Gamma Ray Burst Afterglows - Energetics

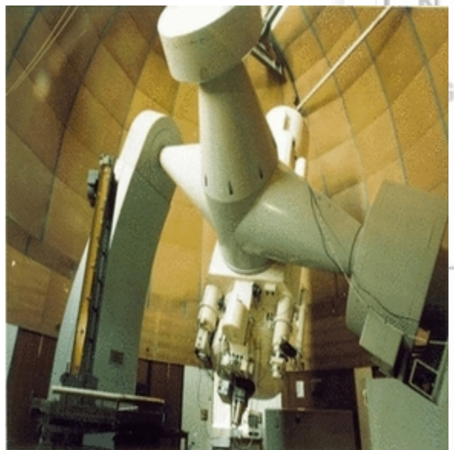
Kuntal Misra
Aryabhatta Research Institute of observational sciencES (ARIES)
Nainital, India

On behalf of a larger collaboration

Longitudinal advantage

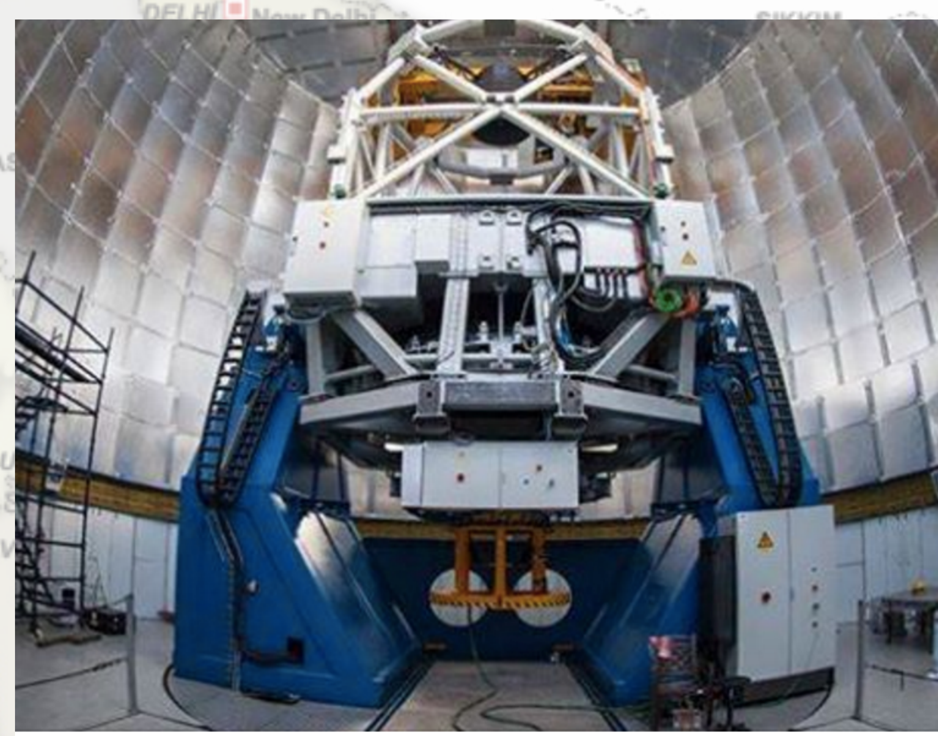
The Optical Eye

1.0m ST



2.3m VBO

3.6m DOT



1.3m DFOT

2.0m HCT

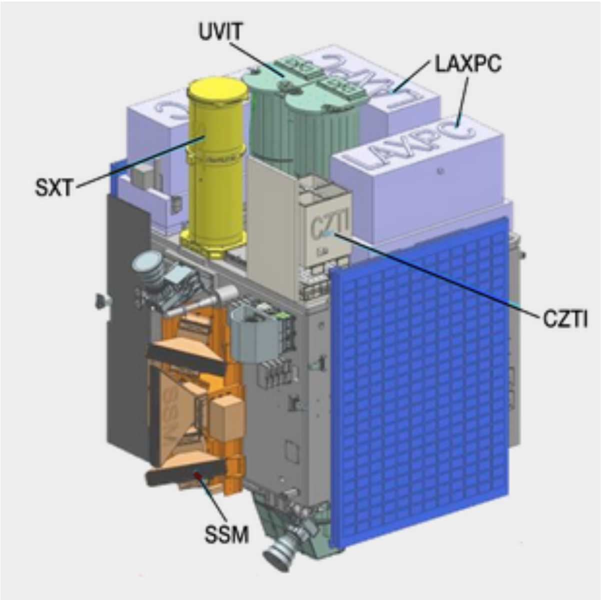
1.2m Mt. Abu

2.0m IGO

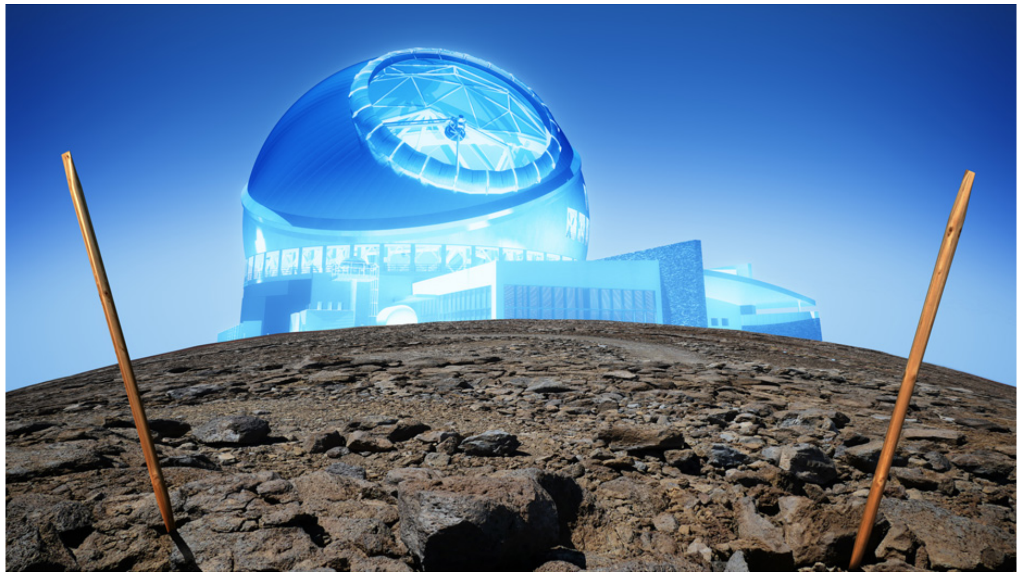
SKA

GMRT

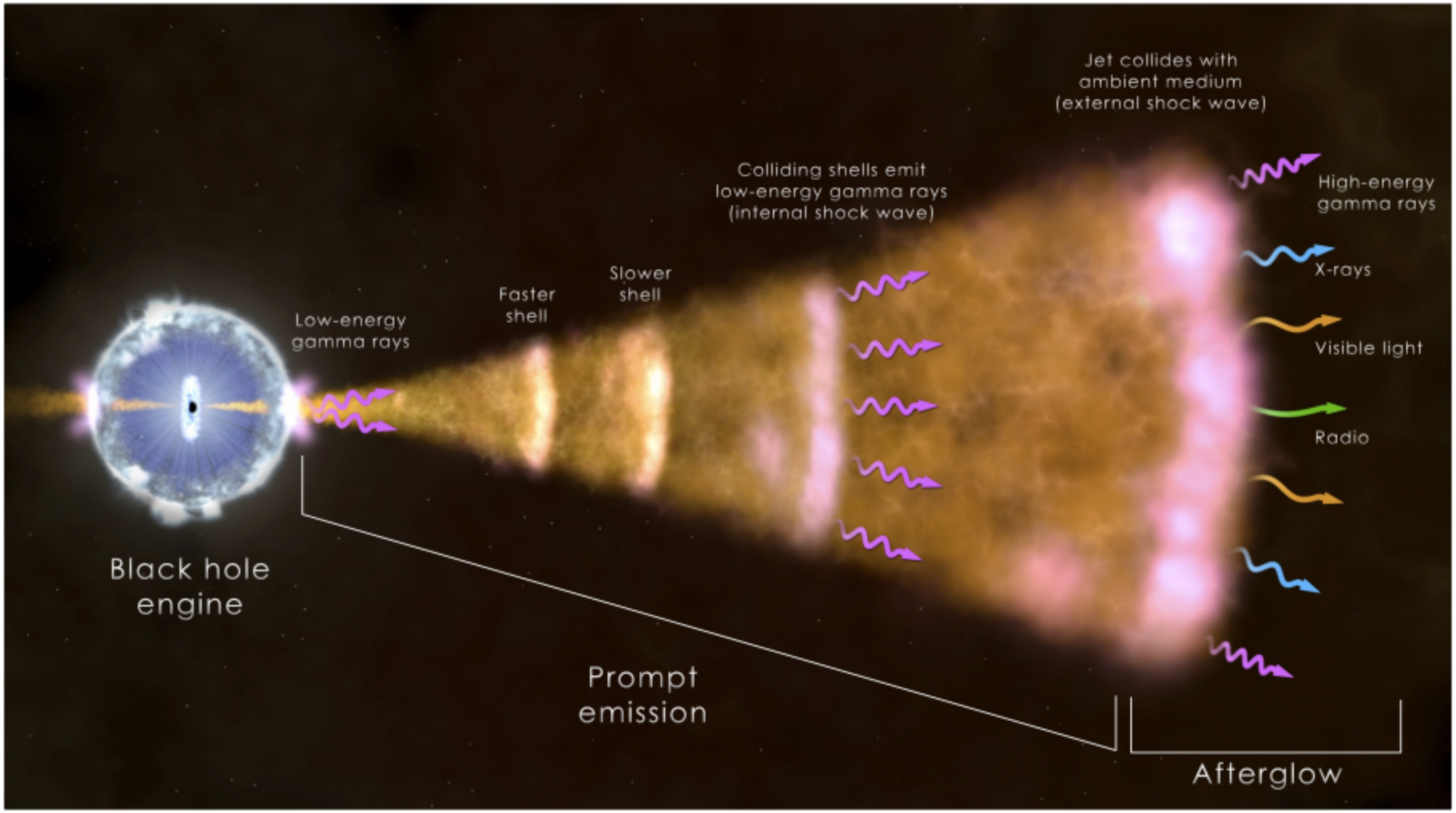
AstroSat



TMT



GRBs: What we know



The Fireball Model

- Prompt energy ($E_{\gamma,iso}$)
- Afterglow energy ($E_{KE,iso}$)
- Collimation (θ)

