Dark Cosmology Centre

Optical and Near-Infrared Flares of GRBs

Thomas Krühler (DARK)

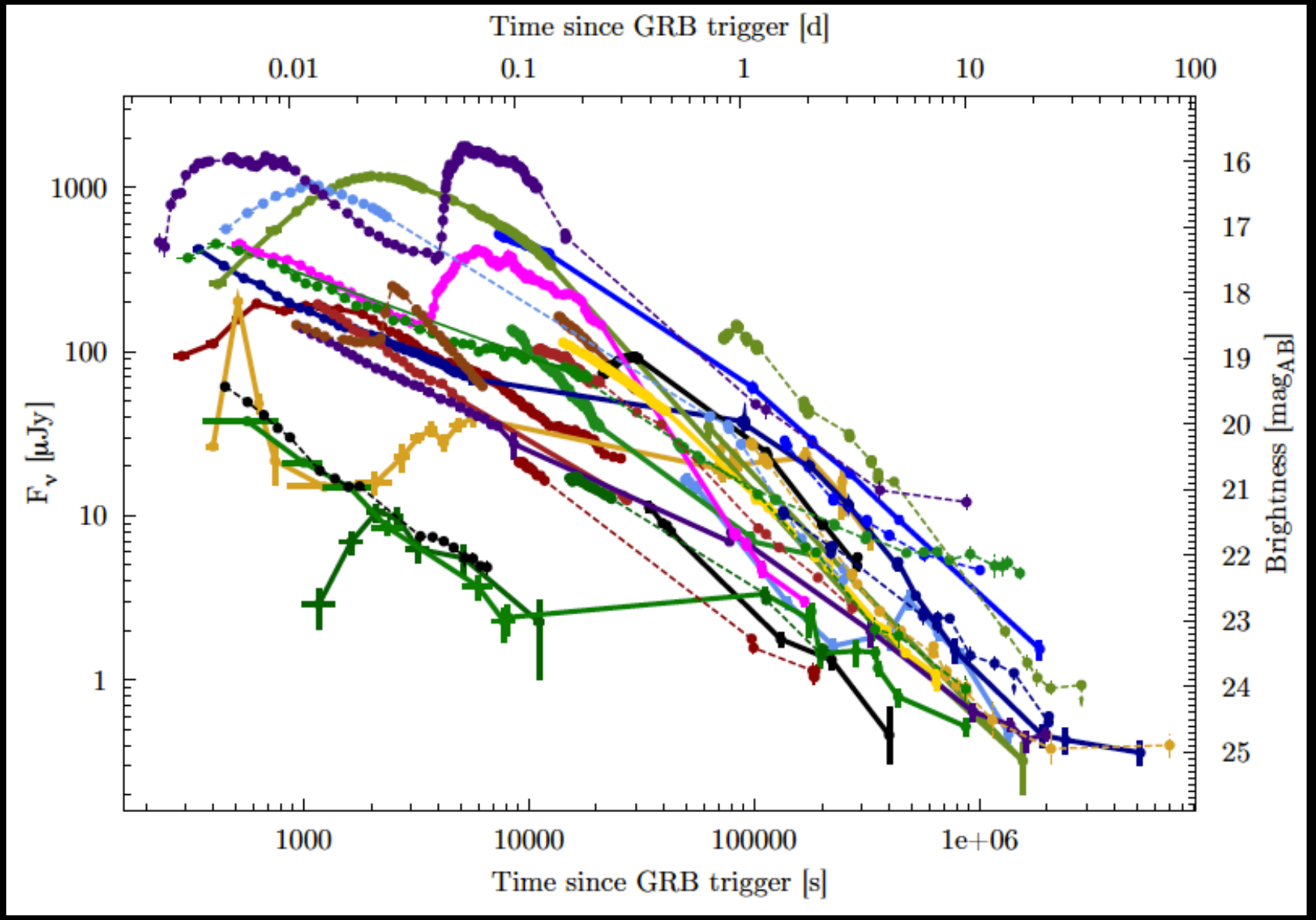
Thanks to D. A. Kann, J. Greiner,

M. Nardini and many others

Death of massive stars – SNe & GRBs @ Nikko

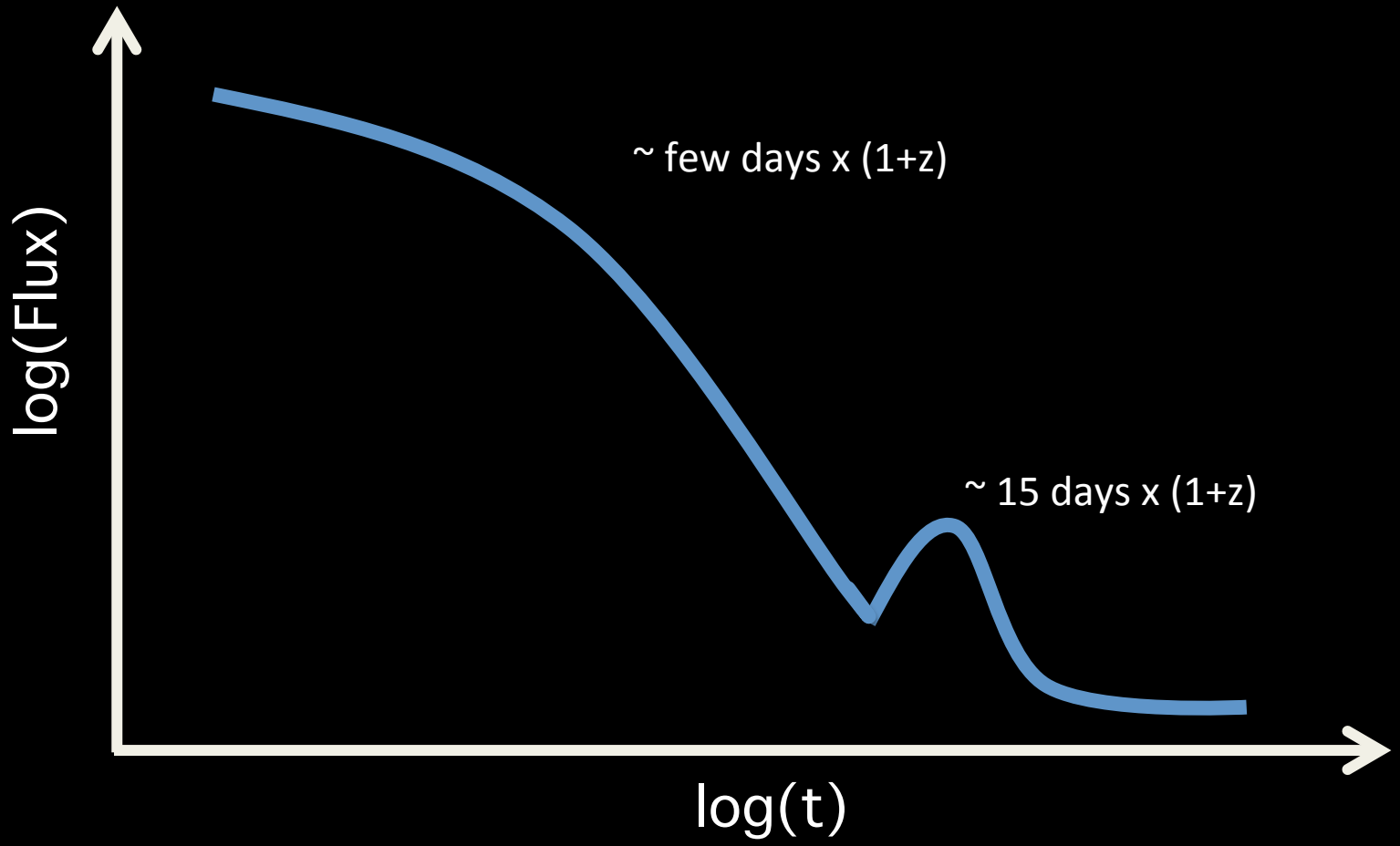
13/03/02

Afterglow light-curves:

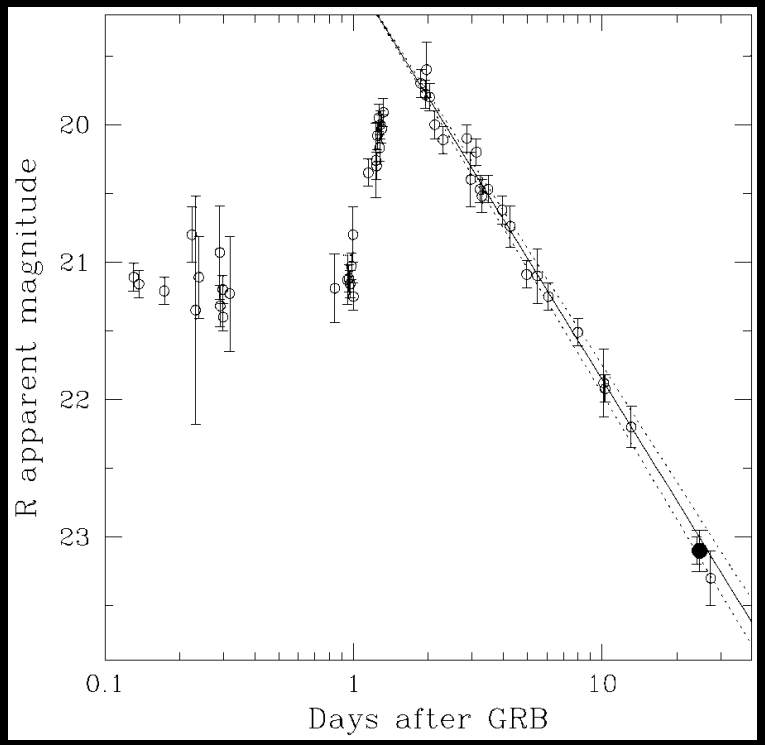


Working hypothesis:

