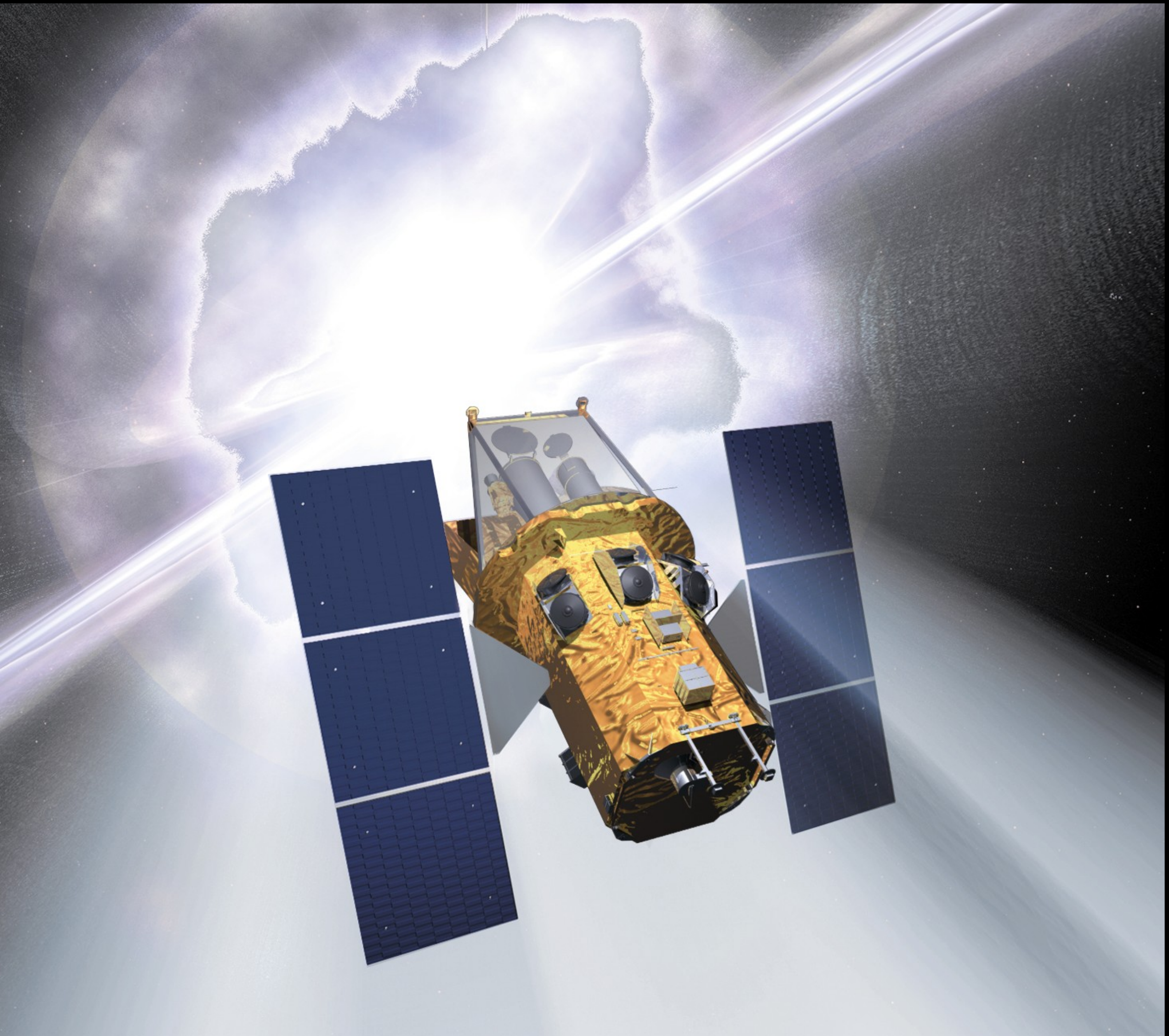
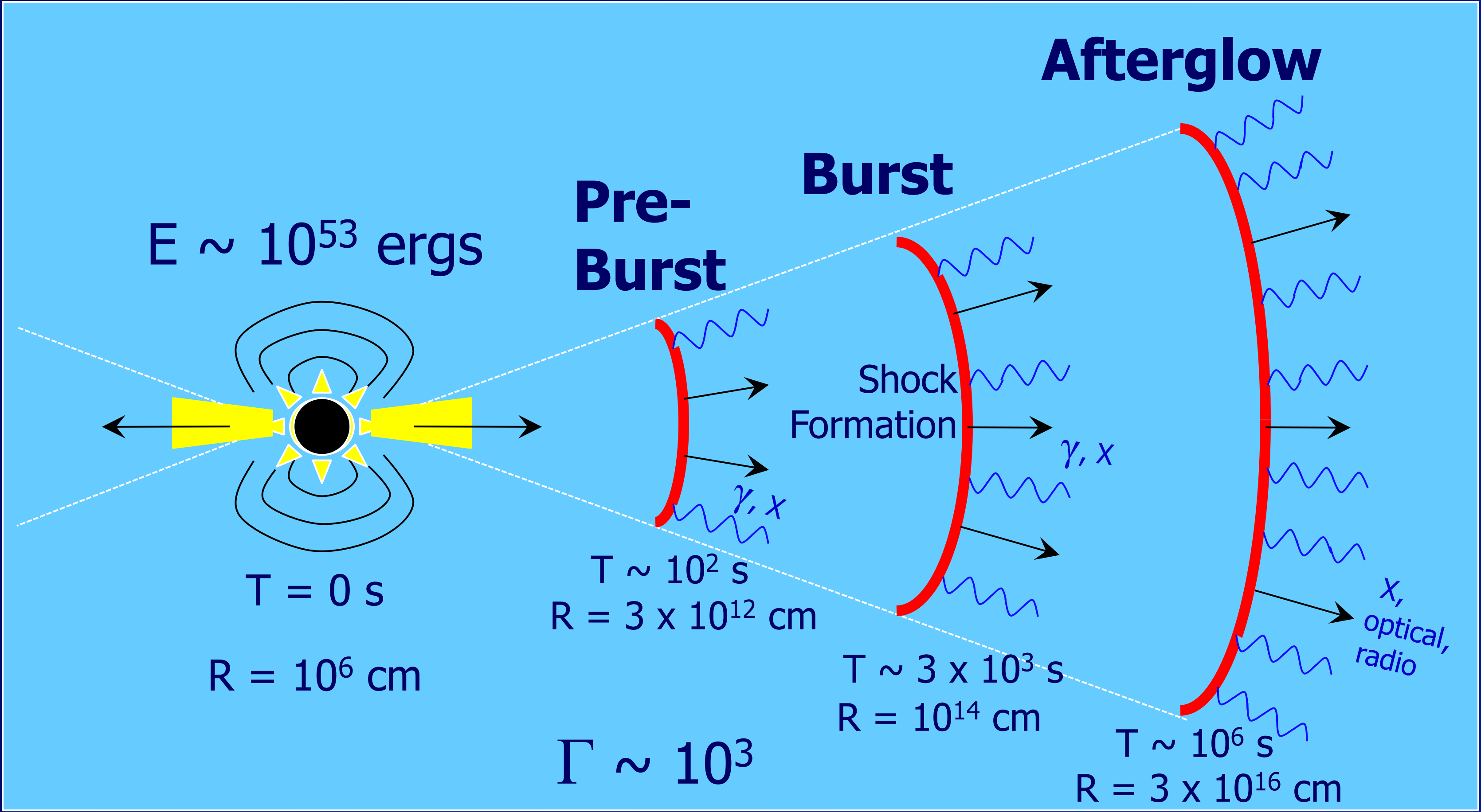
The Swift X-ray Telescope: Surprises in time-domain X-ray astronomy



David Burrows
The Pennsylvania State University

GRB afterglows

Fireball model: synchrotron emission from power-law distribution of electrons in highly relativistic outflows. Energy is ~10^{53} erg = 5% $M_\odot$.

