Gamma-ray burst as a probe of the high-z Universe

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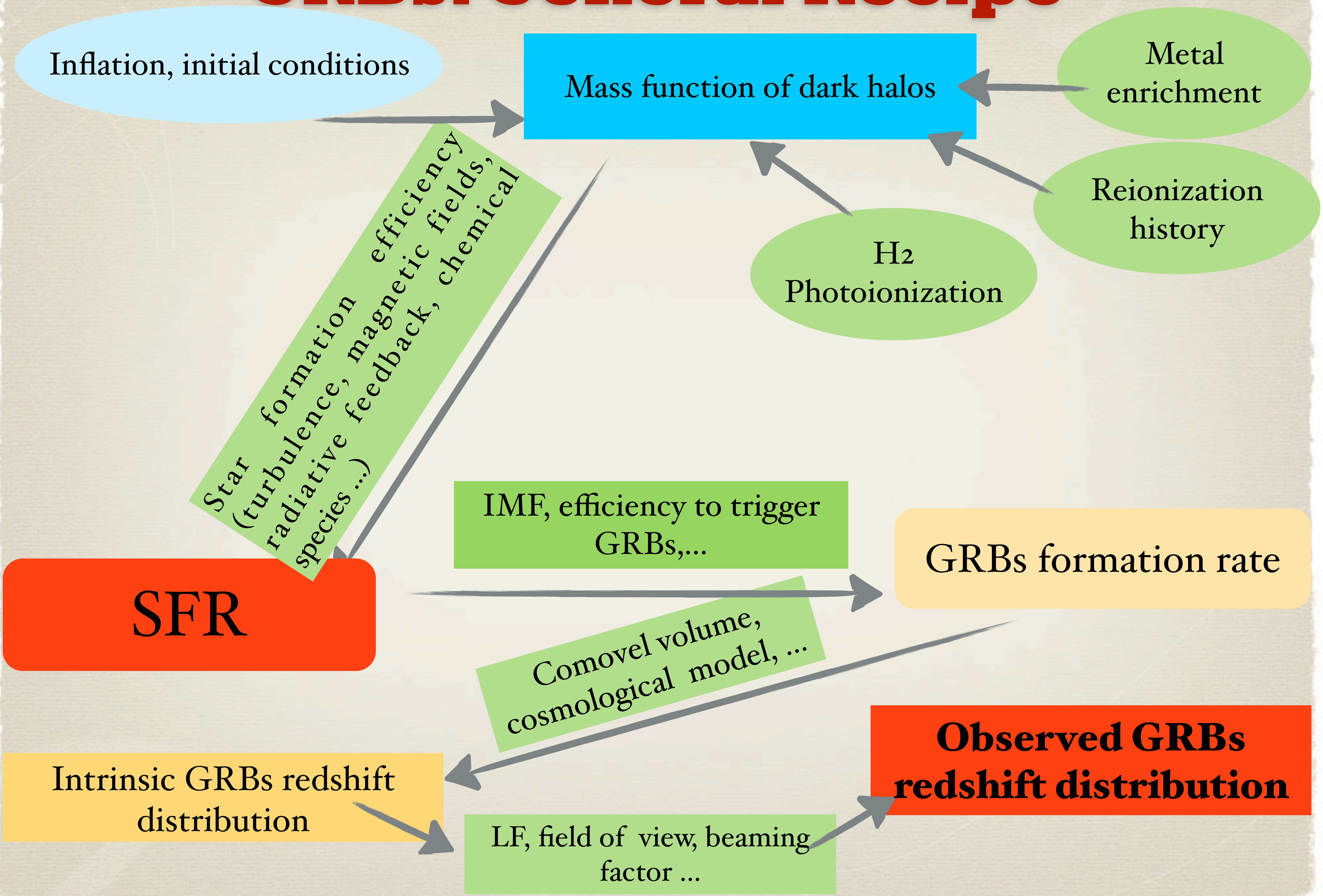
FAPESP

HIGH-Z GRBS AS A PROBE

- Reionization history of the Universe,
- **Star formation history**
- **Nature of Pop III stars**
- Signposts to the First Galaxies
- **Constraints on the Nature of Dark Matter**
- **Dark energy equation of state, ...**

GRBs: General Recipe



Star Formation History

- LGRB are connected with the core-collapse of massive stars (Woosley & Bloom 2006).
- As a result, **LGRBs can be used to trace the star formation rate** of their host environment.
- Knowing the SFH to such high redshifts is of fundamental importance for studying galaxy evolution, when reionizaton occurs, ...
- A question still in debate: **LGRBs are or are not biased tracers of star formation?** The question of biasing was first introduced because core-collapse models should only generate LGRB for a low-metallicity progenitor system, Hirschi et al. 2005; Yoon & Langer 2005; Woosley & Heger 2006.

METALLICITY LIMIT TO TRIGGER GRBS

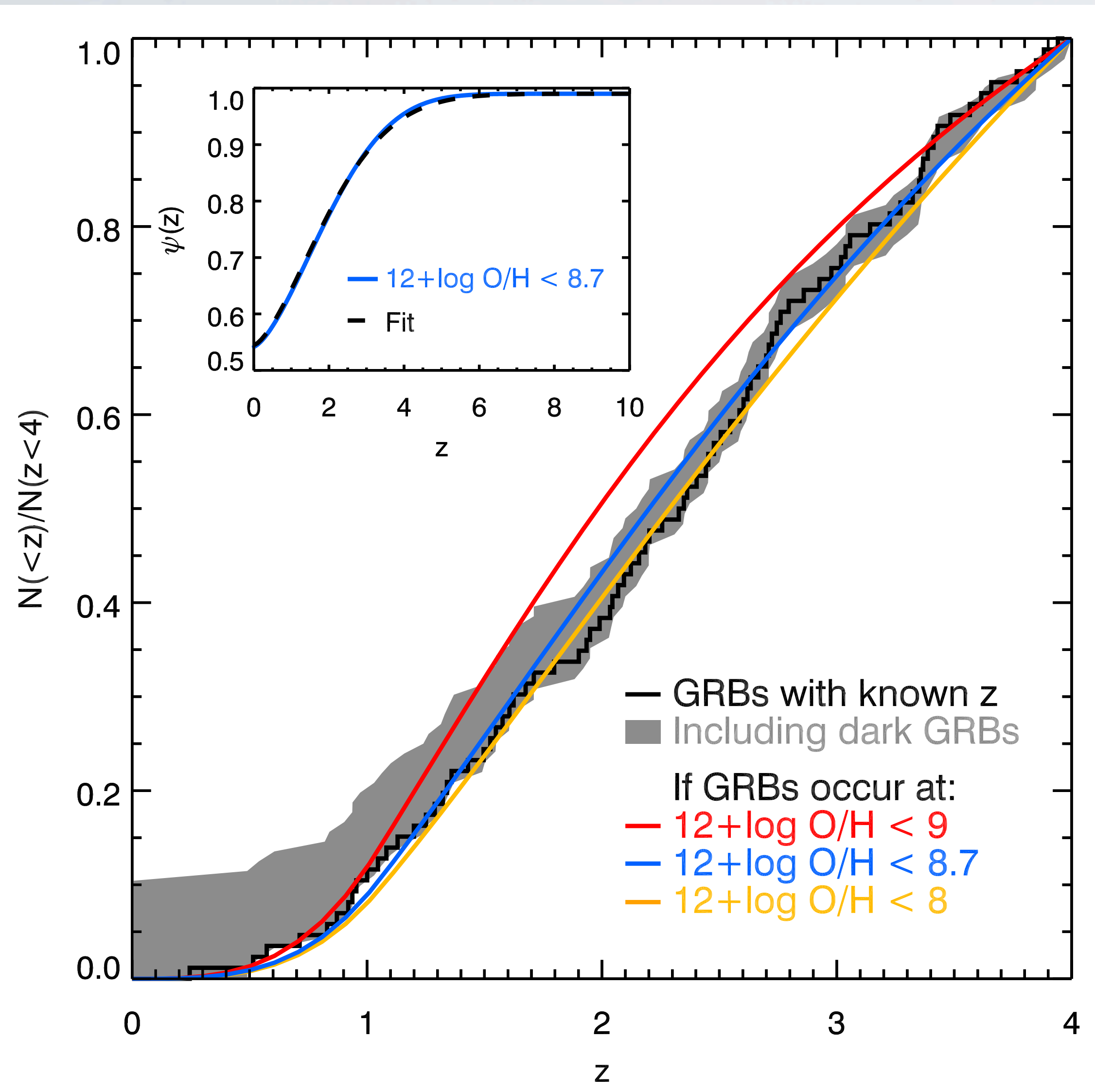
- Several authors have suggested that **progenitors of long duration GRBs have preference for low-metallicity environments** (Langer & Norman 2006; Woosley & Bloom 2006).

- Such an effect would be a consequence of the mass and angular momentum loss caused by winds in high-metallicity stars.

- This would prevent such stars of becoming GRBs and consequently, change their expected redshift distribution (e.g., Salvaterra & Chincarini 2007; Yüksel et al. 2008; Kistler et al. 2009). However, **a standard model for the metallicity connection are still unclear** (see e.g., Modjaz 2011; Robertson & Ellis 2012).

