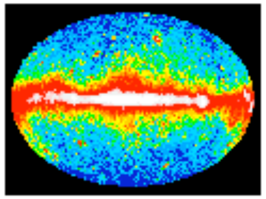
The GRB Luminosity Function in the light of Swift 2-year data

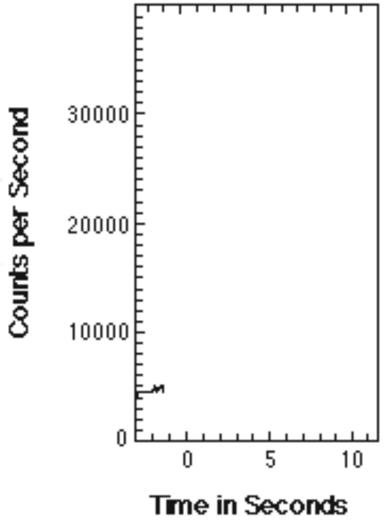
by Ruben Salvaterra

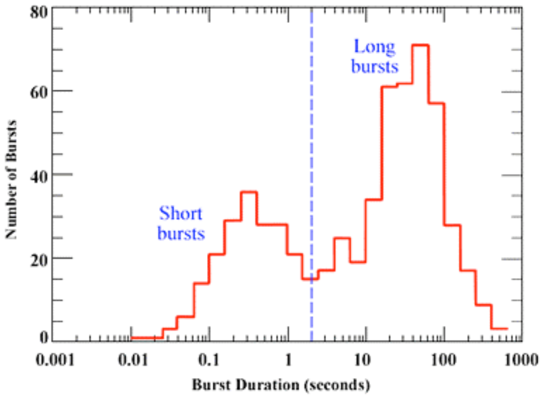
Università di Milano-Bicocca

Introduction: Gamma Ray Burst

GRB are strong burst in the gamma ray:
happens ~1 per day

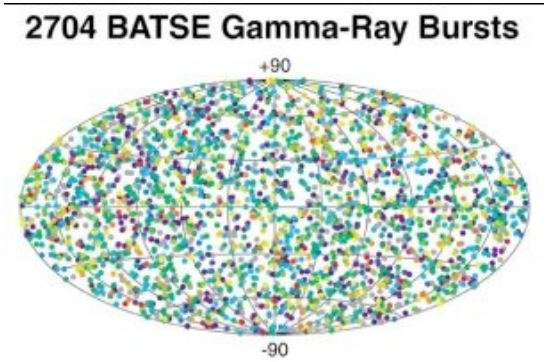






Two classes
Long (>2 s) and short (<2 s)

BATSE (1991-2000): GRBs are isotropically distributed in the sky indicating their EXTRAGALACTIC origin.