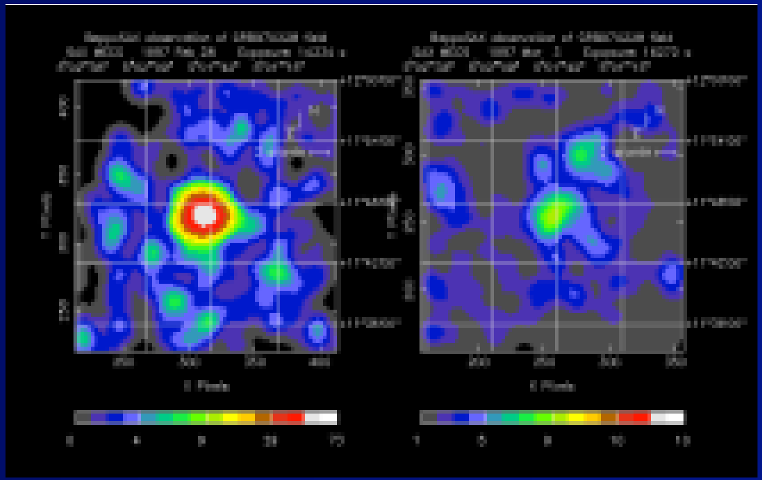


Feb. 1997

Beppo-SAX: Afterglows of long GRBs discovered in 1997

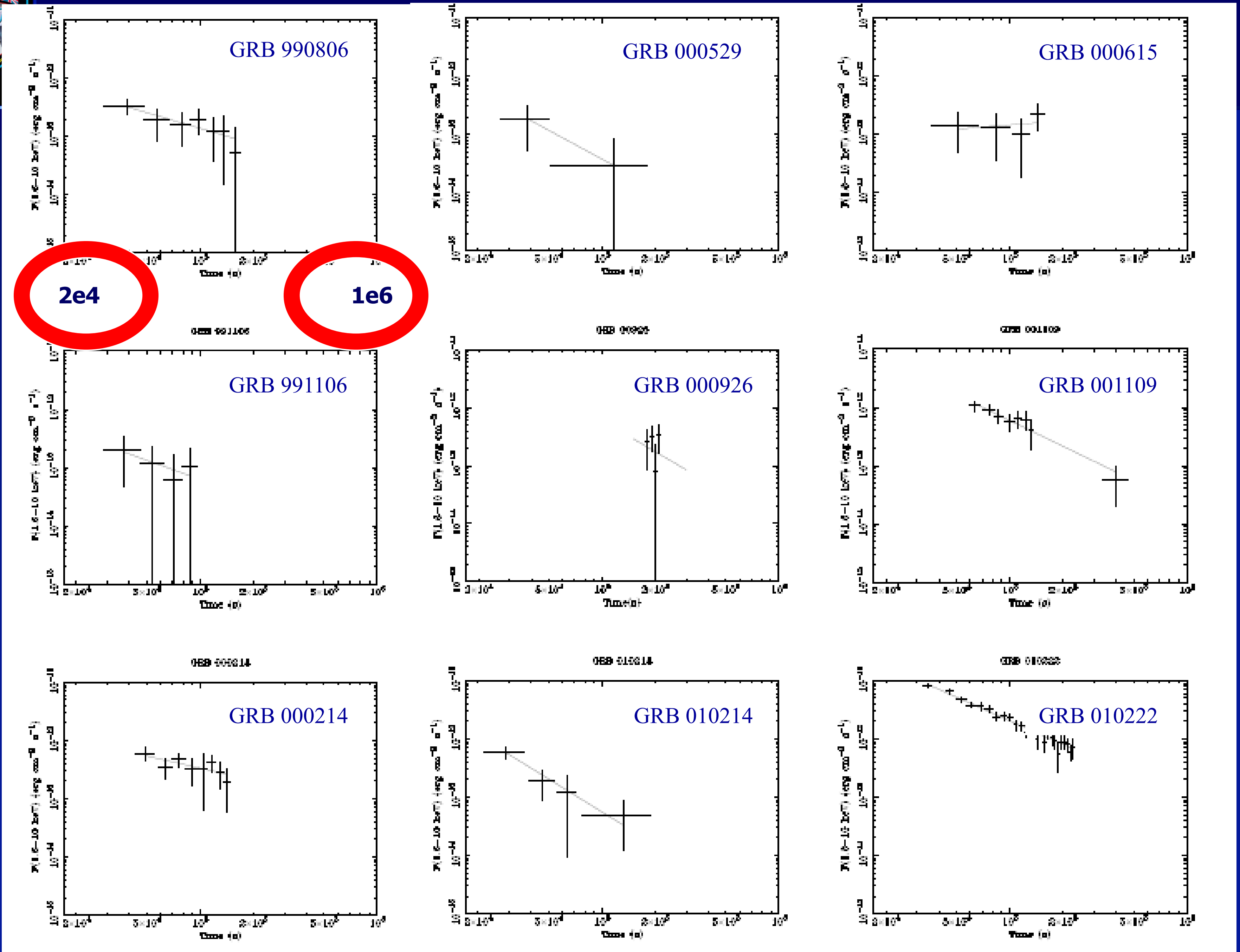
- **Redshift measurements => cosmological, E ~ 10^{51} ergs**
- **Host galaxies => Long GRBs are associated with star-forming regions**

Beppo-SAX: GRB 970228
2/28/97 3/3/97



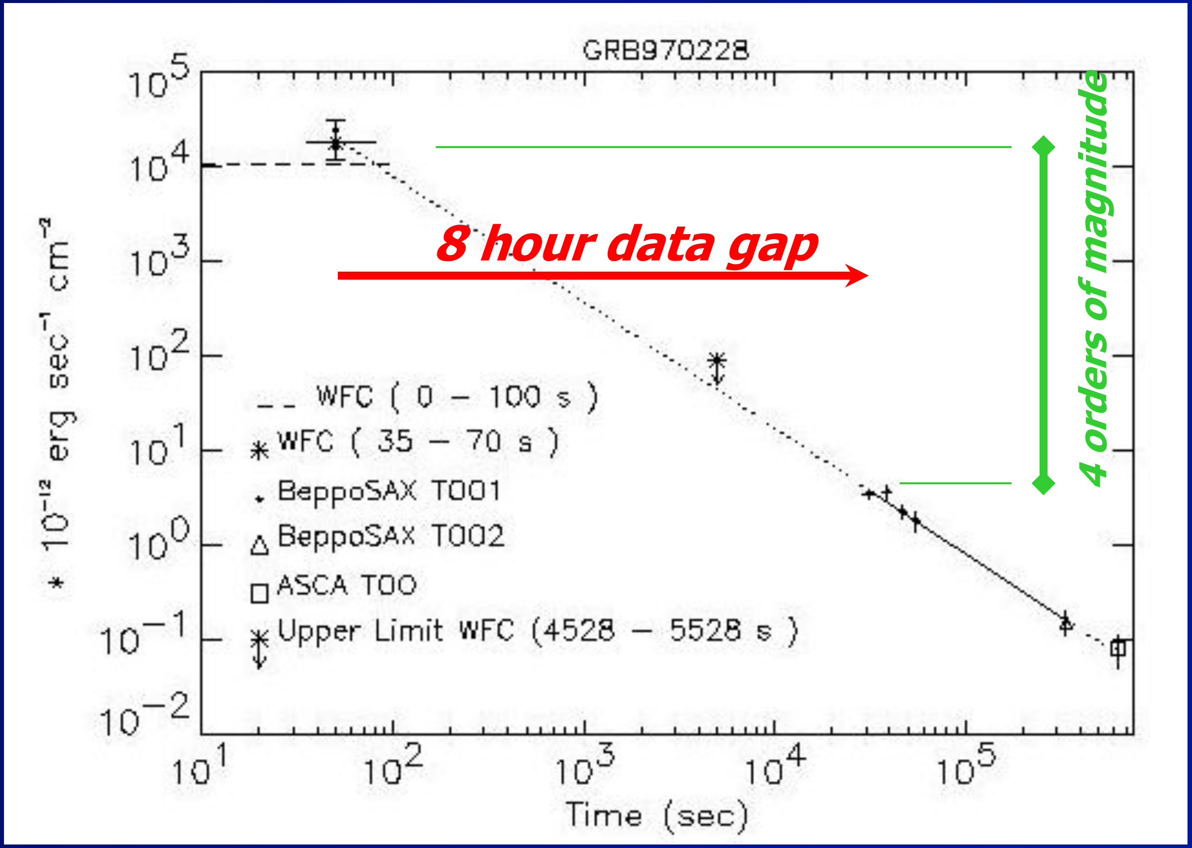
HST: GRB 990123

Beppo-SAX afterglows: de Pasquale et al. 2006, AA, 455, 813



The Data Gap

Beppo-SAX took at least 6-8 hours to perform an afterglow followup observation with its narrow field instruments. The afterglow fades by orders of magnitude, making study at other wavelengths and measurement of redshift difficult.



Too many collaborators to list !

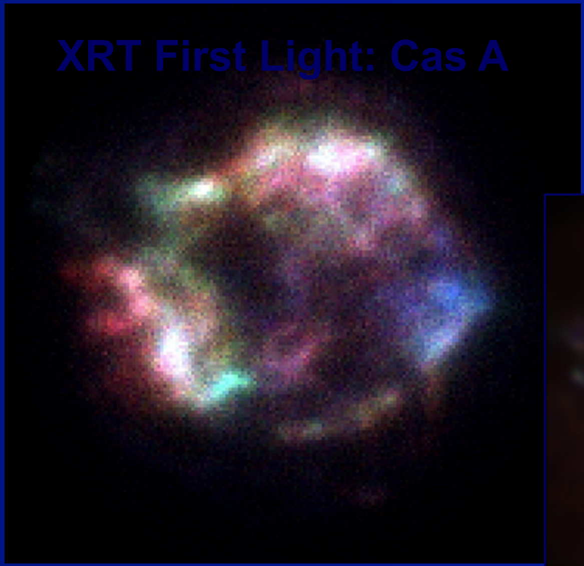
- Neil with a few of his best (Swiftest) friends

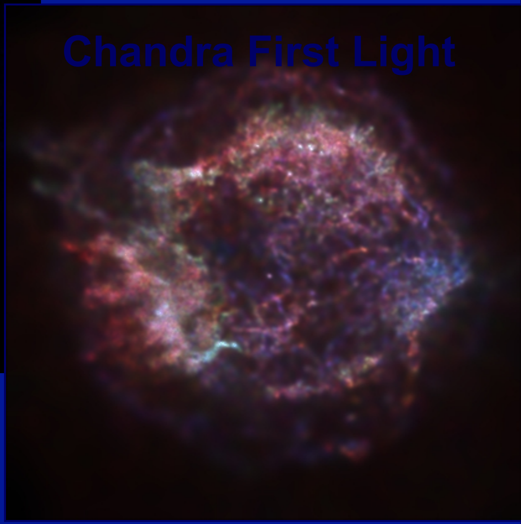
  (Swift team at thermal vac tests, GSFC Building 5)

The Neil Gehrels Swift Observatory

20 November 2004

- BAT First Light: 3 December 2004
- XRT First Light: 11 December 2004



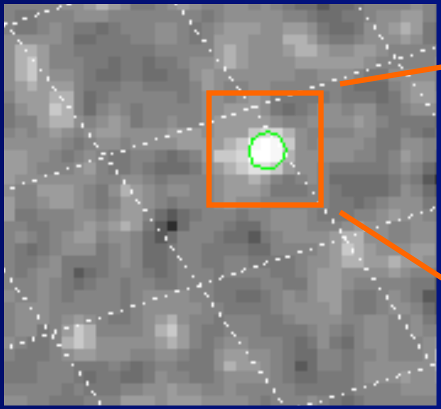


- First BAT Burst: 17 December 2004
- First XRT Afterglow: 23 December 2004
- UVOT First Light: 12 January 2005
- Data public since 5 April 2005

GRBs and Swift

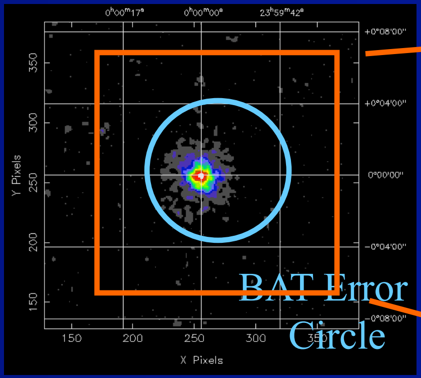
1. Burst Alert Telescope triggers on GRB, calculates position to ~ 1 arcmin
2. **Spacecraft autonomously slews to GRB position in 1-2 minutes**
3. **X-ray Telescope: ~ 5 arcsec prompt, ~2 arcsec delayed position**
4. UV/Optical Telescope images field, transmits finding chart to ground