METALLICITY CONNECTION: **A TALE OF TWO MODELS**

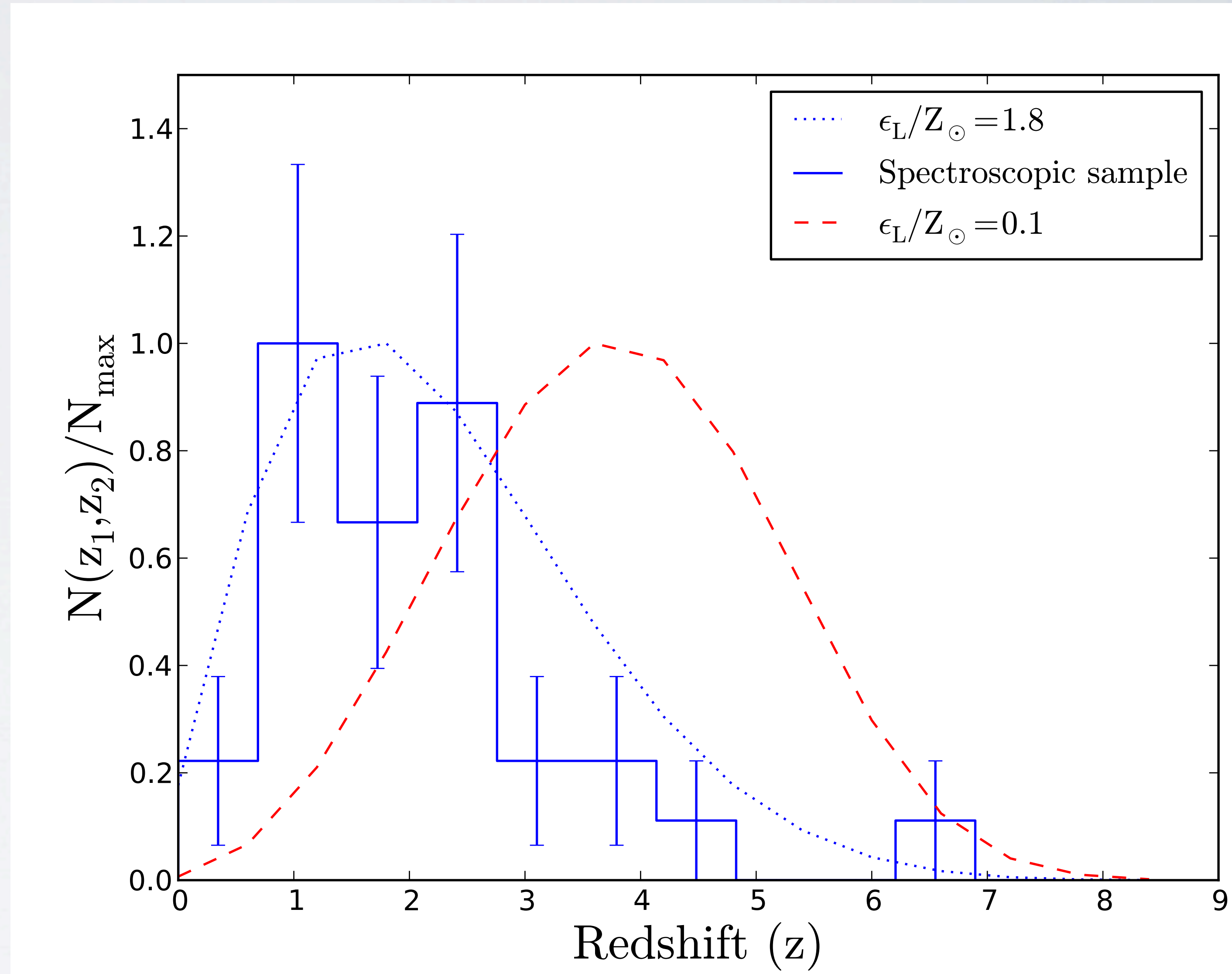
Robertson & Ellis 2012



Metallicity limit fits better the data

(Hirschi et al. 2005; Yoon & Langer 2005; Woosley & Heger 2006, Prochaska et al. 2004; Sollerman et al. 2005; Modjaz et al. 2006; Stanek et al. 2006; Wiersema et al. 2007 , Fruchteretal. 1999, 2006; Le Floc'h et al. 2003; Fynbo et al. 2003; Savaglio et al. 2009).

J. Elliott et al. 2012



No significant relation

Levesque et al. 2010, Soderberg et al. 2010, Han et al. 2010, Savaglio et al. 2009, Ishida et al. 2011, Hashimoto et al. 2010; Savaglio et al. 2012, Levan et. al. 2006; Berger et. al. 2007; Hashimoto et. al. 2010; Hunt et. al. 2011

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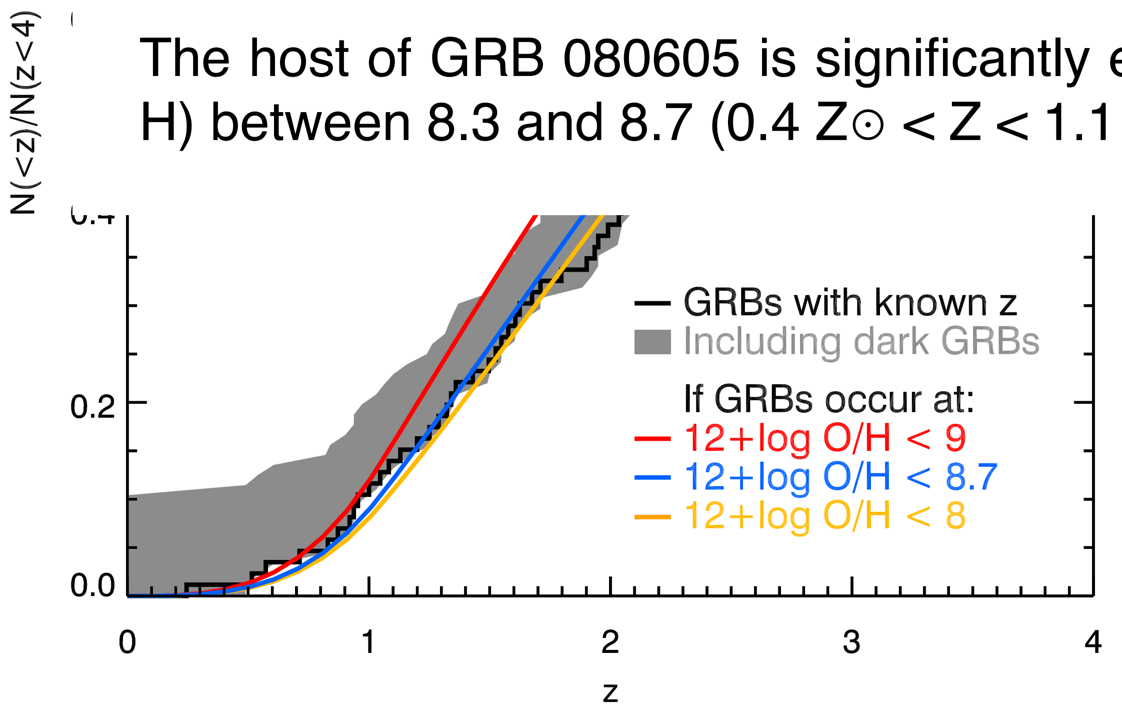
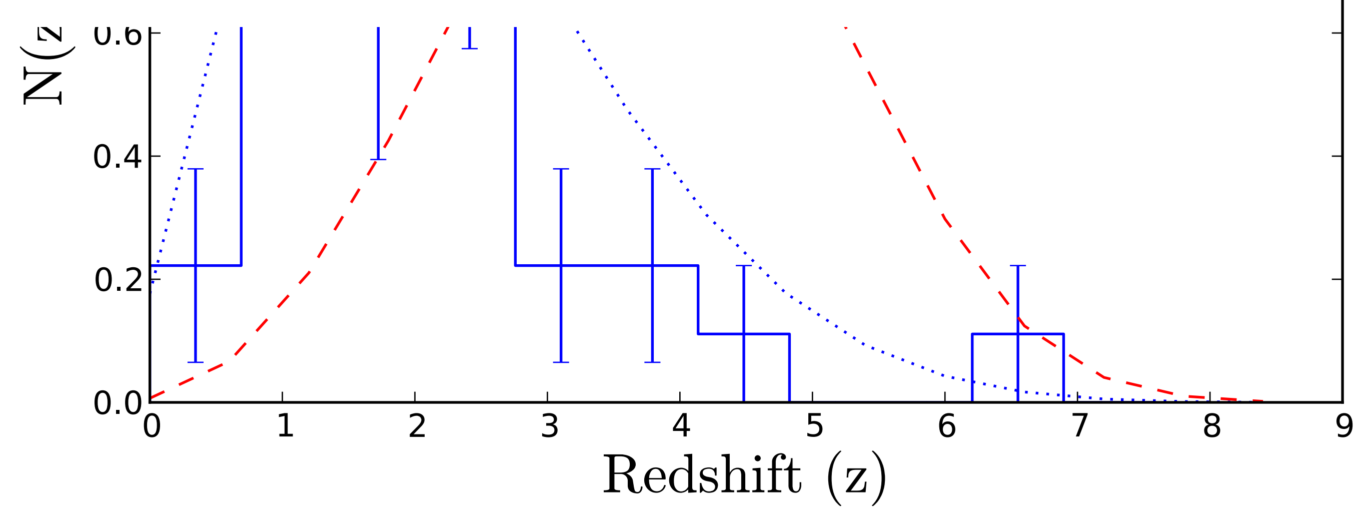
The metal-enriched host of an energetic γ-ray burst at $z \approx 1.6$ ★

T. Krühler[1], J. P. U. Fynbo[1], S. Geier[1], J. Hjorth[1], D. Malesani[1], B. Milvang-Jensen[1], M. Sparre[1], D. J. Watson[1], and T. Zafar[1]

The host of GRB 080605 is significantly enriched with metals with an oxygen abundance 12 + log(O/H) between 8.3 and 8.7 (0.4 Z⊙ < Z < 1.1 Z⊙)