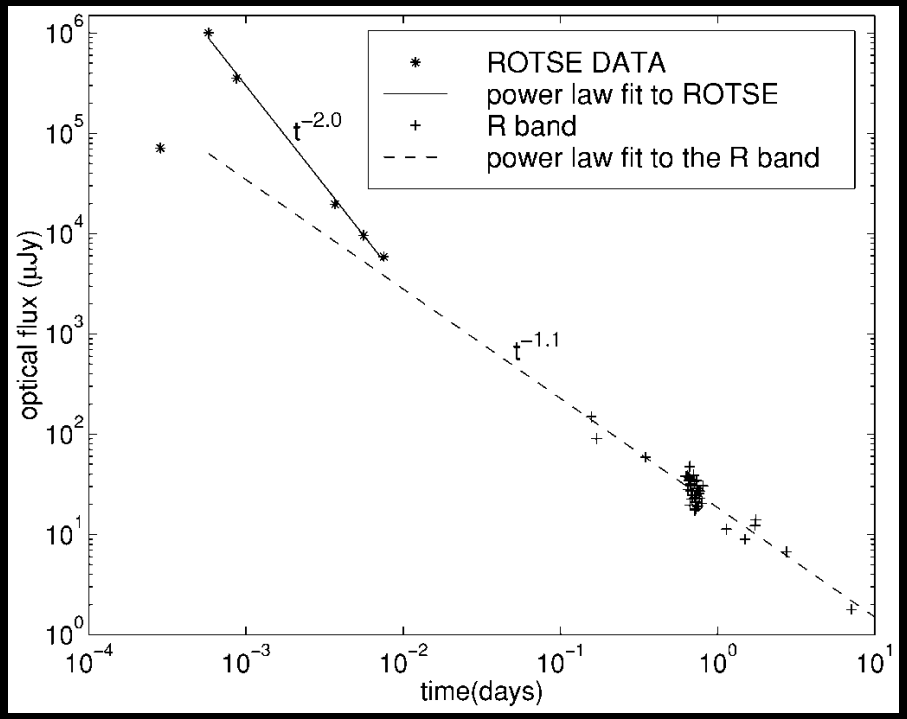
-> A flare is anything that peaks between ~100 s and 10 days after the burst



Some pre-*Swift* events:

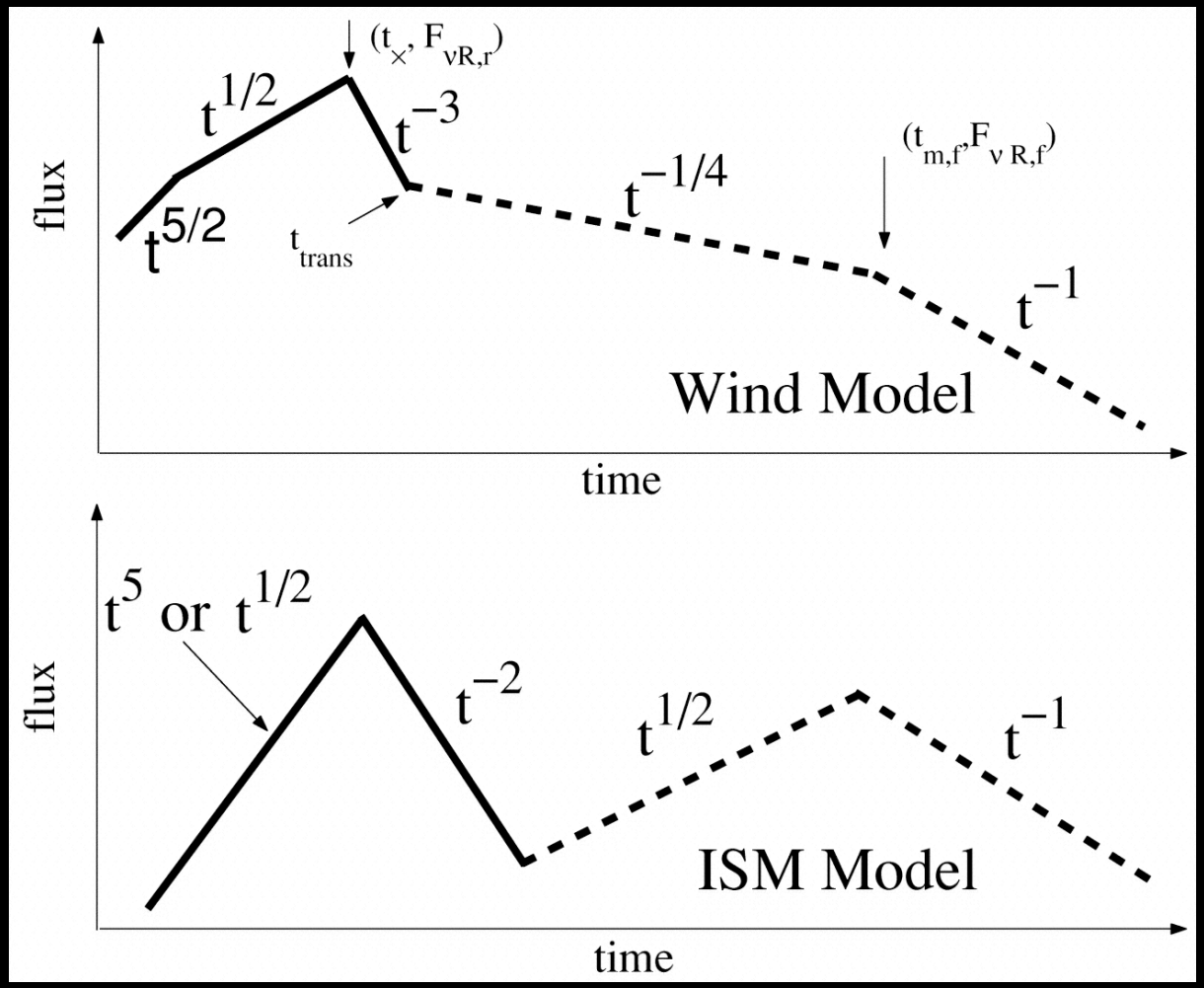


GRB 970508: Pedersen+ 98, Pian+ 98



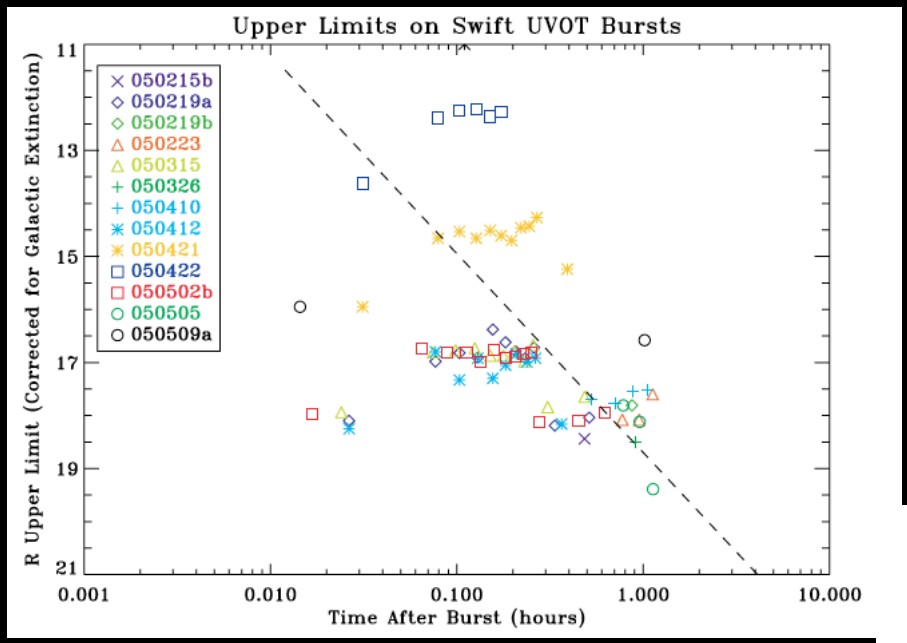
GRB 990123: Sari+ 99, Mészáros+ 99, Fruchter+ 99, Castro-Tirado+ 99

Bright optical flashes due to Reverse Shock



Zhang+03, Kobayashi & Zhang 03

(i) Reverse Shocks:

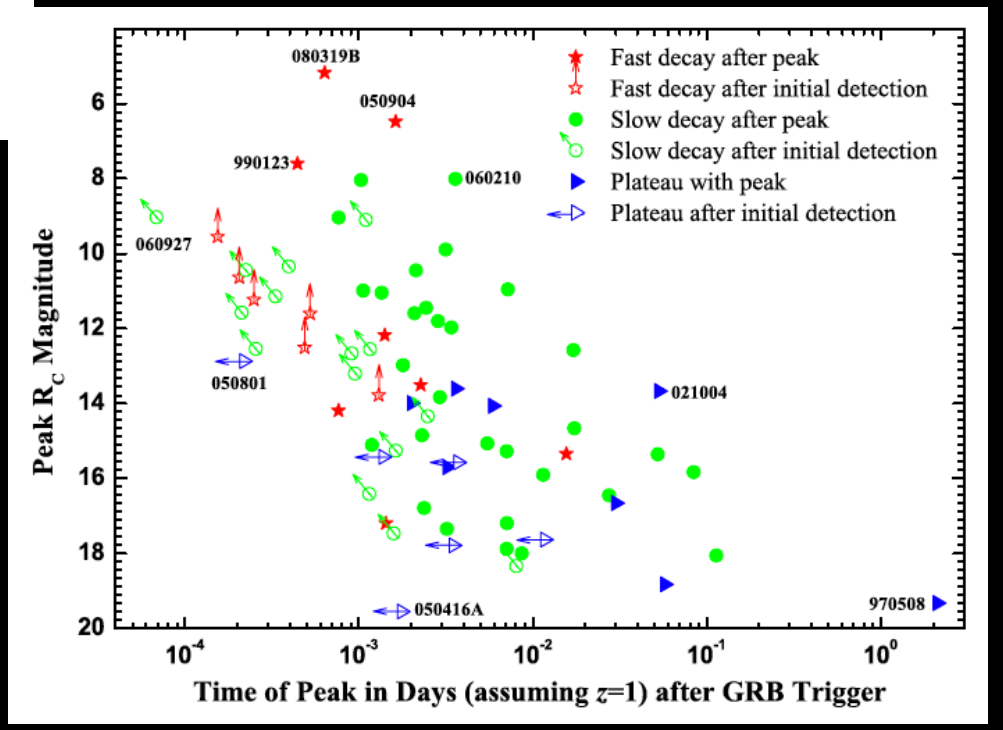


Lack of (many) bright optical flares in Swift GRBs

Roming+ 06

Lack of (many) fast decaying afterglows in Swift GRBs

Kann+ 06, Melandri+ 08



(i) Reverse Shocks:

Prominent Reverse Shock is not detected in the UV/optical/bands, due to:

* High magnetization (Mimica+ 09, Mizuno+ 09)

  -> Suppressing the RS emission

* Low magnetic energy densities (Beloborodov+ 05, Zou+ 09)

