Physics of the afterglow emission and connection with the prompt physical properties

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Outlines

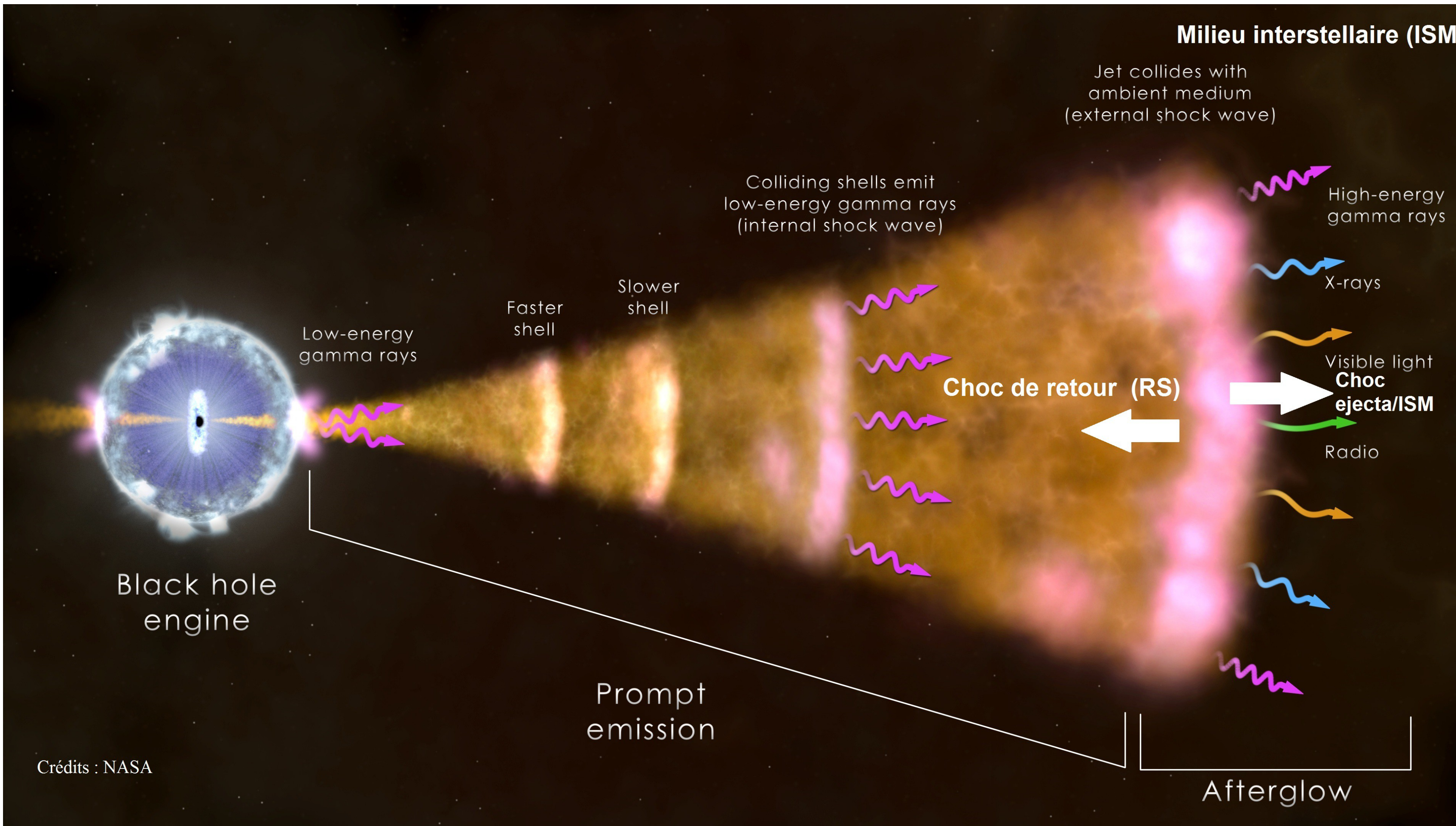
I. Physics of the GRB afterglows

II. Connection between the prompt/afterglow physical properties

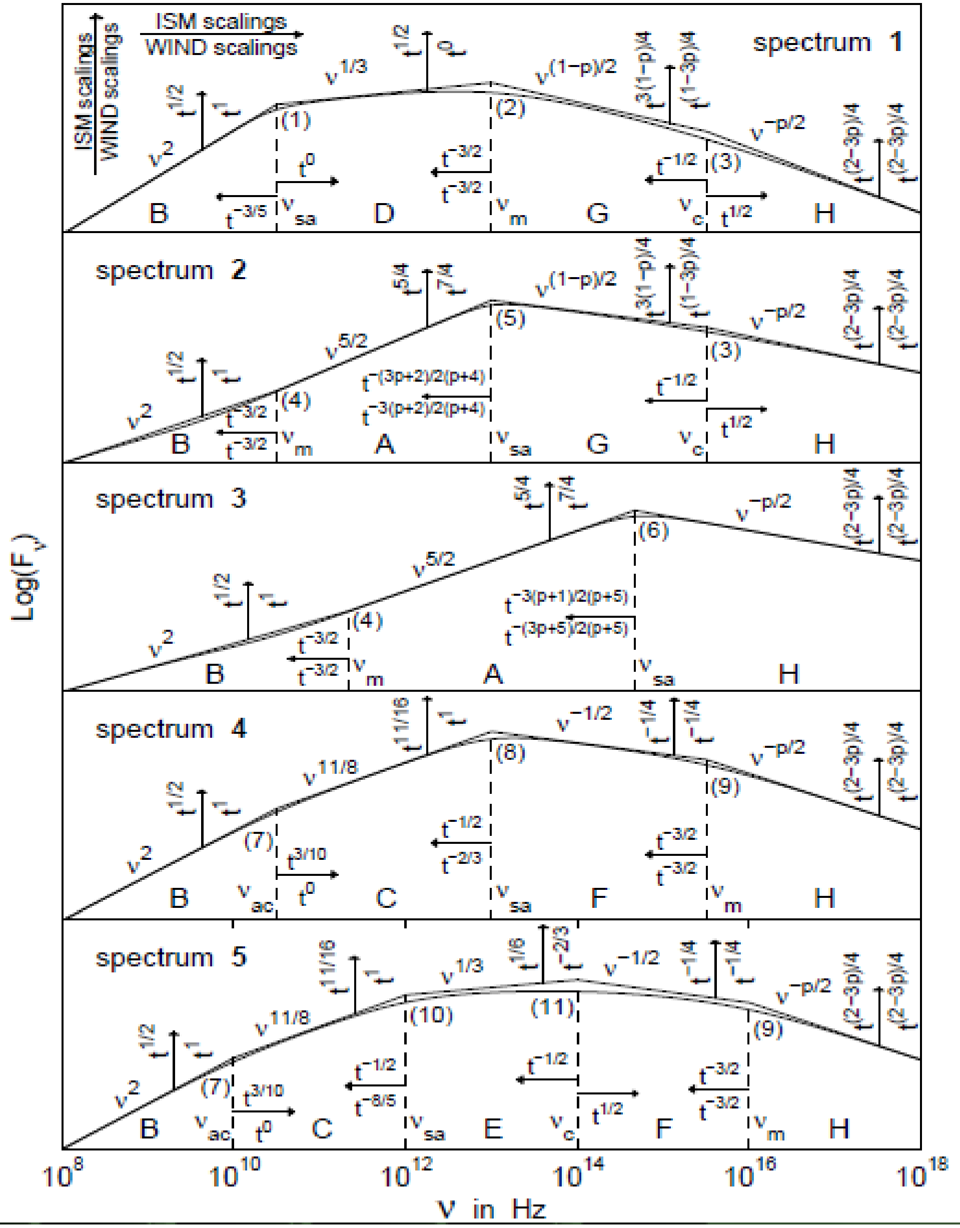
III. Optical selection effects in GRB prompt correlations : the case of the Amati relation

Prompt & afterglow connection ?

I. Physics of the GRB afterglows



Emission from the Forward shock



Synchrotron emission from ISM accelerated electrons

Model of Granot & Sari (2002) :

- **Power law segment joint at several break frequencies (ν_{sa}, ν_m, ν_c)**

ν_{sa} : synchrotron self-absorption frequency

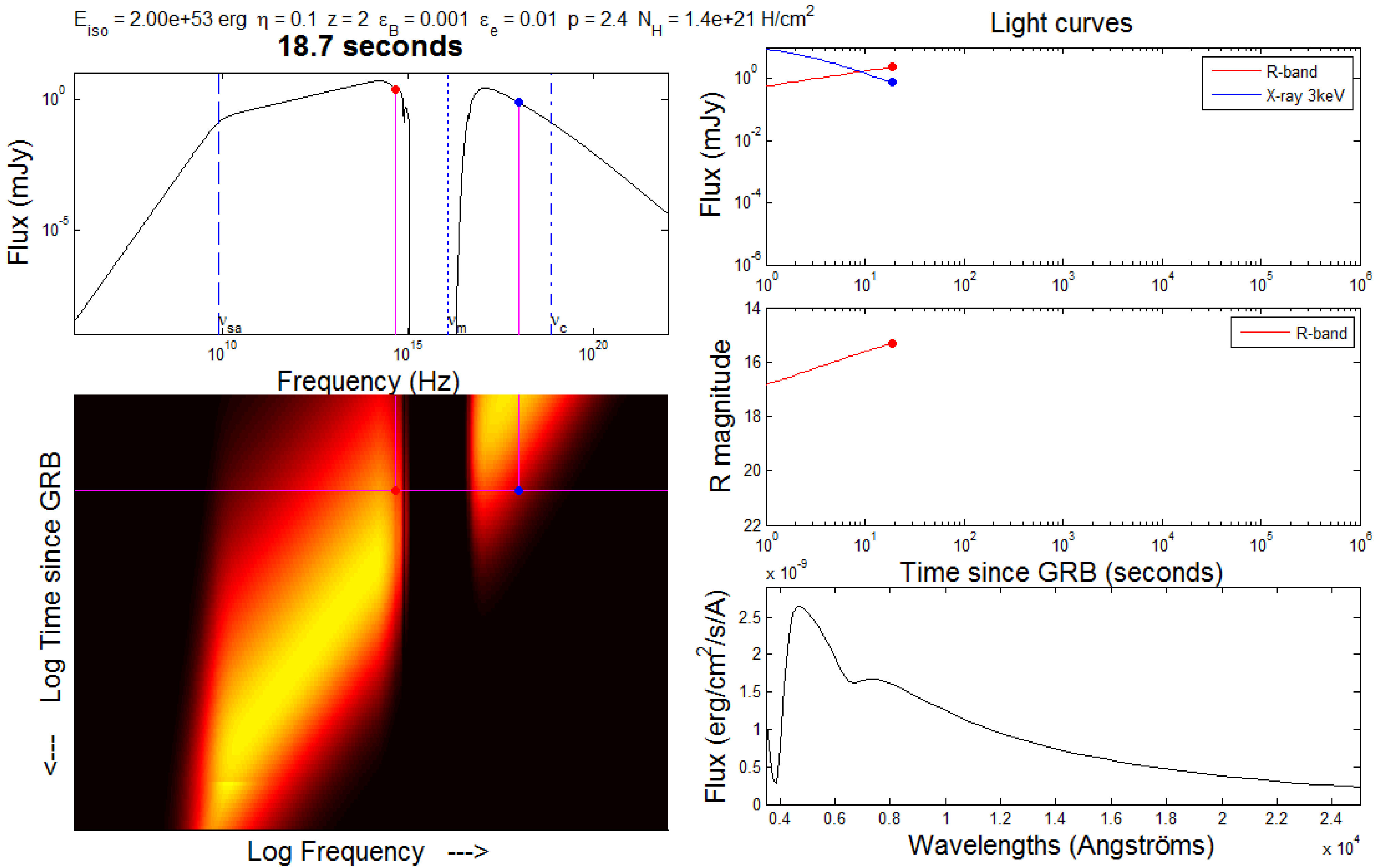
ν_m : typical synchrotron frequency of the minimal electron energy

