GRB population studies: clues on their cosmic evolution

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High Redshift Gamma Ray Bursts in the JWST era
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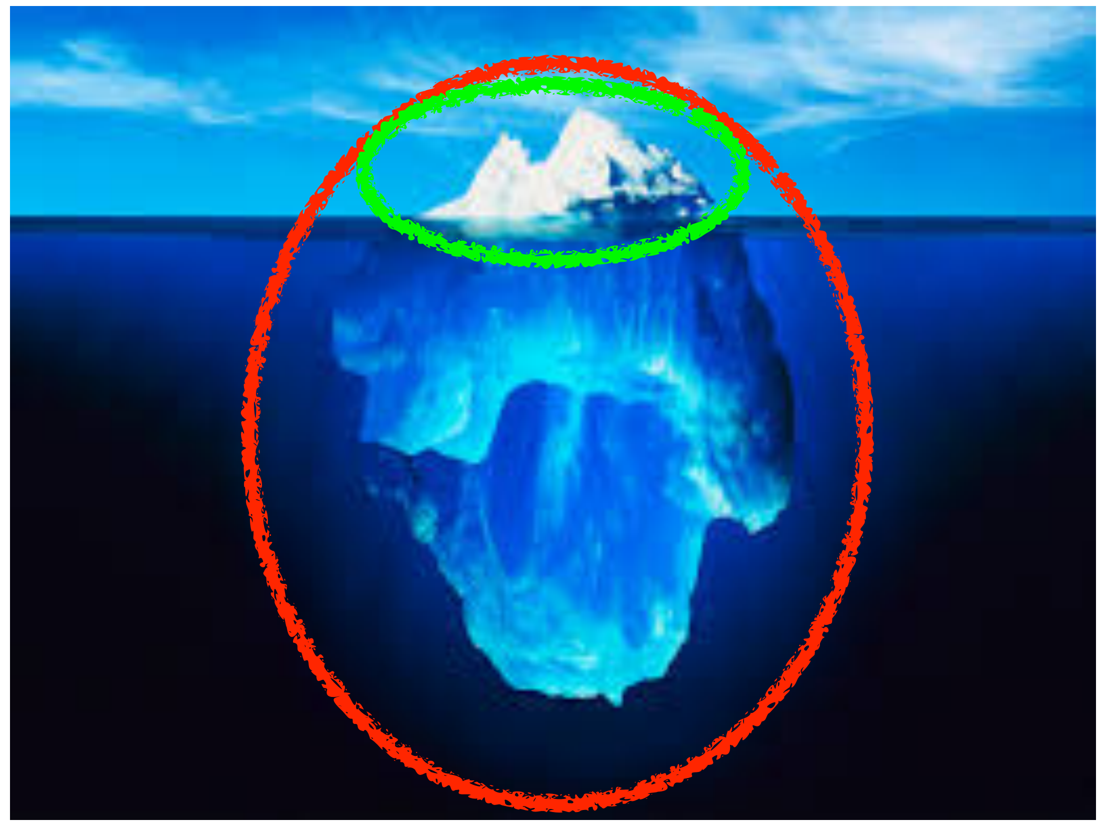
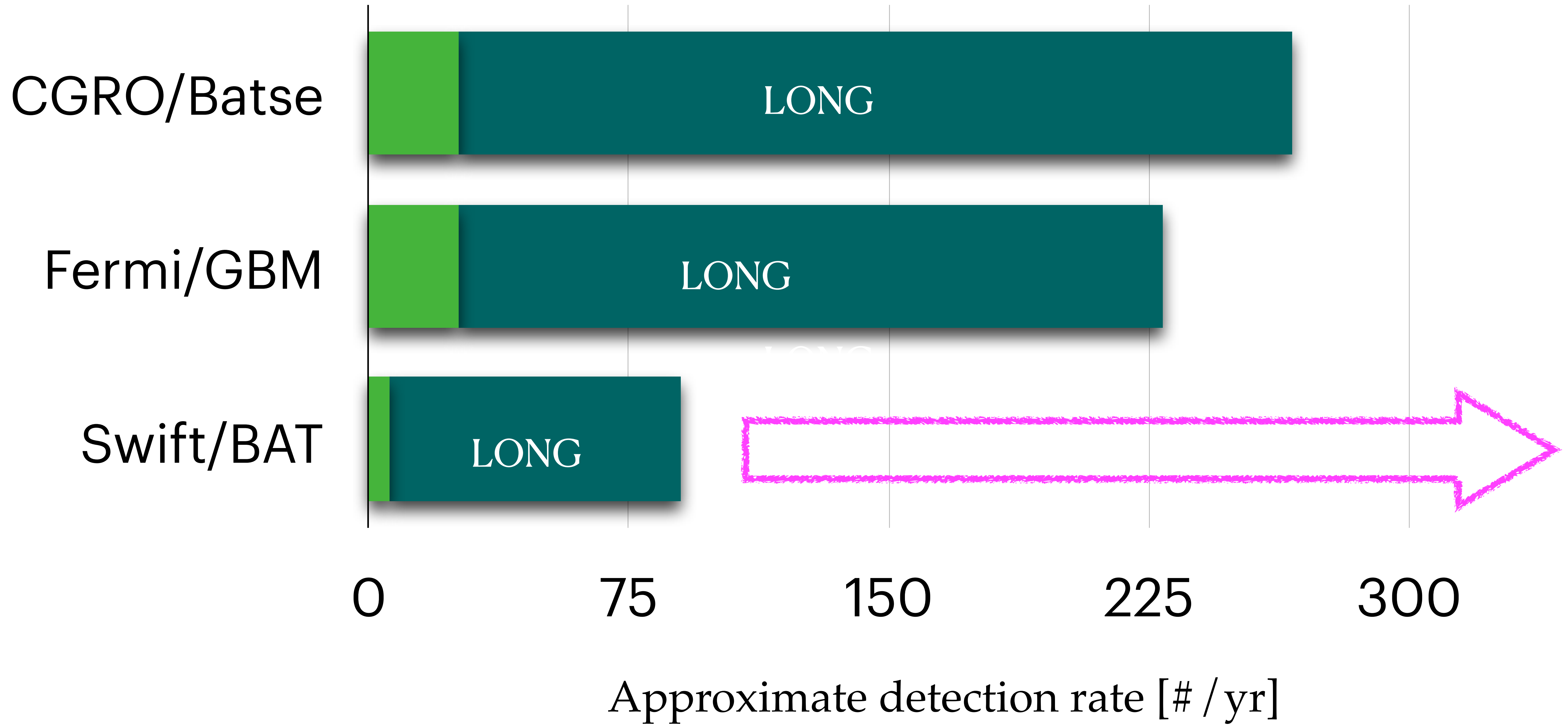
The tip of the iceberg

