The redshift distribution of Gamma-Ray Bursts : Evidence for evolution

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1. Long GRBs can be detected up to very large distances

As pointed out by several authors (e.g. Lamb & Reichart 2000)

- **Long GRBs are intrinsically very bright;**
- **Gamma-rays are un-absorbed;**

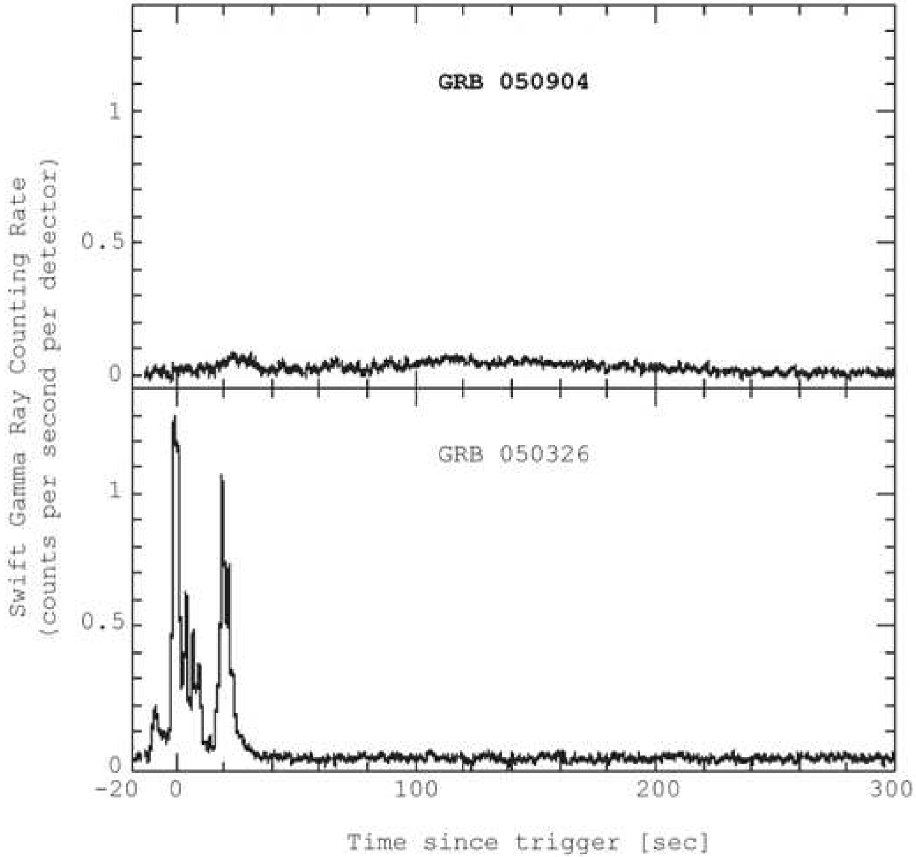
The brightest GRB could be detected up to z > 10.

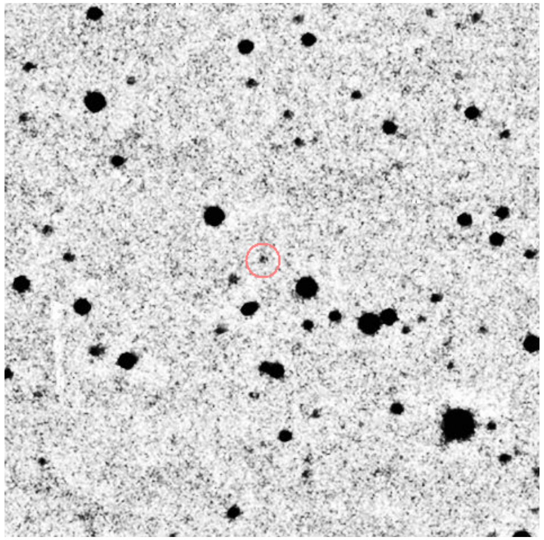
- **With appropriate instruments, it is possible to detect the optical/IR afterglow and measure the distance.**

Bright afterglows could be detected up to z~8-10.

2. GRBs are expected to be produced even at very large distance.

Some have already been detected : SWIFT burst GRB 050904 at z=6.29





TAROT detection :
86 s after the burst : I~16

(Quasar : z = 6.37, I=23.3)

Timescales are multiplied by 1+z = 7.3 ! (T_{90}>200 s)

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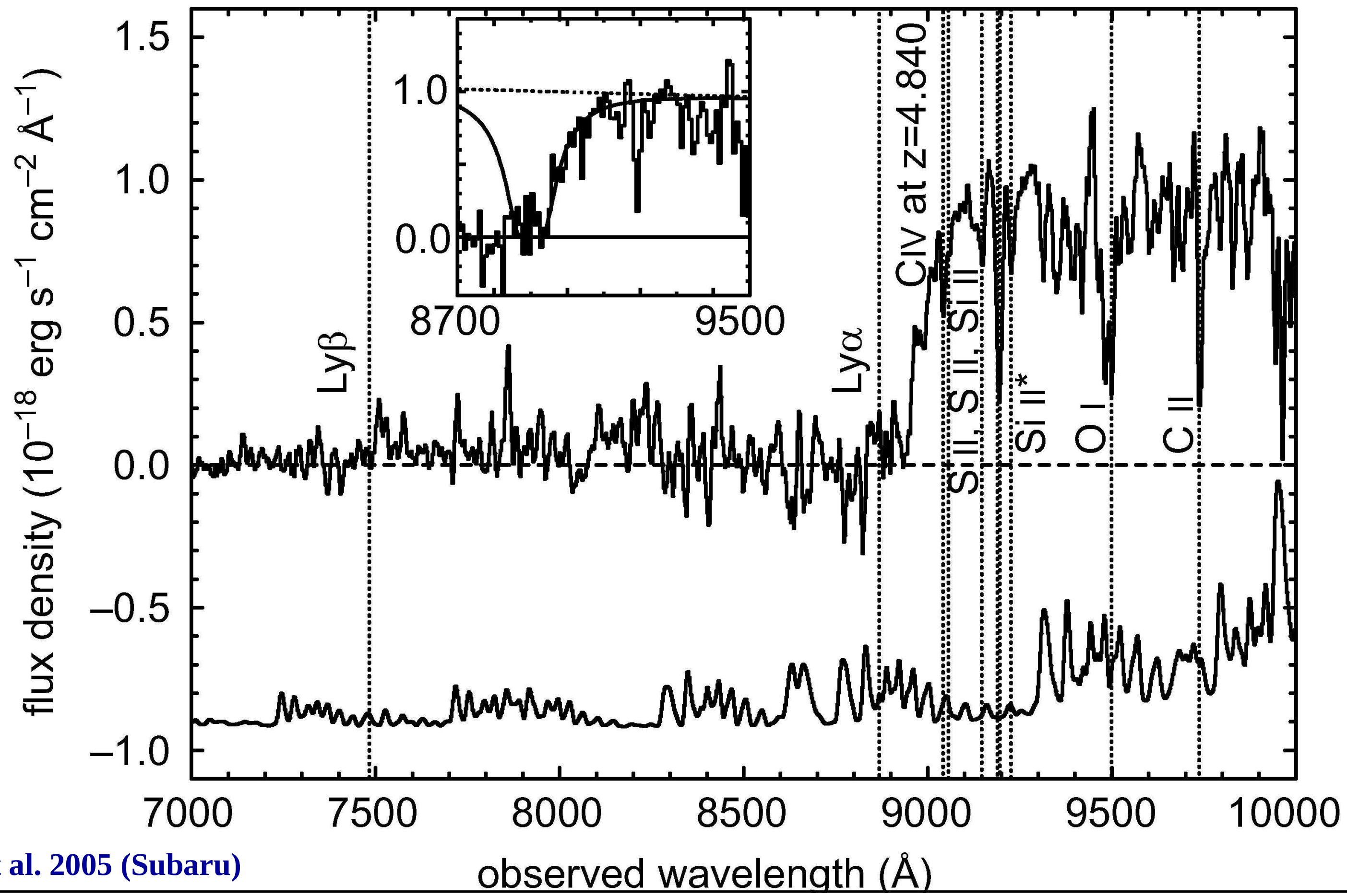


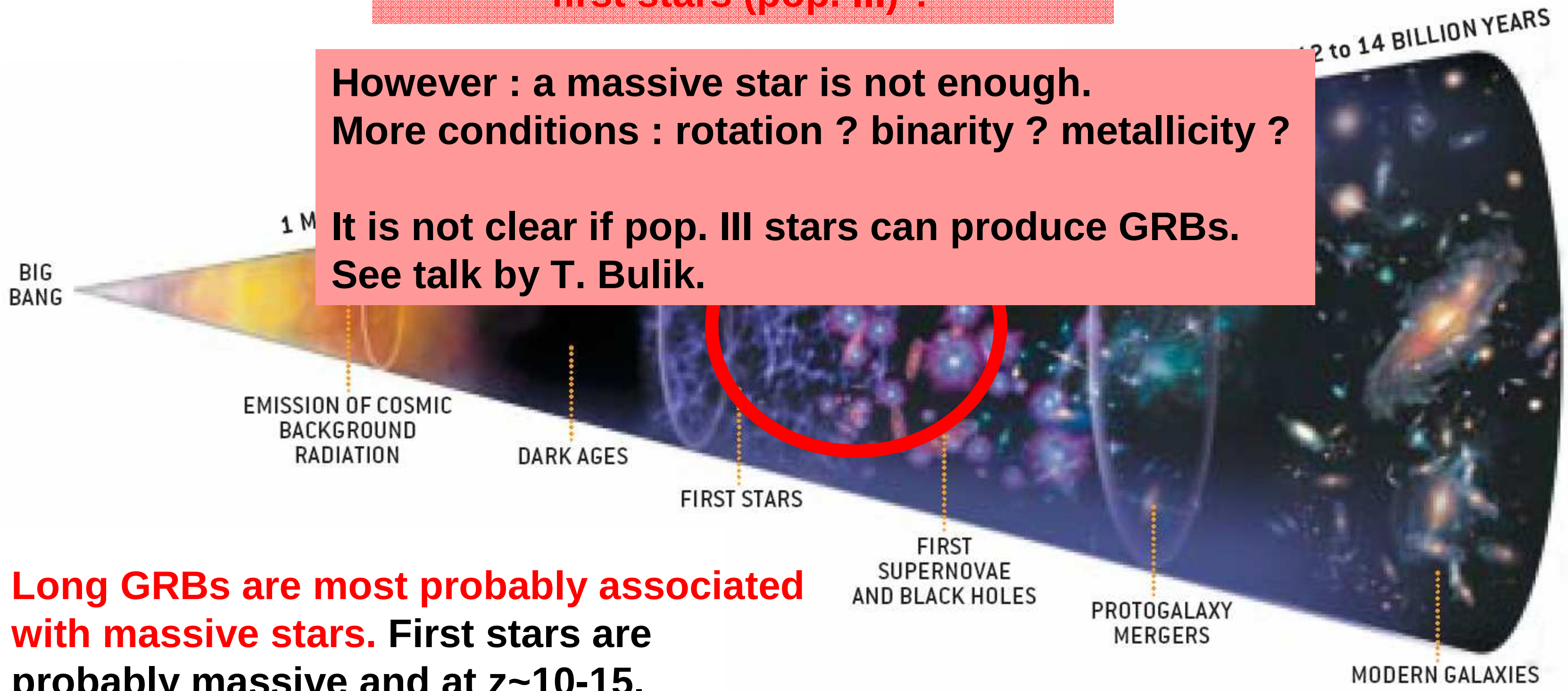
Kawai et al. 2005 (Subaru)

2. GRBs are expected to be produced even at very large distance.

GRBs associated with first stars (pop. III) ?

However : a massive star is not enough.
More conditions : rotation ? binarity ? metallicity ?

It is not clear if pop. III stars can produce GRBs.
See talk by T. Bulik.



Long GRBs are most probably associated with massive stars. **First stars are probably massive and at z~10-15. (cf. WMAP results)**

Larson & Bromm, Scientific American, 2001

3. How to detect the afterglow of a high redshift GRB ?

cf. Nousek's talk on SWIFT

GRB : image mode (cf. GRB 050904) ; X-ray band, …

cf. Schanne's talk on ECLAIRs

Afterglow : (Near-)Infrared
Rapid follow-up

cf. Goldoni's talk on X-SHOOTER

Bonus (e.g. Lamb & Reichart 2001) :

You observe … 10 min after the burst

This means in the source frame … 5 min after the burst @ z = 1
55 s after the burst @ z = 10

The afterglow is intrinsically brighter so that the decrease of the flux due to the larger luminosity distance is partially compensated.

4. What can be done using high z GRBs ?

•Spectrum : intergalactic medium (cf. QSOs)
host galaxy (interstellar medium)

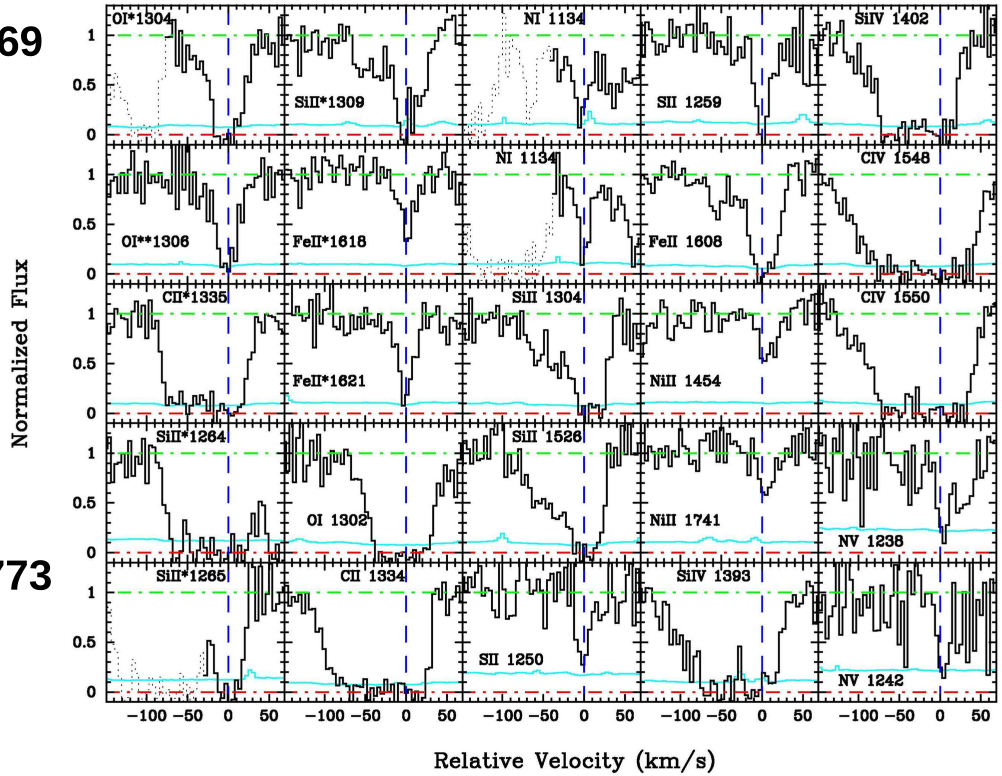
Example : GRB 050730 @ z=3.969

(Chen et al. 2005)

R=17.7, 4 h after the burst.