ν_c : synchrotron frequency of an electron whose cooling time equals the dynamical time of the system

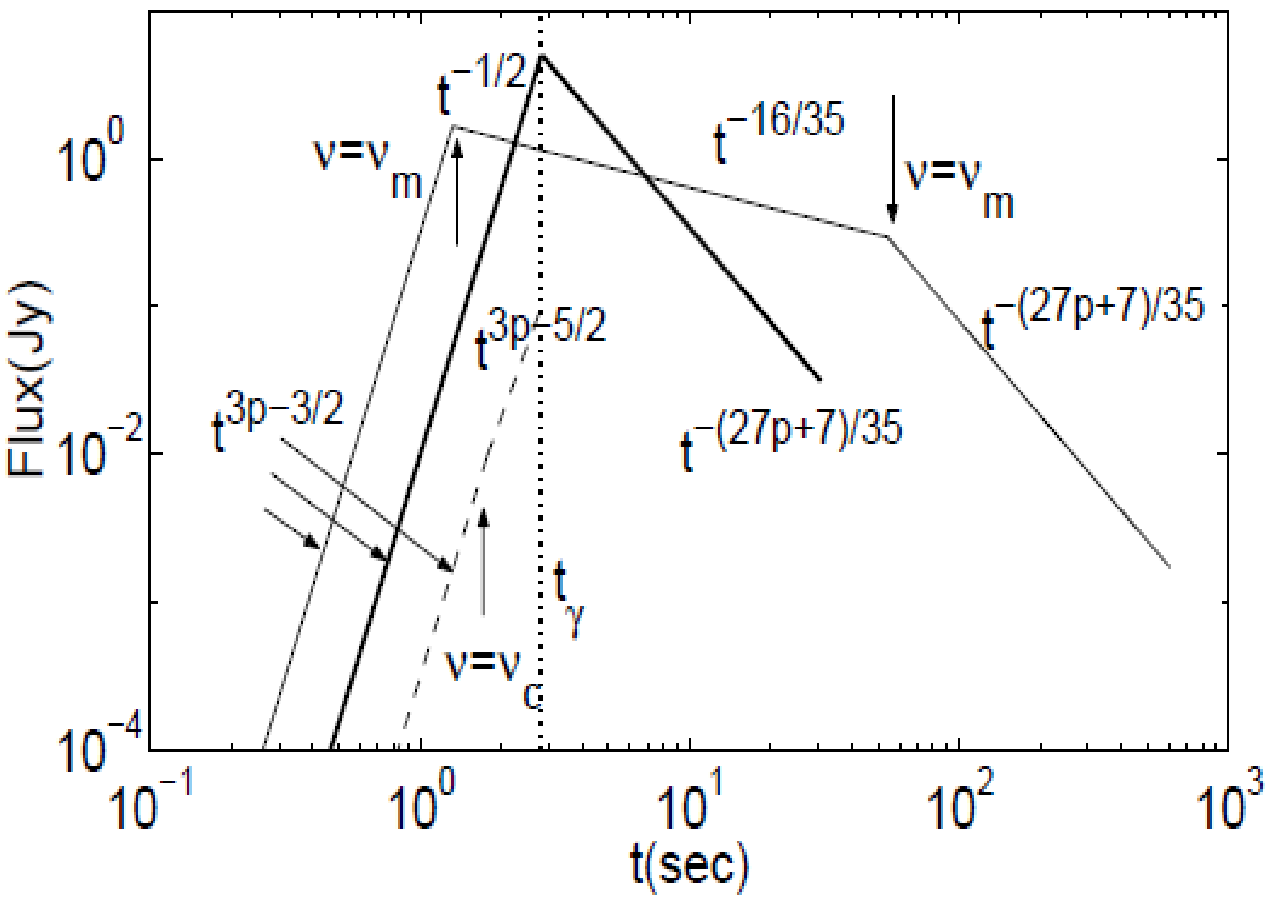
- **Broadband time resolved spectrum from fast cooling ($\nu_m > \nu_c$) to slow cooling ($\nu_m < \nu_c$) regime**

- **Flux : $F_\nu(t) = f(E_{iso}, n_0, \varepsilon_e, \varepsilon_B, p, \eta, A_\nu, N_{H,X}, z, t)$**

Time resolved spectrum from the Forward Shock



Emission from the Reverse Shock



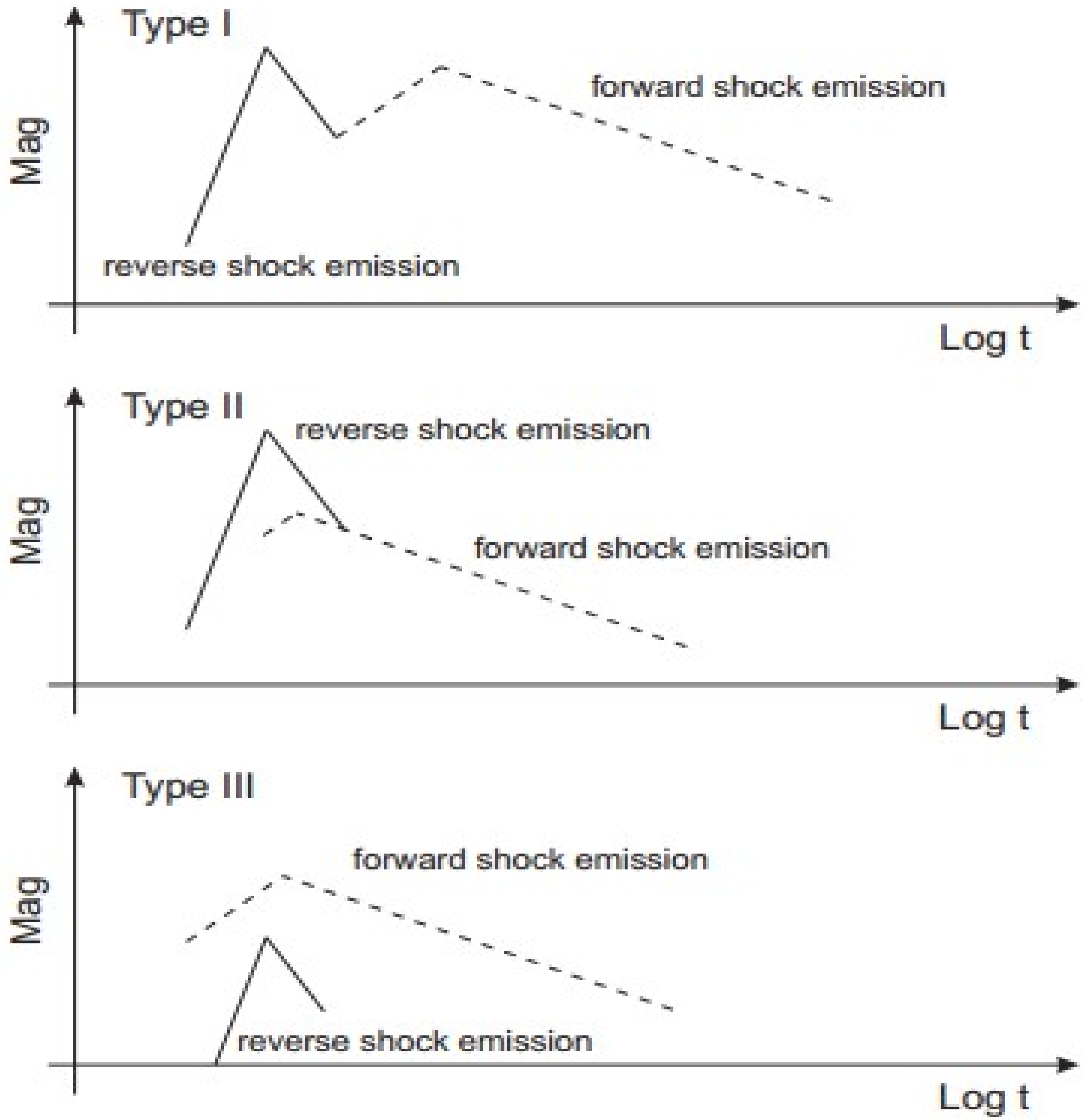
Kobayashi (2000)

$$\nu_m(t_\gamma) \sim 9.6 \times 10^{14} \epsilon_{e0}^2 \, \epsilon_{B0}^{1/2} \, n_{1,5}^{1/2} \, \eta_{300}^2 \text{ Hz} ,$$

$$\nu_c(t_\gamma) \sim 4.0 \times 10^{16} \epsilon_{B0}^{-3/2} E_{52}^{-2/3} n_{1,5}^{-5/6} \, \eta_{300}^{4/3} \text{ Hz} ,$$

$$F_{\nu,\max}(t_\gamma) \sim 5.2 D_{28}^{-2} \, \epsilon_{B0}^{1/2} \, E_{52} \, n_{1,5}^{1/2} \, \eta_{300} \text{ Jy} .$$

