The long γ-ray burst rate and the correlation with host galaxy properties

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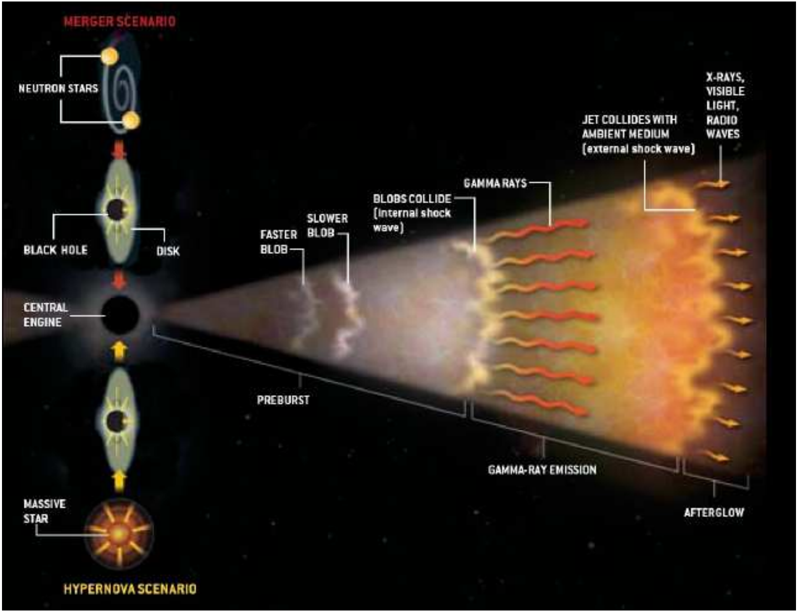
I. What are GRBs



II. Why GRBs?

What makes GRBs good potential probes of the high redshift regime?

- Simple power law spectrum
- Super luminous phenomena
- Host galaxy possibilities

II. Why GRBs?

What benefits do we get from knowing more about high redshift?

- Cosmic star formation history
- Details about the period of re-ionisation
- Cosmological parameters
- Chemical evolution
- and so on....

III. GRB Host Galaxies

Long gamma-ray bursts are usually seen in galaxies with

- Mass
  - $10^{9.3}\mathrm{M}_{\odot}$, Savaglio+05
  - $10^{9.1}\mathrm{M}_{\odot}$, Svensson+10
  - $10^{9.3}\mathrm{M}_{\odot}$, Mannucci+11
- Metallicity
  - $0.26\,\mathrm{Z}_{\odot}$, Savaglio+05
  - $0.54\,\mathrm{Z}_{\odot}$, Svennson+10
  - $0.61\,\mathrm{Z}_{\odot}$, Mannucci+11
- Blue, star-forming

IV. GRB-SN connection

- The long gamma-ray burst model is thought to be the result of the collapse of a massive star (Woosley+93, Paczynski+98, MacFadyen & Woosley+99).
- Spectroscopic evidence of a LGRB with a SN1998bw (Galma+98) argued for this model.
- This was strengthened further by conclusive spectroscopic confirmation of SN2003dh/GRB030329 (Stanek+03, Matheson+03)

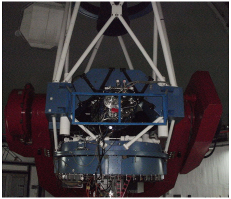
IV. GRB-SN connection

- The long gamma-ray burst rate therefore traces the core-collapse rate, and as a result the cosmic star-formation due to the short lives of these massive stars ($\tau \sim 10\mathrm{Myr}$)
- However, the LGRB rate and cosmic SFR were not seen to match and were believed to differ as a result of:
  - Host galaxy metallicity, e.g., Li+08
  - Top-heavy/evolving IMF, e.g., Wang & Dai+11
  - Evolving LGRB luminosity function, e.g., Butler+10
  - Selection effects, e.g., Coward+08

