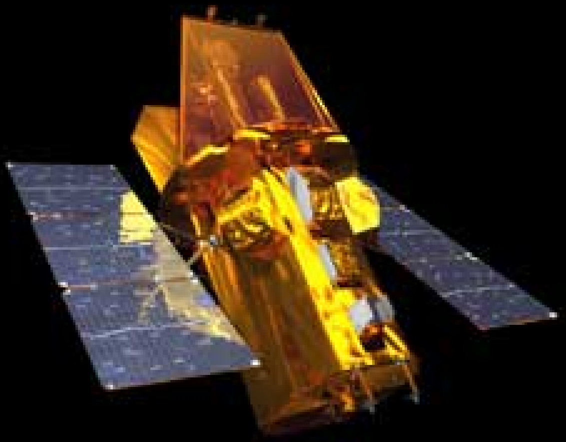
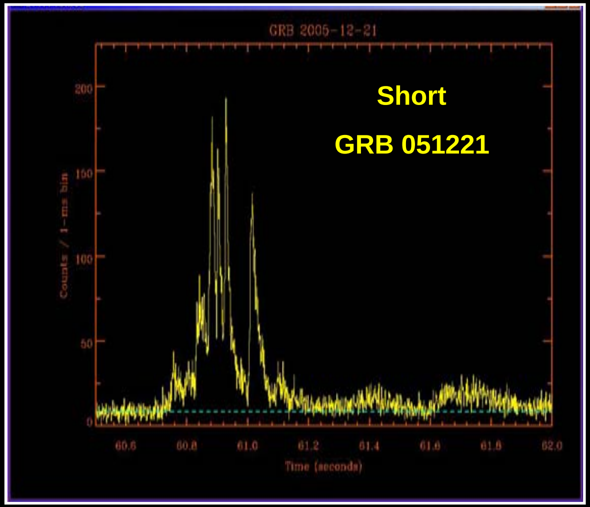
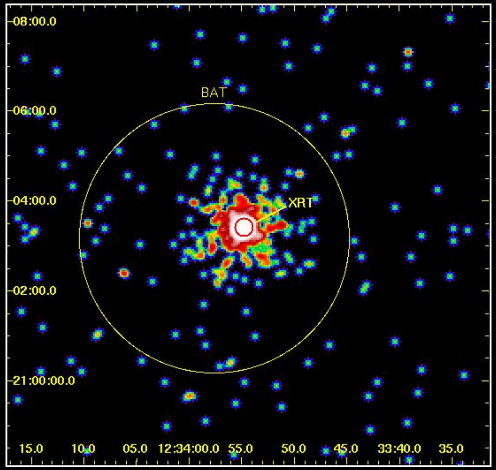


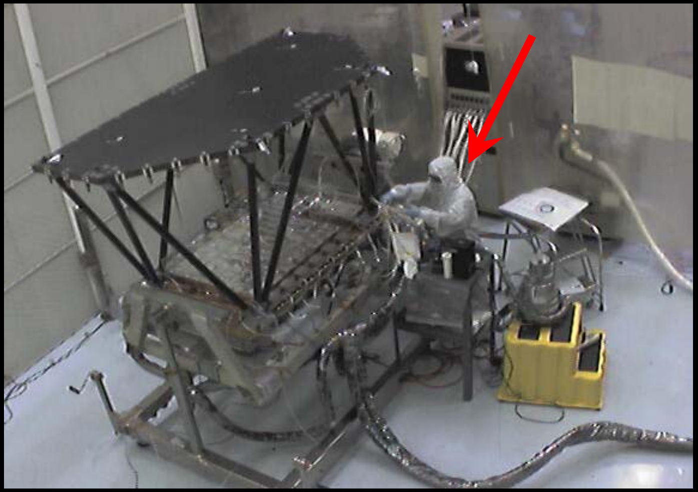


Swift Gamma-ray Burst Explorer Instrumentation & New Puzzles of GRBs



Goro Sato
NASA/GSFC

Let me introduce myself



- Research Areas
  - X-ray and Gamma-ray Astrophysics
    - Gamma-ray Bursts
  - Development of Gamma-ray Detectors
- 2000 -
  - Ph.D. Student
  - @ Univ. of Tokyo and ISAS/JAXA, Japan
  - Development of Gamma-ray Detectors for Space Missions
  - CdTe / CdZnTe semiconductor detectors
- 2002 -
  - Development of Swift/BAT instrument
  - Stayed at NASA/GSFC for ~2 years
  - CdZnTe Detector Calibration & Response
  - GRB Study with Swift
- 2006 March
  - Ph.D. (Physics) @ Univ. of Tokyo
- 2006 May - Present
  - Postdoc @ NASA/GSFC

Calibration test @ NASA/GSFC 2002-2003

Outline

Swift observatory

BAT response/calibration

Swift GRBs

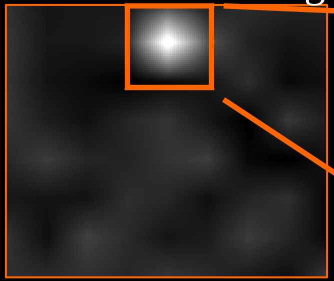
X-ray lightcurves

Jet breaks

Current work & Future

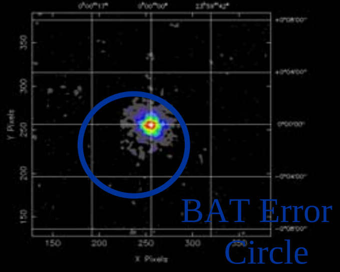
Swift Mission

BAT Burst Image



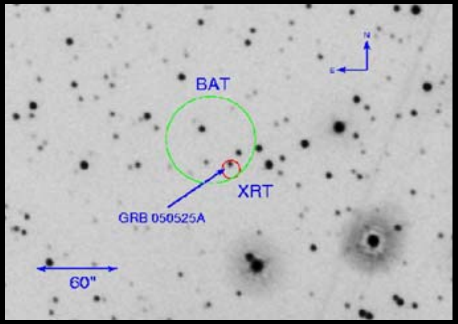
T<10 sec

XRT Image



T<90 sec

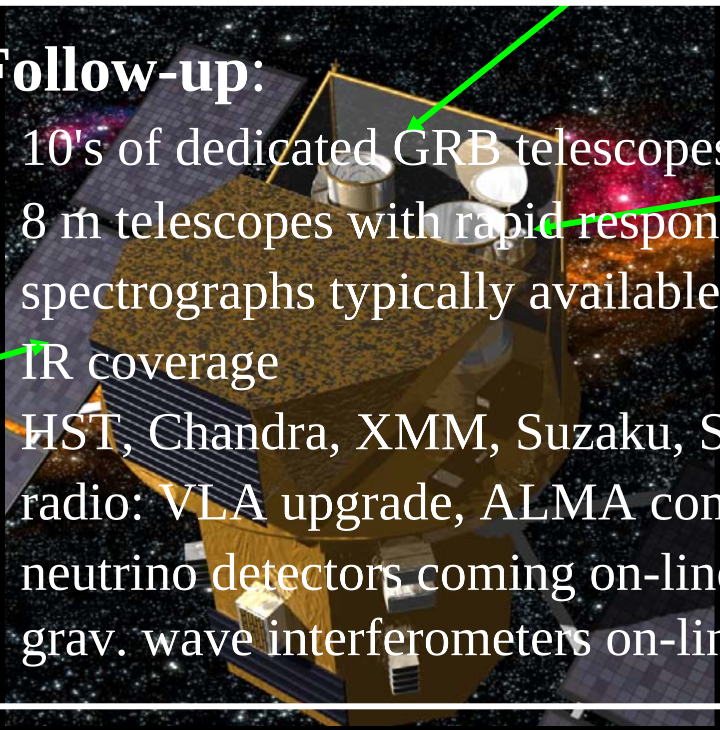
UVOT Image



T<2 min

Swift:

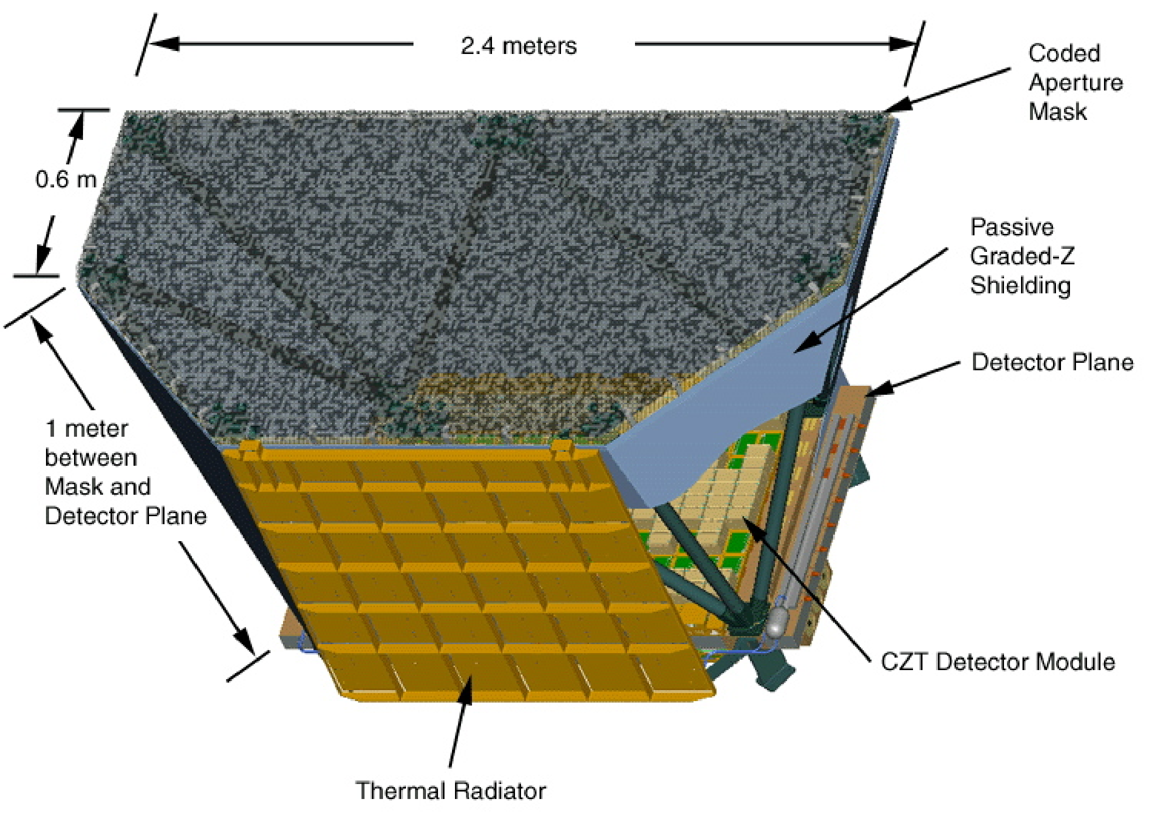
- Sensitive Swift instruments
- 100's of GRBs
- Versatile GRB trigger
- Accurate rapid positions
- Multi-band spectroscopy
- Afterglow on all time scales

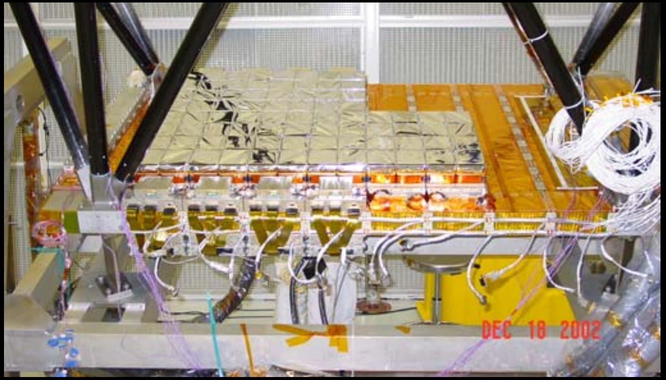


Follow-up:

- 10's of dedicated GRB telescopes
- 8 m telescopes with rapid response
- spectrographs typically available
- IR coverage
- HST, Chandra, XMM, Suzaku, Spitzer
- radio: VLA upgrade, ALMA coming
- neutrino detectors coming on-line
- grav. wave interferometers on-line

Burst Alert Telescope (BAT)



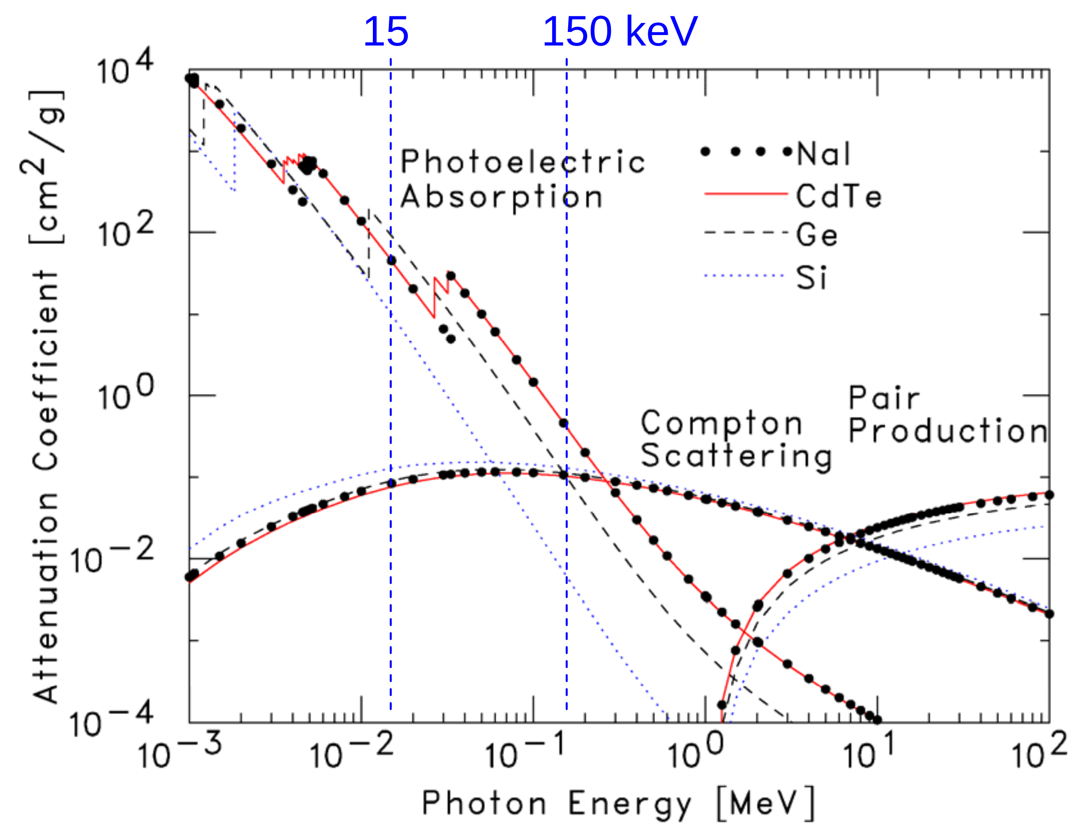


- Energy range: 15-150 keV
- Energy resolution: ~3 keV @ 22 keV, ~7 keV @ 122 keV
- Loc. accuracy: 1-4 arcmin
- PSF: 22 arcmin
- Field of view: 2 steradian
- 4x4 mm^2 with 2 mm thickness, 32K CdZnTe, 5200 cm^2
- Autonomous operations