ISM : N(HI)=22.15
$Z/Z_{\odot}$~1/100

IGM : DLA @ z=3.564
LLS @ 3.022
MgII abs. @ z=2.253,1.773



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•Spectrum : intergalactic medium (cf. QSOs)
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•Tracing the SFR up to high z : knowing the intrinsic properties of GRBs and understanding the progenitors is needed.

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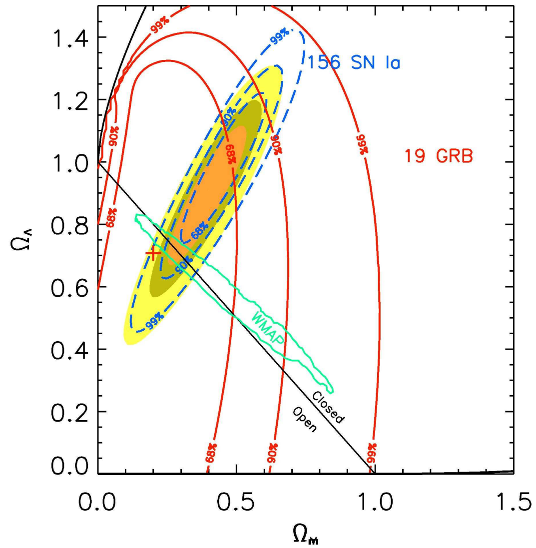
•Measuring cosmological parameters : OK if Amati/Ghirlanda/… relations are understood and if one can measure all required quantities (peak energy, break time).



Ghirlanda et al. 2005

4. What can be done using high z GRBs ?

- **Spectrum :** **intergalactic medium (cf. QSOs)**
  host galaxy (interstellar medium)

- **Tracing the SFR up to high z : knowing the intrinsic properties of GRBs and understanding the progenitors is needed.**

- **Learning something on pop. III stars, on the reionization epoch, … : OK if pop. III stars can produce GRBs…**

- **Measuring cosmological parameters : OK if Amati/Ghirlanda/… relations are understood and if one can measure all required quantities (peak energy, break time).**

- **Etc.**

How many GRBs can be expected for such studies ?

The redshift distribution of long GRBs

Daigne, Rossi & Mochkovitch (astroph/0607618, to appear in MNRAS).

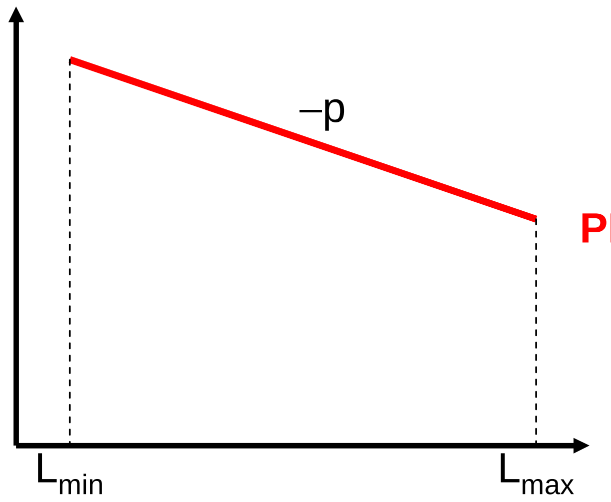
Motivation :

- **Do long GRB trace the star formation rate ?**
- **What is the expected rate of GRBs at high redshift ?**

Method : we use Monte-Carlo simulations. This allows :

- a « realistic » parametrization of the spectrum (α, β, E_p have dispersion).
- a « realistic » treatment of detection criteria by several instruments.
- **a study of the impact of the incertainities in the GRB instrinsic properties on the predicted GRB rate.**

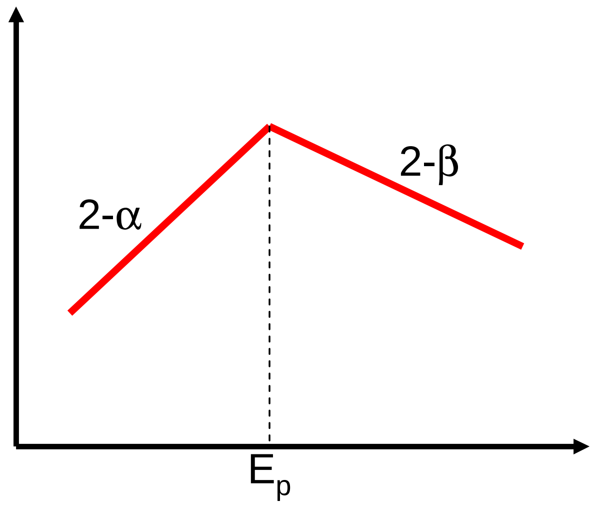
Free parameters



Luminosity function : **power-law**

3 free parameters : L_{min} (or L_*), L_{max} and p.

Free parameters



Spectrum : Low-energy slope α : observed distribution (Preece et al. 2001)
High-energy slope β : observed distribution (Preece et al. 2001)

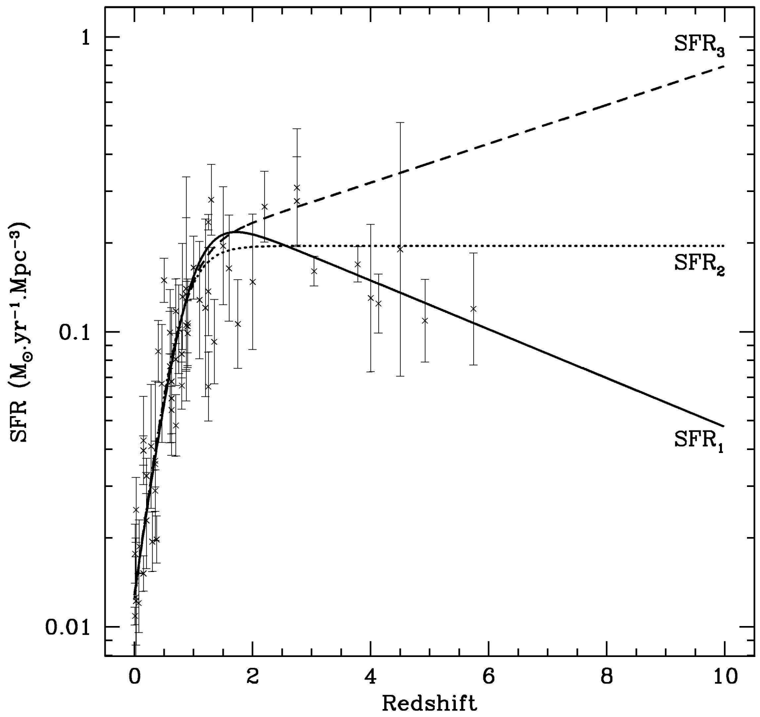
- (1) « Amati-like » relation $E_p \propto L^{0.43}$ with normal dispersion σ =0.2 and E_p=380 keV @ L=1.6 10^{52} erg/s

No free parameter.

- or (2) E_p has a normal distribution with <Log(E_p)>=Log(E_{p0}) and σ=0.3

One free parameter (E_{p0}).

Free parameters



Rate :

Rate(GRB) ∝ SFR ; constant k = Rate(GRB)/Rate(SN) (Porciani & Madau 2001).

Fit to observed SFR (Hopkins et al. 2005) + Extrapolation at high redshift.

- SFR1 : SFR decreases for z > 2
- SFR2 : SFR constant for z > 2
- SFR3 : SFR increases up to z=zmax=20

One free parameter (k).

Constraints

Three different observational constraints :

- BATSE Log(N)-Log(P) diagram (Kommers et al. 2000; Stern et al. 2001,2002).
- Observed Epeak distribution of long bright bursts (Preece et al. 2001).
- Observed fraction of XRF+XRR by HETE-2 (Sakamoto et al. 2004).

Detection

Three instruments :

- BATSE : 50 keV – 300 keV ; same sensitivity as in Kommers et al. 2000; Stern et al. 2001,02.
  Bright bursts (for comparison with Preece et al. 2001) : P > 5 ph/cm^2/s
  (i.e. ~ 5-10 % brightest)

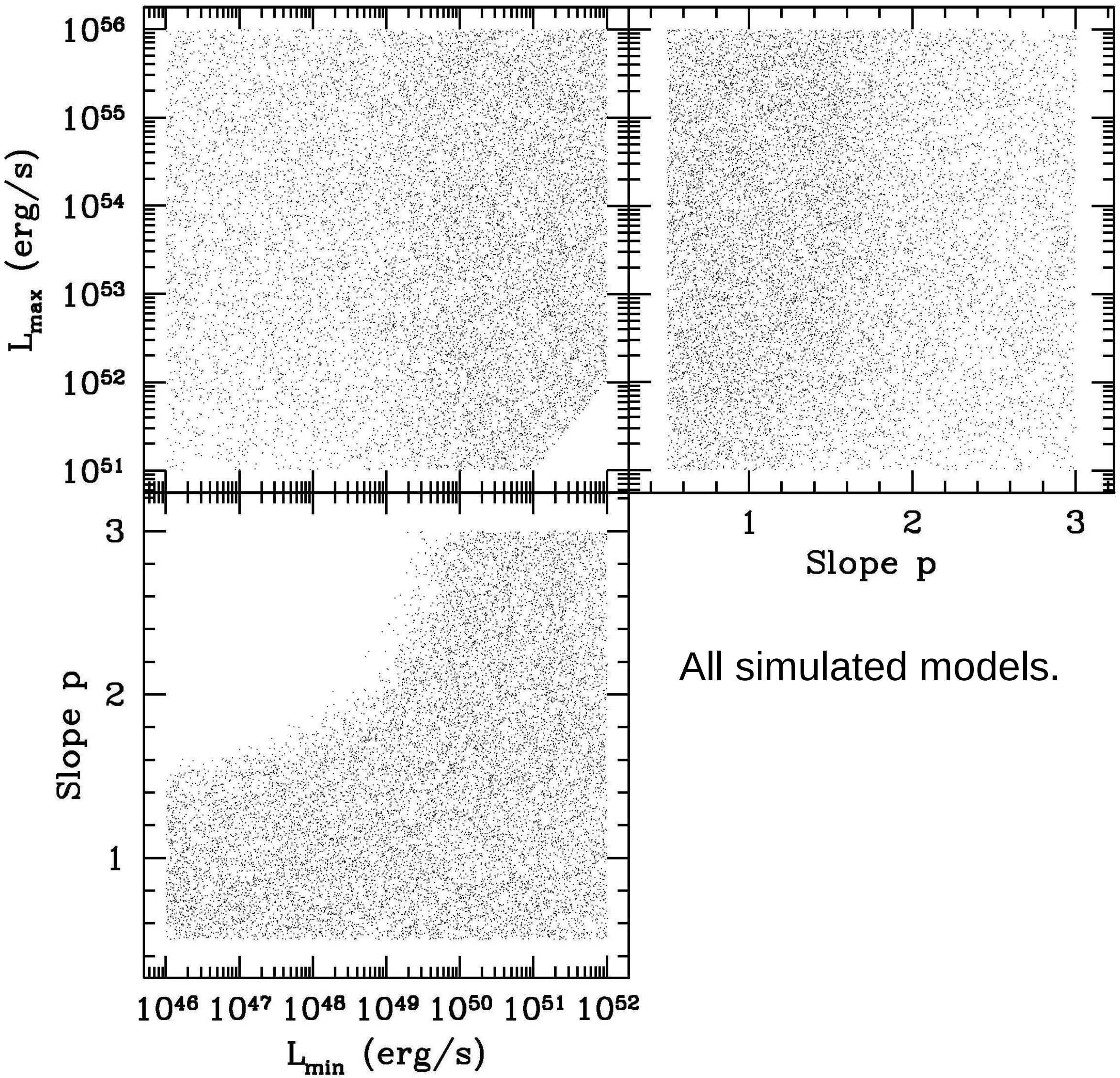
- HETE-2 / WXM : 2-10 keV ; P > 1 ph/cm^2/s
  30-400 keV ; P > 1 ph/cm2/s

- **SWIFT : 15 - 150 keV ; P > 0.2 ph/cm^2/s**
  bright SWIFT GRBs : P > 1 ph/cm^2/s