V. Recent Motivations

- Galaxies found with large masses, Kruehler+11
  - upto $\sim 10^{11}\mathrm{M}_\odot$
- Galaxies found with high metallicties, Savaglio+11, Kruehler+12
  - $0.5 - 0.9\mathrm{Z}_\odot$
- More complete LGRB redshift samples, Greiner+11, Salveterra+11, Fynbo+9(+12 see TOUGH poster)
  - $\sim 87 - 95\%$
  - c.f. *Swift* $\sim 30\%$

VI. LGRB Sample



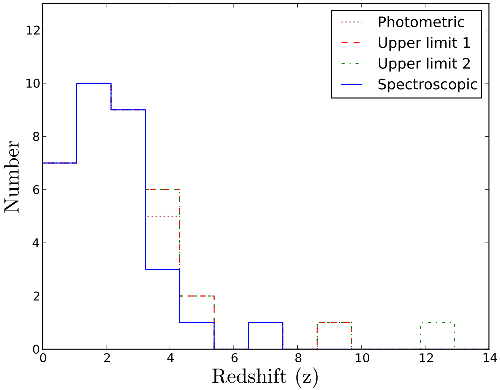
GROND: **G**amma-**R**ay burst **O**ptical **N**ear-infrared **D**etector

- 4 optical channels
- 3 NIR channels
- Dedicated GRB follow-up instrument at 2.2m telescope, ESO La Silla

LGRB sample is selected by (Greiner+11):

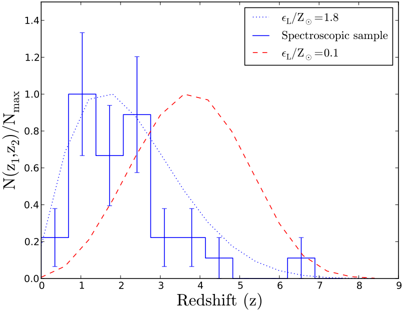
- LGRB followed by GROND $<$ 4 hours after the trigger
- Exhibits an X-ray afterglow

- **31 Spectroscopic**
- **3 Photometric**
- 2 Photometric upper limits (UL1)
- 1 Photometric range (UL2)



Outline:

- Generate a cosmic star formation history (CSFH) from empirical constrained models that have free parameters for mass ranges and metallicities
- Convert CSFH in to a LGRB rate
- Compare to an experimental data set using χ^2 statistics



VIII. Model

The CSFH is the sum of all the star formation (SFR), weighted by the number of galaxies per mass bin (Galaxy Mass Function; GMF):

$$\begin{aligned} CSFH &= \int_{M_1}^{M_2} SFR\,(M_*, z)\, GMF\,(M_*, z)\, \mathrm{d}M_* \\ &= CSFH\,(z, M_1, M_2) \end{aligned}$$

SFR, Bouche+10
GMF, Fontana+06

VIII. Model

We can implement a cut on galaxy properties based on metallicity, $\epsilon_L = \epsilon\left(M_*, z\right)$

$$\begin{aligned} CSFH &= \int_{M_1}^{M_2} \zeta\left(z\right)\gamma\left(M_*, z, \epsilon_{\mathrm{L}}\right) SFR\left(M_*, z\right) GMF\left(M_*, z\right) \,\mathrm{d}M_* \\ &= CSFH\left(z, \epsilon_{\mathrm{L}}, M_1, M_2\right) \end{aligned}$$

