GRB afterglows: beyond the forward shock models

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Workshop on Future Opportunities for SWIFT Science

Penn State University

Swift GRB Science in the Next Few Years

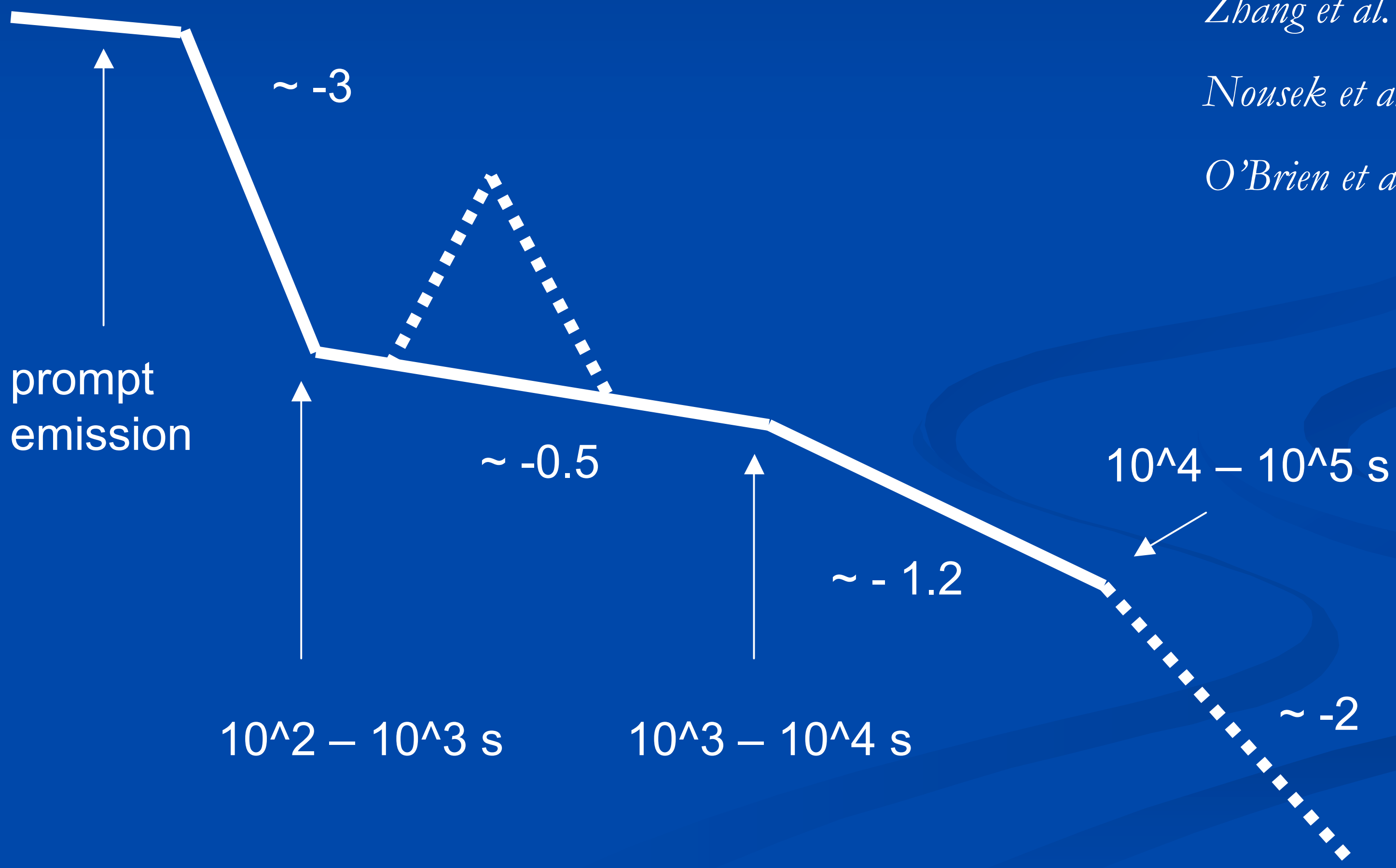
- GRB population study
  - More Short GRBs
  - One more GRB 060614 - like GRB?
  - One more GRB 060218 - like GRB?
- GRB - cosmology connection
  - More high-z GRBs - z record?
  - Probing the high-z universe?
- GRB/afterglow physics
  - Emission physics - multiple emission sites?
  - Shock physics, outflow composition - GLAST connection
  - Geometry: are GRBs jetted? How to tell?
  - Central engine physics - long term activity

The Canonical XRT Lightcurve: How Much Do We Understand?

Zhang et al. 2006;

Nousek et al. 2006;

O'Brien et al. 2006



Five components:

A mixture of external and internal emissions

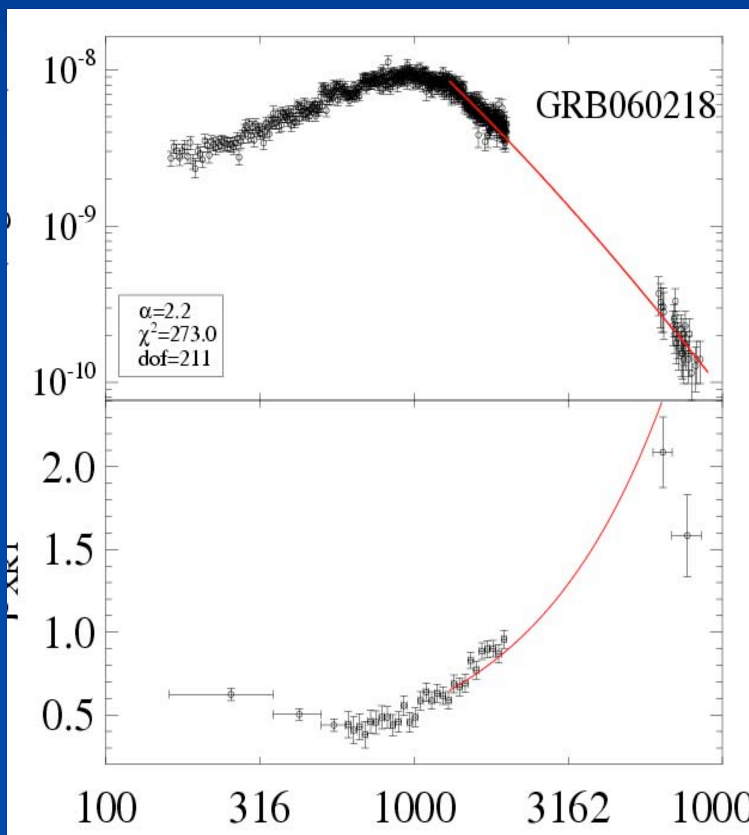
- Steep decay - GRB tail emission (Internal)
  - Curvature effect alone?
- X-ray flares: late central engine activity (Internal)
- Normal decay: standard afterglow (External)
- Post jet break steep decay: (External)
- Shallow decay (plateau) (External vs. Internal?)
  - Refreshed shocks?
  - Engine-driven plateau?

GRB afterglows not from the forward shock

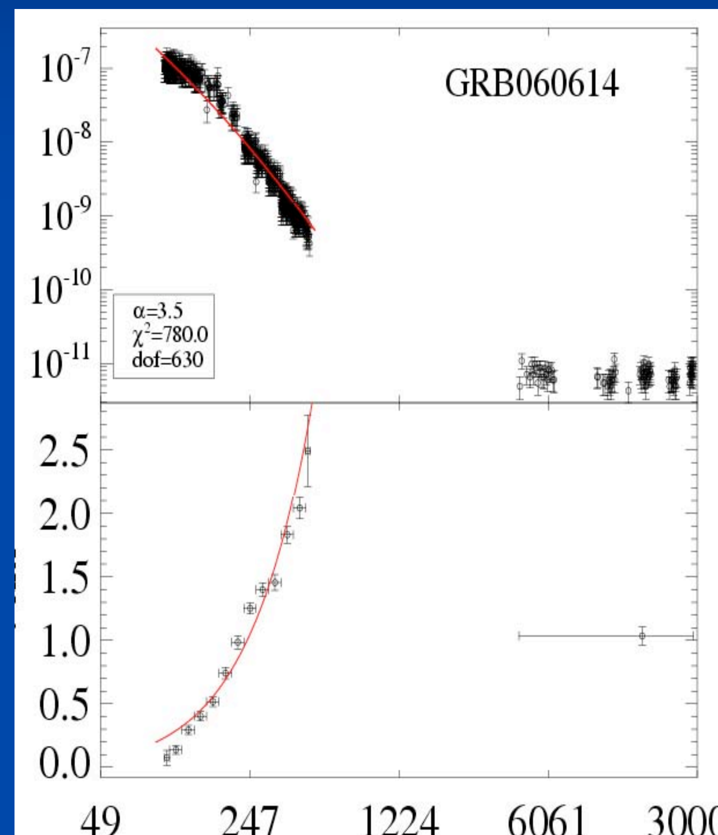
- X-ray flares: case solid, not discussed
- Steep decay:
  - Curvature effect is not the sole story
  - Spectral evolution in the tail - cooling of the internal region
- Shallow decay: diverse origin
  - Case of refreshed shocks: evidence & issues
  - Internal origin of some plateaus
  - Comments on other suggestions
    - Reverse shock dominated afterglow?
    - Completely internal origin of the X-ray afterglow?

