GLAST observation of high-redshift GRBs

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on behalf of the GLAST GRB science group

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Outline

- **High redshift GRB distribution**
  - Association of GRBs with **Type Ib/c SNe**
  - Study of **local and cosmic rates** by means of detailed chemical evolution models
    - Comparison with observed local $SN_{Ib/c}$ rates and with calculated local GRB rates
    - GRB – $SN_{Ib/c}$ ratio estimates

      ➔ **Work accepted by A&A**

- **Detectability with GLAST – LAT**
  - **Choice** of a preferred **$SN_{Ib/c}$ distribution model** to be adopted within the GLAST – LAT framework
  - Simulation of a **high redshift GRB population** adopting the $SN_{Ib/c}$ distribution model

$SN_{Ib/c}$ rates

- **Hypothesis - $SN_{Ib/c}$ candidate progenitors:**
  1. **Wolf-Rayet (WR) stars**
     - Single massive stars
       - $M \geq 25\ M_{\odot}$ **(Maeder 1992)**
  2. **Massive stars in close binary sistems**
       - $M = 12 - 20 M_{\odot}$ **(Baron 1992)**
  3. **Take both models into account!**

- Use of detailed **chemical evolution models** for galaxies of different morphological types with different histories of star formation
  - Calura & Matteucci 2003 (**CM03**)

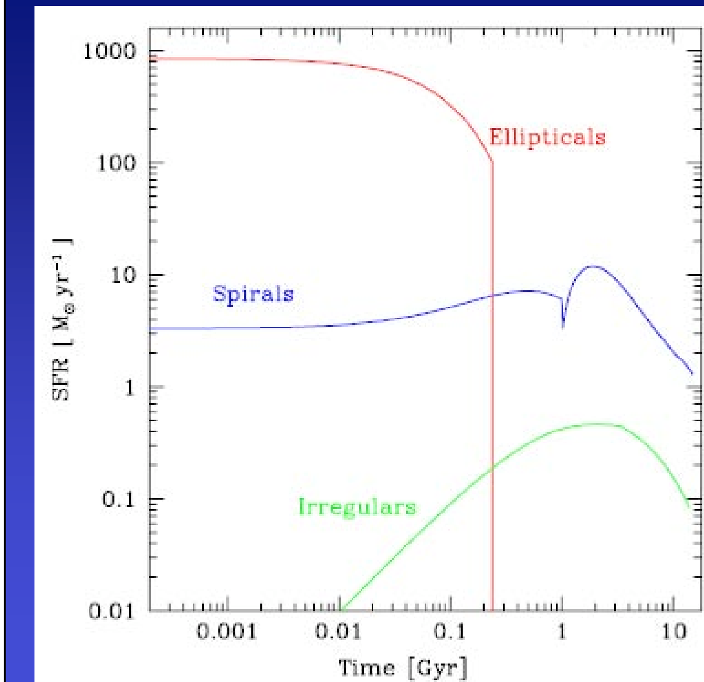
- Calculation of cosmic Star Formation Rates (**SFRs**) and derivation of **$SN_{Ib/c}$ rates** accounting for all morphological types per unit comoving volume of the Universe.

Chemical evolution models

- Chemical evolution models of galaxies:
  - Depending on the morphological type
    - **Spheroids and galactic bulges (Ellipticals)**
      - **(Matteucci 1994)**
    - **Irregulars**
      - **(Bradamante et al. 1998)**
    - **Spirals**
      - **(Chiappini et al. 2001)**

- Basic ingredients:
  - **Initial conditions**
  - **SFR**
    - **ψ(t)**
  - **Initial Mass Function (IMF)**
    - **Φ(M)**

SFR



IMF

$$\Phi_{Salpeter}(M) = 0.17\ M^{-2.35}$$

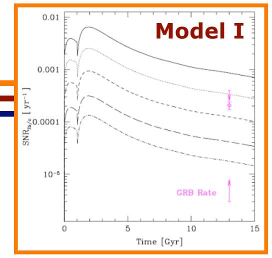
(Salpeter 1955)

Models of $SN_{Ib/c}$ rate

$$\mathrm{SNR}^{\mathrm{Model\,I}}_{\mathrm{Ib/c}}(t) = \int_{M_{inf}}^{100} \phi(M)\,\psi(t-\tau_M)\,dM \simeq \psi(t)\int_{M_{inf}}^{100}\phi(M)\,dM\,,$$