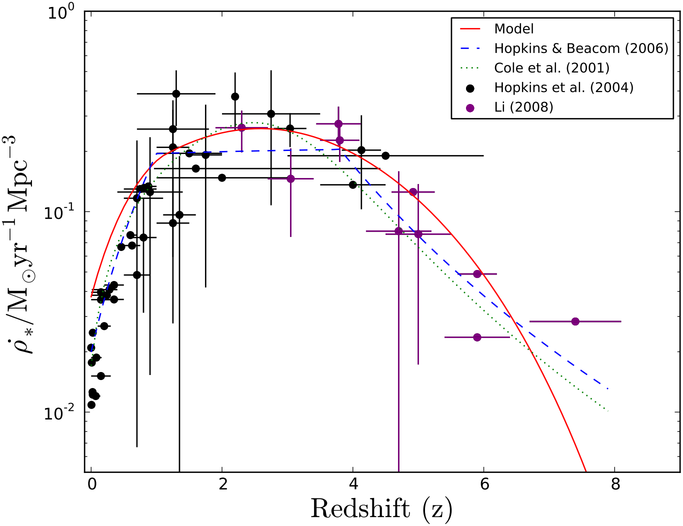
where we have assumed:

$$\gamma\left(M_*, z, \epsilon_{\mathrm{L}}\right) = \begin{cases} 1 & \text{if } \epsilon\left(M_*, z\right) < \epsilon_{\mathrm{L}} \quad \mathit{Savaglio} + 05 \\ 0 & \text{if } \epsilon\left(M_*, z\right) \geq \epsilon_{\mathrm{L}} \end{cases}$$

$$\zeta(\mathrm{z}) = \begin{cases} 1 & \text{if } M_{\mathrm{Q}}\left(z\right) > M_* \qquad \mathit{Bundy} + 09 \\ 0 & \text{if } M_{\mathrm{Q}}\left(z\right) \leq M_* \end{cases}$$

VIII. Model

CSFH model with no cuts:



VIII. Model

The LGRB rate is calculated by:

$$N(z_1, z_2) = \eta_{\mathrm{grb}} \int_{z_1}^{z_2} \frac{f(z)\, CSFH(z, \epsilon_L, M_1, M_2)\,(1+z)^{\delta}\, \frac{\mathrm{d}V}{\mathrm{d}z}}{(1+z)}\, \mathrm{d}z,$$

e.g, Bromm & Loeb +06, Langer & Norman +06, Daigne +06, ...

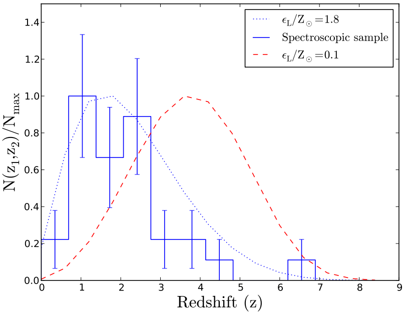
- δ is a "black" approach that includes any other redshift effects of the form $(1+z)^{\delta}$
- η_{grb} converts the star rate into an observed LGRB rate
- $f(z)$ is the fraction of LGRBs detectable by an instruments limiting depth

$\eta_{\rm grb}$ is a probability that contains information on:

- The fraction of stars available to form a BH (from a stellar IMF)
- Sample selection effects (X-ray afterglow, observed from La Silla < 4 after the burst, etc.)
- Length of survery
- Collimation of afterglow

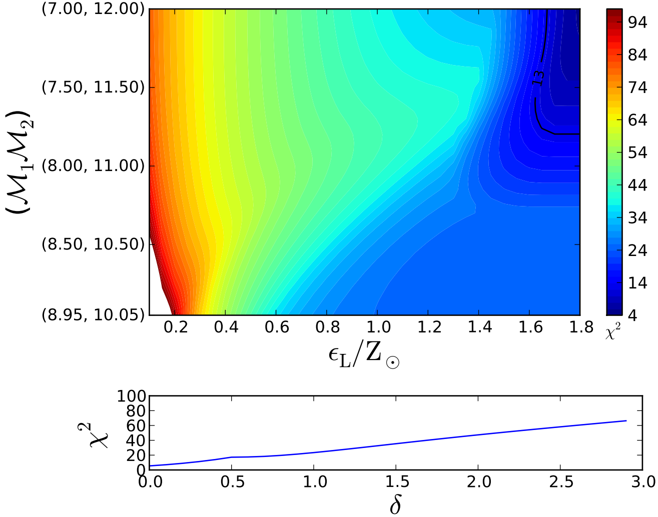
Final form:

$$N = N\left(z_1, z_2, \epsilon_L, M_1, M_2, \delta\right)$$



IX. Methodology

1. Generate a CSFH for a given mass range, metallicity limit and δ
2. Convert to a LGRB rate for a given instrument
3. Compare the LGRB number density to experimental data using least-χ^2