CdTe/CdZnTe semiconductors

CdTe
Atomic Number: 48/52
Density: 5.85 g cm^{-3}
Egap: 1.4 eV

CdZnTe
Atomic Number: 48/30/52
Density: 5.81 g cm^{-3}
Egap: 1.6 eV



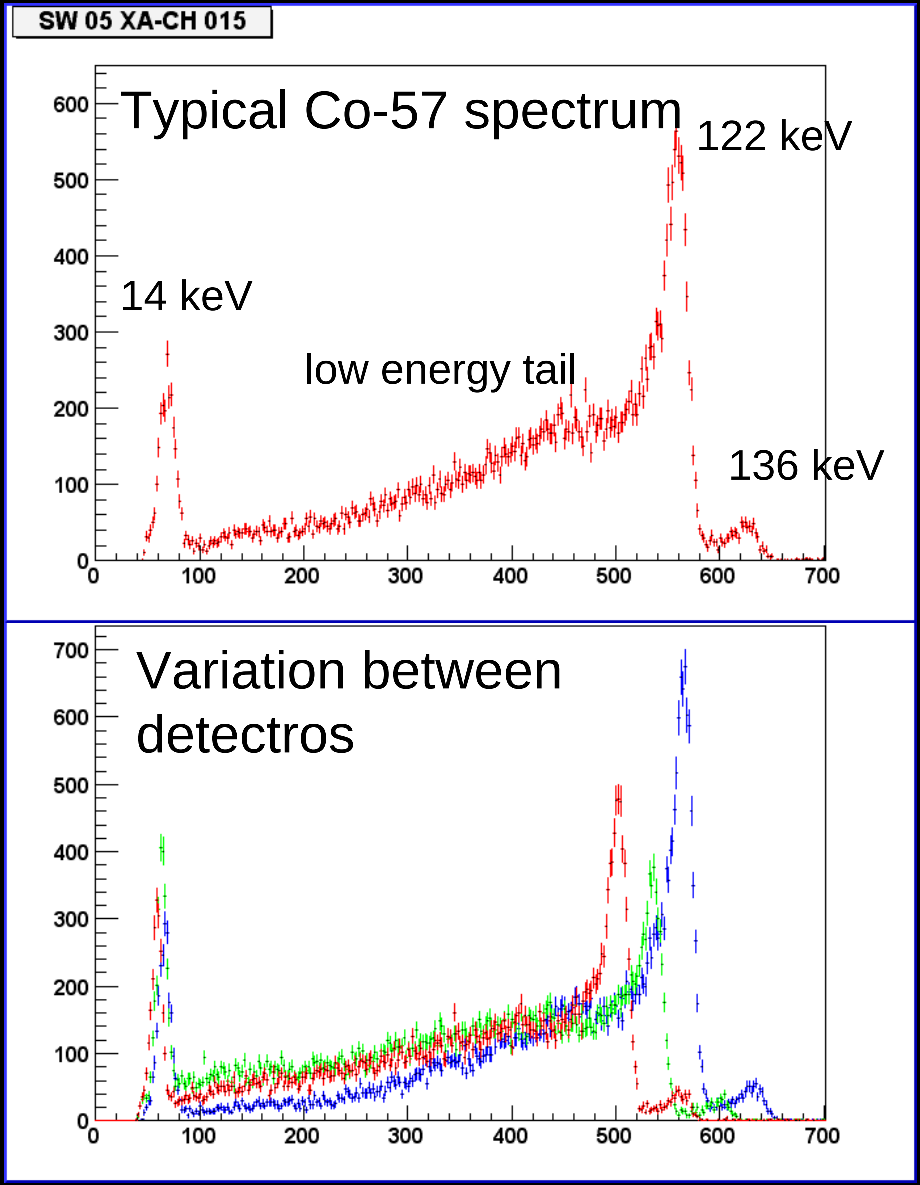
High quantum efficiency
~ NaI

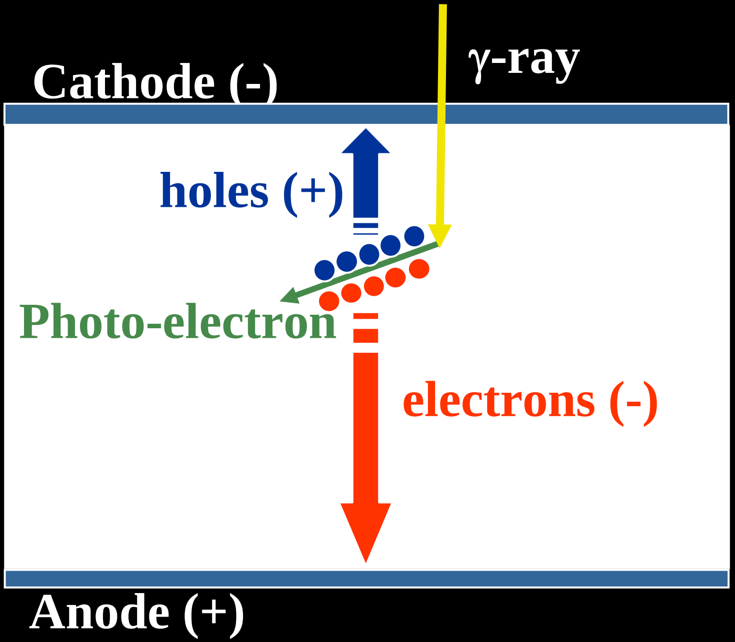
Operate at room temp.

Energy resolution
x 5-10 higher than NaI

Can be fabricated
in a compact array

Charge Transport Properties




γ-ray

Cathode (-)

holes (+)

Photo-electron

electrons (-)

Anode (+)

low mobility (μ)
and short lifetime (τ)
especially for holes

→ depth-dependent efficiency

→ tail shape depends on
energy & incident angle

New method to measure μτ

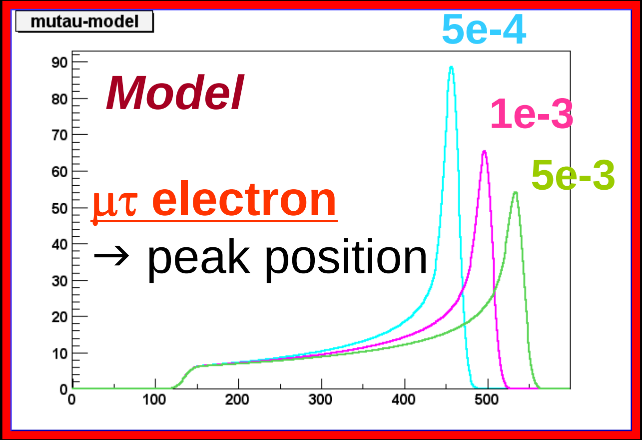
Traditional method: α-particles

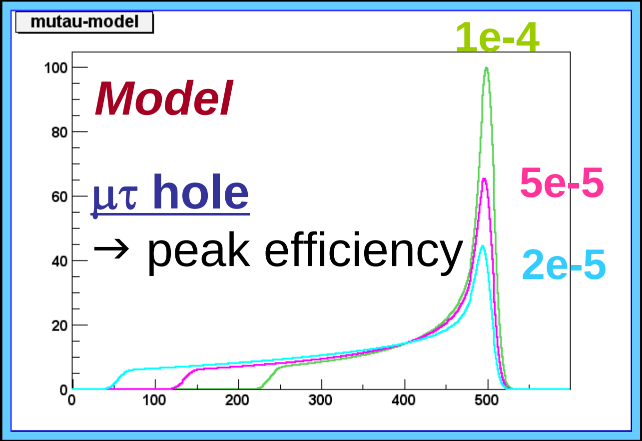
My method: spectrum

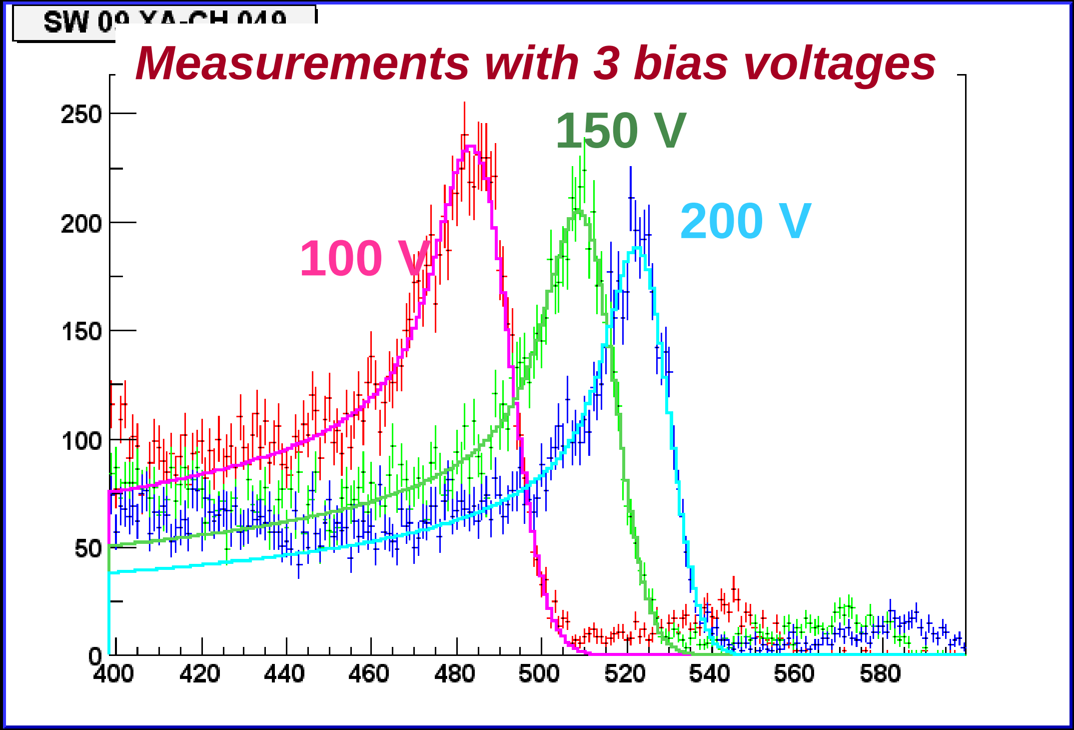
Sato et al. 2002 IEEE NS 49

electron **hole**

$$\eta(x)=\frac{(\mu\tau)_e E}{D}\left[1-\exp(\frac{D-x}{(\mu\tau)_e E})\right]+\frac{(\mu\tau)_h E}{D}\left[(1-\exp(\frac{x}{(\mu\tau)_h E})\right]$$



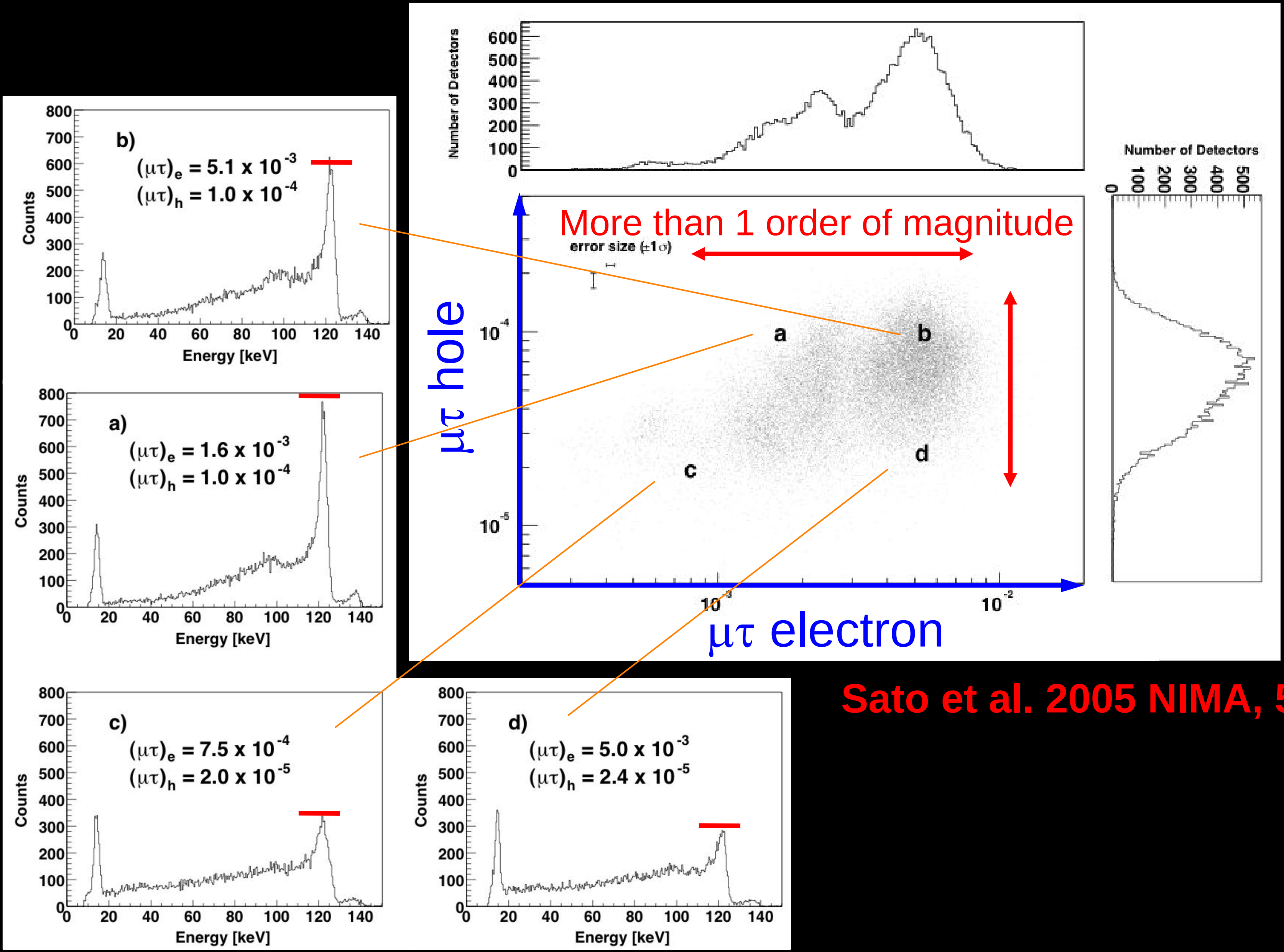




→ spectral fitting

→ determine μτ for electrons and holes simultaneously

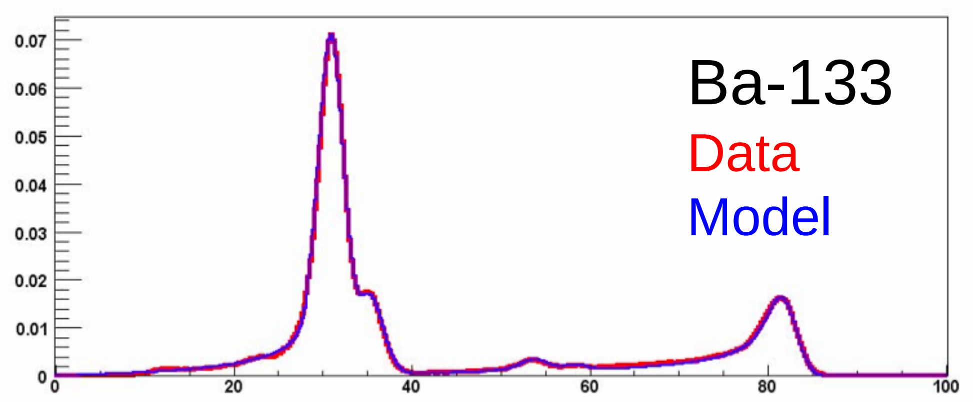
Measured 32K sets of $\mu\tau$ products



Sato et al. 2005 NIMA, 541

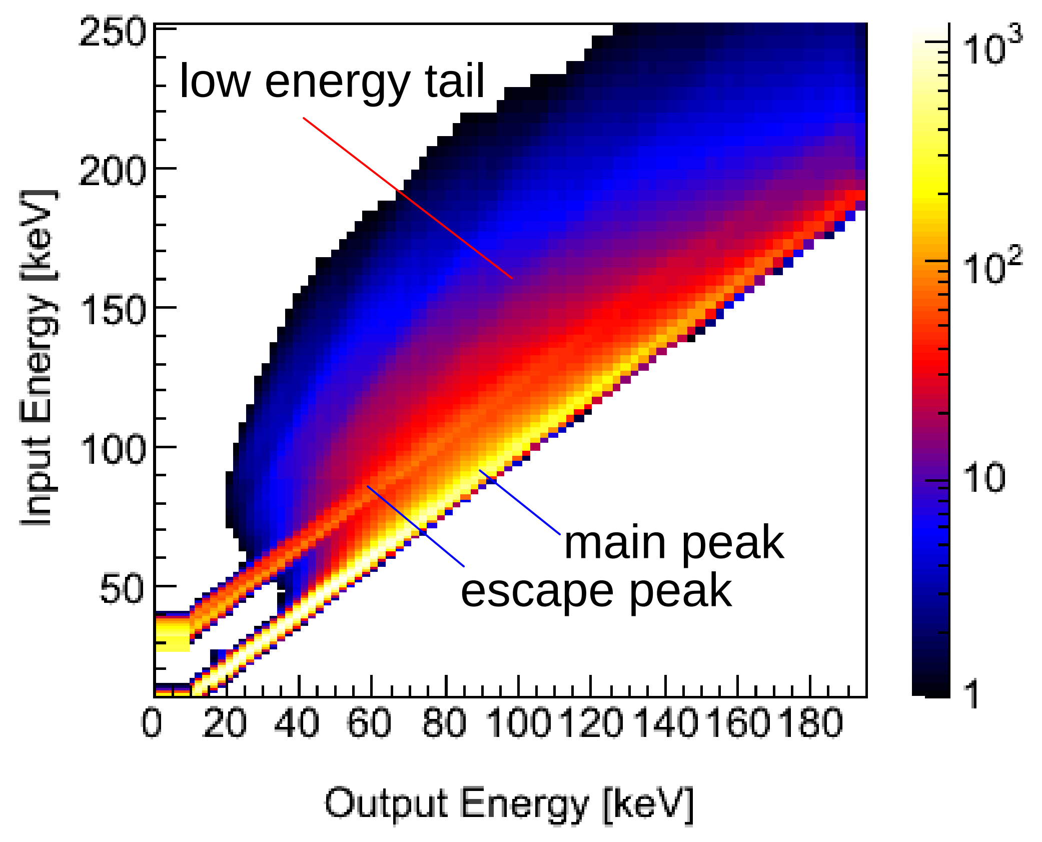
Development of BAT DRM

With the use of $\mu\tau$ products obtained from Co-57 spectra, we can reproduce spectral shapes for any incident energy/angles