(1) $E_p \propto L^{0.43}$

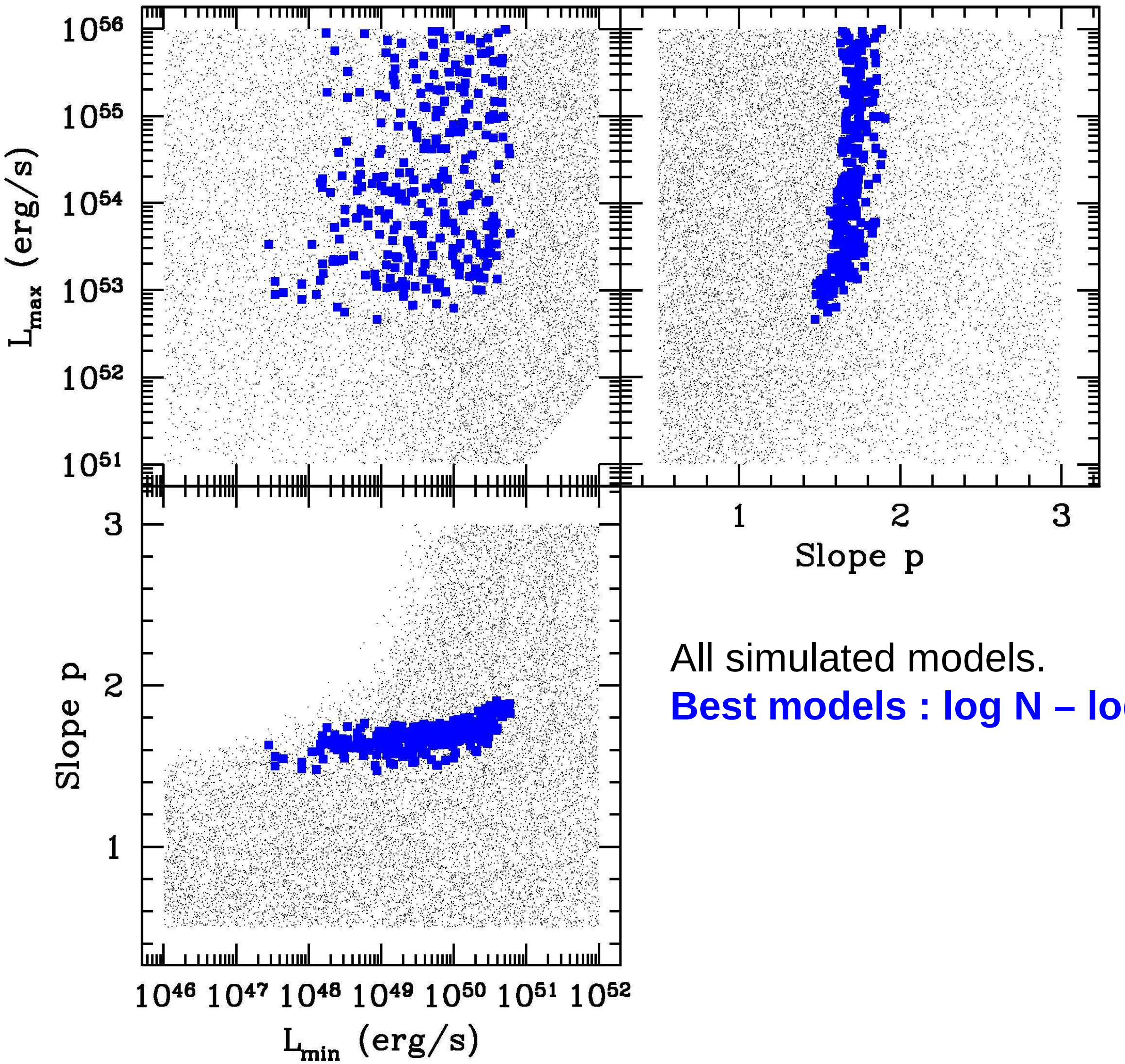
4 parameters : L_{min}, L_{max}, p, k

Parameter space



All simulated models.

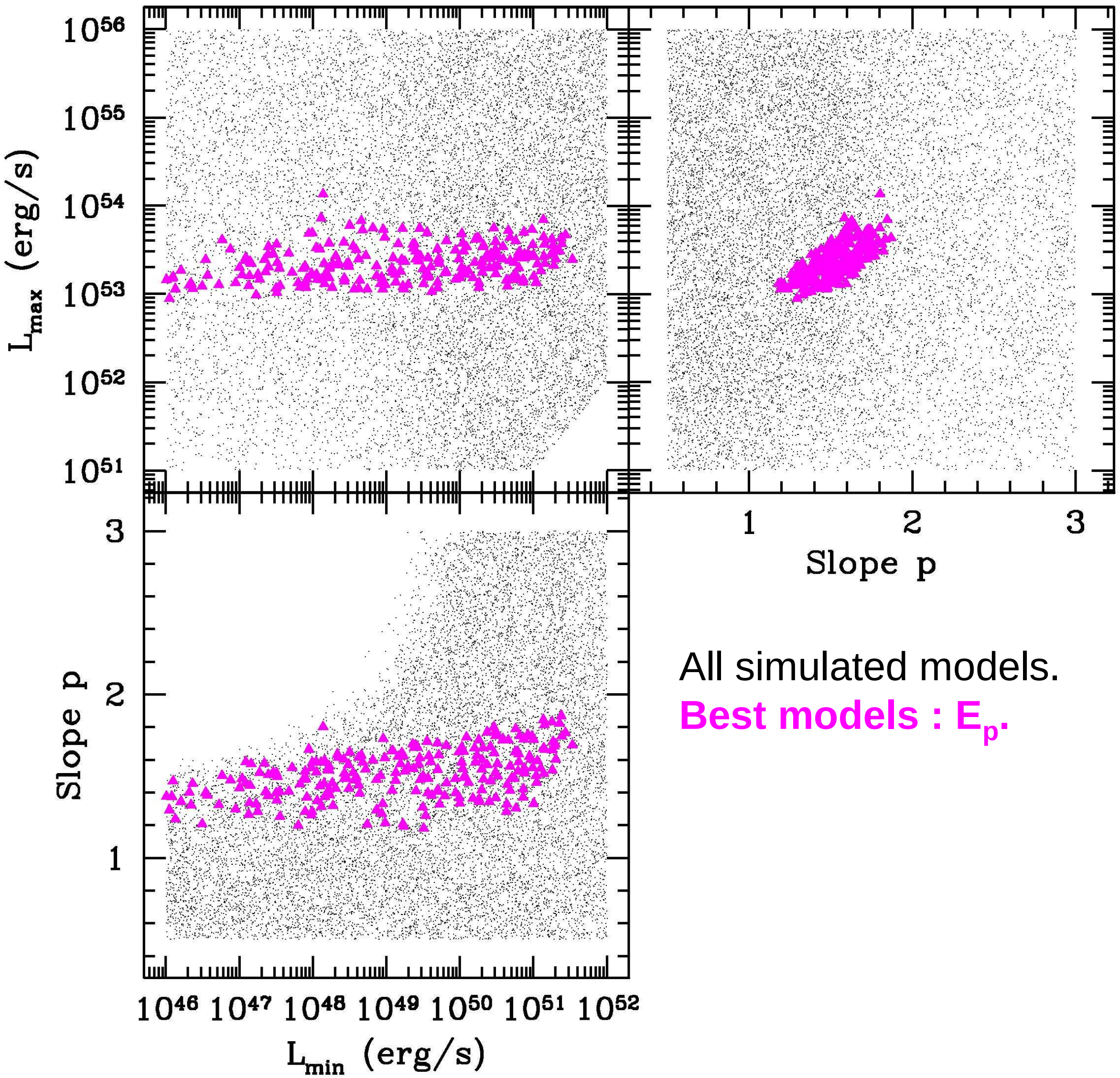
Parameter space



All simulated models.

Best models : log N – log P.

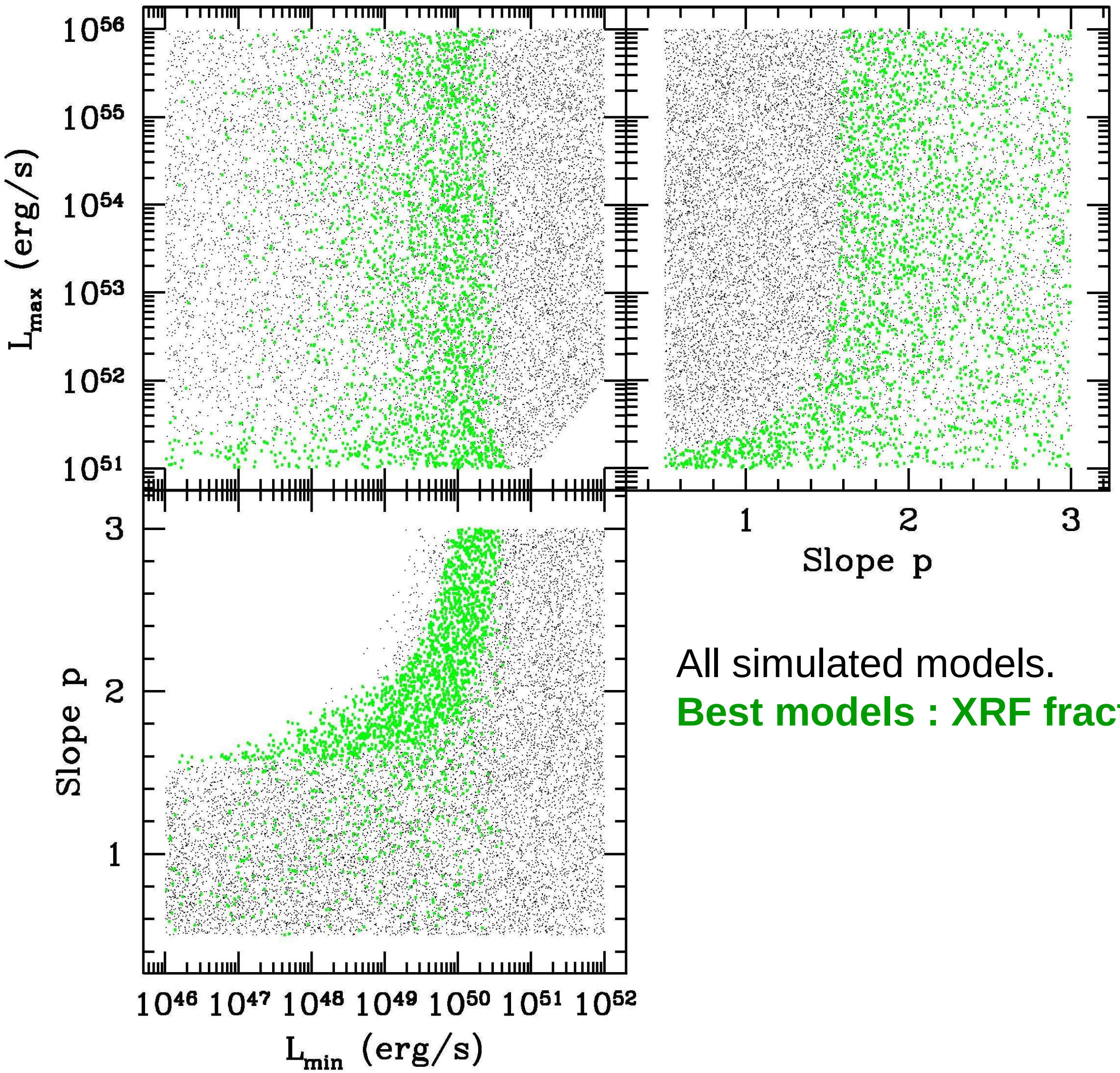
Parameter space



All simulated models.

Best models : E_p.

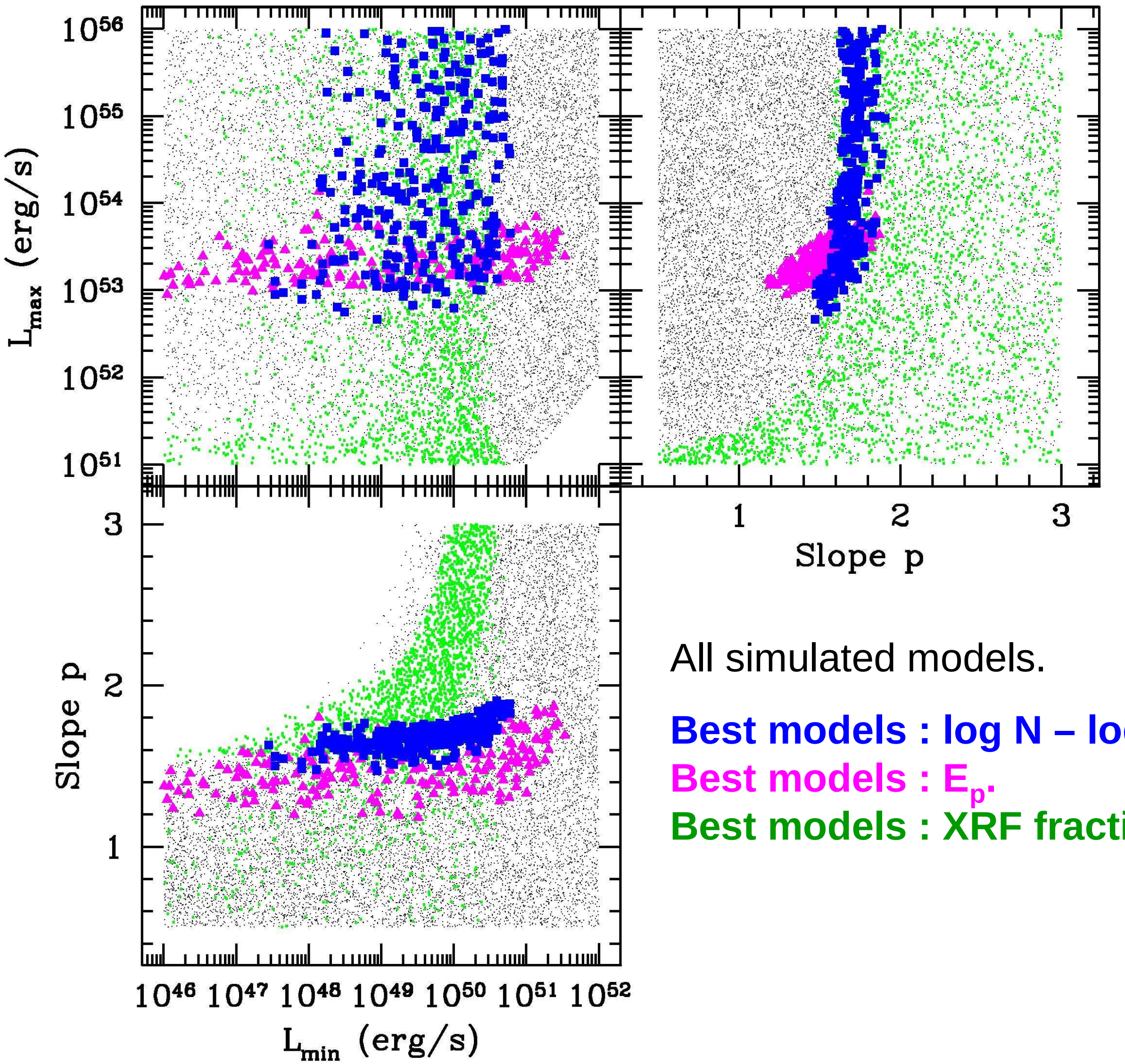
Parameter space



All simulated models.