Afterglow lightcurve model



Fitting methods and physical parameter estimations

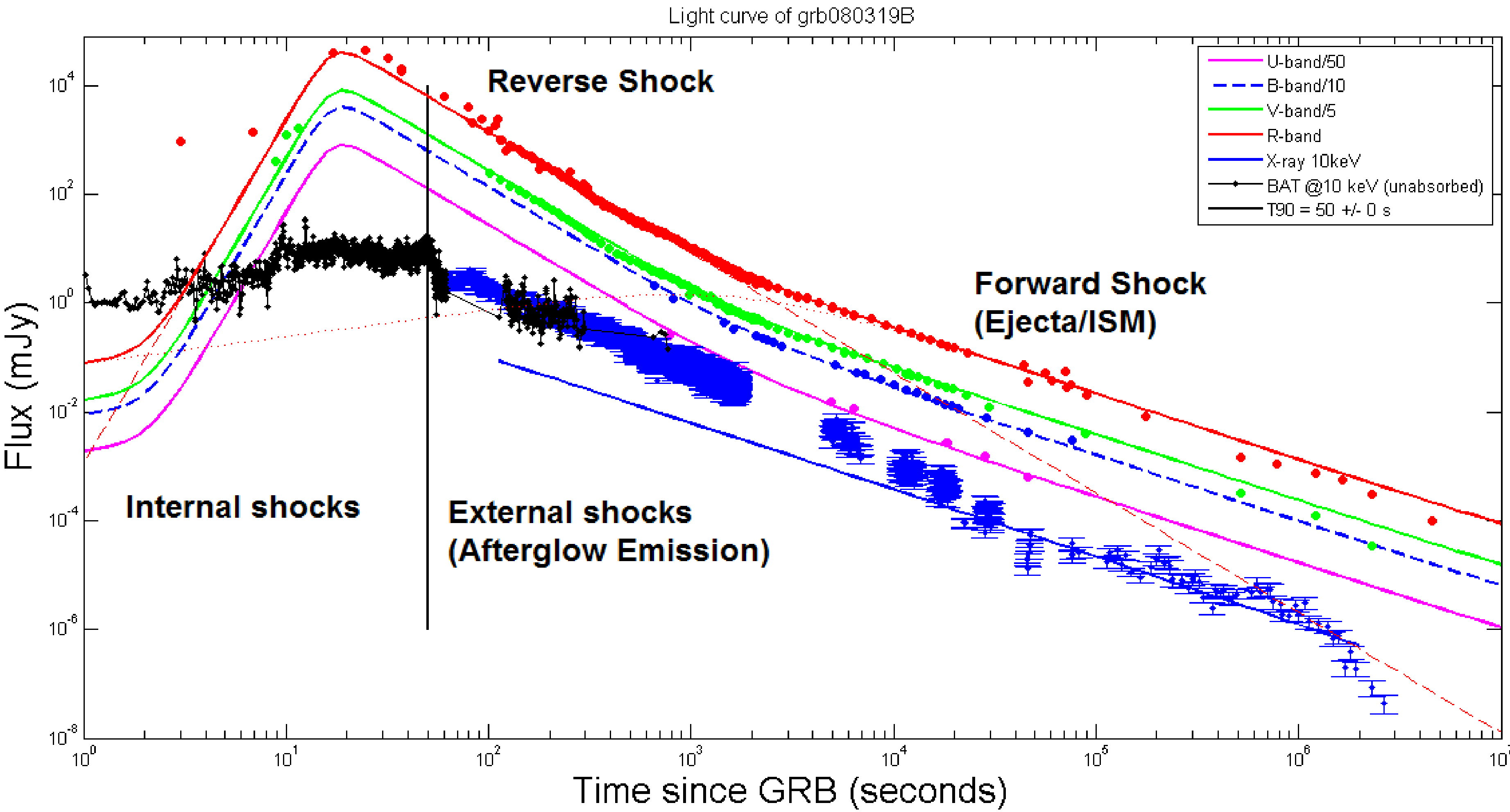
- χ^2 fitting method of the lightcurve (multi-band simultaneously)

$$\chi^2 = \sum [(\text{data} - \text{Afterglow model})/\ \text{error}]^2$$

- MCMC fitting method of the lightcurve (multi-band simultaneously)

$$L(X) = \exp(-\chi^2(X)/2)$$

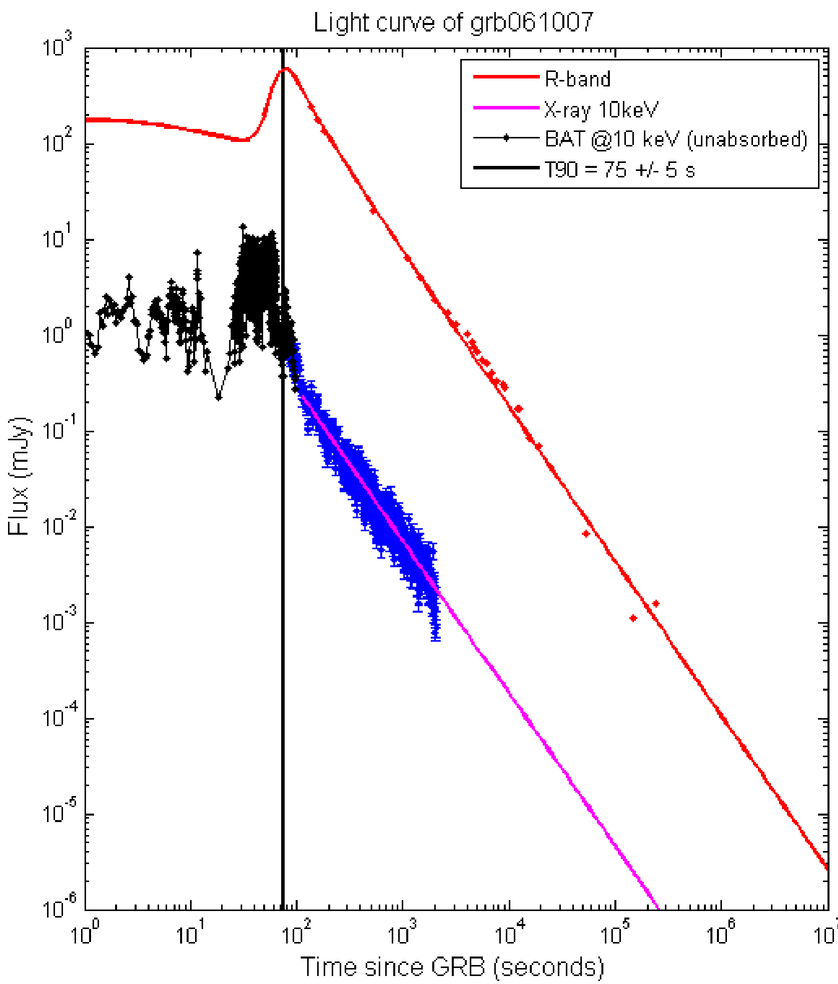
GRB 080319B (χ^2 fit)

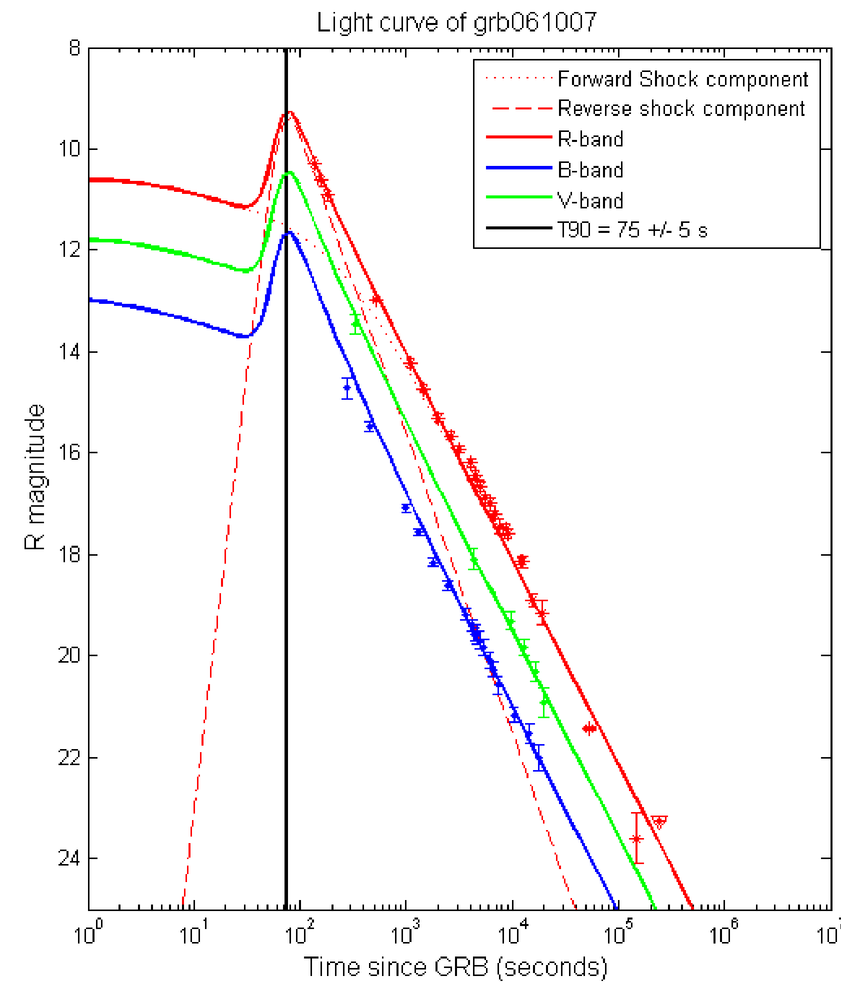


grb	z	E_{iso} $(10^{52}$erg)	E_{pi} (keV)	η	Γ_{tpeak}	n_0 (cm^{-3})	ϵ_{ef}	ϵ_{Bf}	p
080319B	0.937	$120^{1.5}_{1.5}$	$1261.0^{27.1}_{25.2}$	0.60	~ 449	1.1	0.23	1.2×10^{-6}	2.69

tpeak (s)	ϵ_{er}	ϵ_{Br}	R_B	$A_{V host}$
19	0.0001	0.1	~ 7817	0.07

GRB 061007 (χ^2 fit)

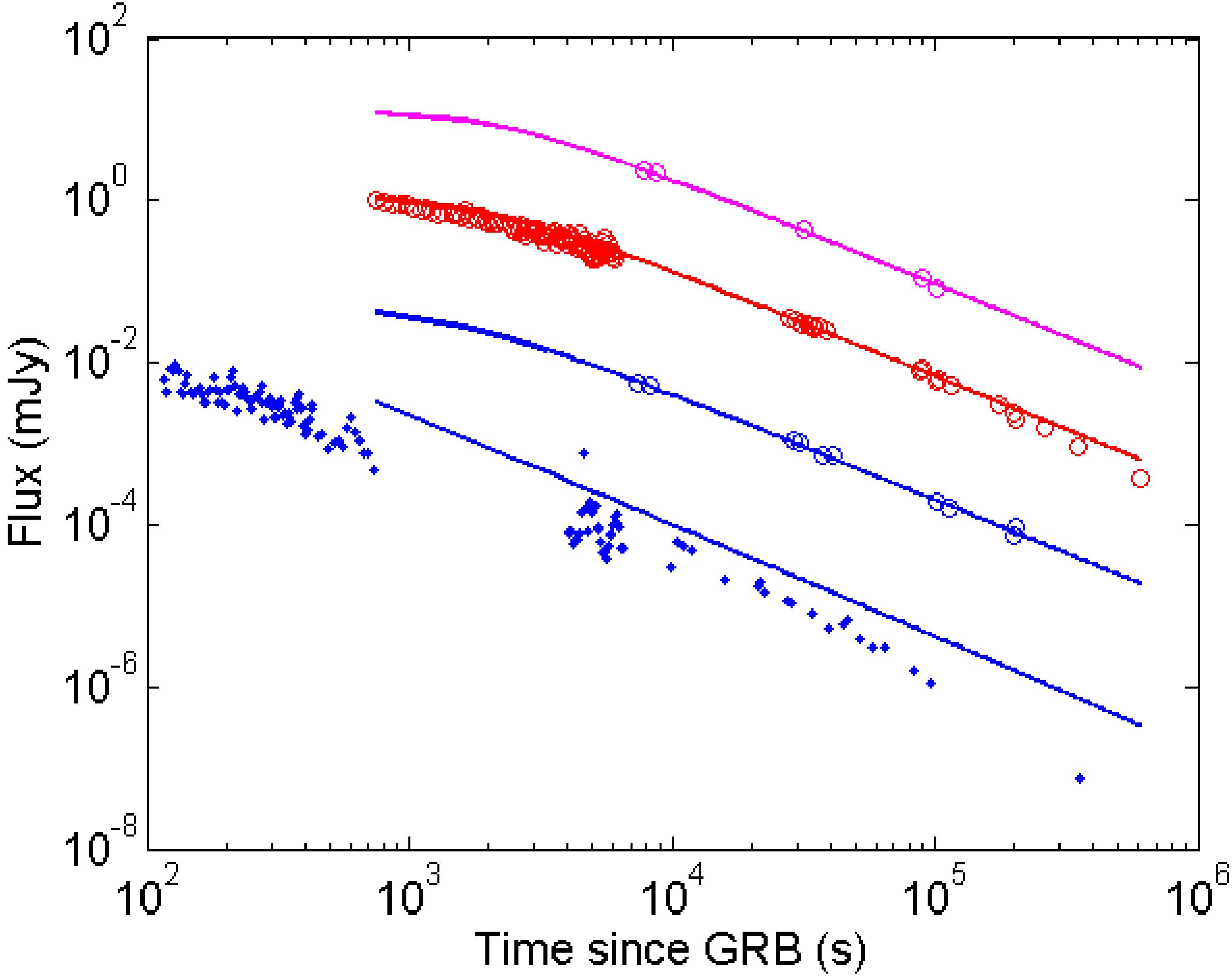




grb	z	E_{iso} (10^{52}erg)	E_{pi} (keV)	η	Γ	n_0 (cm^{-3})	ϵ_e	ϵ_B	p	tpeak (s)
061007	1.261	$91^{1.1}_{1.1}$	$1065.4^{81.4}_{81.4}$	0.15	...	280	0.01	0.0006	2.9	80