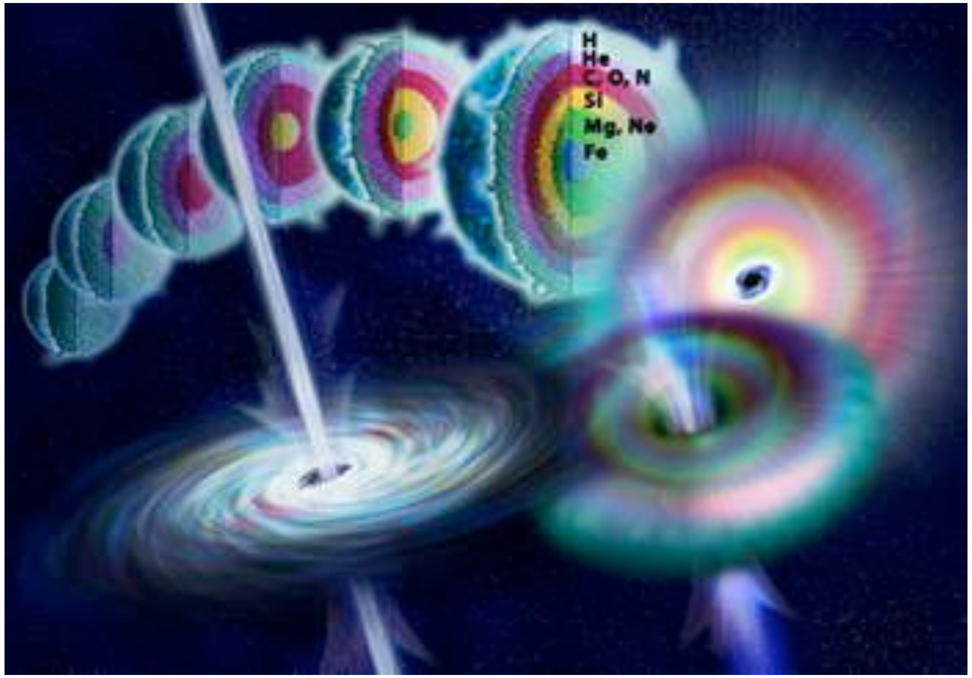


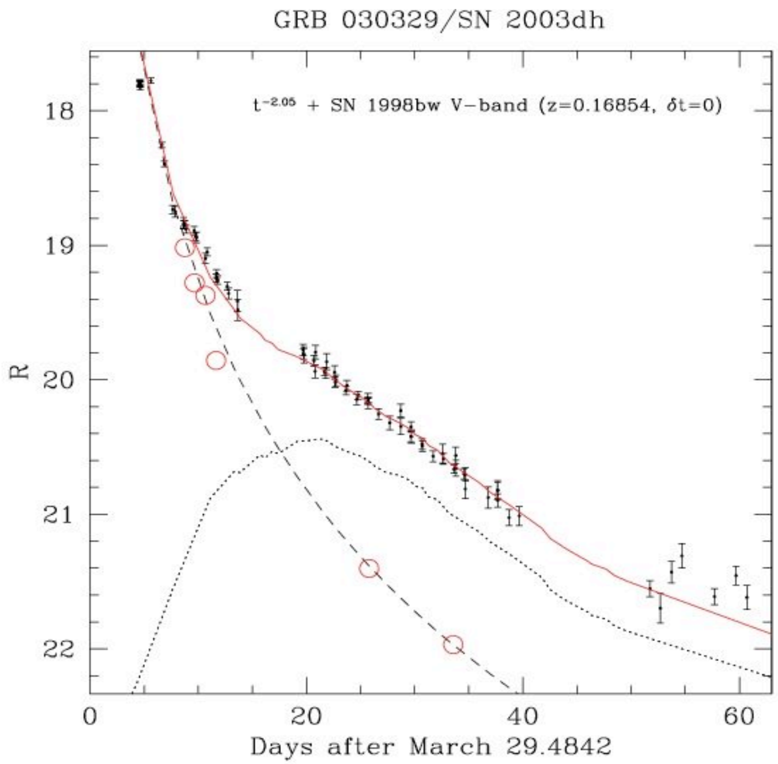
Beppo-SAX (1996): afterglow (i.e. counterpart in X-ray, optical and radio) observation, allowing redshift measurements.

Introduction: long GRBs

Long GRBs are thought to be linked to the dead of massive stars: in particular with the SN explosion of Wolfe-Rayet stars (SN I b/c), as observed is some cases

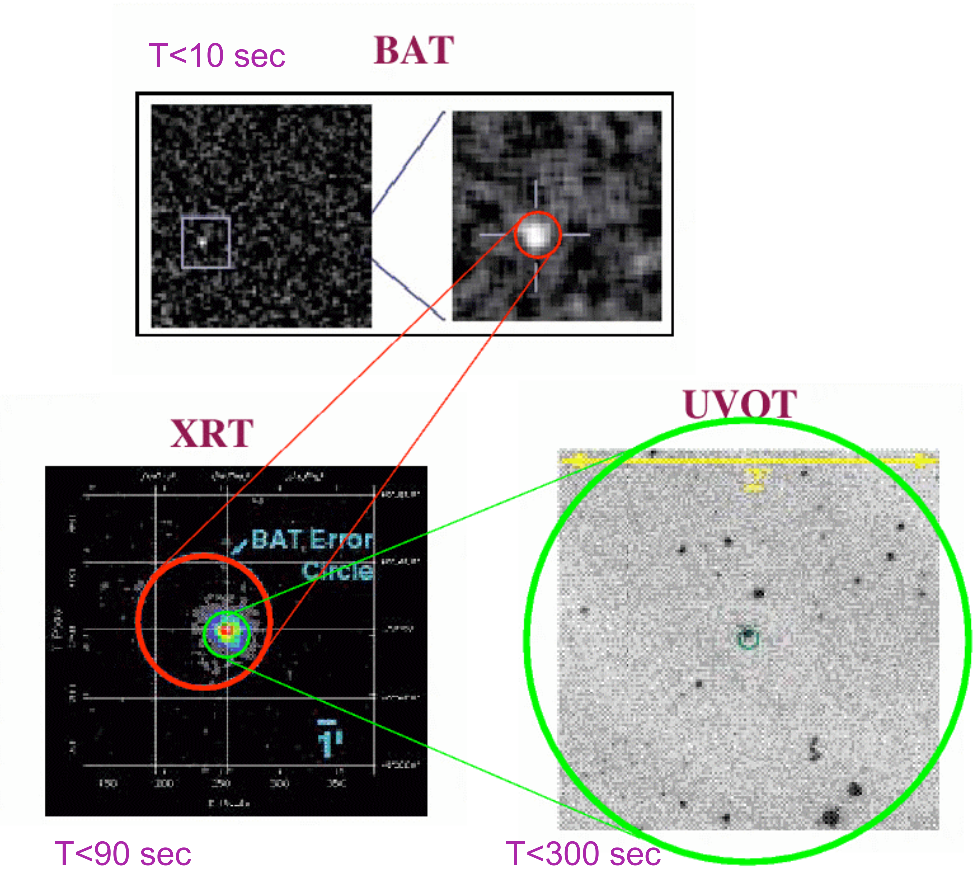
Support the idea that long GRBs are tracer of cosmic star formation