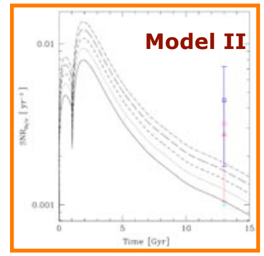
$$\mathrm{SNR}^{\mathrm{Model\,II}}_{\mathrm{Ib/c}}(t) = \alpha\int_{12}^{20} \phi(M)\,\psi(t-\tau_M)\,dM \simeq \alpha\,\psi(t)\int_{12}^{20}\phi(M)\,dM\,,$$

Tuning of parameters



Model I
(Single massive stars)

$M_{inf} \geq 40\ M_{\odot}$



Model II
(Massive stars in close binary systems)

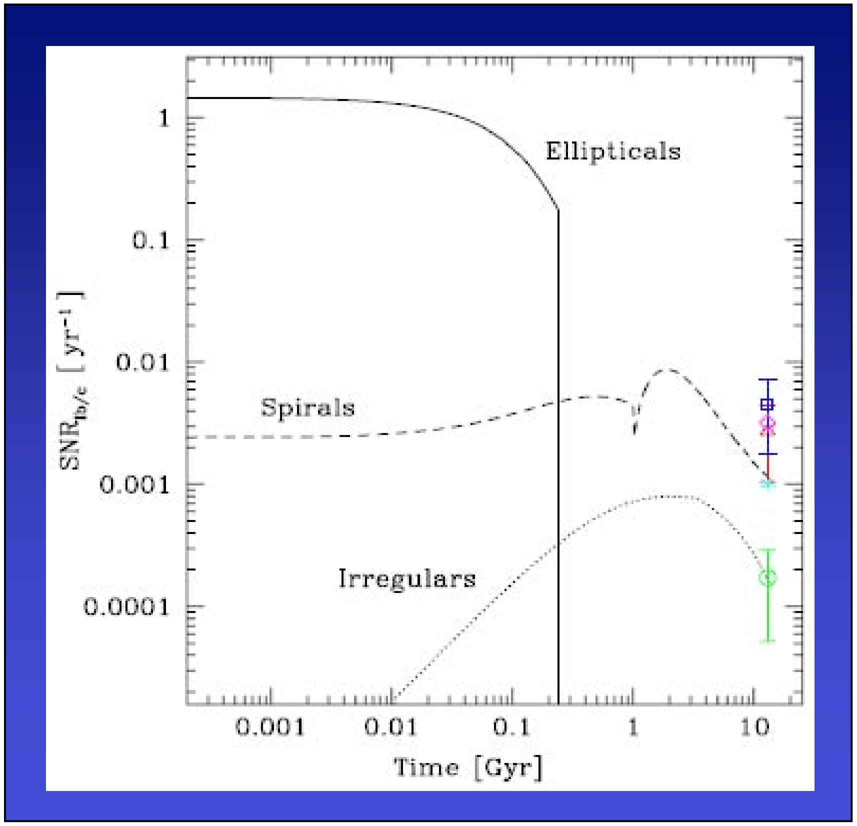
$\alpha \sim 0.15$ (Calura & Matteucci 2006)

Model III = Model I + Model II

$$\mathrm{SNR}^{\mathrm{Model\,III}}_{\mathrm{Ib/c}}(t) = \mathrm{SNR}^{\mathrm{Model\,I}}_{\mathrm{Ib/c}}(t) + \mathrm{SNR}^{\mathrm{Model\,II}}_{\mathrm{Ib/c}}(t) \simeq \psi(t)\left(\alpha\int_{12}^{20}\Phi(M)\,dM + \int_{M_{inf}}^{100}\Phi(M)\,dM\right)$$