Long and short GRBs:
obs. duration (><2 sec) + multi-feature classification

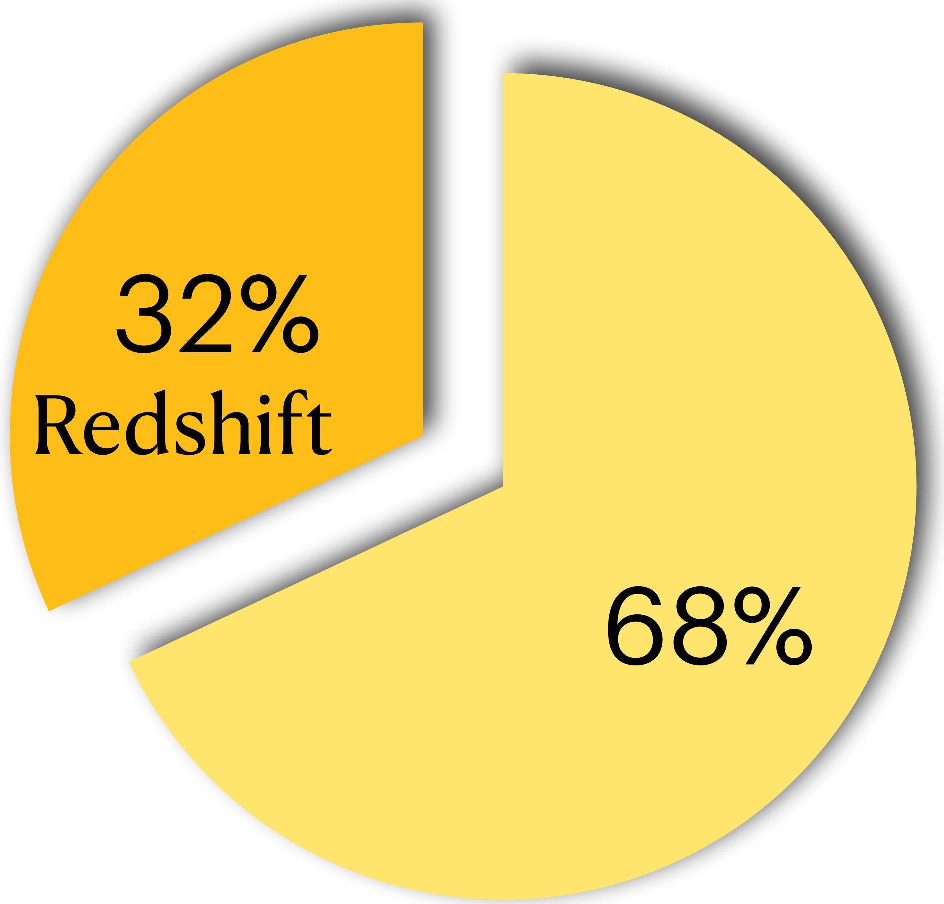
but (overlap and contamination - e.g. Bromberg 2013)

