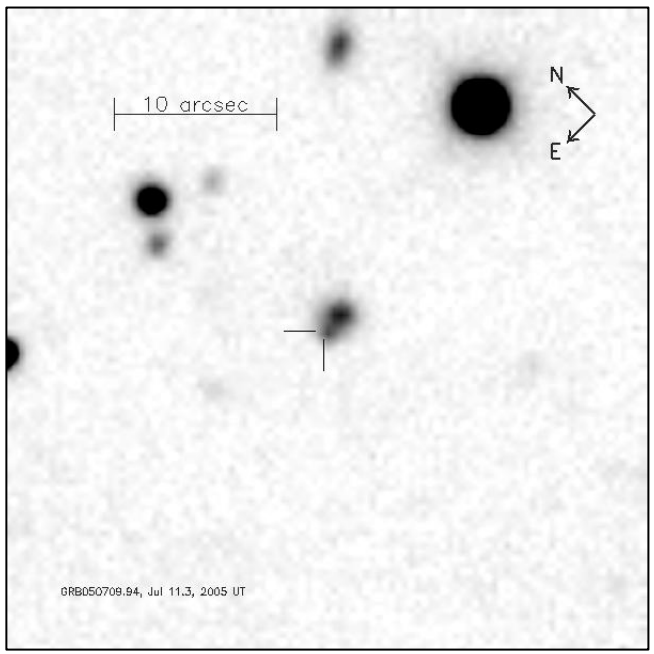

Location in cluster at z=0.226, near early-type galaxy (z=0.2249). But what about S1??

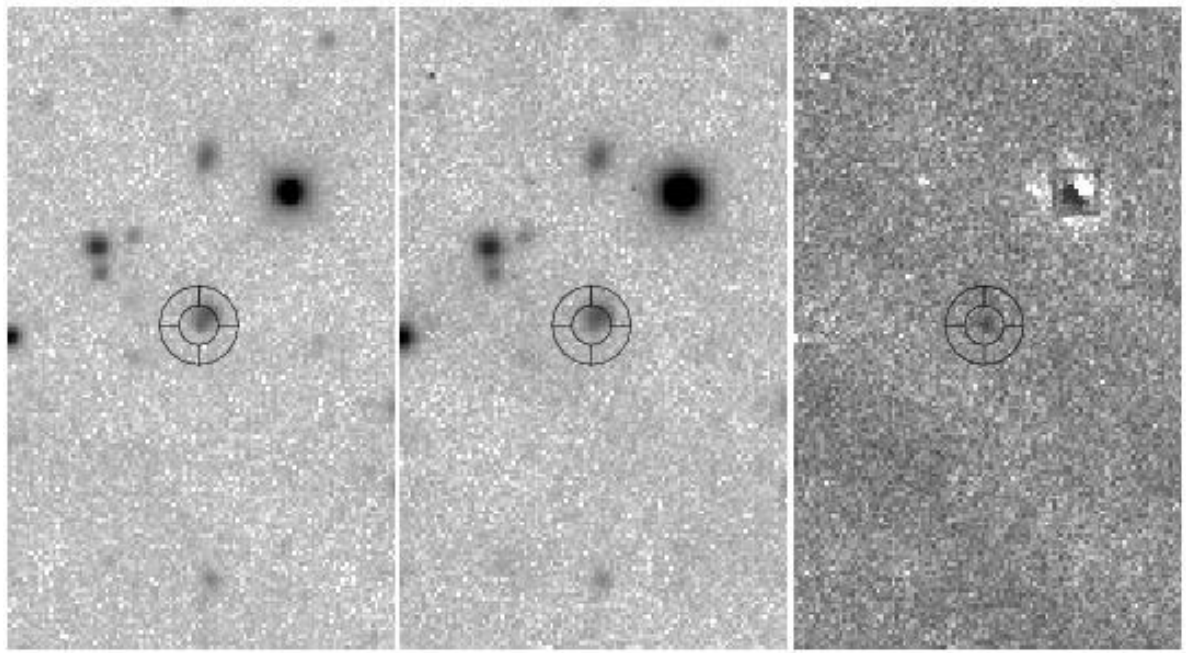
- S1 found to not fade
- S1 is extended
- S1 is blue in color
- S1 is presumably a background star-forming galaxy

# GRB050709: Second Short GRB Afterglow




- Discovered by the HETE-II satellite
- X-ray counterpart found by Chandra X-ray Observatory
- Optical counterpart found by ground-based telescopes
  - Located at edge of elliptical galaxy at z=0.16



Danish 1.54m La Silla telescope: courtesty Jensen et al. 2005, GCN 3589; Price et al. 2005, GCN 3612)

# Summary

- BAT is working flawlessly and producing great data!
- BAT has now observed 53 GRBs (as of 26 July 2005)
  - 5 XRFs
  - 9 FREDs (3 are multiple FREDs)
  - 3 short bursts
  - One extremely dark burst (Rc  than 26$^{th}$ mag)
  - Relatively few false triggers
  - Average rate is ~ 90/year
  - Average on-board positional accuracy for the 34 with XRT positions: **55 arcseconds**

- UVOT has now observed 38 afterglows
  - Excellent UV telescope
  - 8 GRB afterglow detections, one redshift measurement
  - Major mystery: why so few UVOT detections?

# Summary

- XRT has now observed 40 afterglows
  - 39 detected
  - 24 prompt slews (< 5 minutes after burst)
  - Two prompt emission
  - Three short burst afterglows
  - Average positional accuracy for the 24 with ground positions: **3.4 arcseconds**
  - > 50% of spectral fits have excess (intrinsic) $N_H > 10^{21}$

- XRT is observing afterglows $10^2$ – $10^3$ times fainter than similar observations with Beppo-SAX. New behaviors are appearing at early times.

# Summary

- Public data release began April 5, 2005
  - http://swift.gsfc.nasa.gov/docs/swift/sdc/
- As Swift observations become routine, we expect new insights into GRB formation and environments
  - Solution to Short GRB mystery (merging NS?)
  - Systematic investigation of GRB environments (ISM vs wind)
  - Redshifts
  - X-ray spectral lines???

# XRT Collaborators

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