Local $SN_{Ib/c}$ rate

Model III for each morphological type



Local $SN_{Ib/c}$ rates

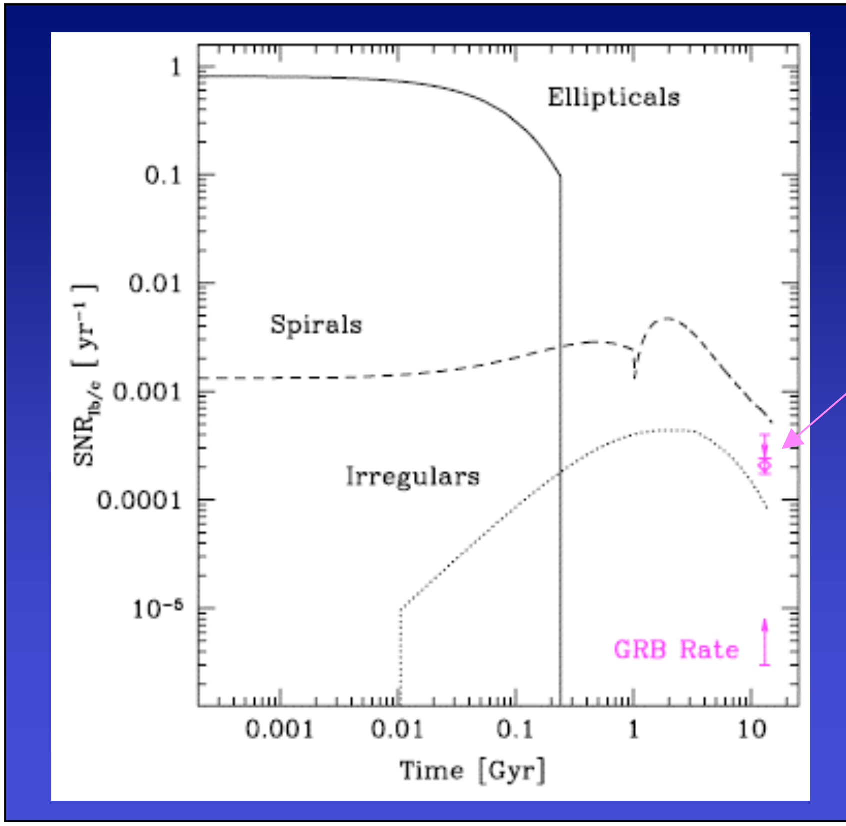
Cappellaro et al. (1999)
Della Valle (2005)
Mannucci et al. (2005)
Podsiadlowski et al. (2004)

Calculated $SN_{Ib/c}$ rate for irregular galaxies

- Models for **spiral** and **irregular galaxies** correctly reproduce the observational values
- Elliptical galaxies do not show $SN_{Ib/c}$ at present time (t ~ 13 Gyr)

Local $SN_{Ib/c}$ rate vs. GRB rates

Model III for each morphological type



Zhang & Meszaros (2004)

Range of possible GRB rate values

- Models of **irregular galaxies** in agreement with the predicted GRB rates
  - Consistent with recent observations of host galaxies (**Fruchter et al. 2006**)

Results

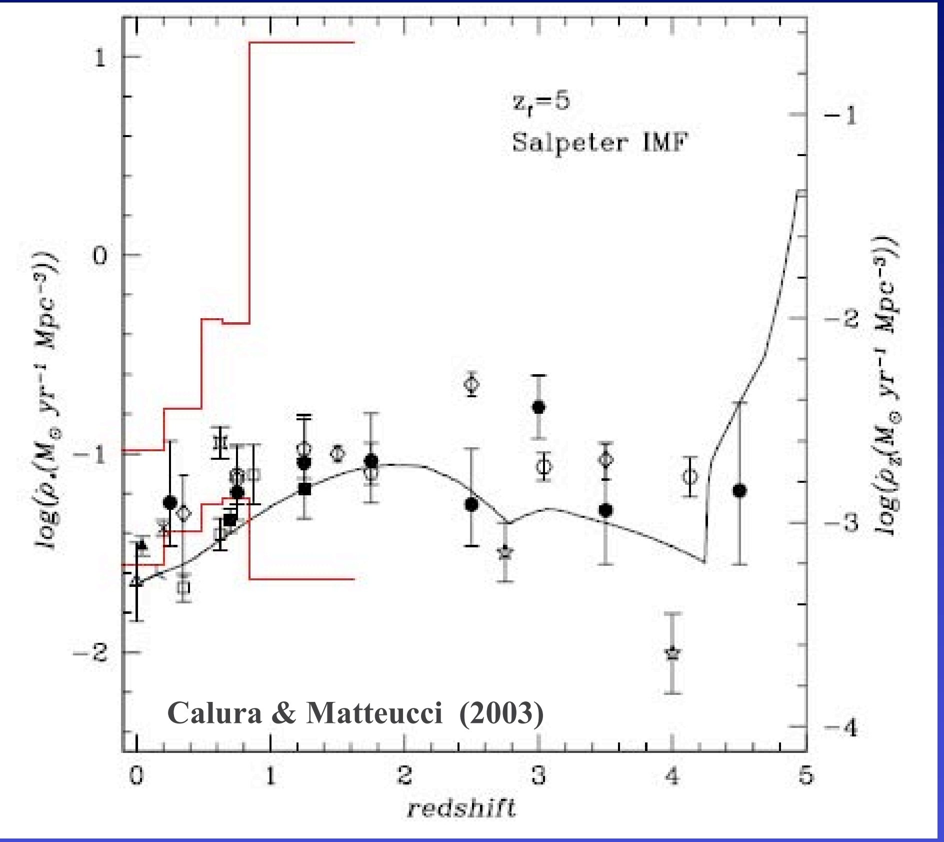
- Estimate of the local **GRB – $SN_{Ib/c}$ ratio (R)**
  - Taking into account:
    - Different models adopted throughout the analysis
    - Uncertainties affecting the GRB beaming factor