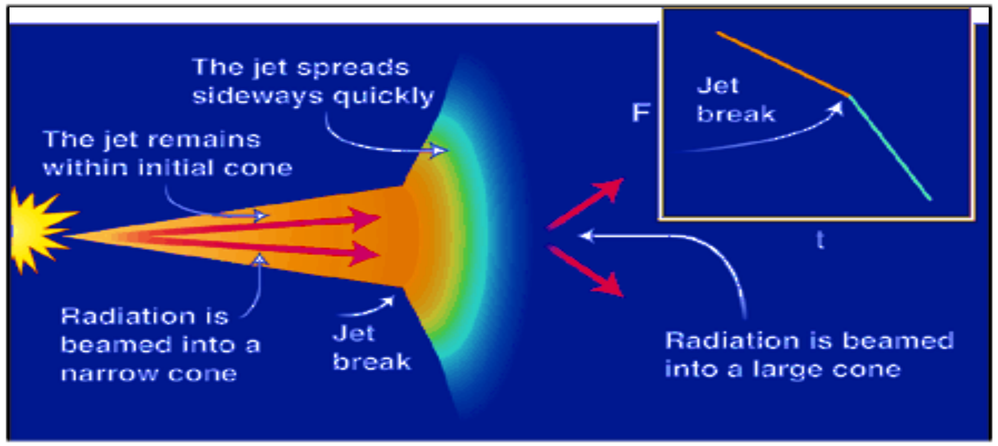
Context: Jet geometry of GRB afterglows

Afterglow studies so far

★Nature of the explosion - GRBs are highly beamed (jet opening angles of a few degrees)

★Extent of collimation through achromatic breaks in light curves

Signature of a jet-break



Constant density medium

$$\theta_j = 0.057 \left(\frac{t_j}{1 \text{ day}}\right)^{3/8} \left(\frac{1+z}{2}\right)^{-3/8} \left[\frac{E_{\rm iso}(\gamma)}{10^{53} \text{ ergs}}\right]^{-1/8} \times \left(\frac{\eta_\gamma}{0.2}\right)^{1/8} \left(\frac{n}{0.1 \text{ cm}^{-3}}\right)^{1/8},$$

Sari & Piran 1999
Frail et al. 2001

Wind medium

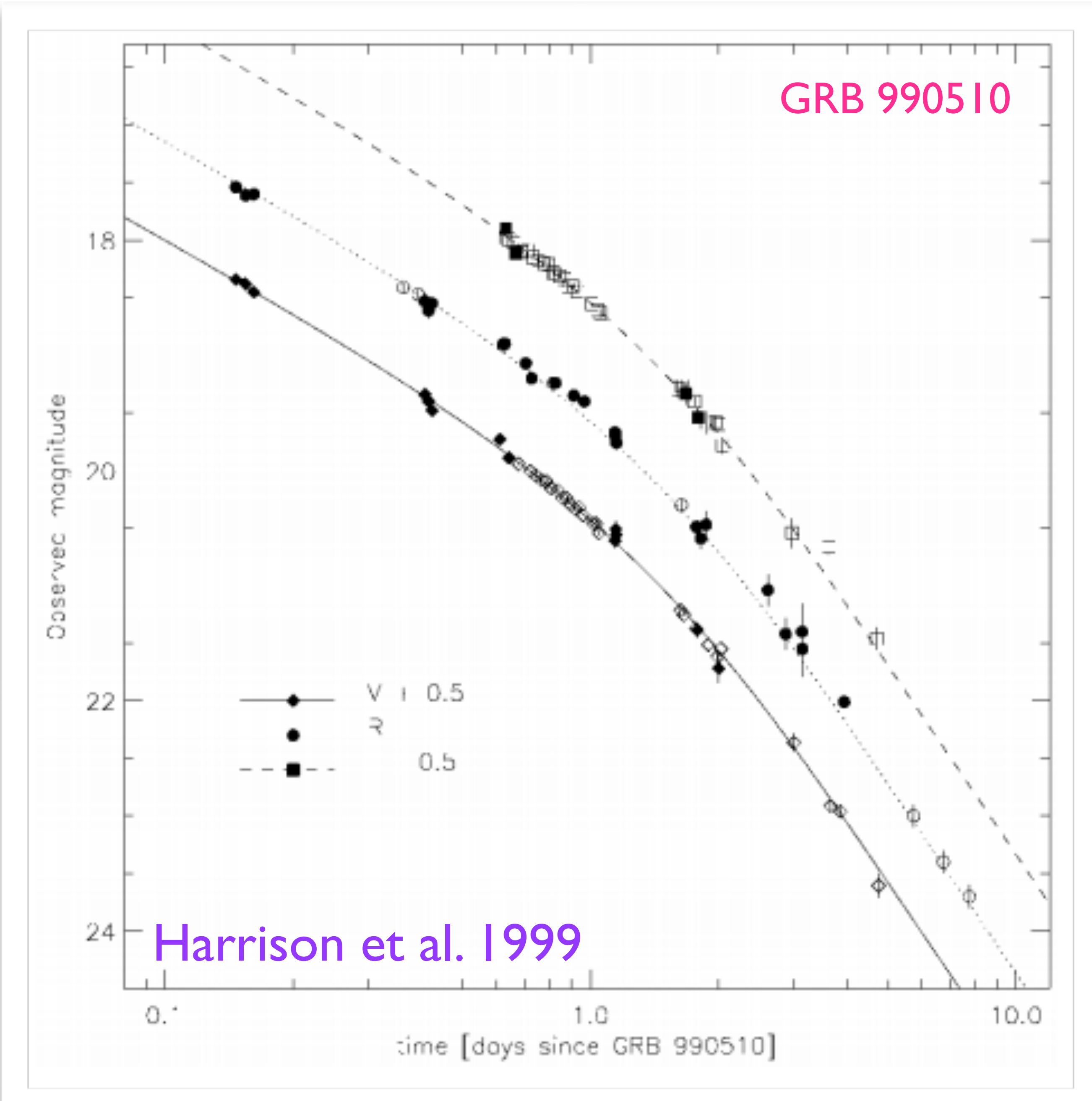
$$t_{\rm jet} = 2\left(\frac{1+z}{2}\right)\left(\frac{\theta_0}{0.2}\right)^4 E_{52} A_*^{-1} \text{ days}$$

Chevalier & Li 2000

Context: Jet geometry of GRB afterglows

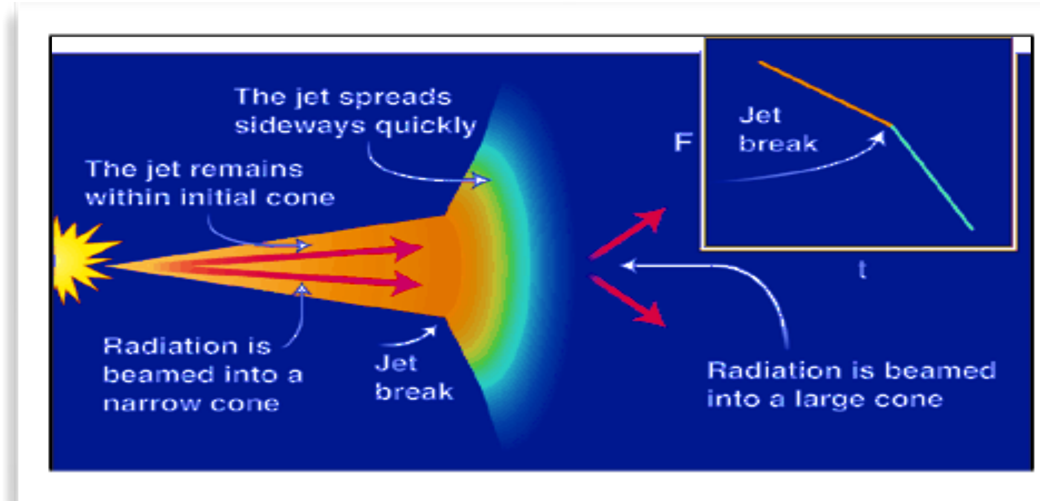
★Nature of the explosion - GRBs are highly beamed (jet opening angles of a few degrees)