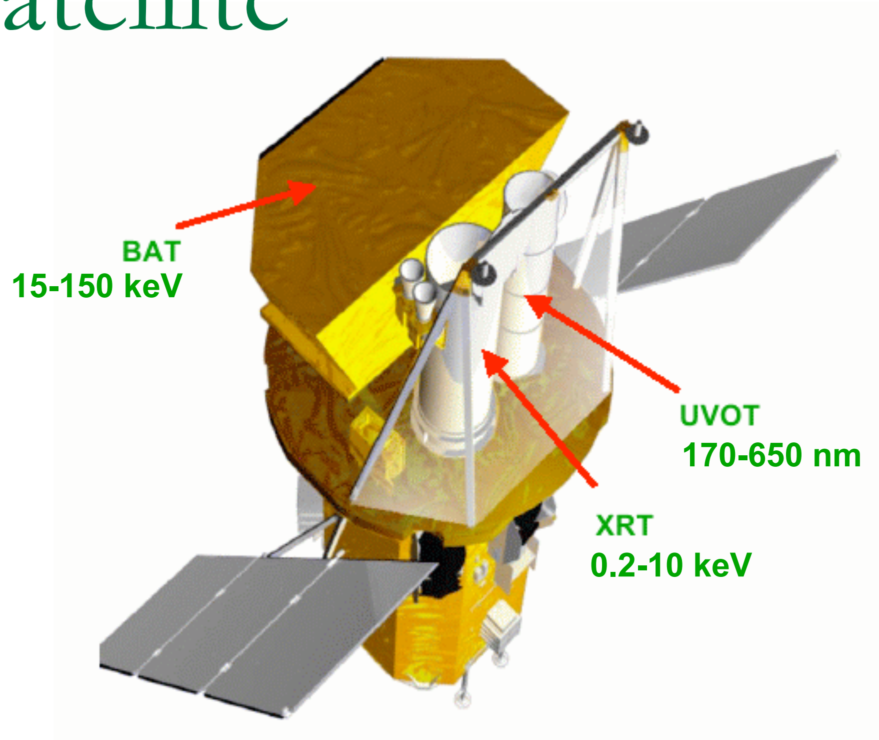




Introduction: Swift satellite

Launched in Nov. 2004:
2 years of mission, ~100 burst/yr





95% of triggers yield to XRT detection

50% of triggers yield to UVOT detection

30% with known redshift

GRB peak flux distribution

The number of GRBs observed for unit time with photon flux $P_1<P<P_2$ is given by

$$\frac{dN}{dt}(P_1 < P < P_2) = \int_0^\infty dz \frac{dV(z)}{dz} \frac{\Delta\Omega_s}{4\pi} \frac{\Psi_{\rm GRB}(z)}{1+z} \times \int_{L(P_1,z)}^{L(P_2,z)} dL' \phi(L') \epsilon(P),$$

where Ψ_{GRB} is the comoving GRB formation rate and $\Delta\Omega_s$ is the sky solid angle covered by the survey. Finally $\phi(L)$ is the GRB luminosity function given by

$$\phi(L) \propto \left(\frac{L}{L_{\rm cut}}\right)^{-\xi} \exp\left(-\frac{L_{\rm cut}}{L}\right).$$

L is the isotropic burst luminosity (we assume here that the GRB spectrum is described by the usual Band function)

Salvaterra & Chincarini, 2007, ApJL, 656, L49

Three GRB scenarios

We explore three different scenarios for GRB formation and evolution

A. GRBs are good tracer of the global SFR and the LF is constant in redshift

$$\Psi_{GRB} = k_{GRB}\,\Psi_*$$

$$L_{cut} = cost = L_0$$

SFR from Hopkins & Beacom (2006)

B. GRBs are good tracer of the global SFR but the LF varies with redshift

$$\Psi_{GRB} = k_{GRB}\,\Psi_*$$

$$L_{cut} = L_0\,(1+z)^{\delta}$$

C. GRBs form in galaxies below a threshold metallicity Z_{th} and the LF is constant in redshift

$$\Psi_{GRB} = k_{GRB}\,\Sigma(Z_{th}, z)\,\Psi_*$$

$$L_{cut} = cost = L_0$$

Σ(Zth,z) from Langer & Norman (2006)

Salvaterra & Chincarini, 2007, ApJL, 656, L49

GRB peak flux distribution: BATSE

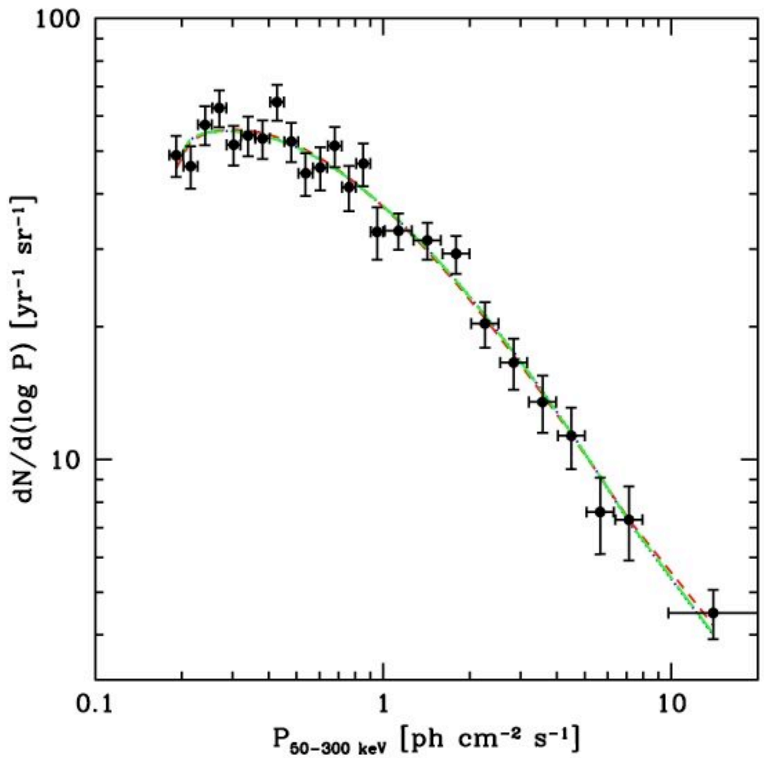
We fit the peak flux differential distribution of GBRs, observed by BATSE in the 50-300 keV band, by minimizing on our free parameters.