Spectral evolution of some GRB tails

(Zhang, Liang, Zhang 2007; Butler & Kocevski 2007)



Campana et al. 2006



Mangano et al. 2007

GRB tails

- 44 strong tails for Swift GRBs before Feb. 2007
- 11 has no strong spectral evolution
- 33 has strong hard to soft evolution
  - 16 are clean tails
  - 17 have flare contaminations

Mechanisms of spectral evolution

- A structured jet with angular-dependent spectral index? - NO!
- A superposition effect between a hard component and an underlying decaying soft component? - Work for some with weak evolution but cannot interpret GRB 060218, GRB 060614 and GRB 050724 - NO!
- A cooling model - YES!

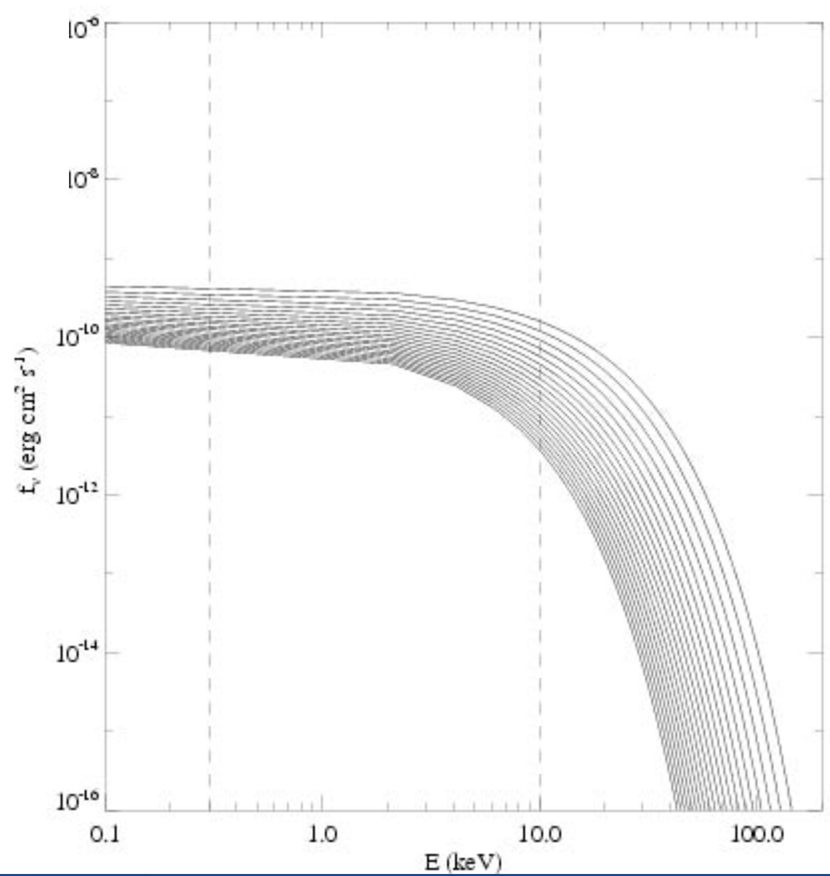
A cooling model for GRB tails

Zhang, Liang & Zhang, 2007, ApJ

$$F_\nu(E,t) = F_{\nu,m}(t)\left[\frac{E}{E_c(t)}\right]^{-\beta} e^{-E/E_c(t)}$$

$$F_{\nu,m}(t) = F_{\nu,m,0}\left(\frac{t-t_0}{t_0}\right)^{-\alpha_1}$$

$$E_c(t) = E_{c,0}\left(\frac{t-t_0}{t_0}\right)^{-\alpha_2}$$



A cooling model for GRB tails

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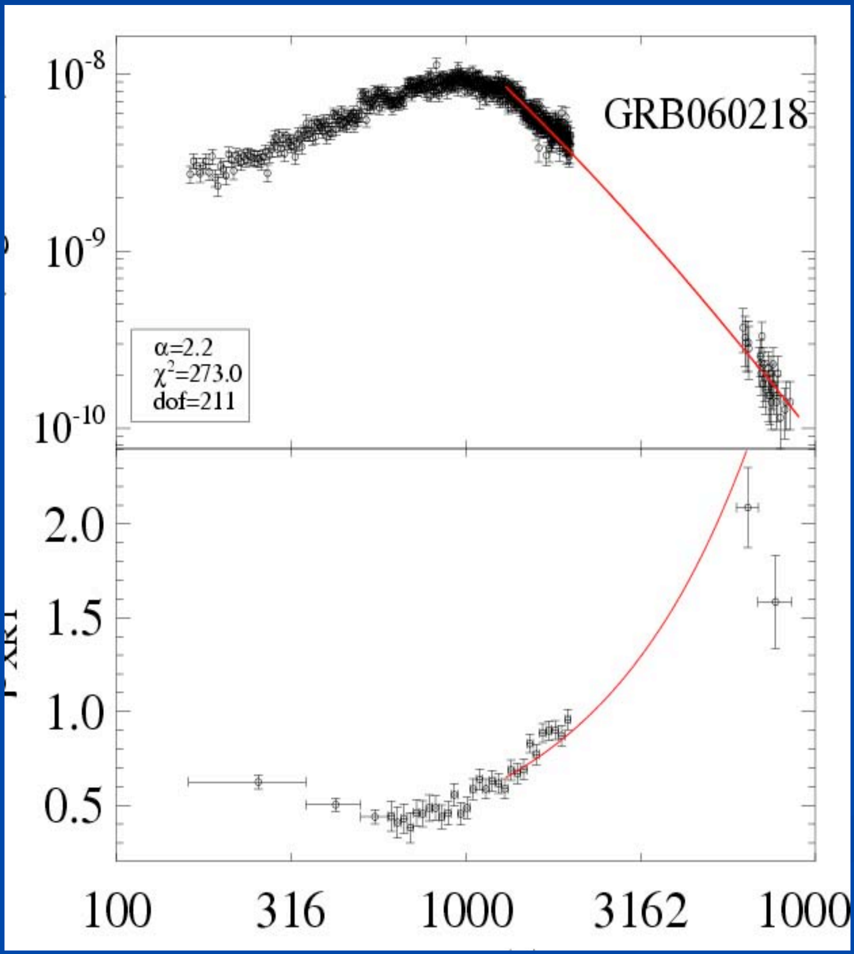
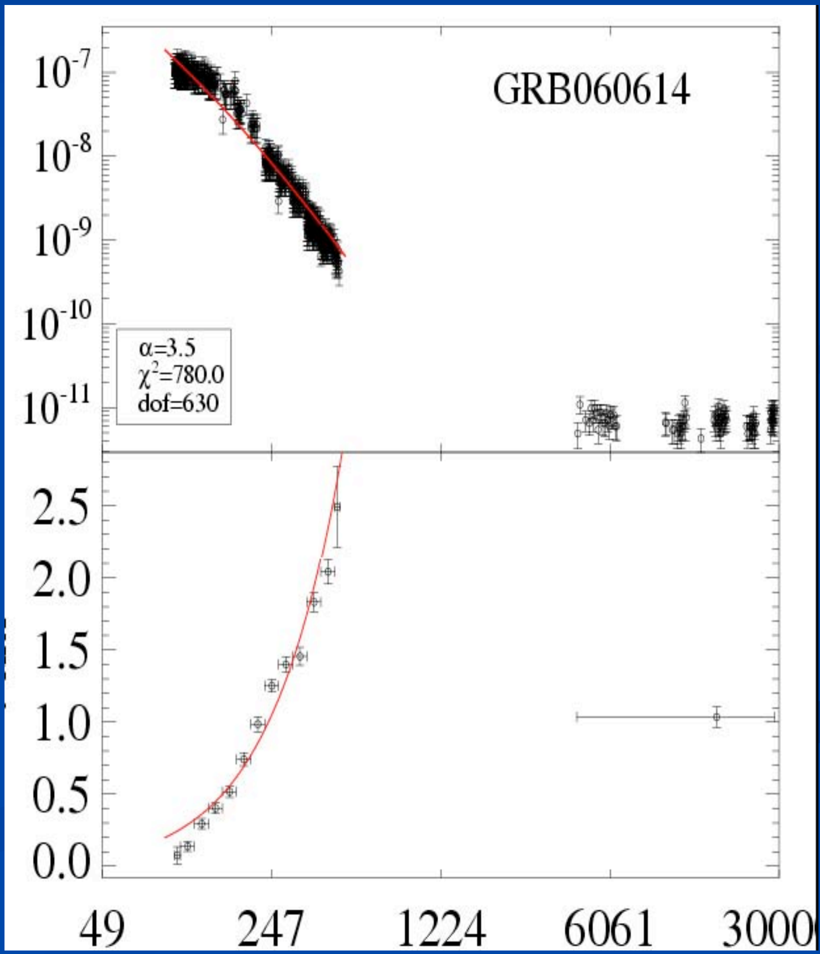
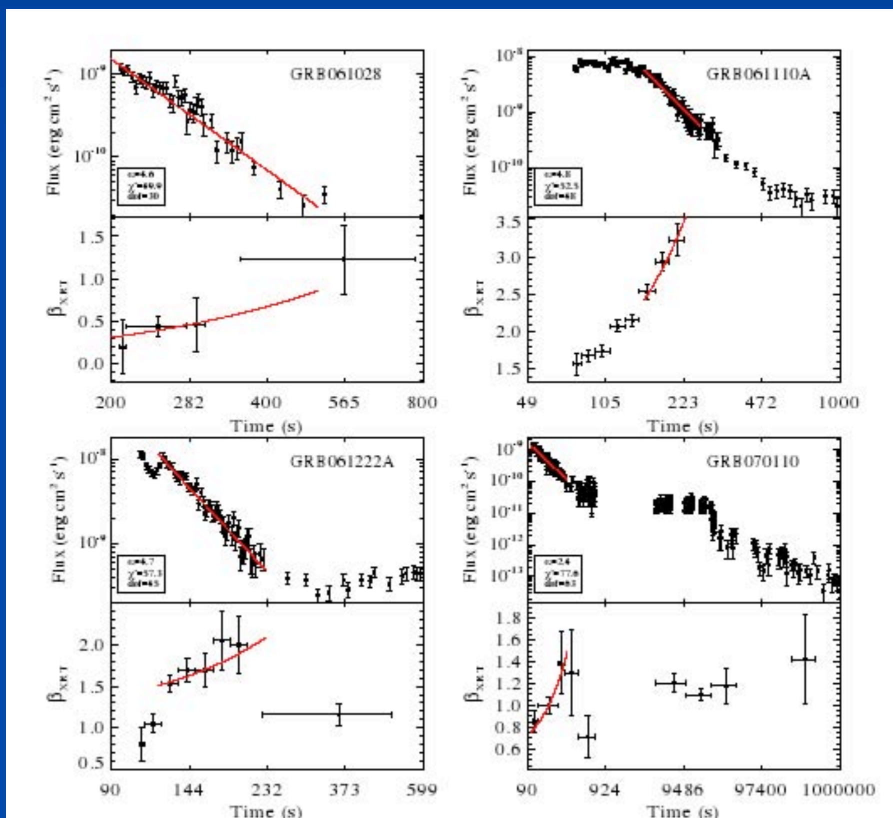
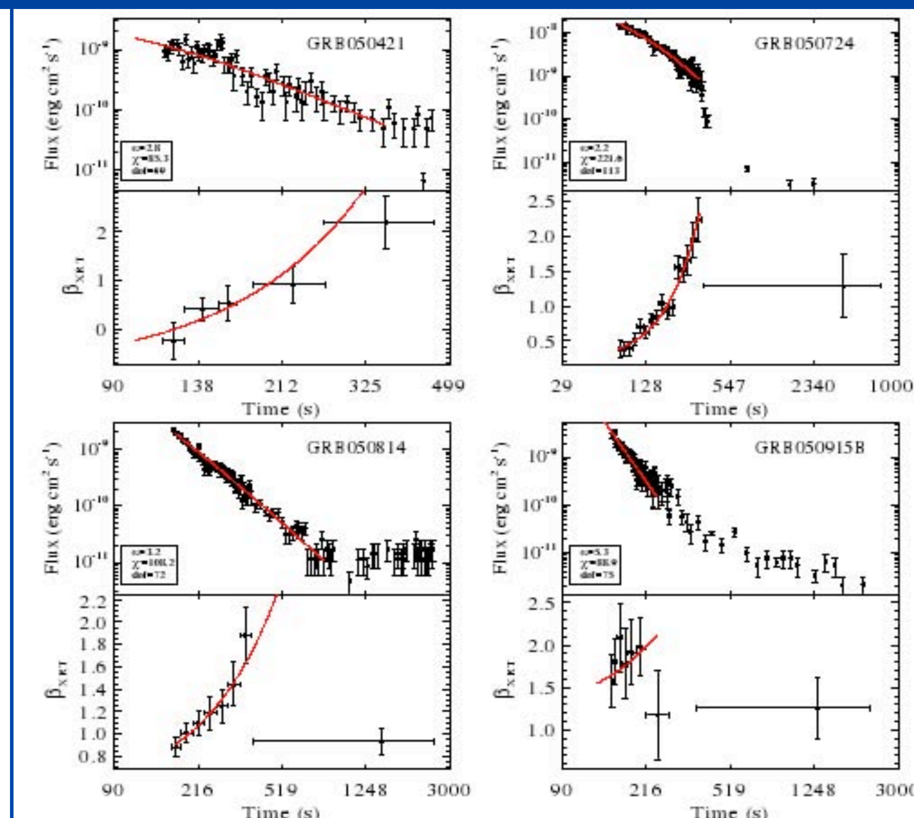