	R_{MAX}	R_{MIN}
Model I [a, c]	$\sim 1.2 \times 10^{-2}$	$\sim 9.7 \times 10^{-4}$
Model II [b, c]	$\sim 4.9 \times 10^{-2}$	$\sim 4.1 \times 10^{-3}$
Model III [a, b, c]	$\sim 9.4 \times 10^{-3}$	$\sim 7.9 \times 10^{-4}$

  - Ratio: **R ~ 10^{-2} – 10^{-4}**
    - **Consistent** with recent results
      - **(Podsiadlowsky 2004, Della Valle 2005, Le & Dermer 2006)**
    - Value is **intrinsically small**
      - Other mechanisms at play (rotation **(Woosley &Heger 2006)**, metallicity **(Fruchter et al. 2006)**, binarity **(Mirabel 2004)**, asymmmetric explosions **(Maeda et al. 2006)**, …)

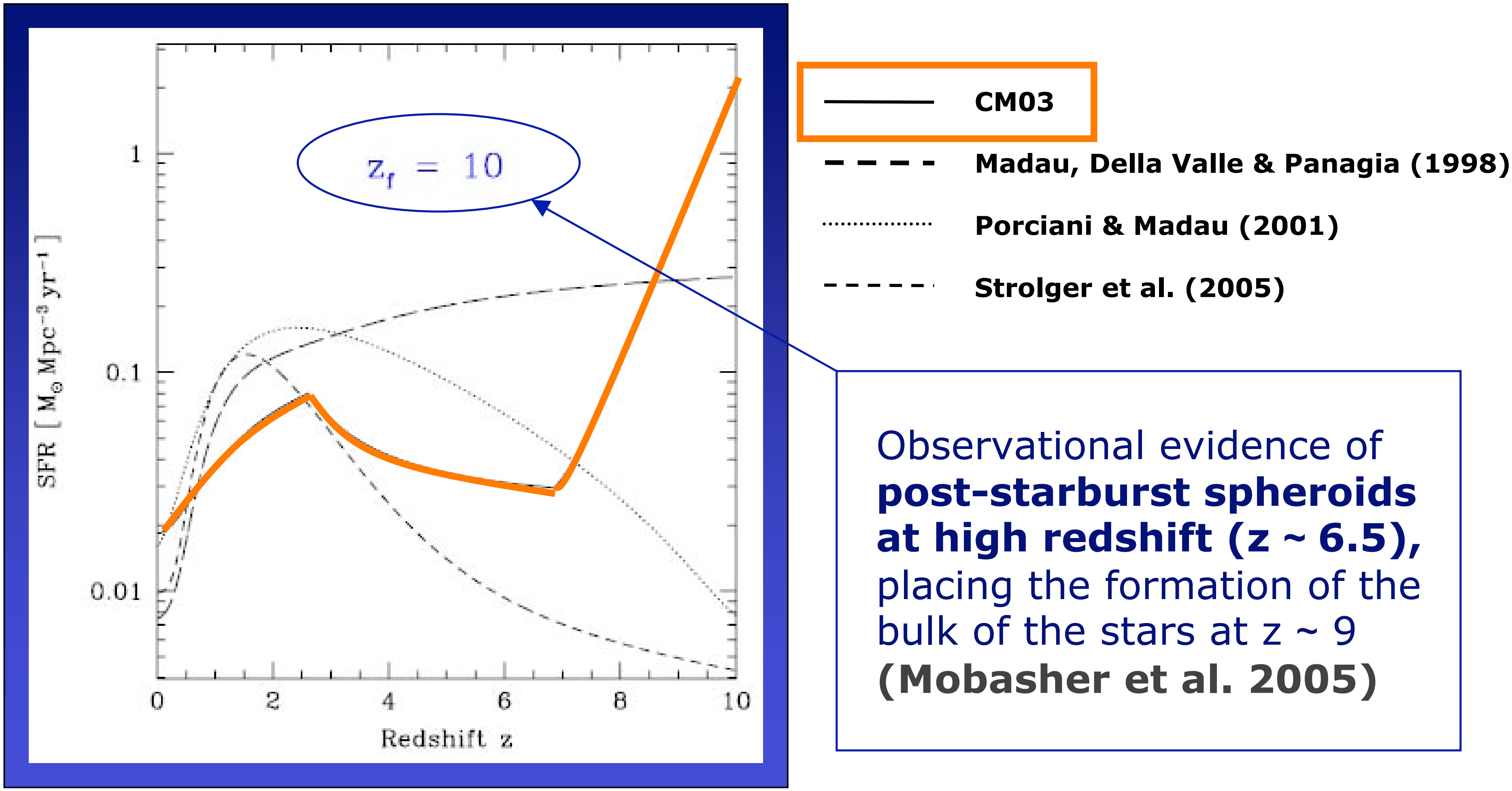
Cosmic $SN_{Ib/c}$ rate