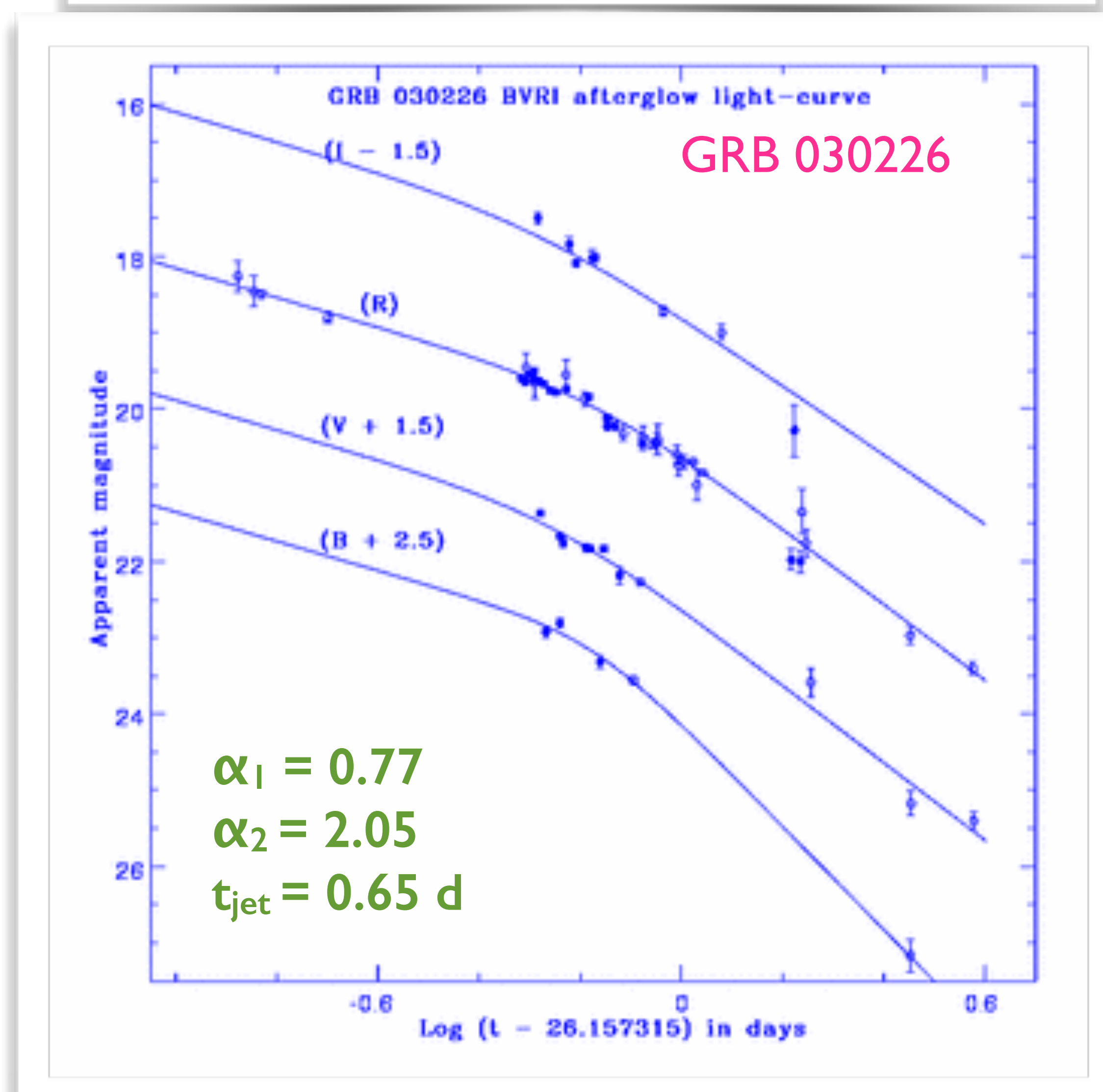
★Extent of collimation through achromatic breaks in light curves



GRBs in the Pre-*Swift* era

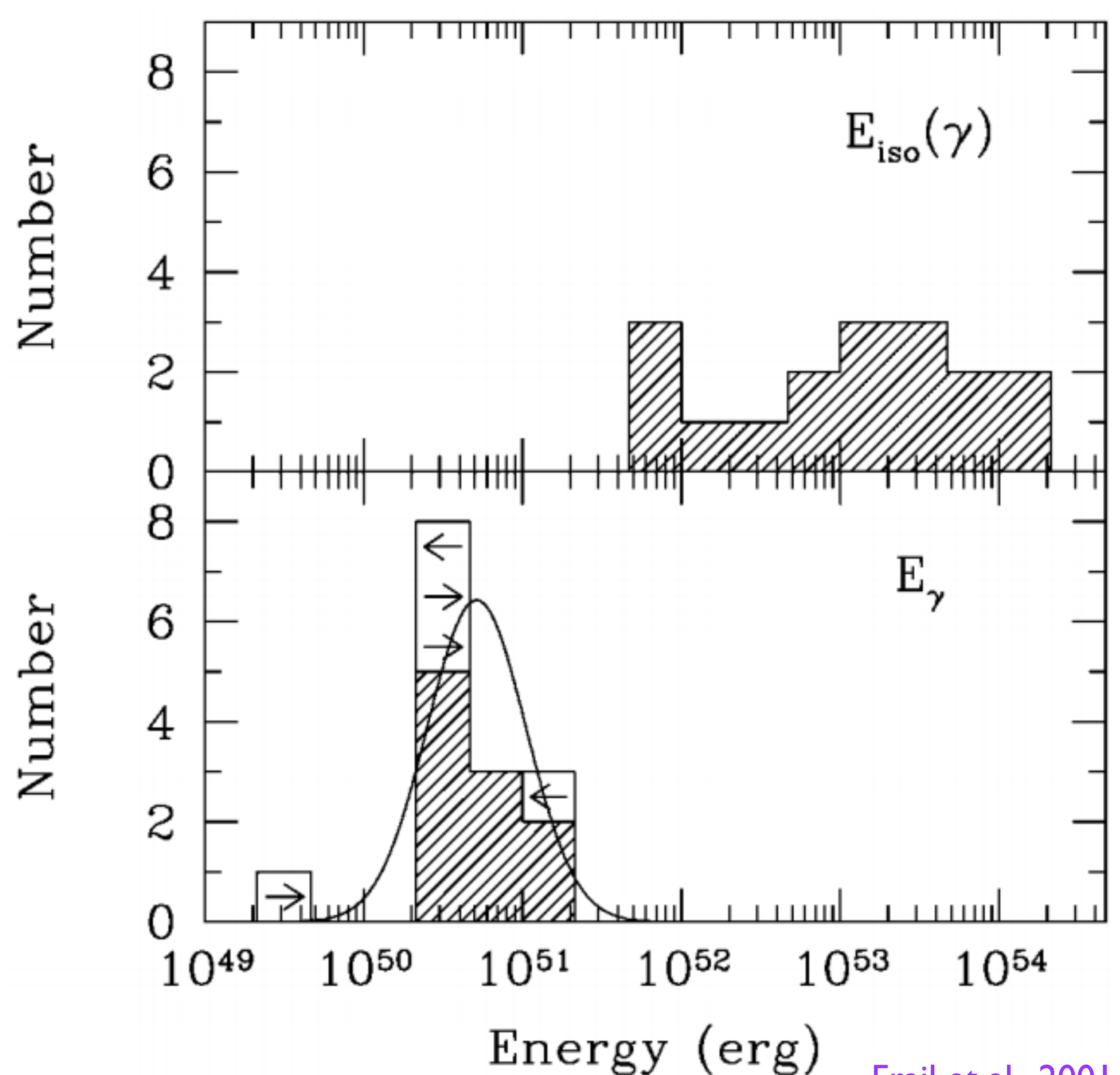
Signature of a jet-break





Pandey et al. 2004

Energetics - Pre-*Swift* GRBs



Frail et al. 2001

GRBs in the *Swift* era

Launched November 2004

Swift Burst Alert Telescope (BAT): 15 to 150 keV
Swift X-Ray Telescope (XRT) : 0.2 to 10 keV
Swift Ultra-Violet Optical Telescope (UVOT): 6 filters in the UV and optical range

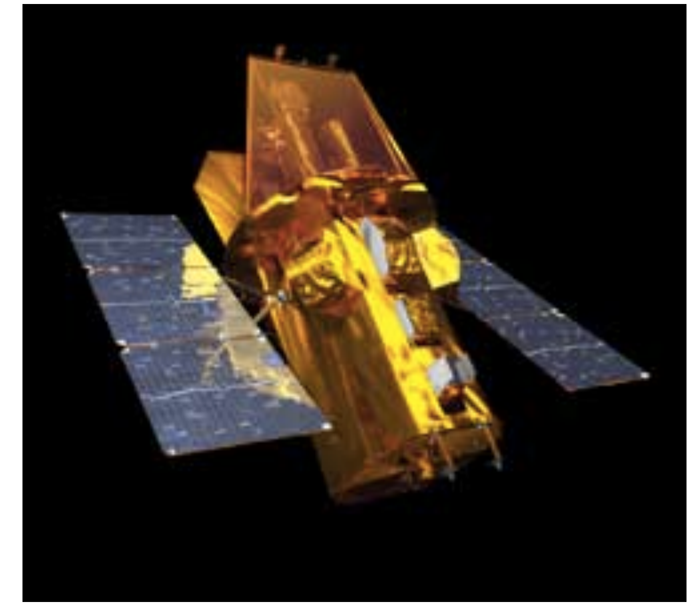
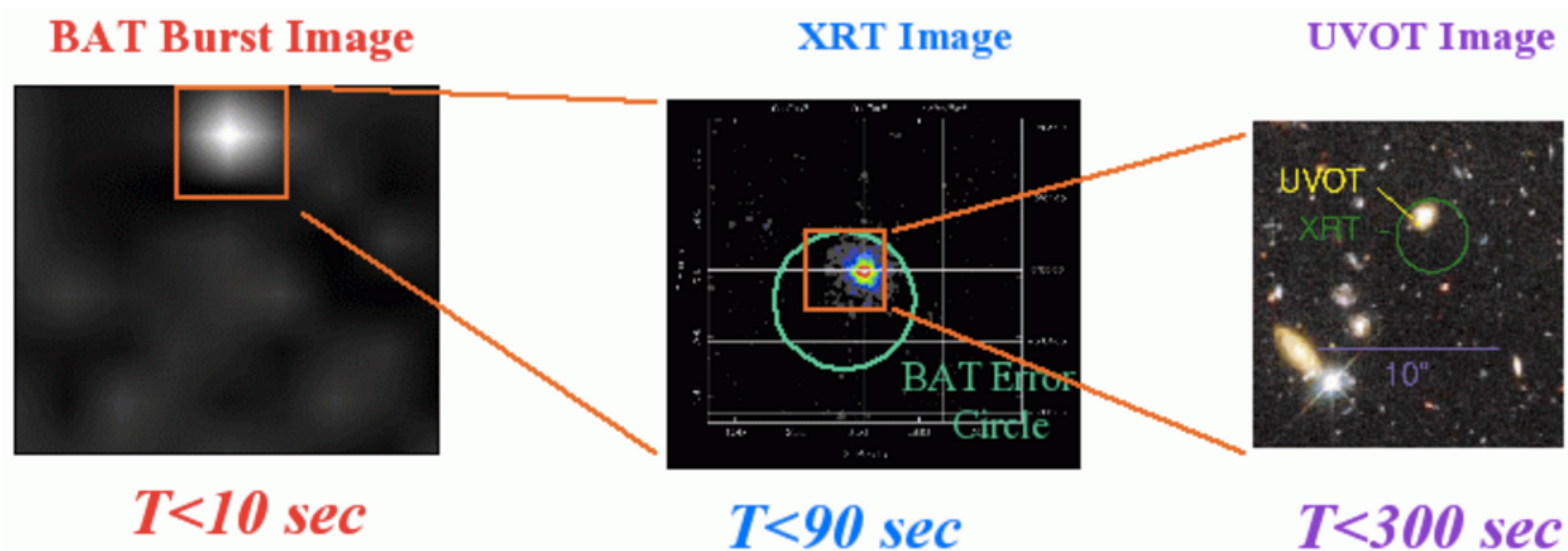