A cooling model for GRB tails

Zhang, Liang & Zhang, 2007, ApJ





A cooling model for GRB tails

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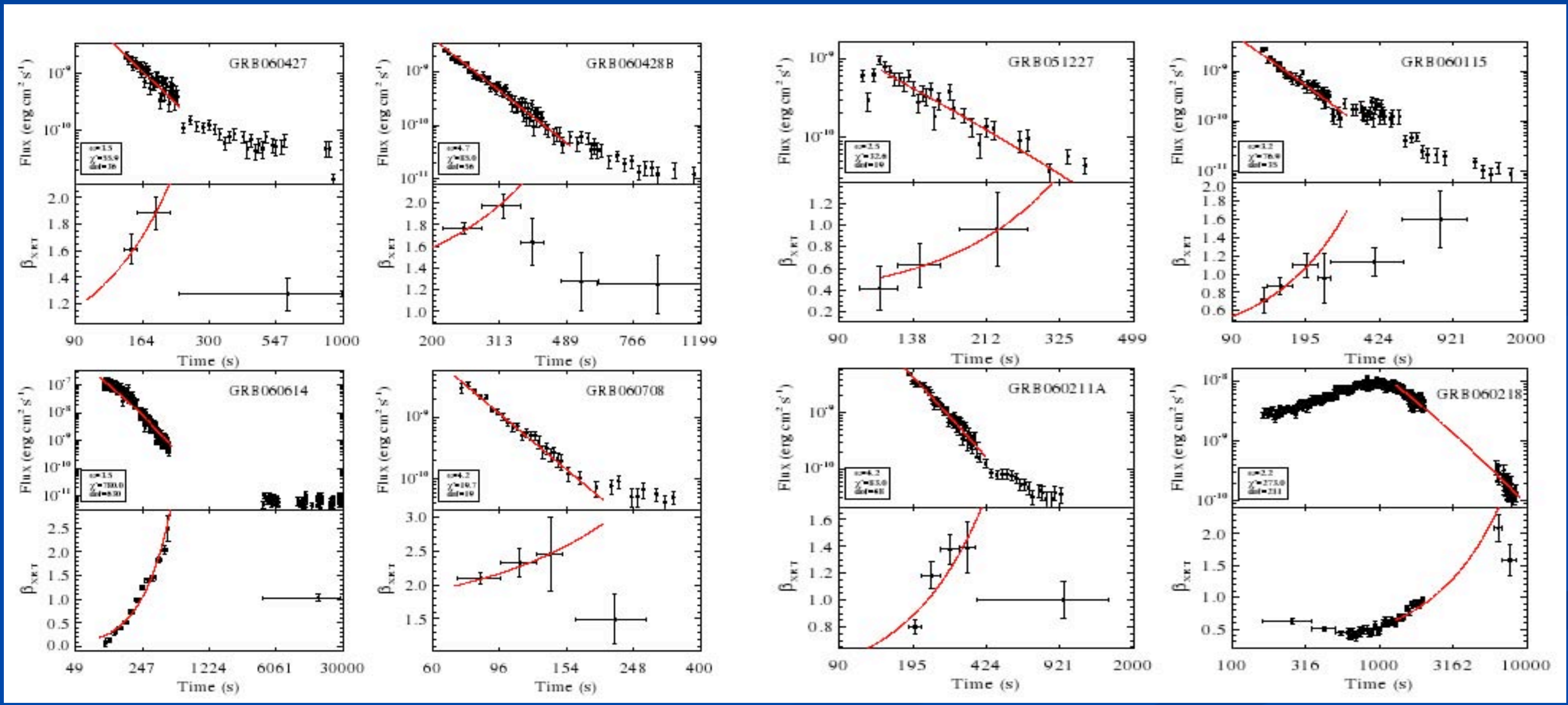
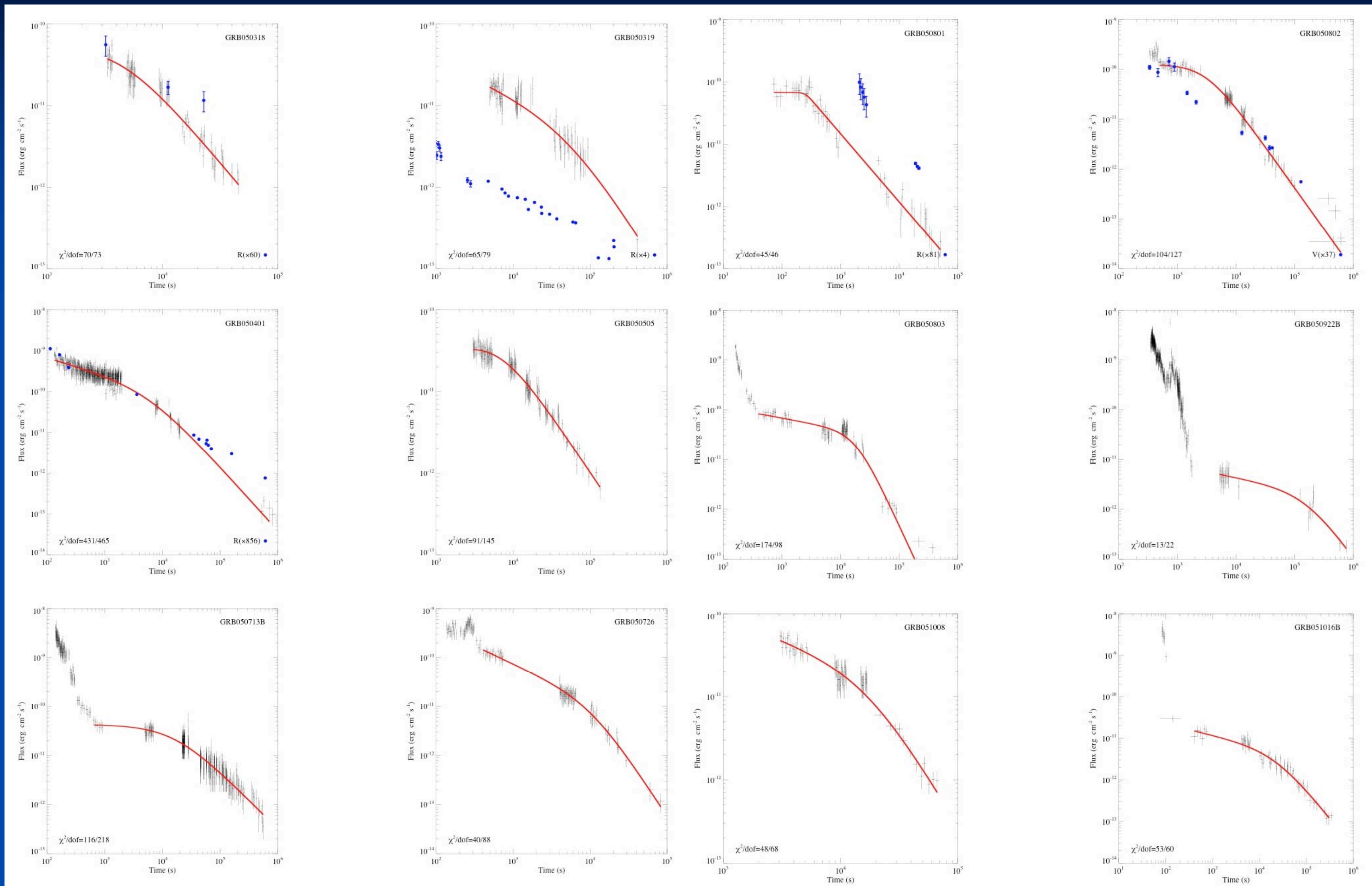
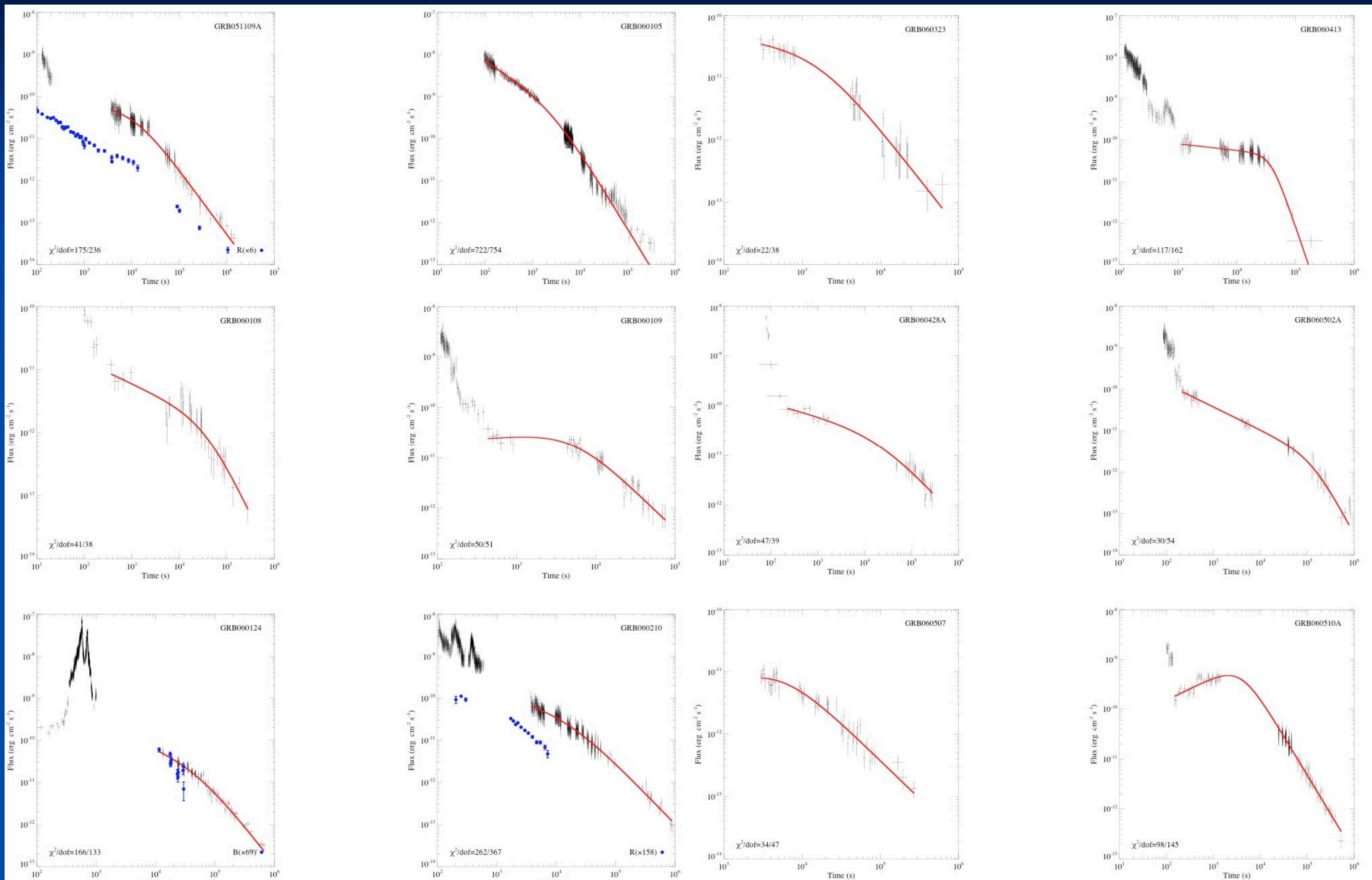


Diverse origins of the plateaus

Liang, Zhang & Zhang, 2007, ApJ

- 48 clear cases of the shallow decay segment for Swift GRBs before Feb. 2007
- 36 are followed by a "normal decay" segment that satisfies the isotropic forward shock models, no spectral change across the break
  - 7 has optical observations across the break
  - 4 chromatic cases, 3 achromatic cases
- 8 are followed by a steeper decay segment that satisfied the jet models
- 3 are followed by a very steep decay segment that is inconsistent with any external shock models
  - 2 with optical detection across the break, all chromatic
- 1 shows significant spectral change across the break (however a big gap in the data)


GRB050318
χ²/dof=70/73
R(×60)
GRB050319
χ²/dof=65/79
R(×4)
GRB050801
χ²/dof=45/46
R(×81)
GRB050802
χ²/dof=104/127
V(×37)
GRB050401
χ²/dof=431/465
R(×856)
GRB050505
χ²/dof=91/145
GRB050803
χ²/dof=174/98
GRB050922B
χ²/dof=13/22
GRB050713B
χ²/dof=116/218
GRB050726
χ²/dof=40/88
GRB051008
χ²/dof=48/68
GRB051016B
χ²/dof=53/60
Flux (erg cm⁻² s⁻¹)
Time (s)