ϵ_{er}	ϵ_{Br}	R_B	A_{Vhost}
0.0006	0.1		1.9

GRB 050922C (MCMC fit)



GRB 050922C

Optical band : BRI

X-ray band : XRT 10Jy

E_{iso} = 4.56 x10^{52} erg
z = 2.198
A_v^G = 0
A_v^H = 0.1
n_0 = 1084.2 part/cm^3
ε_e = 0.24
ε_B = 2.0 x10^{-7}
η = 0.11
p = 2.71

II. Connection between the prompt/afterglow physical properties

Afterglow emission in the standard fireball model

Synchrotron emission parametrized with 3 main frequency breaks (ν_{sa}, ν_m, ν_c)

ν_{sa} : synchrotron self-absorption frequency

ν_m : typical synchrotron frequency of the minimal electron energy

ν_c : synchrotron frequency of an electron whose cooling time equals the dynamical time of the system

- In the slow cooling regime ($\nu_m < \nu_c$) :

$$\text{X-ray flux} : F_{\nu,X} \sim E_k^{(p+2)/4}$$

Granot & Sari 2002

$$\text{Optical flux} : F_{\nu,opt} \sim E_k^{(p+3)/4}\ n_0^{1/2}$$

Where $E_k = (1-\eta/\eta)\ E_{iso}$ => **prompt physics**

Some correlations !

$L_{R,1day} \sim E_{iso}^{0.37}$ => Kann et al. 2010

$L_{R,11h} \sim E_{iso}^{0.93}$ => Nysewander et al. 2009

$L_{X,10h} \sim E_{iso}$ => Kaneko et al. 2007

$E_{X,iso} \sim E_{\gamma,iso}^{0.8}$ => Margutti et al. 2013

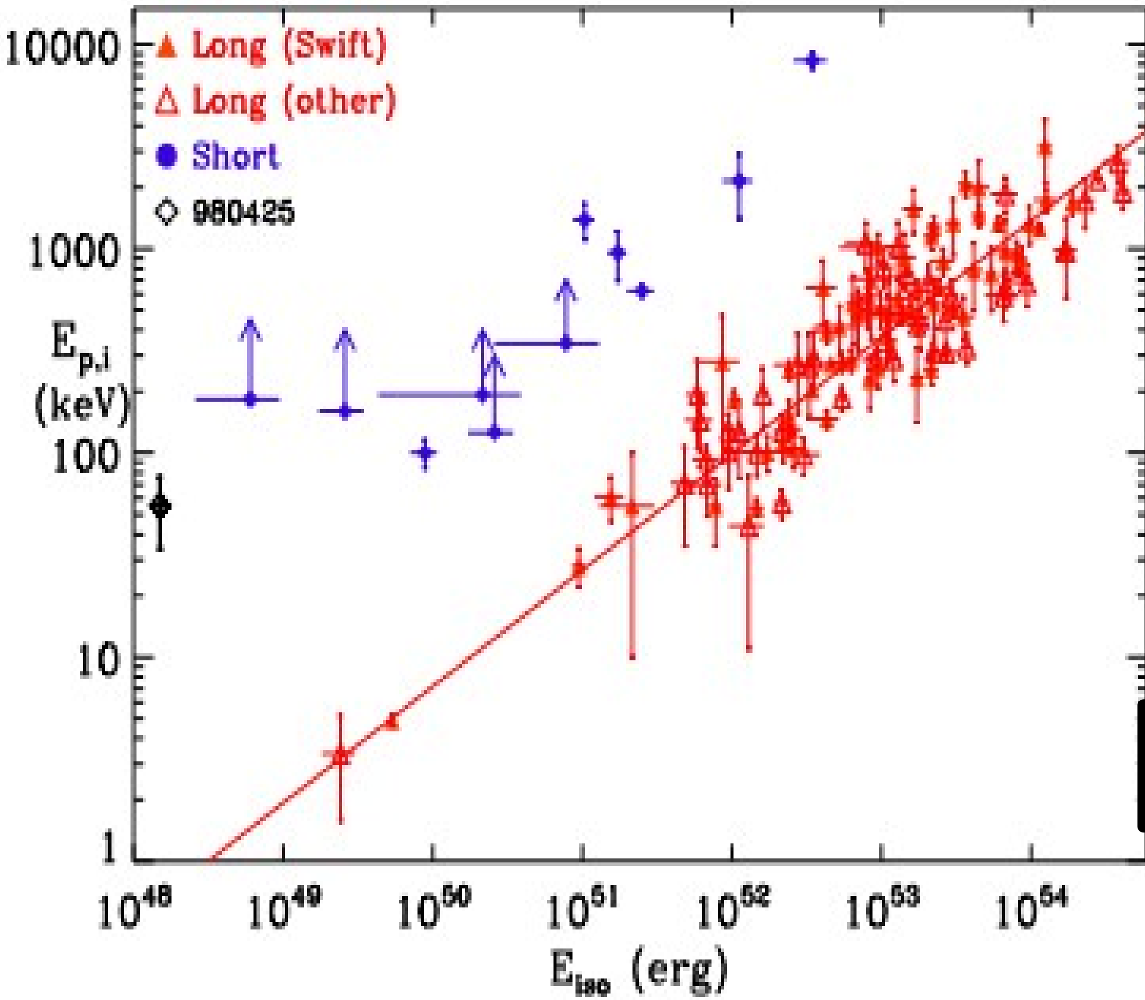
etc …..

Some correlations …. biased

- The $L_{X\,-}\ E_{iso}$ and $L_{opt\,-}\ E_{iso}$ correlations are strongly biased (Malmquist bias) by the preferential detection of intrinsically bright GRBs => Coward et al. 2014
- Gamma-ray detection selection effect in the rest frame properties of the prompt emission. Heussaff et al. (2013)
- GRBs with a spectroscopic redshift are not representative of the whole GRB population (bright in gamma rays and less attenuated in X-rays, few dark GRBs) => Fynbo et al. 2009

- Since redshifts are usually measured from the optical spectrum of the afterglow, does the afterglow brightness introduce subtle biases in the distribution of rest-frame properties of the prompt emission ?

II. Optical selection effects in GRB prompt correlations : the case of the Epi-Eiso relation



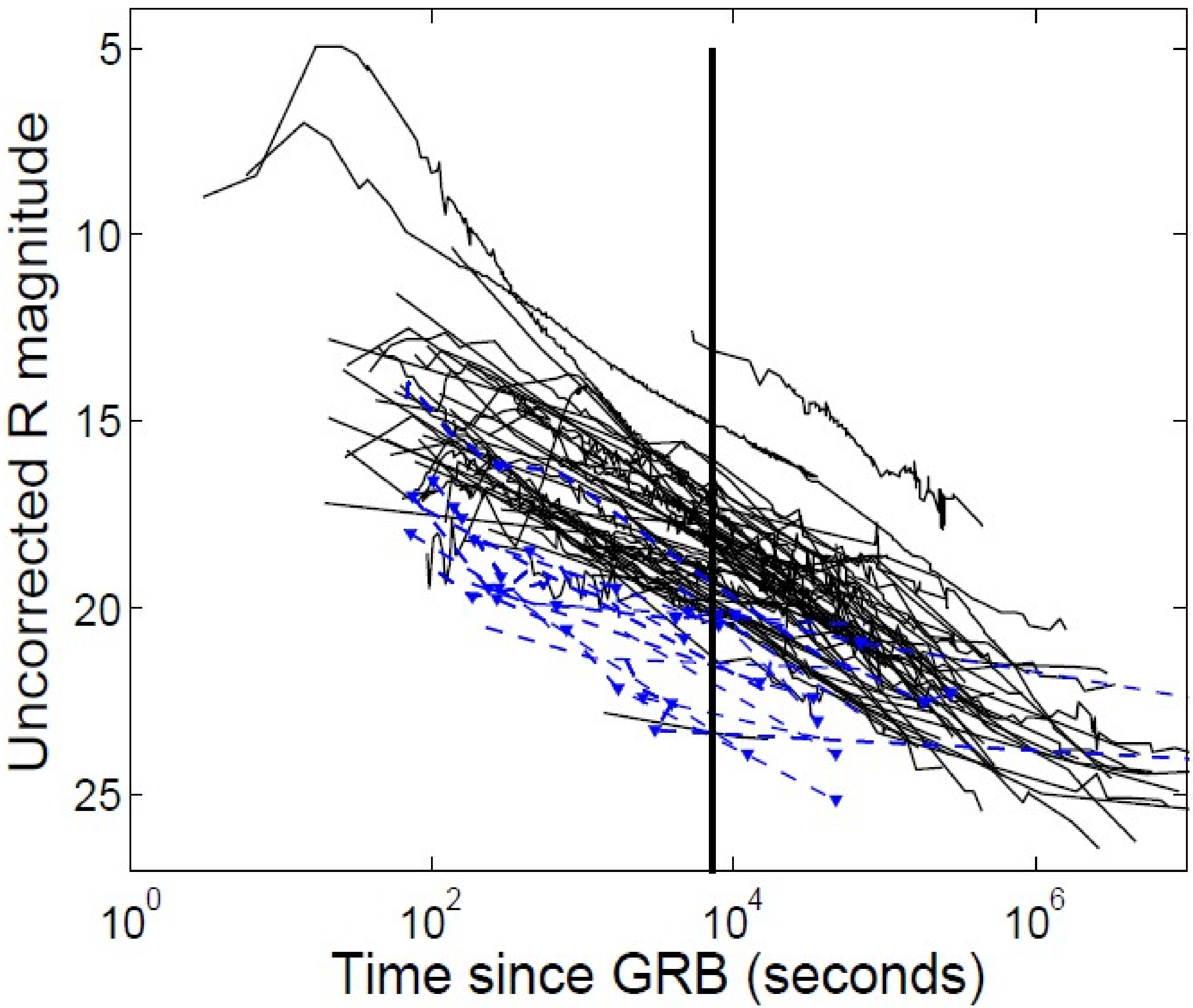
Amati (2010)

arXiv1002.2232A

Heussaff et al. (2013)
Gamma-ray detection selection effect in the upper part of the Epi-Eiso plane.