- GRB 211211A - Rastinejad et al 2022
- GRB 200826A - Rossi et al. 2022

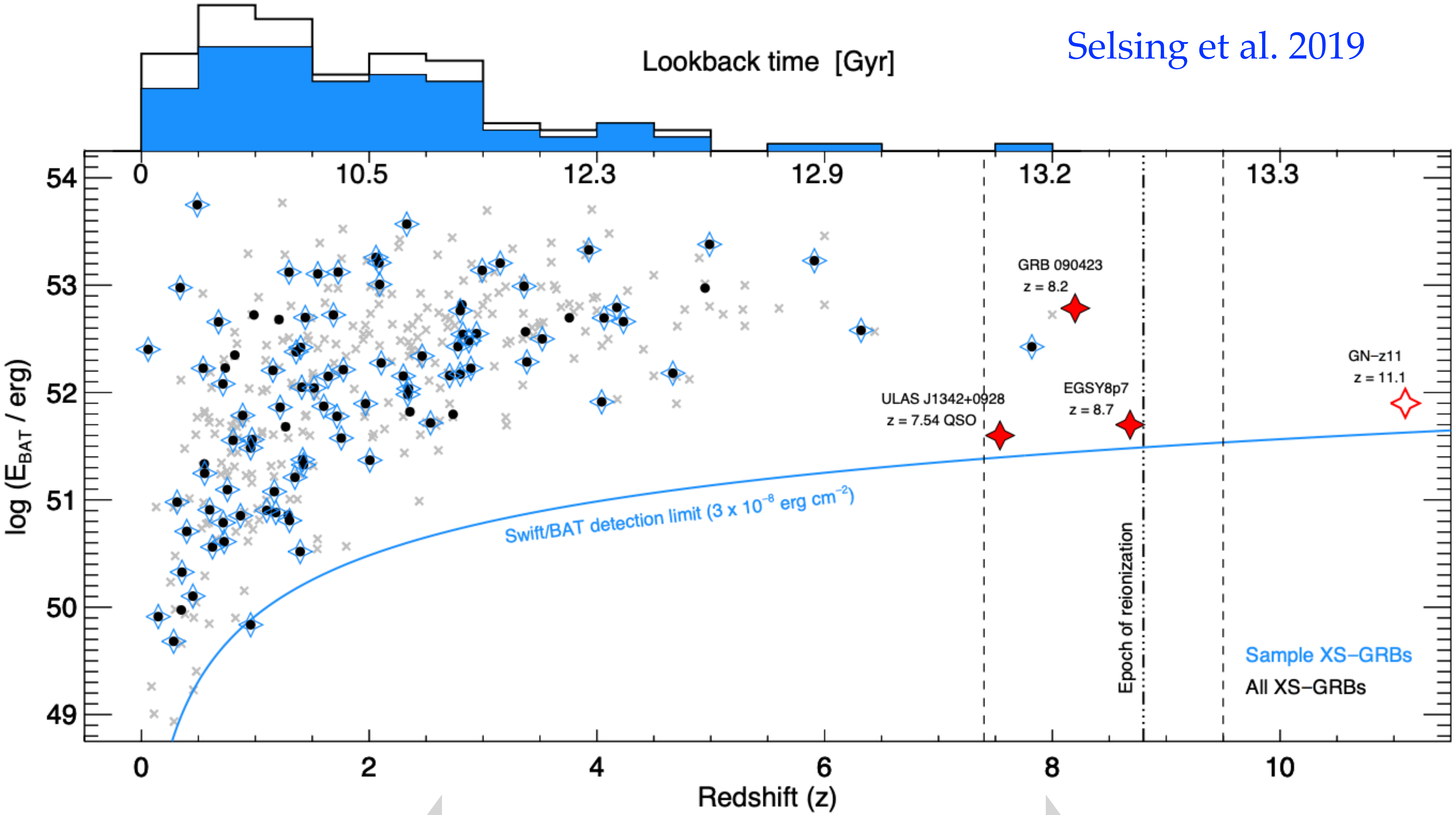




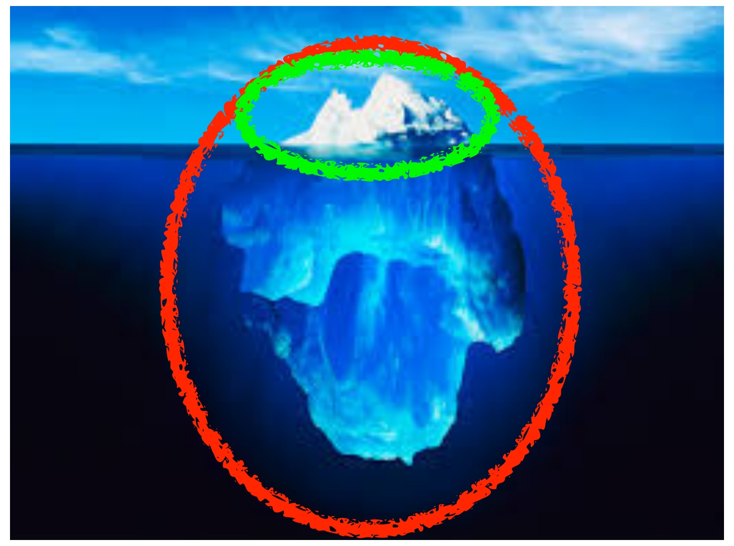
Combination of instrumental / observational biases