- Sum over the three different morphological types
  (Calura & Matteucci 2003, CM03)
  - **The model predicts a peak at the redshift of galaxy formation due to the strong starburst in spheroids**



Different cosmic $SN_{Ib/c}$ rate models

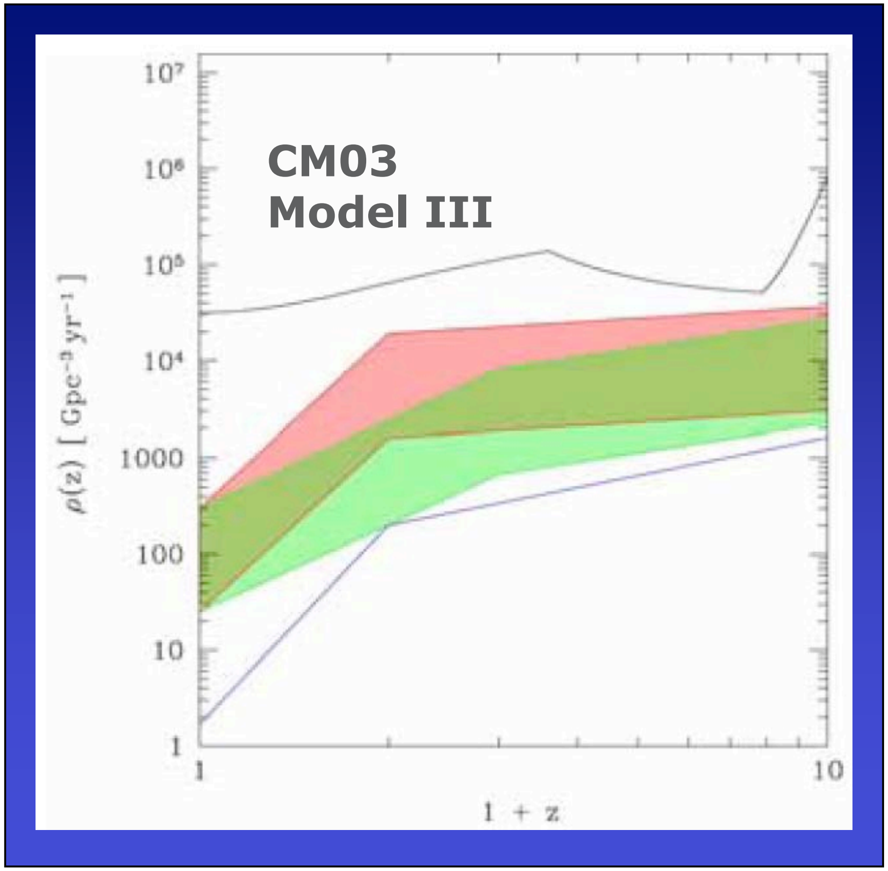
Model III



Observational evidence of **post-starburst spheroids at high redshift (z ~ 6.5),** placing the formation of the bulk of the stars at z ~ 9 **(Mobasher et al. 2005)**

Cosmic GRB rates

- Comparison between predicted cosmic $SN_{Ib/c}$ rate (Model III) and 3 theoretical cosmic GRB rate models, accounting for the uncertainties of the GRB beaming factor.