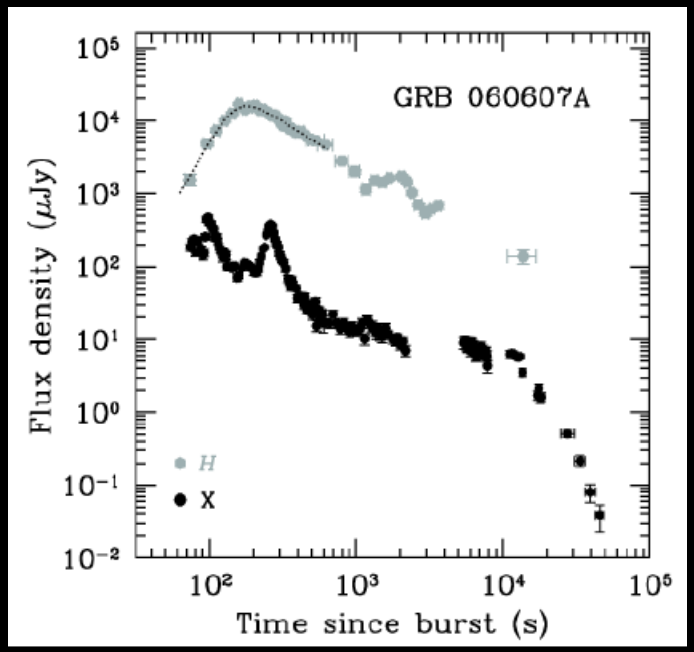
  -> Shifting the RS to higher energies

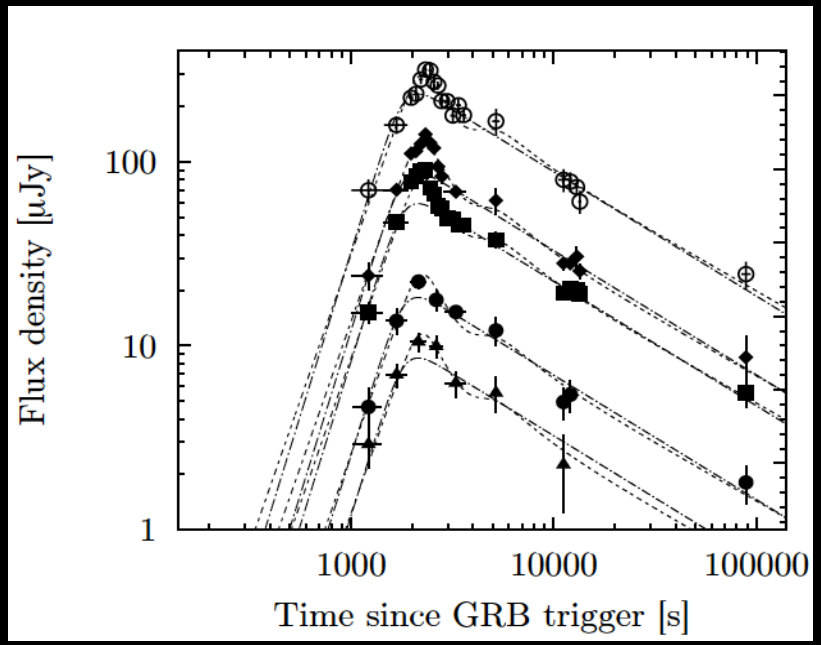
* ν_m of the RS at lower frequencies (Mundell+ 07, Melandri+ 09)

  -> Radio flares

(ii) The onset of the afterglow

- Early rise ($t^{0.5\text{-}4}$)
- Peaking at < 100 … 1000 s
- Smooth turnover to decay
- Achromatic





e.g., Molinari+ 07, Krühler+ 08,09, Greiner+ 09, Perley+ 10, Melandri+ 10, Liang+ 10, Oates+ 10, Cucchiara+ 11

(ii) The onset of the afterglow

Forward shock is dominating the optical emission most of the time:

* Lorentz-factor Γ = 100-500

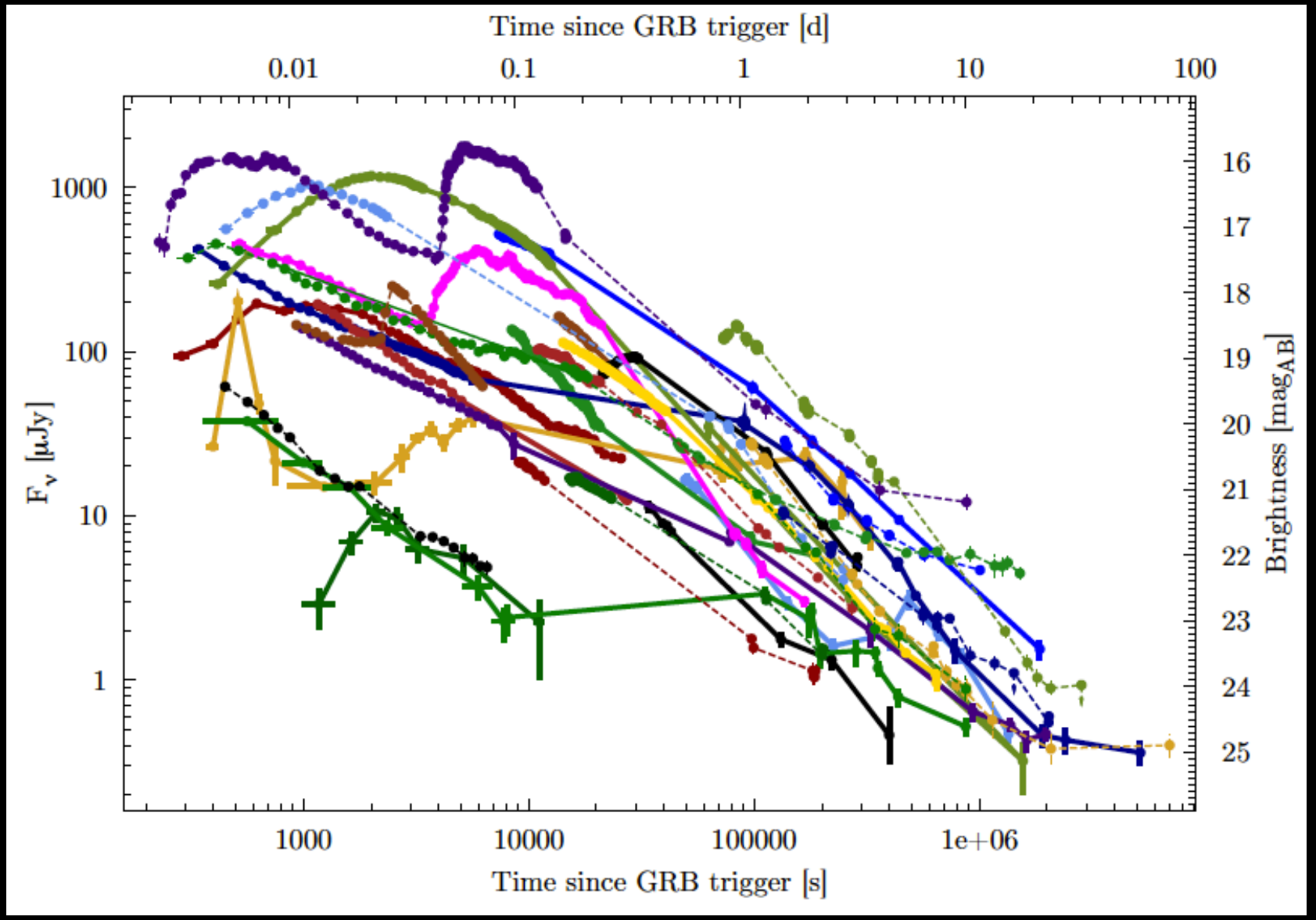
  -> Direct measurement of ultra-relativistic nature

* Deceleration radius $R_{dec} \sim 10^{17}$-10^{18} cm

  -> Direct measurement of emission region

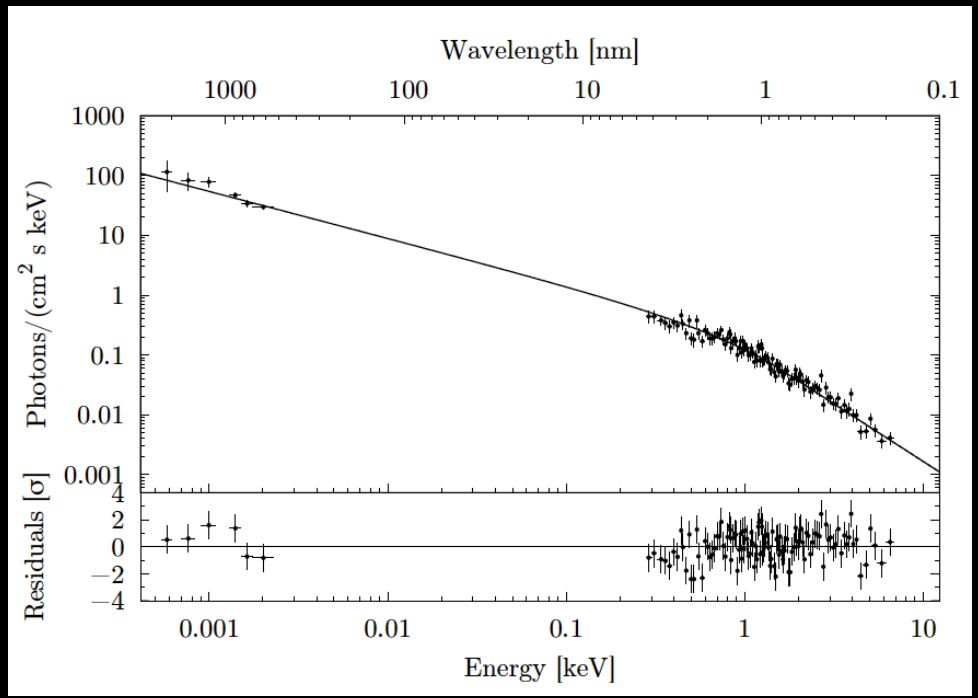
* Correlation between Γ and $E_{\gamma,iso}$ (Liang+ 10)