Best models : XRF fraction.

Parameter space



All simulated models.

Best models : log N – log P.

Best models : E_p.

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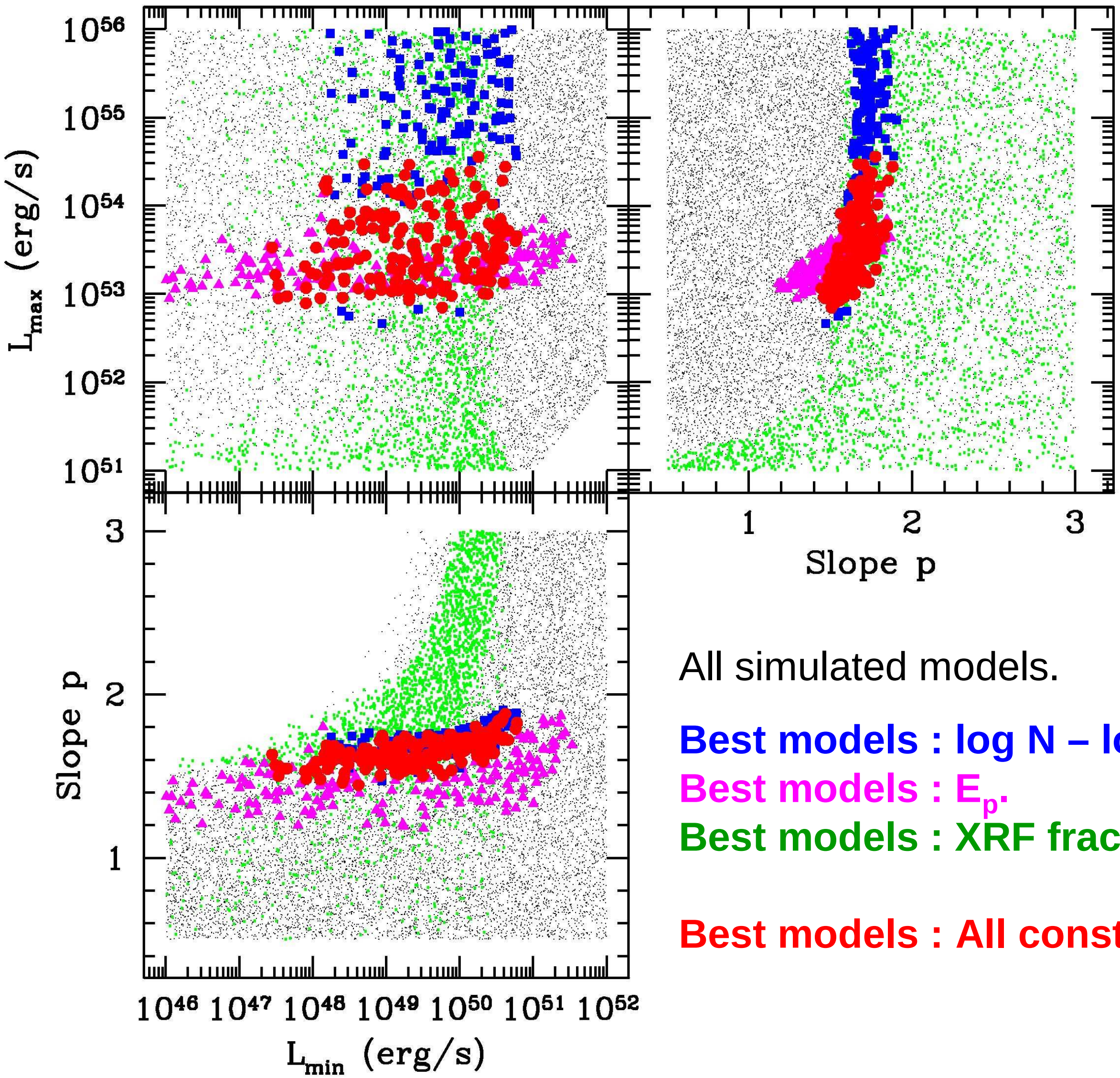
Parameter space



All simulated models.

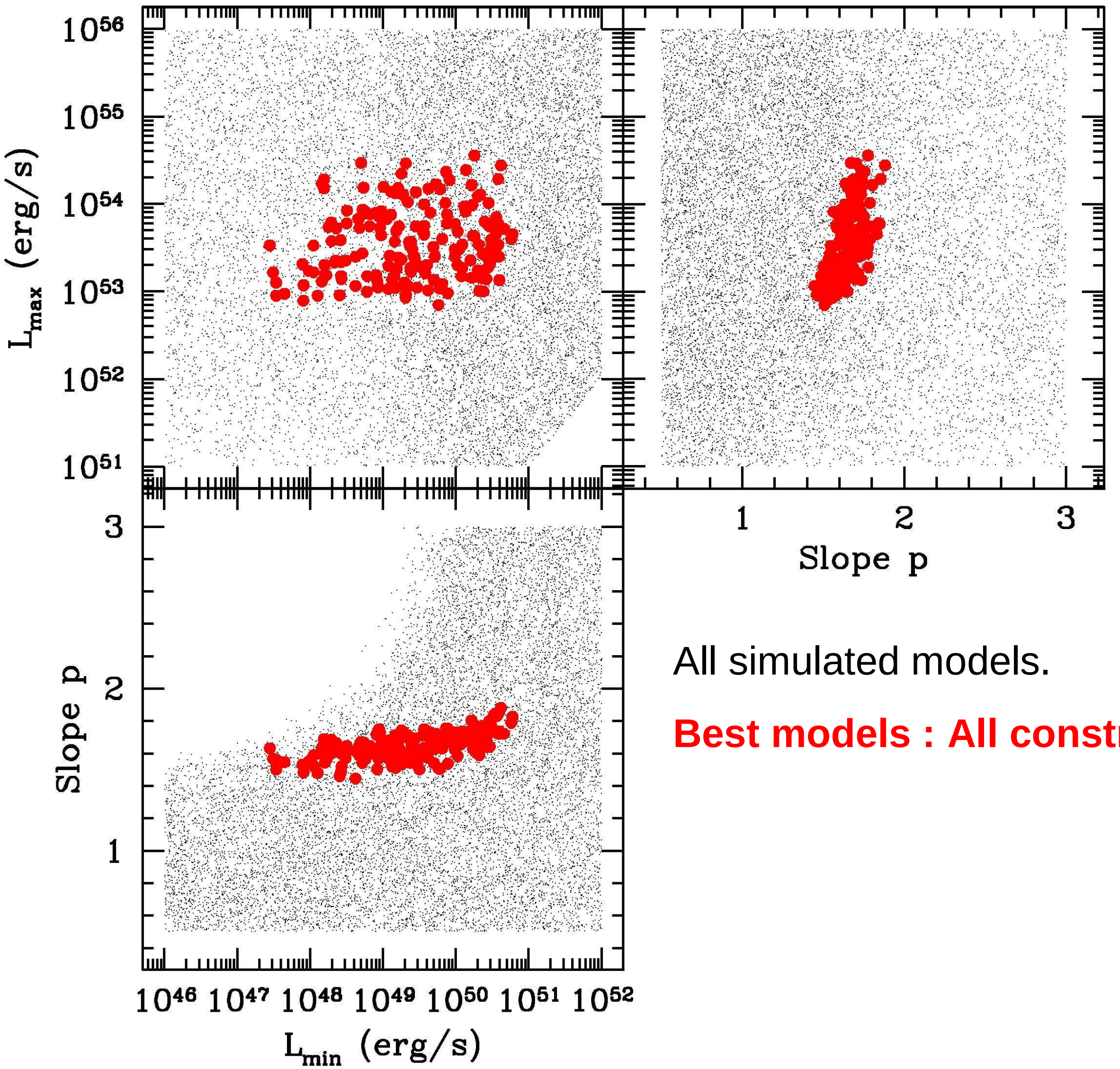
Best models : log N – log P.

Best models : E_p.

Best models : XRF fraction.

Best models : All constraints.

Parameter space



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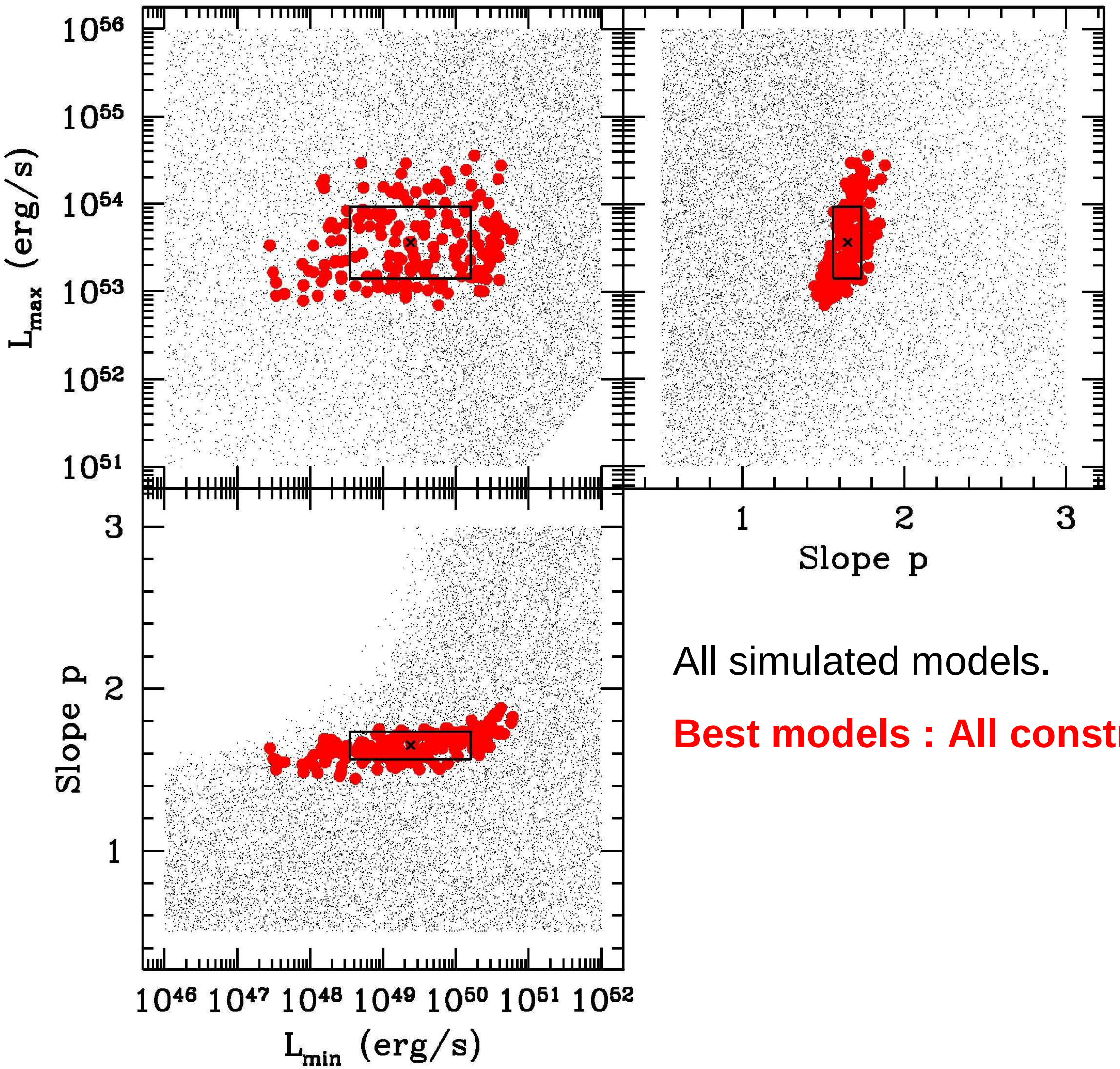