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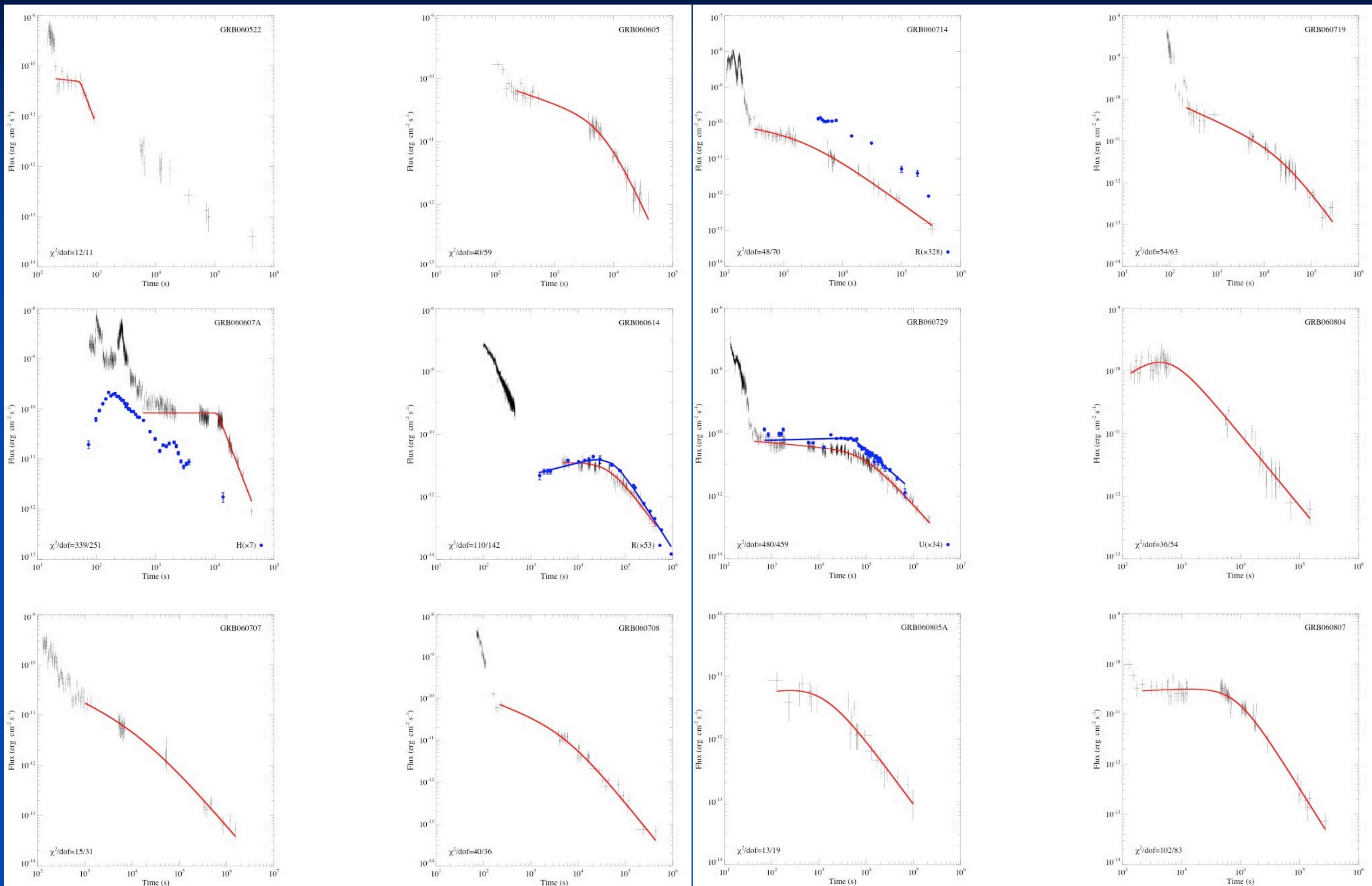
χ²/dof=175/236
R(×6)
GRB060105
χ²/dof=722/754
GRB060323
χ²/dof=22/38
GRB060413
χ²/dof=117/162
GRB060108
χ²/dof=41/38
GRB060109
χ²/dof=50/51
GRB060428A
χ²/dof=47/39
GRB060502A
χ²/dof=30/54
GRB060124
χ²/dof=166/133
B(×69)
GRB060210
χ²/dof=262/367
R(×158)
GRB060507
χ²/dof=34/47
GRB060510A
χ²/dof=98/145
Time (s)
Flux (erg cm⁻² s⁻¹)