(7.00, 12.00)
(7.50, 11.50)
(8.00, 11.00)
(8.50, 10.50)
(8.95, 10.05)
$(\mathcal{M}_1\mathcal{M}_2)$
0.2 0.4 0.6 0.8 1.0 1.2 1.4 1.6 1.8
$\epsilon_L/Z_\odot$
13
94 84 74 64 54 44 34 24 14 4
χ^2
100 80 60 40 20 0
χ^2
0.0 0.5 1.0 1.5 2.0 2.5 3.0
δ

X. Results

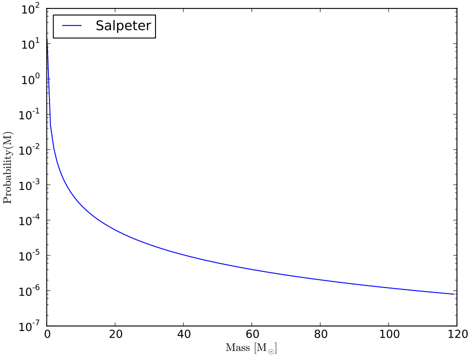
Overview:

1. No strong mass range preference
2. No strong metallicity preference
3. No evolution preference

X. Results

Assumptions made?

- **IMF**
- GRBLF
- Sample



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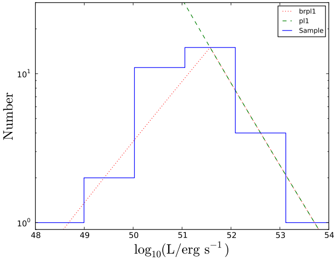

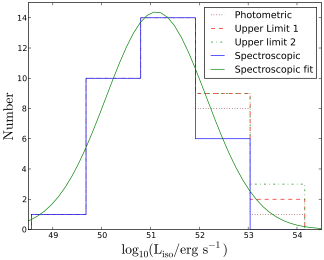

X. Results

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- IMF
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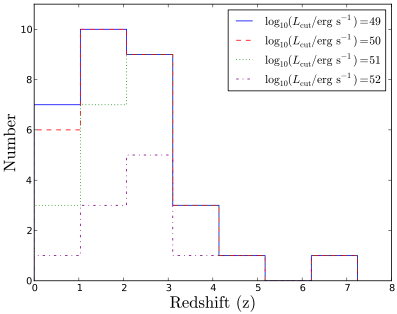
X. Results

- Samples selected by luminosity constraints causes the peak of the distribution to shift
- This is ok, however, not if:
- the sample is biased in redshift detection, it will change the peak of the distribution



Summary

1. LGRBs do not prefer a specific type of galaxy
2. There is no preference for an evolving luminosity function
3. Redshift biases can introduce a preference for metallicity/mass constraints, etc.

Summary

1. LGRBs do not prefer a specific type of galaxy
2. There is no preference for an evolving luminosity function
3. Redshift biases can introduce a preference for metallicity/mass constraints, etc.
4. **The CSFH is gradually decreasing at high-z**

XII. High-z Predictions

- Recent work shows there may be a possible plateau of the CSFH
- Our model is reliable upto redshifts of $z \sim 4$
- We extend the model to allow a flattening from $z > 3$

$$\dot{\rho}(z) = \begin{cases} \dot{\rho}(z) & \text{if } z \leq 3 \\ \dot{\rho}(z=3) - az & \text{if } z > 3 \end{cases},$$