What about optical selection effect ?

Our GRB sample



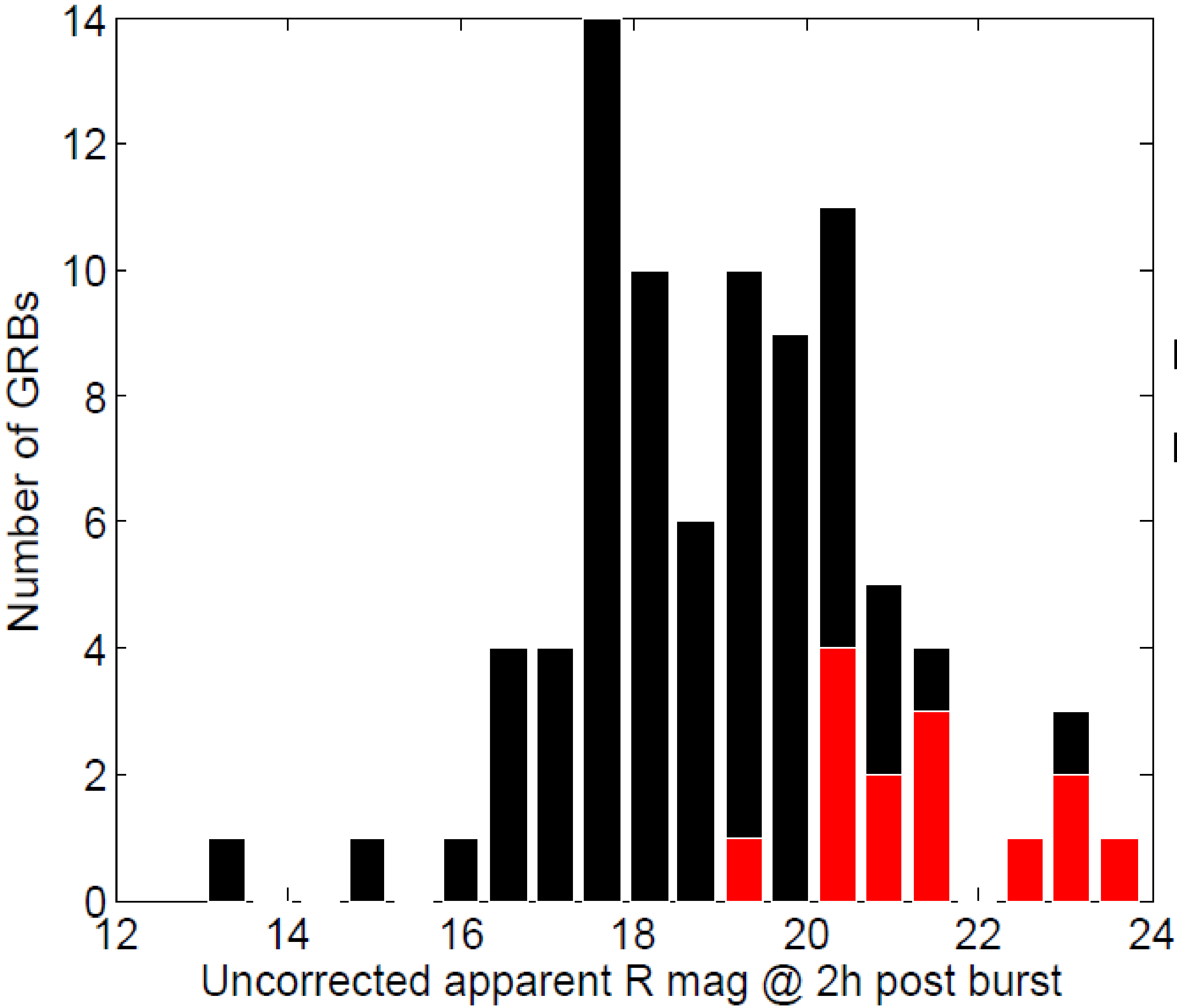
71 GRBs with a redshift
(black lines)

14 GRBs without a redshift
(blue dashed-dotted line)

Proxy of the afterlow optical brightness :