Lloyd-Ronning et al. (2002)

Yonetoku et al. (2004)

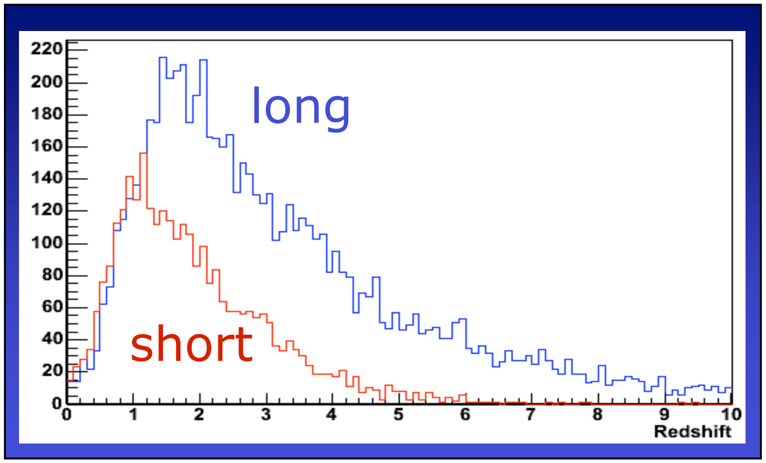
Matsubayashi et al. (2005)

Different cosmic analytical GRB rate models obtained analyzing samples of GRBs with redshift estimates derived from empirical relations.

GRB simulations with the LAT

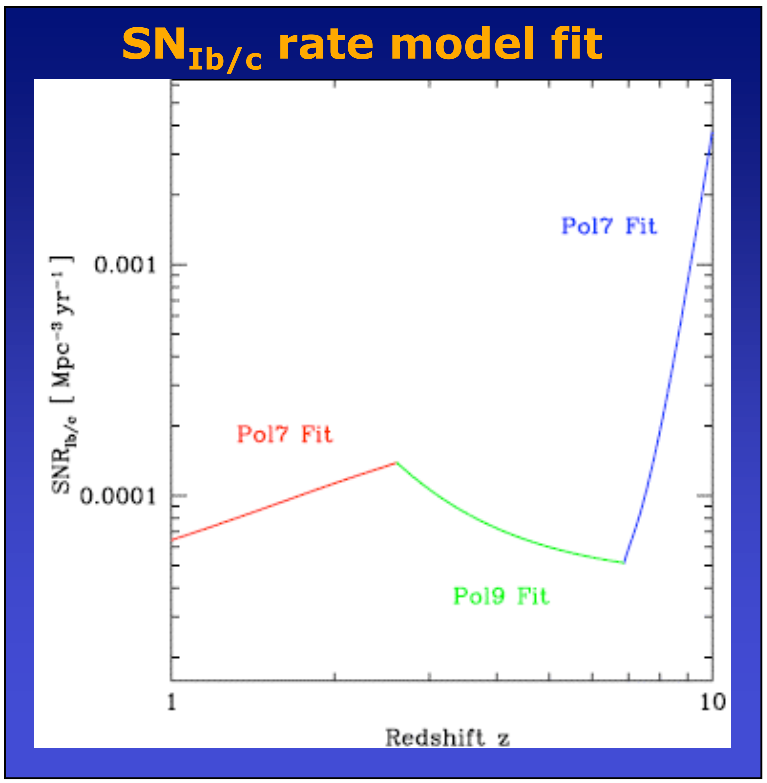
- Calculation of the **number of GRB per year** predicted for the LAT (see Nicola Omodei's poster **P16.18**)

- **Fast Montecarlo simulations**
  - Extrapolation of the **spectral parameters** from BATSE to the energy range of LAT **(Preece et al. 2000)**
    - Model dependent
  - **GRB redshift distribution**:
    - Long GRBs: SFR Model calculated by **Porciani & Madau (2001)**
    - Short GRBs: Binary Mergers Model calculated by **Fryer et al. (1999)**
  - **EBL** attenuation model
    - **(Primack et al. 2005)**