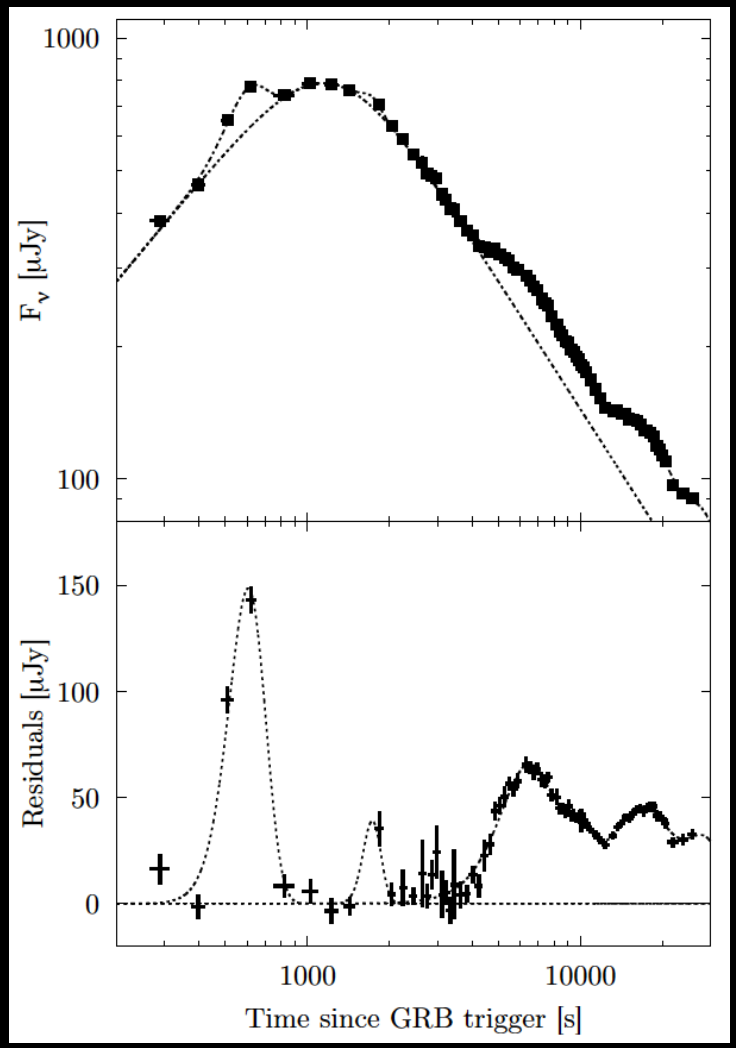
Afterglow light-curves:



(iii) Optical 'X-ray' flares

- Steep rise, steep decay (t^{5-12})
- Multiple events in single burst, to several ks
- Sharp turnover to decay
- Chromatic, extension of the X-ray spectrum

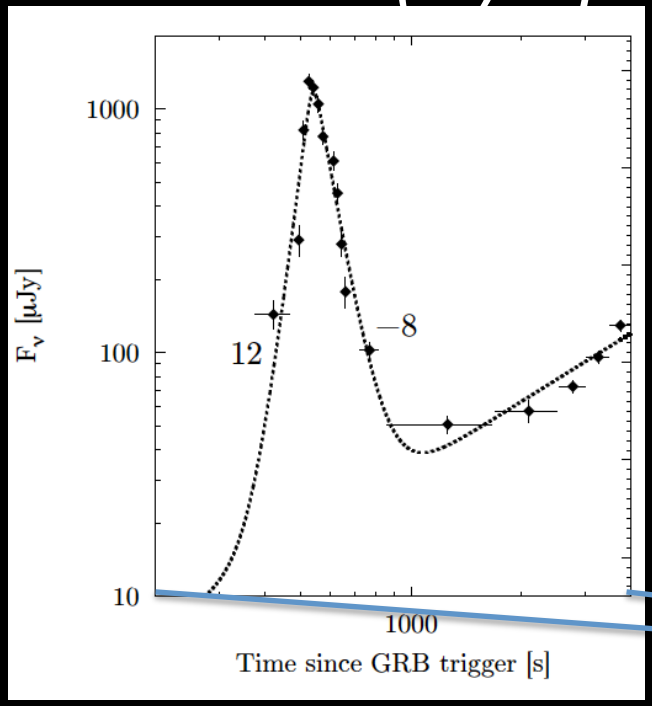


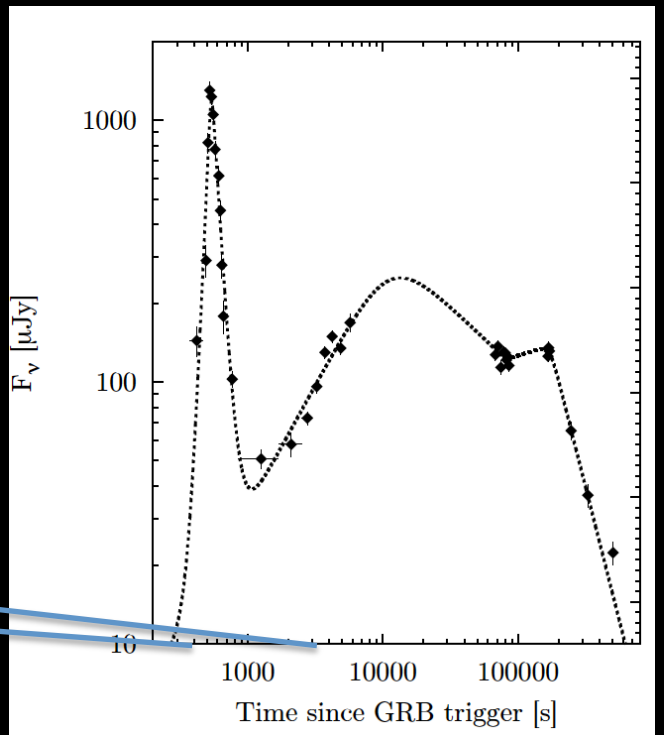


Krühler+ 09

Greiner+ 09

(iii) Optical 'X-ray' flares

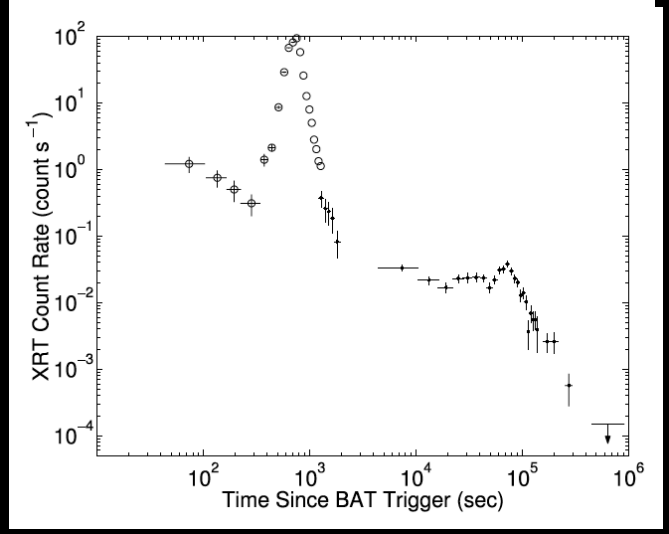




- Shape reminiscent of the large X-ray flares
- Paucity of detection:

-> Bright optical afterglow

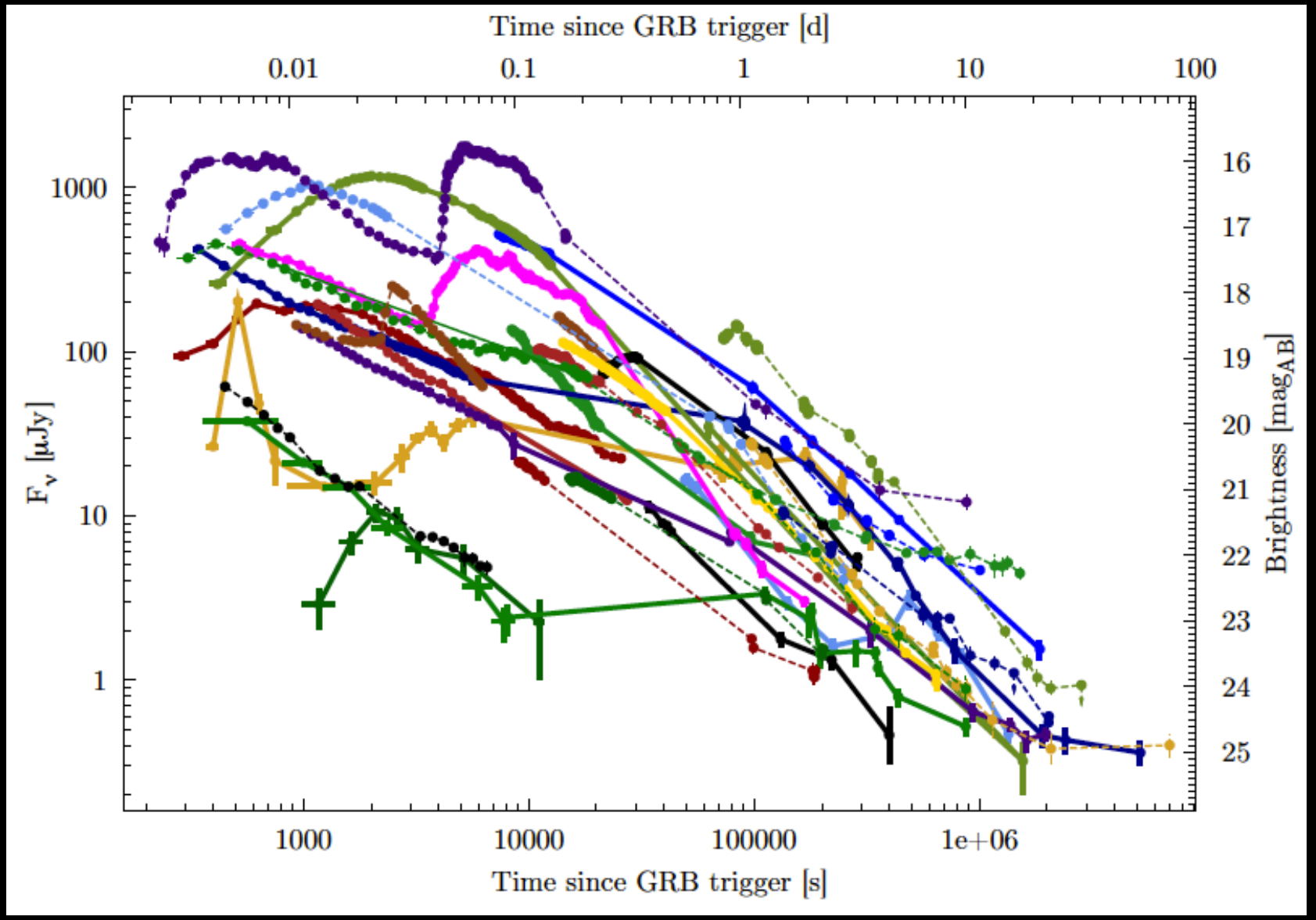
-> Spectra peaking in the few keV range



Burrows+ 05

Falcone+ 06

Afterglow light-curves:



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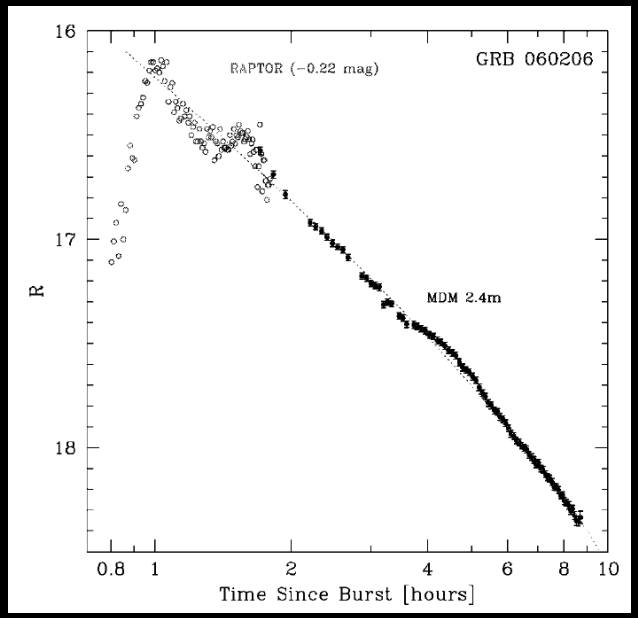
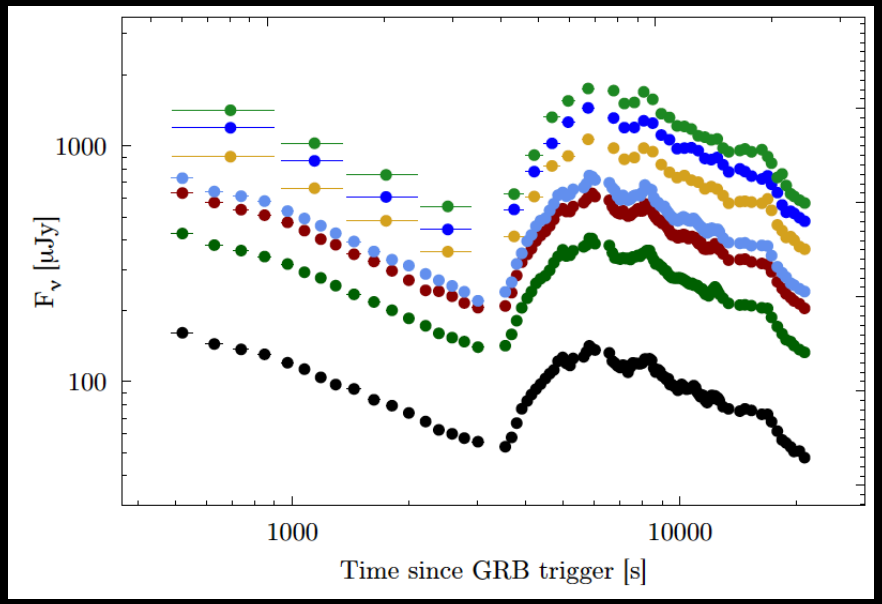
(iv) 'Jumps'

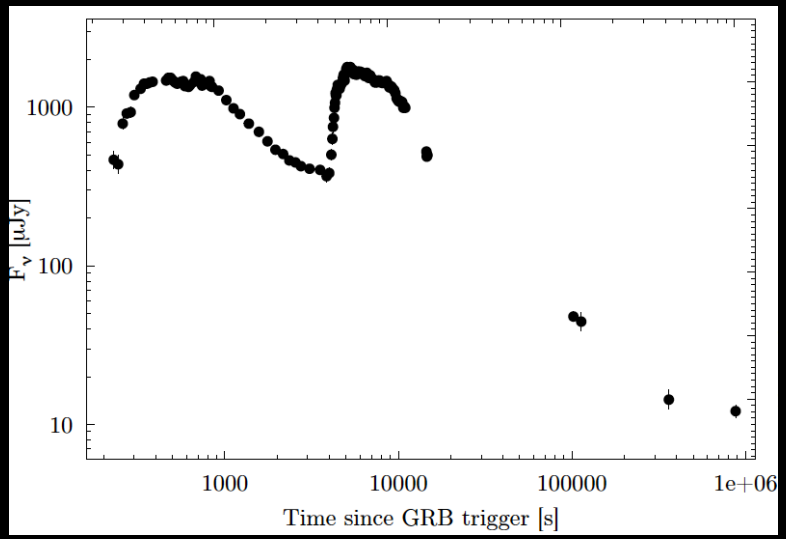


Stanek+ 07

Monfardini+ 06



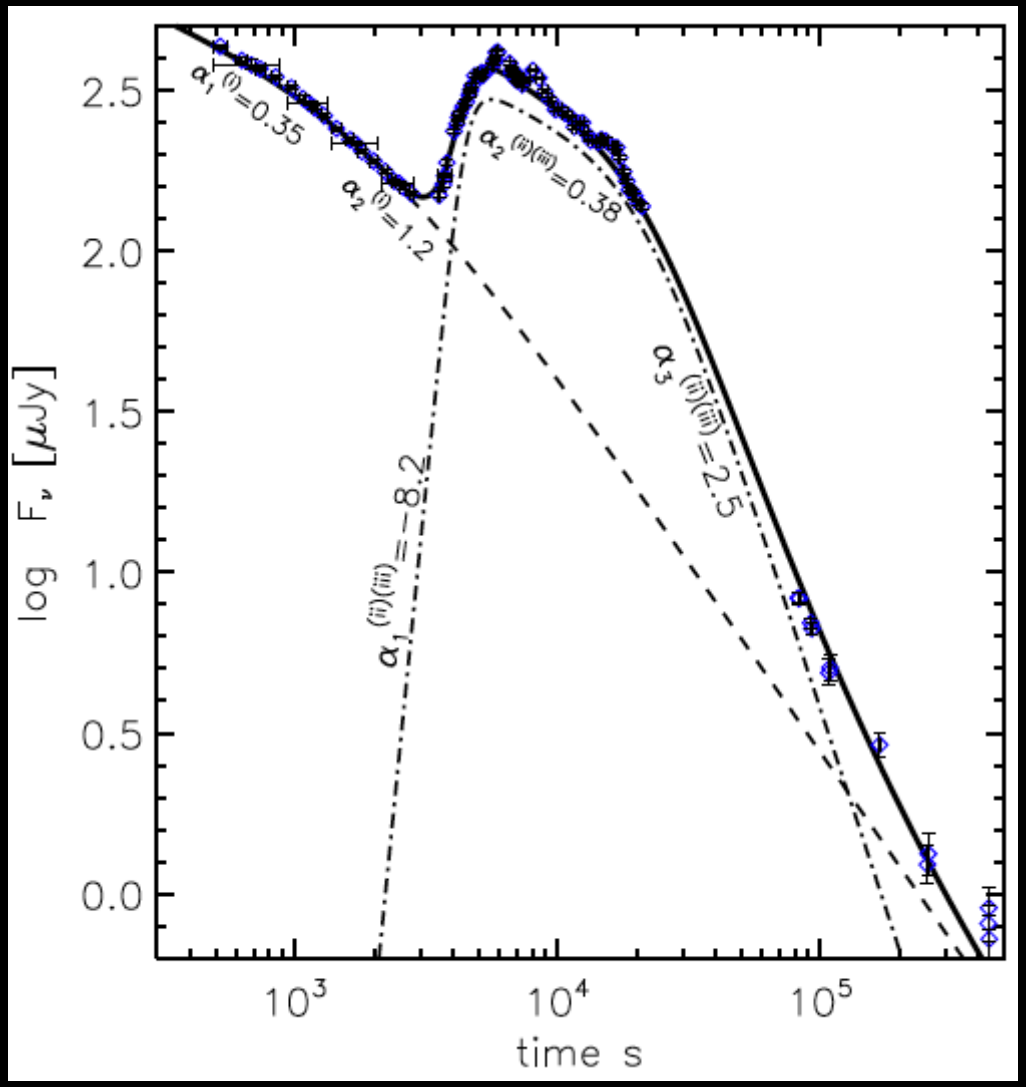
Nardini+ 11



Krühler+ 11

(iv) 'Jumps'

- A closer look to GRB 081029



Morphology:

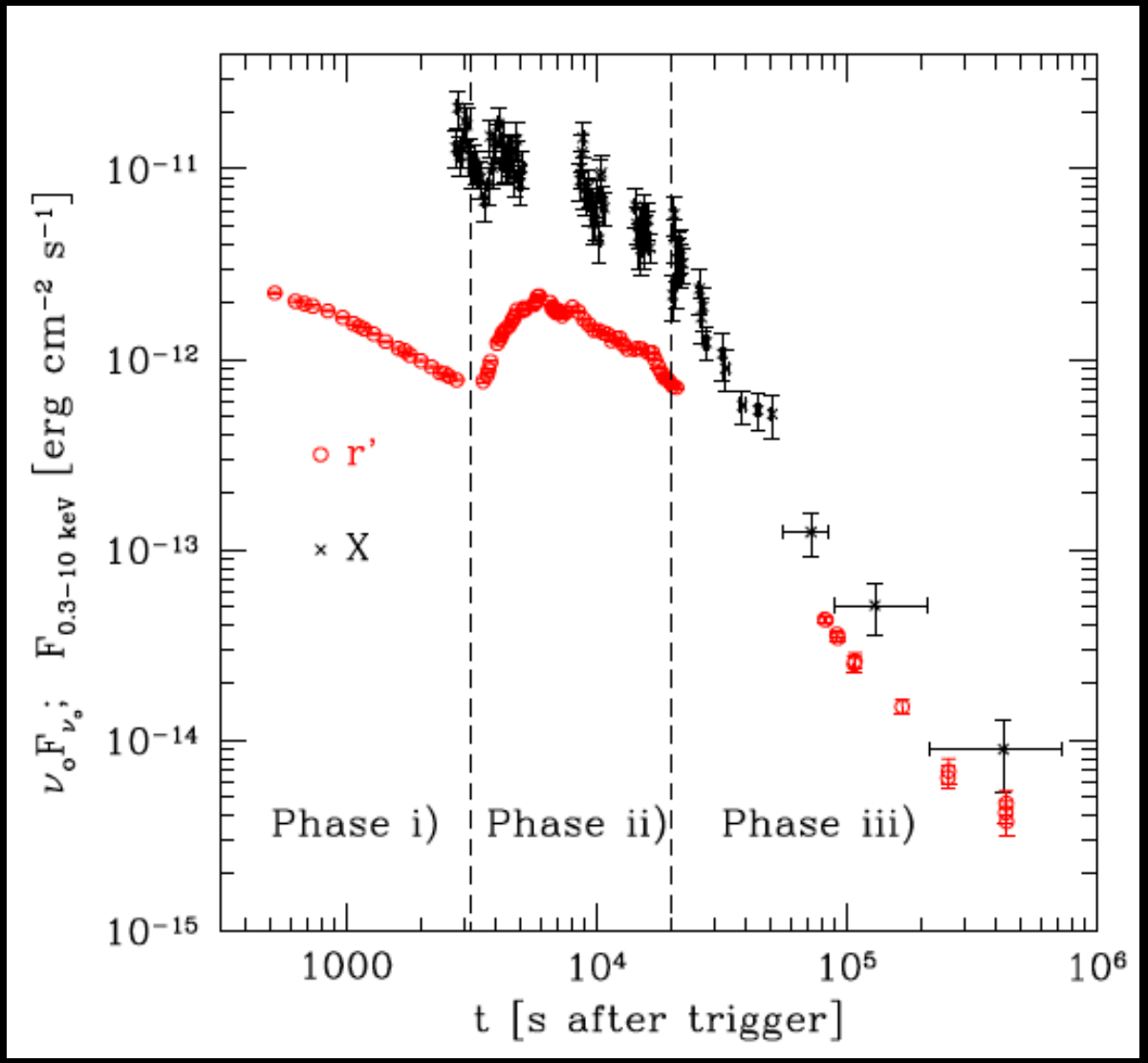
- Afterglow decay has already started
- Very steep rise
- Shallow to steep decay
- Late afterglow seems to connect well