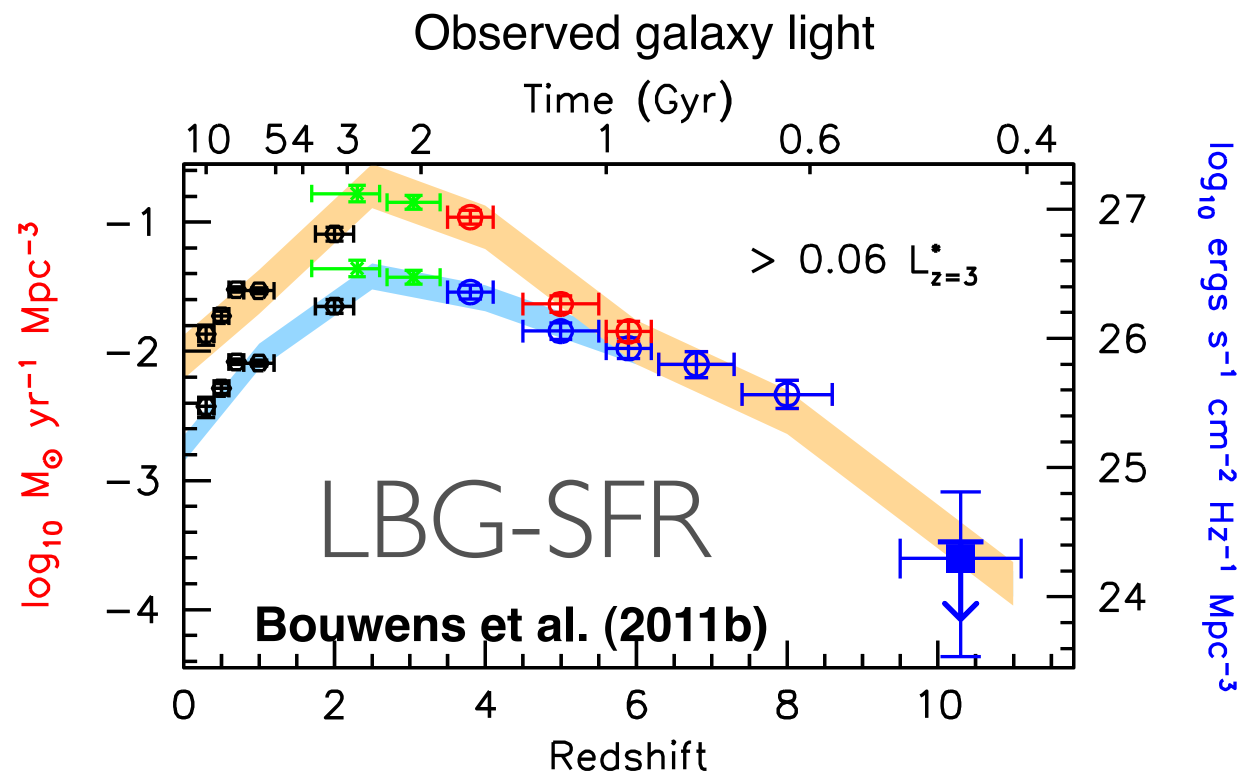
Metallicity limit fits better the data

No significant relation

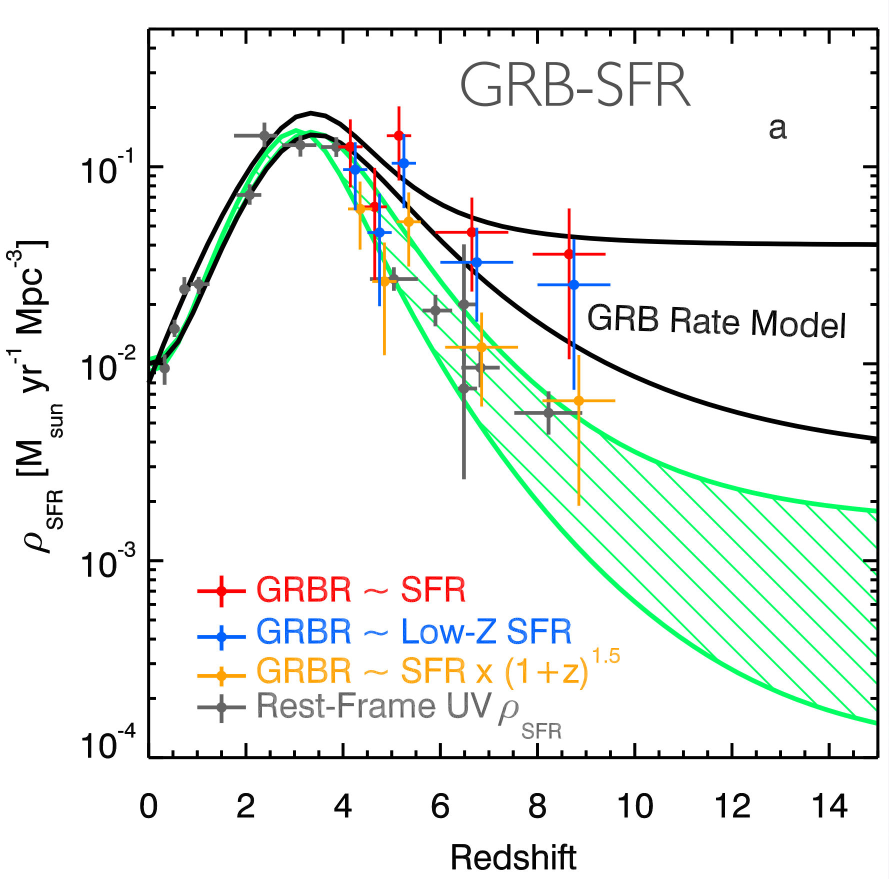
STAR FORMATION HISTORY

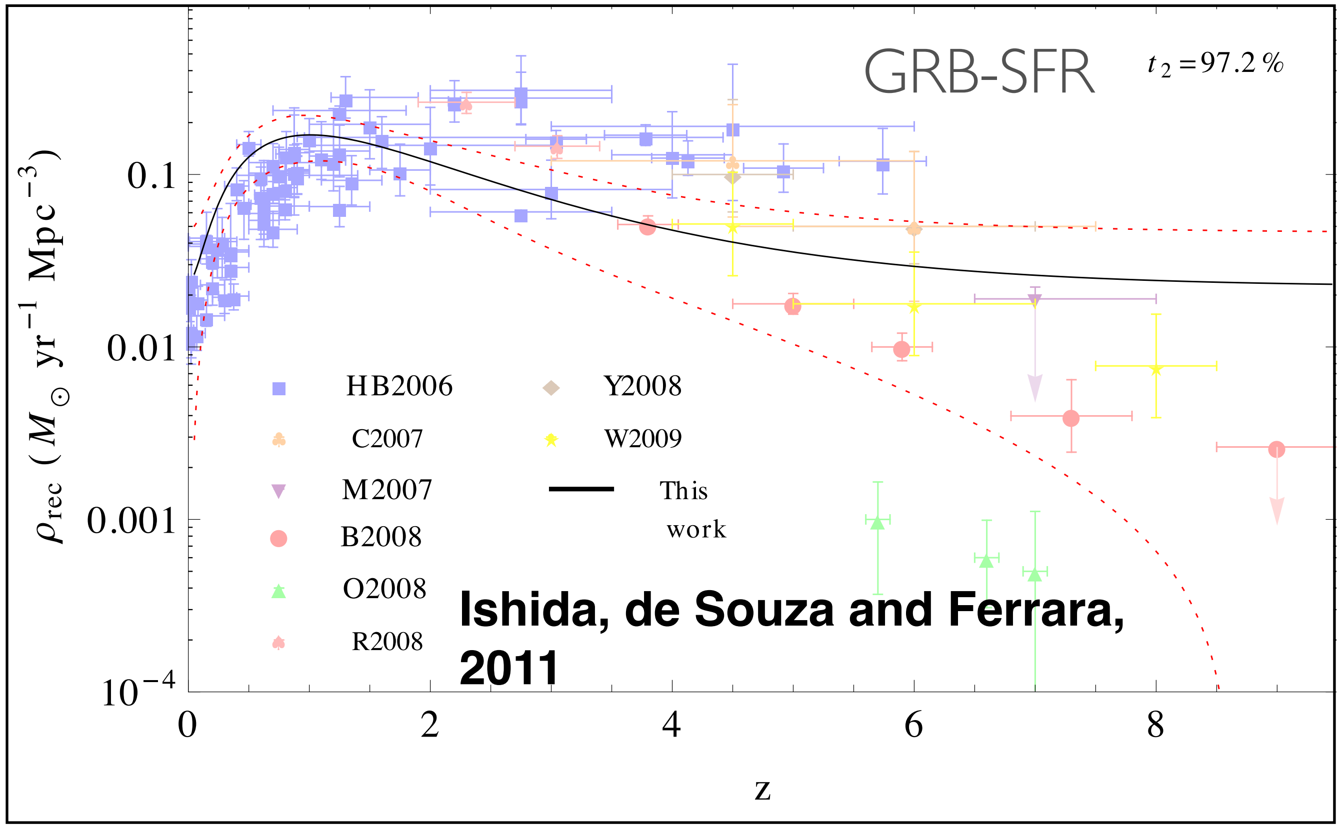
GRB-SFR is systematically above the LBG SFR.

A possible explanation for the difference is that there is **significant star formation in small galaxies below the LBG detection limit.**
(Kistler et al. 2009; Ishida, de Souza and Ferrara, 2011, Robertson & Ellis 2012).



Robertson & Ellis 2012.