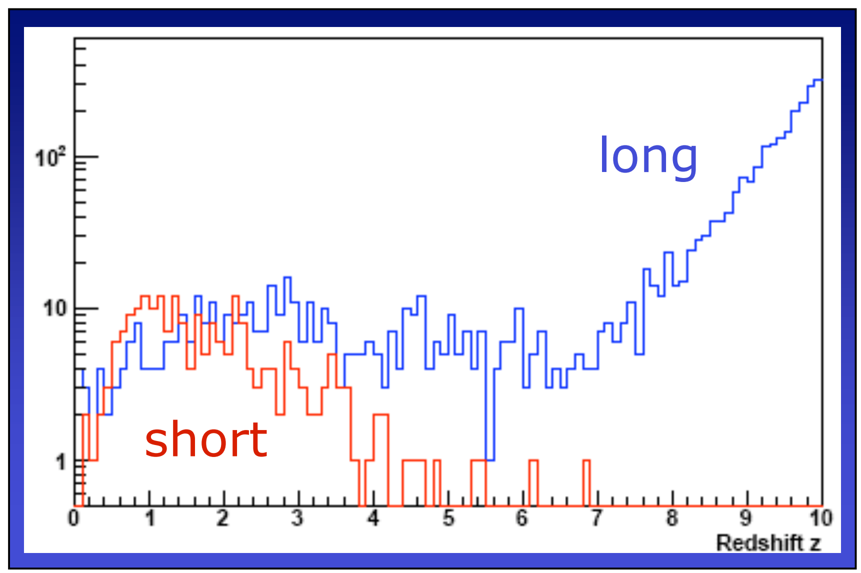


High z GRB detectability

- **Main assumptions in the simulation:**
  1. Assumed a new **GRB rate** following the previously calculated $SN_{Ib/c}$ rate:
     - Simulation of **2800 GRBs per year** up to **z ~ 10**



- **Redshift distribution**
  - Normalization to Omodei up to z < 6
  - No changes to the short GRB redshift distribution