Image: *Swift* NASA

Image: *Swift* NASA



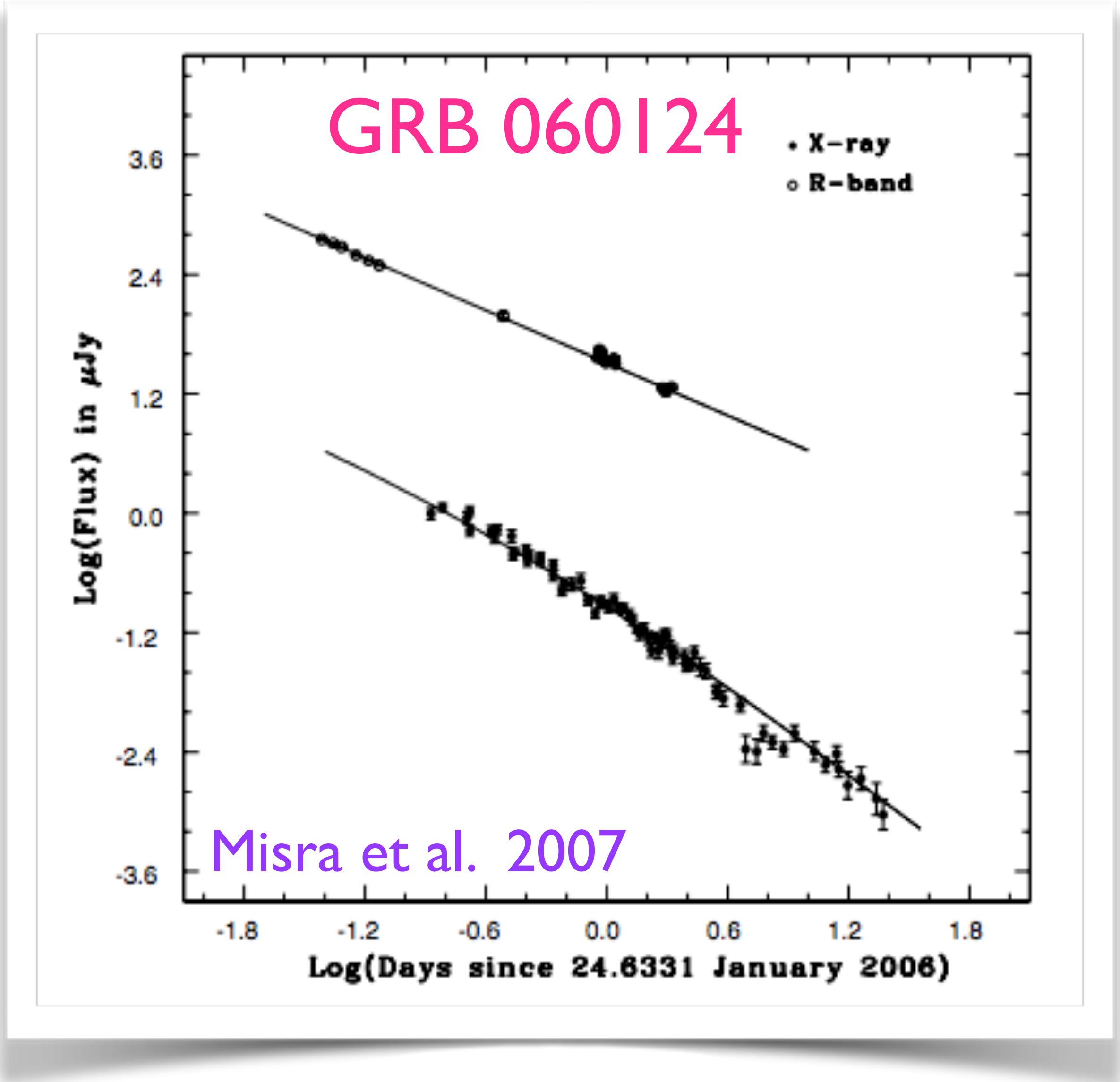
Position ~ 3 arcmin | Position ~ 3 arcsec | Position ~ 3 arcsec

- Limited spectral coverage
- Often miss $E_{p,i}$ (keV)
- Leads to large uncertainties in $E_{\gamma,iso}$

Puzzles in the *Swift* era

✓ Absence of achromatic breaks: Different behavior seen in X-ray & optical light curves (no breaks or chromatic breaks)

✓ Can the energetics be trusted?