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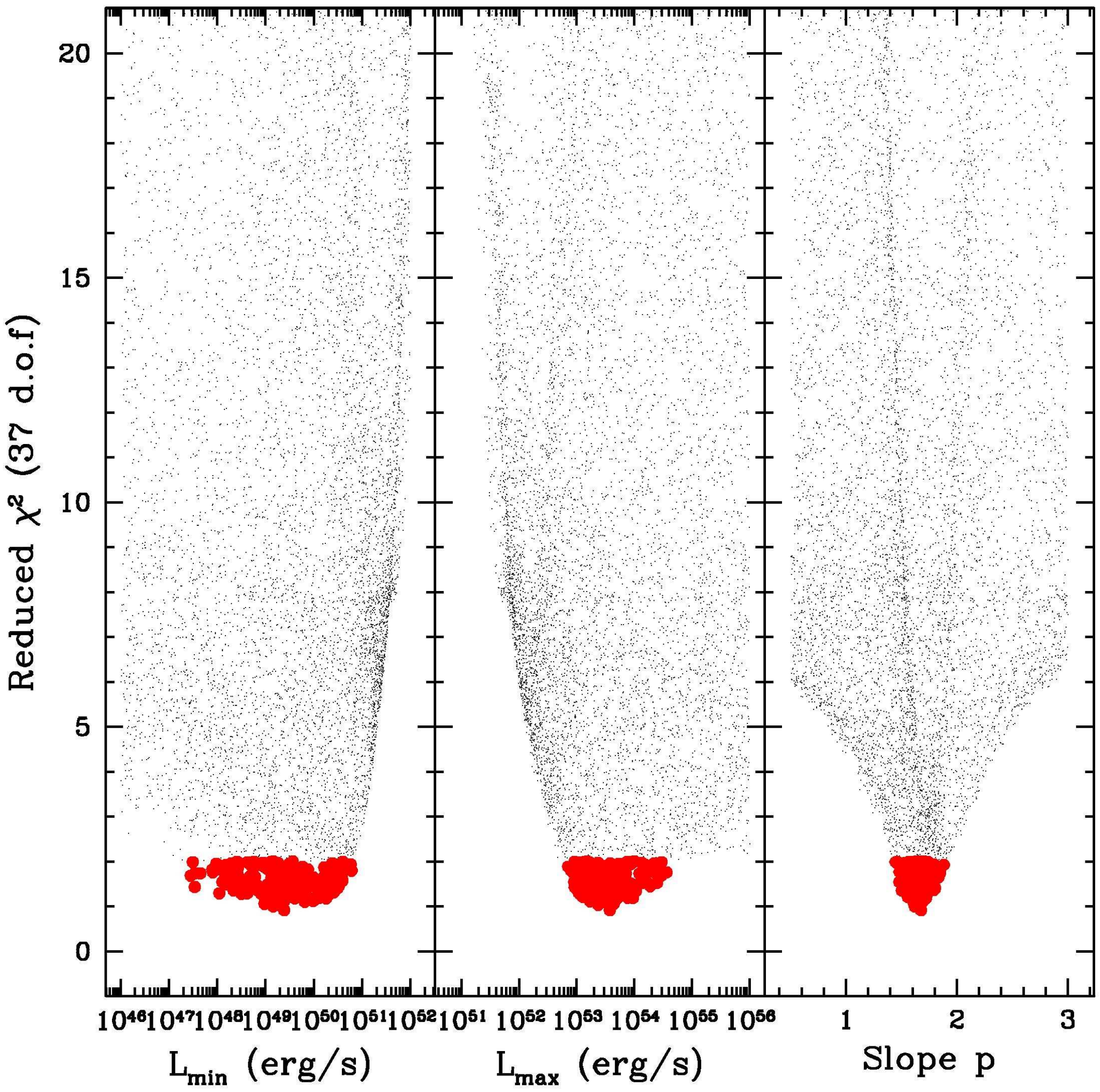
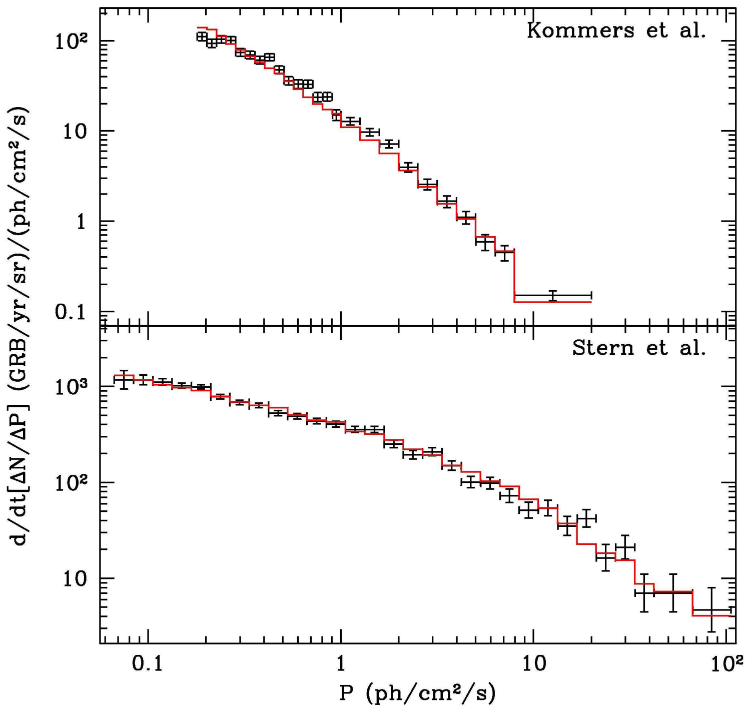
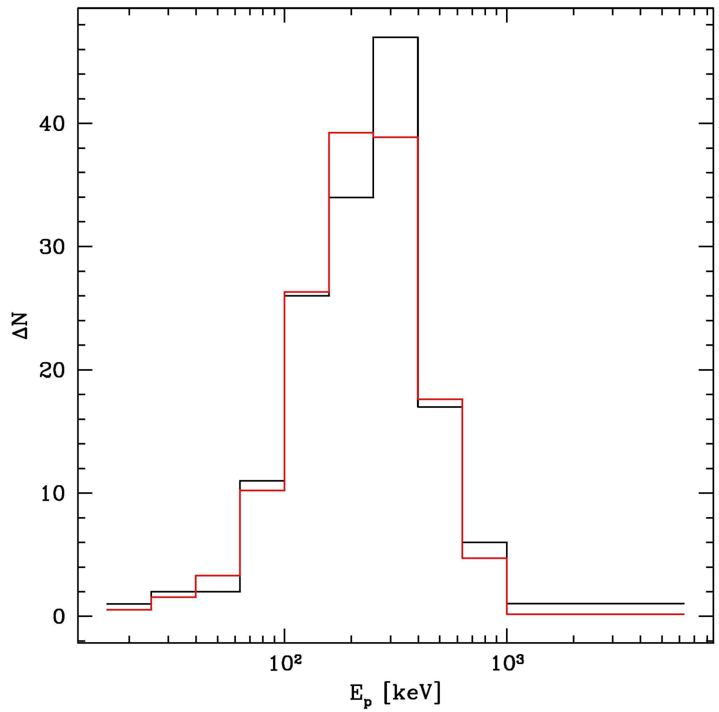
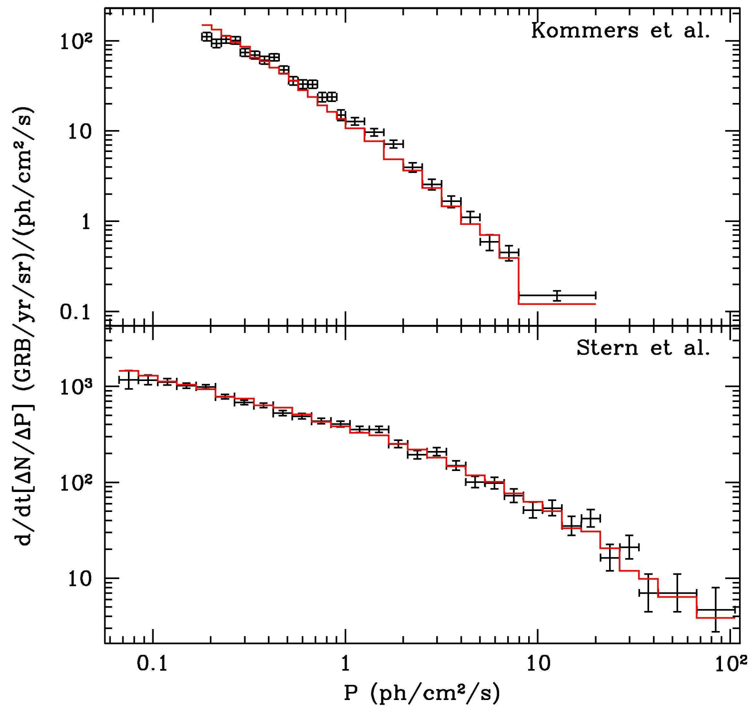


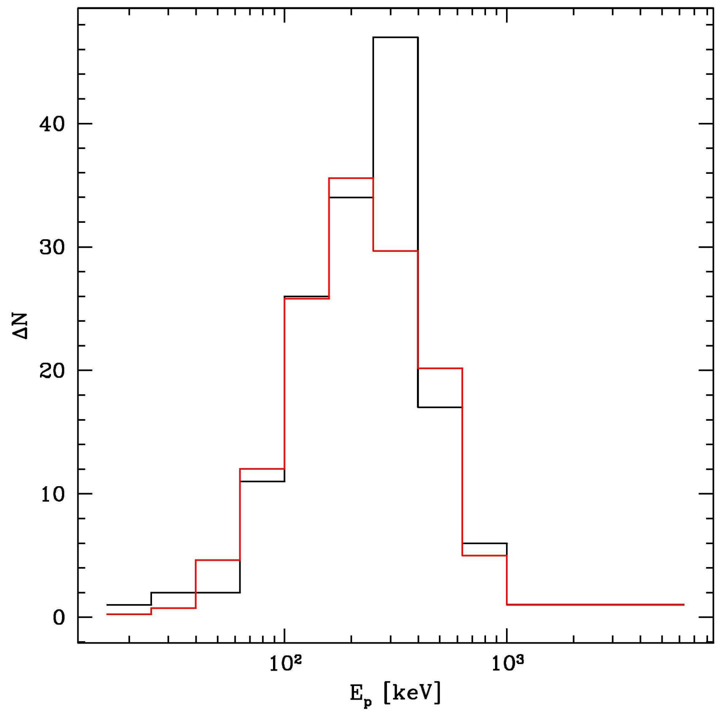
Best fit : SFR1



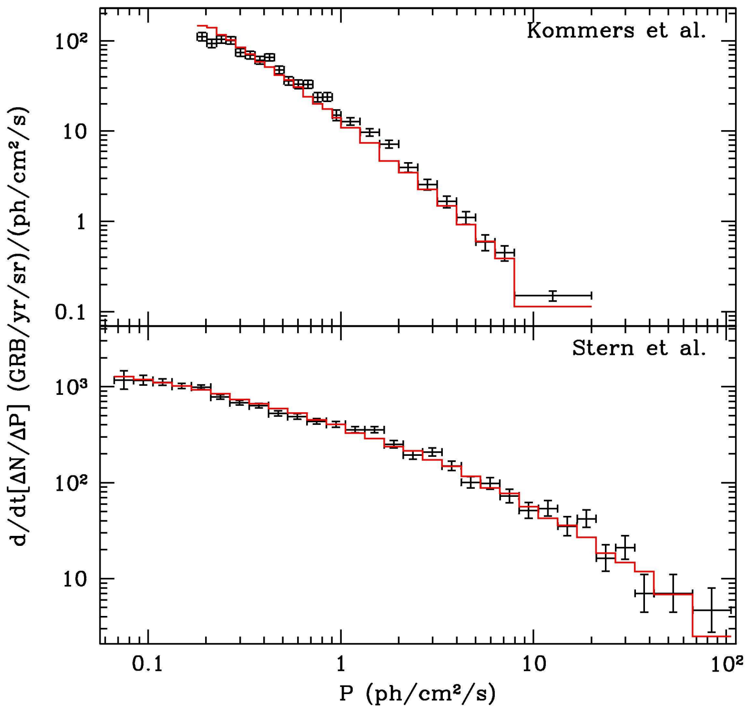


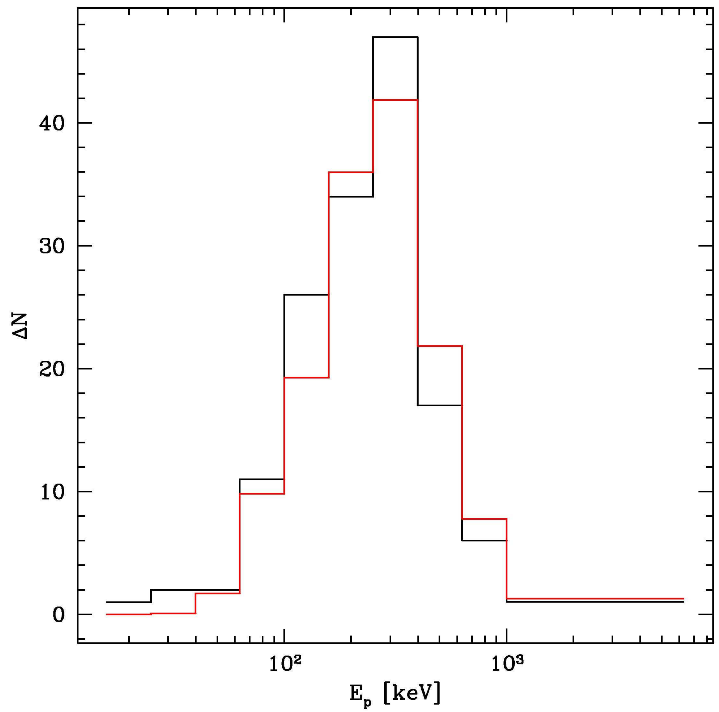
Best fit : SFR2





Best fit : SFR3



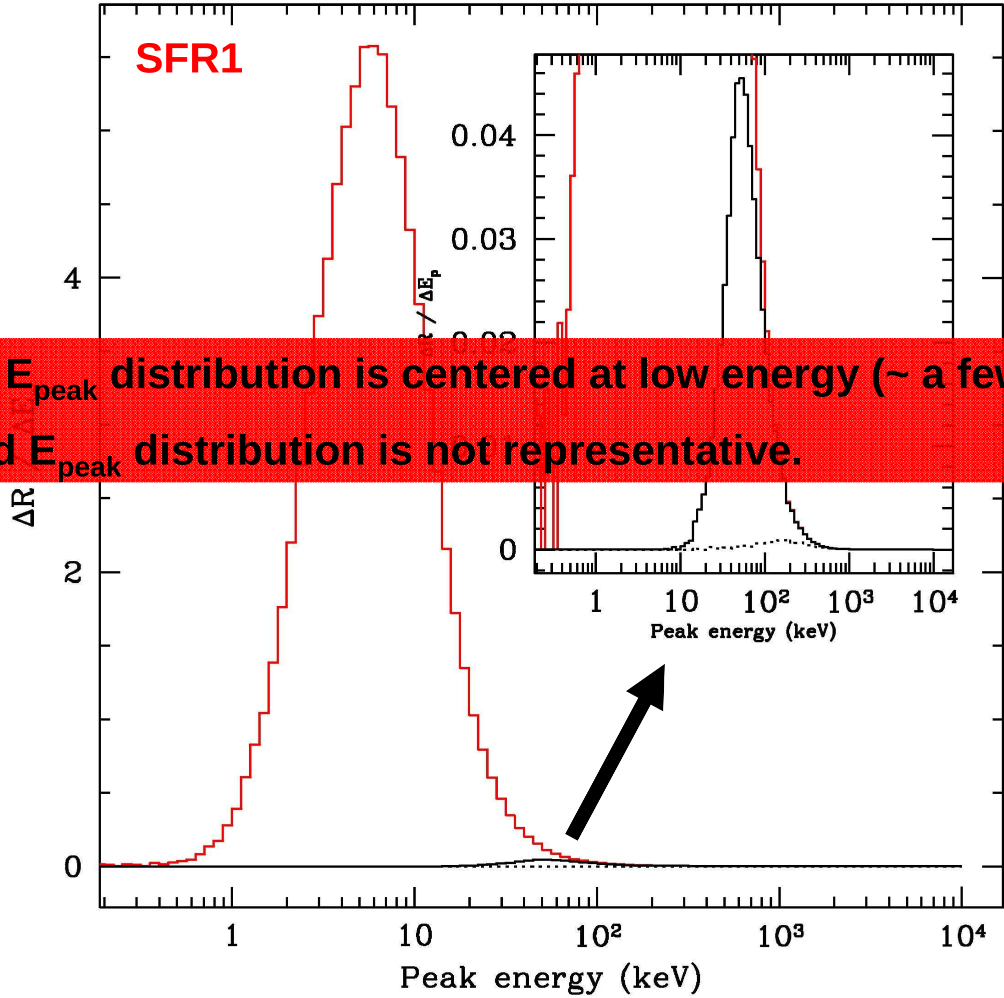


Results

SFR	$\log L_{\rm min}$	$\log L_{\rm max}$	δ	$\log k$
Amati-like relation $E_{\rm p} \propto L^{0.43}$				
1	49.9 ± 0.5	53.7 ± 0.4	1.70 ± 0.08	-5.4 ± 0.3
2	50.0 ± 0.5	53.7 ± 0.5	1.68 ± 0.10	-5.5 ± 0.3
3	50.3 ± 0.7	53.5 ± 0.4	1.54 ± 0.18	-6.0 ± 0.2