Developed the BAT response generator (FTOOL batdrmgen)

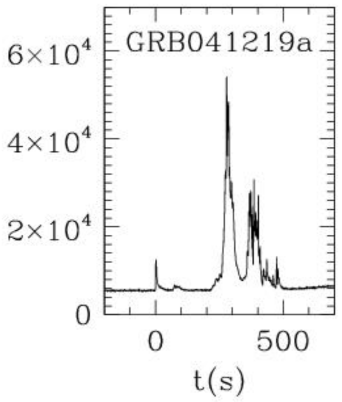
Distributed to the world as a part of Swift science software



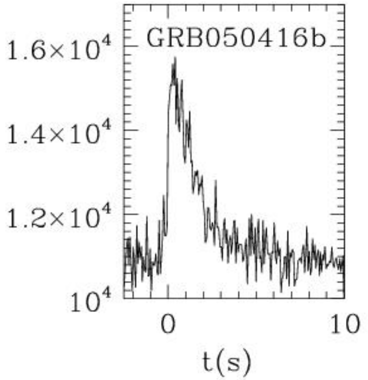
Swift Statistics

196 GRB as of 2006 Nov.
~105 GRBs per year
85% with x-ray detections
95% with XRT @ T<200 ks
~58% with optical detection

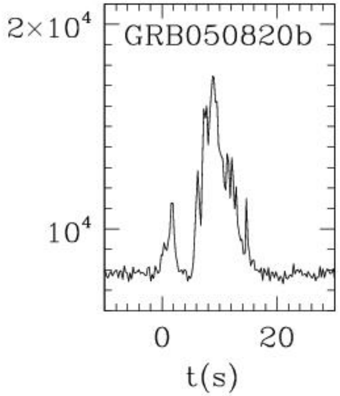
187 non-GRB TOO's
60,000 slews



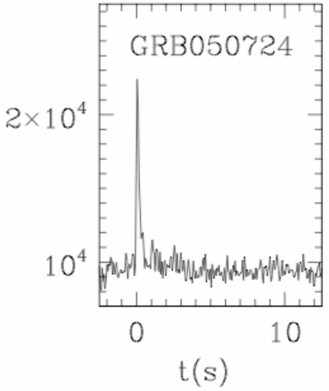
FRED

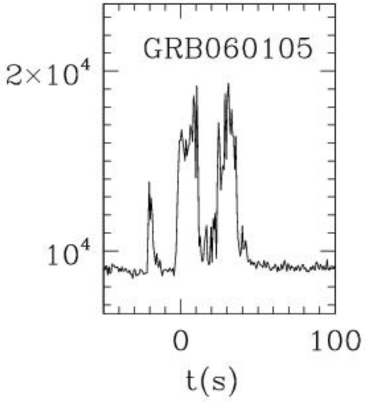


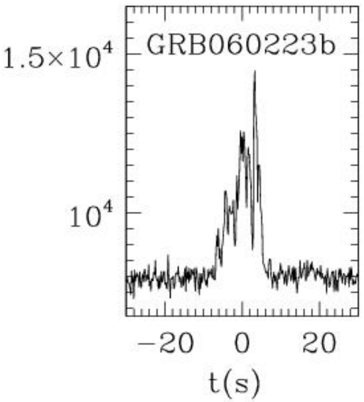
Fast Rise Exponential Decay



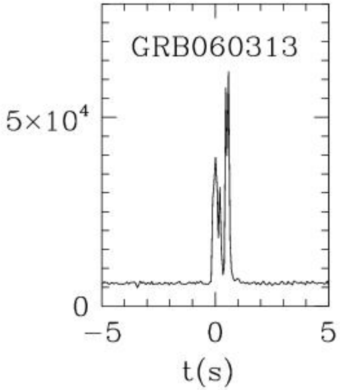
Short GRB

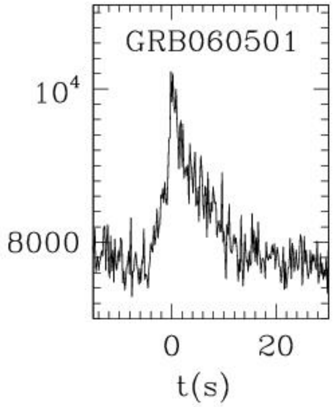




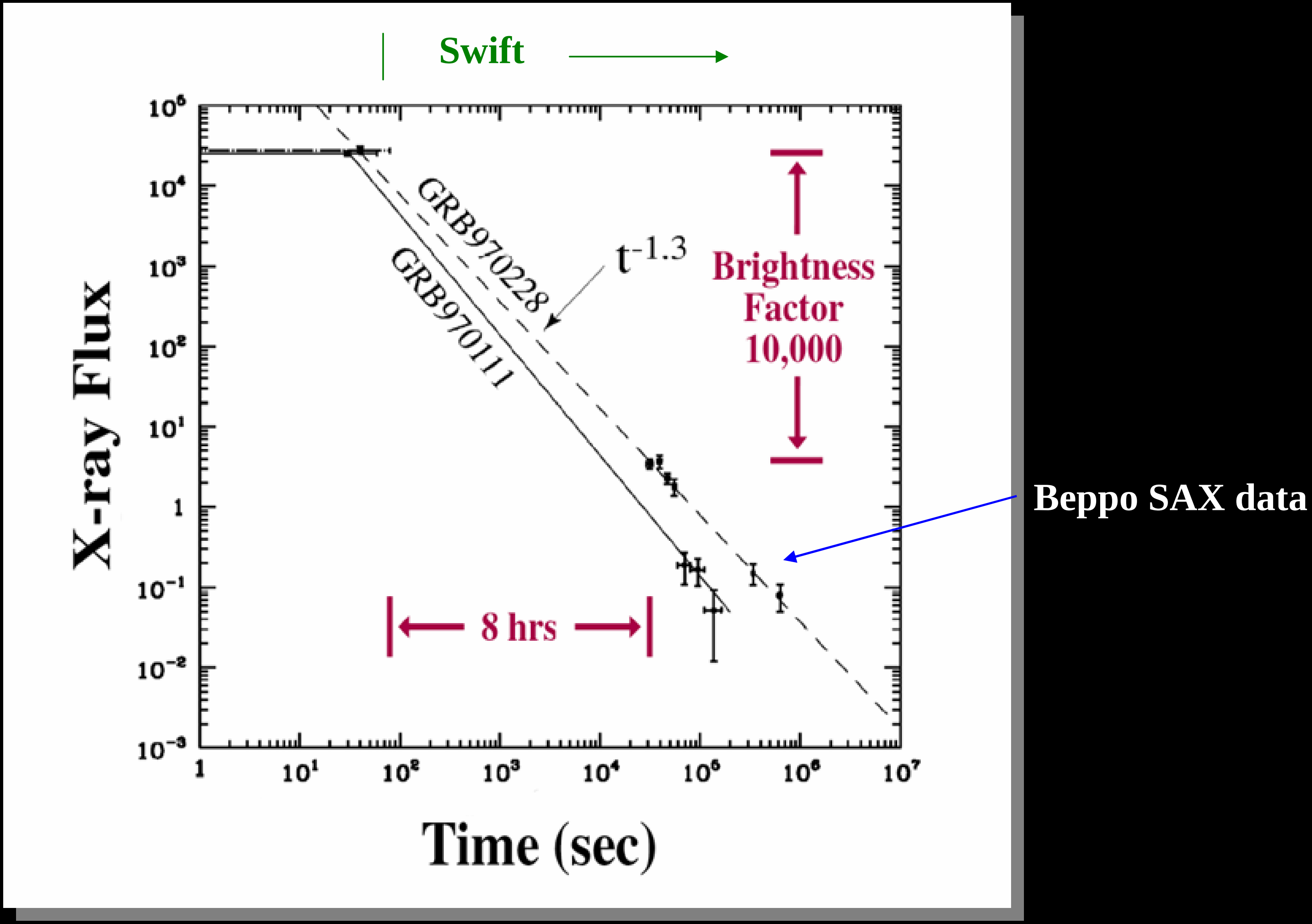


Short GRB



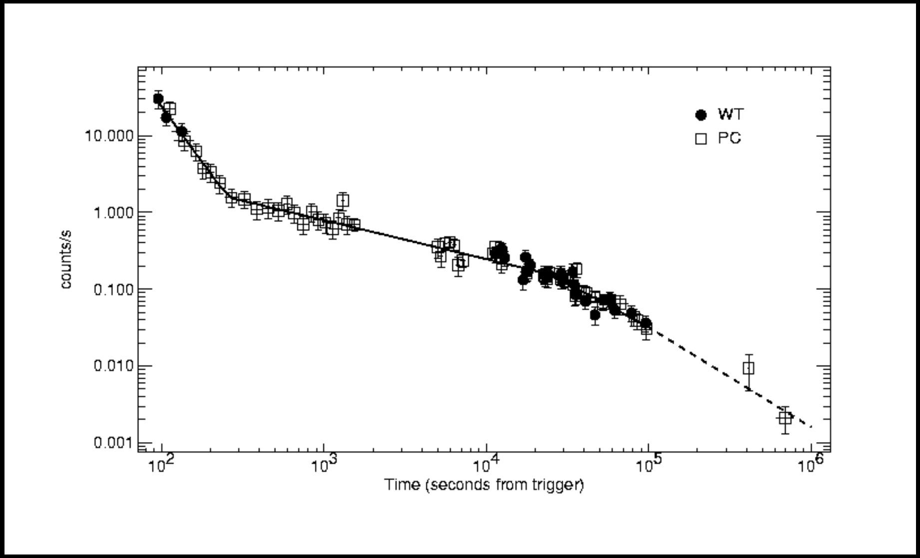


Pre-Swift Afterglow Data

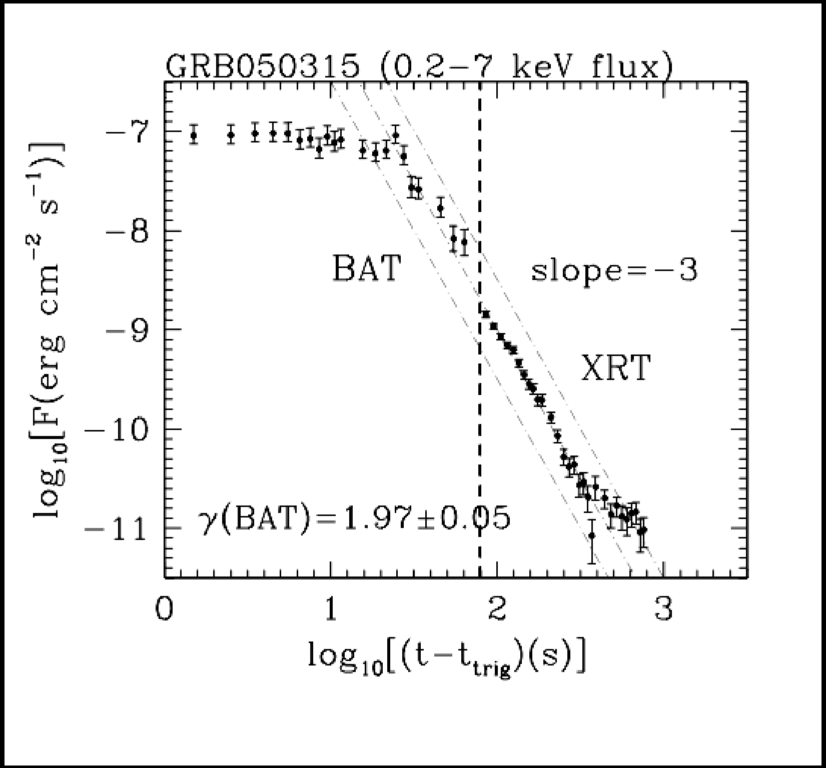


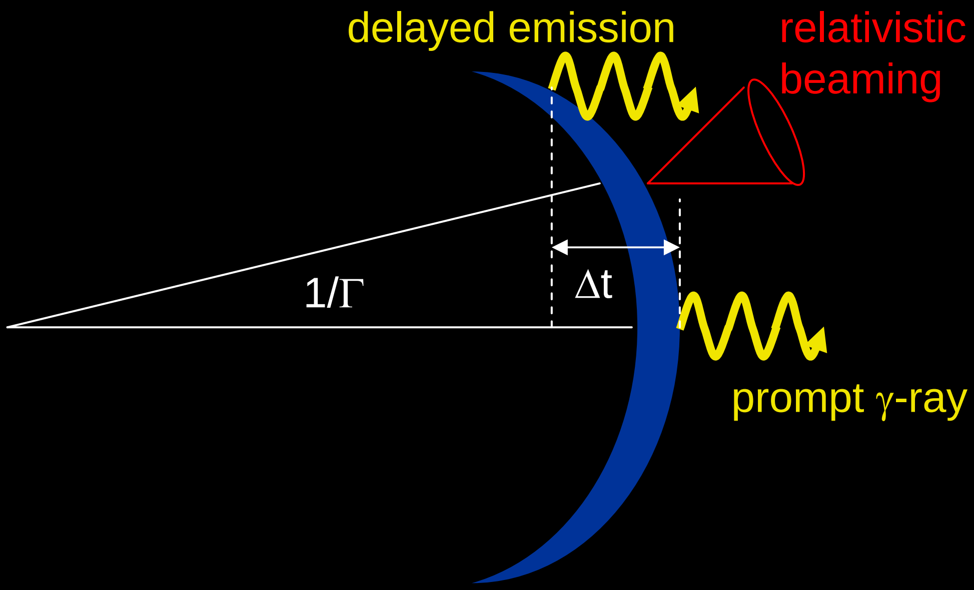
Beppo SAX data

Discovery of bright Early afterglow



Initial rapid decay

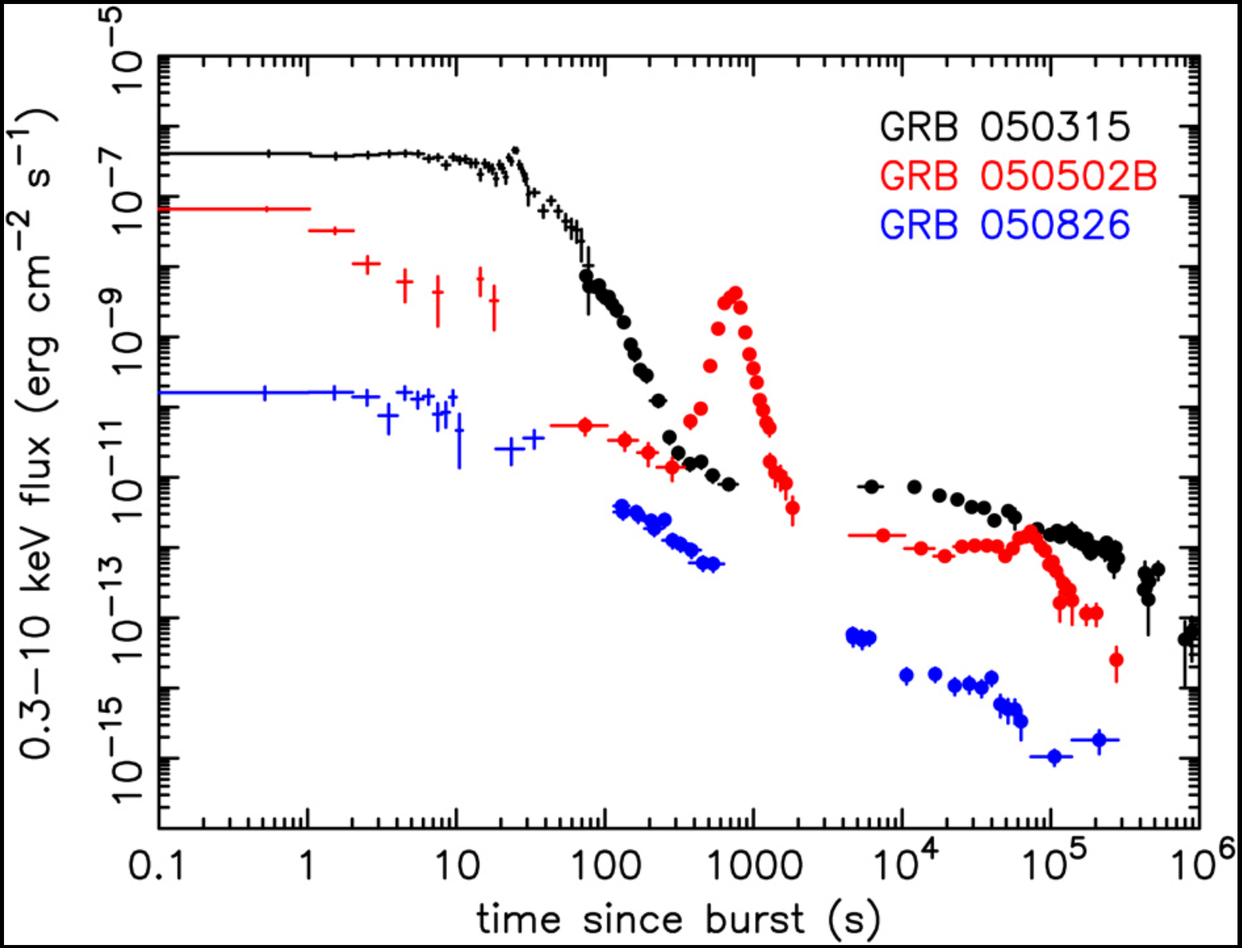




High latitude emission of the prompt γ-ray emission (Curvature effect)
Kumar & Panaitescu 2000

X-ray Afterglow Behaviors

Burrows et al.



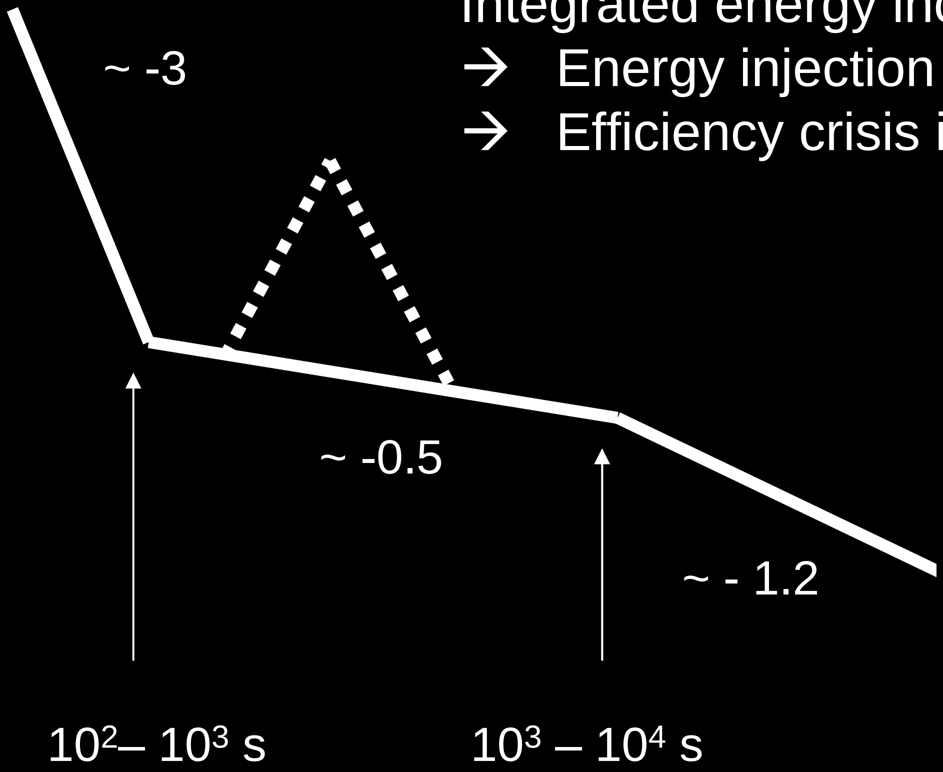
X-ray flares: Late time internal shock emission?
This may be answered by GLAST with IC component observation

Generic X-ray light curve

Shallow decay is very problematic for the standard GRB-Afterglow theory

Integrated energy increases by time