The tip of the iceberg



Selsing et al. 2019



$\Phi(L)$

Population luminosity function

Event cosmic rate

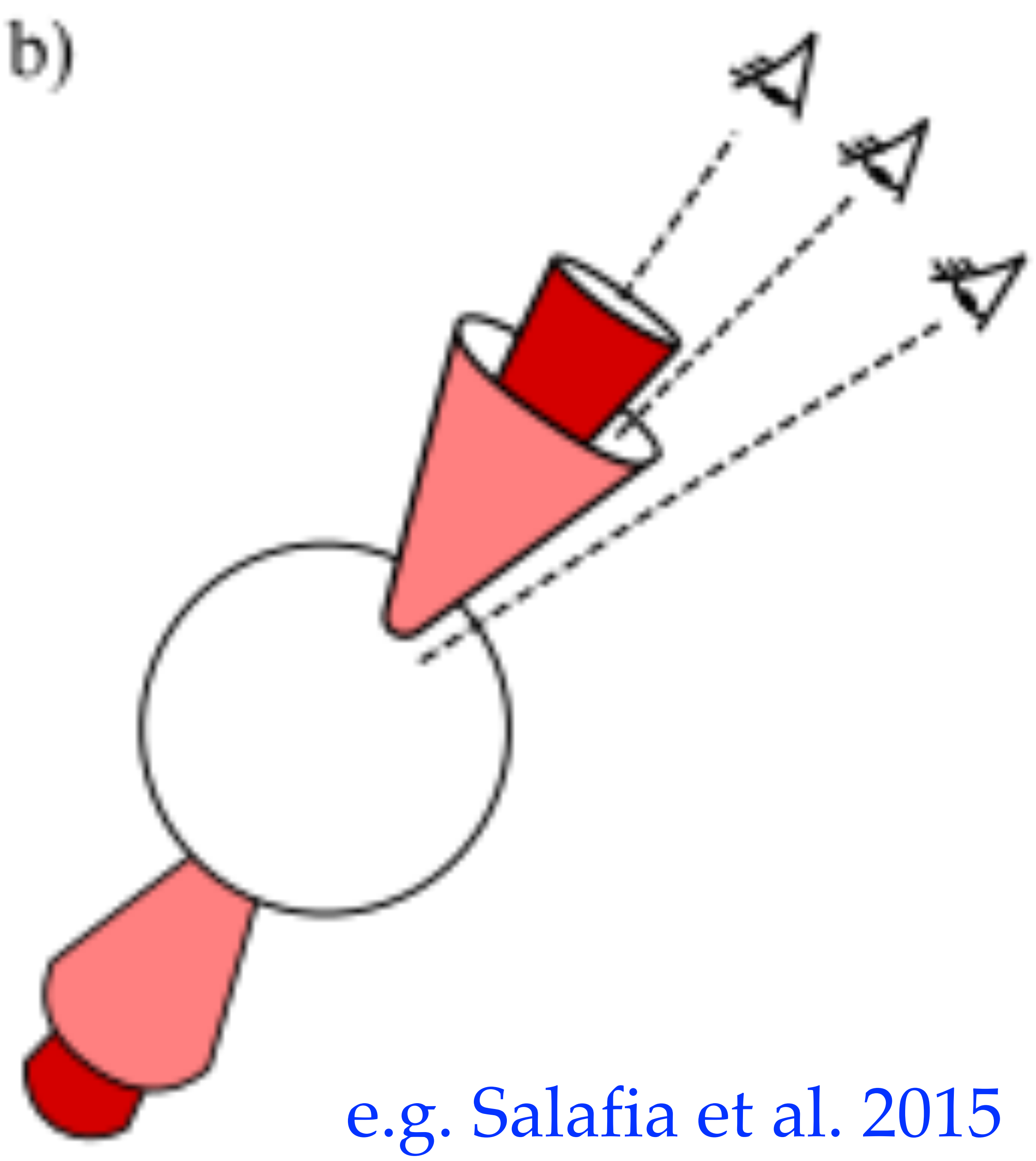
$\Psi(z)$

Physical motivations

$\Phi(L, z)$ & $\Psi(z)$

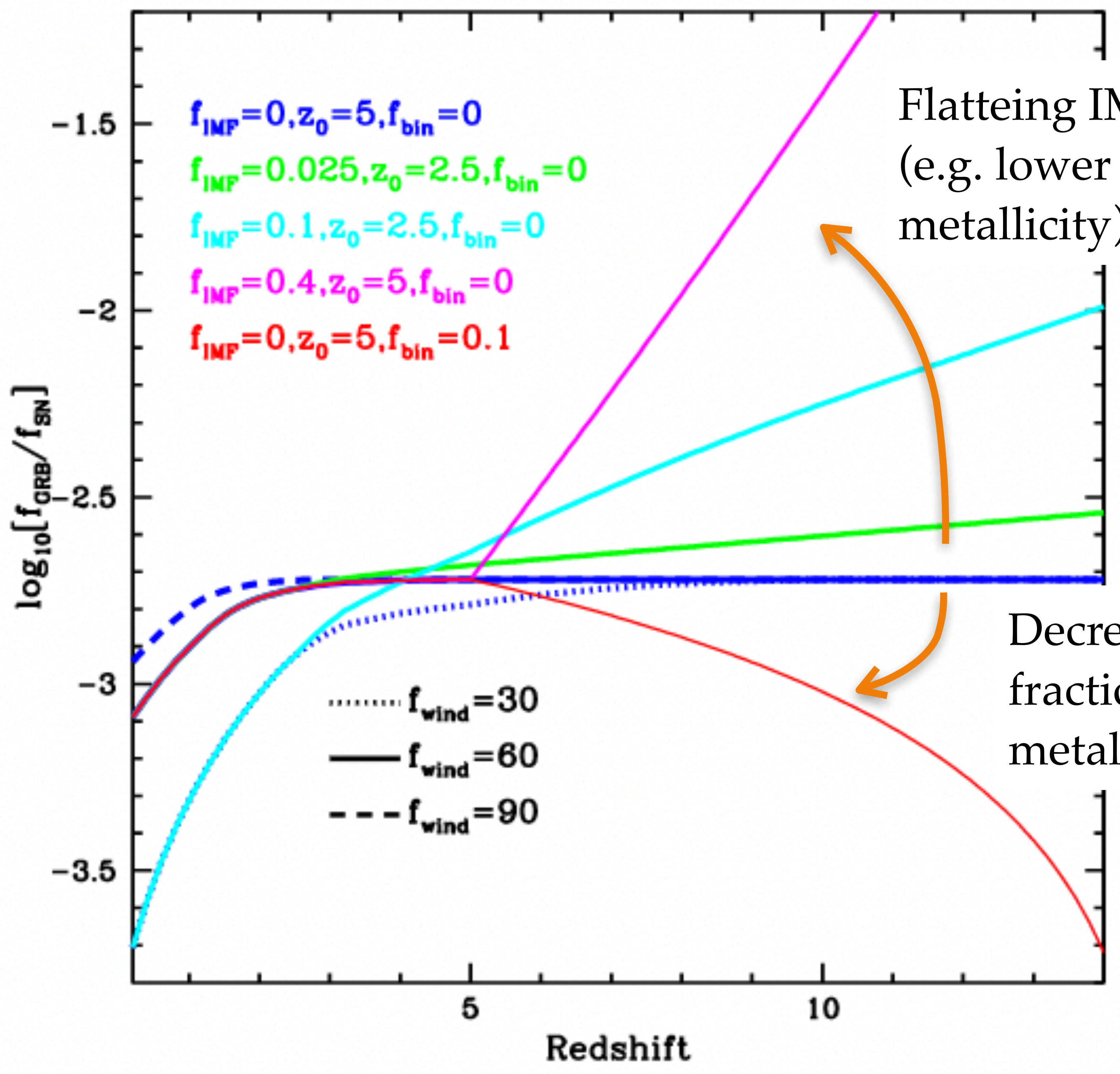
Progenitors and ambient

Jet properties



e.g. Salafia et al. 2015

Fryer+2022



Methods

Direct (non-parametric)

A 2D binned method - Lynden-Bell 1971
Kocevski+2006; Wu+2012;Yu+2015; Petrosian+2015; Tsvetkova+2017; Lloyd et al. 2019

B 2D binned method - Wanderman & Piran 2010

Parametric (forward folding)