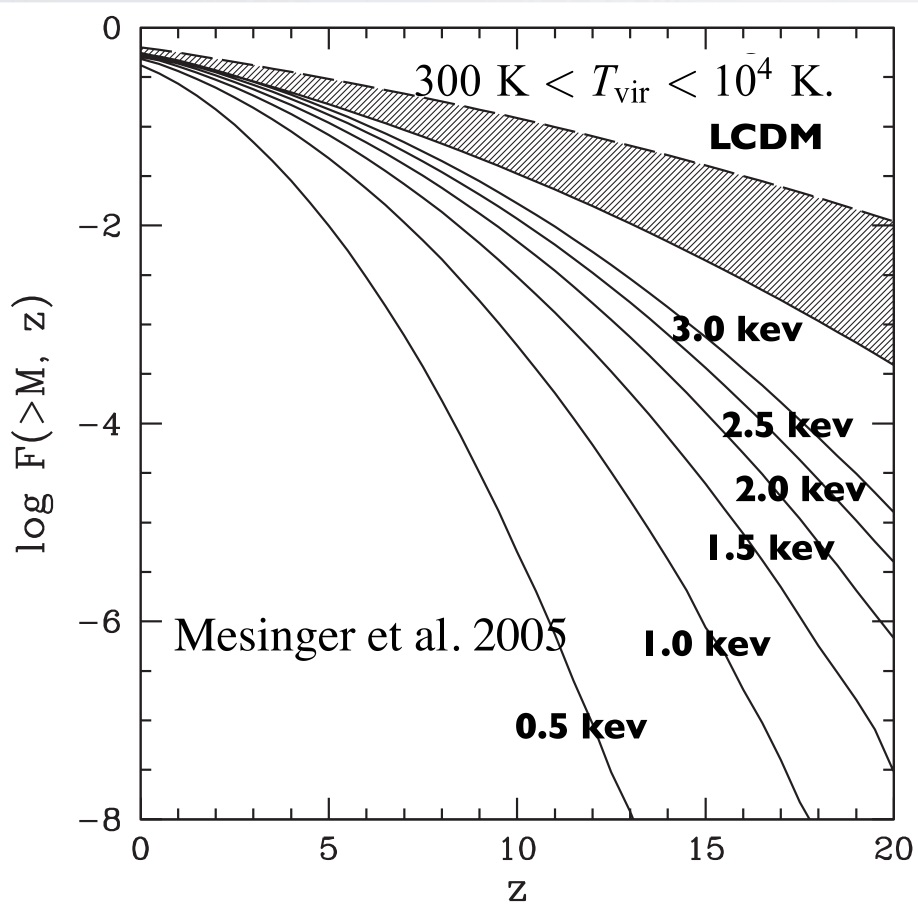




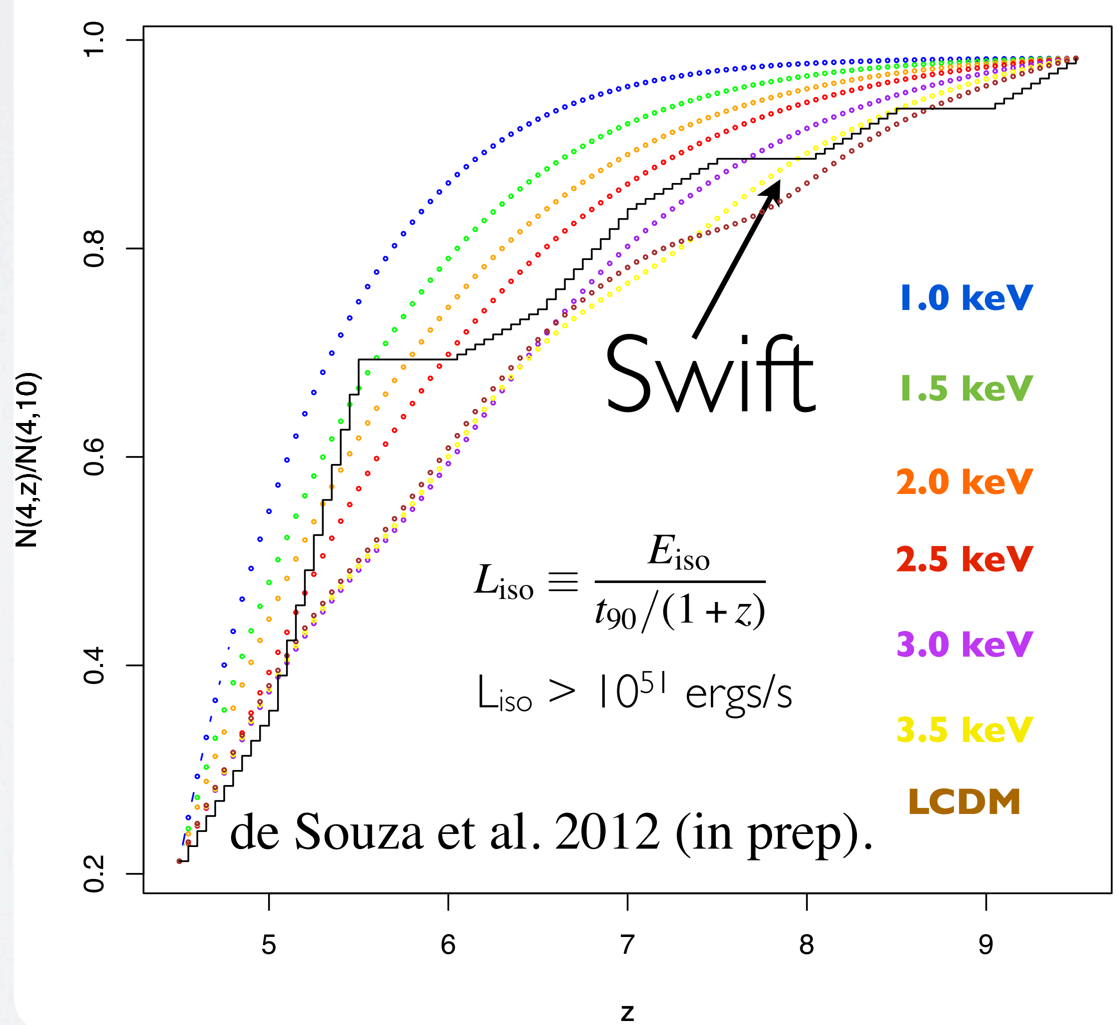
High-z GRBs contraint the warm dark matter mass

Cosmological models that include suppression of the power spectrum of density fluctuations on small scales exhibit an exponential reduction of high-redshift, nonlinear structures, including a reduction in the rate of gamma-ray bursts, Mesinger et al. 2005, de Souza et al. 2012 (in prep).

Fraction of the total mass collapsed into halos of mass M or greater.



Cumulative Number of GRBs



- **How far away can we observe GRBs? Would be possible to observe GRBs from the first generation of stars?**
- **With the lack of observations we have to rely on robust theoretical models**

Pop III Stars

First generation of metal free stars that were formed from initial conditions determined cosmologically (no astrophysical feedback).

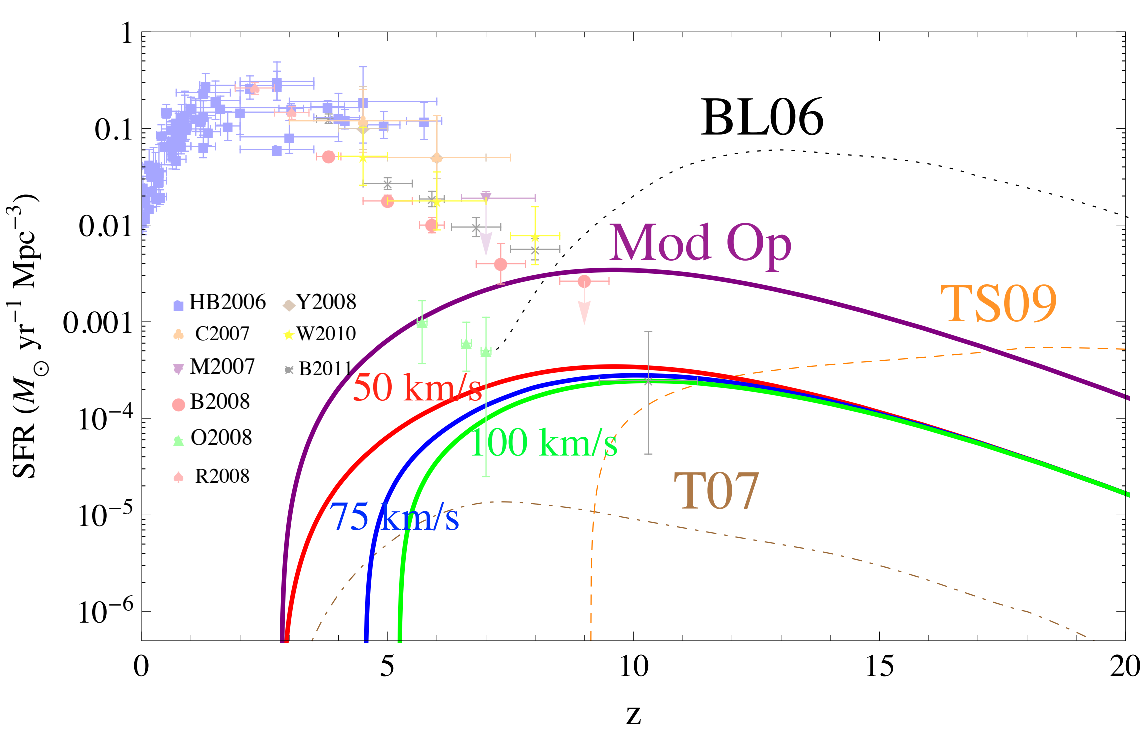
End of Dark Ages

No observation so far

GRBs could be the best approach to look this objetcs.

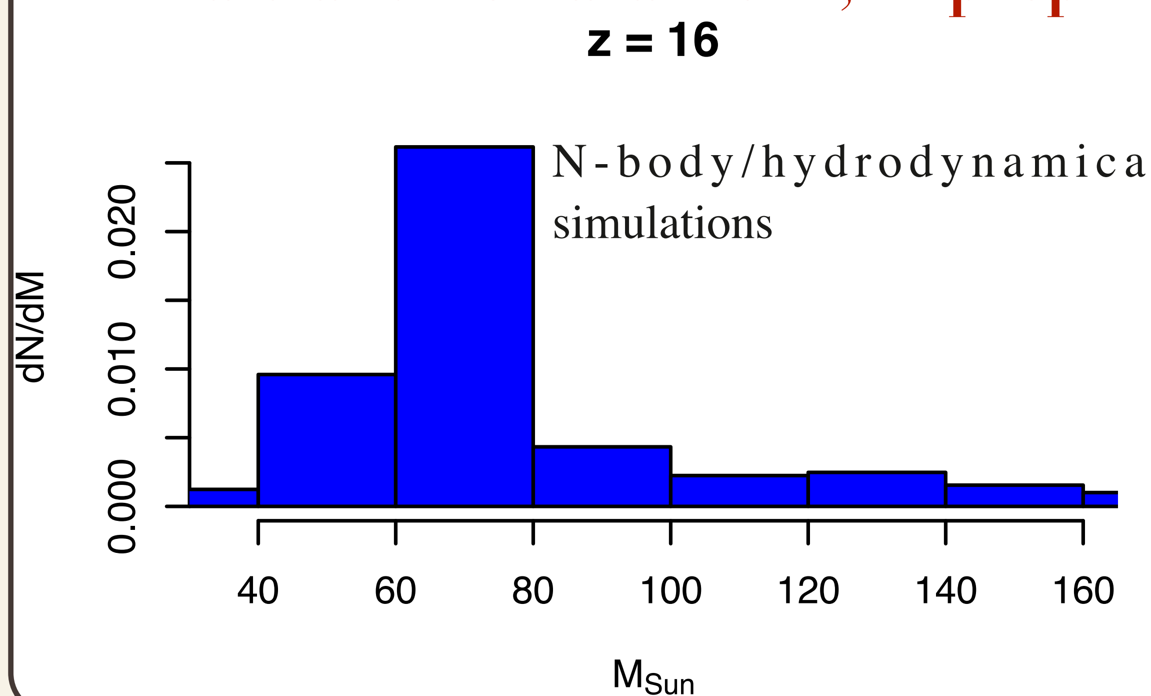
Many Unkown Quantitites

Efficiency to trigger GRBs, Luminosity Function, Pop III Initial Mass Function, SFH...



de Souza, Yoshida & Ioka 2011

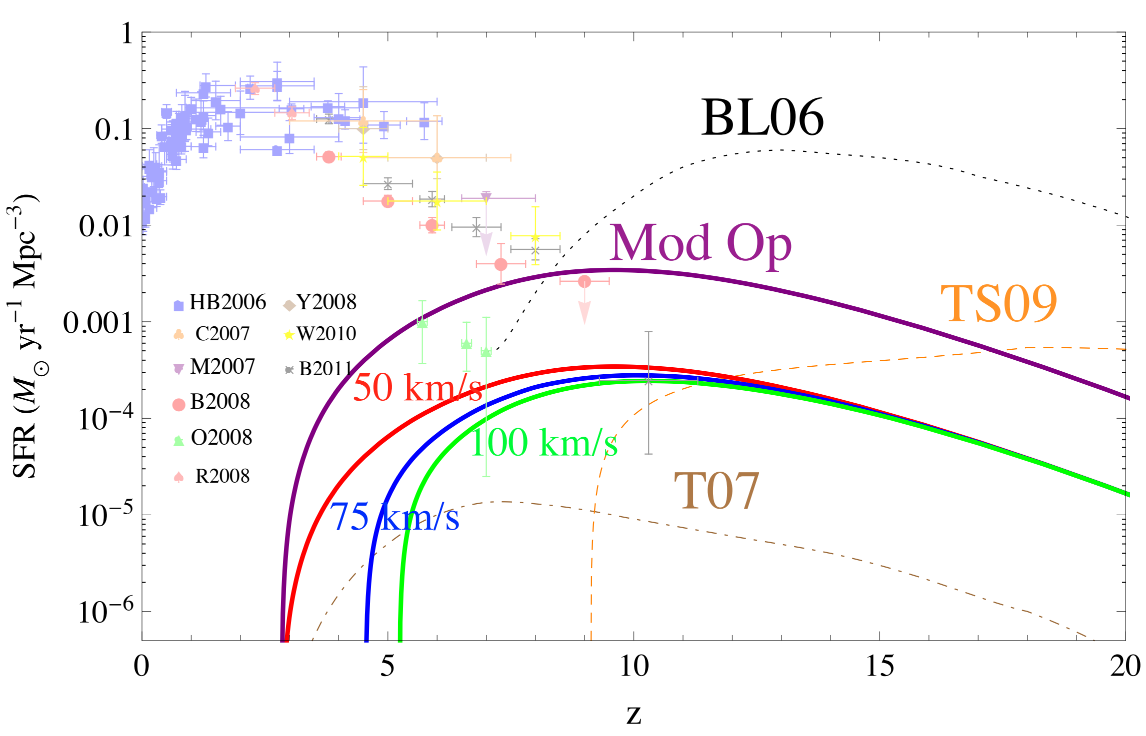
Evolving IMF, de Souza, Ciardi, Maio and Ferrara 2012, in prep