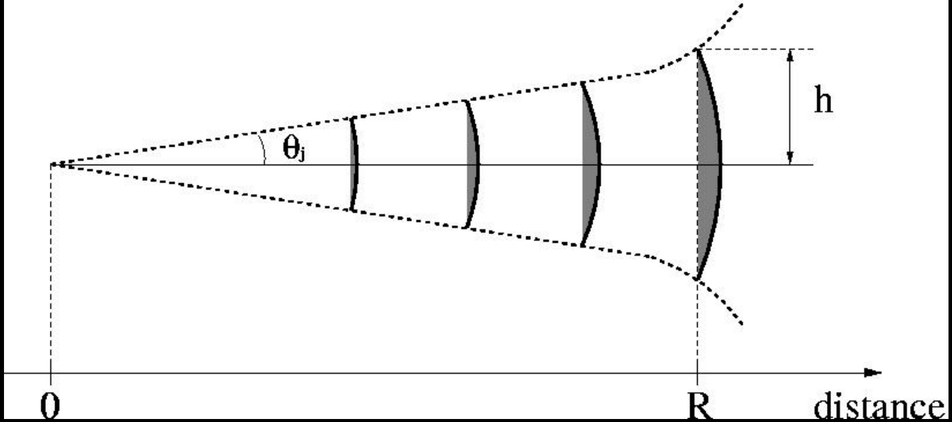
- → Energy injection from the central engine?
- → Efficiency crisis in the prompt emission



Zhang et al., Nousek et al. 2005

Jet Break: Evidence of Collimation

The most fundamental feature of the standard GRB-Afterglow scenario



- kinematic expansion
  rest frame: $t \sim R/c$
- Thermal expansion
  co-moving frame: $t \sim R/c\Gamma$

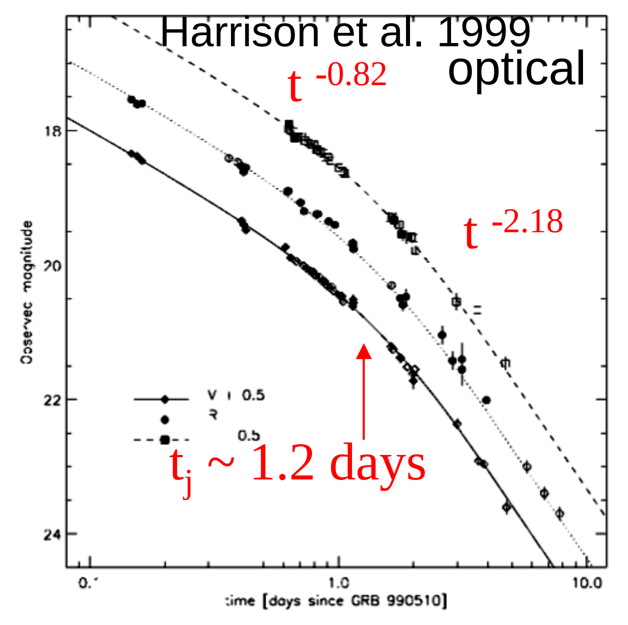
$$h = R\left(\theta_{\mathrm{j}} + \frac{1}{\Gamma}\right)$$

decelerated by ISM

- beaming effect becomes small
- hydro-dynamical transition (jet broadening)

→ should be wavelength independent (achromatic)

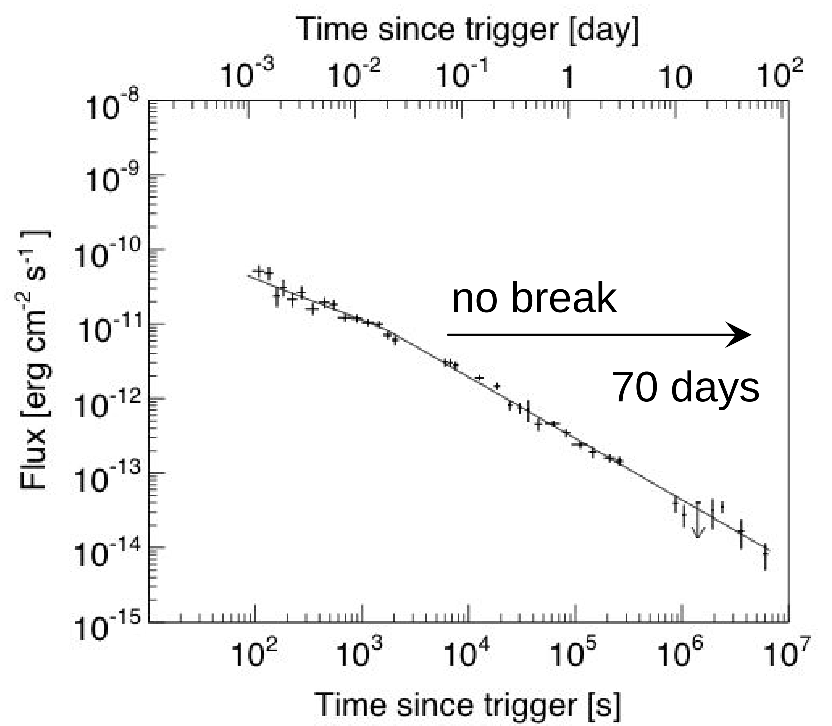
It has been highly expected that Swift clearly detect achromatic breaks, however …


Harrison et al. 1999

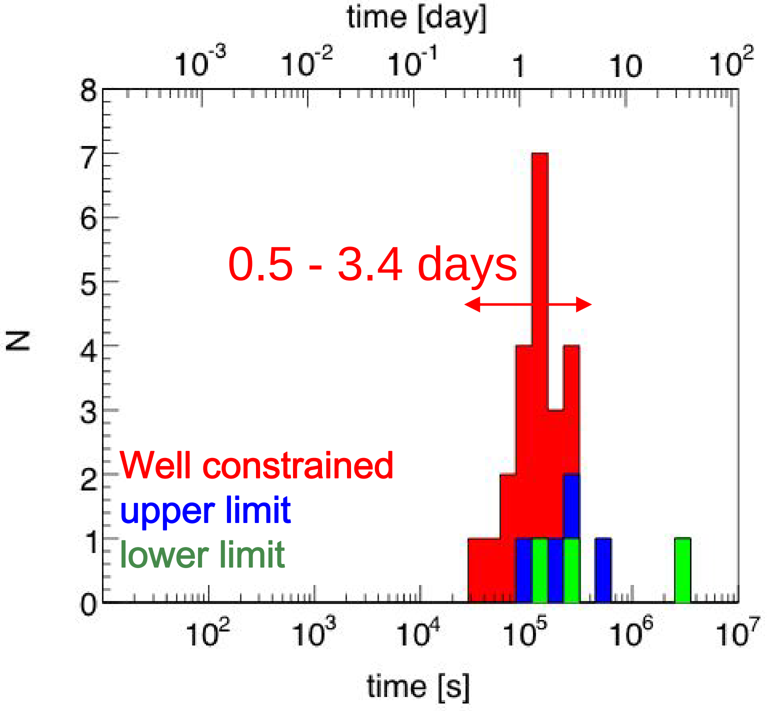
optical

No evidence for the most of cases

(Note: ~6 possible jet breaks / ~200 Swift GRBs)



Jet break time in pre-Swift era



Produced from Ghirlanda et al. 2004

no clear answers

just the observation is not long enough?
very energetic GRB?
low density environment?

quantitative
jet break search

Jet break search in X-ray

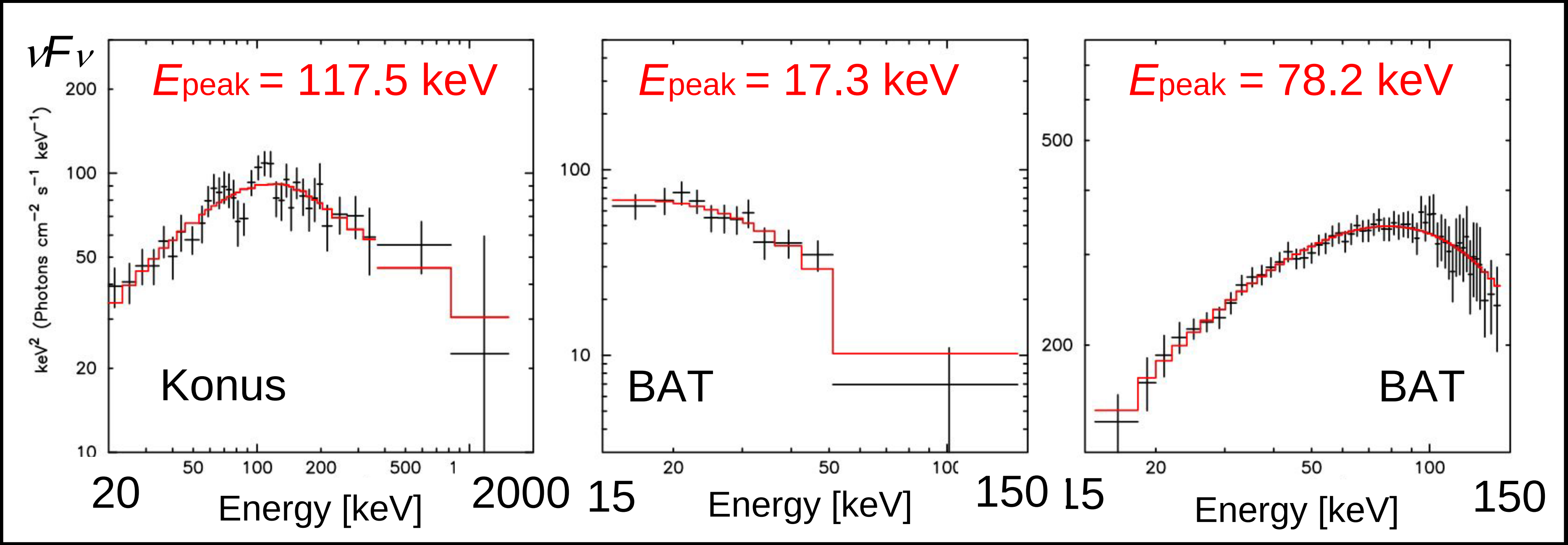
Sample selection

From the 10 Swift GRBs
with redshifts
up to July 2005

Sato Ph. D. thesis 2006
Sato et al. 2007 (astro-ph/0611148)

- redshift determination
- well-constrained prompt emission
- well-sampled X-ray light curve