Uncorrected R magnitudes measured 2h after the GRB trigger

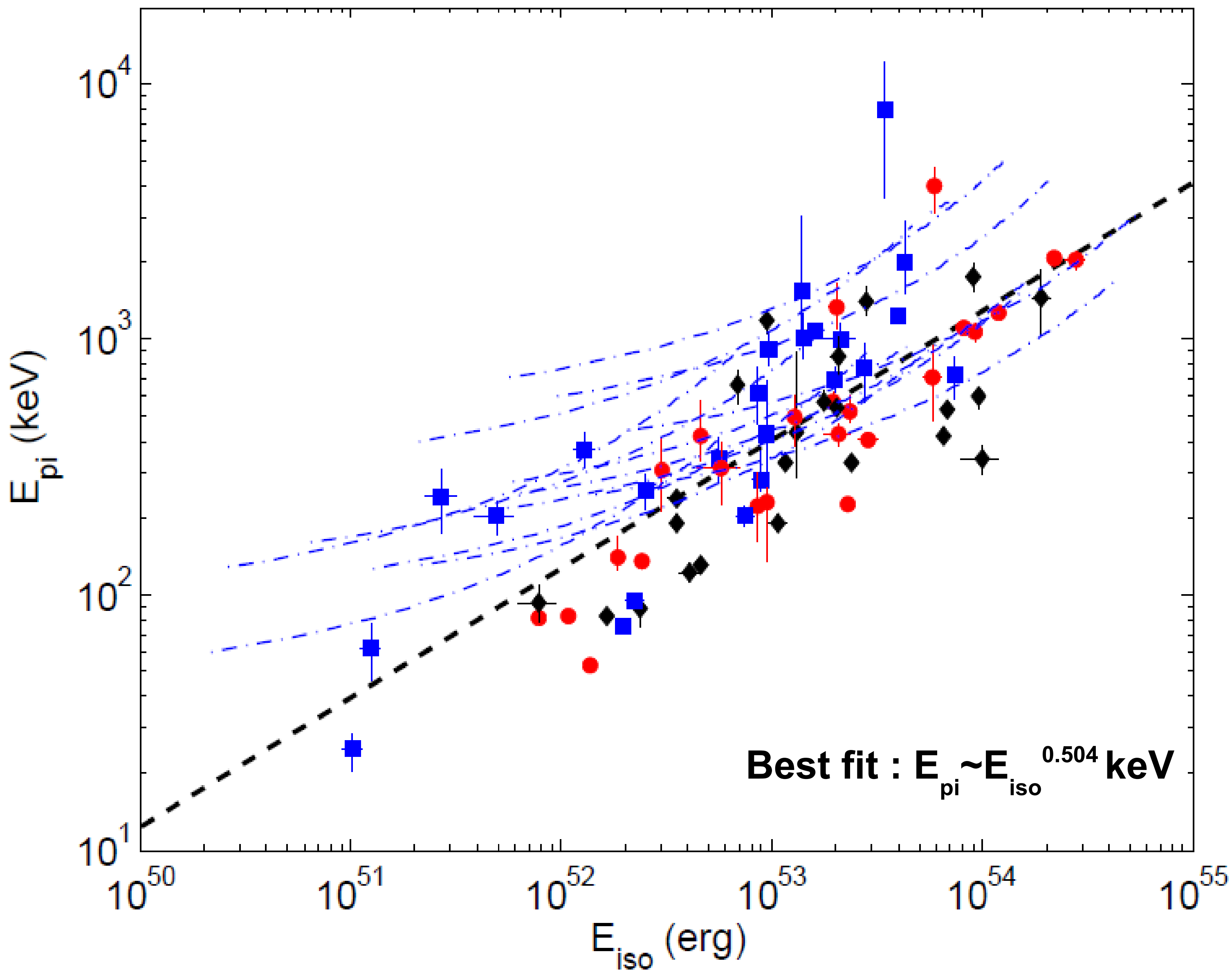
Our GRB sample



Red : GRBs without a redshift

Black : GRB with a redshift

Our GRB sample in the Epi-Eiso plane

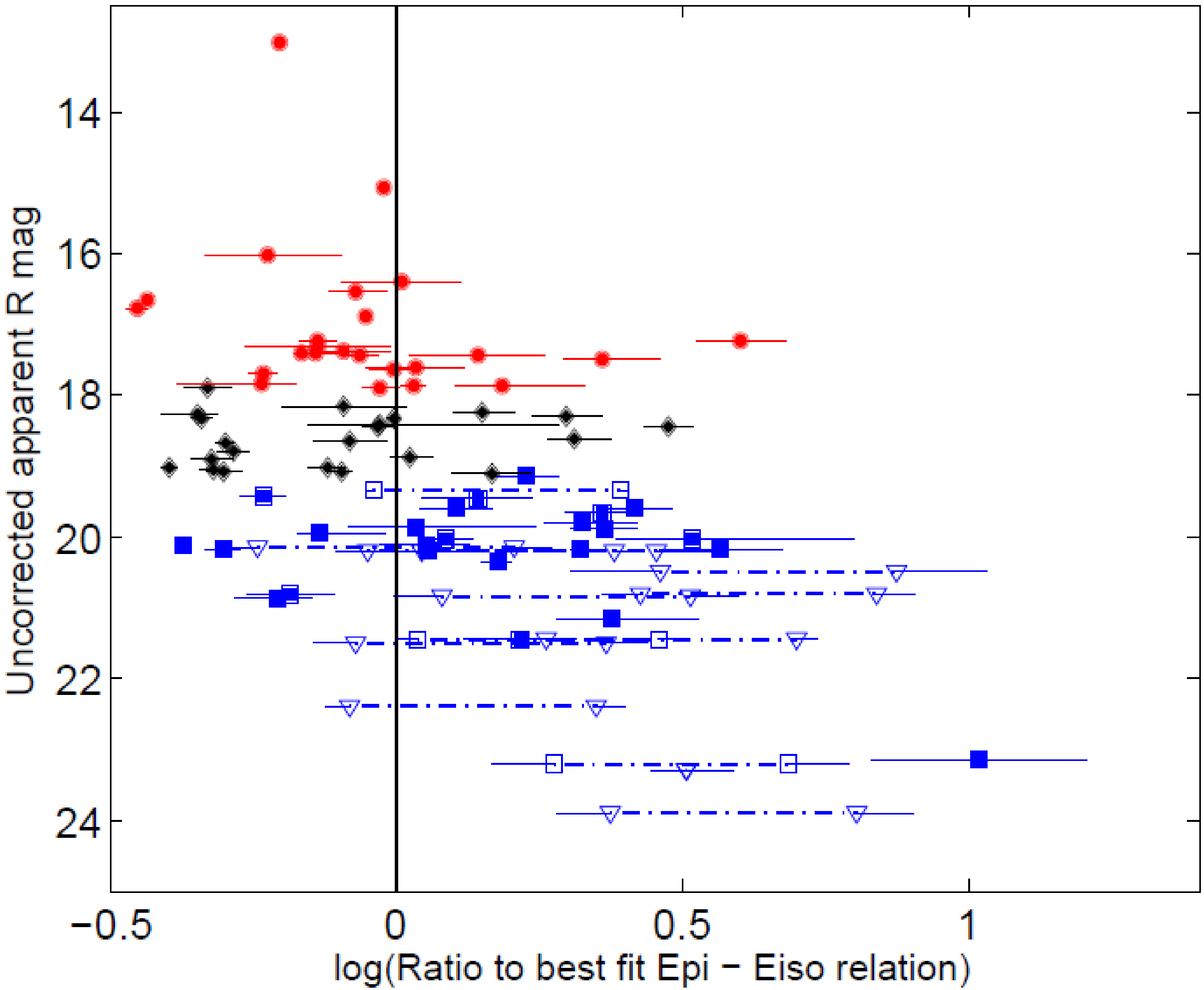


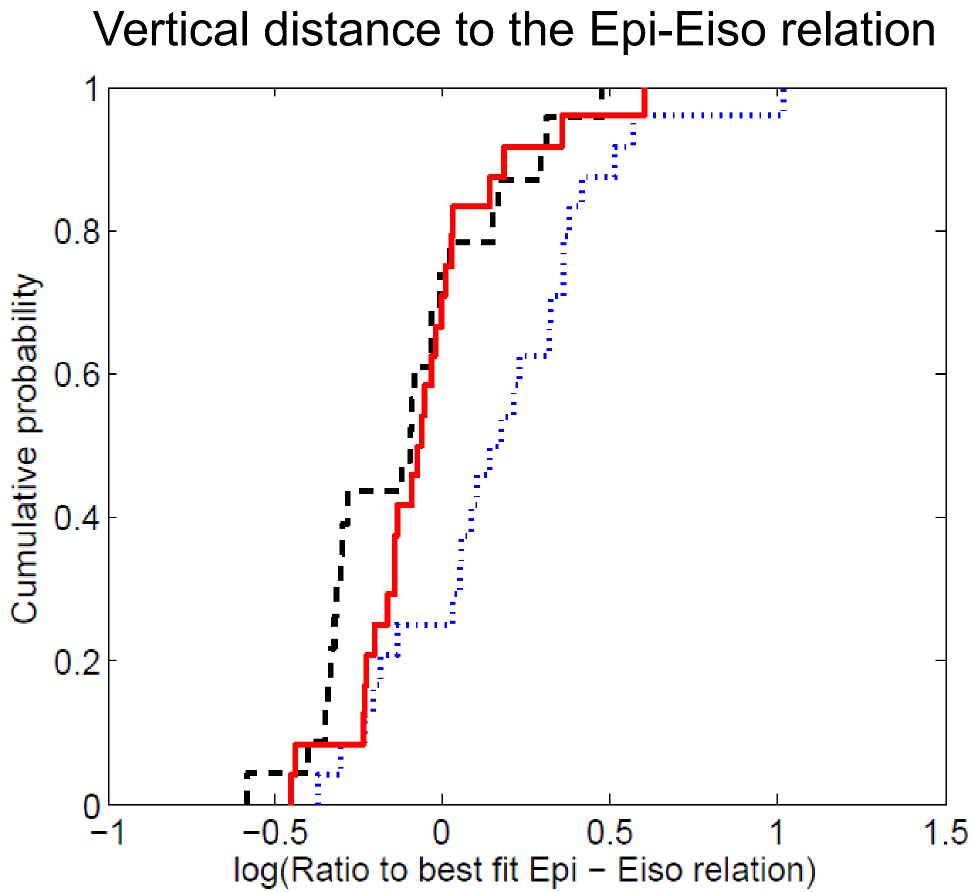
Blue : faint afterglow brightness (R^{2h}>19.1)

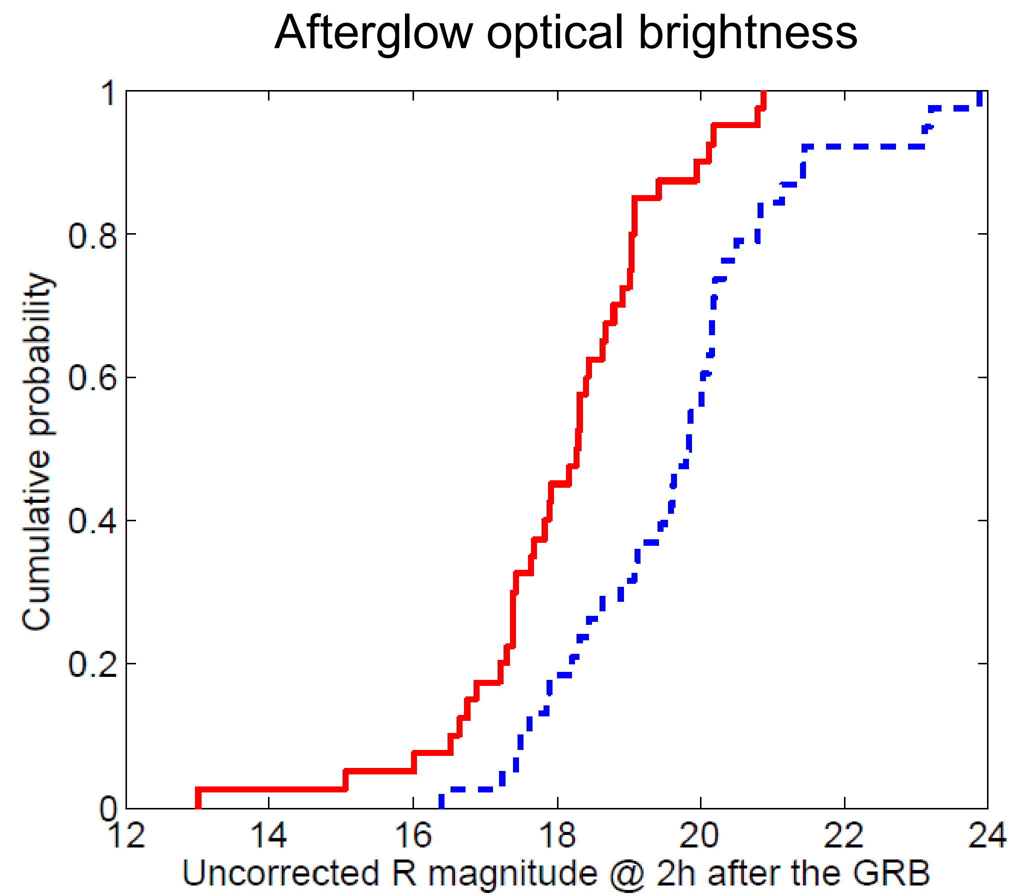
Black : Intermediate afterglow brightness (17.9<R^{2h}<19.1)

Red : bright afterglow brightness (R^{2h}<17.9)

Afterglow optical brightness distribution in the Epi-Eiso plane







median[dist_amati(Bright)] = -0.06861 (red)

median[dist_amati(Faint)] = 0.1585 (blue)

Diff (median[dist]) = 0.2271

KS-test : p-val = 0.0009312

Bootstrapping-test :
p-val = 0.009

mean[Rmag(below)] = 18.10 (red)

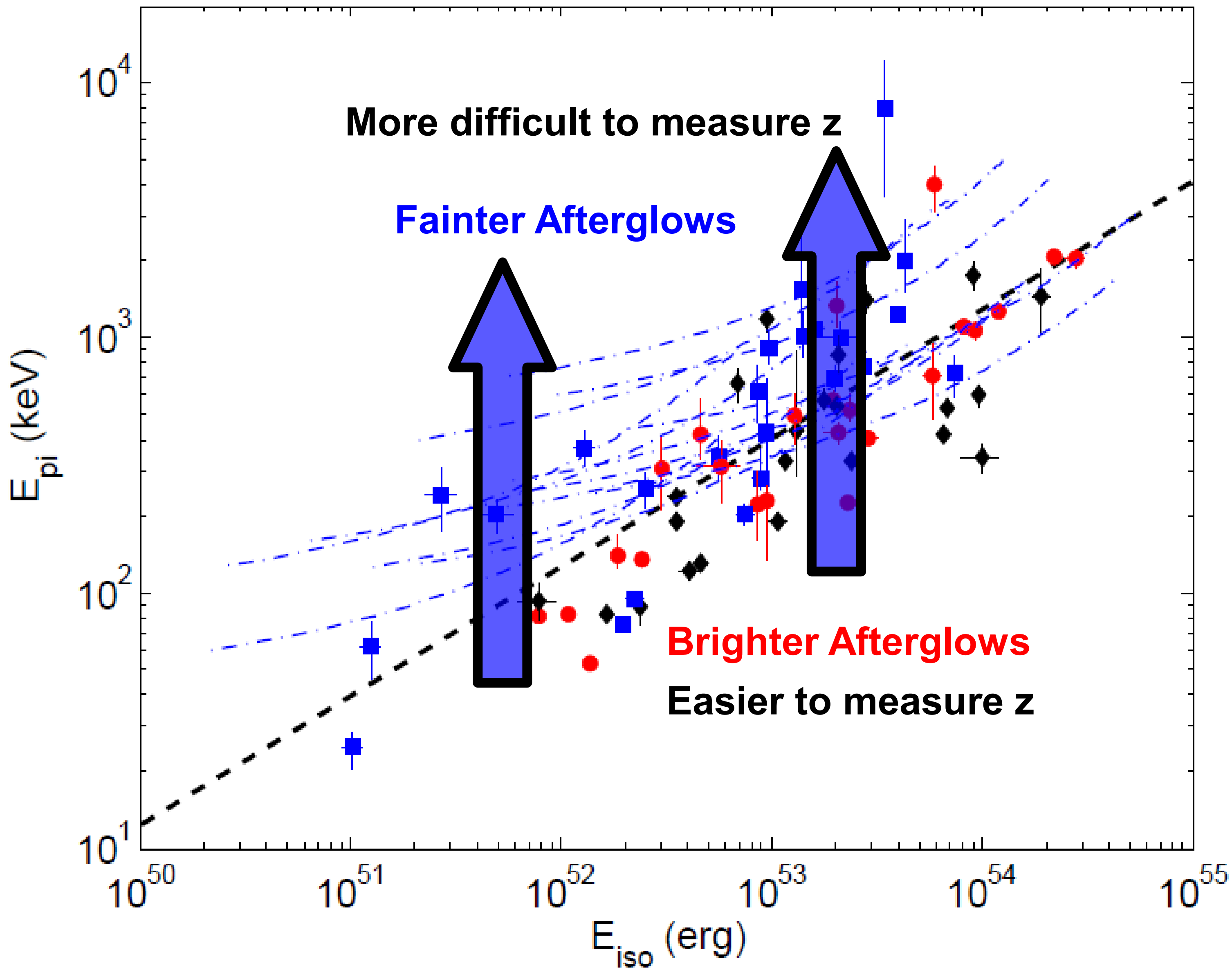
mean[Rmag(above)] = 19.69 (blue)