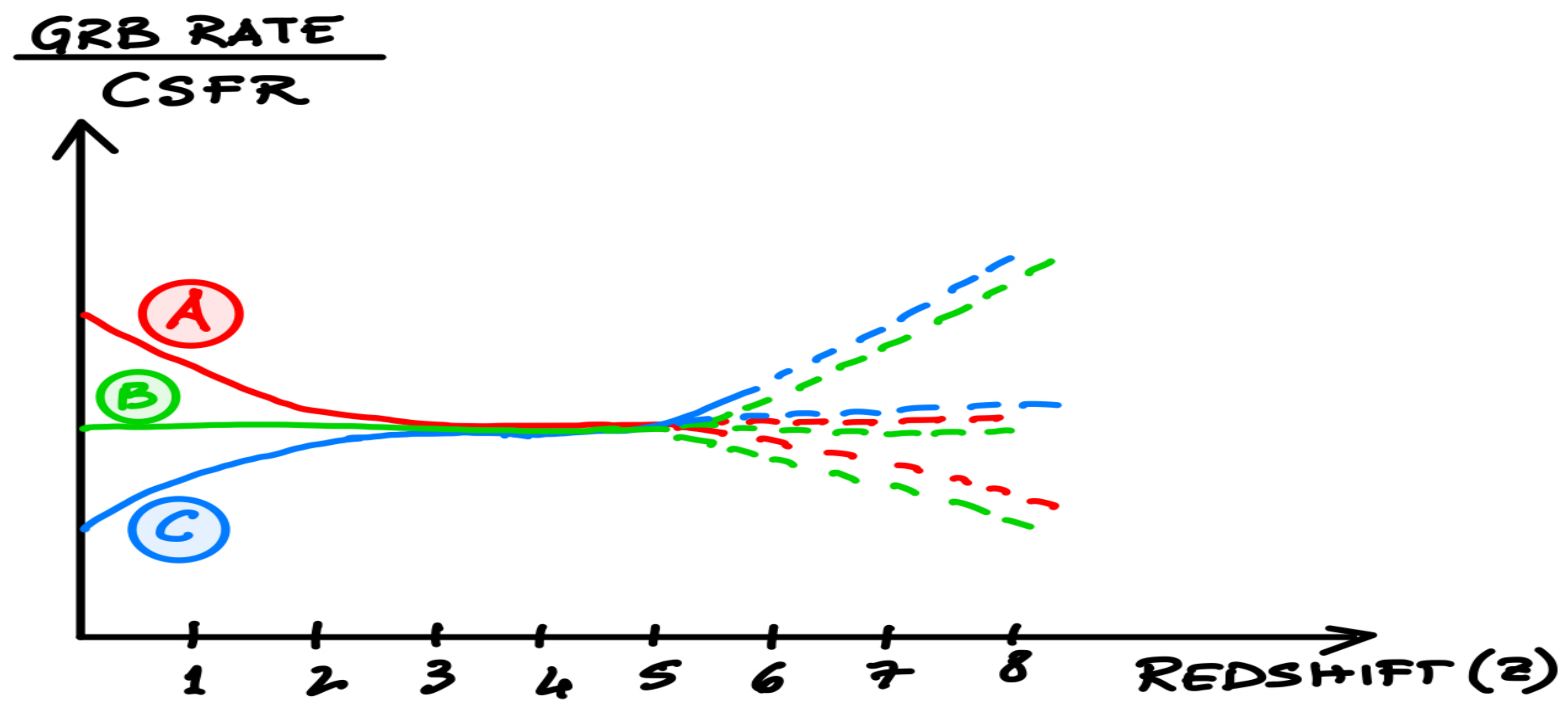
C Constrain model parameters by N(z), N(P) …
Daigne et al. 2006; Salvaterra et al. 2012; Ghirlanda et al. 2015; Palmerio & Daigne 2021

Agreement on

$$\Phi(L \,|\, \alpha = 1.5 \pm 0.25,\ \beta = 2.3 \pm 0.5,\ L_b = 10^{52.5 \pm 0.5})$$

Limitations and issues:

- Sample incompleteness
- Extrapolations
- Treat L,z independently



Limitations and issues:

- Degeneracy
- Often treat L,z independently

Jet opening angle (not accounted or a-posteriori)