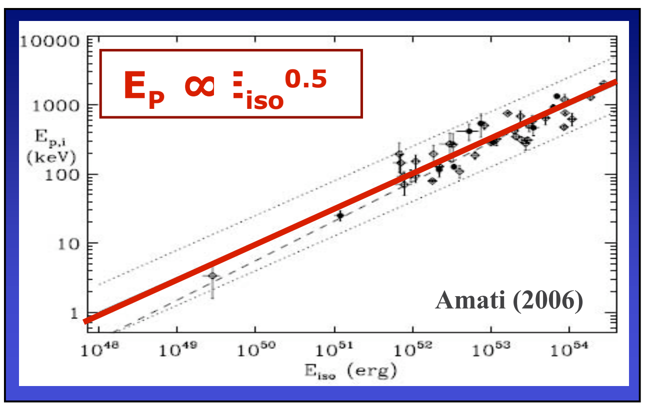


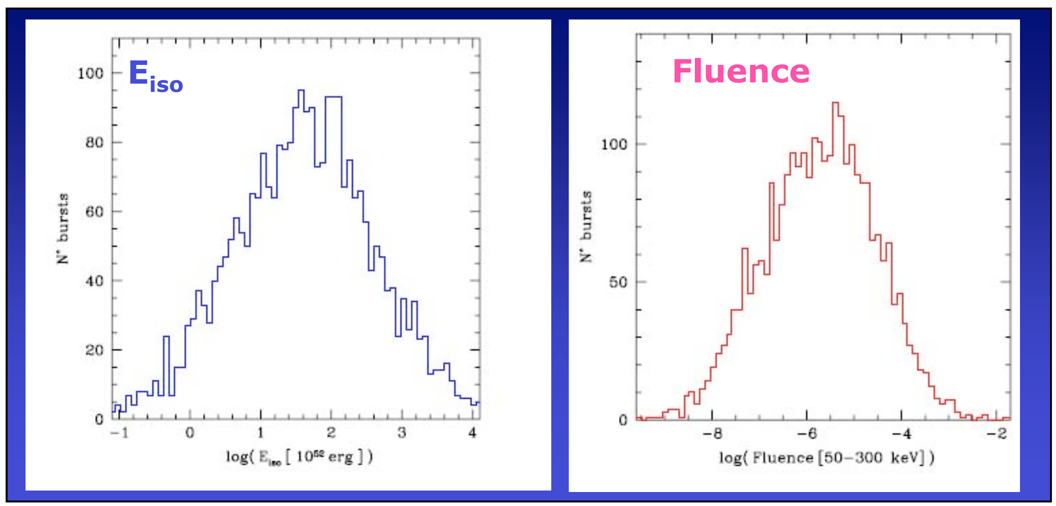
High z GRB detectability

- **Main assumptions in the simulation:**

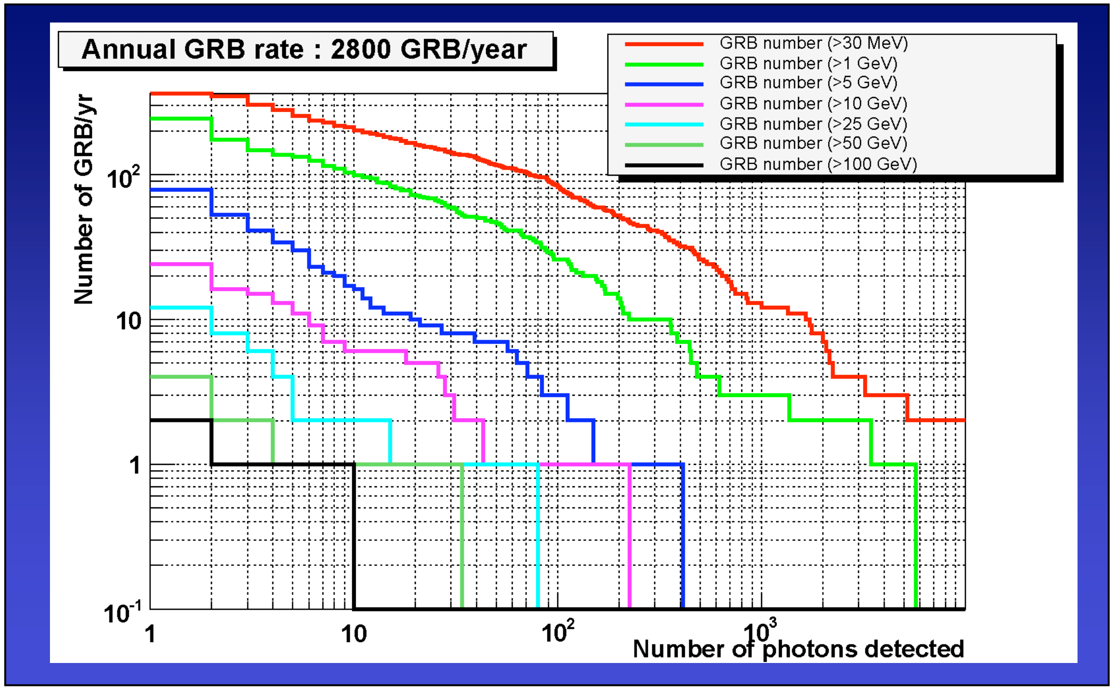
2. Adopted the E_P – E_{iso} correlation **(Amati et al. 2002)**
    - Model independent
    - High-redshift extension

3. Calculated E_{iso} and the Fluence in the BATSE energy band with cosmological corrections.





High z results



	GRB rate
LAT	**~ 300/yr (200/yr >10 counts)**

- **LAT GRB sensitivity:**
  - **Consistent with previous results up to z < 6**
  - **Population of GRBs at z > 6 is clearly visible!**
    - **High number of GRBs observed at energies lower than 1 GeV consistent with EBL attenuation**

Conclusions

- **Study of GRBs as star formation tracers up to high z seems promising**
  - Single WR or massive stars in close binary systems are good candidates
  - Irregular galaxies are favored
  - The large number of GRBs at high redshift predicted by the analyzed model for cosmic $SN_{Ib/c}$ rate is in agreement with observational evidences of post-starburst spheroids at z ~ 6.5
- **Possibility for GLAST to observe GRBs at z > 6**
  - Probable detection of a population of cosmological GRBs

To do list

Concerning the SNRIb/c models…

- Explore more mass ranges for both the single WR and the massive close binary components
- Optimize metallicity effects in the models
  - Low metallicity GRB hosts

Concerning the GLAST GRB simulations…

- Better cross-check of **EGRET results**
  - Extension of EGRET searches
- Inclusion in **complete simulations**
  - Background estimates
- Improvements in **GRB models**
  - Spectral evolution
  - Duration and variability at high z
- Validation of the **Amati relation** at high z