Nardini+ 11

(iv) Jumps

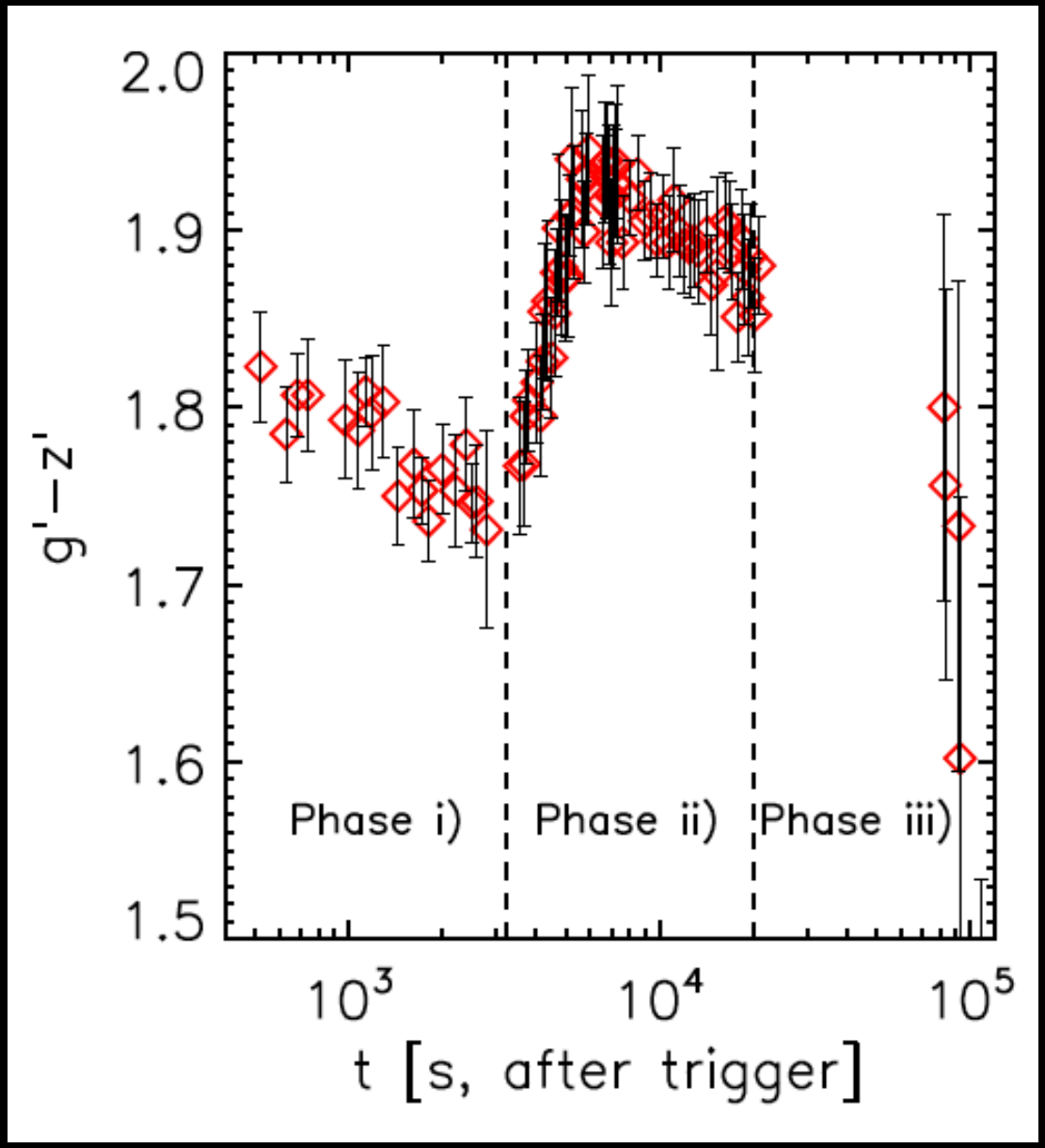
Broad-band behavior:

- No/weak signature in the X-rays
- Late afterglow seem to track each connect well



Nardini+ 11

(iv) Jumps



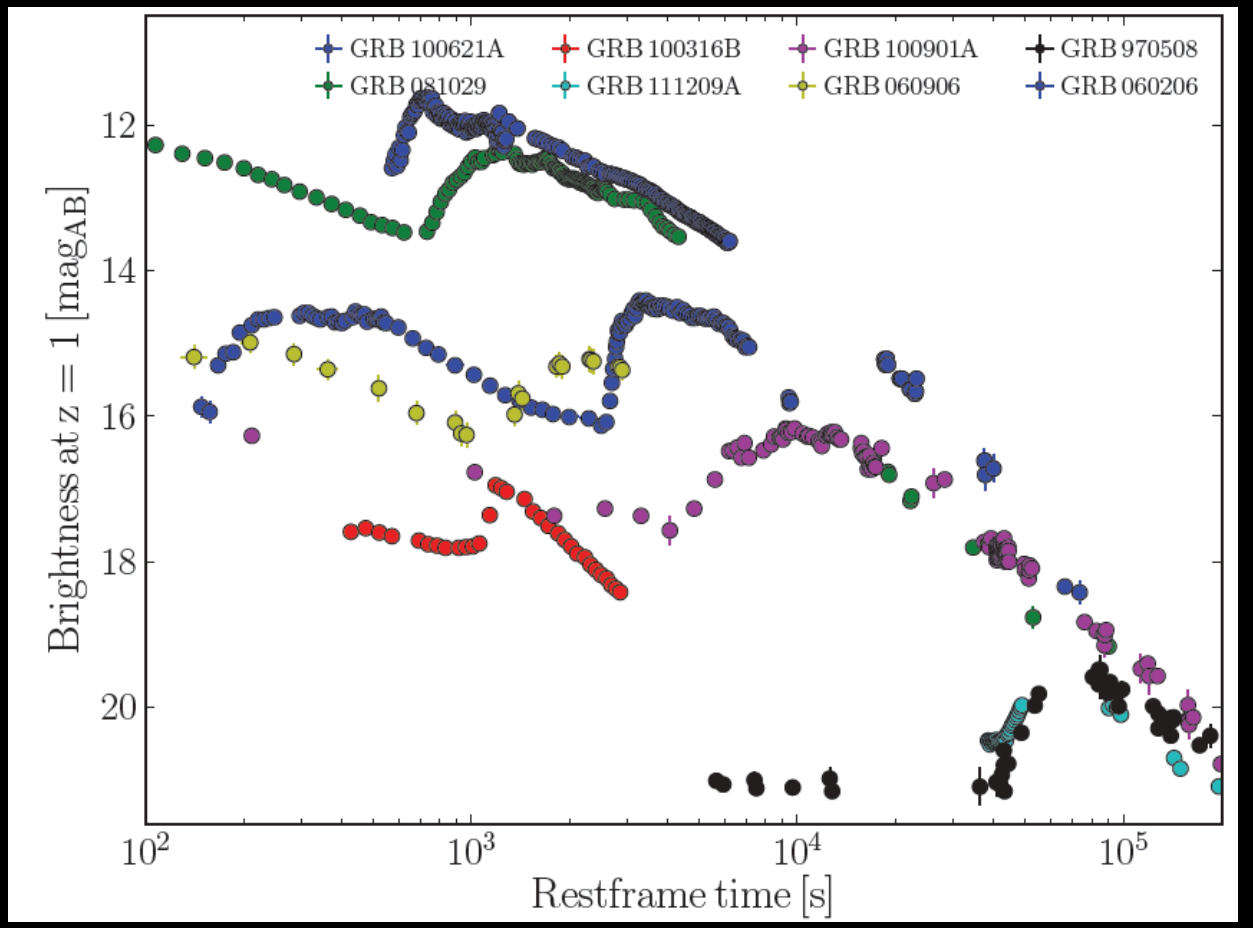
Spectral evolution

- Strong reddening is observed during the jump
- Not due to dust, but an intrinsic feature of the emission process

Nardini+ 11

(iv) Jumps

- Different times
- Afterglow already established
- Flare contrast is similar (does not correlate with time)



Pian+ 98, Pedersen+ 98, Stanek+ 06, Wozniak+ 06, Cenko+ 09
Volnova+10, Nardini+ 11, Kruehler+ 11, Greiner+ 12, Kann+ 12