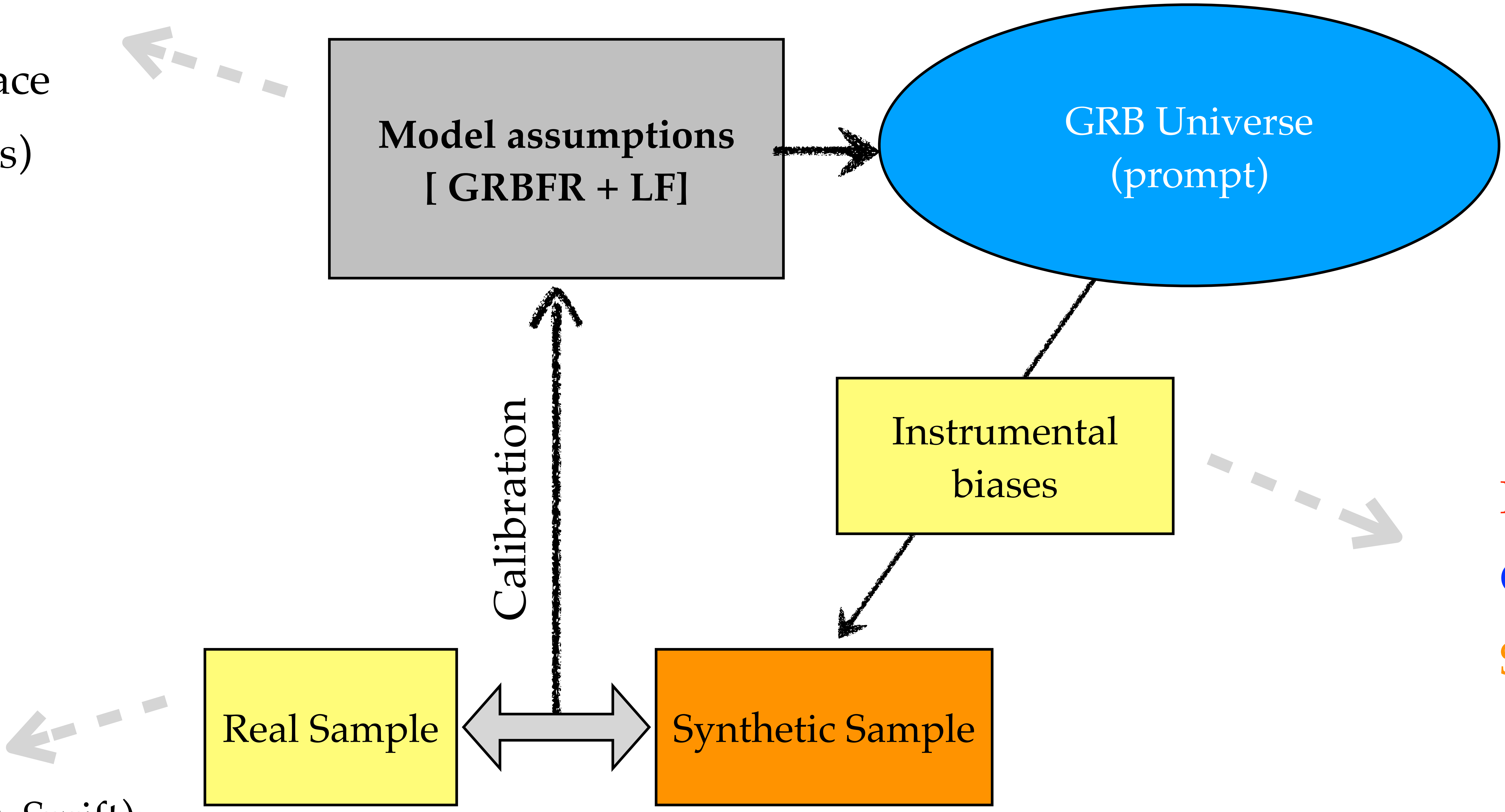
Long GRB population

Ghirlanda & Salvaterra 2022

1. Long GRBs follow a free-parametric $\Psi(z)$
2. Implement jet opening angle
3. Allow for both luminosity and rate density evolution

18-D parameter space

(11 free parameters)



Fermi/GBM

CGRO/Batse

Swift/BAT(z)

14 constraints (Fermi, CGRO, Swift):

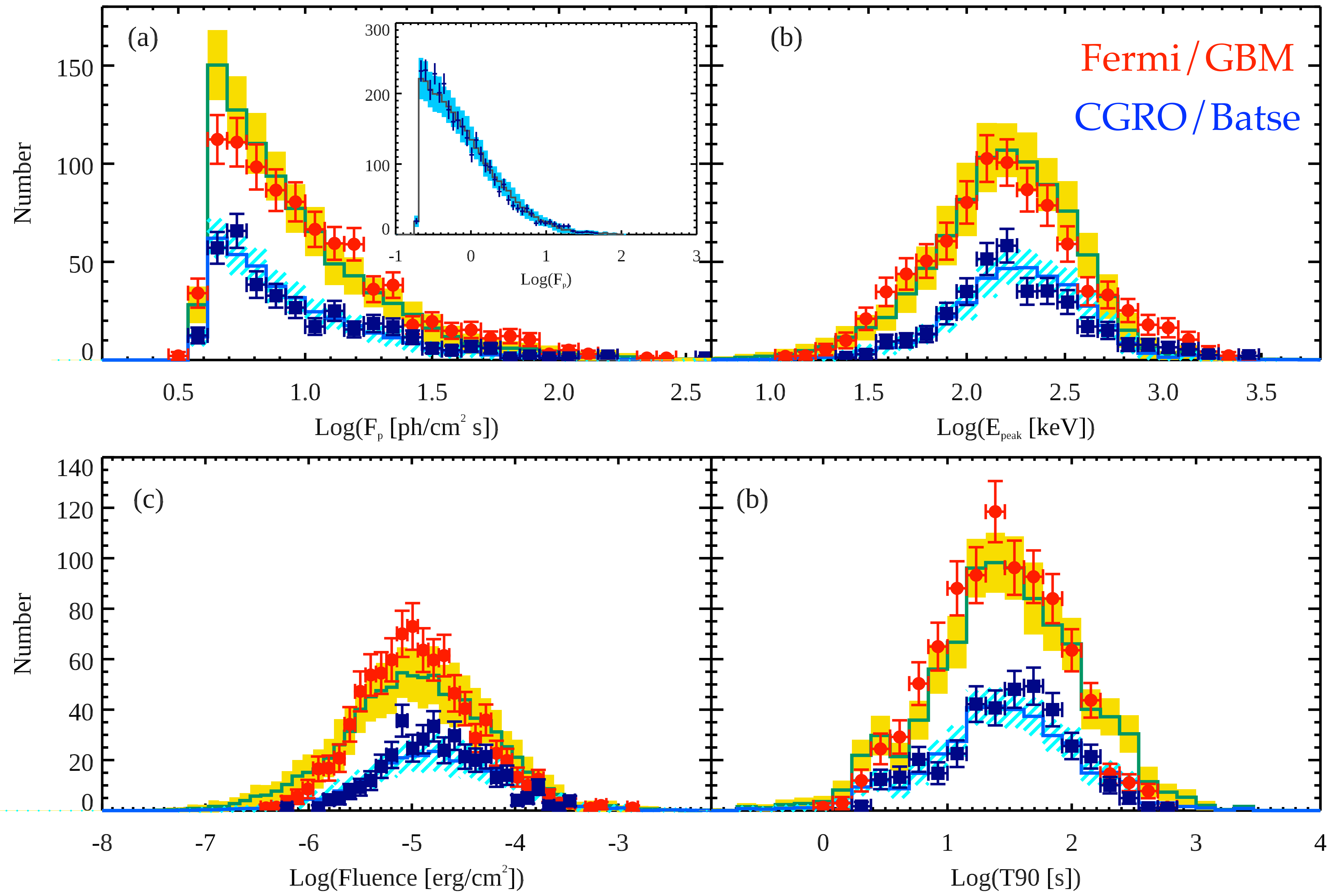
- Observer frame (e.g. Peak flux, Fluence, duration …)
- Rest frame (Energy, Luminosity, Redshift)