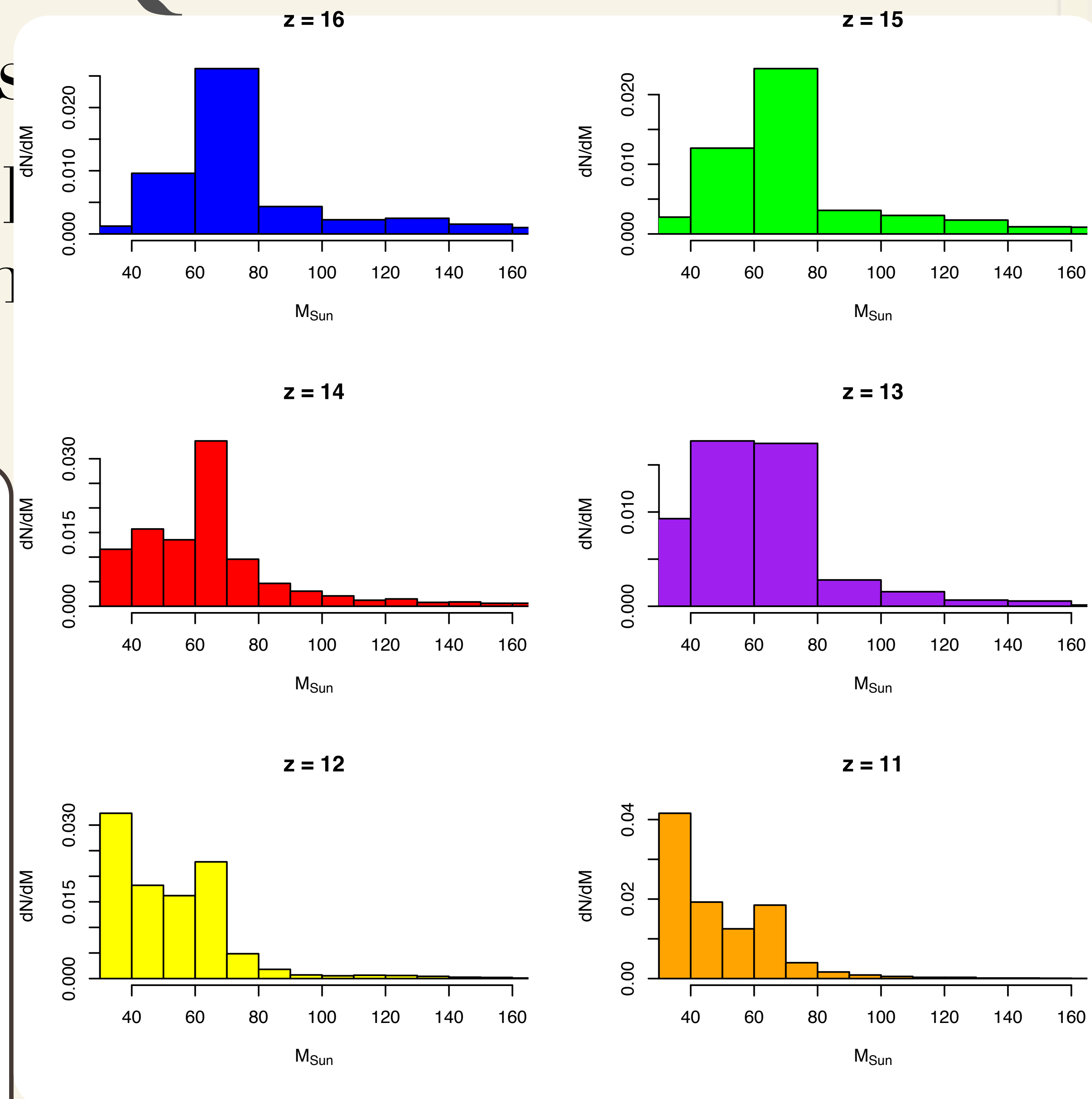


See also Abel, et al. 2002, Omukai & Palla 2003; Yoshida et al. 2006, Clark et al. 2011 and Greif et al. 2011, Hosokawa et al. 2011

Many Unkown Quantitites

Efficiency to trigger GRBs
Luminosity Function, Po
III Initial Mass Function
SFH...