GRB060522
χ²/dof=12/11
GRB060605
χ²/dof=40/59
GRB060714
χ²/dof=48/70
R(×328)
GRB060719
χ²/dof=54/63
GRB060607A
χ²/dof=339/251
H(×7)
GRB060614
χ²/dof=110/142
R(×53)
GRB060729
χ²/dof=480/459
U(×34)
GRB060804
χ²/dof=36/54
GRB060707
χ²/dof=15/31
GRB060708
χ²/dof=40/36
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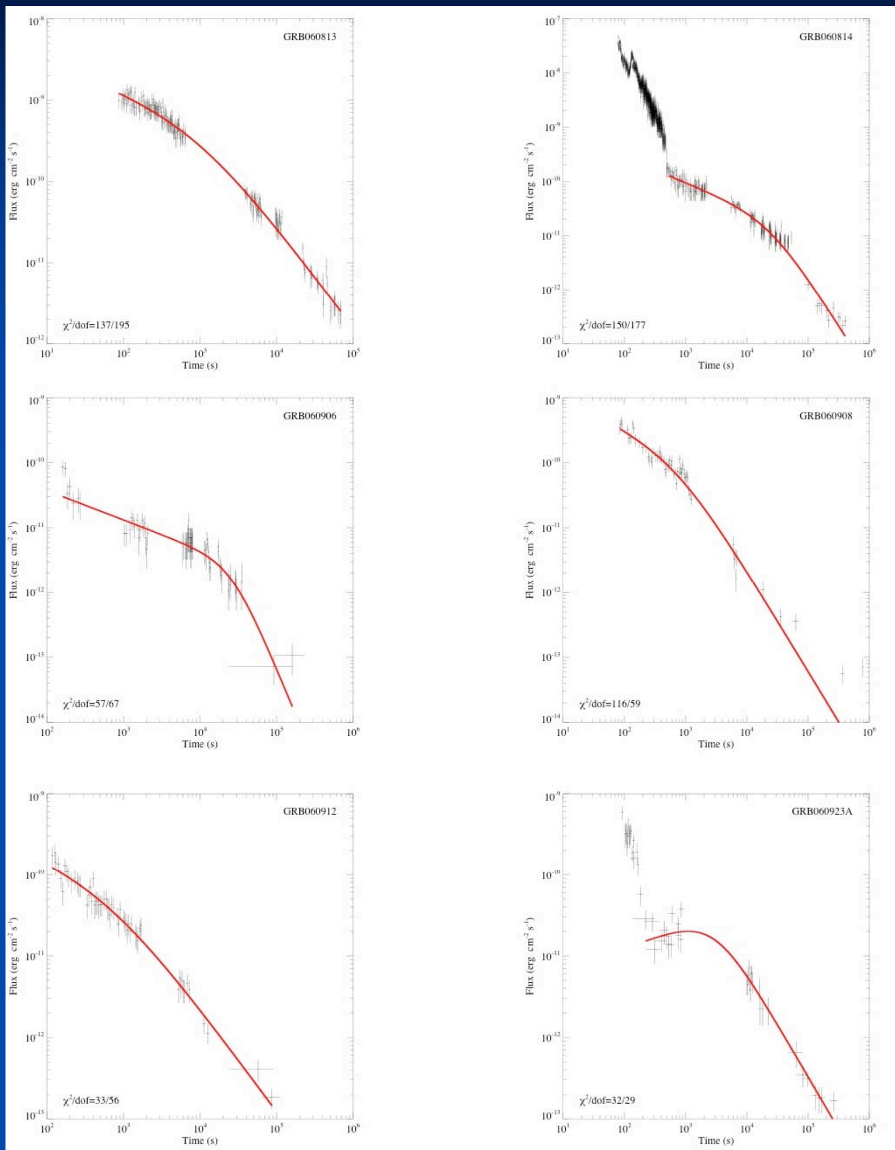
χ²/dof=102/83
Time (s)
Flux (erg cm⁻² s⁻¹)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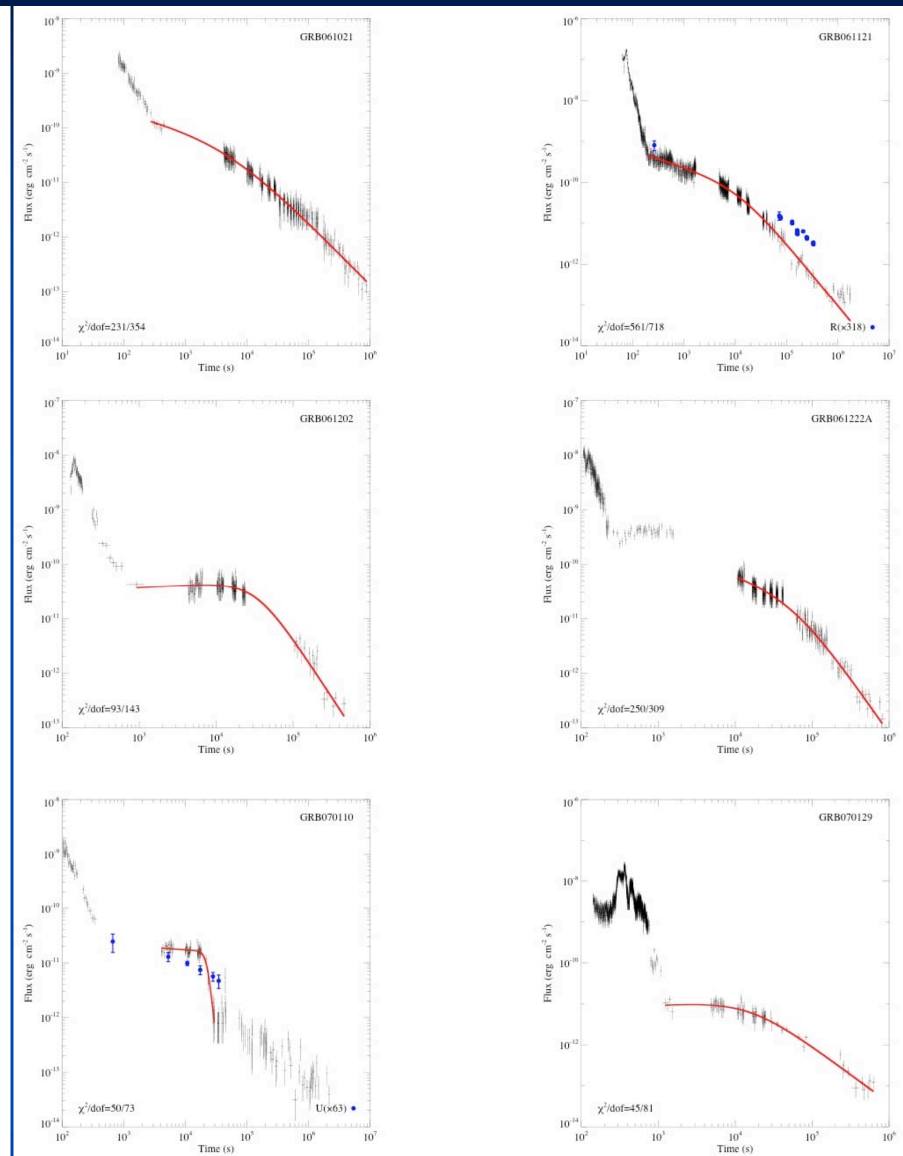
χ2/dof=137/195
GRB060814
χ2/dof=150/177
GRB060906
χ2/dof=57/67
GRB060908
χ2/dof=116/59
GRB060912
χ2/dof=33/56
GRB060923A
χ2/dof=32/29
Flux (erg cm-2 s-1)
Time (s)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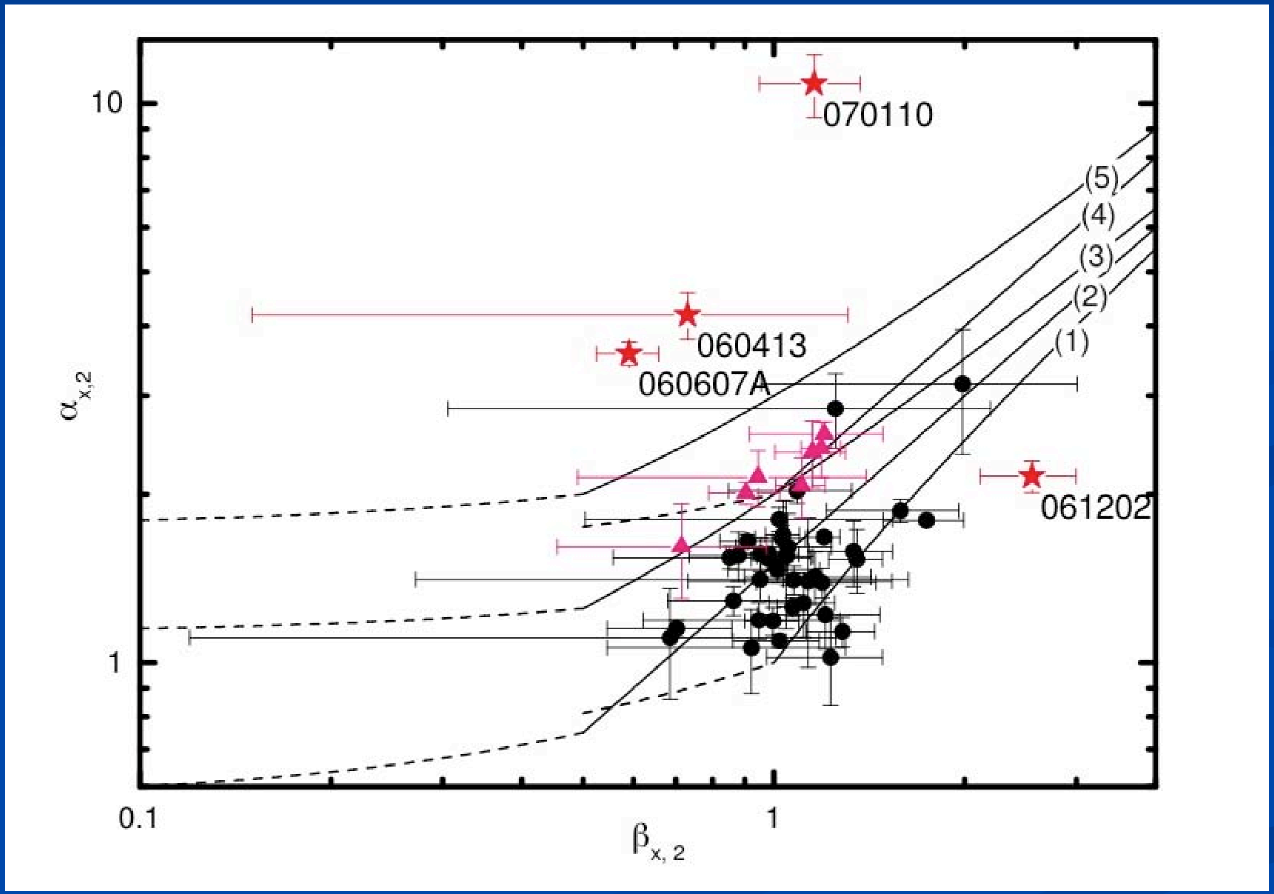
χ2/dof=231/354
GRB061121
χ2/dof=561/718
R(×318)
GRB061202
χ2/dof=93/143
GRB061222A
χ2/dof=250/309
GRB070110
χ2/dof=50/73
U(×63)
GRB070129
χ2/dof=45/81
Flux (erg cm-2 s-1)
Time (s)

How bad is the external shock model?