The model free parameters are:

k_{GRB} (L_0 ξ)

Best fit parameters

Model	$k_{GRB}/(10^{-8} M_{\odot}^{-1})$	$L_0/(10^{51}\ \mathrm{erg\ s^{-1}})$	ξ	χ_r^2
no evolution	1.14 ± 0.07	9.54 ± 4.55	3.54 ± 0.78	0.83
luminosity evolution	1.05 ± 0.05	0.77 ± 0.13	2.19 ± 0.95	0.80
metallicity evolution	10.0 ± 0.5	16.7 ± 5.7	2.94 ± 0.34	0.84



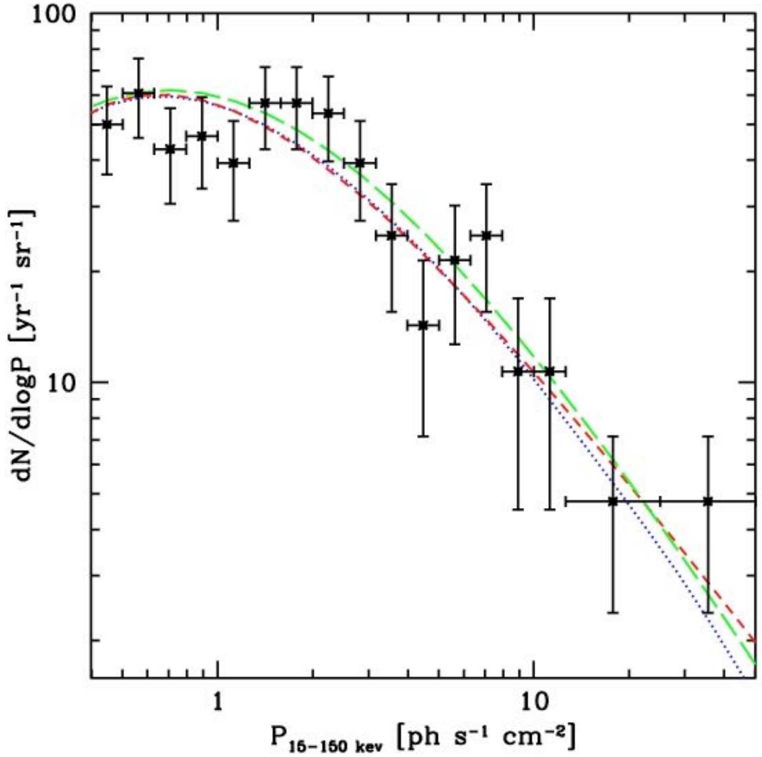
It's always possible to find a good agreement with BATSE data

Salvaterra & Chincarini, 2007, ApJL, 656, L49

GRB peak flux distribution: Swift

Using the best-fit value computed fitting the BATSE data, we compute the expected peak flux differential distribution of GBRs observed by Swift in the 15-150 keV band. A f.o.v. of 1.4 sr is assumed.

Good agreement with Swift data without any change in the LF free parameters and of the formation efficiency in all three scenarios



BATSE & Swift are observing the same GRB population

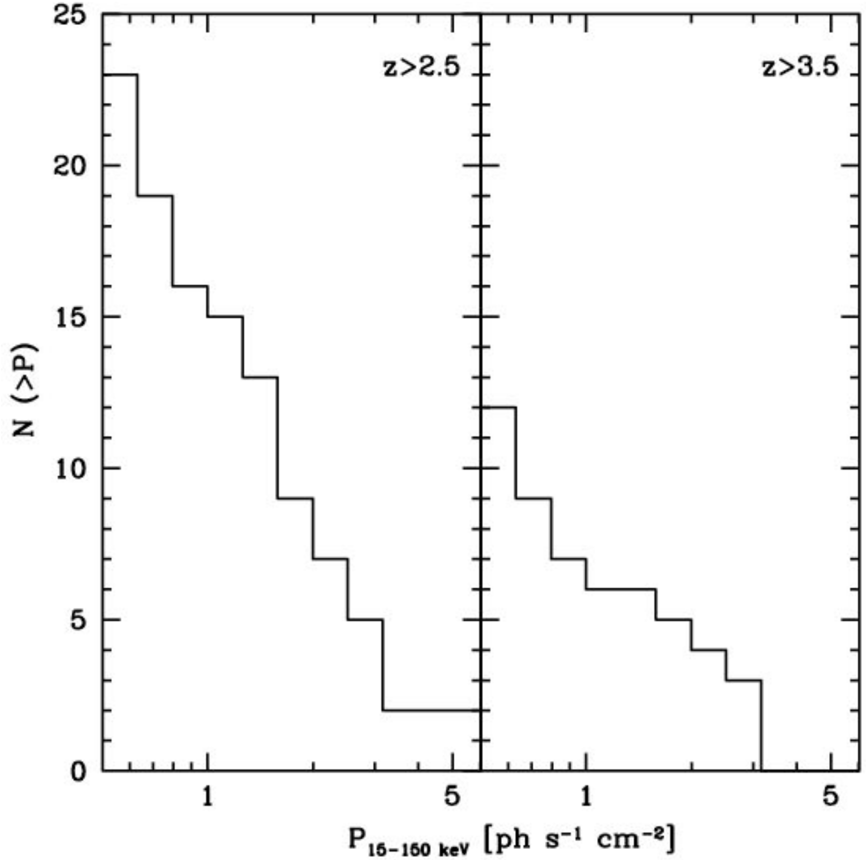
Salvaterra & Chincarini, 2007, ApJL, 656, L49

Redshift distribution: methodology

We compare the results of our models with the number of high-z GRB detected by Swift in the 2 years of mission

This comparison is robust since:

- No assumption on the distribution of GRBs that lack of redshift measurement
- Takes into account that also bright GRBs are observed at high redshift
- CONSERVATIVE: numbers are strong lower limits.