Rate	All	SWIFT	Bright SWIFT
Amati-like relation $E_{\rm p} \propto L^{0.43}$			
SFR1	3.1	1.6	1.3
SFR2	8.0	1.9	1.5
SFR3	10.5	3.3	2.1

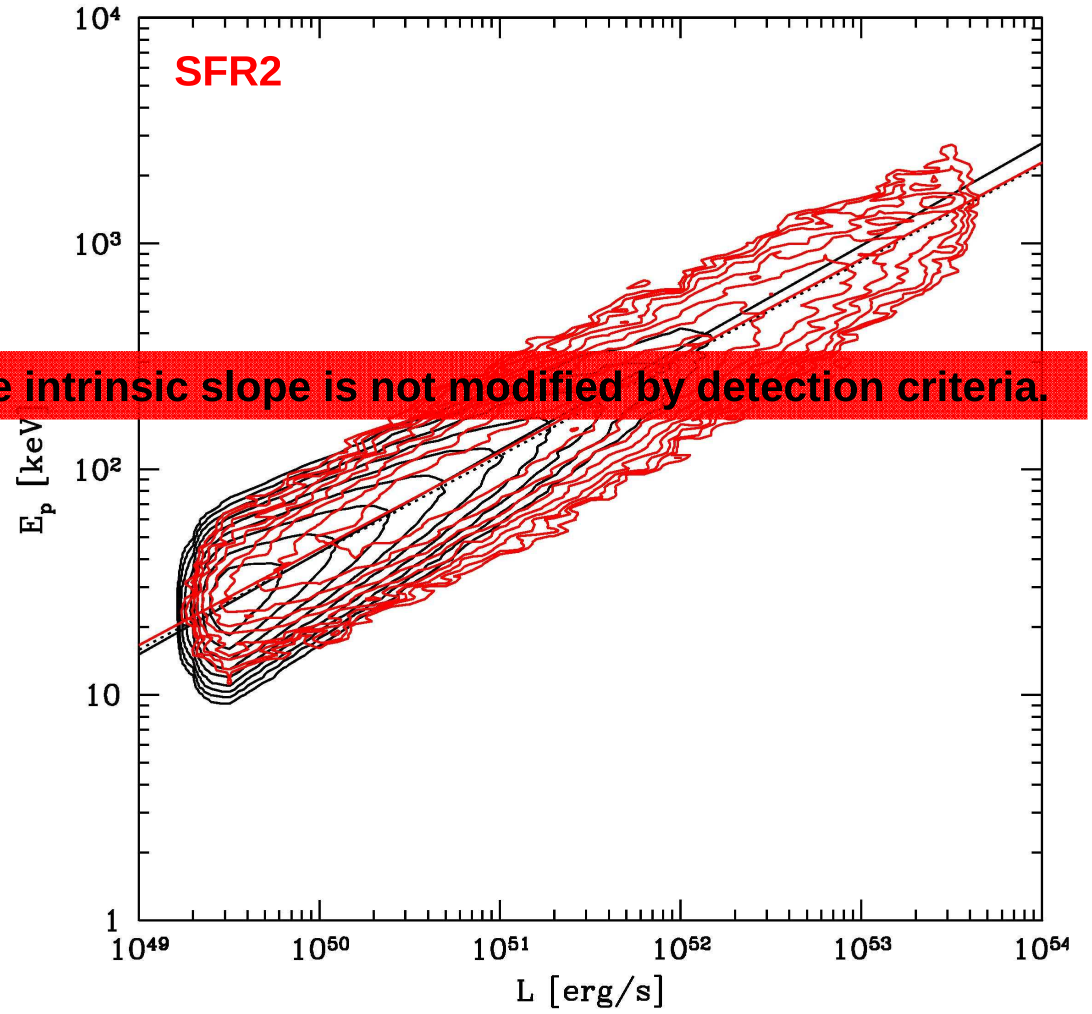
Best fit : intrinsic E_{peak} distribution



The intrinsic E_{peak} distribution is centered at low energy (~ a few keV).

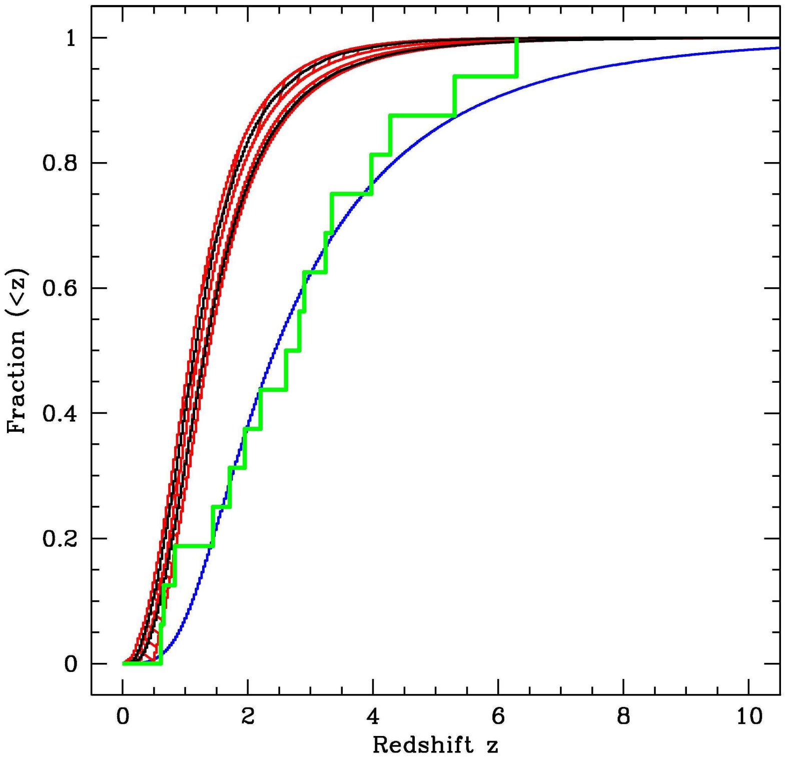
The observed E_{peak} distribution is not representative.

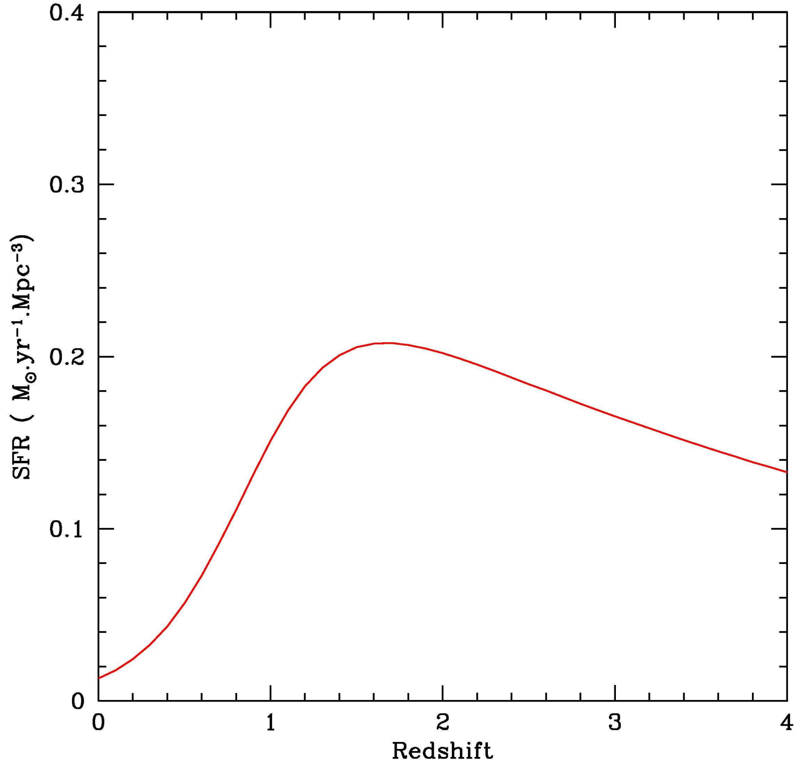
Best fit : Amati-like relation



The intrinsic slope is not modified by detection criteria.

Best fit : Redshift distribution (SFR1)



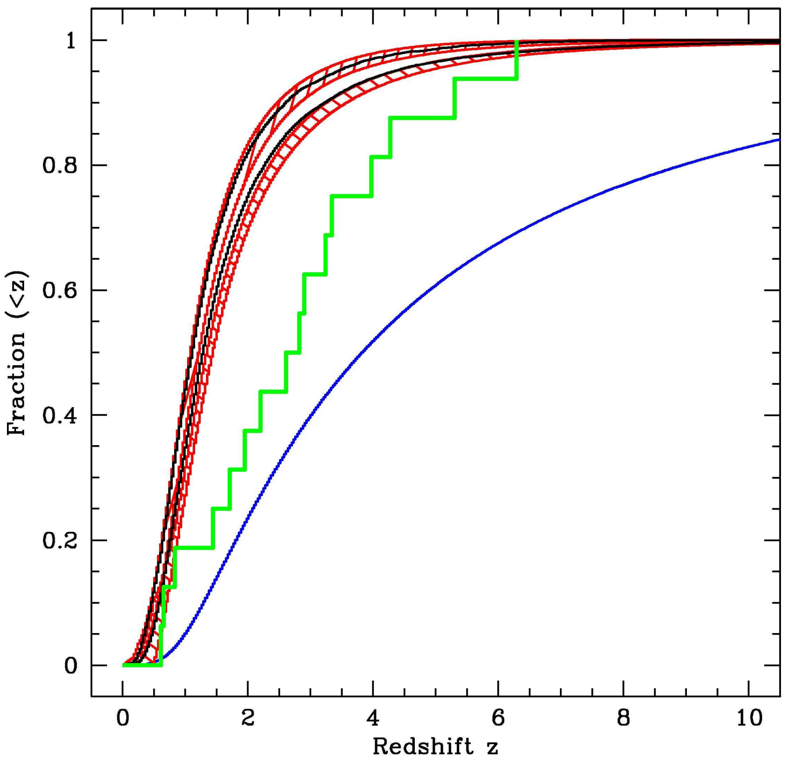


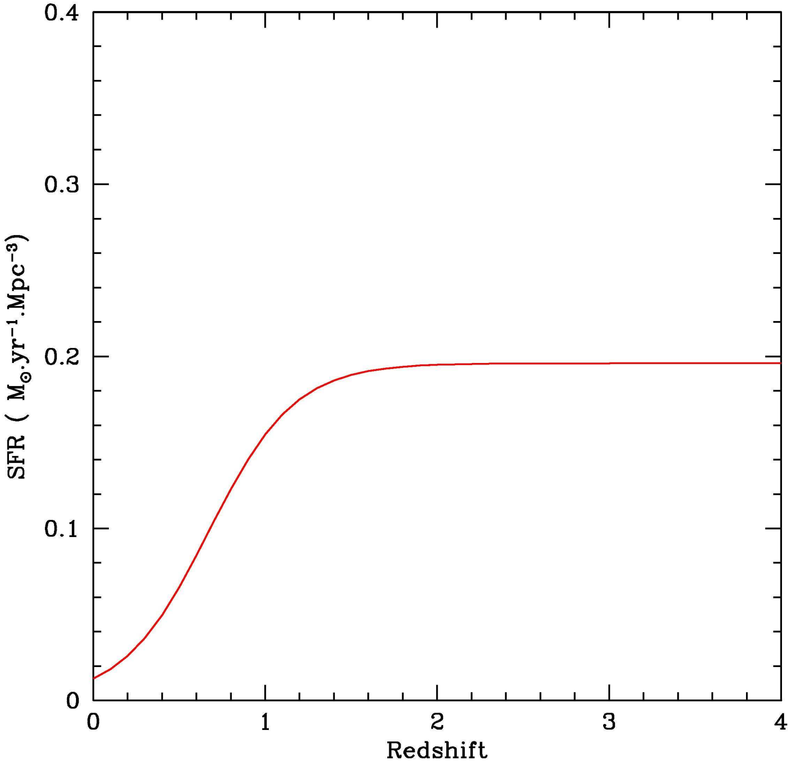
All GRBs

SWIFT observations (Jakobsson et al. 2005)

Best model : SWIFT GRBs (all/bright)