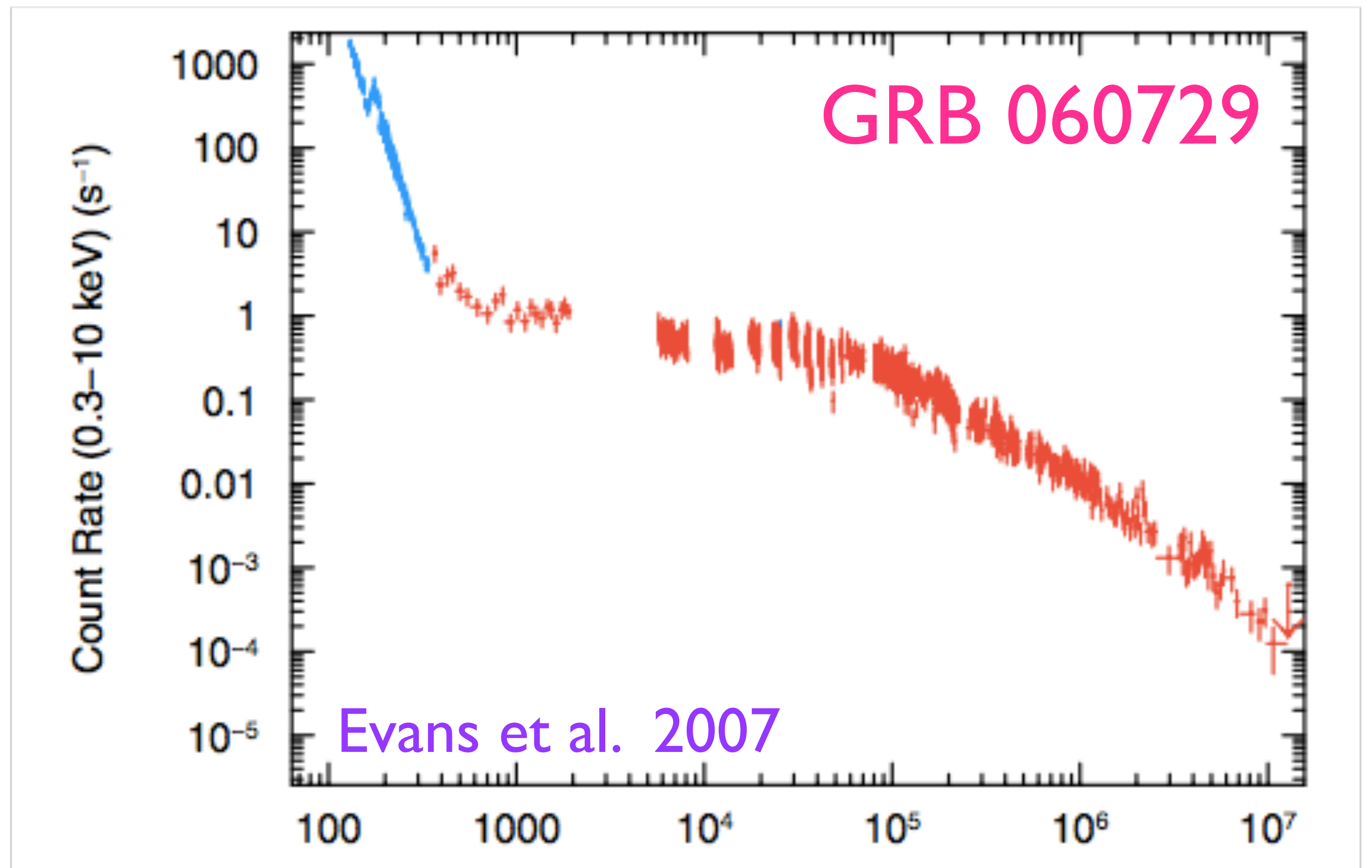


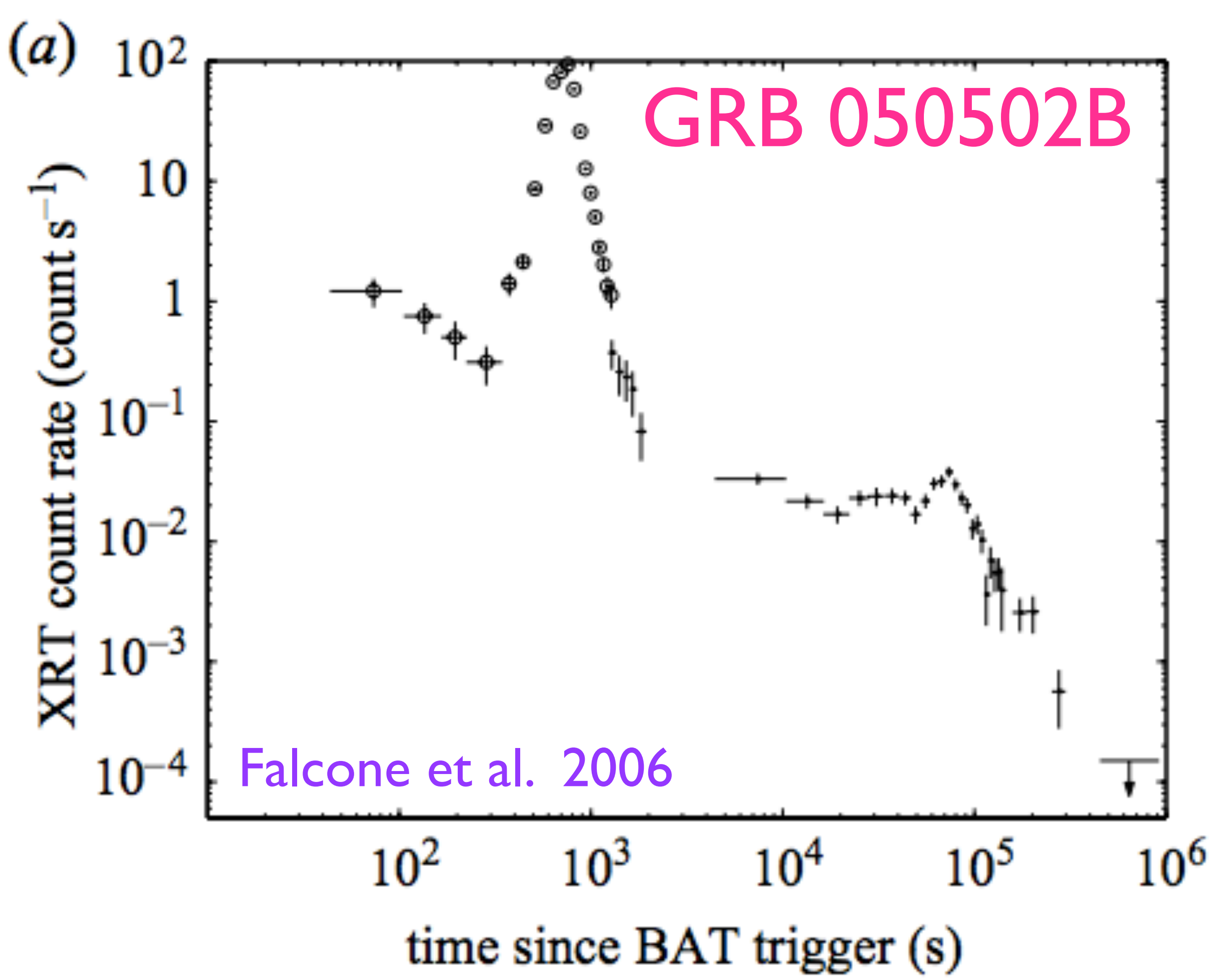
Puzzles in the *Swift* era

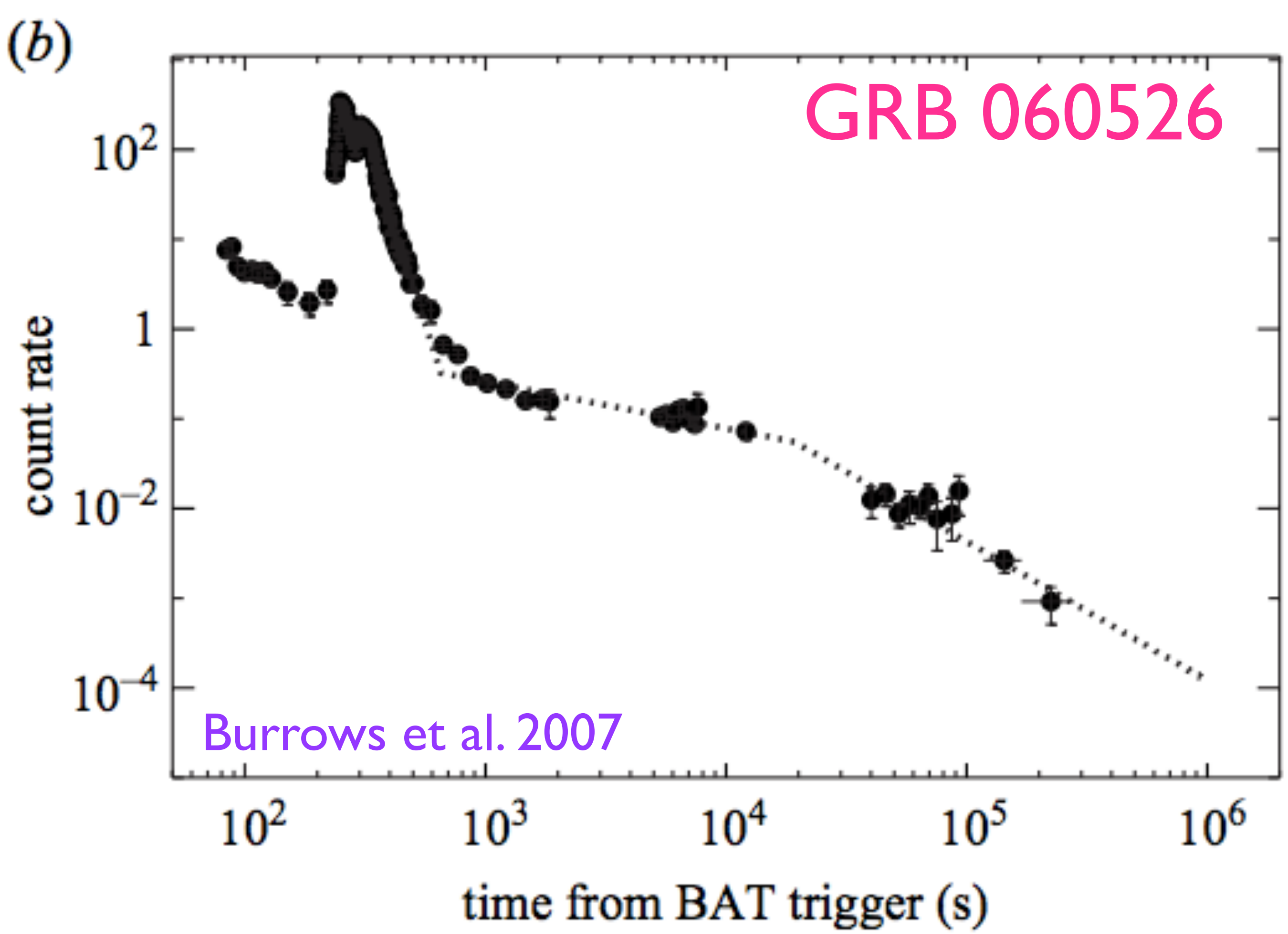
✓Absence of achromatic breaks: Different behavior seen in X-ray & optical light curves (no breaks or chromatic breaks)

✓Bright flares and long lived plateaus in X-ray afterglows

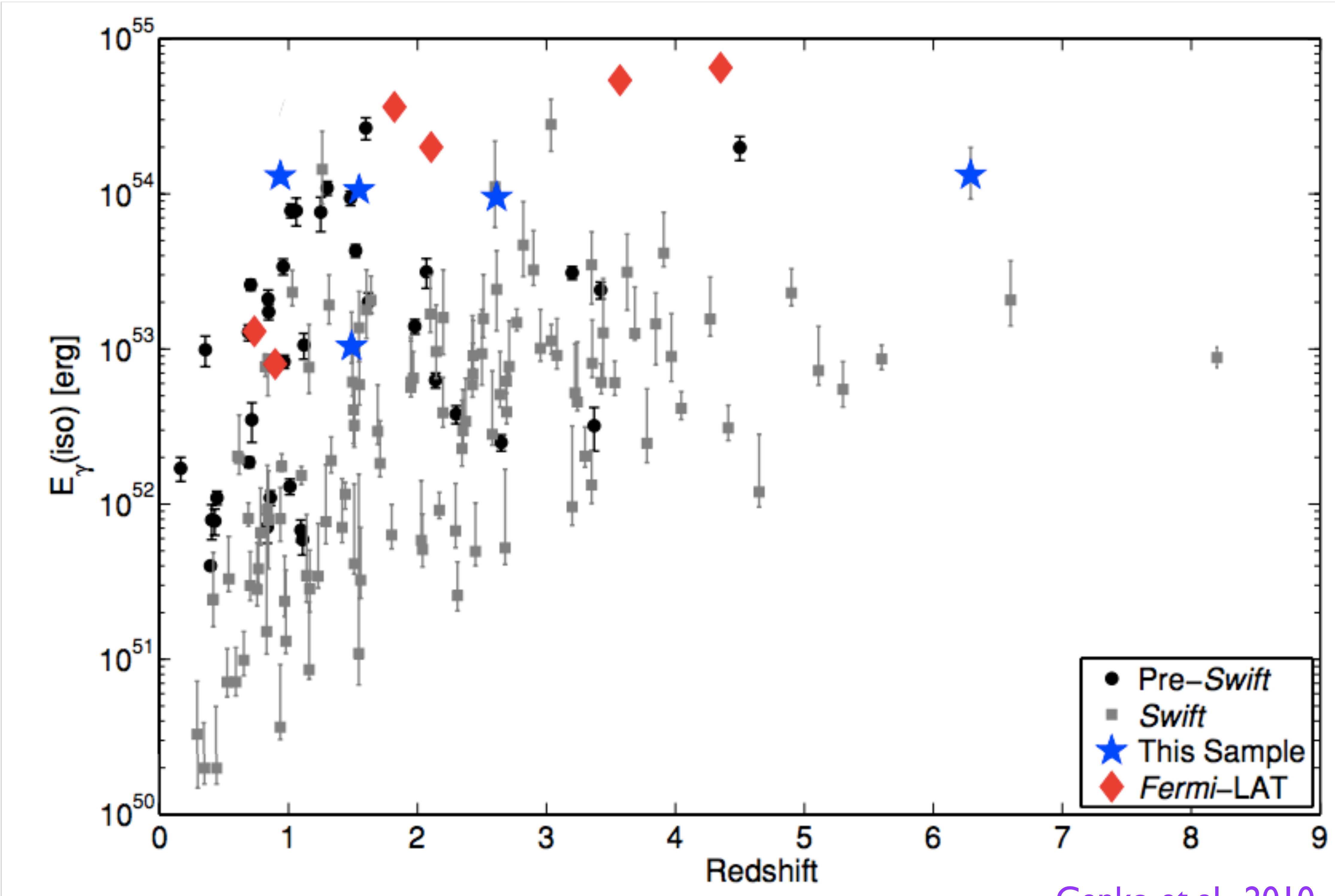
✓Can the energetics be trusted?