Salvaterra & Chincarini, 2007, ApJL, 656, L49

Results: Scenario A – no evolution

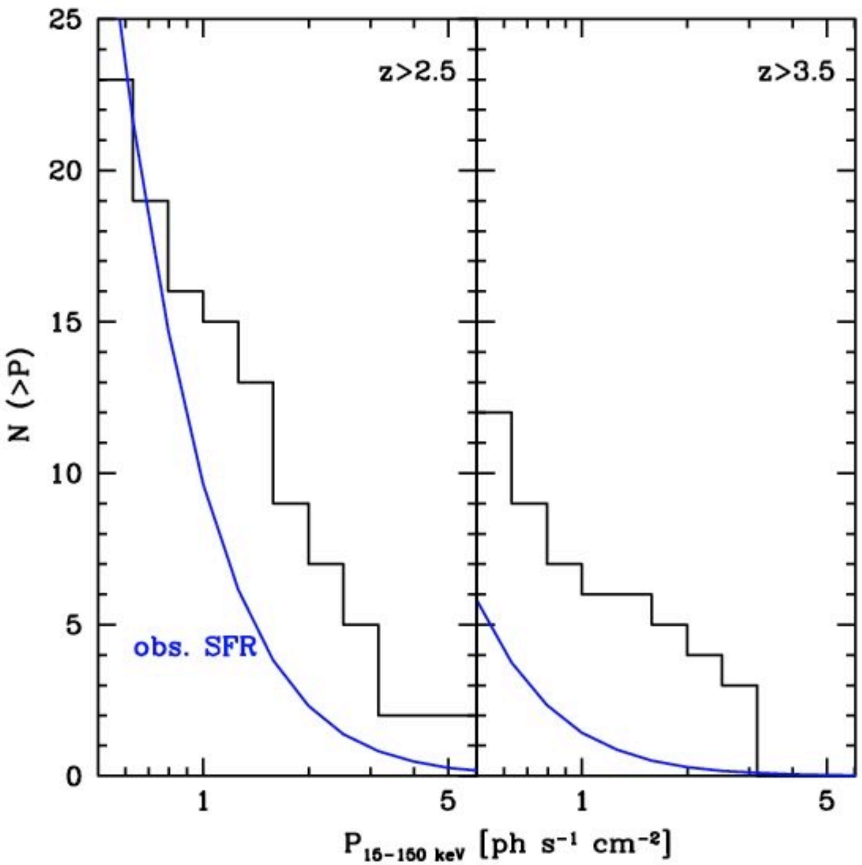
GRBs follow the global SFR and the LF is constant with redshift

Never consistent with the observed number of bursts at high redshift

The model largely underpredicts the number of high-z GRBs

This conclusion **DOES NOT** depend on

1. the GRBs that lacks of redshift
2. the assumed SFR at high-z
3. the faint-end of the GRB LF



No evolution scenarios are robustly ruled out

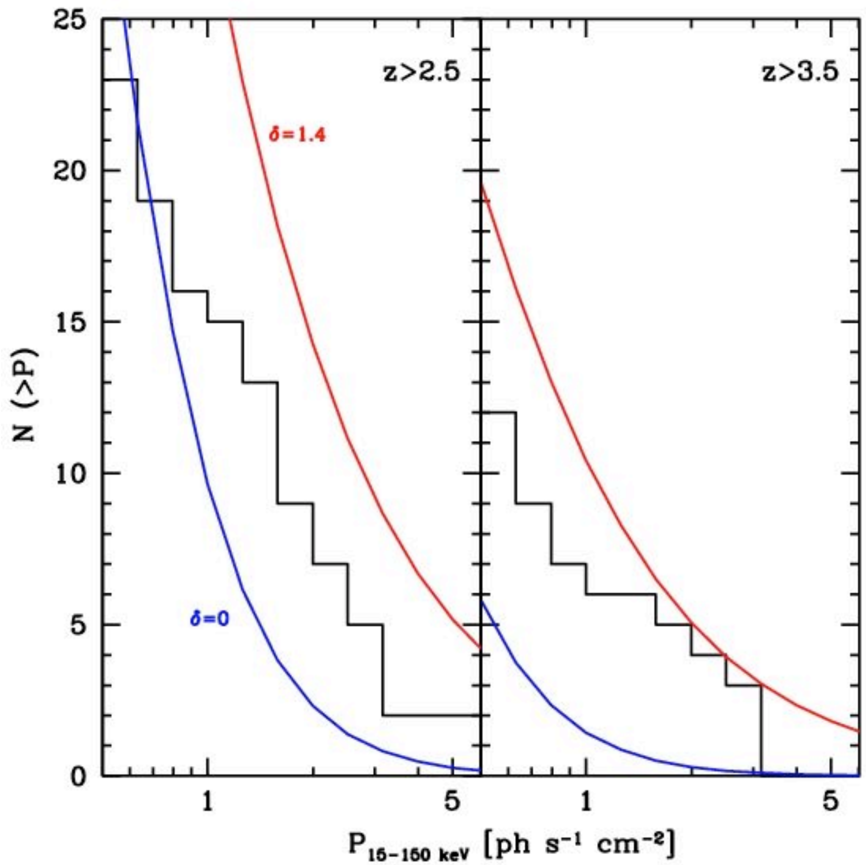
Salvaterra & Chincarini, 2007, ApJL, 656, L49

Results: Scenario B – luminosity evolution

GRBs follow the global SFR but the LF varies with redshift

$L_{cut}=L_0\,(1+z)^{\delta}$ with $\delta = 1.4$

- The model overproduces the number of bursts detected at z>2.5 at all photon fluxes and at z>3.5 for low P
- The model is just consistent with the number of detection at z>3.5 and P>2 ph s^{-1} cm^{-2}.
- **Strong evolution**: GRB at z=3 are 7 times brighter than at z=0



GRB ∝ SFR requires strong luminosity evolution (δ>1.4)