BAT Burst Image



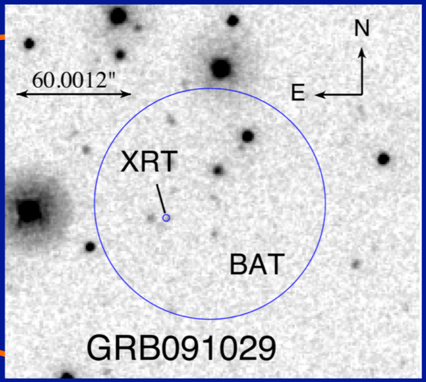
T~10 sec

XRT Image



T~100 sec

UVOT Image



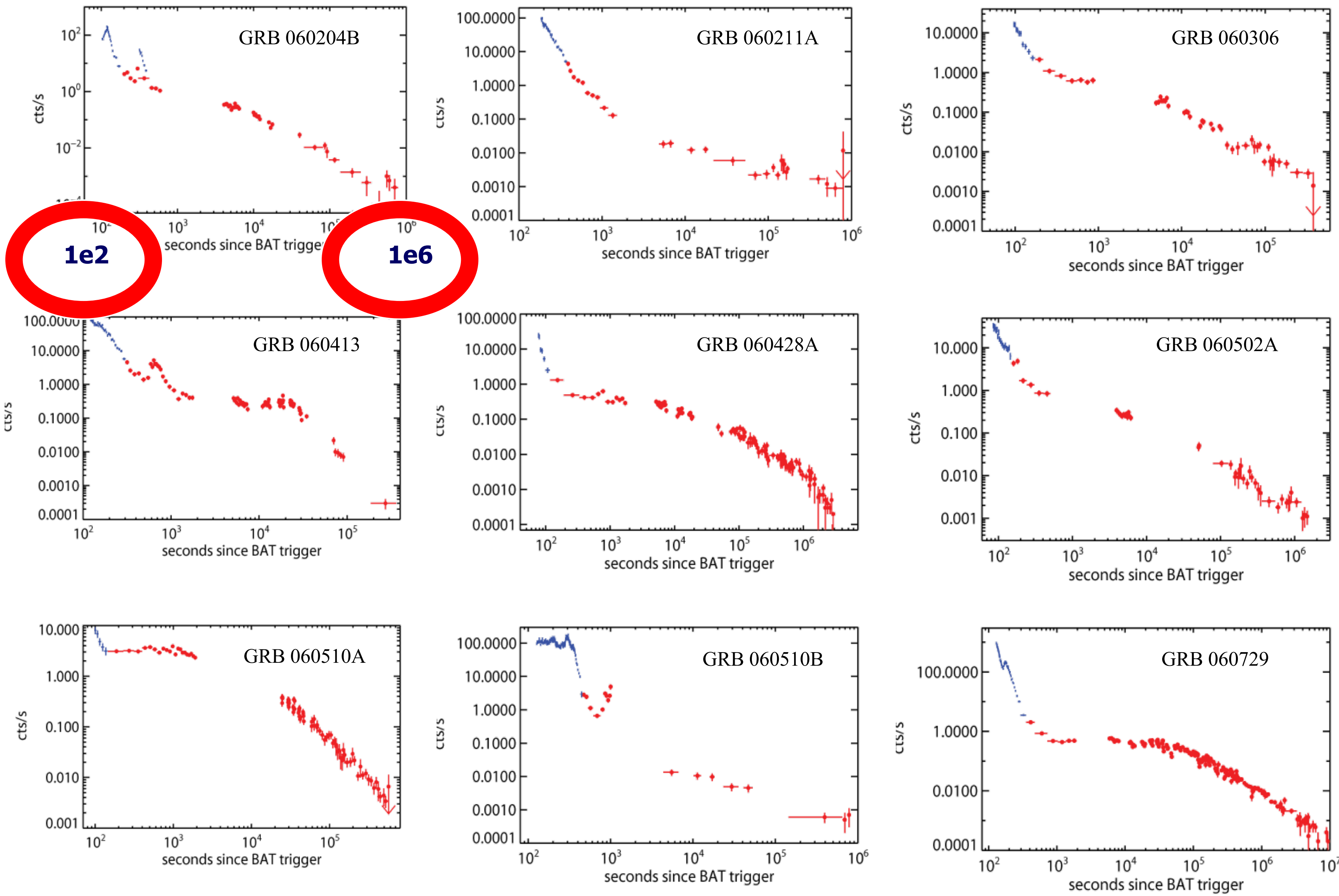
T~300 sec

1) Lightcurves

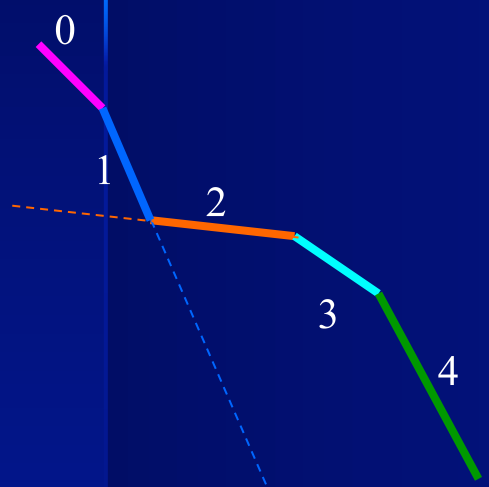
Rapid slew, complete light curve coverage from ~ 100 s to > 10^6 s

Swift X-ray Afterglows

977 X-ray Light Curves as of May 17, 2018

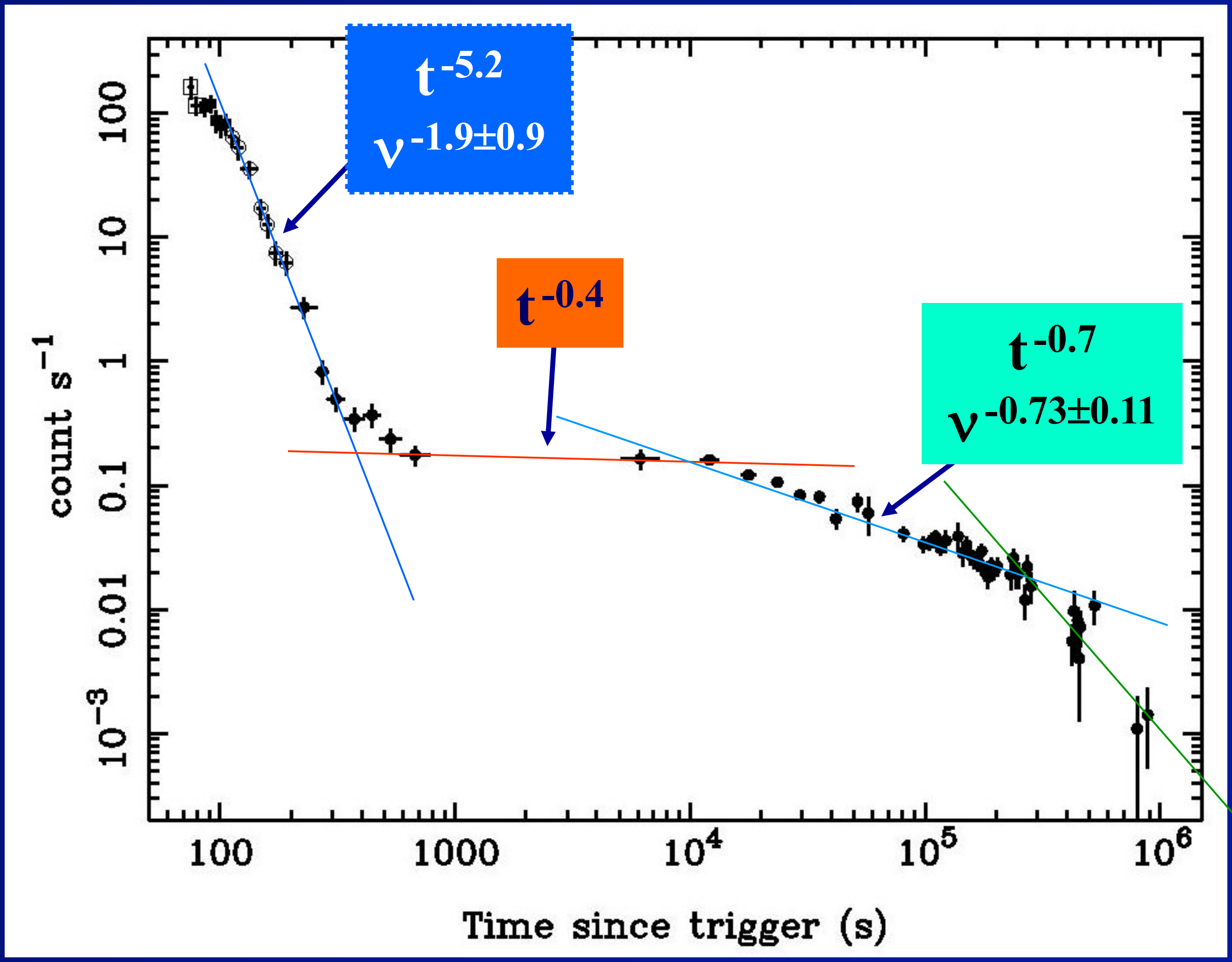


Canonical LC: GRB 050315A



Zhang et al. 2006, ApJ, 642, 354

Vaughan et al. 2005



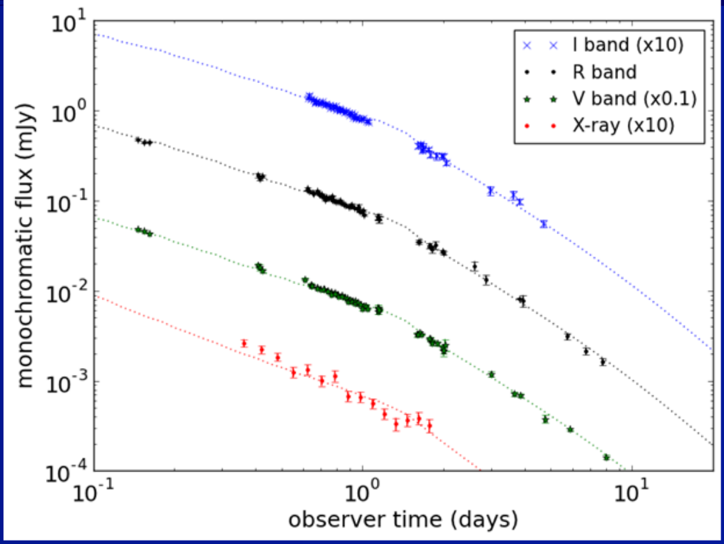
2) Jet breaks

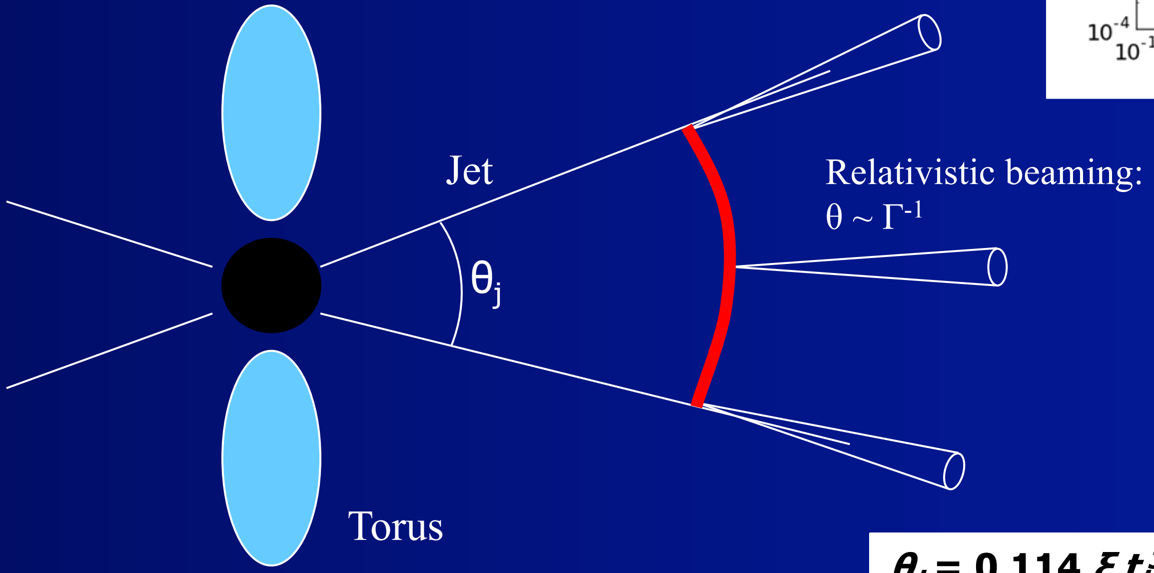
Rapid slew, complete light curve coverage from ~ 100 s to > 10^6 s