GRB 050401 **XRF 050416a** **GRB 050525a**



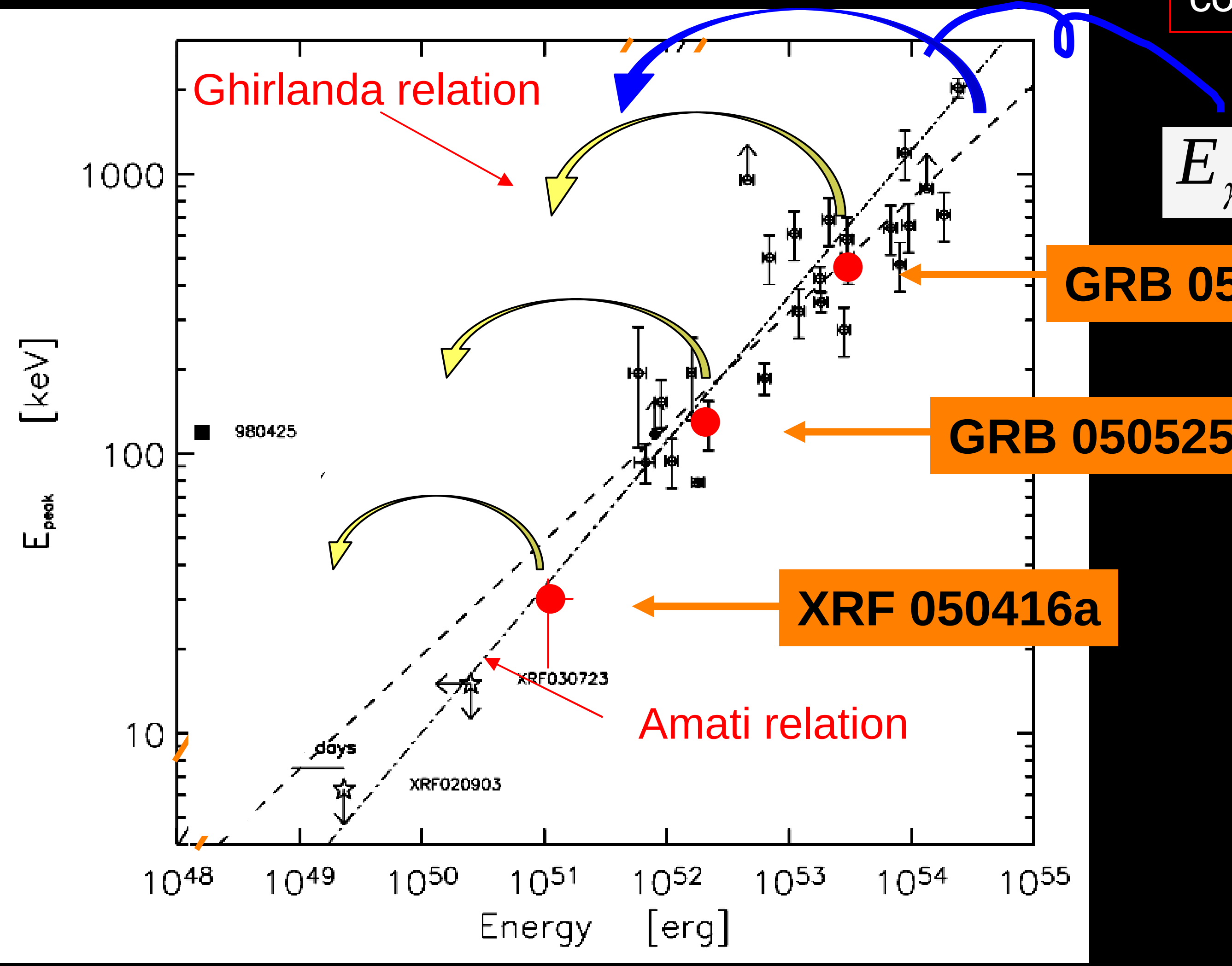
z = 2.9 z = 0.606 z = 0.65

Methodology

tighter correlation with
collimation correction

Ghirlanda et al. 2004

$$E_{\gamma} = (1-\cos\theta_{\mathrm{j}})E_{\mathrm{iso}}$$



GRB 050401

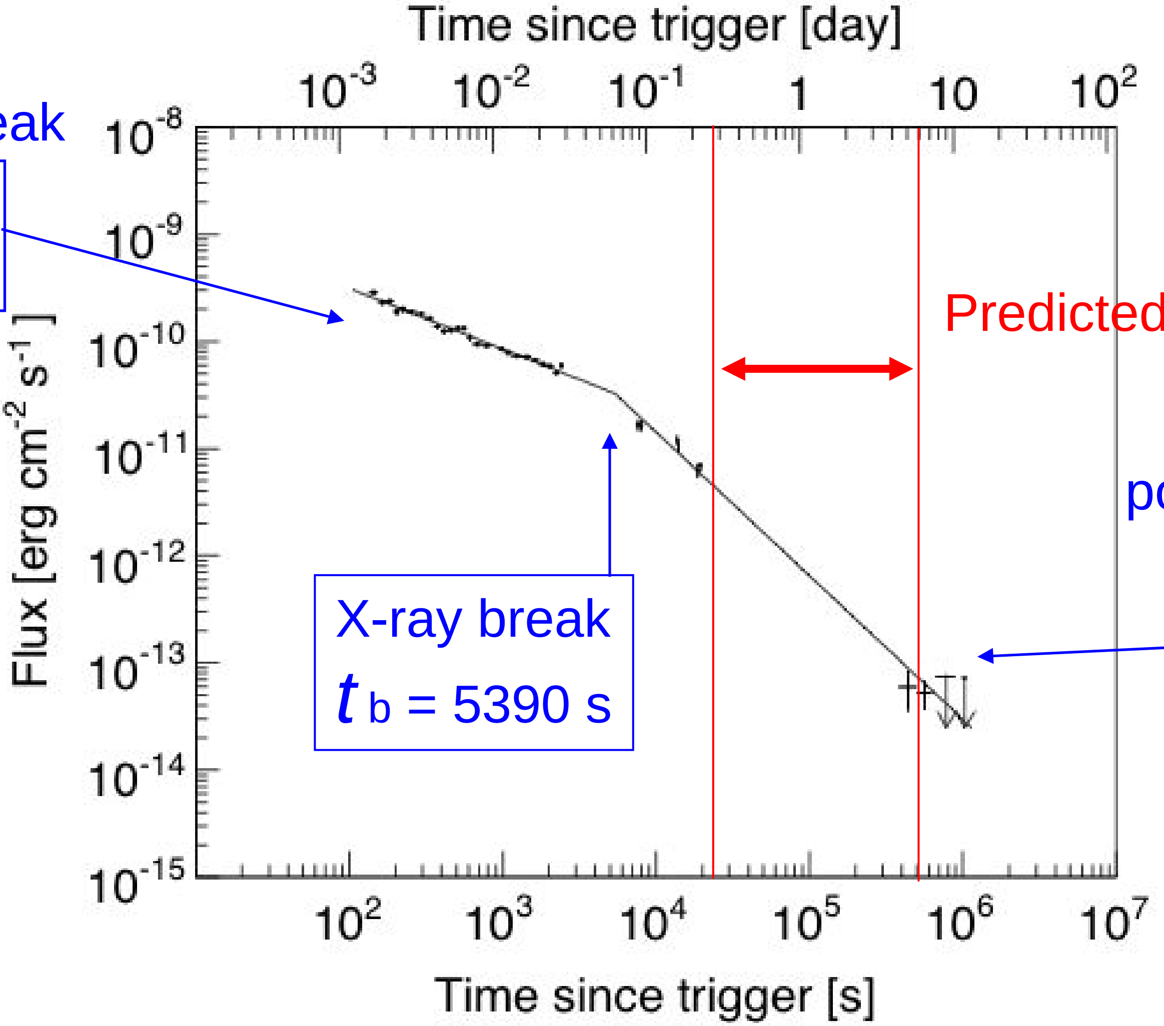
GRB 050525a

XRF 050416a

GRB 050401

$F_{\nu} = F_0 t^{\alpha} \nu^{\beta}$

X-ray light curve
in 2 - 10 keV



pre- X-ray break

$\alpha = -0.57$
$\beta = -1.03$

Predicted time interval

X-ray break
$t_{\mathrm{b}} = 5390$ s

post- X-ray break

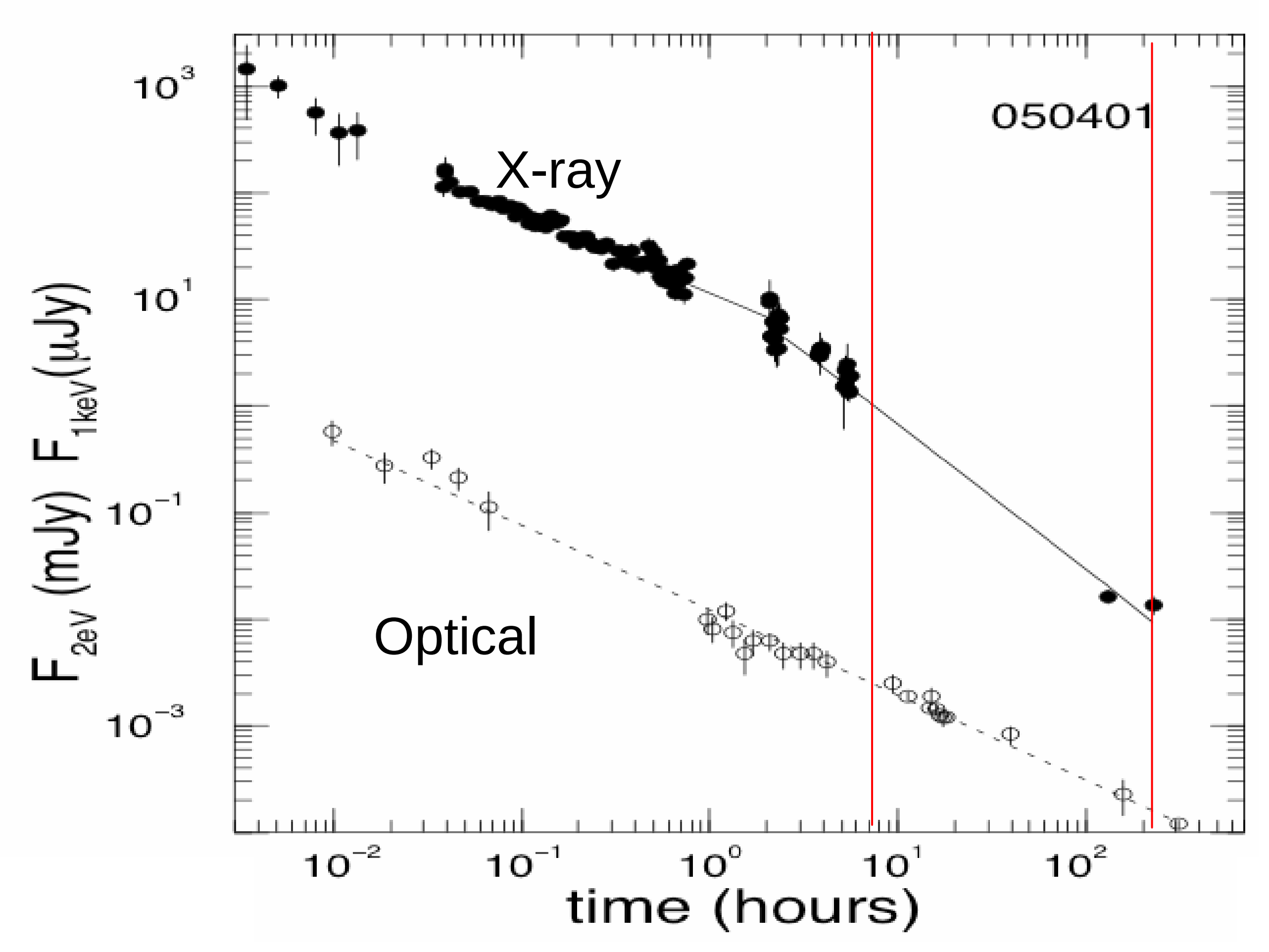
$\alpha = -1.34$
$\beta = -0.98$

The time interval can be joined with a single power law

GRB 050401 cont.