Diff (mean[Rmag]) = 1.59

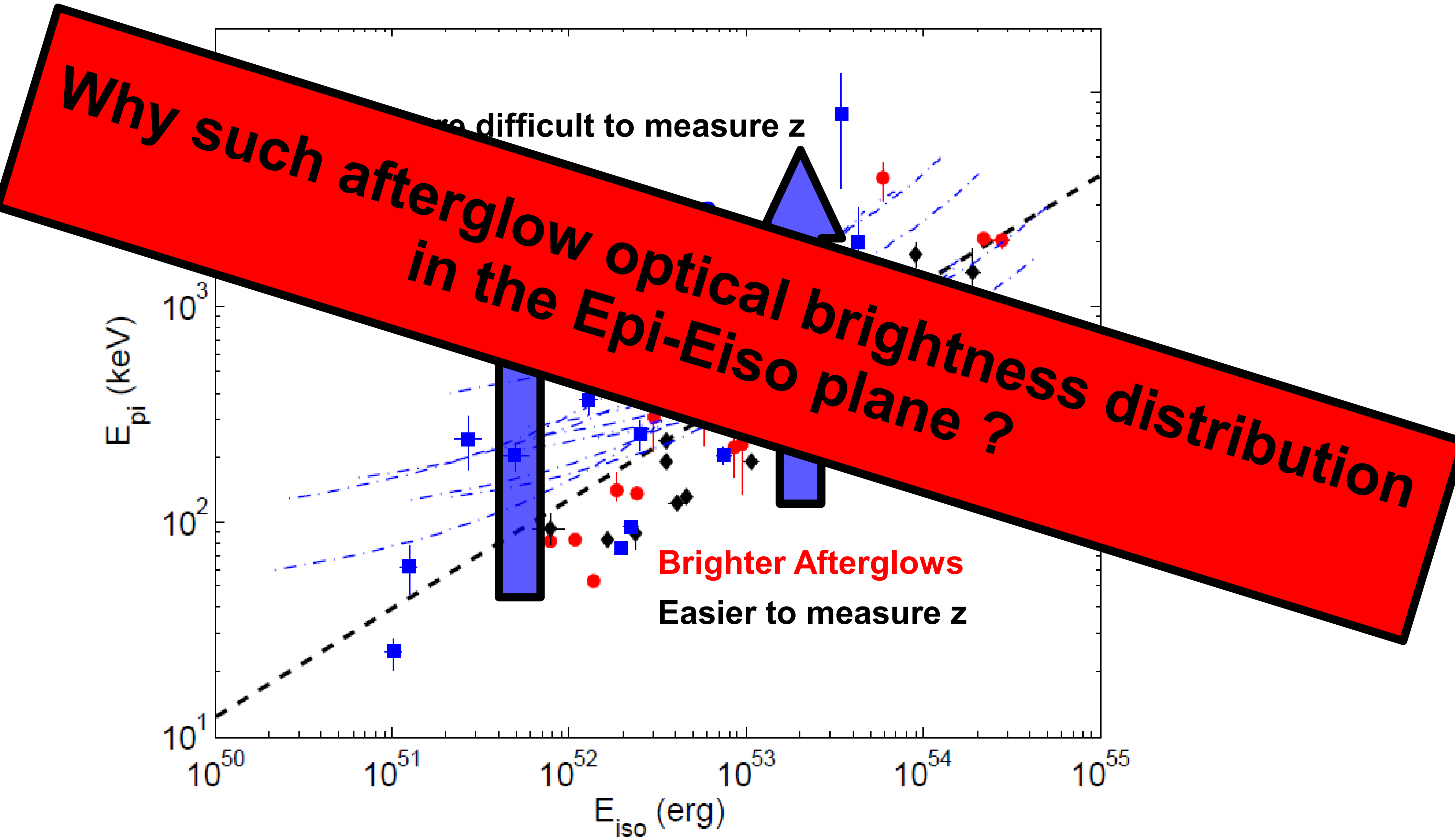
KS-test : p-val = 0.000014

Bootstrapping-test :
p-val = 0.00003

Optical selection effect in the Epi-Eiso plane

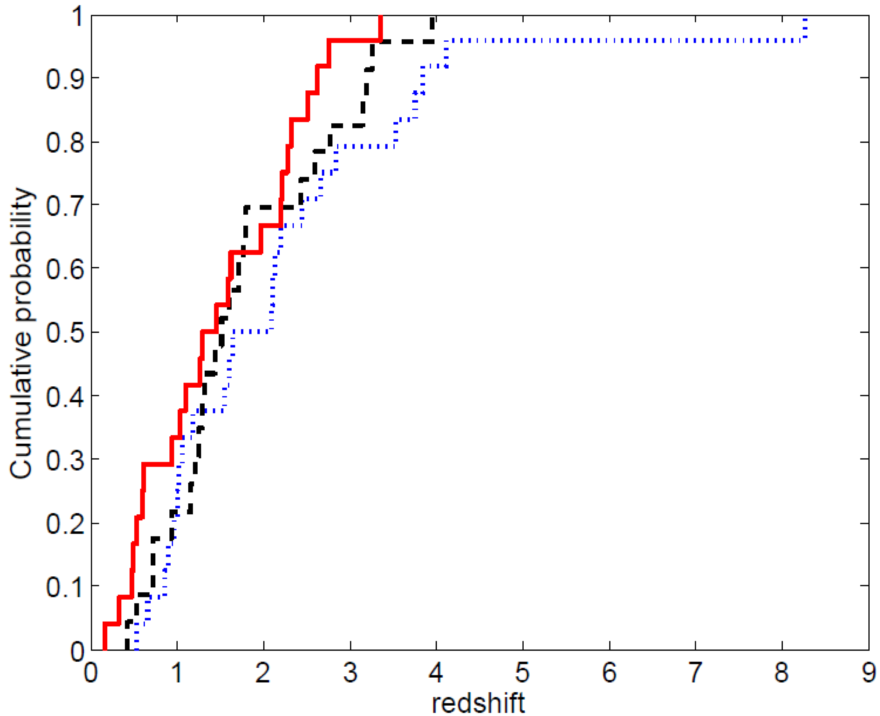


Optical selection effect in the Epi-Eiso plane



Afterglow brightness : extrinsic or intrinsic factors ?

<u>Extrinsic effect</u> : redshift influence



median[z(Bright)] = 1.3765 (red)

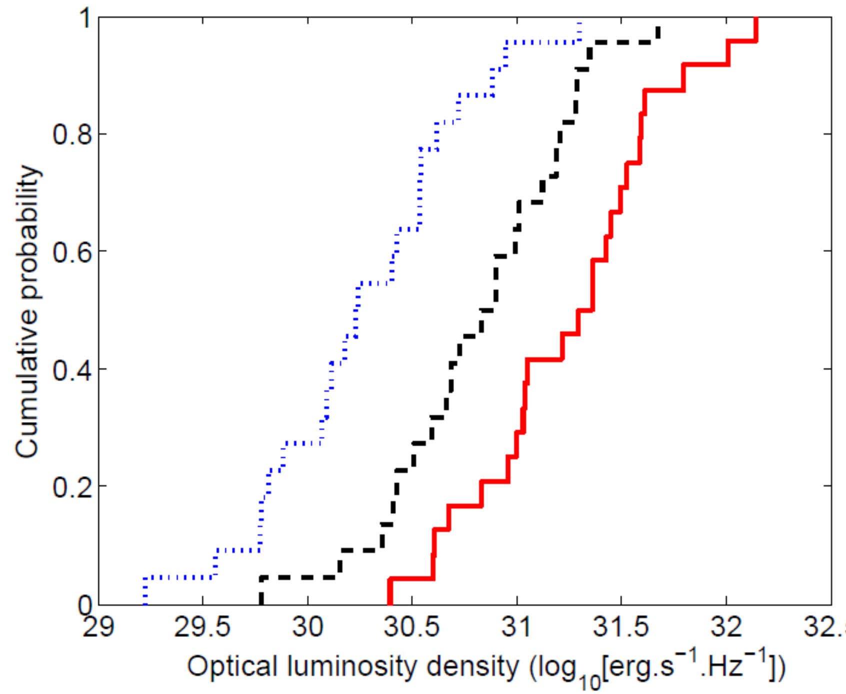
median[z(Faint)] = 1.886 (blue)

Diff (median[z]) = 0.4895

KS-test : p-val = 0.378

Bootstrapping-test :
p-val = 0.337

<u>Intrinsic effect</u> : Luminosity at rest frame



median[LR(Bright)] = 31.33 $\log_{10}$(erg/s/Hz) (red)

median[LR(Faint)] = 30.23 $\log_{10}$(erg/s/Hz) (blue)

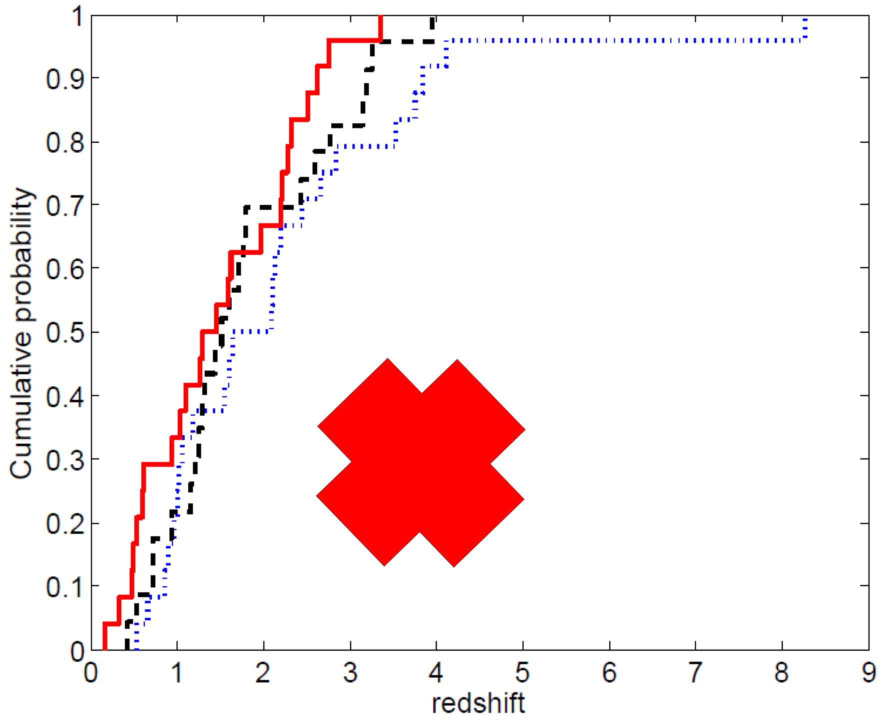
Diff (median[LR]) = 1.1 $\log_{10}$(erg/s/Hz)

KS-test : p-val = 1.73 x 10^{-6}

Bootstrapping-test :
p-val = 0.0

Afterglow brightness : extrinsic or intrinsic factors ?