Salvaterra & Chincarini, 2007, ApJL, 656, L49

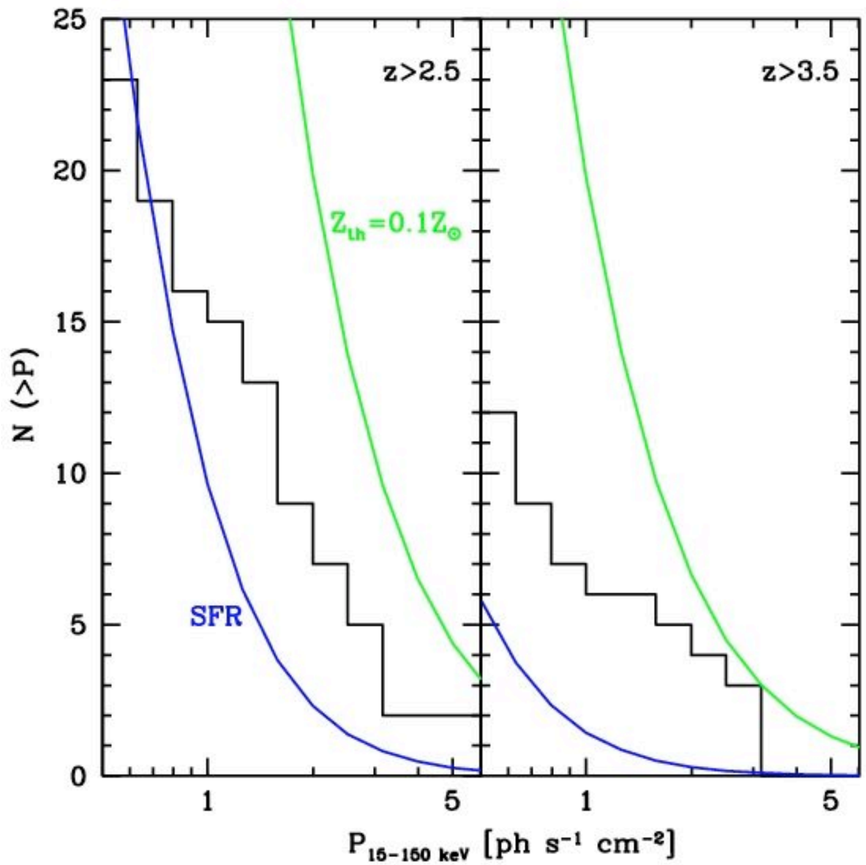
Results: Scenario C – metallicity evolution

GRBs are BIASED tracer of the SFR: preferentially form in low-metallicity environments

We assume Z_{th}=0.1 $Z_\odot$

- Good results both at z>2.5 and at z>3.5 without the need of any evolution of the LF
- Consistent with a fraction of GRBs without z at high redshift

- We find that Swift data require Z_{th}<0.3 $Z_\odot$ but larger Z_{th} can be obtained if some luminosity evolution is allowed



GRBs MAY BE TRACER OF SF IN LOW-METALLICITY REGIONS

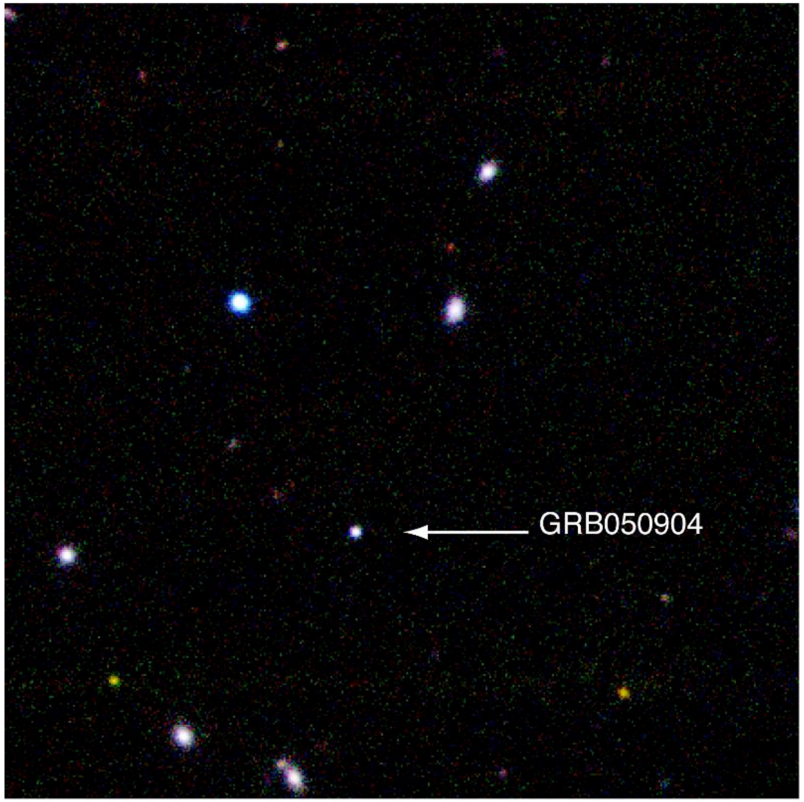
Salvaterra & Chincarini, 2007, ApJL, 656, L49

GRBs at z>6

The discovery of GRB 050904 (Antonelli et al. 2005, Tagliaferri et al. 2005, Kawai et al. 2006) during the first year of Swift mission has strengthened the idea that many bursts should be observed out to very high redshift.

Very promising but no other detection at z>6 in the second year of mission

How many GRBs at z>6 can be detected by Swift?