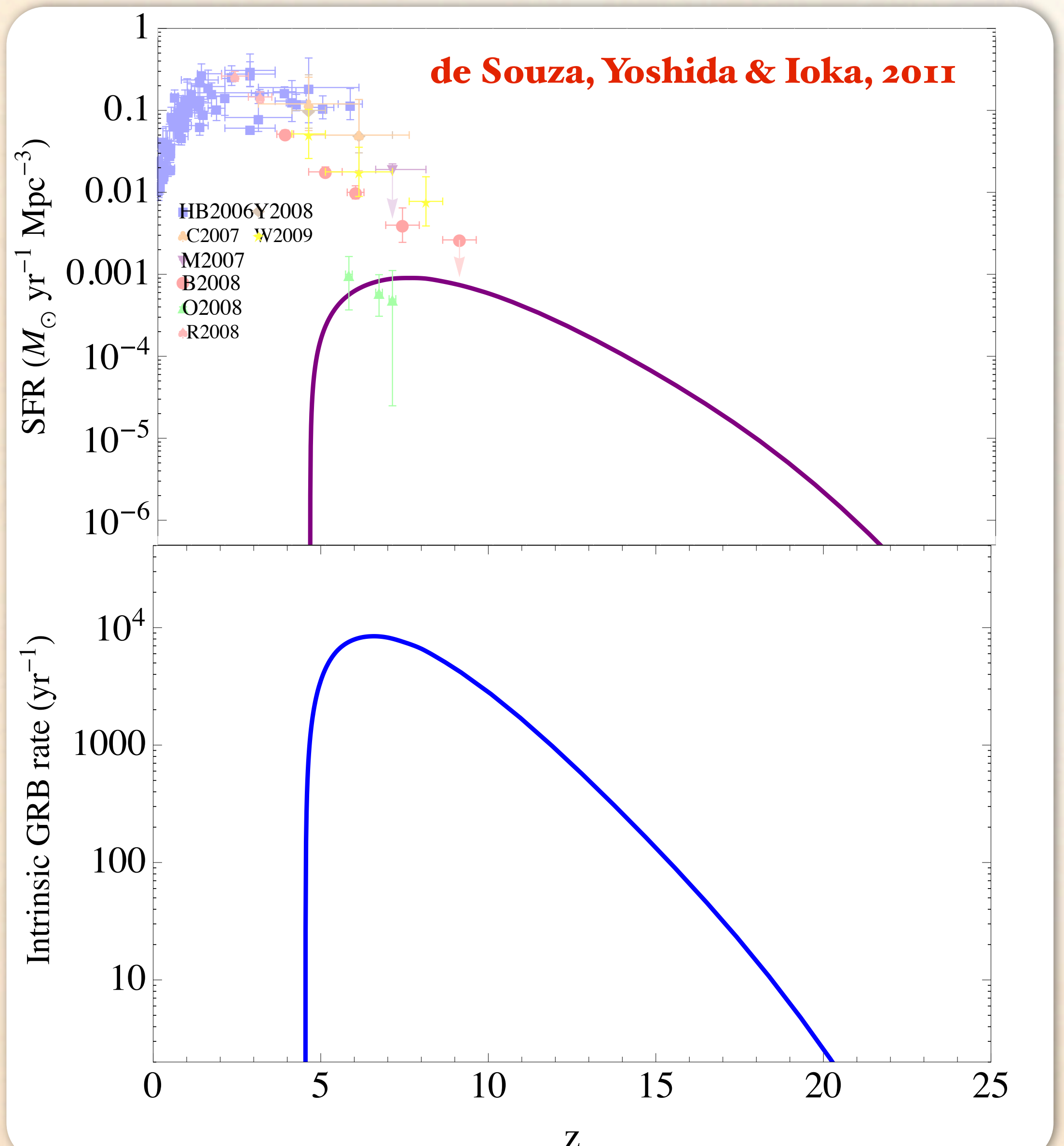


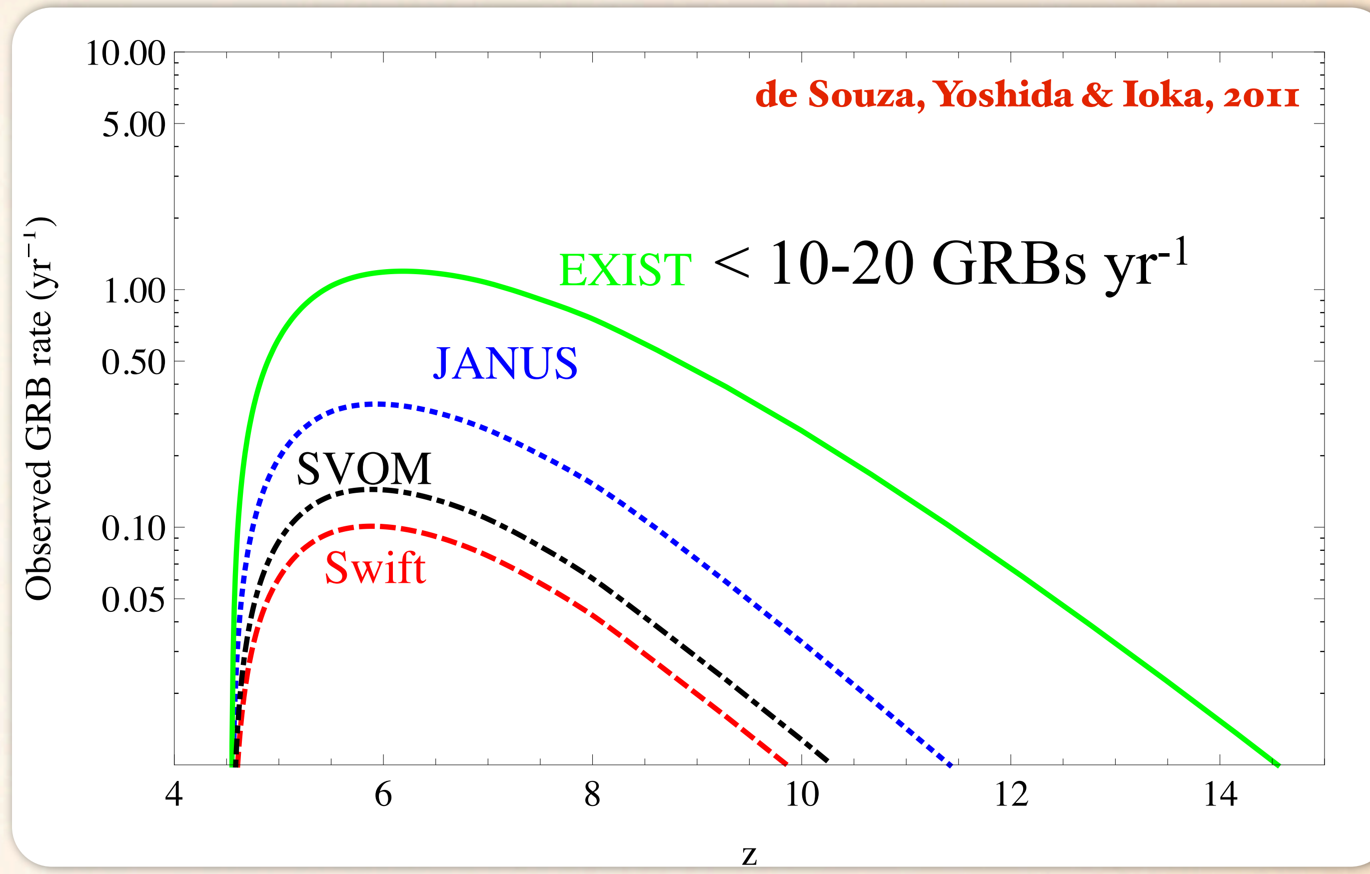


de Souza, Yoshida & Ioka 2011

Pop III GRBs

We employ a self-consistent model that considers inhomogeneous hydrogen reionization, chemical evolution of the intergalactic medium and H_2 photoionization

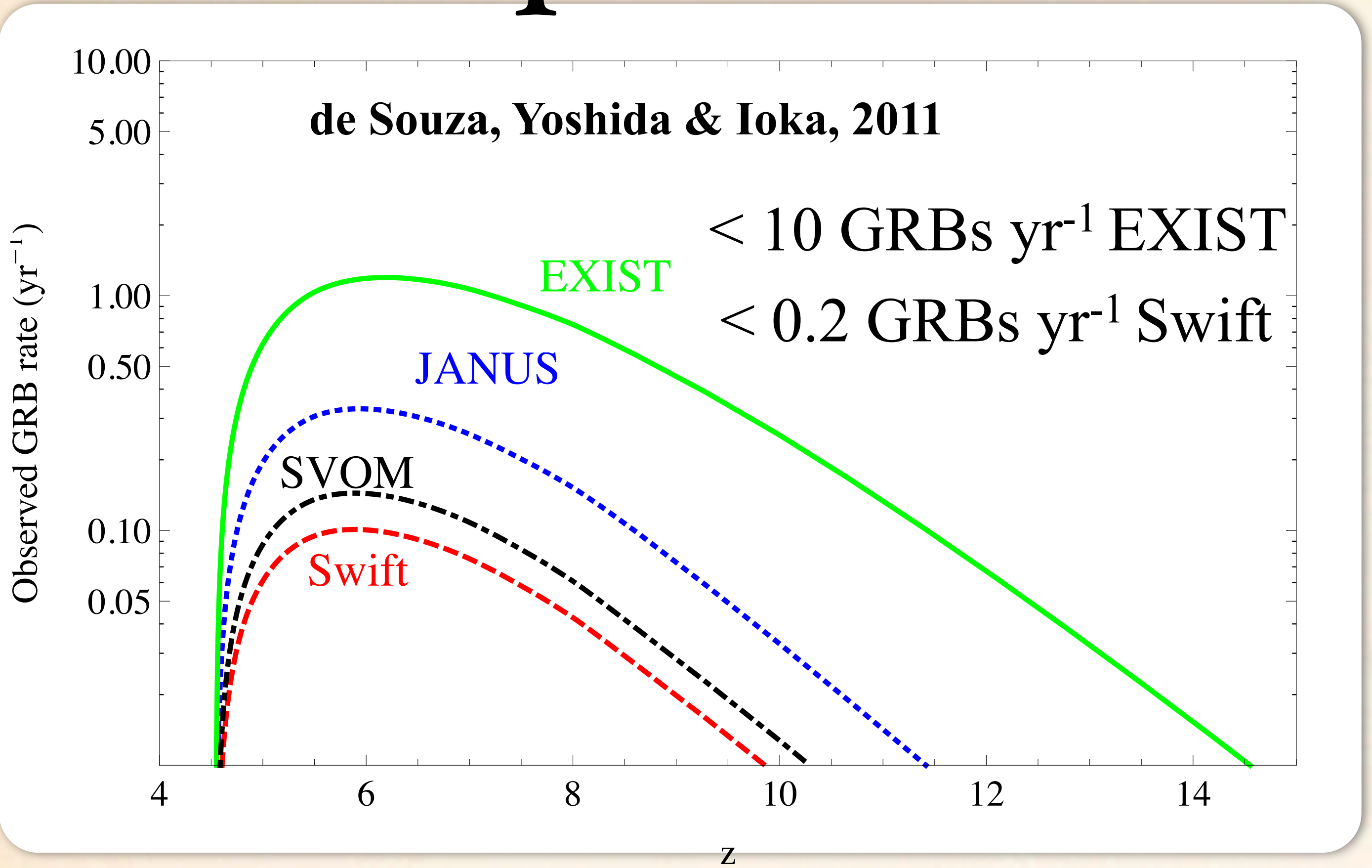




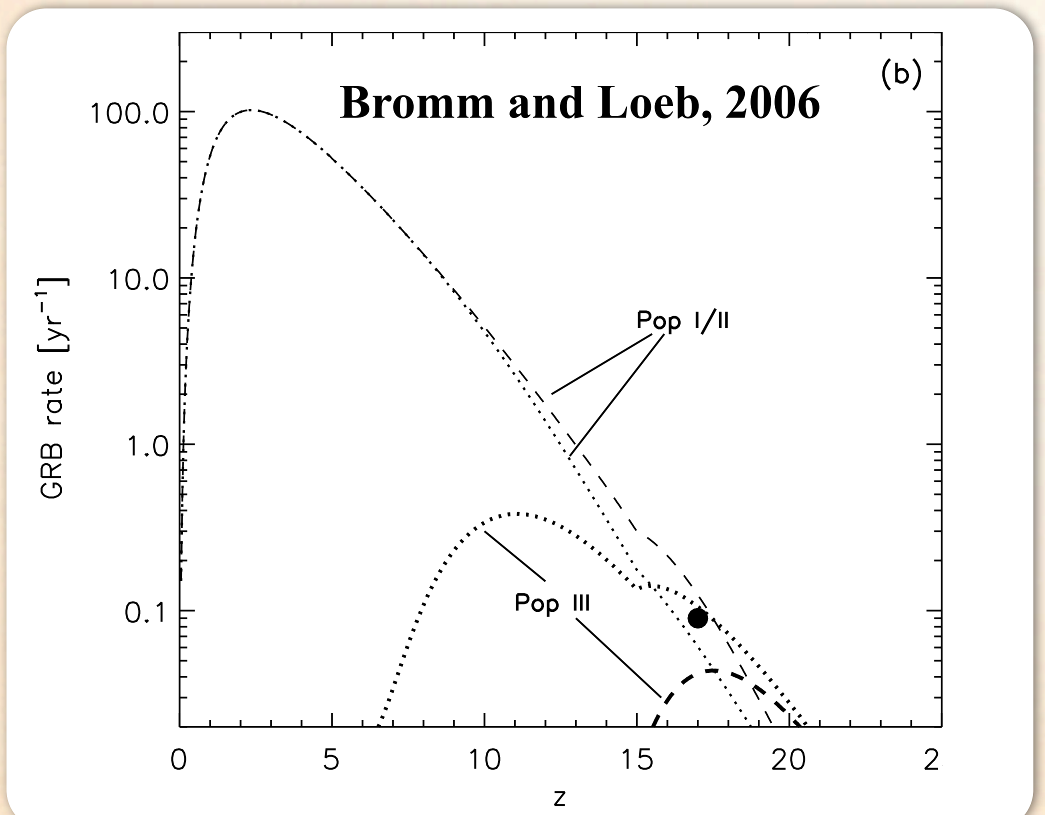
A fraction of the bursts at high-z will be dark due IGM absorption.

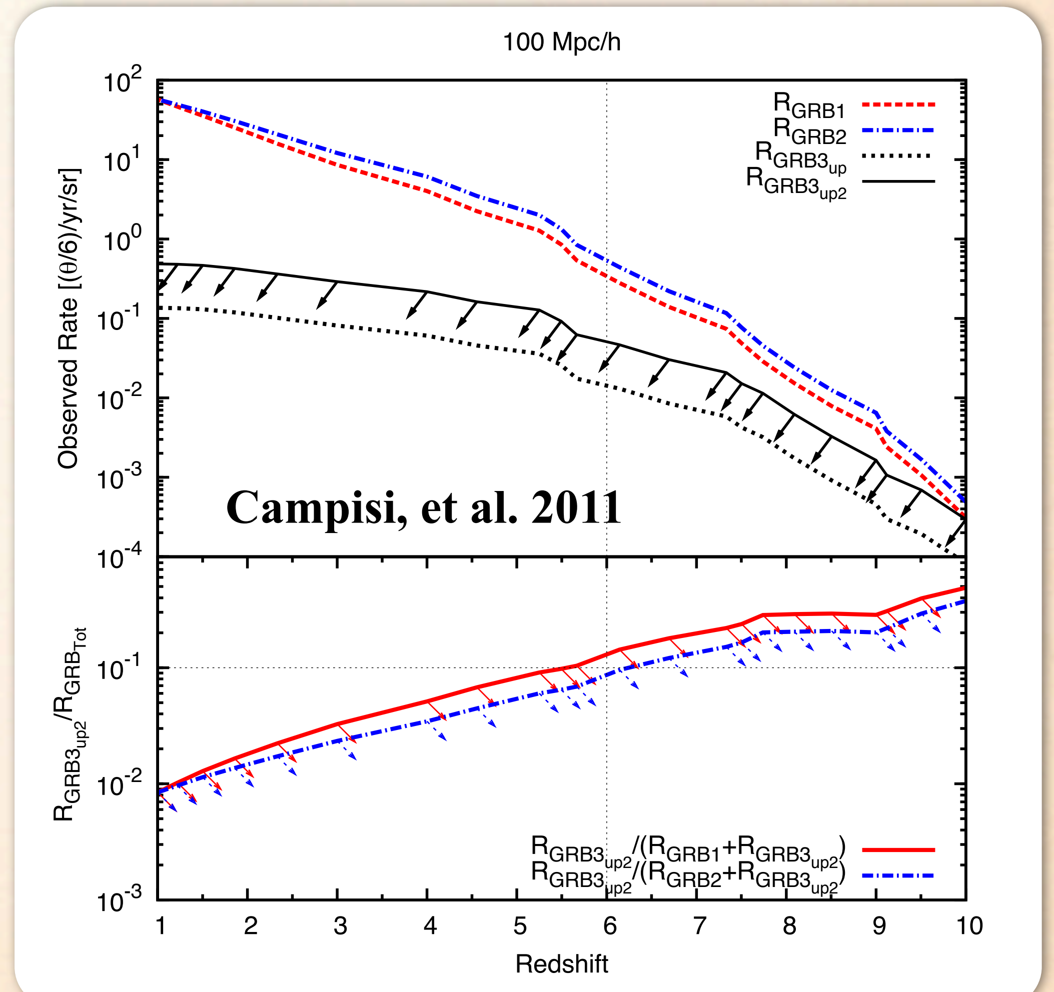
A couple of unknown quantities: Cosmic Metallicity Evolution, star formation efficiency, IMF, ...