Jet Breaks expected in every afterglow

GRBs

- > 97% of world X-ray afterglows
  - Complex X-ray lightcurves and flares
  - Jet breaks (or not…)



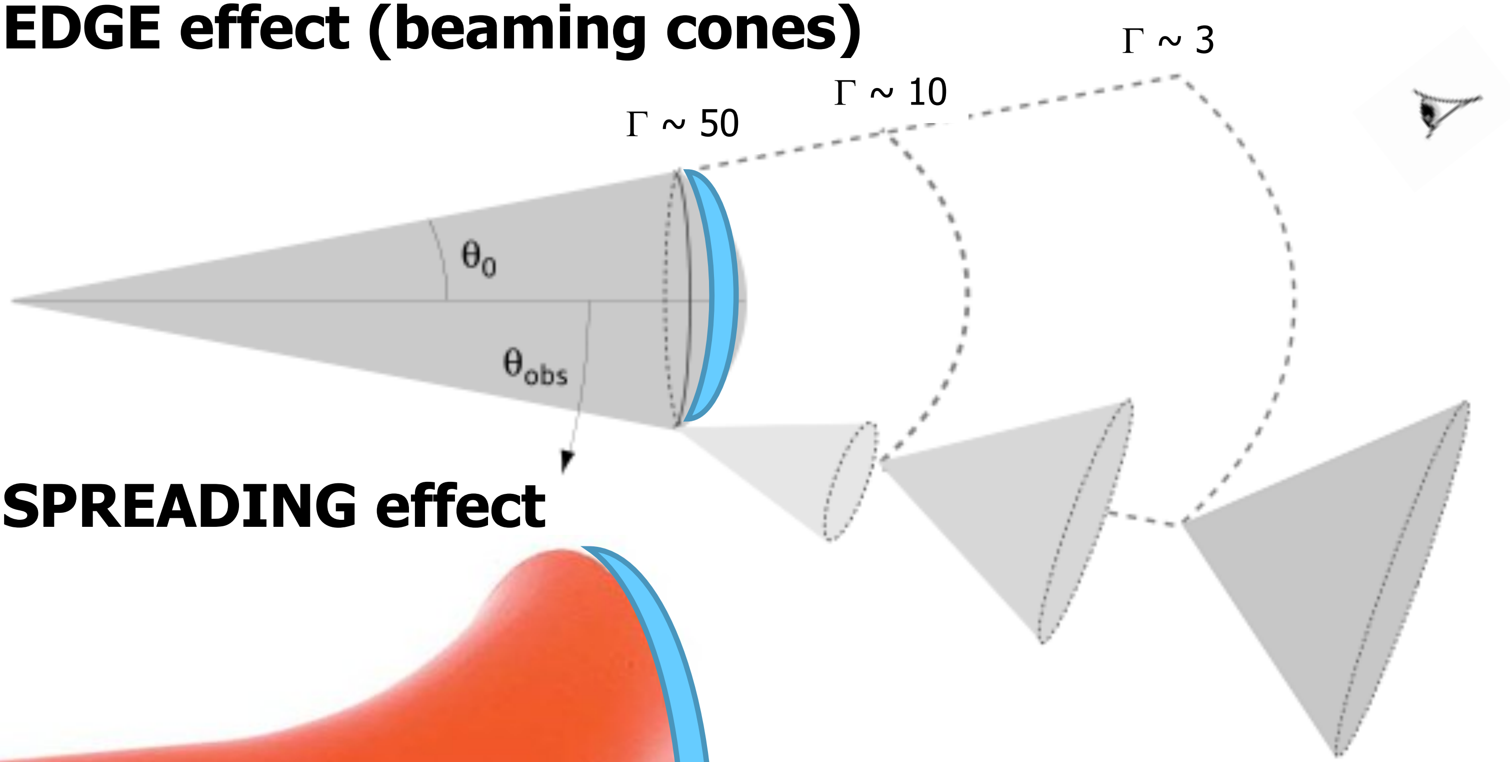


$\theta_j = 0.114\ \xi\ t_j^{3/8}$

where
$\xi = (3.5/1+z)^{3/8}\ \ (\eta/0.2)^{1/8}\ \ (n/E_{iso,53})^{1/8}$,
η = **radiation efficiency.**

Two types of afterglow 'jet' breaks

1. The EDGE effect (beaming cones)

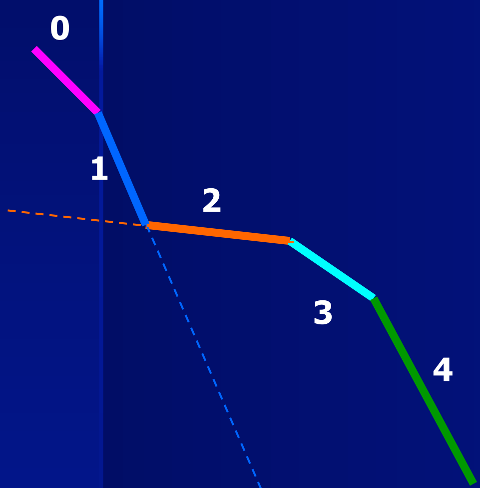


2. The SPREADING effect

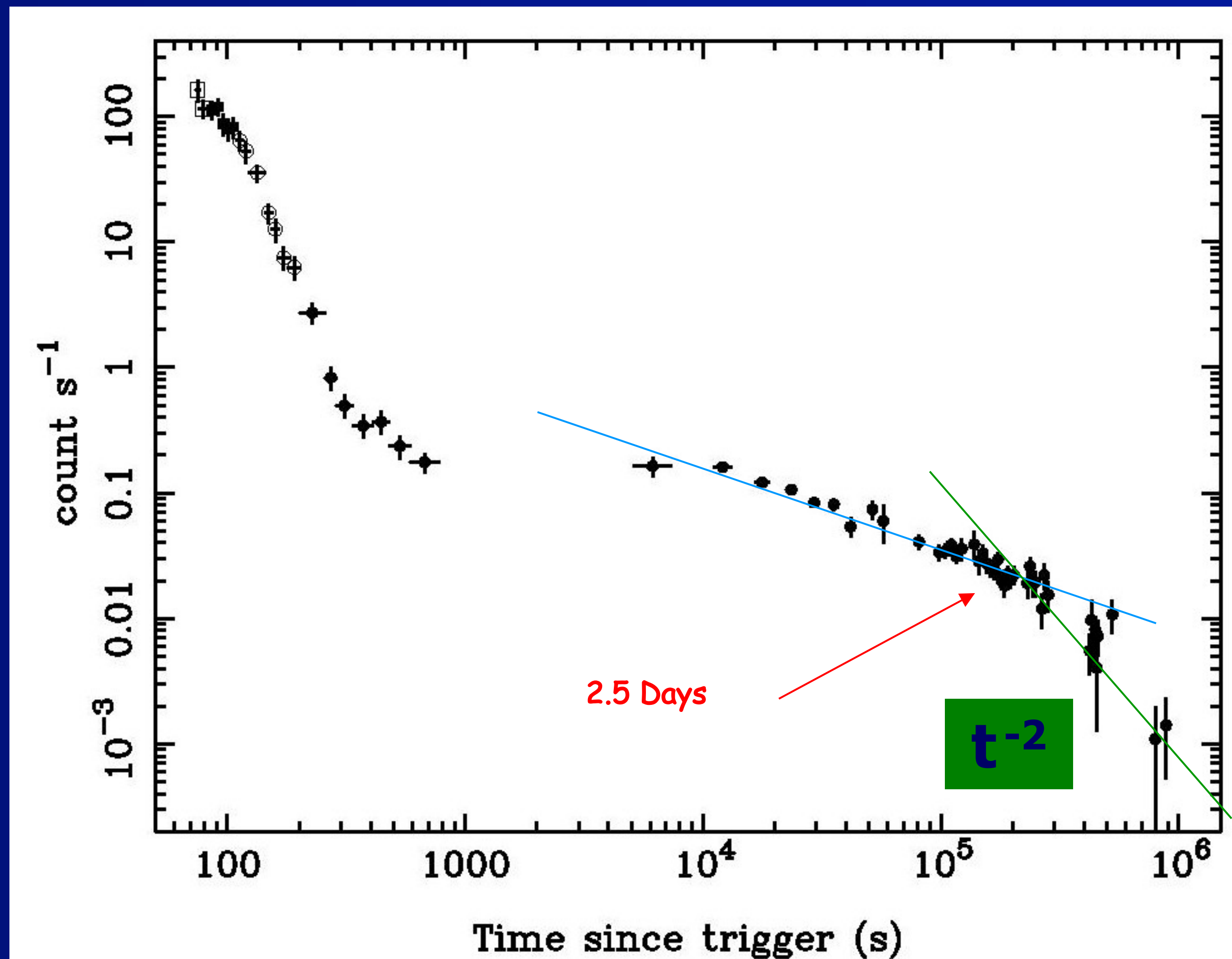
1. width of beaming cones
2. onset of spreading