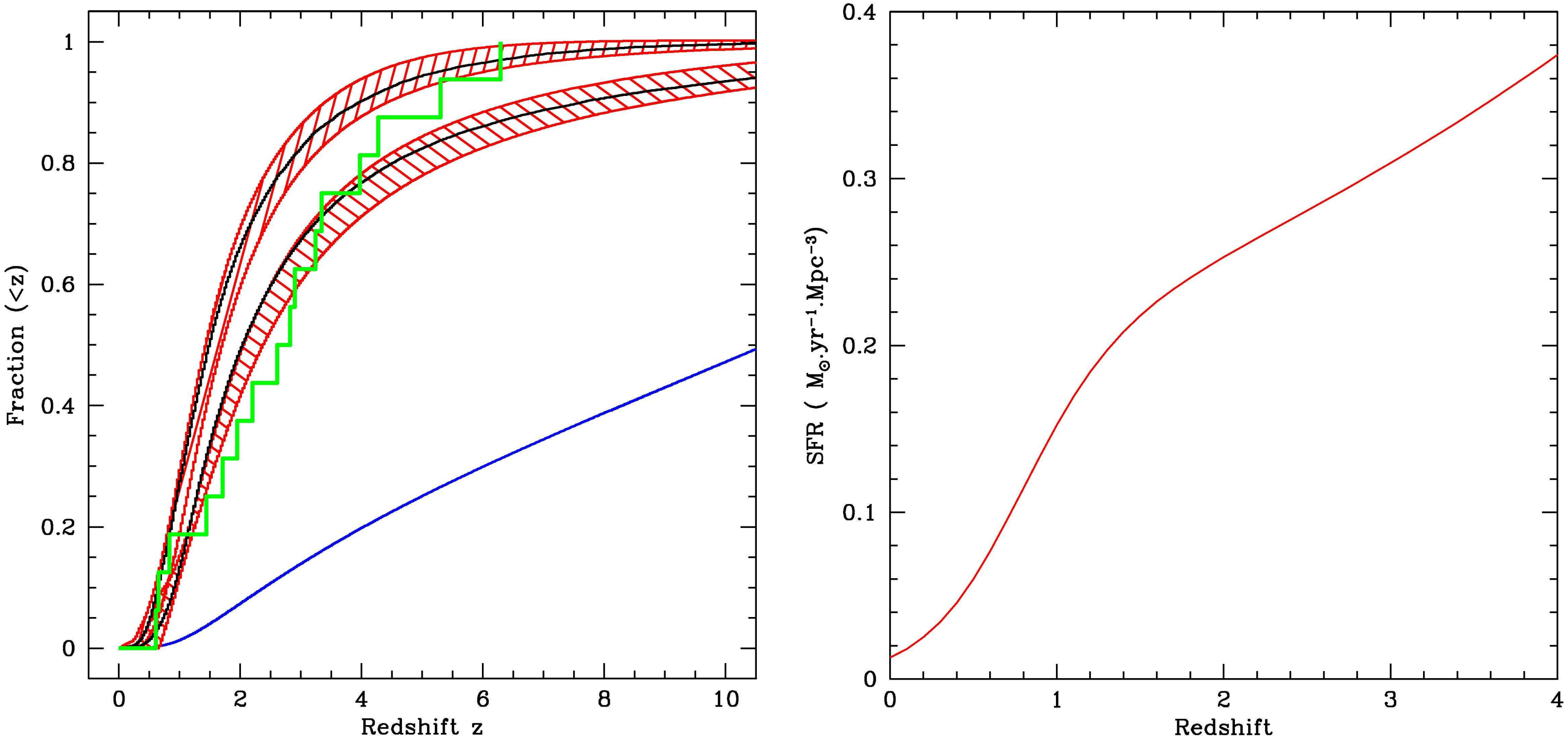
Best fit : Redshift distribution (SFR2)





All GRBs
SWIFT observations (Jakobsson et al. 2005)
Best model : SWIFT GRBs (all/bright)

Best fit : Redshift distribution (SFR3)



All GRBs

SWIFT observations (Jakobsson et al. 2005)

Best model : SWIFT GRBs (all/bright)

(2) $E_p = C^{ST}$

5 parameters : L_{min}, L_{max}, p, k and E_{p0}

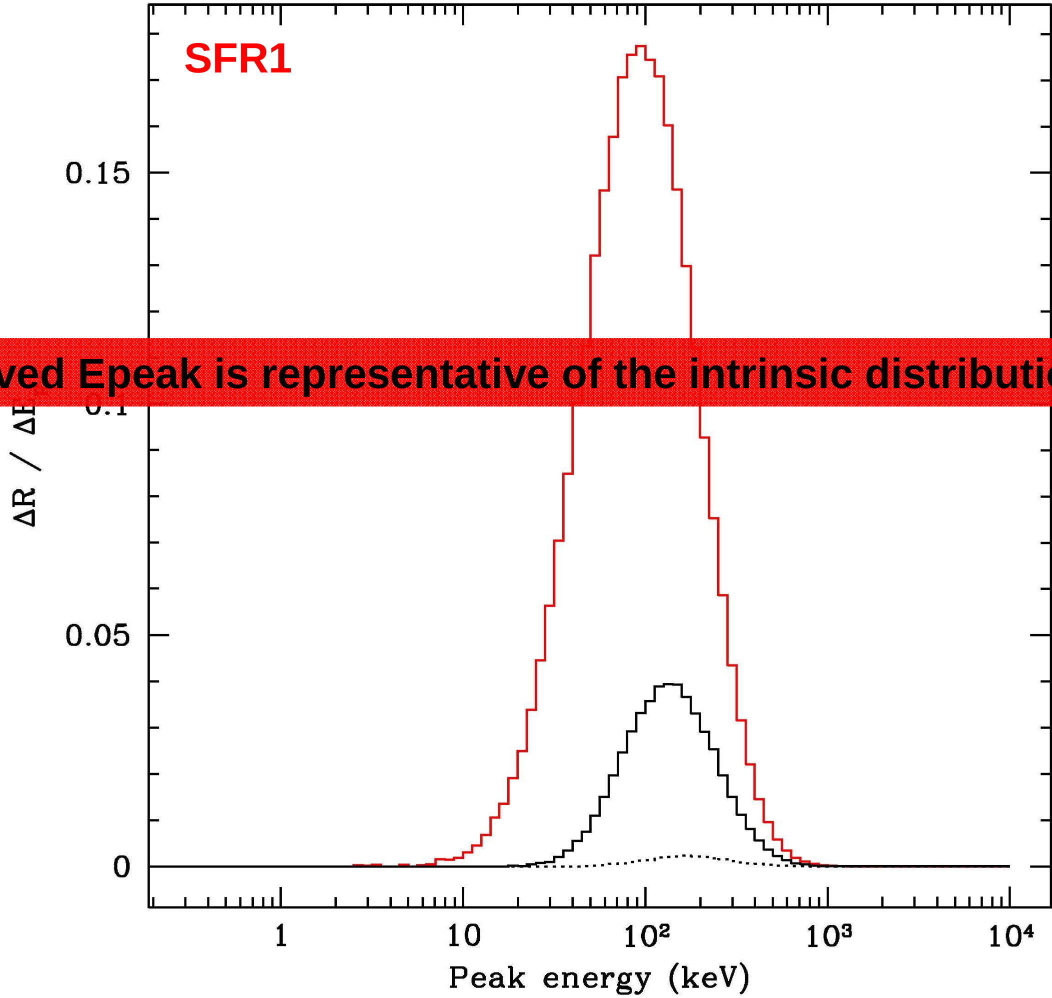
Results

SFR	$\log L_{\rm min}$	$\log L_{\rm max}$	δ	$\log k$
log-normal distribution peak energy distribution				
1	50.2 ± 0.9	53.6 ± 0.8	1.62 ± 0.18	-5.6 ± 0.3
2	50.2 ± 1.1	53.6 ± 0.9	1.62 ± 0.27	-5.7 ± 0.3
3	50.5 ± 1.3	53.7 ± 0.9	1.52 ± 0.48	-6.2 ± 0.2

SFR	$\log E_{\rm p,0}$
log-normal distribution peak energy distribution	
1	2.74 ± 0.08
2	2.73 ± 0.08
3	2.79 ± 0.08

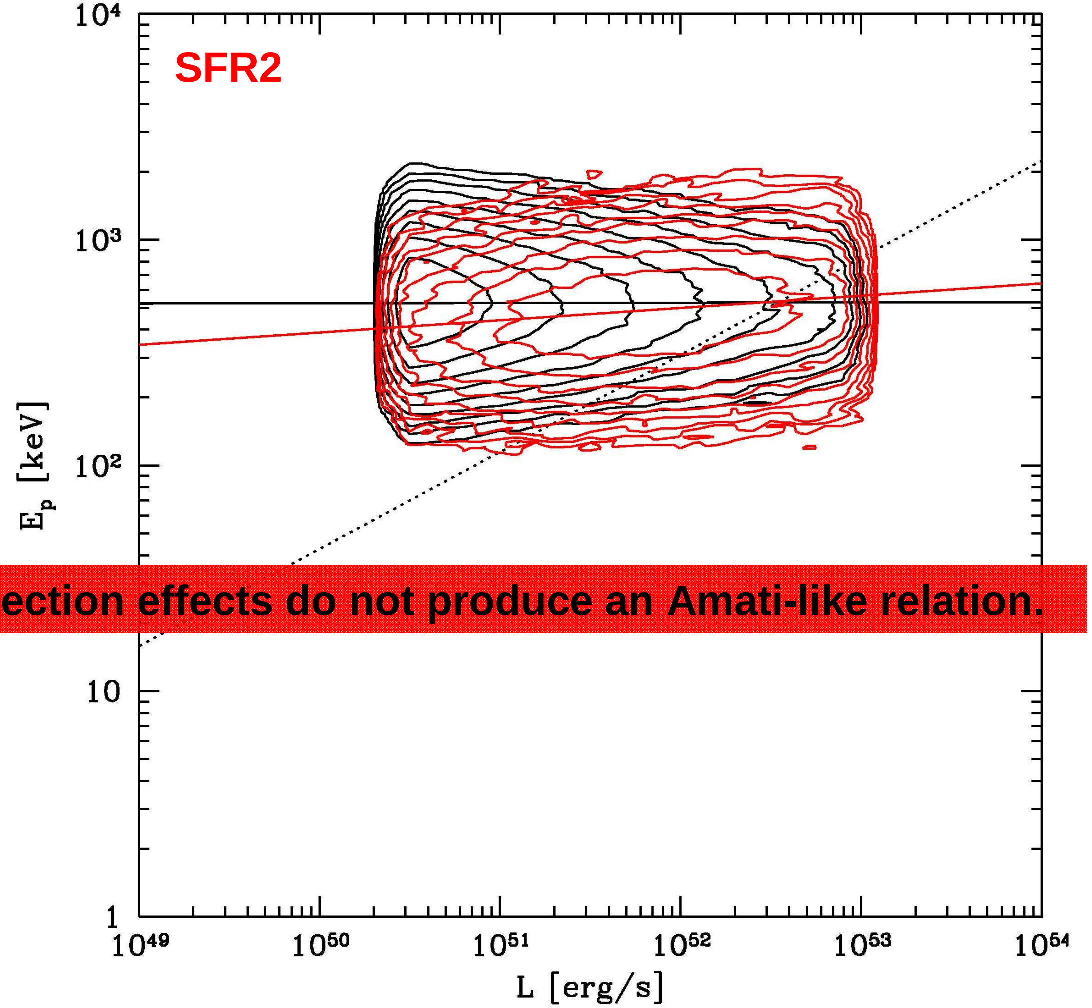
Rate	All	SWIFT	Bright SWIFT
log-normal peak energy distribution			
SFR1	3.1	1.9	1.6
SFR2	8.0	2.4	1.8
SFR3	10.5	4.8	2.7

Best fit : intrinsic E_{peak} distribution



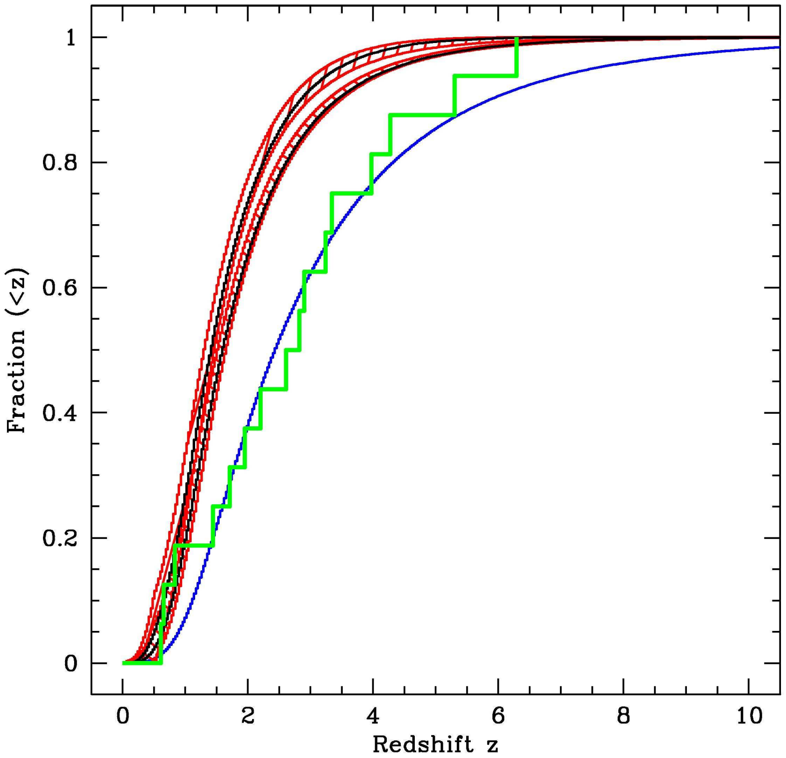
The observed Epeak is representative of the intrinsic distribution.

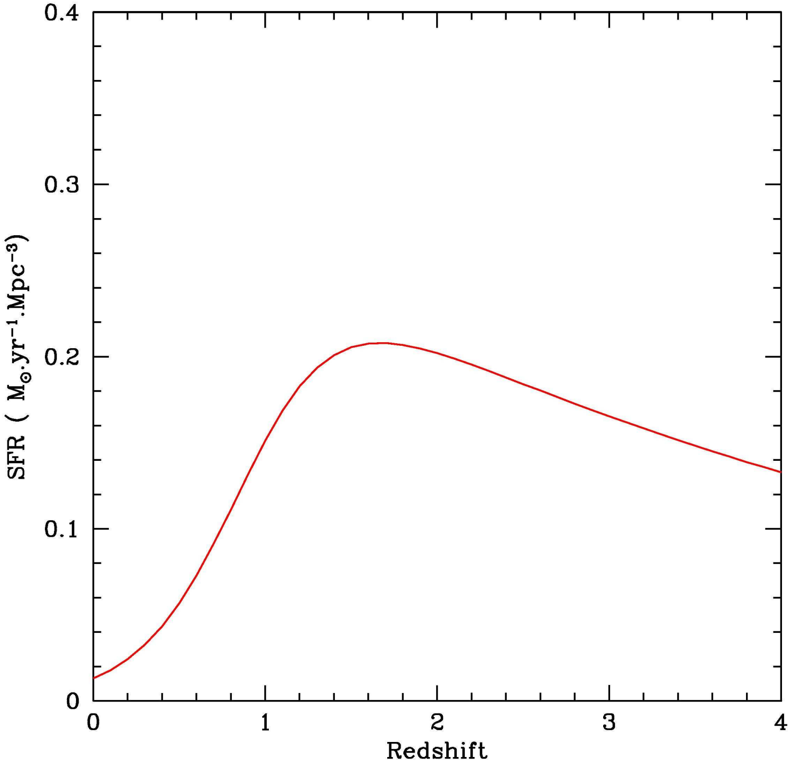
Best fit : Amati-like relation



Selection effects do not produce an Amati-like relation.