Pop III GRB Event Rate



Different approaches reaches similar results.

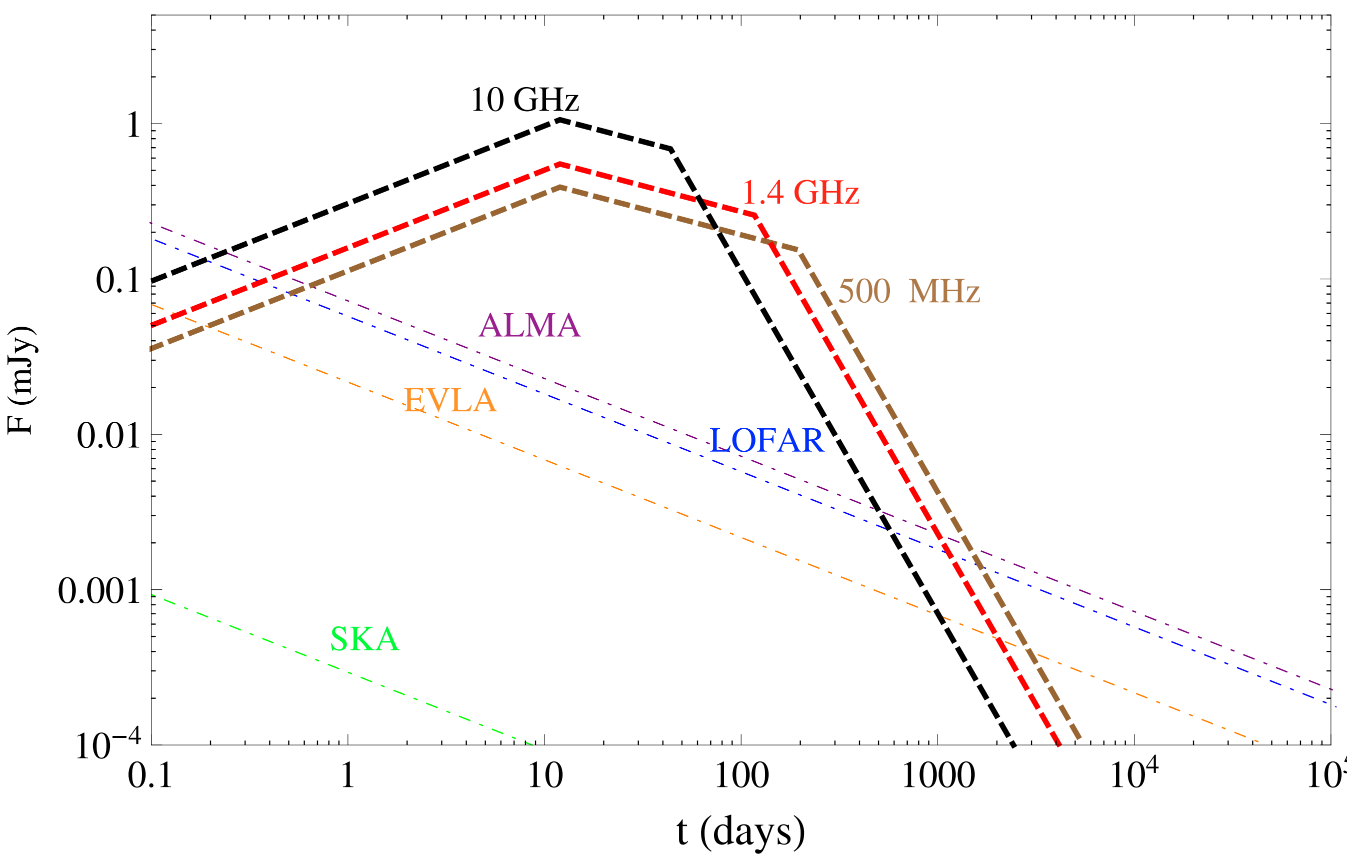




Pop III Radio Afterglows

We expect ~ 10 – 10^4 radio afterglows above ~ 0.3 mJy on the sky with ~ 1 year variability and mostly without GRBs (orphans), which are detectable by ALMA, EVLA, LOFAR, and SKA. de Souza, Yoshida & Ioka 2011.

GRB radio afterglows may be detected up to z ~ 30 (Ioka & Mészáros 2004)



The theoretical light curve of radio afterglow of a typical Pop III.2 GRB at $z \sim 10$, de Souza et al. 2011

Optical Afterglows

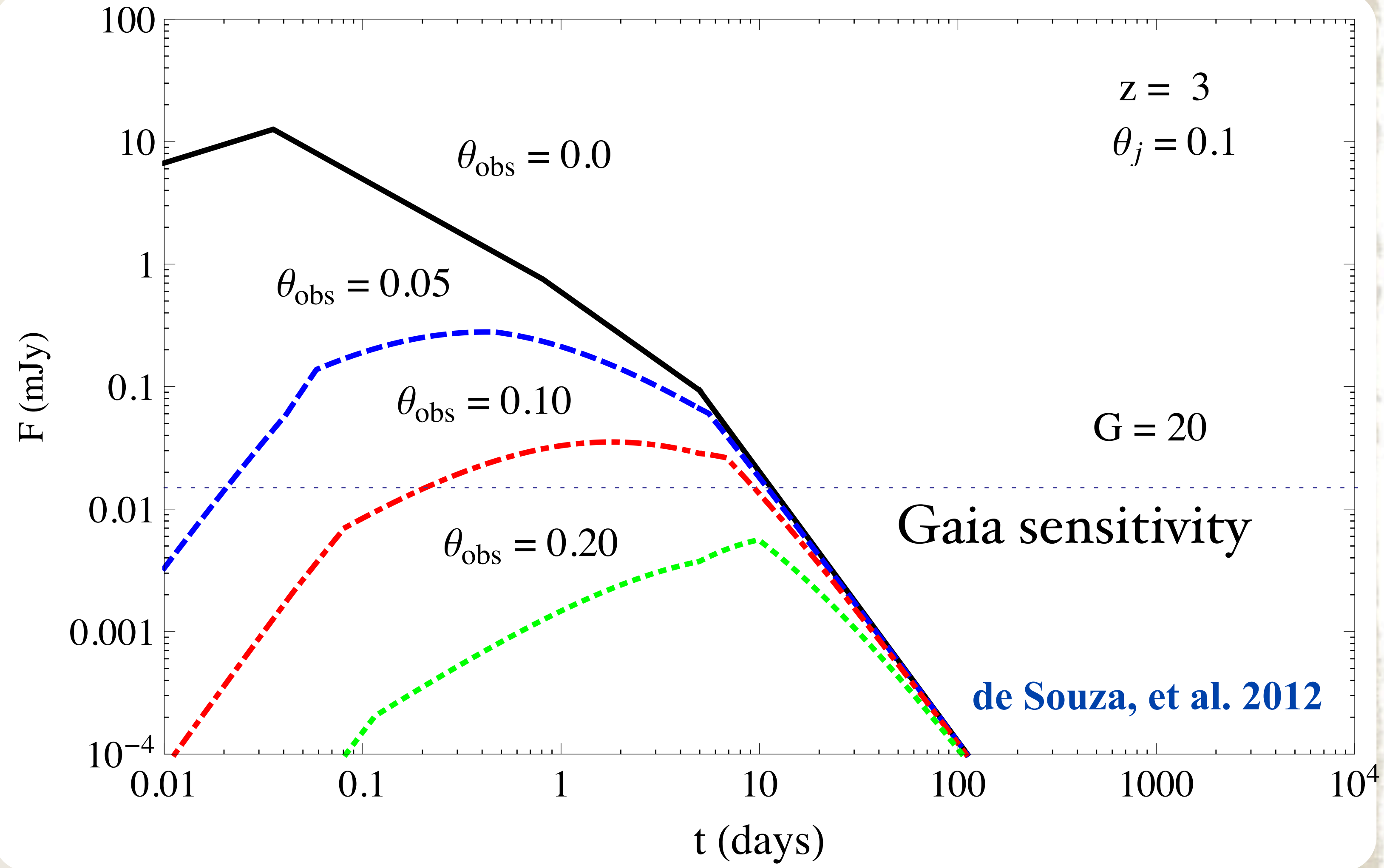
Gaia mission

- One of the most ambitious projects of modern Astronomy. It aims at the creation of a very precise tridimensional, dynamical and chemical census of our Galaxy, from astrometric, spectrophotometric and spectroscopic data.
- Gaia satellite will perform observations of the entire sky in a continuous scanning created from the coupling rotations and precessions movements, called ‘scanning law’.
- **One type of possible transients to be detected by Gaia are gamma-ray burst optical afterglows.**

Pop III GRBs Afterglows

Due a large number of free parameters, the Afterglow events are generated via Monte-Carlo.