Credit: Hendrick van Eerten

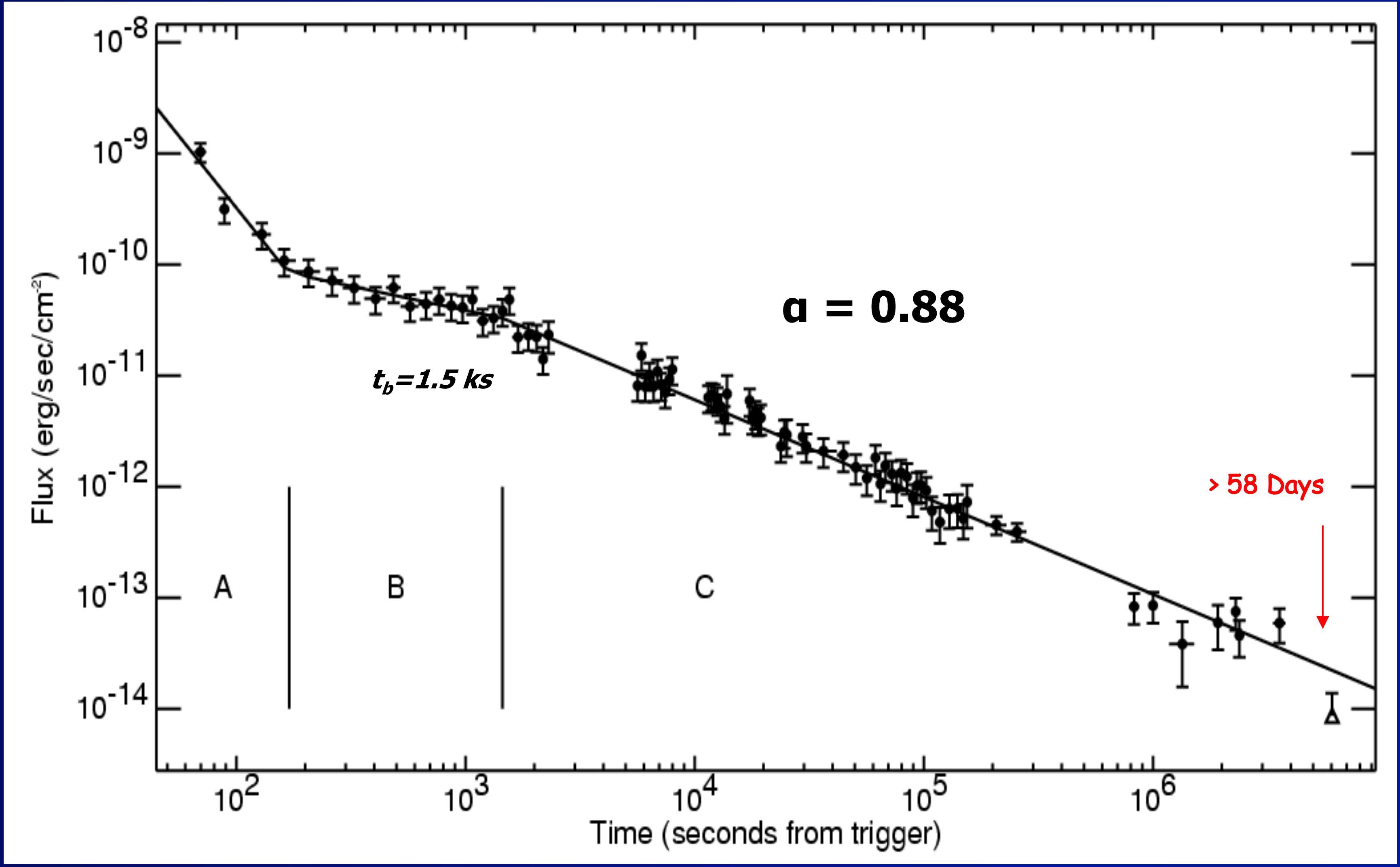
Jet Break in GRB 050315A



Vaughn et al. 2005



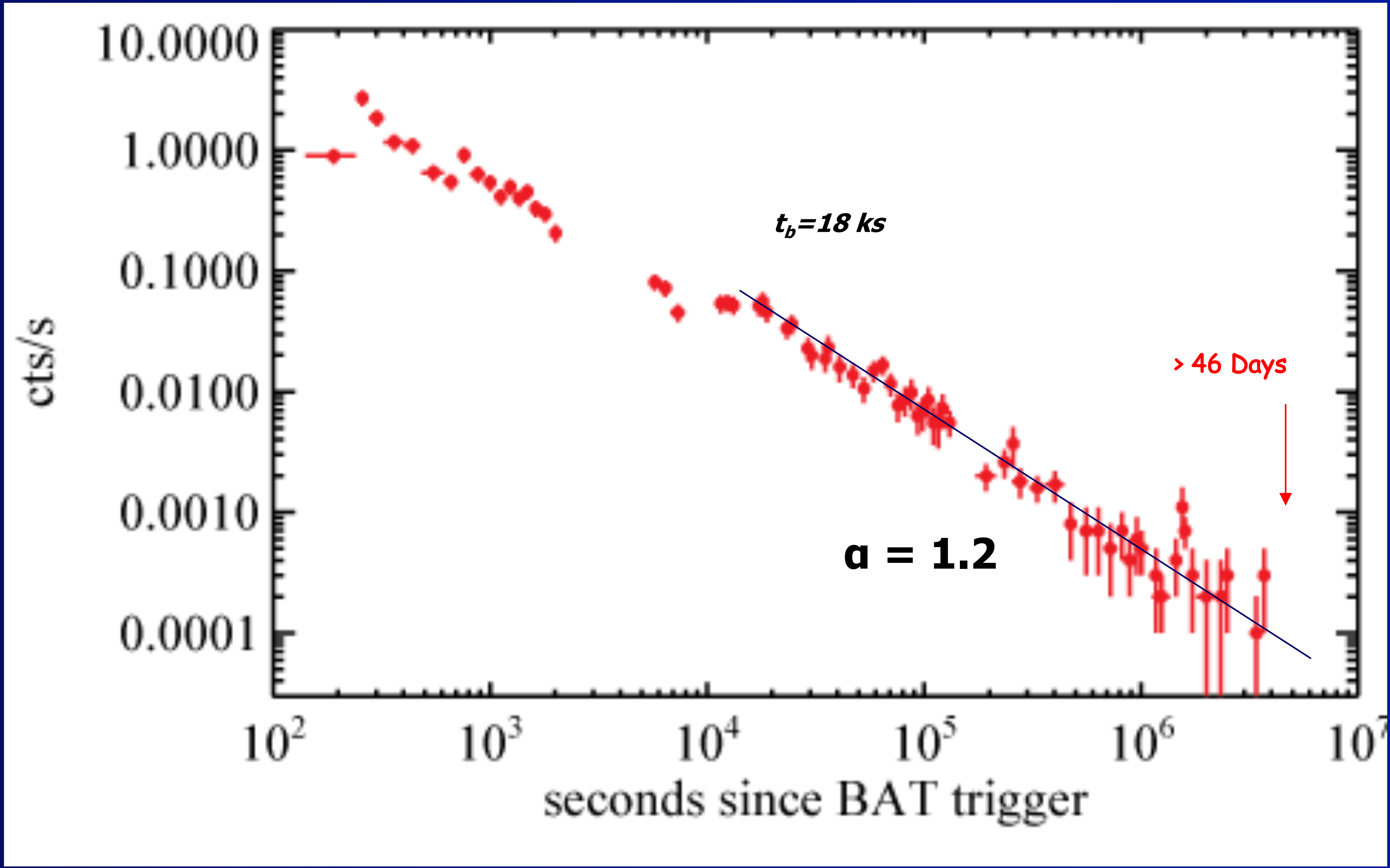
On the other hand: GRB050416A



$z = 0.65$, $\theta_j > 33^\circ$ $n^{1/8}$

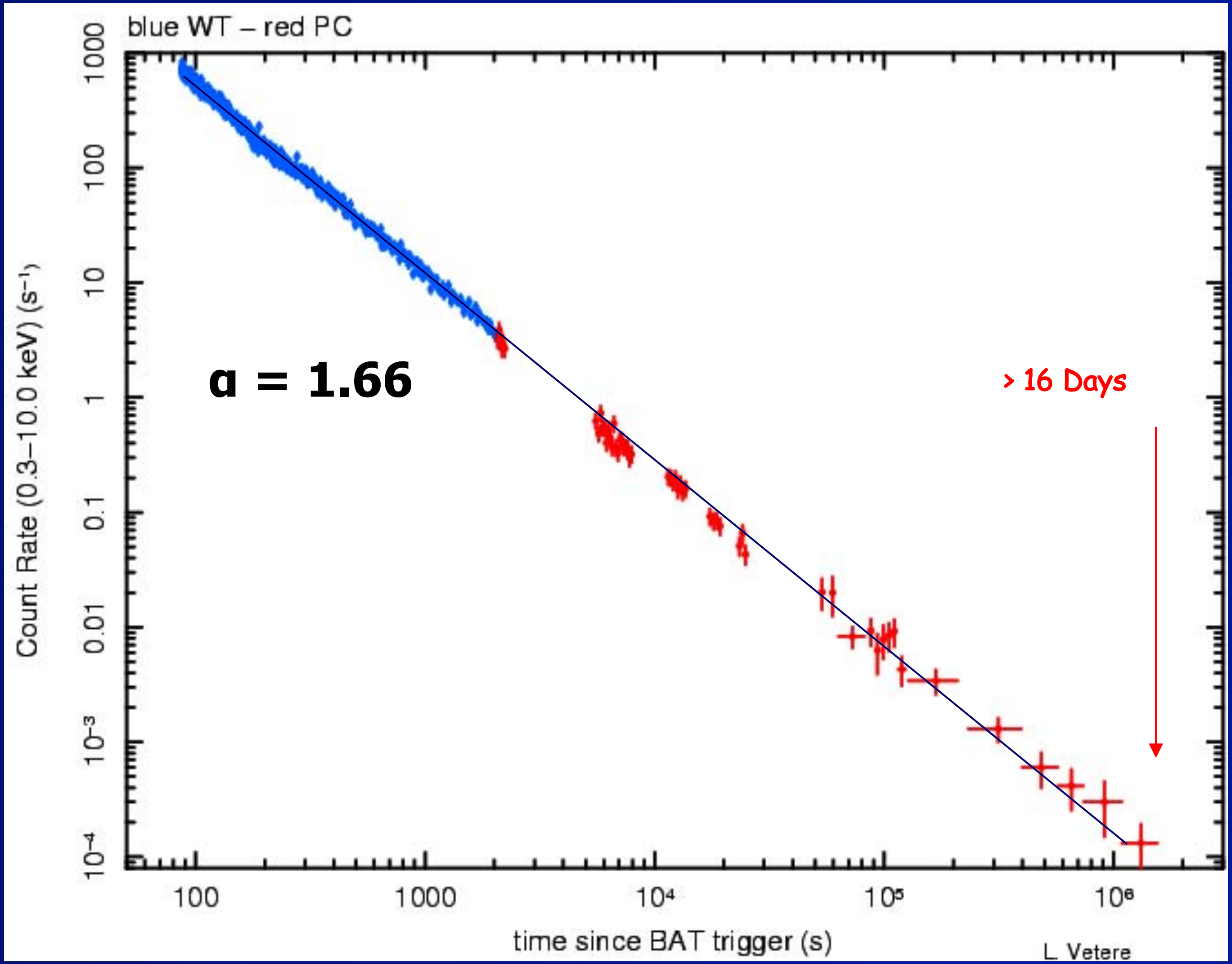
Mangano et al. (2006)