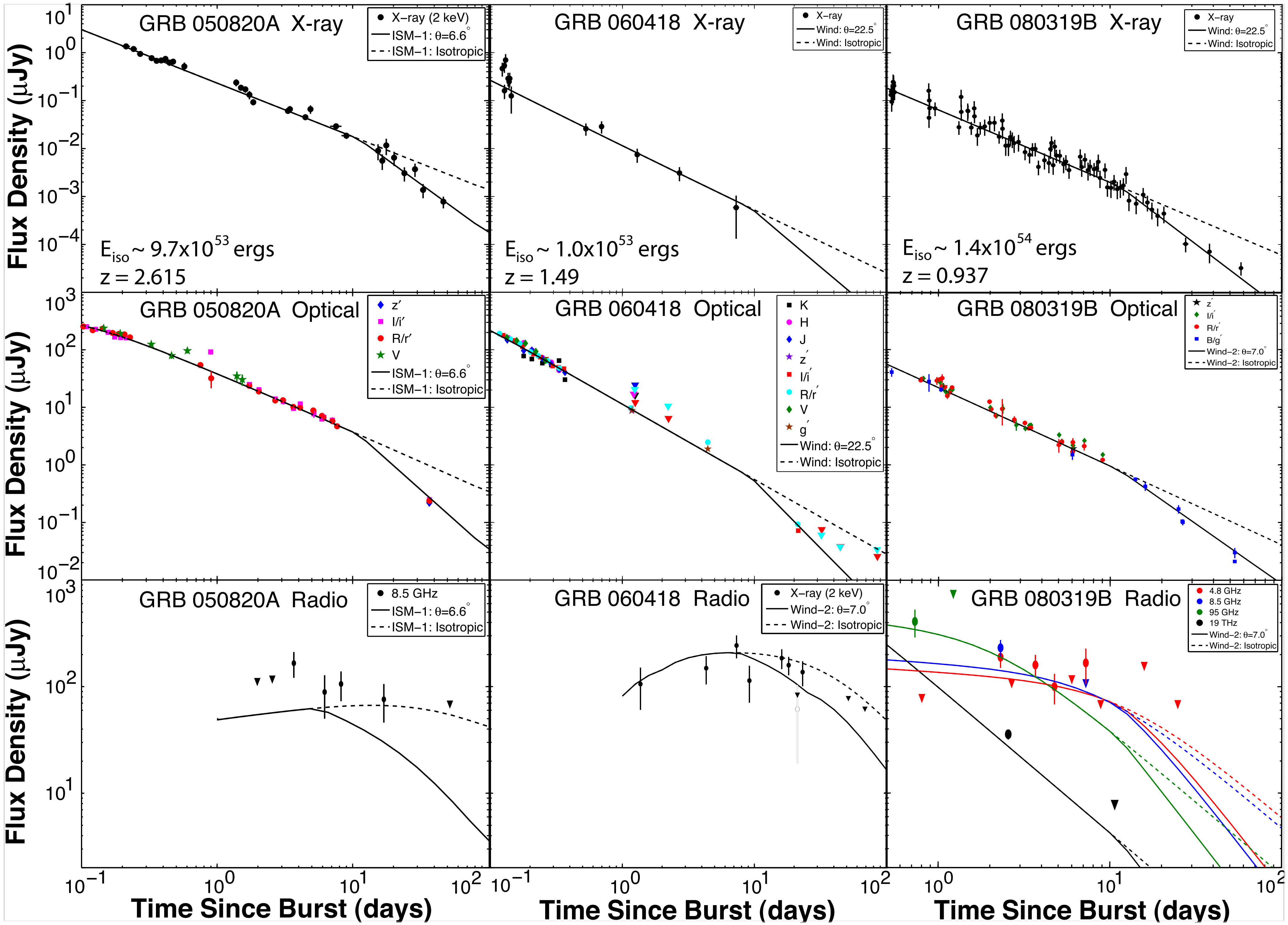


The brightest *Swift* GRBs



Cenko et al. 2010

The brightest *Swift* GRBs



Cenko et al. 2010

✓ Brightest (E_{iso} ~ 10^{54} ergs) *Swift* bursts show an achromatic break

Collimation and Energetics of *Swift* GRBs

GRB	$t_{\rm jet}$ (d)	θ (°)	E_γ (10^{51} erg)	$E_{\rm KE}$ (10^{51} erg)
050820A	$11.1^{+0.1}_{-1.7}$	$6.6^{+0.5}_{-0.3}$	$6.4^{+3.2}_{-1.5}$	$35.6^{+11.3}_{-9.4}$
050904	2.6 ± 1.0	8.0	$12.9^{+6.6}_{-3.9}$	$8.6^{+8.4}_{-4.3}$
060418	$7.6^{+2.0}_{-2.2}$	$22.5^{+0.9}_{-2.5}$	$3.0^{+3.8}_{-1.1}$	$0.94^{+0.22}_{-0.35}$
070125	$3.69^{+0.03}_{-0.07}$	13.2 ± 0.6	$25.3^{+5.1}_{-4.6}$	$1.7^{+0.4}_{-0.2}$
080319B	$11.8^{+0.8}_{-1.3}$	$7.0^{+0.7}_{-0.1}$	$10.2^{+3.2}_{-0.1}$	$0.35^{+0.38}_{-0.01}$

Cenko et al. 2010

GRBs in the *Fermi* era

Launched June 2008

Fermi Large Area Telescope (LAT): 20 MeV to 300 GeV
Fermi Gamma Ray Burst Monitor (GBM): 8 keV to 40 MeV
~250 GRBs/year detected by GBM
~half in the LAT field of view
Greater than 130 GRB detections with LAT