Panaitescu et al. 2006

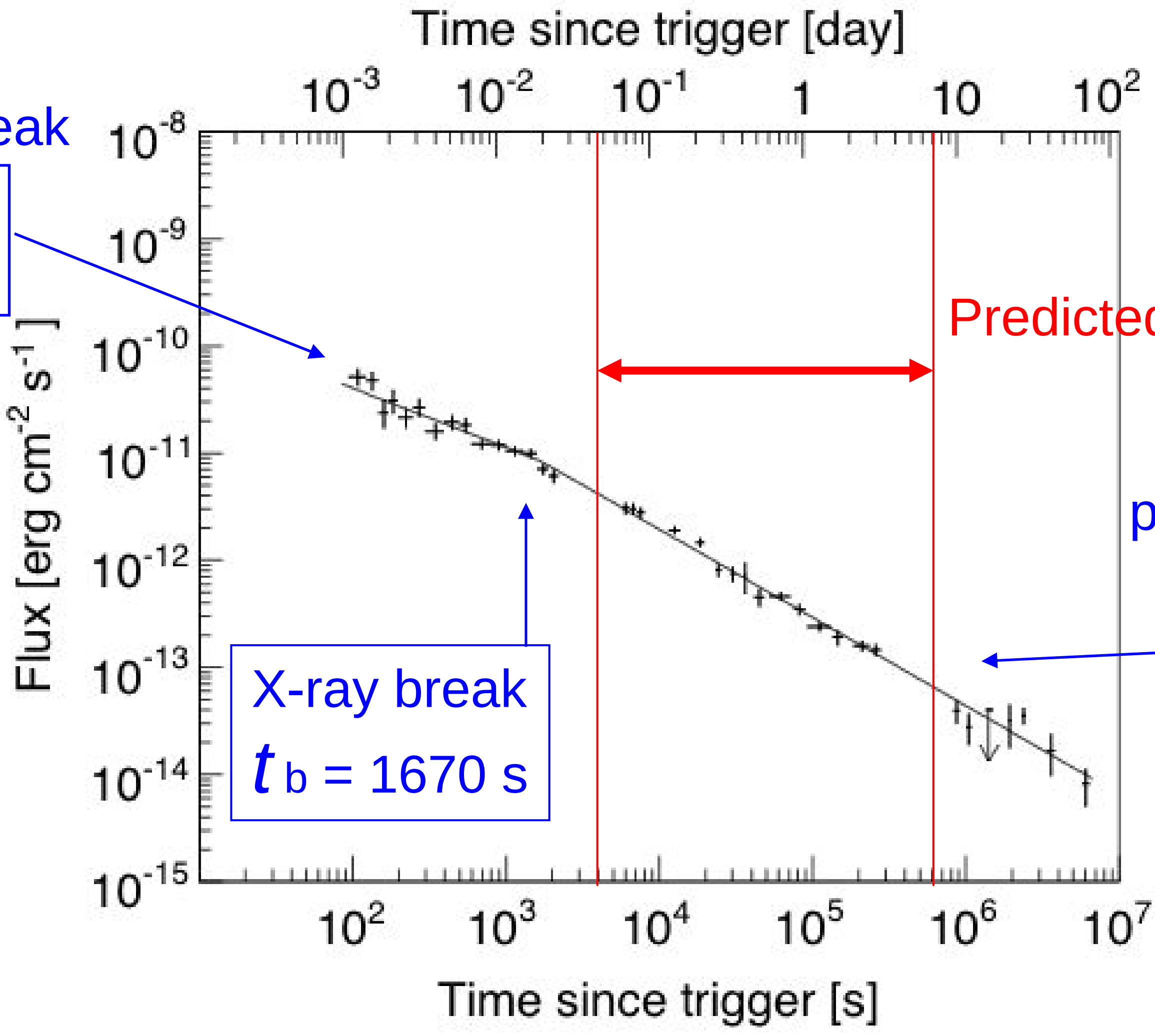
no break is found in optical band too



XRF 050416a

$F_\nu = F_0 t^{\alpha} \nu^{\beta}$

X-ray light curve
in 2 - 10 keV



pre- X-ray break

α = -0.55
β = -1.20

X-ray break
$t_{\rm b}$ = 1670 s

Predicted time interval

post- X-ray break

α = -0.82
β = -1.04

shallow decay
to 75 days

No temporal break is observed within the time interval

c.f. no optical long observation

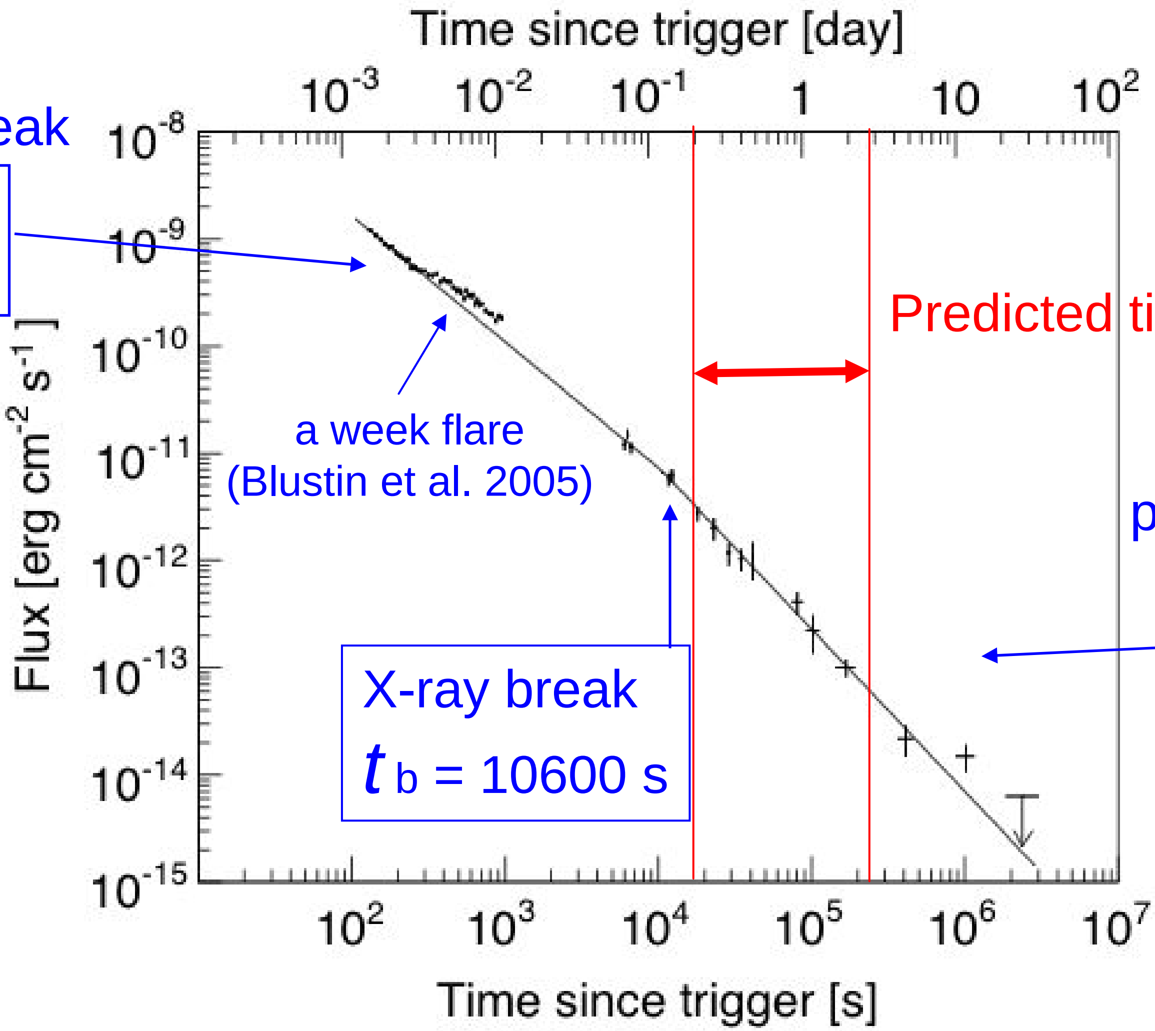
GRB 050525a

$F_\nu = F_0 t^\alpha \nu^\beta$

X-ray light curve
in 2 - 10 keV

pre- X-ray break

α = -1.18
β = -0.92



a week flare
(Blustin et al. 2005)

X-ray break
t_b = 10600 s

Predicted time interval

post- X-ray break

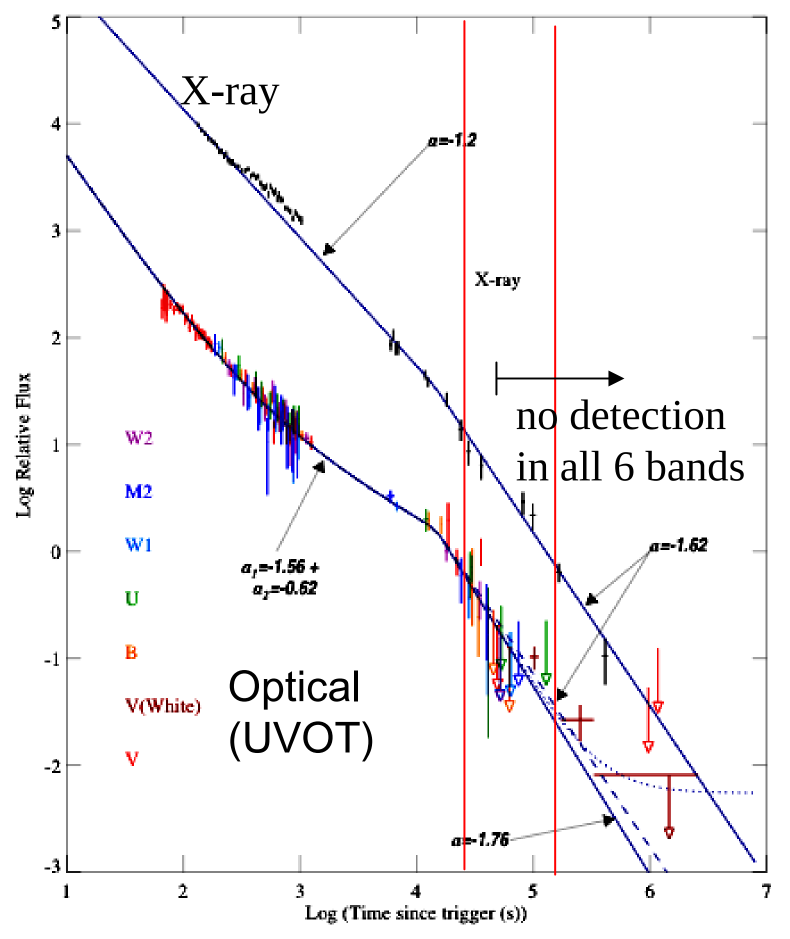
α = -1.51
β = -1.11

still shallow

The X-ray break is at a marginal time, but does not follow α–β relation
→ No jet break feature in X-ray

GRB 050525a cont.

Blustin et al. 2005



X-ray

no detection in all 6 bands

Optical (UVOT)

Della Valle et al. 2006

break @~0.3 days

QuickTimeý Ç²
TIFFÅià èkÇ»ÇµÅj êLí£ÉvÉçÉOÉâÉÄ
Ç™Ç±ÇÃÉsÉNÉ`ÉÉÇ¾å©ÇÈÇžÇ½Ç…ÇÕïKóvÇ-Ç ÅB

Sampling rate is low, but looks like the old-fashioned, our familiar “jet break”

Implication of no jet break in X-ray

	X-ray		
	break?	**predicted time?**	**$\alpha-\beta$ relation?**
GRB 050401	**yes**	**no**	**no**
XRF 050416a	**yes**	**no**	**no**
GRB 050525a	**yes**	**marginal**	**no**

(1) no jet break feature in X-ray
→ masked in the X-ray band by one or more additional components?

(2) GRB 050401: jet break at a later time compared to the time in previous GRBs?
→ Ghirlanda relation has a larger scatter than previously thought

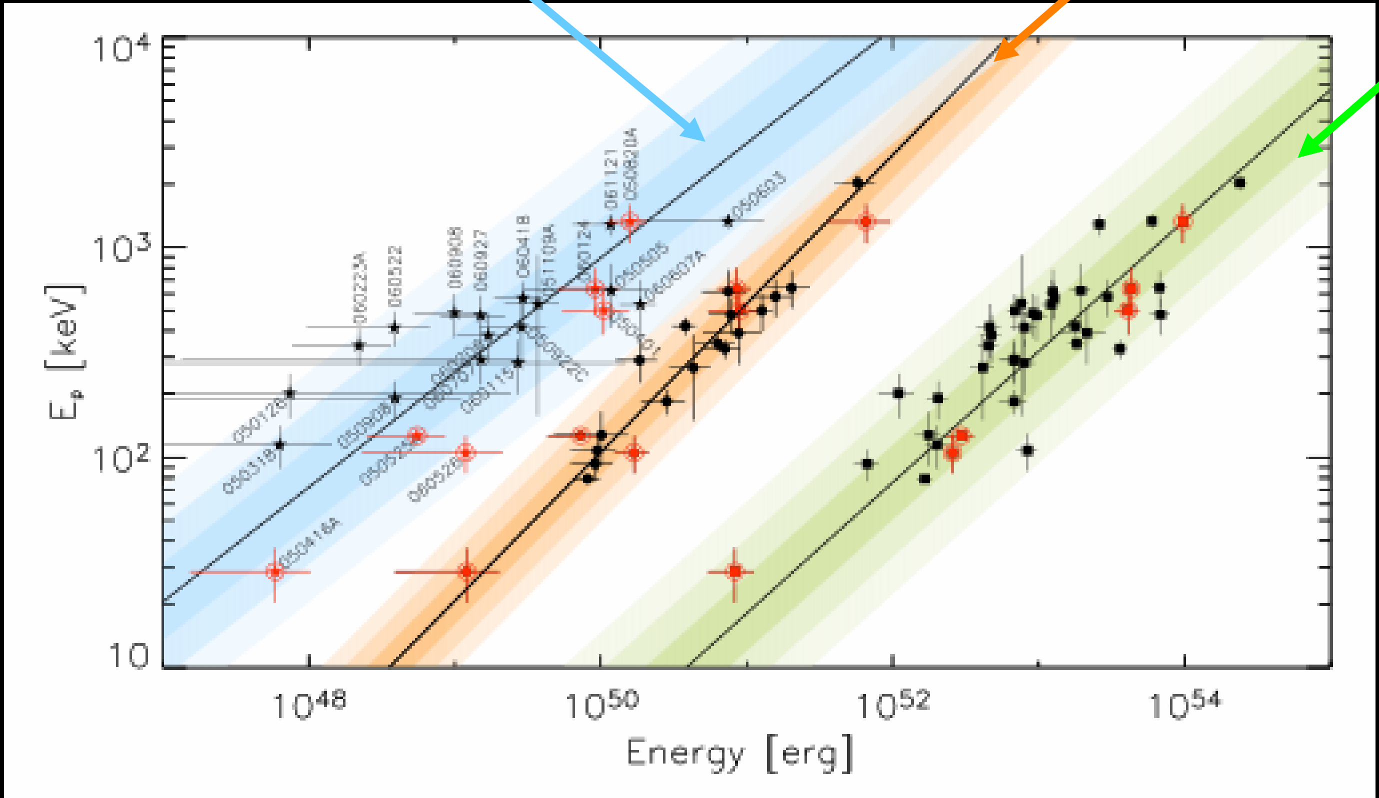
(3) GRB 050525a: achromatic break, but X-ray does not follow the theory
→ pre-Swift “jet breaks” are indeed jet breaks

Epeak is still key to interpret afterglows

corrected by
shallow to normal X-ray break

corrected by “jet break”

Eiso

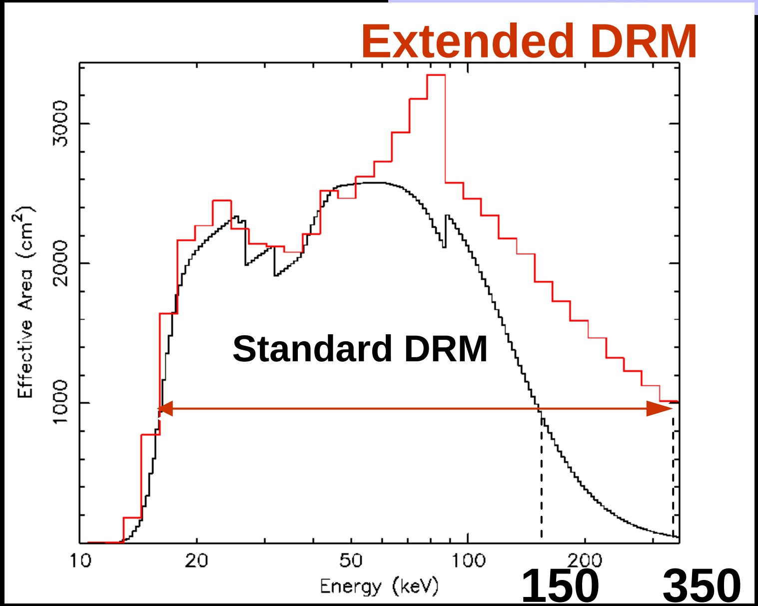


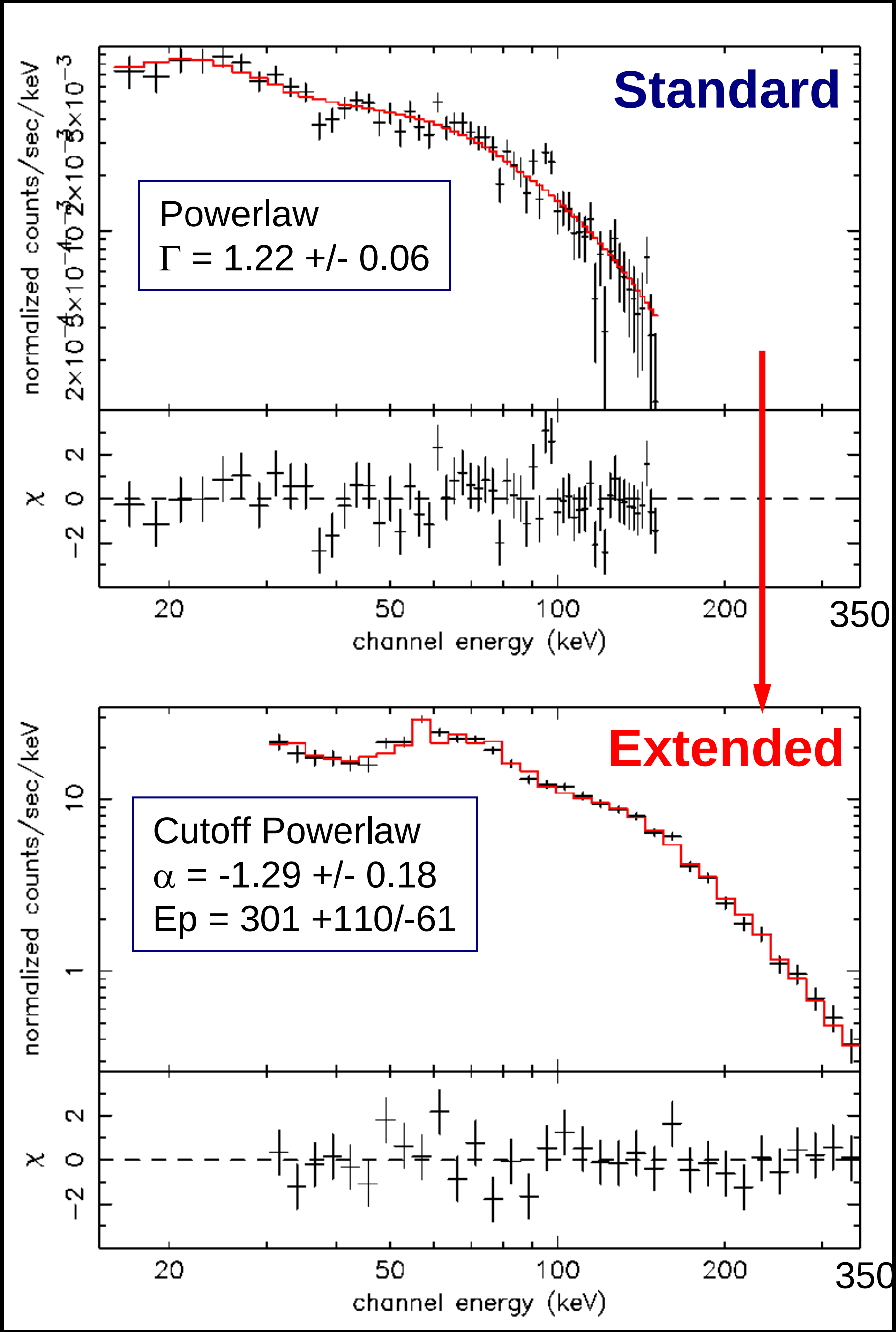
Nava et al. 2007 astro-ph/0701705

Need to determine Epeak for more GRBs

BAT Extended DRM (my current work)

Spectrum without mask modulation
(i.e. inc. scattered comp.)