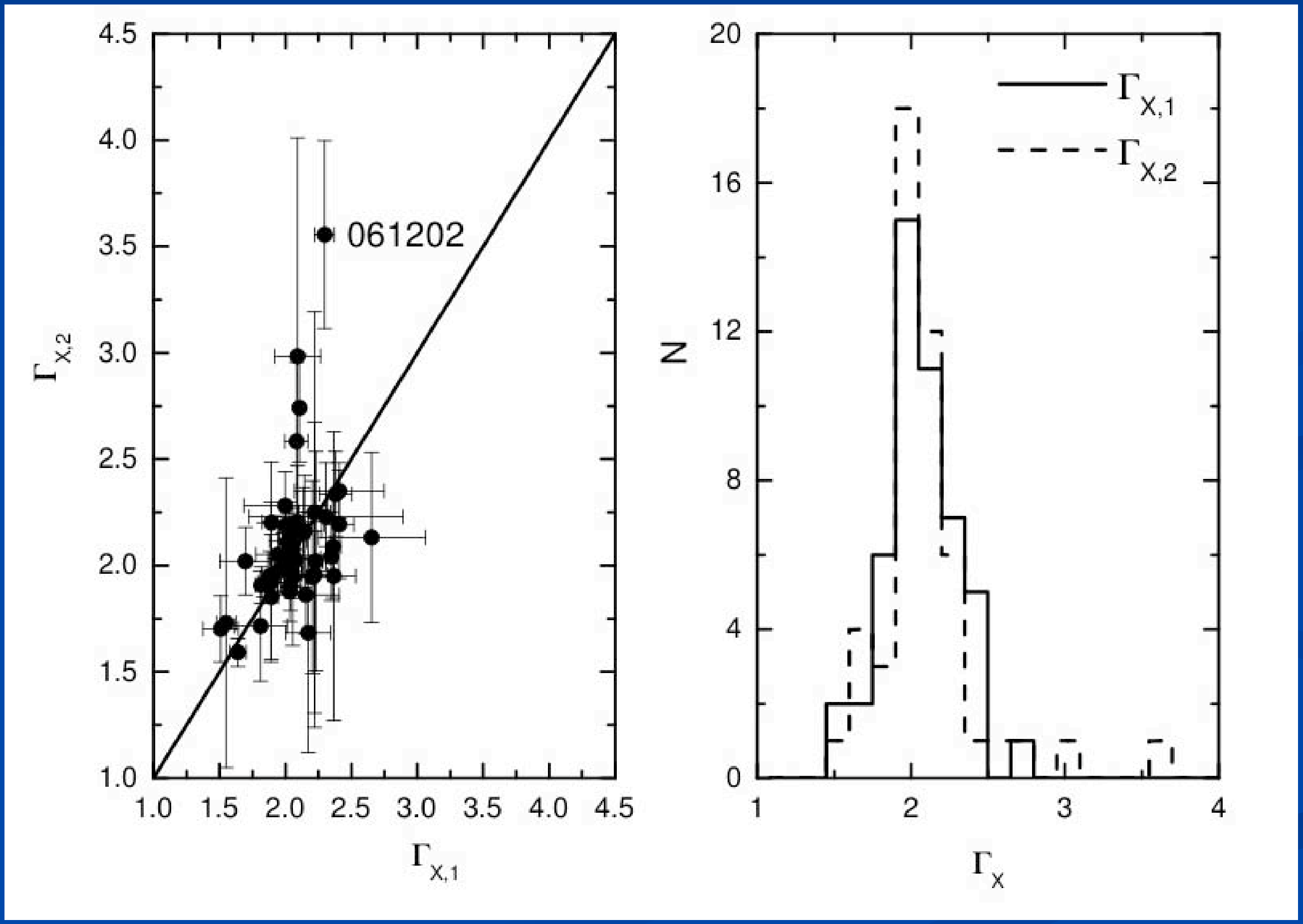
Liang, Zhang & Zhang, 2007, ApJ



See also Willingale et al. (2007)

Spectral evolution across the break?

Liang, Zhang & Zhang, 2007, ApJ

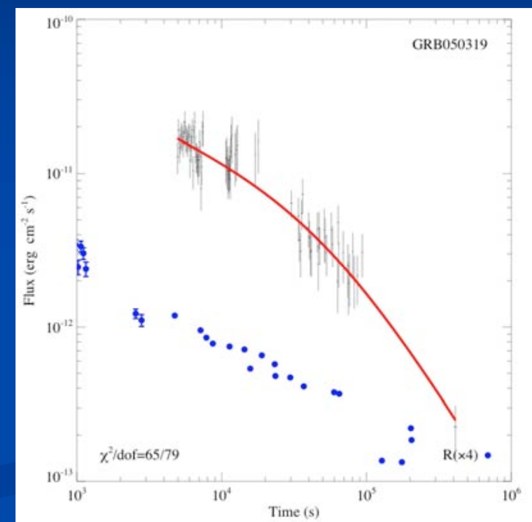


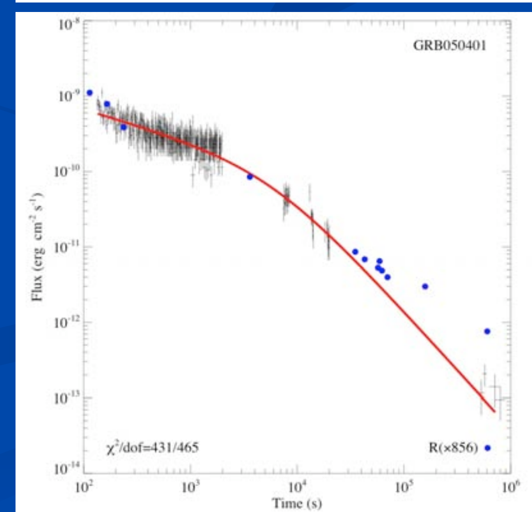
See also Willingale et al. (2007)

External origin of some plateaus? (Refreshed shocks)

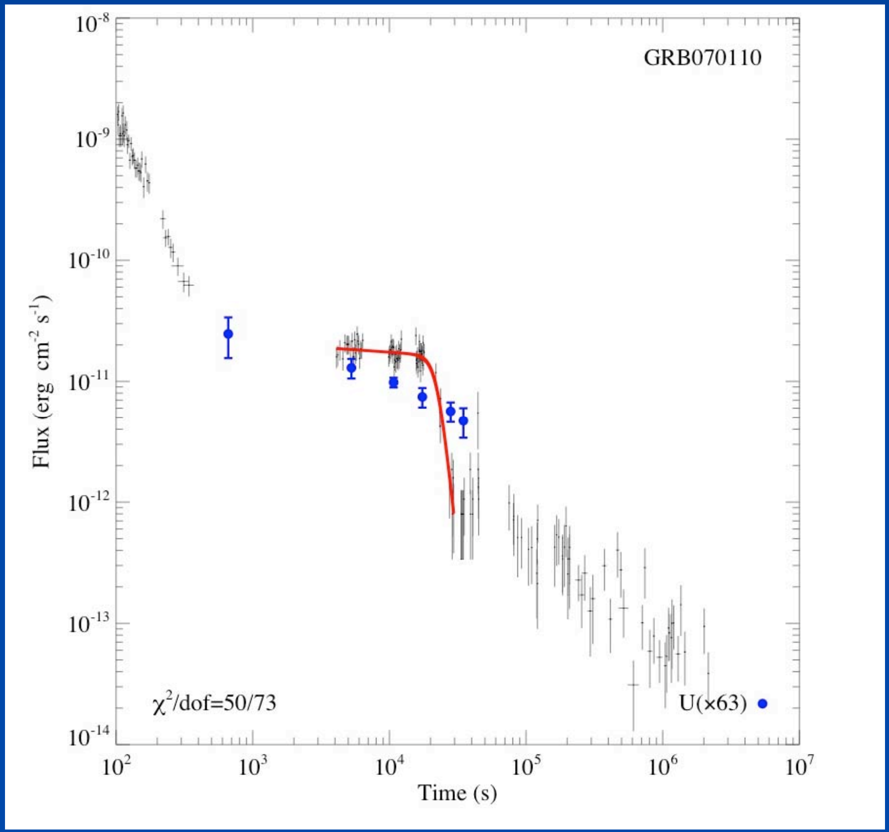
Liang, Zhang & Zhang, 2007, ApJ

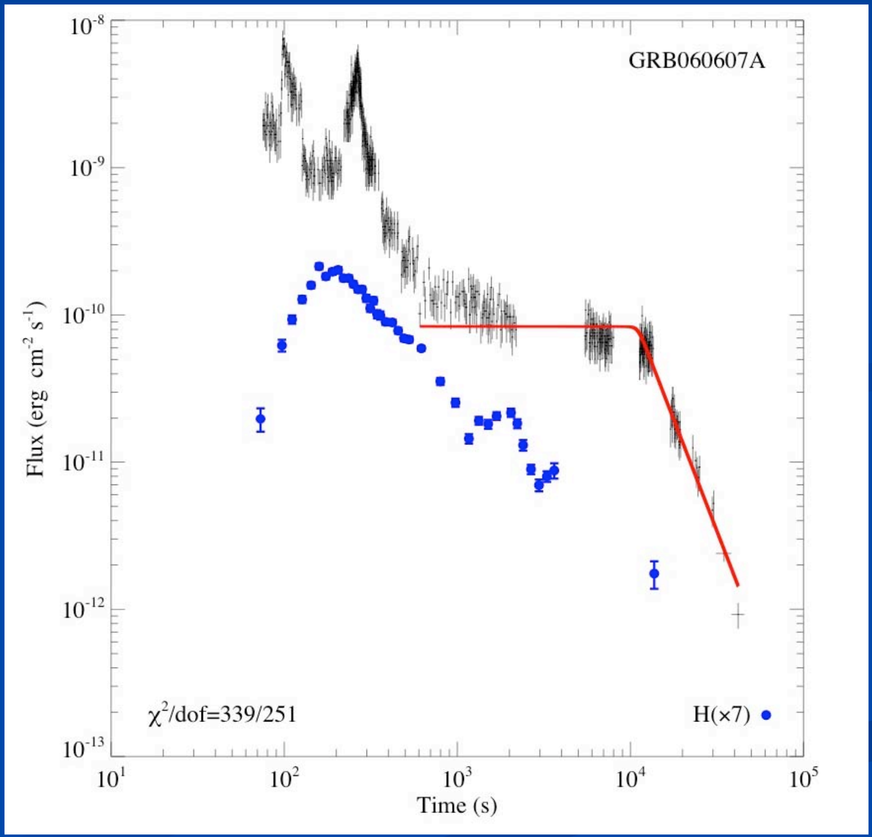
- Evidence:
  - Most post break segment satisfies closure relations
  - No spectral evolution across the break
  - Reasonable "q" values [L(t) $\propto t^{-q}$], mean value ~ 0
- Issues:
  - Some chromatic breaks (Panaitescu et al. 2006)
  - Large error bars