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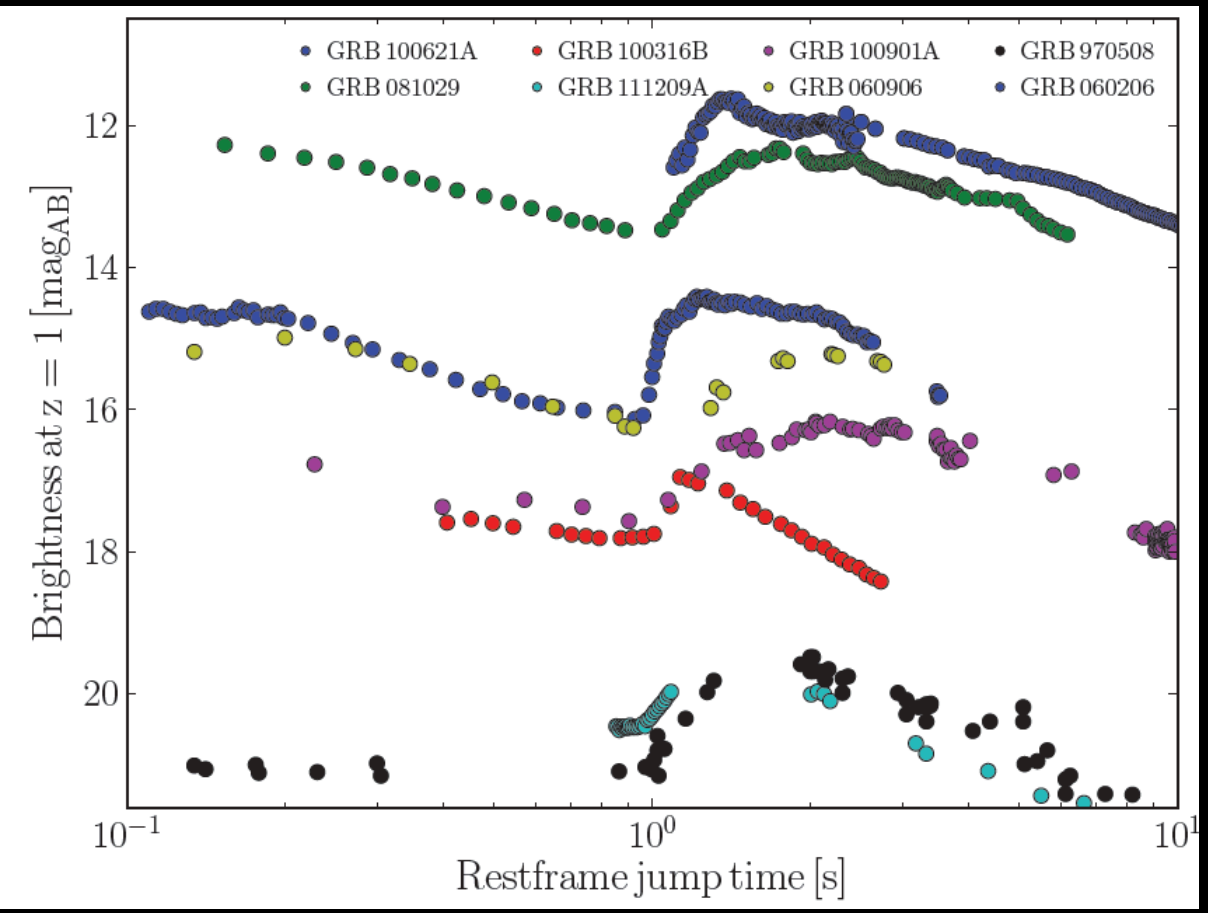
(iv) Jumps



- Steepness does not correlate with peak amplitude
- Rise index is different for different events
- Decay index is roughly similar

Pian+ 98, Pedersen+ 98, Stanek+ 06, Wozniak+ 06, Cenko+ 09
Volnova+10, Nardini+ 11, Kruehler+ 11, Greiner+ 12, Kann+ 12

(iv) Jumps

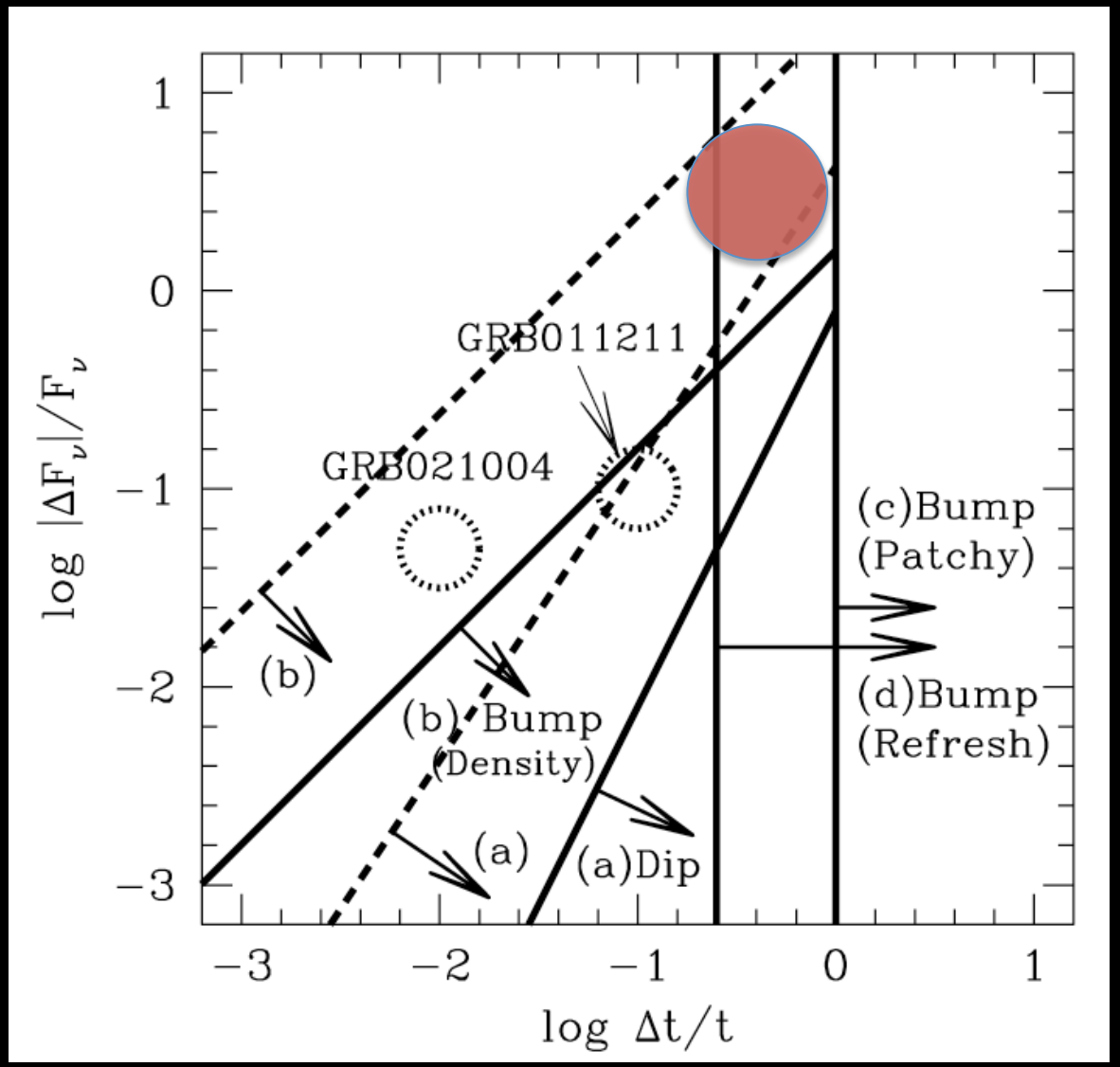
Observational constraints:

- FS established before jump
- Very steep rise ($t^{6..12}$)
- Plateau - shallow decay after peak ($t^{0..1}$)
- Steeper decay after plateau ($t^{0.5..1.5}$)
- Chromatic evolution (intrinsic reddening, no/ weak signature in the X-ray)
- Large time range (several hundred to several ten thousand s after T_0)
- Flux increase 1-2 mag (depends on afterglow)

(iv) Jumps in theoretical models

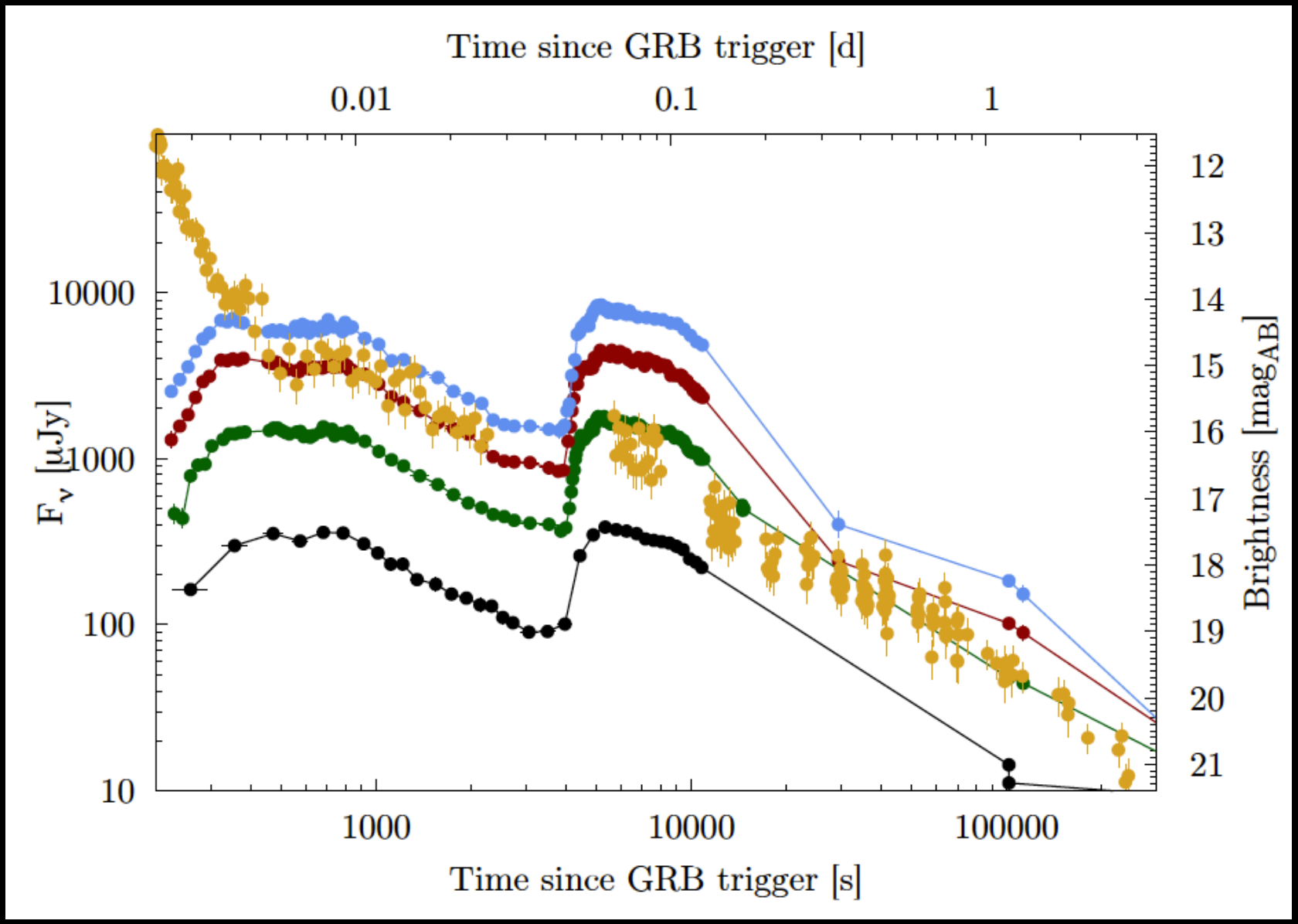
- Refreshed Shocks
- Patchy Shells
- External medium inhomogenities
- Decouple jumps from afterglow emission (flares, multi-component, late prompt, ….)