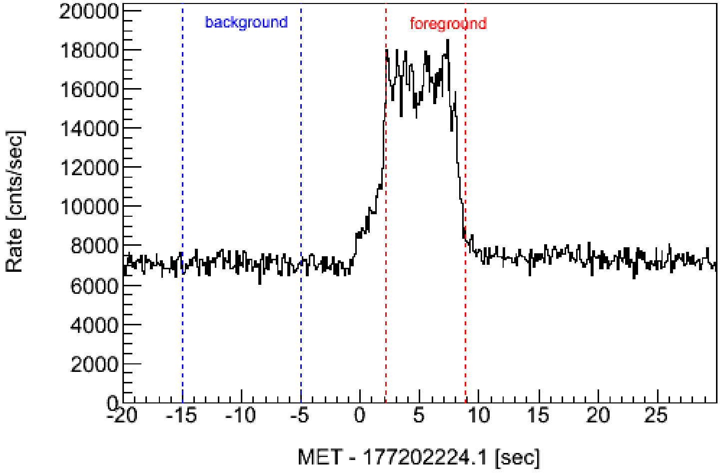




Powerlaw
Γ = 1.22 +/- 0.06

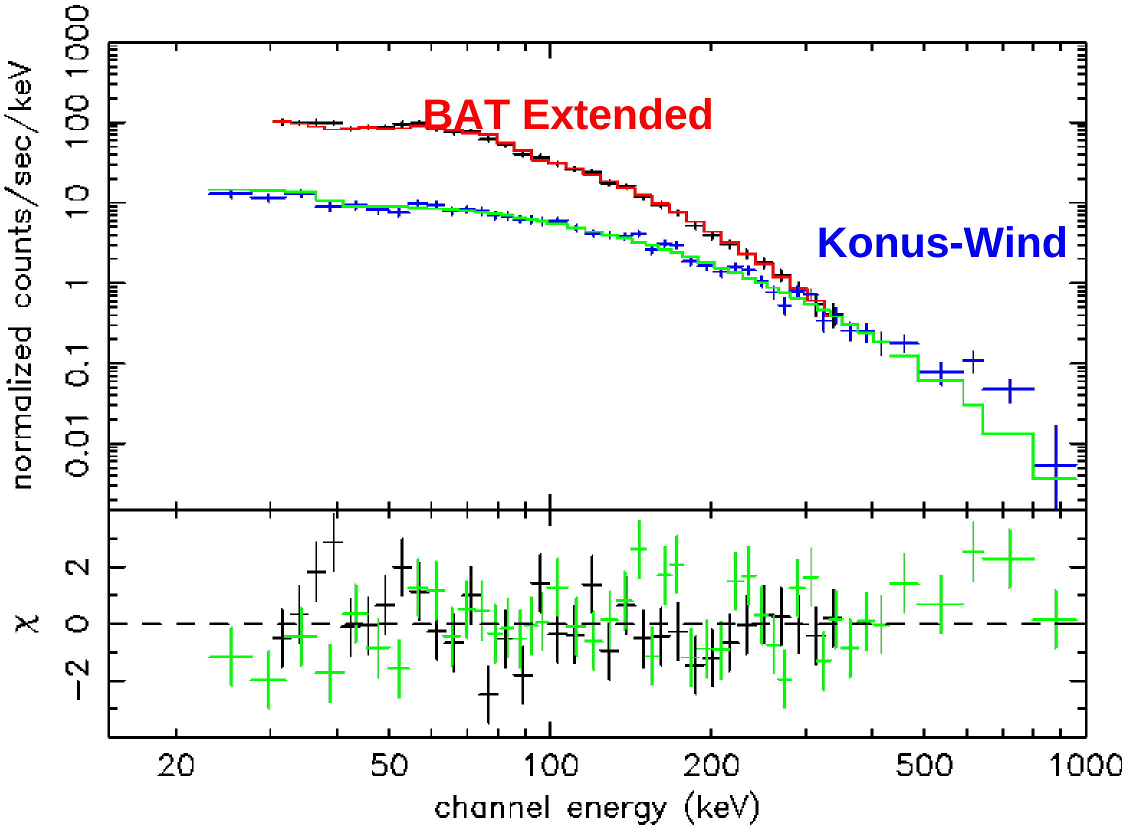
Cutoff Powerlaw
α = -1.29 +/- 0.18
Ep = 301 +110/-61

GRB 060813



Preliminary!!

JOINT-FIT with Konus-Wind

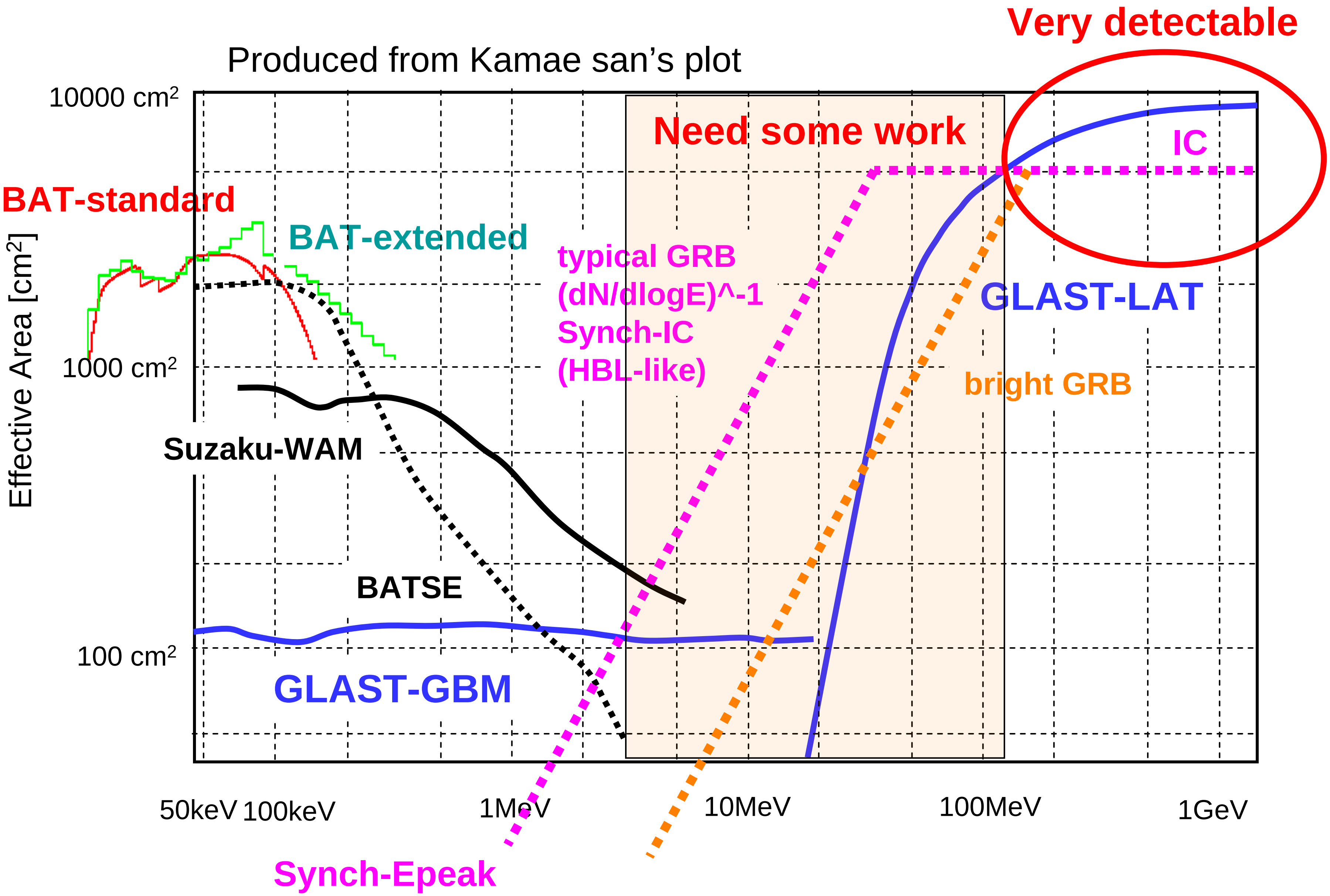


Cutoff Powerlaw
α = -0.74 +/- 0.09
Ep = 208 +/- 12

Normalizations are consistent within 6%

To be verified by cross-calibrations with more GRBs

Effective Area



Produced from Kamae san's plot

Very detectable

Need some work

GRB Observation with GLAST

- Electron Synchrotron: Epeak, Energetics, (GBM)
- Electron inverse-Compton (LAT)
- Proton Synchrotron (LAT)
- Hadronic process (LAT)
- γ–γ absorption in the prompt emission: Γ, r (LAT)
- γ–IR (TeV + l eV), γ–UV (100 GeV + 10 eV): probe of radiation field (LAT)

Karin, my first baby

Born at the night of Christmas eve, 2006

Swift Team

University of Leicester

NASA

GSFC

PENNSTATE

UCL MSSL

asi agenzia spaziale italiana

ISAS

OSSERVATORIO ASTRONOMICO DI BRERA

SPECTRUMASTRO

eV PRODUCTS

MPE

SONOMA STATE UNIVERSITY

THE UNIVERSITY OF CALIFORNIA 1868

SwRI

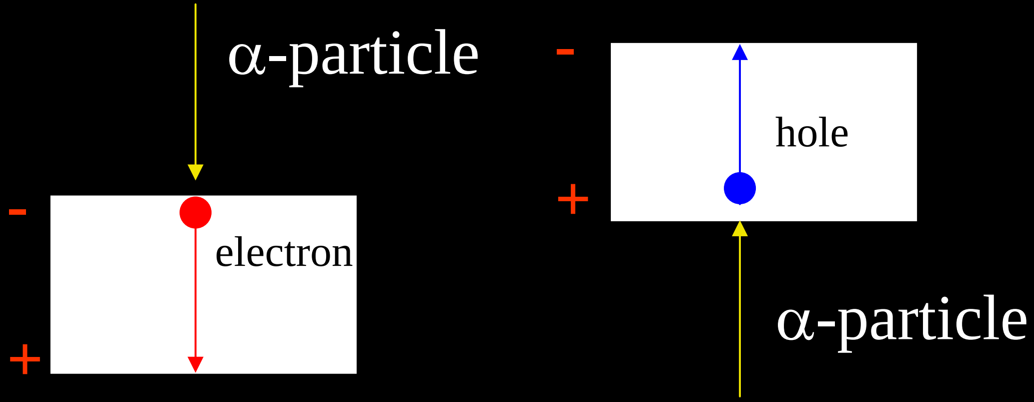
SWALES AEROSPACE

Los Alamos NATIONAL LABORATORY

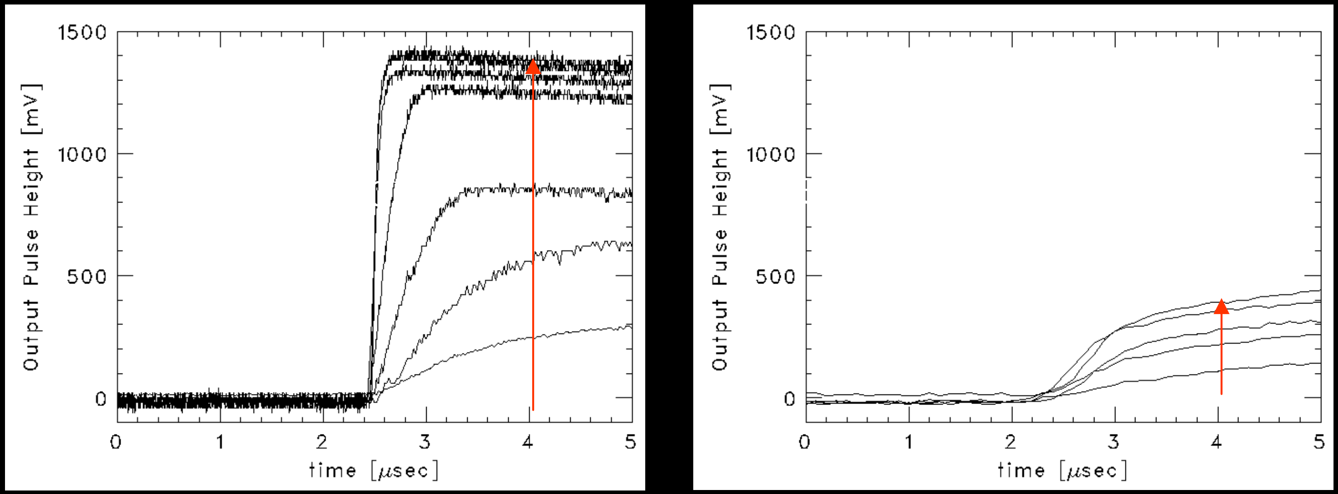
Omitron inc.

Characterization: measure μτ

Traditional method: utilize α-particles



output pulse

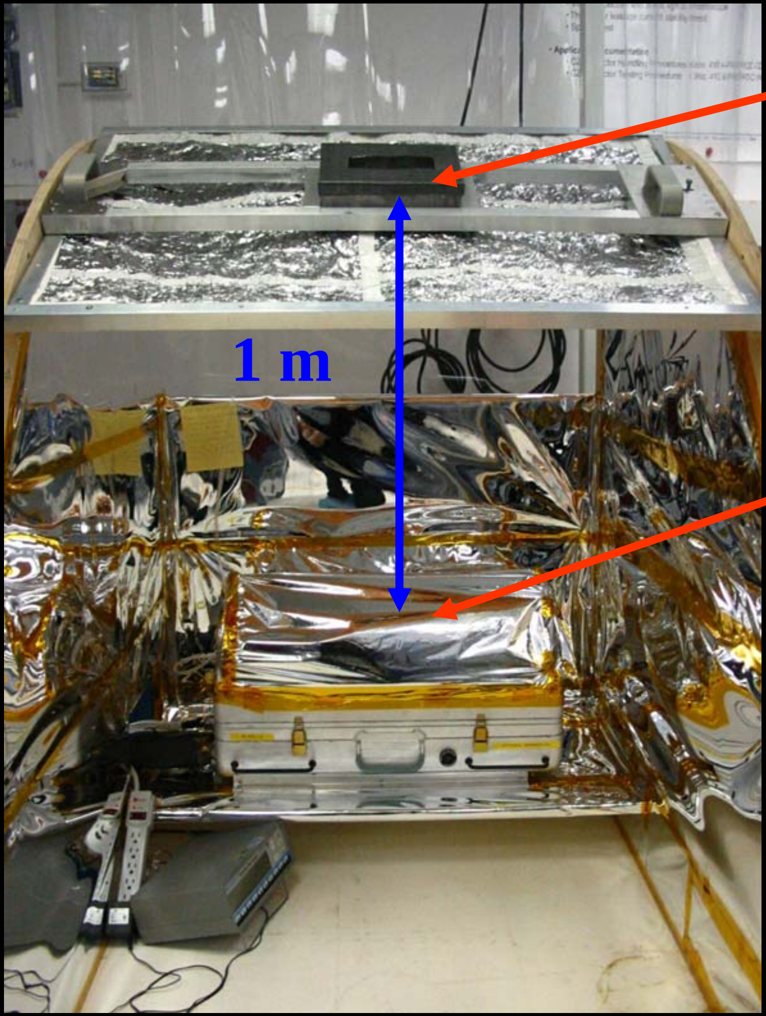


dependence on the bias voltage --> μτ procuts

However, easily affected by the surface condition

BAT CdZnTe Calibration

I proposed to apply the method to the BAT CdZnTe detectors



RI Source
in lead
Anti-Occulter

Block
(2048CZTs)

Each CZT detector is calibrated individually in “block” sub-array (2048 detectors, = 32K/16 blocks) by gamma-rays from radioactive sources at various incident angles, basis volagtes.