GRB060319



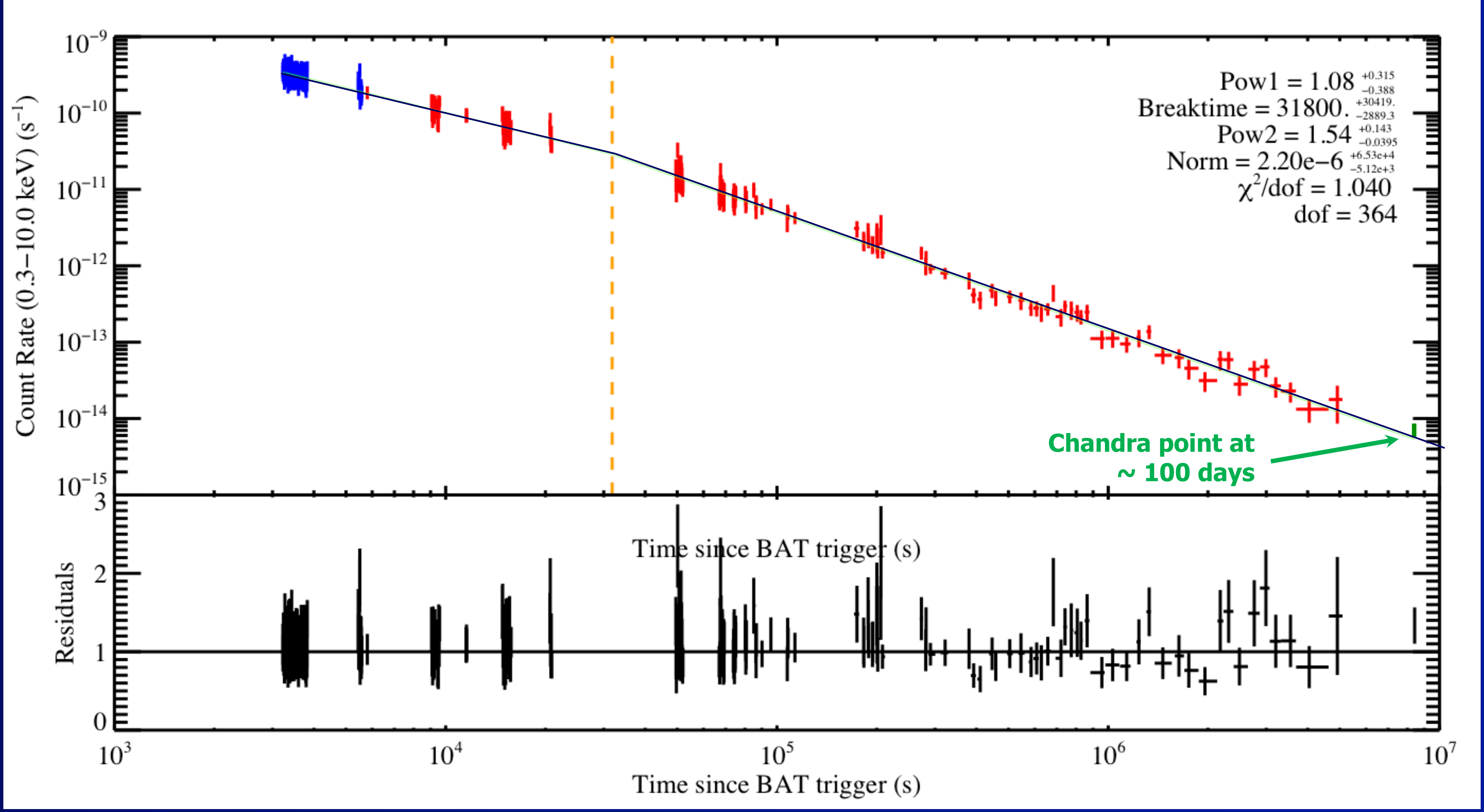
$z = ?,\ \theta_j > 28^\circ\ \ \xi$

GRB061007



z = 1.26, $\theta_j > 8^\circ$ $n^{1/8}$ OR $\theta j < 1^\circ$ $n^{1/8}$

GRB091127A

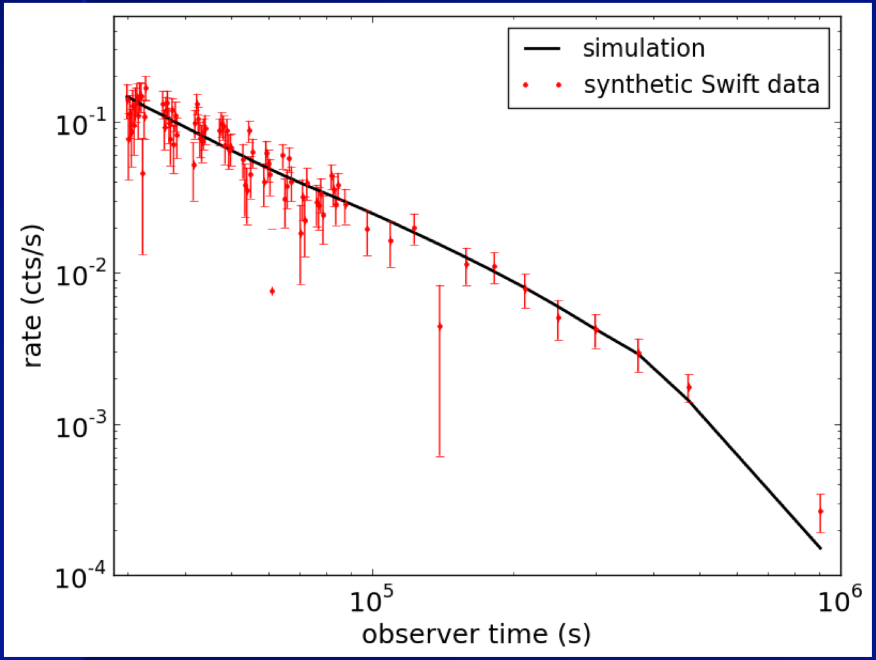


Pow1 = 1.08 +0.315 −0.388
Breaktime = 31800. +30419. −2889.3
Pow2 = 1.54 +0.143 −0.0395
Norm = 2.20e−6 +6.53e+4 −5.12e+3
χ²/dof = 1.040
dof = 364
Chandra point at ~ 100 days
Count Rate (0.3−10.0 keV) (s⁻¹)
Residuals
Time since BAT trigger (s)
Time since BAT trigger (s)

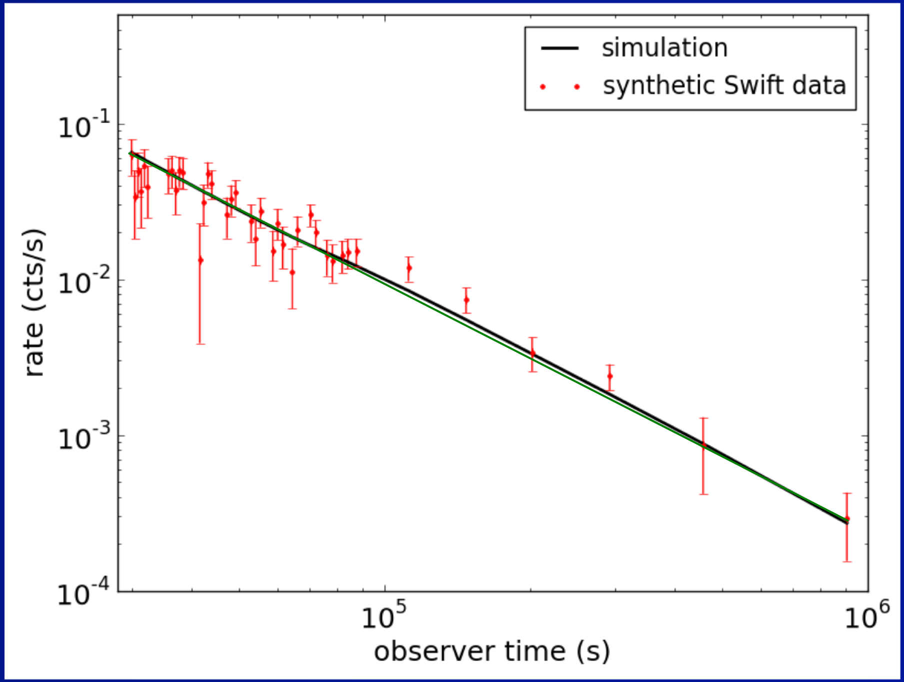
The observer angle & hidden jet breaks

A completely typical Swift long GRB *simulated* afterglow seen from two different angles:

0.1 radian jet seen ON-AXIS



0.1 radian jet seen ON-EDGE



van Eerten, MacFadyen & Zhang (2011) AIP Conf. Proc, 1358, 173

For an off-axis observer: the far edge of jet becomes visible later than the close edge

"the odds that a Swift light curve from a randomly oriented 0.1 radians jet at z = 2.23 will exhibit a jet break at the 3σ level are only 12 percent"

The Swift X-ray Telescope:
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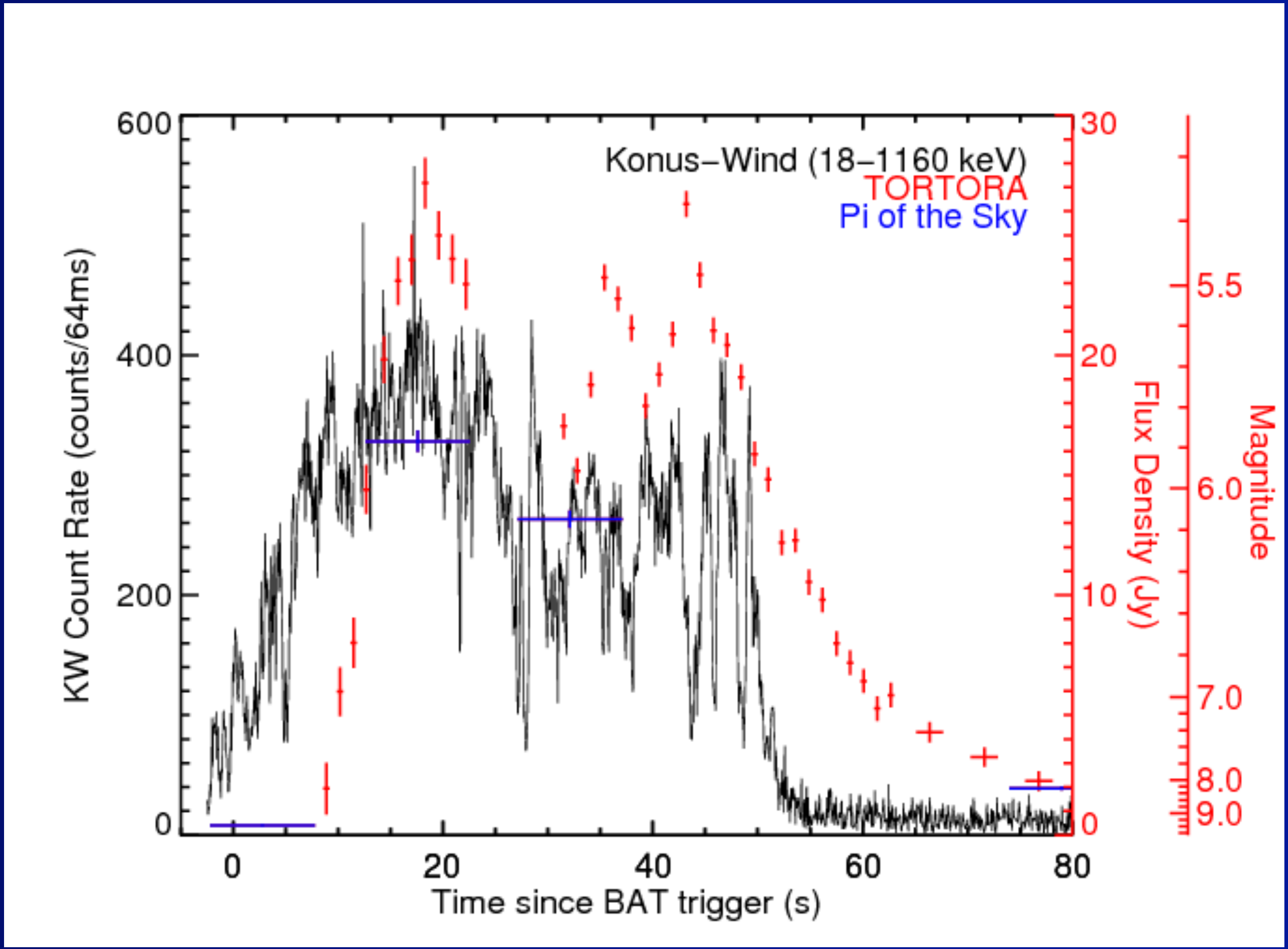
3) The Naked Eye Burst