The Distant Gamma-Ray Burst GRB050904
(ISAAC/VLT)

ESO PR Photo 27a/05 (September 12, 2005)

Salvaterra & Chincarini, 2007, ApJL, 656, L49

GRBs at z>6: model results

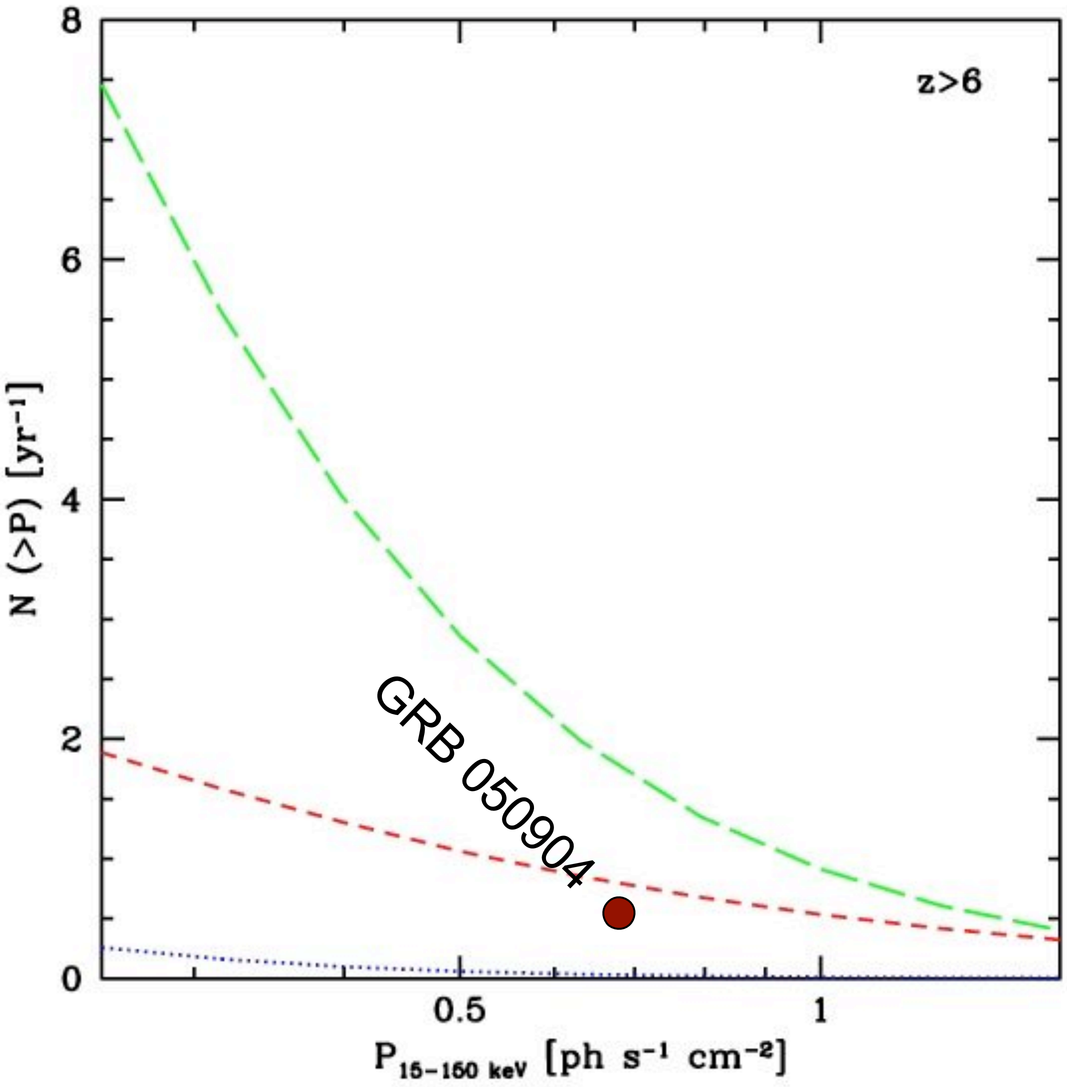
Cumulative number of GRBs at z>6 per year detectable by Swift

No evolution model predicts almost no bursts at very high-z

Luminosity evolution model predicts 2 burst/yr for $P>0.2$ ph s^{-1} cm^{-2}

Metallicity evolution model predicts 8 burst/yr, one or two being at z>8

At the flux of GRB050904 we expect 1 (2) GRB/yr at z>6 in the luminosity (metallicity) scenario



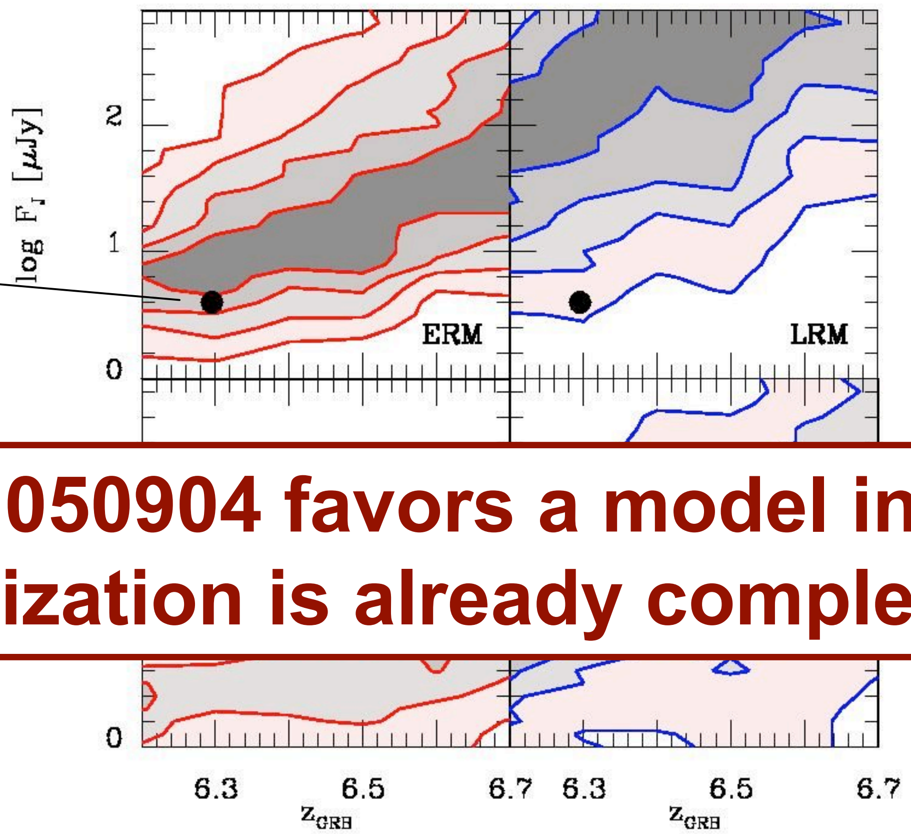
Salvaterra & Chincarini, 2007, ApJL, 656, L49