Best fit : redshift distribution (SFR1)



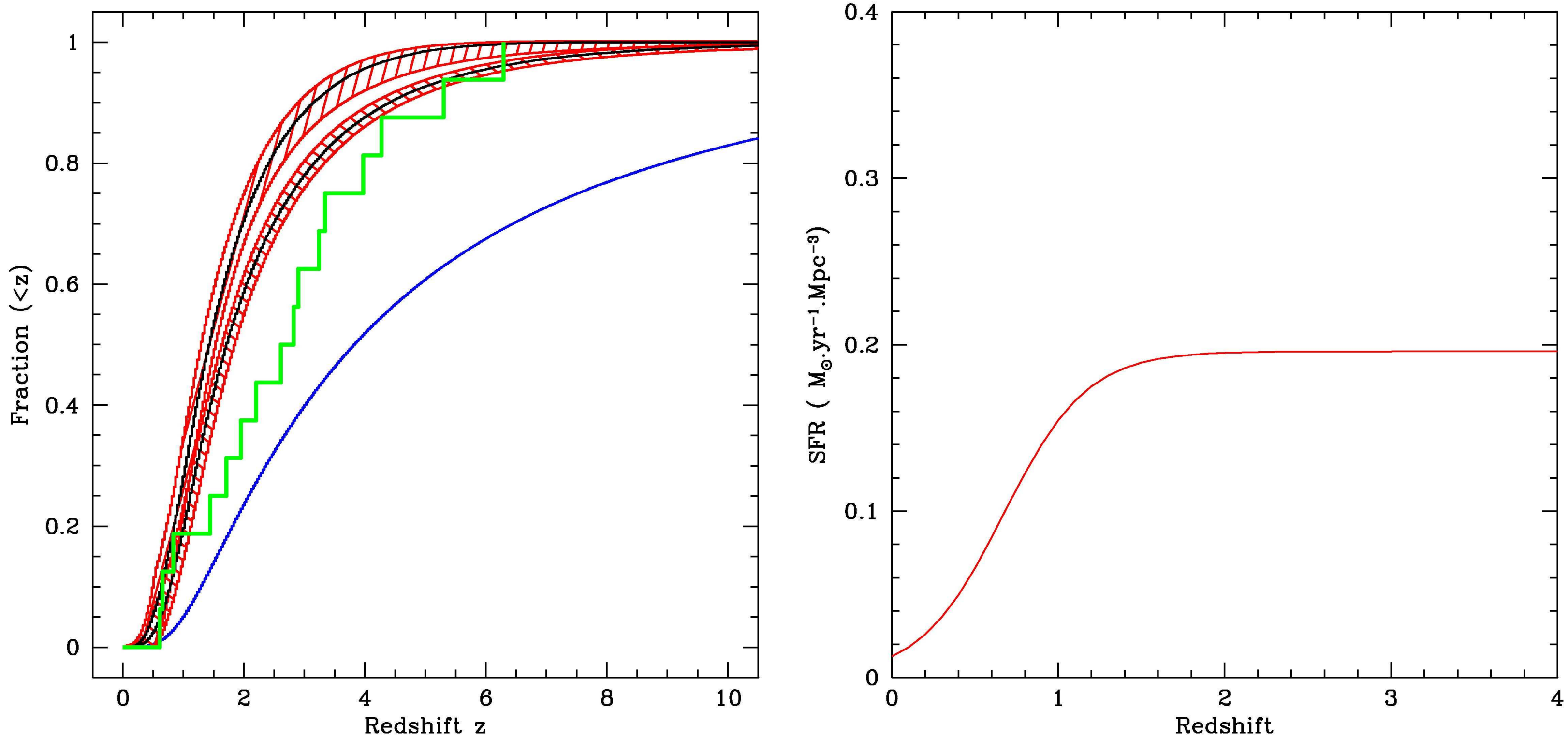


All GRBs

SWIFT observations (Jakobsson et al. 2005)

Best model : SWIFT GRBs (all/bright)

Best fit : redshift distribution (SFR2)



All GRBs

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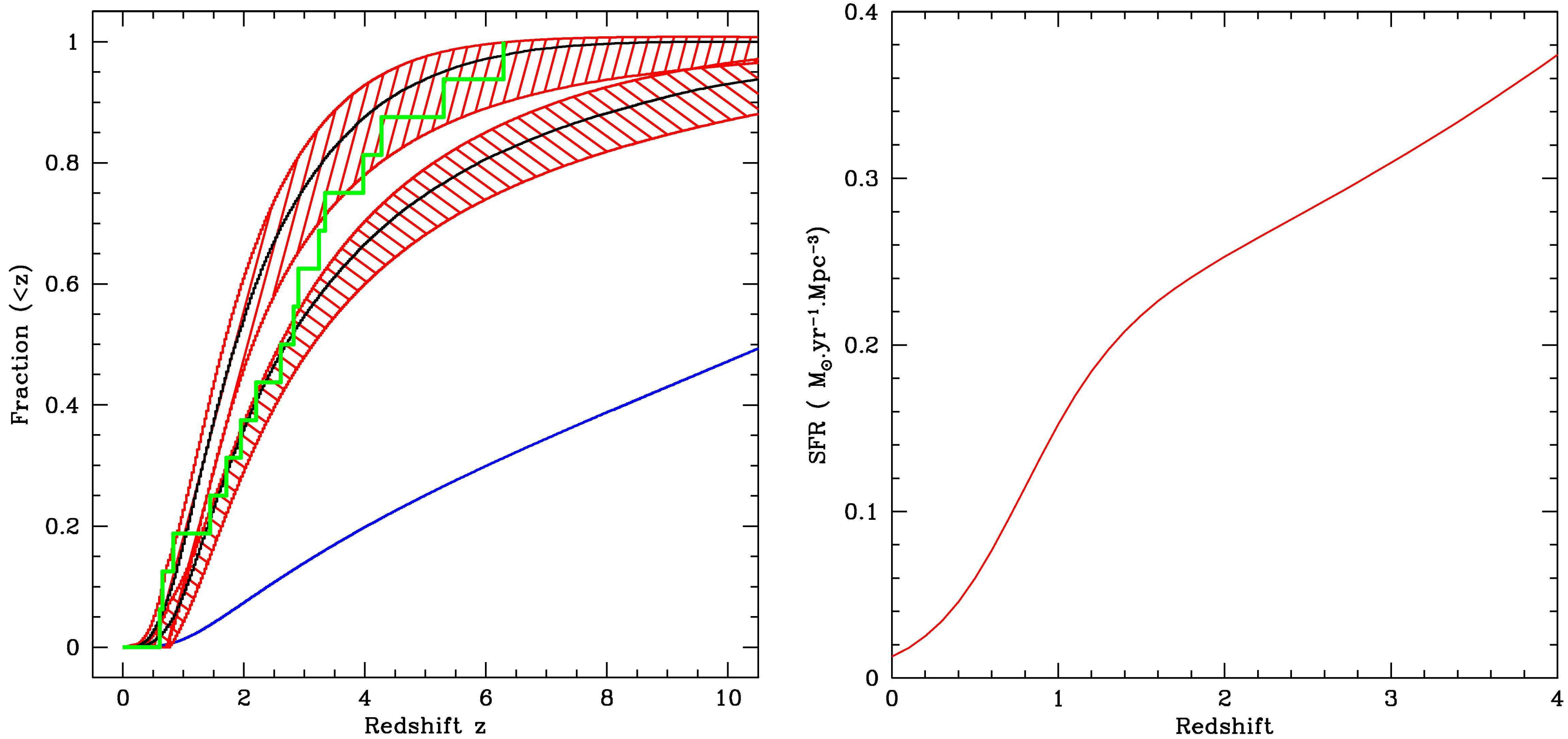
Best fit : redshift distribution (SFR3)



All GRBs

SWIFT observations (Jakobsson et al. 2005)

Best model : SWIFT GRBs (all/bright)

Summary

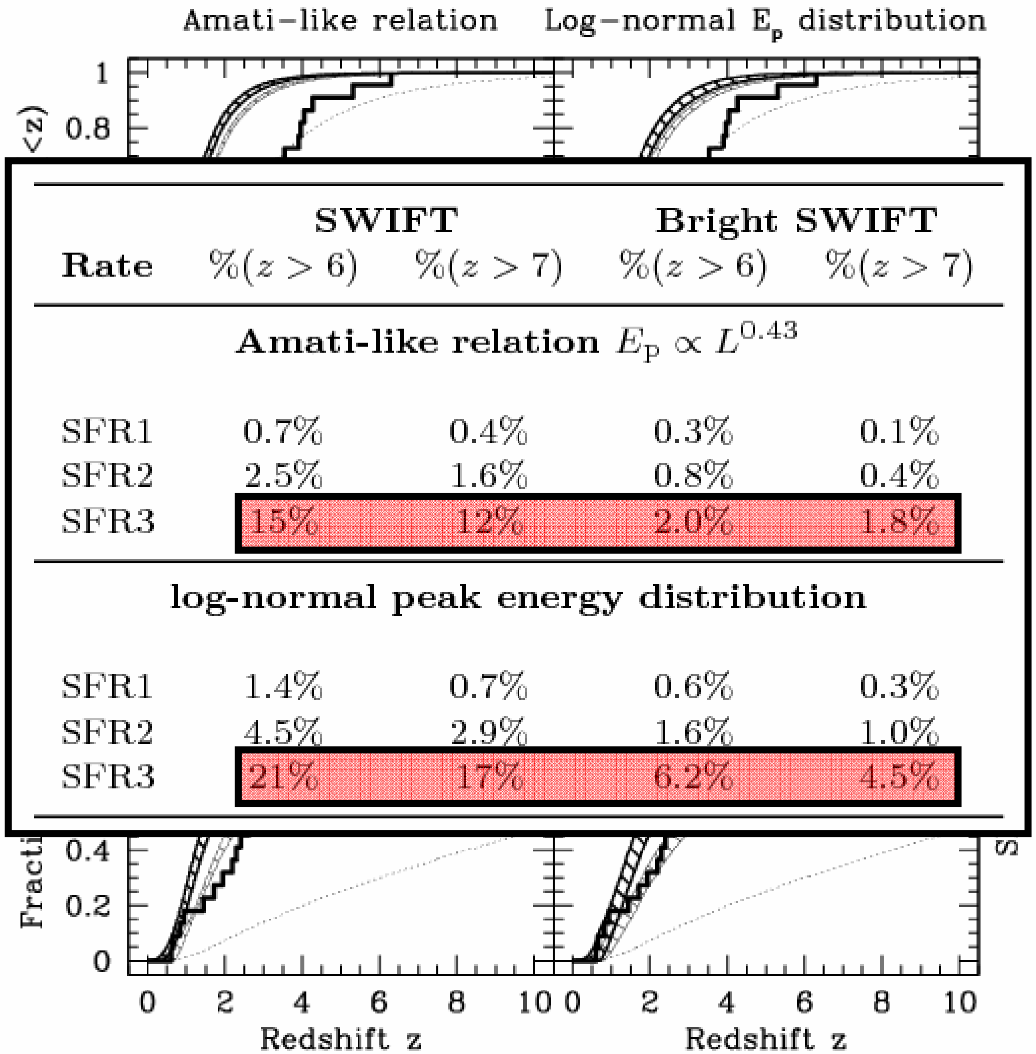
Luminosity function :

- **Slope very well constrained : p ~ 1.5-1.7**
- Minimum and maximum luminosity less constrained :
  L_{min} ~ $2\times10^{49} - 2\times10^{50}$ erg/s ; L_{max} ~ $2\times10^{53} - 4\times10^{53}$ erg/s

Intrinsic E_{peak} distribution:

- **AMATI : Peaks at low energy (a few keV) ⇒ many un-detected XRRs/XRFs.**
- EPCST : Peaks at E_{peak} ~ 100 keV (Amati relation is not reproduced).

Summary



Rate	SWIFT $\%(z>6)$	SWIFT $\%(z>7)$	Bright SWIFT $\%(z>6)$	Bright SWIFT $\%(z>7)$
Amati-like relation $E_\mathrm{p} \propto L^{0.43}$				
SFR1	0.7%	0.4%	0.3%	0.1%
SFR2	2.5%	1.6%	0.8%	0.4%
SFR3	15%	12%	2.0%	1.8%
log-normal peak energy distribution				
SFR1	1.4%	0.7%	0.6%	0.3%
SFR2	4.5%	2.9%	1.6%	1.0%
SFR3	21%	17%	6.2%	4.5%

Summary

Rate :

- One GRB for 10^5 –10^6 supernovae.

- **The present redshift distribution of SWIFT GRBs strongly favors SFR3 (i.e. increases above z=2).**

« Bright SWIFT GRBs » (P>1 ph/cm²/s) :	**5** % (9%) @ z > 5
All SWIFT GRBs :	**19** % (27 %) @ z>5
« Bright SWIFT GRBs » (P>1 ph/cm2/s) :	**2** % (4%) @ z > 7
All SWIFT GRBs :	**12** % (17 %) @ z>7

cf. Jakobsson et al. 2005 : 7-40 % @ z > 5
Bromm & Loeb 2006 : 10% @ z > 5

The detected rate of high z GRBs can still be improved.

Summary

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cf. Jakobsson et al. 2005 : 7-40 % @ z > 5
Bromm & Loeb 2006 : 10% @ z > 5

- **This SFR is unrealistic : it implies some evolution effects, i.e.**
  - ►**higher efficiency for GRB production at high z ?**
  - ►**and/or higher GRB luminosity at high z ?**

Do GRB really trace the SFR ? (metallicity effects ? see E. Le Floch et al. 06)