Bright LAT bursts with good localizations are followed-up by *Swift*

Image: *Fermi* NASA

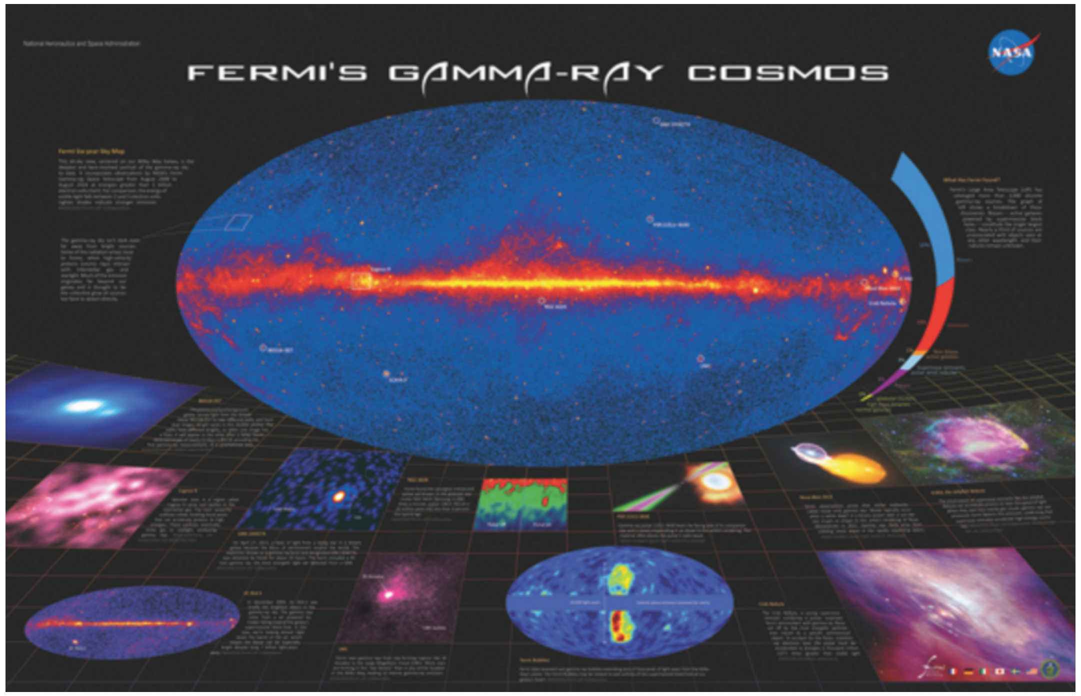
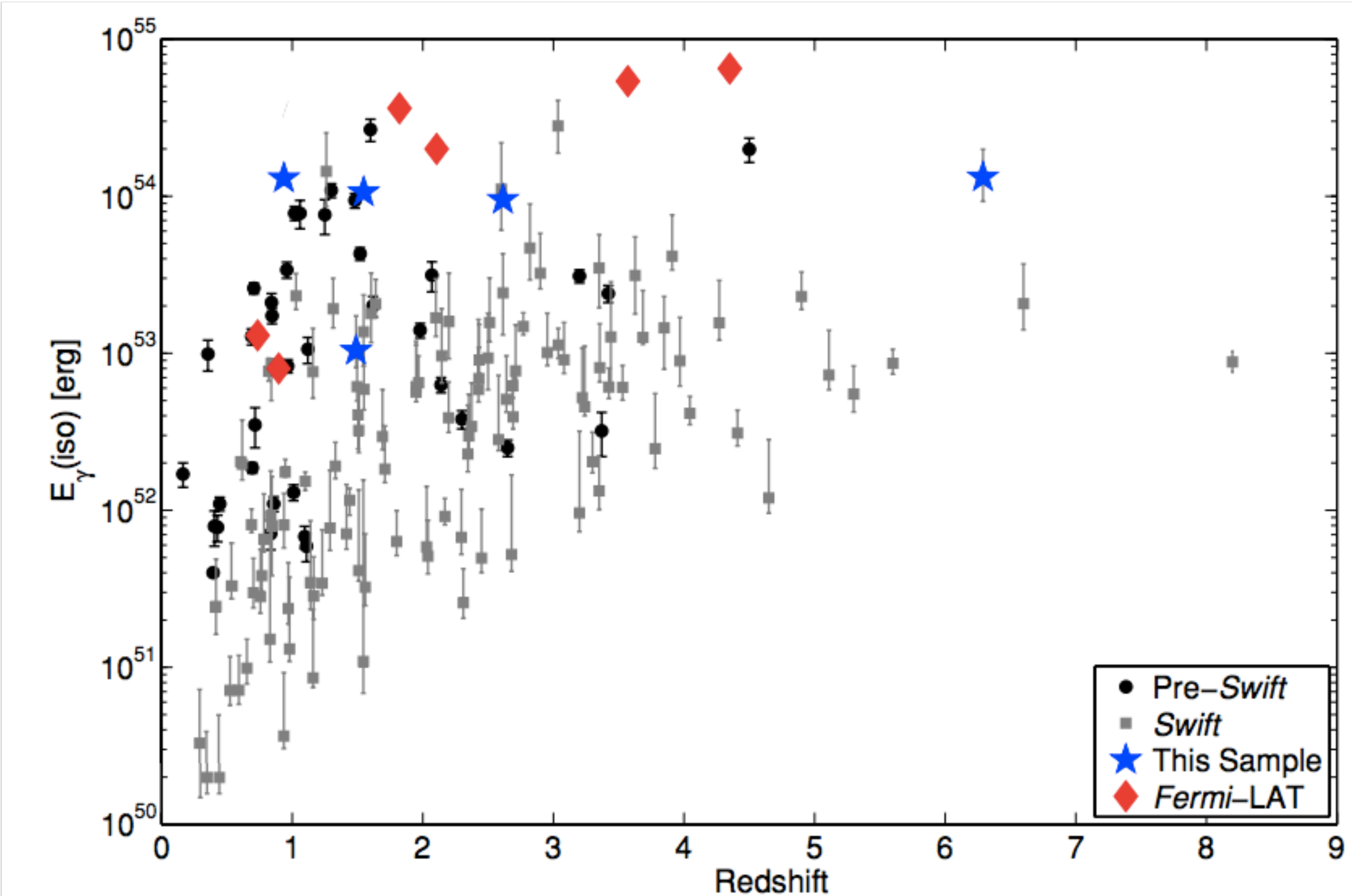
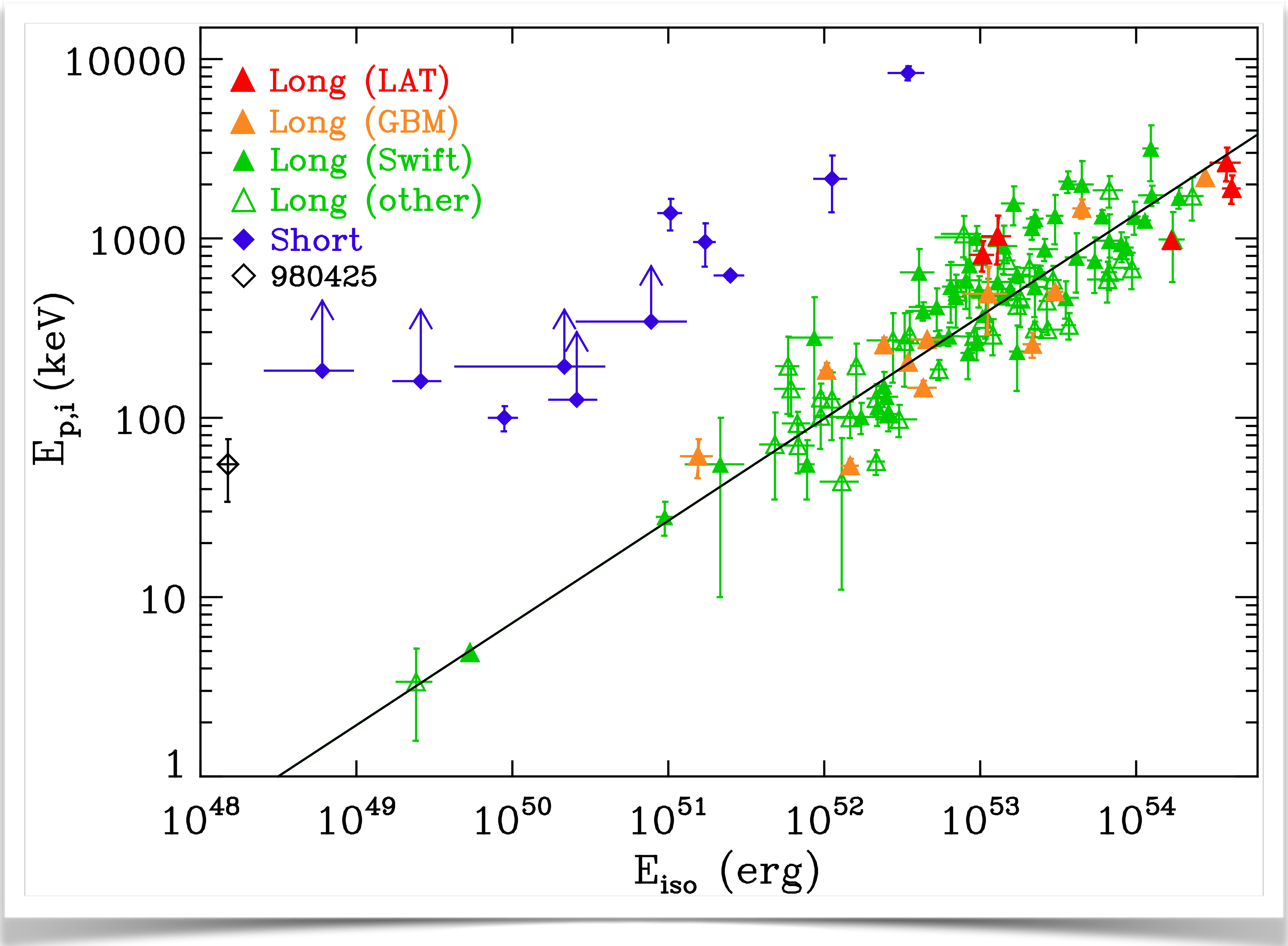


Image: *Fermi* NASA

The brightest *Swift/Fermi* GRBs



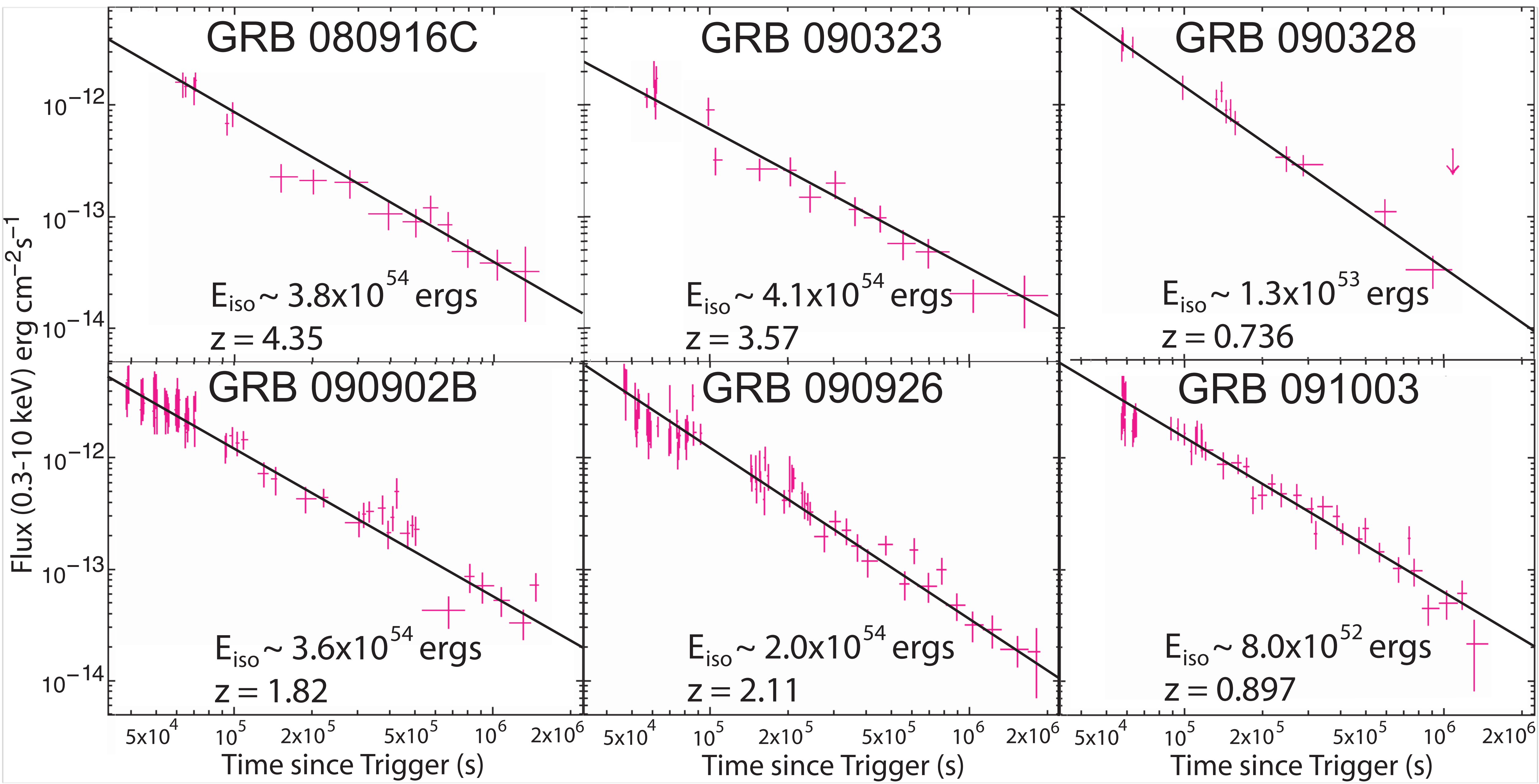
Cenko et al. 2010



Long (LAT)
Long (GBM)
Long (Swift)
Long (other)
Short
980425
10000
1000
100
10
1
$E_{p,i}$ (keV)
10^{48}
10^{49}
10^{50}
10^{51}
10^{52}
10^{53}
10^{54}
E_{iso} (erg)