Extrinsic effect : redshift influence



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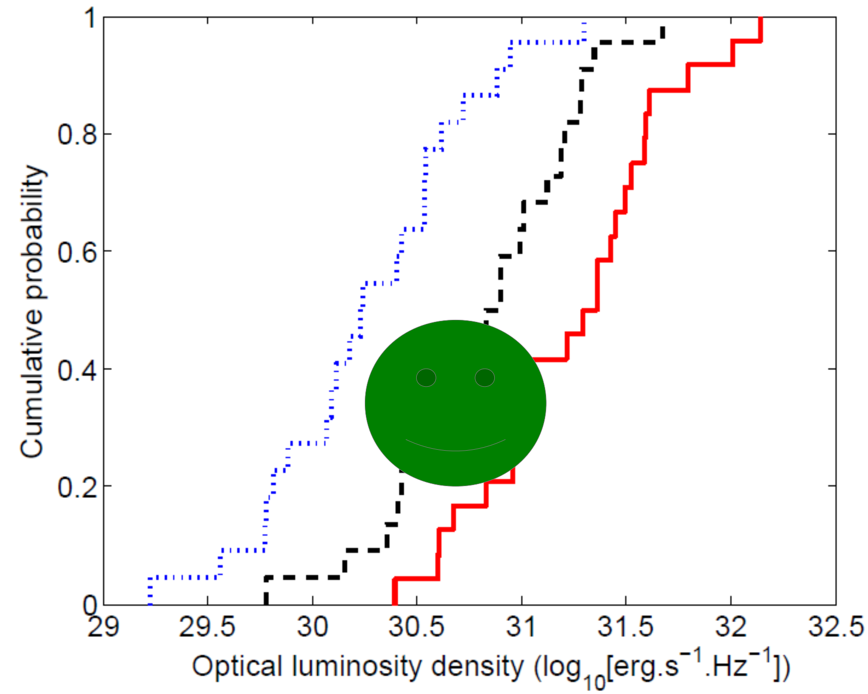
Intrinsic effect : Luminosity at rest frame



median[LR(Bright)] = 31.33 $\log_{10}$(erg/s/Hz) (red)

median[LR(Faint)] = 30.23 $\log_{10}$(erg/s/Hz) (blue)

Diff (median[LR]) = 1.1 $\log_{10}$(erg/s/Hz)

KS-test : p-val = 1.73 x 10^{-6}

Bootstrapping-test : p-val = 0.0

What's next ?

(1) We found a significant optical selection effect in the Epi-Eiso plane.

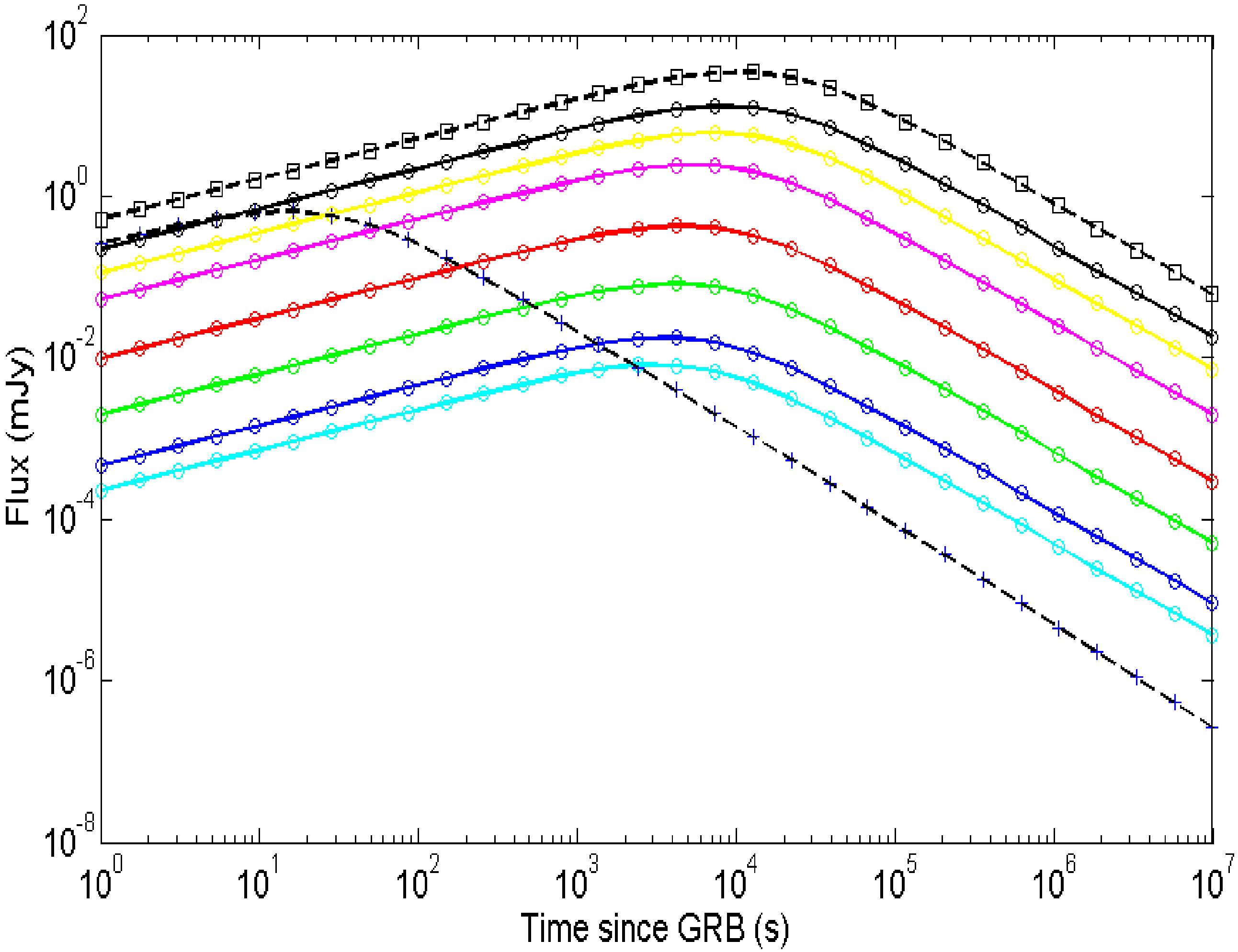
(2) It's due to a particular distribution of the afterglow optical brightness in the Epi-Eiso plane.

(3) Optical brightness of our selected GRBs is mainly driven by the intrinsic luminosity of the afterglow

What are the physical properties of the GRB afterglows ? Can we correlate afterglow physical parameters to the rest frame properties of the prompt emission ?

Back up

1. Test of the procedure (data without noise)



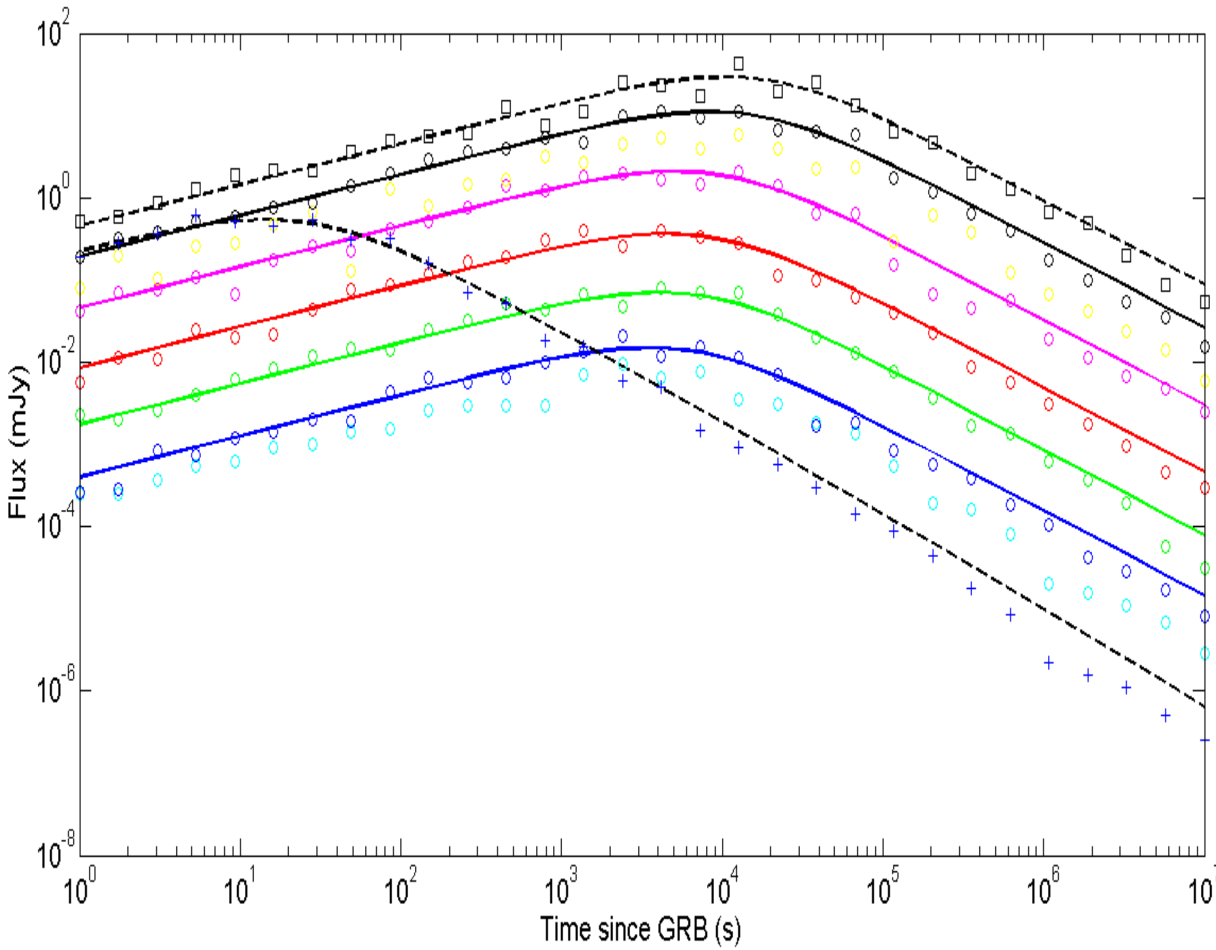
Multi wavelength emission (X-rays to K-band) from a simulated GRB afterglow (dots)

E_{iso} = 4.56 x10^{52} erg
z = 2.198
A_v^G = 0
A_v^H = 0.1
n_0 = 0.1 part/cm^3
ε_e = 0.4
ε_B = 1.0 x10^{-4}
η = 0.1
p = 2.5

χ^2 fit model (lines)

n_0^{model} = 0.6 part/cm^3
ε_e^{model} = 0.57
ε_B^{model} = 0.5 x10^{-4}
η^{model} = 0.14
p^{model} = 2.5

1. Test of the procedure (noisy data)



Multi wavelength emission (X-rays to K-band) from a simulated GRB afterglow (dots)

$E_{iso} = 4.56 \times 10^{52}$ erg

$z = 2.198$

$A_v^G = 0$

$A_v^H = 0.1$

$n_0 = 0.1$ part/cm^3

$\varepsilon_e = 0.4$

$\varepsilon_B = 1.0 \times 10^{-4}$

$\eta = 0.1$

$p = 2.5$

χ^2 fit model (lines)

$n_0^{model} = 0.4$ part/cm^3

$\varepsilon_e^{model} = 0.64$

$\varepsilon_B^{model} = 0.6 \times 10^{-4}$

$\eta^{model} = 0.17$

$p^{model} = 2.44$