Constrain reionization history with GRBs

We can constrain the reionization history using the largest dark gap in the absorbed GRB optical afterglow

See Gallerani's talk !

z_{reion}~7 z_{reion}~6



40<W_{max}<80 A

GRB 050904 largest dark gap is W_{max}~63 A

Early reioniz ~50%

Late reioniza ~20%

20 A

GRB 050904 favors a model in which reionization is already complete at z~7

Gallerani, Salvaterra, Ferrara, Choudhury, 2007, in preparation

Pre-selecting high-z GRB candidates

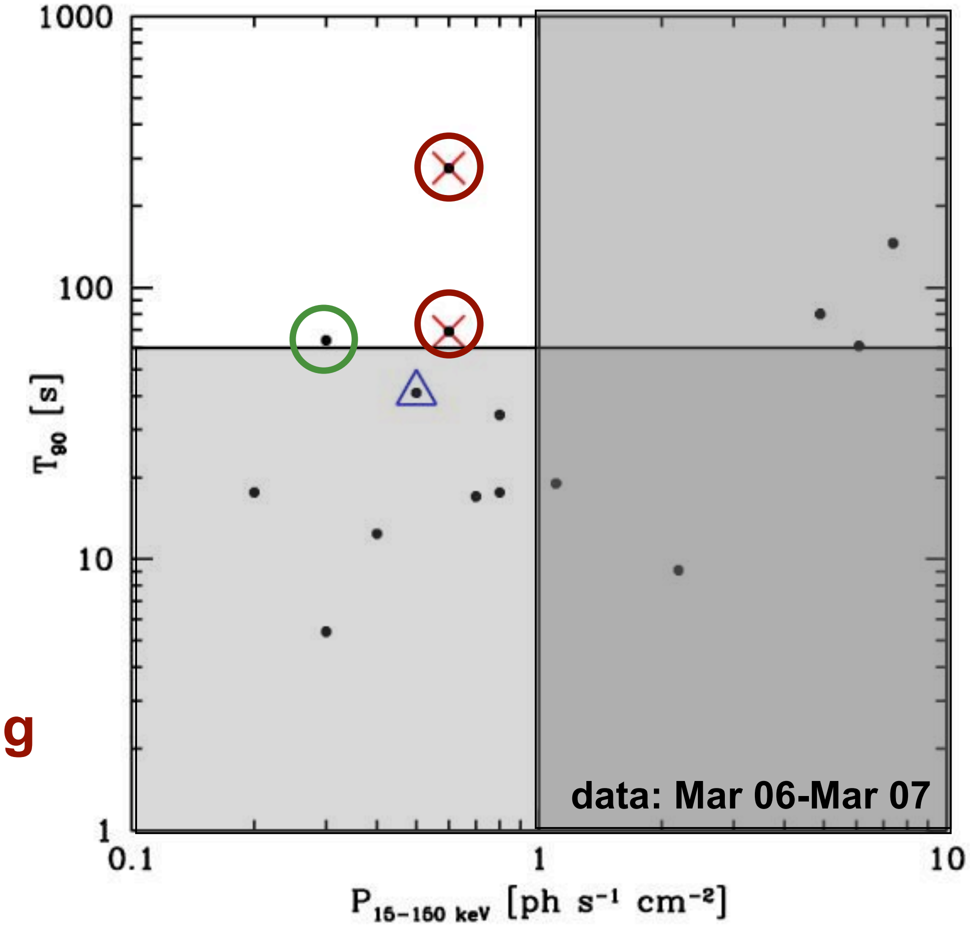
High resolution, high SNR, spectra of high-z GRB afterglow require rapid follow-up measurement with ground-based 8-meter telescopes

We can pre-select good high-z GRB targets on the bases of some promptly-available information provided by Swift:

1) **long due to time dilation: T_{90}>60 s**
2) **faint: P<1 ph $s^{-1}cm^{-2}$ (prob. > 10% to lie at z>5 in our ref. model)**
3) **no detection by UVOT: V>20**

All these infos are available in the first Swift circular (i.e. <1 hour from burst)!

Quite efficient (>66%) in selecting GRB at z>5 and no low-z interlopers



Salvaterra, Campana, Chincarini, Tagliaferri, Covino, 2007, MNRAS, 380, L45

Conclusions

- BATSE & Swift are observing the same population of bursts
- The existence of a large sample of high-z GRBs in Swift data robustly rules out scenarios where GRBs follow the observed SFR and are described by a LF constant in redshift.
- Swift data are easily explained assuming strong luminosity evolution (δ>1.4) or that GRBs form preferentially in low-metallicity environments (Z_{th}<0.3 Zsun)

- 2 (8) GRBs/yr should be detected at z>6 in luminosity (metallicity) evolution scenario for P>0.2 ph s^{-1} cm^{-2}.
- GRB afterglow spectra at z>6 can be used to constrain the reionization history → **GRB 050904 supports an early reionization model**
- Good z>5 candidates can be efficiently pre-selected using promptly-available information provided by Swift