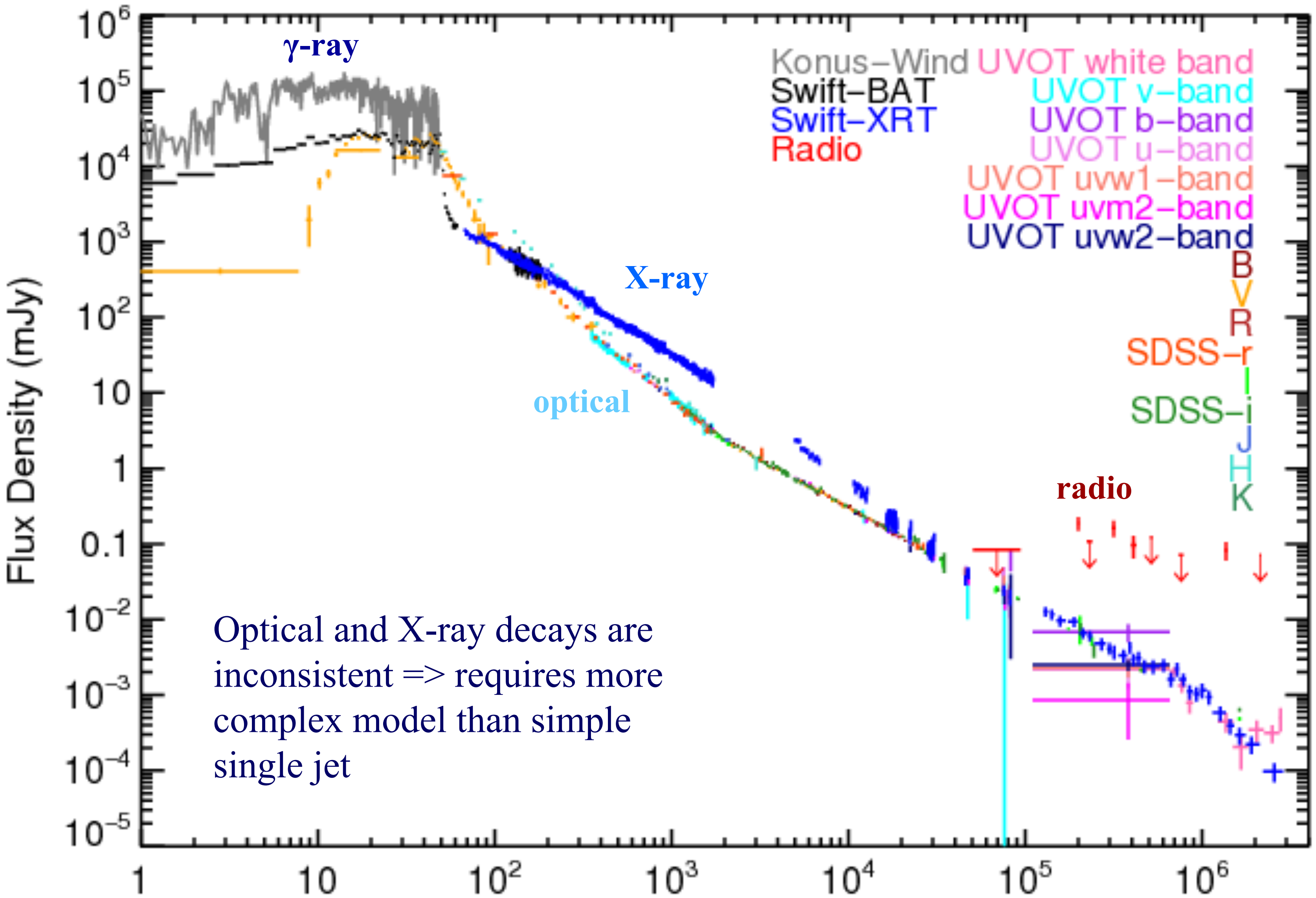
GRB 080319B

V=5.3 @ z=0.937 !



Racusin et al. 2008, Nature; see also Bloom et al 2008, ApJ;
Kumar and Panaitescu 2008, MNRAS

Full Light Curves

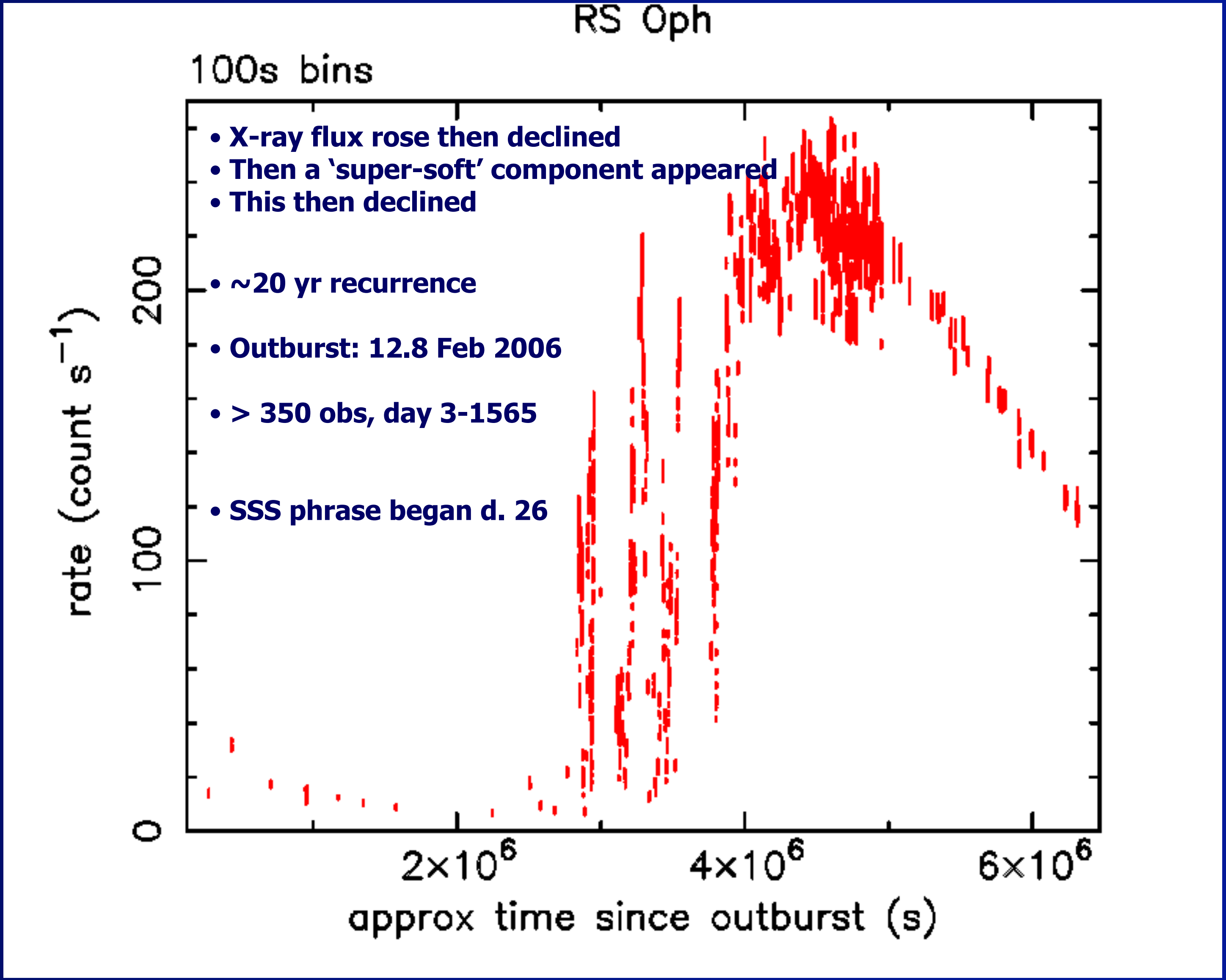


Racusin et al. 2008, Nature, 11 Sept 2008

4) Novae

Rapid slew, flexible scheduling, efficient X-ray and UV monitoring, complete light curve coverage from ~ 100 s to > 10^6 s