Amati 2010

The astrophysics of the most energetic bursts



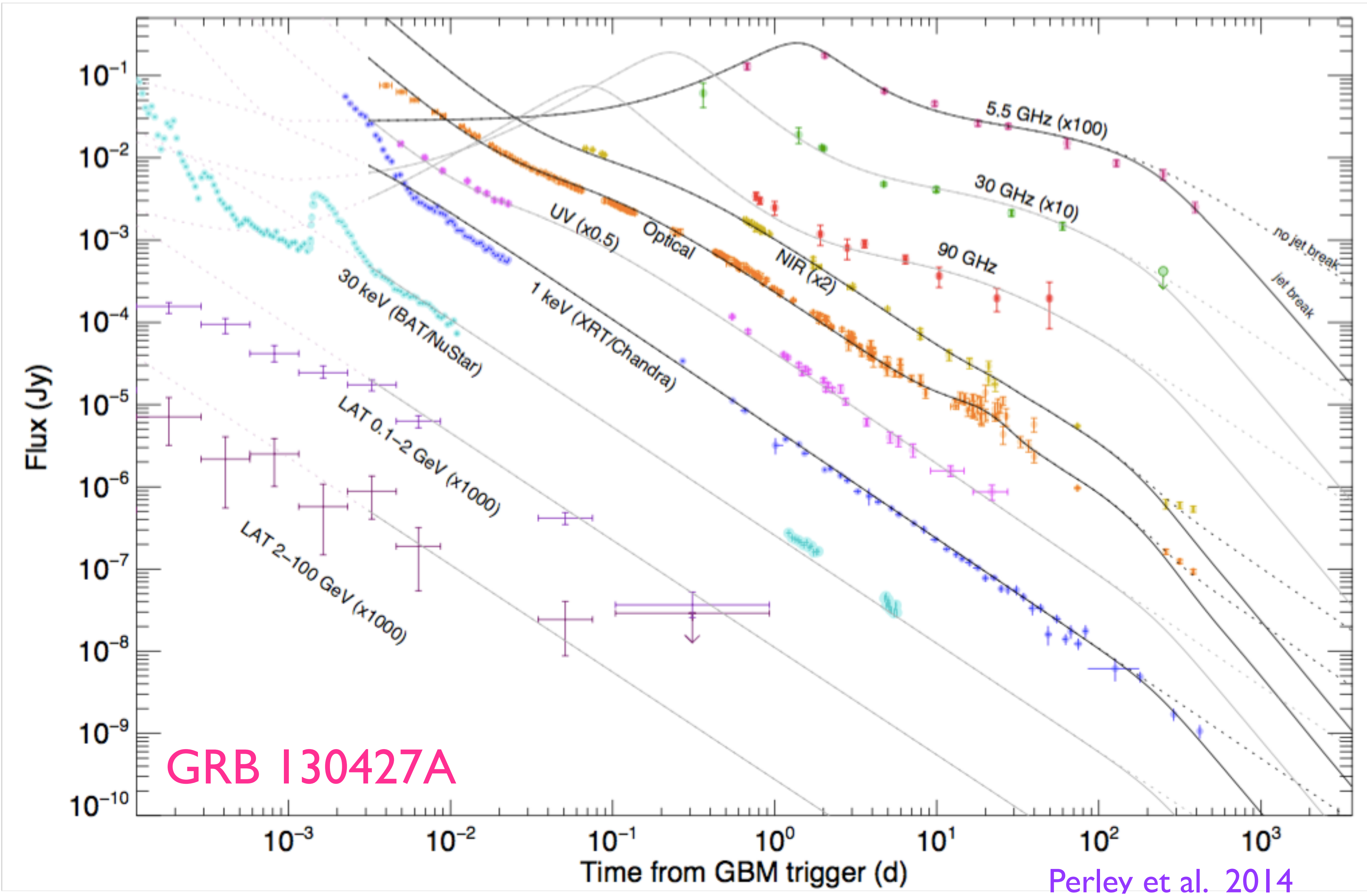
✓ *Swift* XRT light curves of *Fermi* LAT GRBs with no break

The astrophysics of the most energetic bursts

Joint *Chandra-HST-JVLA* Program: Fruchter, Misra & Others
Chandra (120 ks); *HST* (11 orbits); JVLA (18 hours)

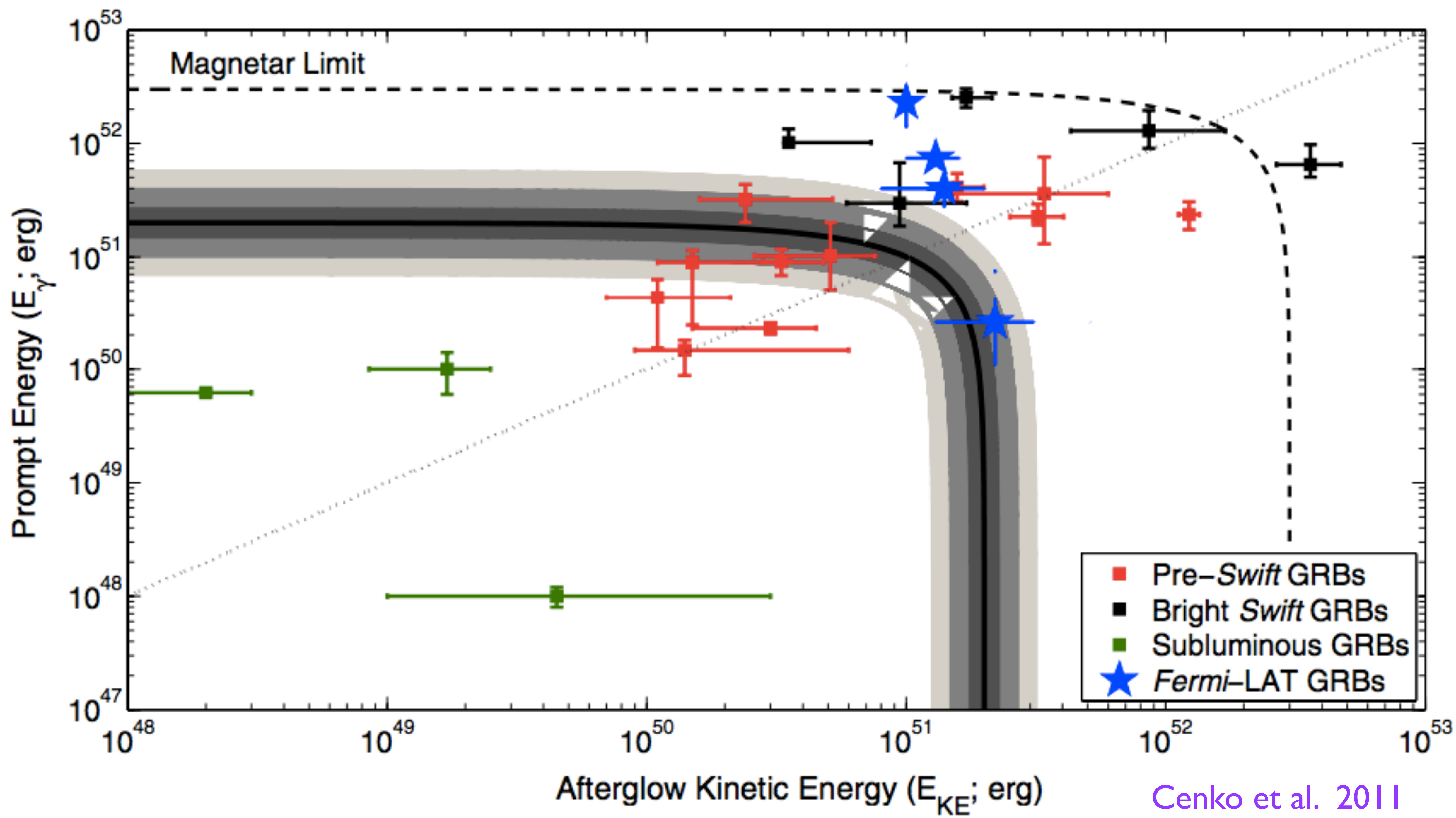
✓ *Fermi* LAT detected burst with $E_{iso} \sim 10^{54}$ ergs
✓ Good multi-wavelength observations
✓ 3 visits each with *Chandra* & *HST*
Sampling based on the decay of the afterglow

✓ Host galaxy measurements with *HST* (typically 6-12 months after the burst)



5.5 GHz (x100)
30 GHz (x10)
90 GHz
NIR (x2)
Optical
UV (x0.5)
1 keV (XRT/Chandra)
30 keV (BAT/NuStar)
LAT 0.1–2 GeV (x1000)
LAT 2–100 GeV (x1000)
no jet break
jet break
Flux (Jy)
Time from GBM trigger (d)
GRB 130427A
Perley et al. 2014

The brightest *Swift/Fermi* GRBs - Energetics



Cenko et al. 2011

Conclusions

✓ *Jet break signature seen in Pre-Swift era GRB afterglows - responsible for estimating the true energetics of the burst*

✓ *Swift era witnessed complexities in the afterglow light curve; however the brightest Swift GRBs show evidence for collimation (Cenko et al. 2010); selection effects*

✓ *No evidence of a jet break in Fermi LAT bursts up to very long time*
✓ *Bursts occurring in low density environments (observations of GRB 130427A best explained by a tenuous wind stratified density profile (Perley et al. 2014))*

✓ *Can the energetics be trusted in the absence of a jet break?*
✓ *Late-time radio calorimetry*