Internal origin of some plateaus





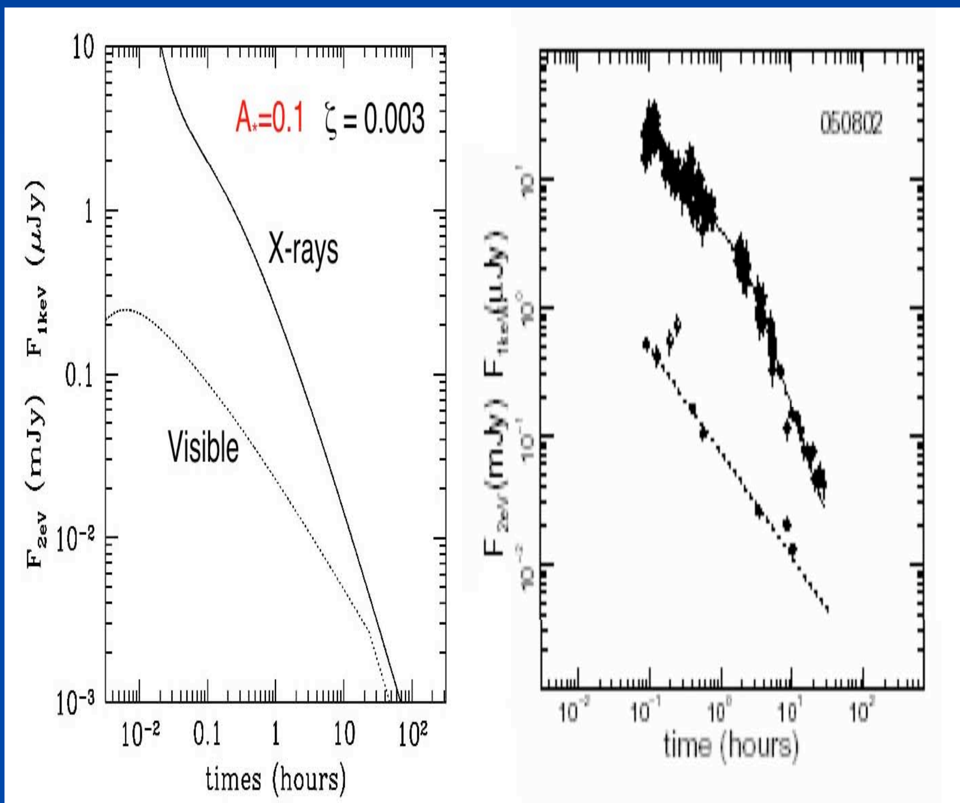
Troja et al. (2007)

Internal origin of some plateaus

- Extended central engine activity
- Different behavior from X-ray flares
- Maybe we are witnessing two types of the central engine behavior
  - Accretion power - flares
  - Spin down power - smooth plateau
- Break the degeneracy of the refreshed shock model - at least in some cases, a long-lived central engine is indeed at work

Reverse shock dominated emission

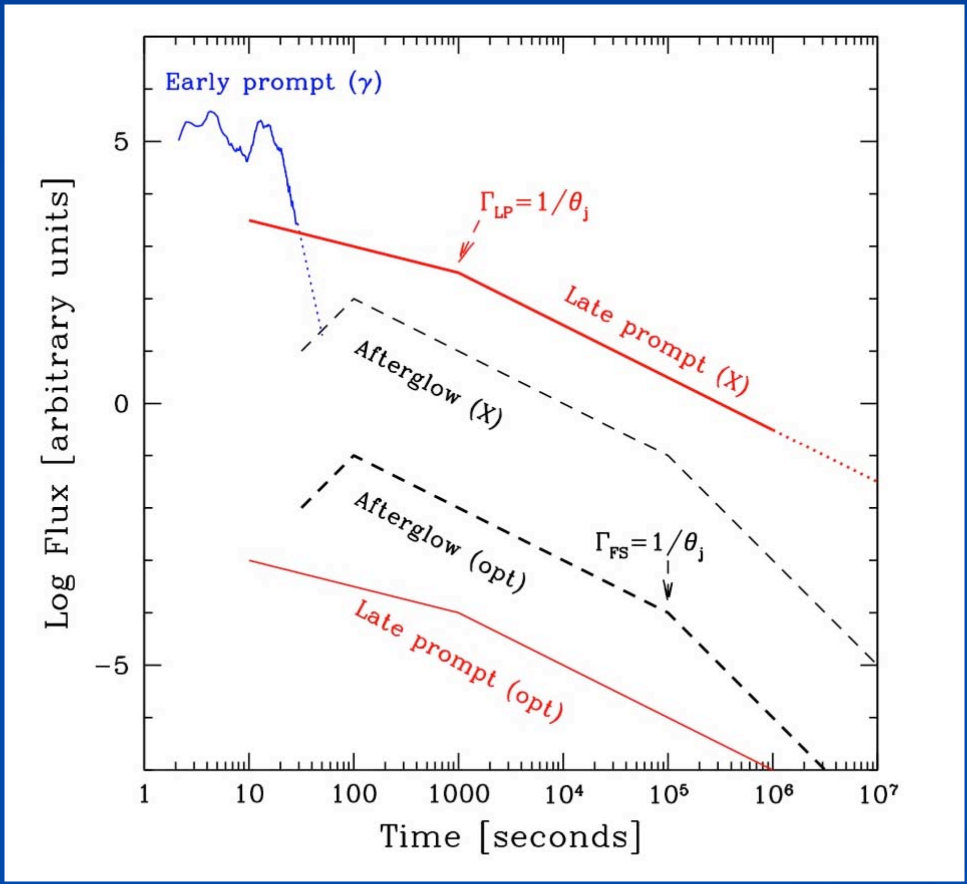
(Genet, Daigne & Mochkovitch 2007; Lucas & Beloborodov 2007)



- Two ingredients in the model:
  - Reverse shock
  - Injection parameter ς
- It is ς that makes chromatic breaks
- Issues:
  - How to hide forward shock component (carries most of energy)
  - The forward shock works well

X-rays as "late prompt" emission?

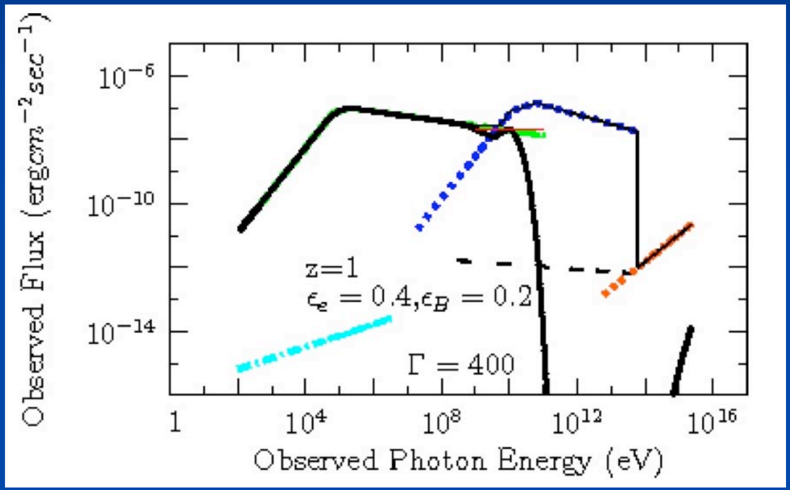
(Ghisellini et al. 2007)

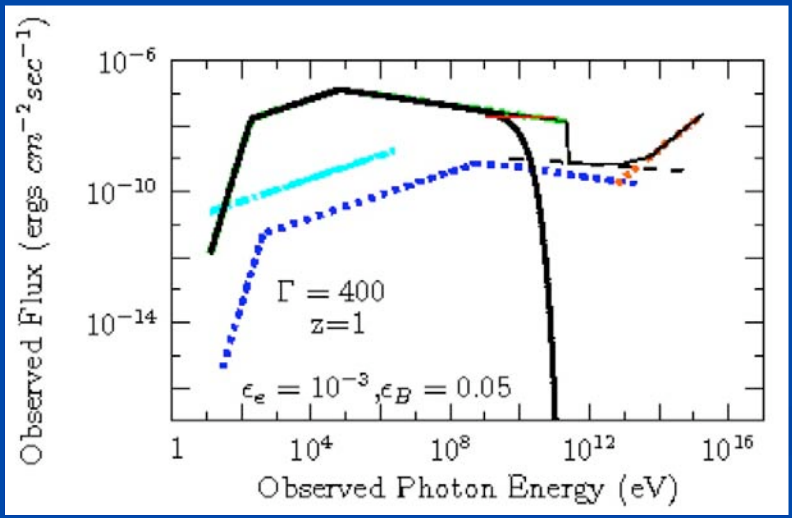


- Issues:
  - The forward shock works well, how late prompt emission satisfies the closure relations of the forward shock model?
  - How to produce a smooth lightcurve via internal shocks? What makes the difference between plateaus and flares?

Swift is needed for GLAST bursts

(Gupta & Zhang 2007)





- High energy spectrum along cannot be used to differentiate leptonic/hadronic origin of gamma-rays
- Distinct radiative efficiency
- Swift is needed to measure the kinetic energy/radiative efficiency

Conclusions

- An important task of Swift in the coming years is to provide more data to understand the physical origin of the X-ray/optical afterglows
- The tails are not solely controlled by the curvature effect. The cooling process of the prompt emission region may be probed.
- Most X-ray data are still consistent with the forward shock model. Fundamental revolution may not be demanded.
- Chromatic decay without spectral variation is a great puzzle.
- In some cases, an internal-origin plateau is observed. It may be connected to the spindown power of the central engine.
- Swift can assist GLAST to diagnose GRB composition.