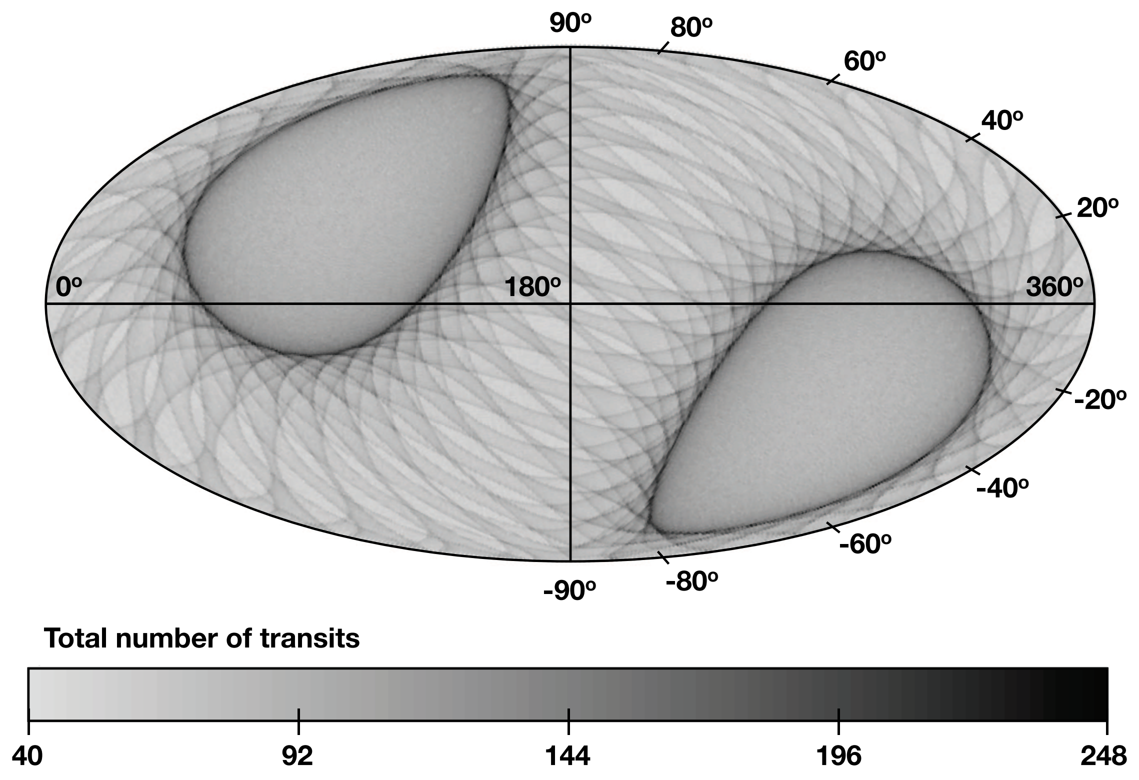
Then, by simulating the Gaia's scanning law we derive the probability to observe Pop III GRBs events.



Example of afterglows light-curve from gamma-ray bursts (GRBs) triggered by Pop III.2 stars.

Gaia Scanning Law

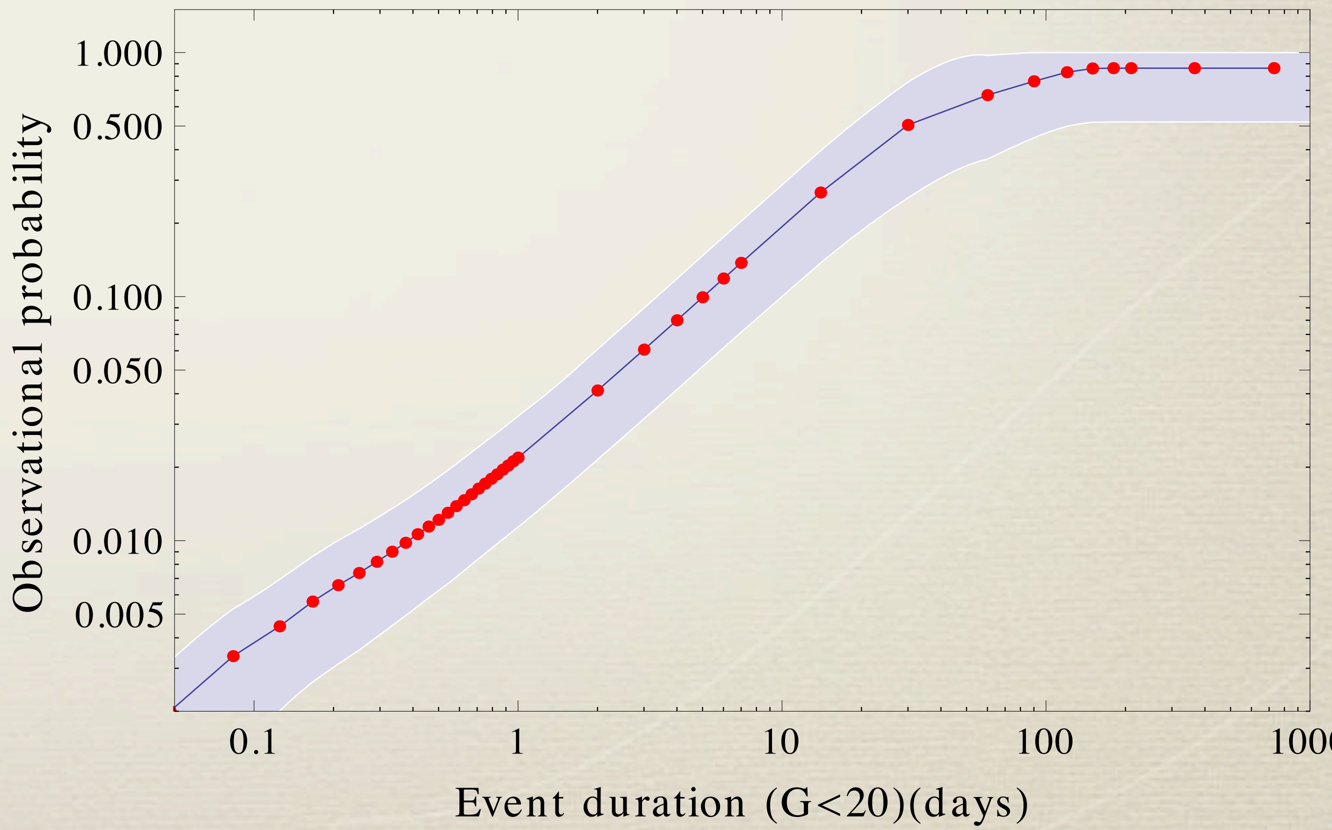
Gaia will observe the entire sky, using a continuous scanning formed by the coupling of rotation and precession movements - the ‘scanning law’.

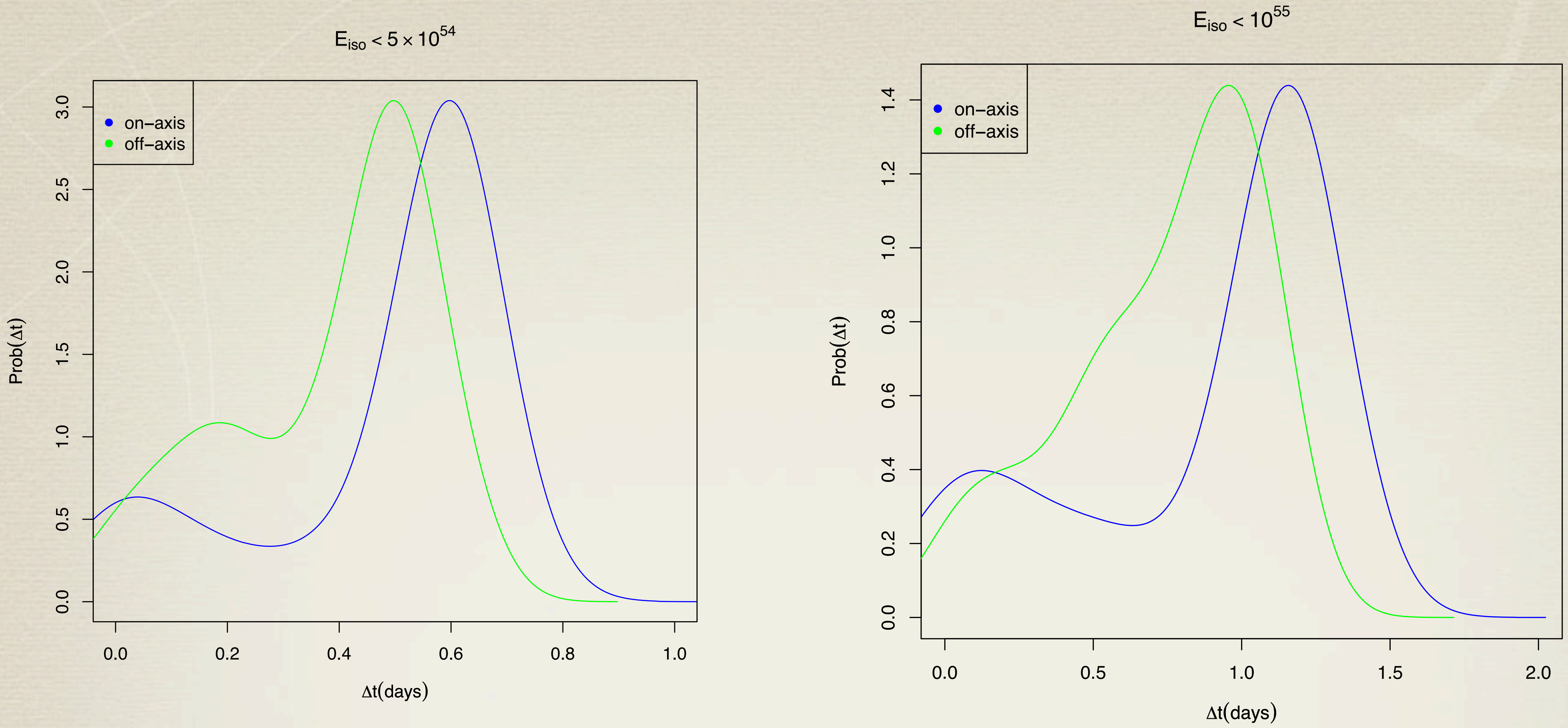


For a given coordinate in the sky, we compute the inverse Gaia scanning law adopting the Gaia Data Processing and Analysis Consortium’s nominal implementation of it.

We randomly select a point in time during the entire mission lifetime in order to place an event of a certain duration Δt.

We check if that event was observed, within a time window of 4.4 seconds around each transit - this is the time needed for the signal to cross the detection CCD and enter the confirmation CCD. **If there is a superposition between the event duration and this time window, the event is considered detected!!!!**





Probability of an OA to appear above the Gaia flux limit during given time interval.

Gaia can observe up to 6.27 ± 3.4 Pop III off-axis afterglows and 5.43 ± 3.1 on-axis during the 5 years nominal mission. Which implies that among all afterglows observed by Gaia, a non-negligible percentage of them could have Pop III stars as progenitors.

SUMMARY

- High-z GRBs are a very promissor way to probe early Universe and the first generation of stars.
- Even one GRB observed at $z > 10$, would already rule out models with WDM mass < 2 keV
- We also expect a larger number of radio afterglows than X-ray prompt emission because the radio afterglow is long-lived, for $\sim 10^2$ days
- Star formation history already constrained up to $z = 9.4$, Ishida, de Souza & Ferrara, 2011
- Fast identification is essential: automatic classifier to indentify objects of interest.
- Realistic simulations of Pop III GRBs SED and light curves to study the best strategy to look for such objects.

REFERENCES

- de Souza, R., Yoshida, N., Ioka, K., A&A, 533, A32, 2011
- Ishida, E. E. O, de Souza, R., Ferrara, A., MNRAS, 418, 500, 2011.
- de Souza, R., Krone-Martins, A., Ishida, E., Ciardi, B., arXiv:1112.6270