(e.g., Rees & Meszaros 98, Panaitescu+ 98, Kumar & Piran 00, Wang & Loeb 00, Zhang & Meszaros 02, Lazzati+ 02, Granot+ 03, Guidorzi + 05, Peng+ 05, de Ugarte Postigo+ 05, Zhang+ 06, Nakar & Granot 07…)



Ioka+ 05

(iv) Jumps in theoretical models



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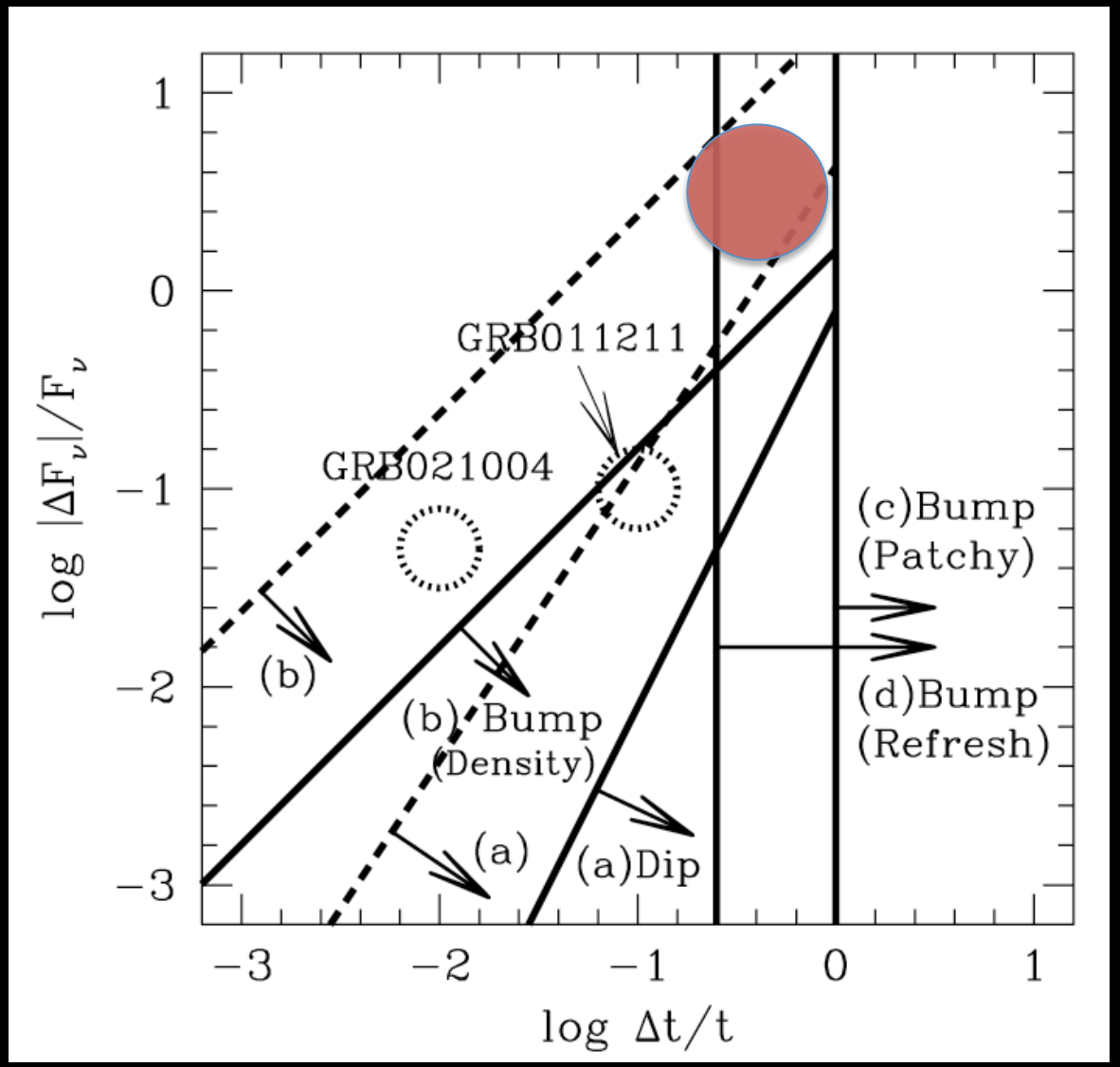
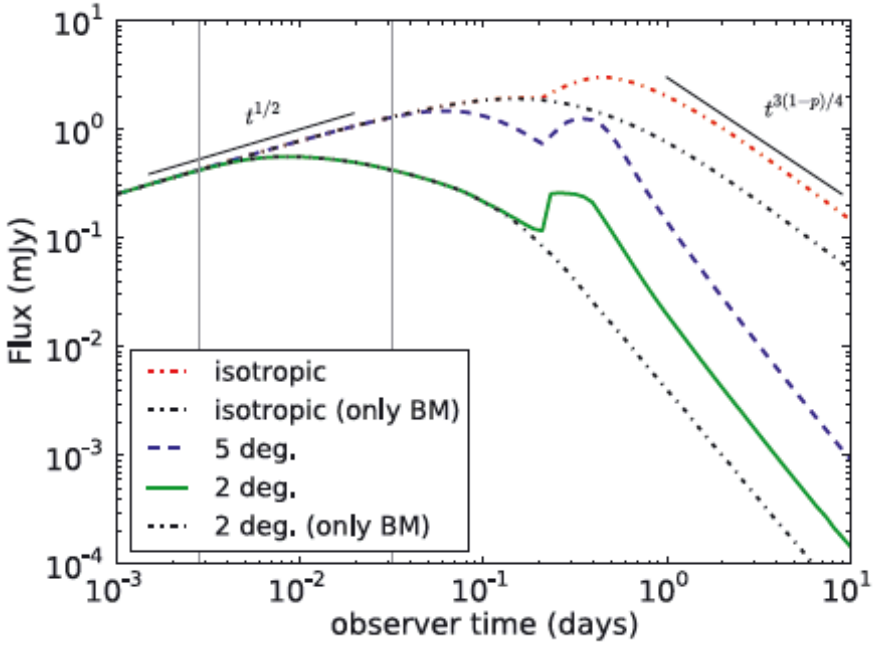
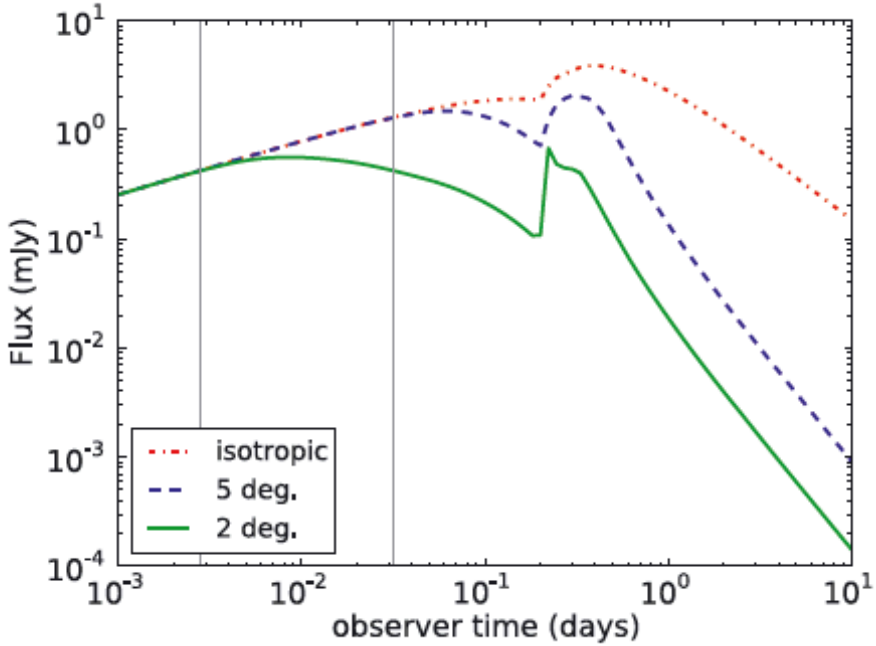


Ioka+ 05

(iv) Jumps as refreshed shocks





- 2-shell collisions (Vlasis+ 2011)
- AMR simulations of a late/slow shell catching up on a Blandford-McKee shocked ISM
- Varying opening angle, Lorentzfactor, shell-energy

Conclusions I

- Several physical origins for optical flares
- Different morphologies

-> Reverse shock – not prominent (but exist)

-> Onset of the afterglow:

- Achromatic ($\nu_m < \nu$)
- Common feature in all light-curves
- Allows to put physical constraints on the properties and inner engine models

Γ = 100-500 (rarely above)

$R_{dec} \sim 10^{17}$-10^{18} cm

Conclusions II

-> True flares:

- Optical/NIR counterpart of X-ray flares
- Share morphologies
- Extension of the X-ray spectrum to soft energies
- Typically hidden under a bright afterglow component
- Provide compelling evidence for a prolonged central engine activity

Conclusions III

-> Jumps as refreshed shocks in 2-shell collisions:

- Not a rare feature after the FS peak
- Extremely steep, but varying rise index, slow decay *(Opening angle)*
- Different times *(Relative Lorentz-factors)*
- Chromatic evolution, no/weak X-ray counterpart *(shock microphysics)*
- Super-imposed on afterglow component *(Energy/Lorentz-factor of second shell)*