We evaluated all the 32 K CdZnTe detectors individually

μτ distribution on the detector plane

μτ electron color map

QuickTimeý Ç²
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μτ hole color map

QuickTimeý Ç²
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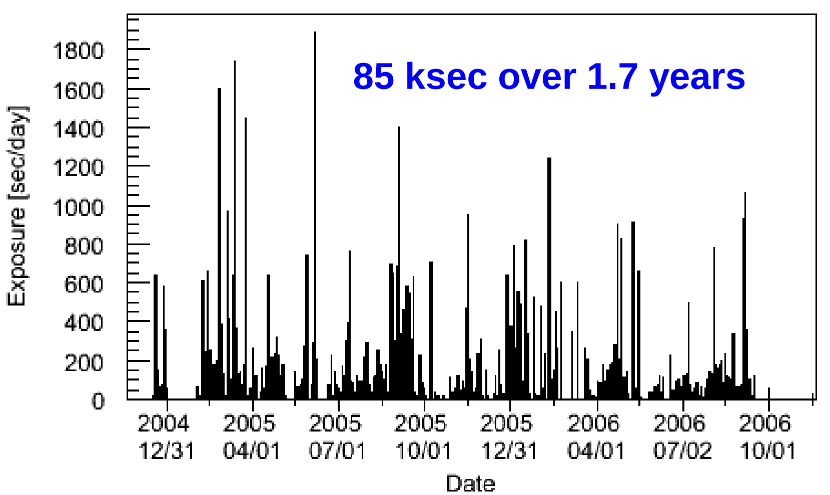
Geometrical pattern in the BAT detector plane

→ The diversity of μτ attributes to a difference of crystal ingots

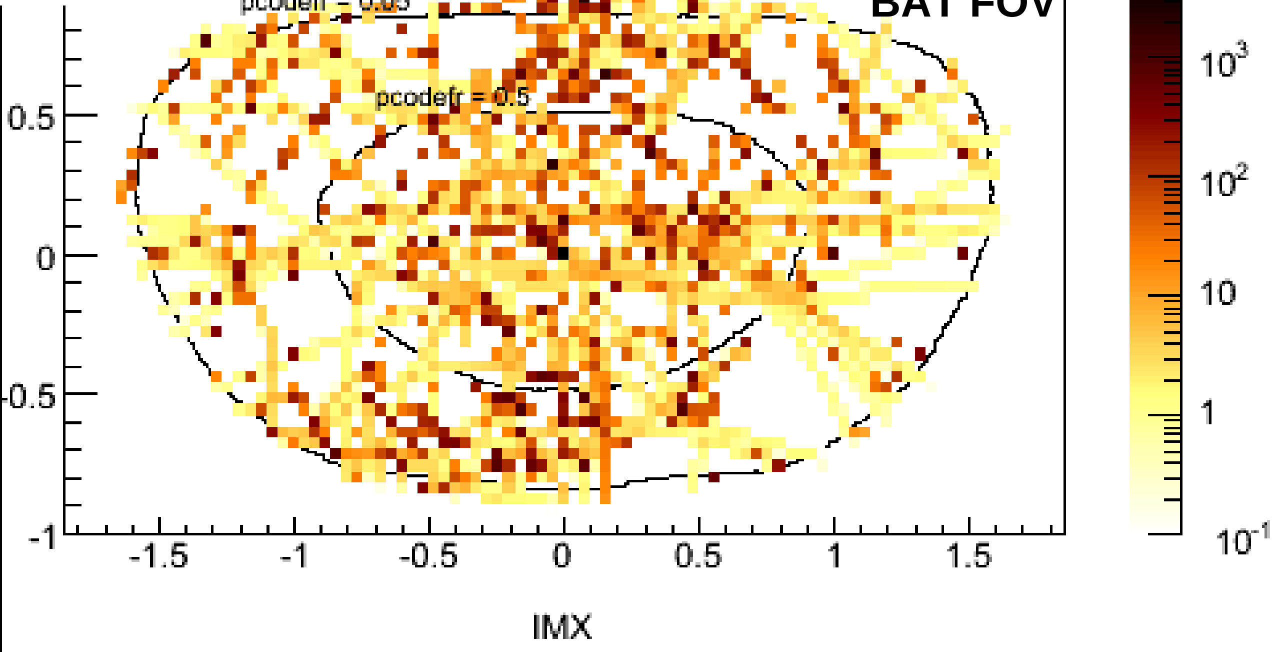
In-flight Calibration with Crab Pulsar

Observation



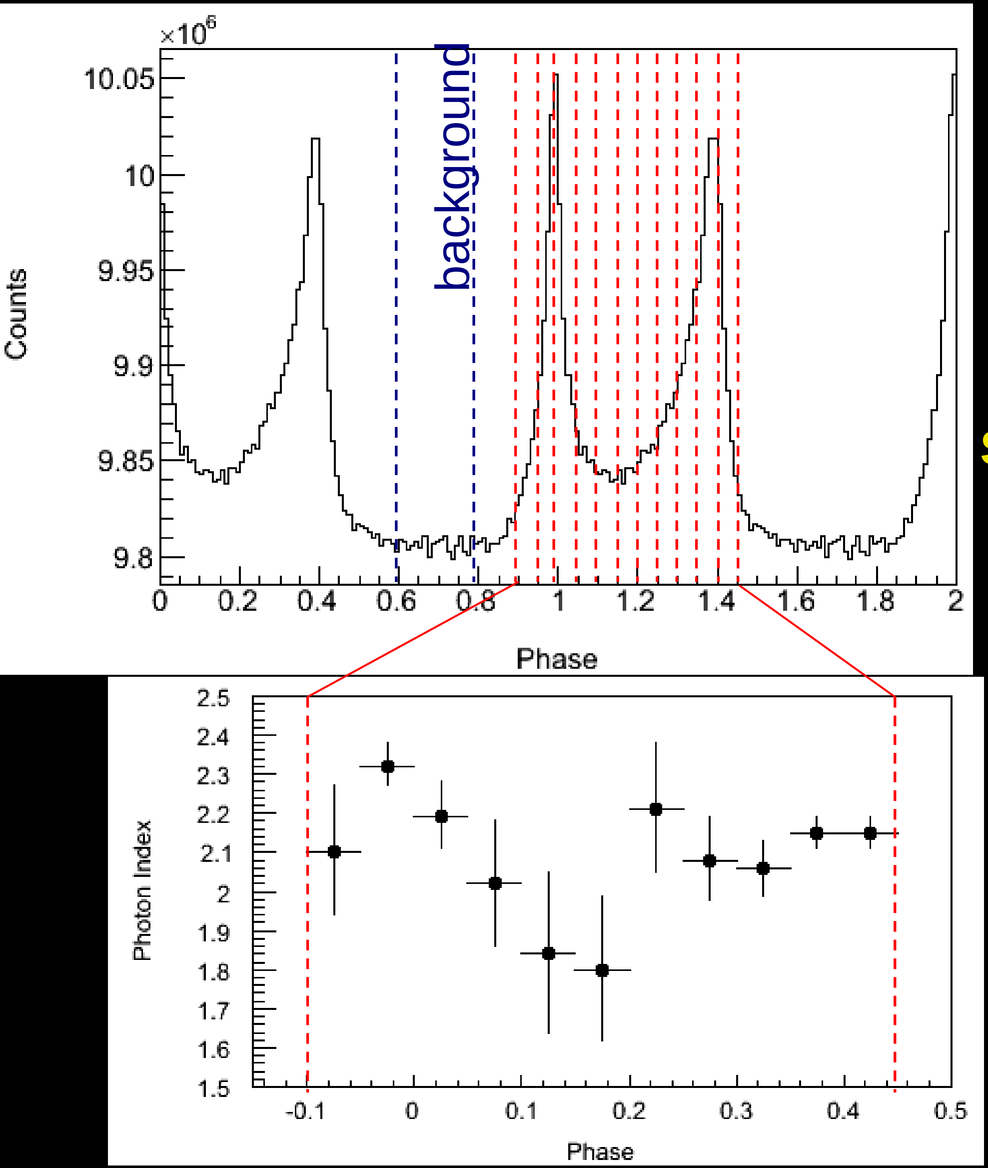
- All the event-by-event data are accumulated from December 2004 to September 2006.
- We selected time intervals when the Crab is in the BAT FOV.

Sky exposure map in the tangent plane



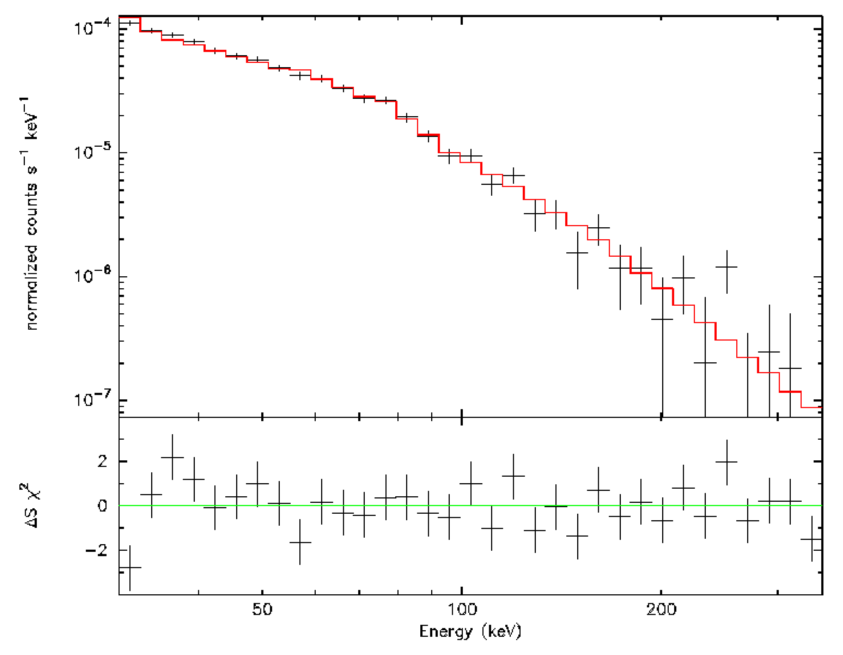
Timing and Spectral analysis

Folded light curve (15-350 keV)

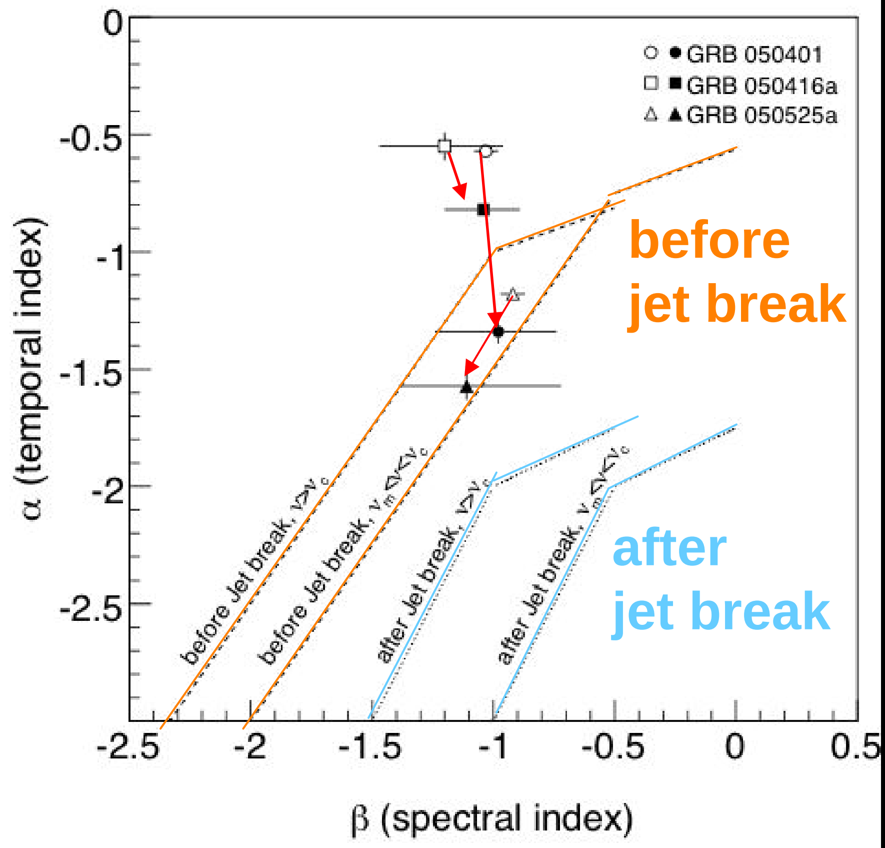


- Arrival times were converted to the Solar System Barycenter
- The values of P and Pdot for each observation are derived fro Jodrell Band Crab Pulsar Monthly Ephemeris

Spectrum of the phase interval 0.95-1.00



α–β relation



before jet break

after jet break

Ourliers of Ghirlanda relation

1. Earlier case:

The slight X-ray breaks = jet breaks ?
(not likely because of the shallow decay after the breaks)

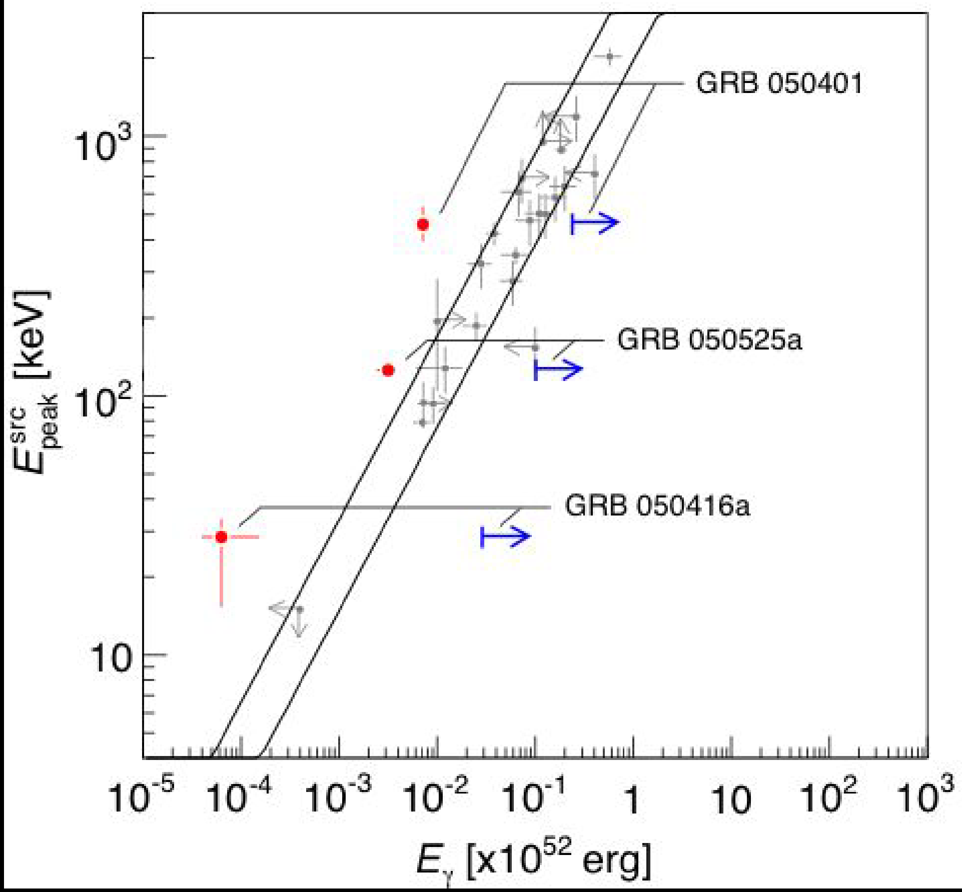
Assuming them as jet breaks,
we can calculate “$E\gamma$”

2. Later case:

The last detection time
= lower limit of the jet break time

→ Lower limit of opening angle

→ Lower limit of $E\gamma$



The 3 bursts become outliers of the Ghirlanda relation !!

New Puzzles of GRBs

1. Cosmological Distance OK
   confirmed for short GRBs
2. Relativistic Jet ?
   The pre-Swift “jet breaks” are indeed jet breaks?
3. Afterglow: Synchrotron Shock Model ?
   Shallow decay is due to energy injection?
4. GRB: Internal Shock ?
   If energy injection,
   an efficiency problem arises from the prompt γ-ray burst
5. Long: Collapsar - Massive Star Explosion, ?
   Short: NS-NS, NS-BH Merger
   Short GRB in star forming region
   GRB with Mixed characteristics of "short" and "long" GRBs