The recurrent nova RS Ophiuchi



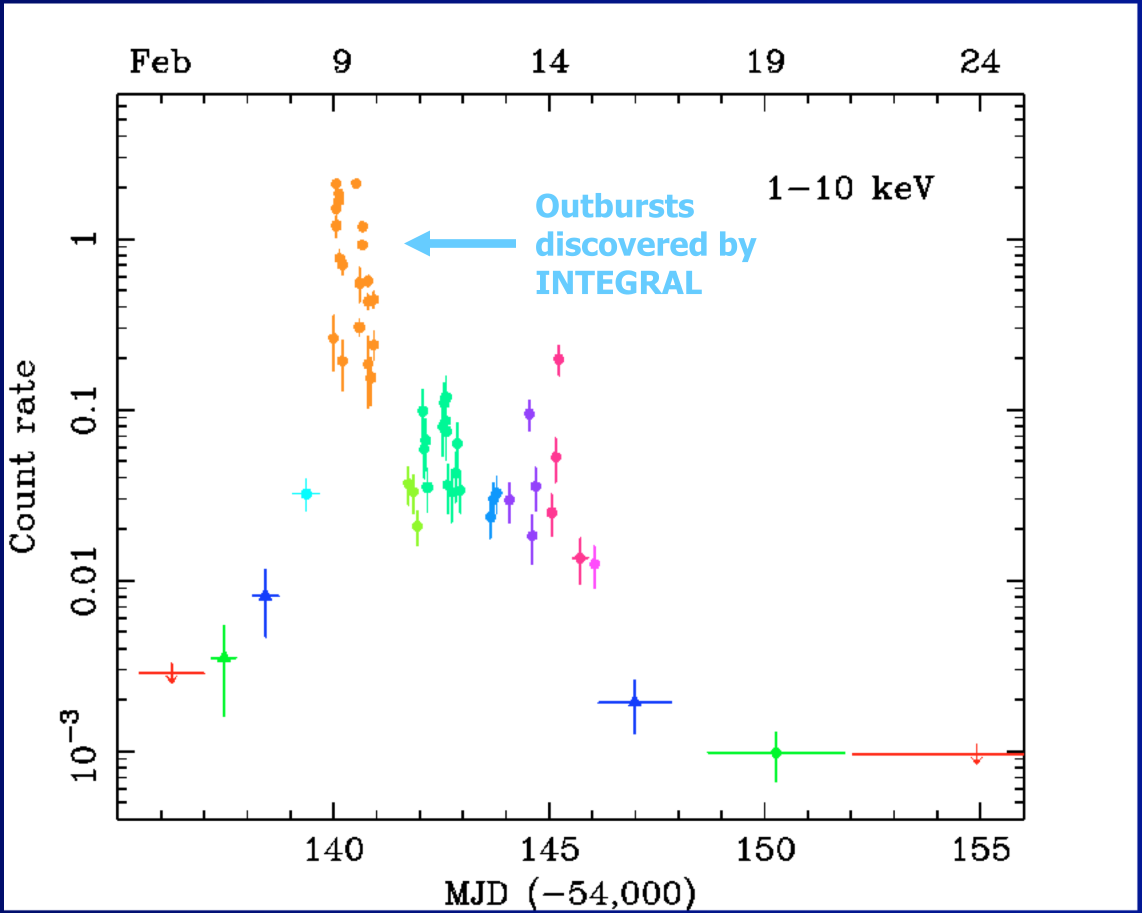
5) SFXTs

(Supergiant Fast X-ray Transients)

Rapid slew, flexible scheduling, efficient X-ray and UV monitoring, complete light curve coverage from ~ 100 s to > 10^6 s

Swift observations of 5th expected outburst of IGR J11215-5952

Supergiant Fast X-ray Transients

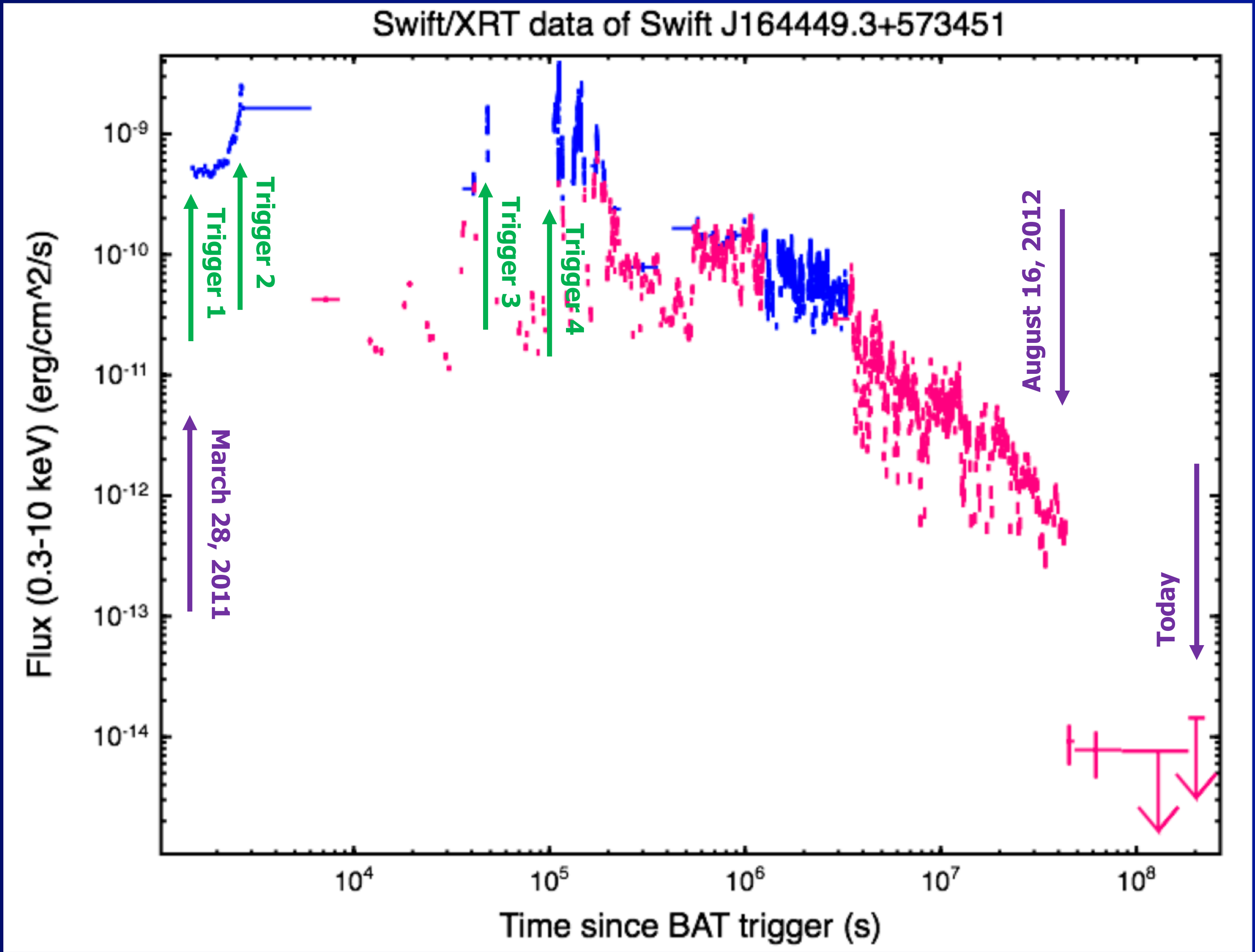


1. Below detectability ($L< 3.7 \times 10^{33}$ cgs)
2. Slow rise
3. Outburst (1 day)
    - Rapid variability
    - $L \sim 1 \times 10^{36}$ cgs
4. Decline phase with plateau
5. Declines to $< 1 \times 10^{33}$ cgs after 15 days

- SFXTs have dynamic range > 1000, hard spectrum

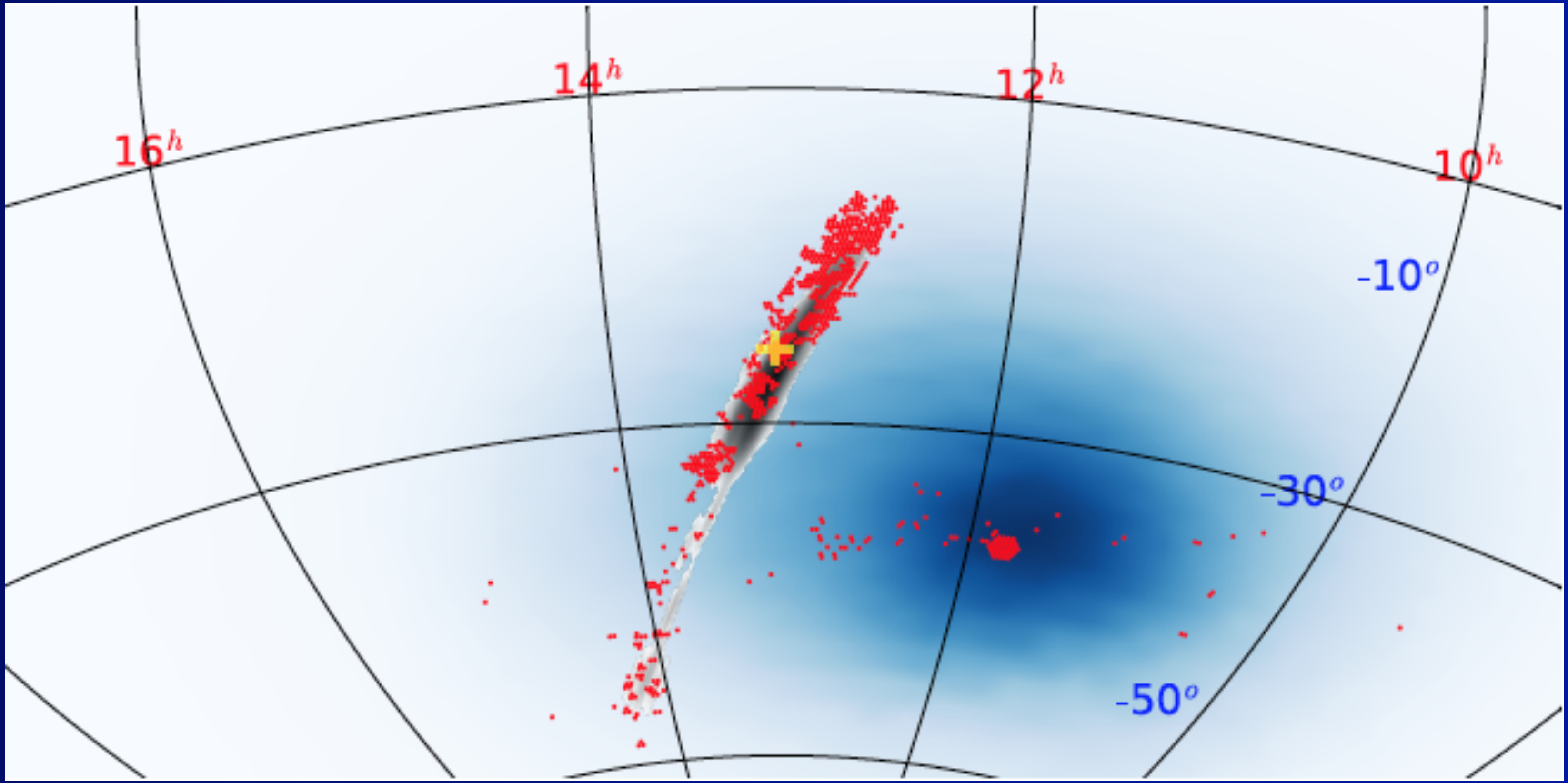
6) Relativistic jet from TDE

Swift J1644+57: the recurring "GRB"



7) From the incredible to the impossible

Swift's Latest Amazing Feat



Swift coverage of the GW170817 error region obtained 120s X-ray images of 744 fields covering 92% of the distance-weighted GW localization region and set an X-ray flux upper limit of 10^{-12} cgs !!

UVOT detected the fading UV afterglow of the NS-NS merger!

Conclusions

- *The keys to the success of Swift are:*
  - *Rapid-response robotic multiwavelength observatory*
  - *Immediate followup of anything that triggers the BAT*
  - *Extremely productive ToO program that provides followup of sources discovered elsewhere*
  - *Ability of the Swift Team to repeatedly reinvent Swift by adding new capabilities never contemplated when the mission was designed*
  - *Neil's vision and team-building genius*