Method: MCMC + parallel stretch move

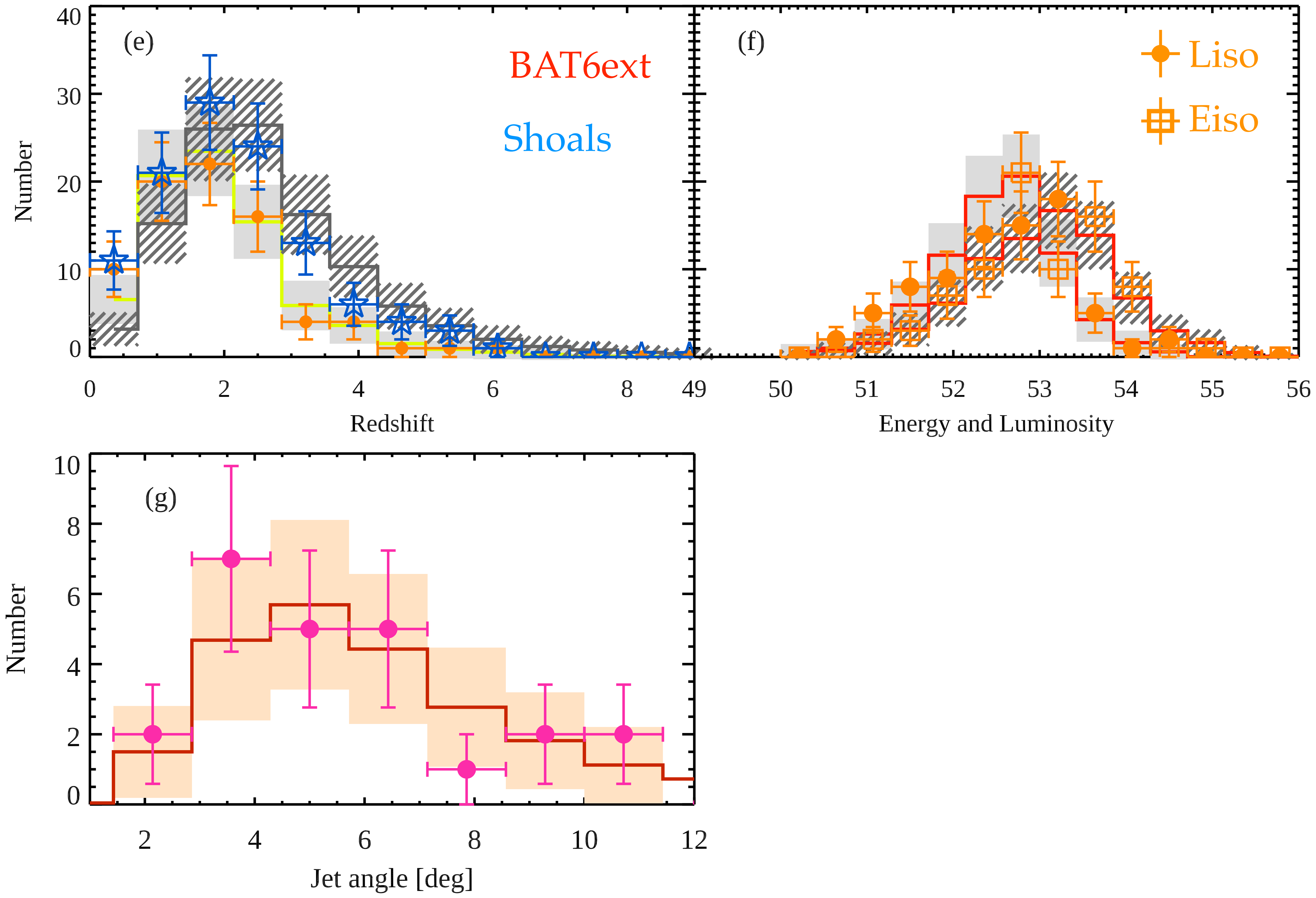
Long GRB population

Ghirlanda & Salvaterra 2022

Observer frame multiple constraints



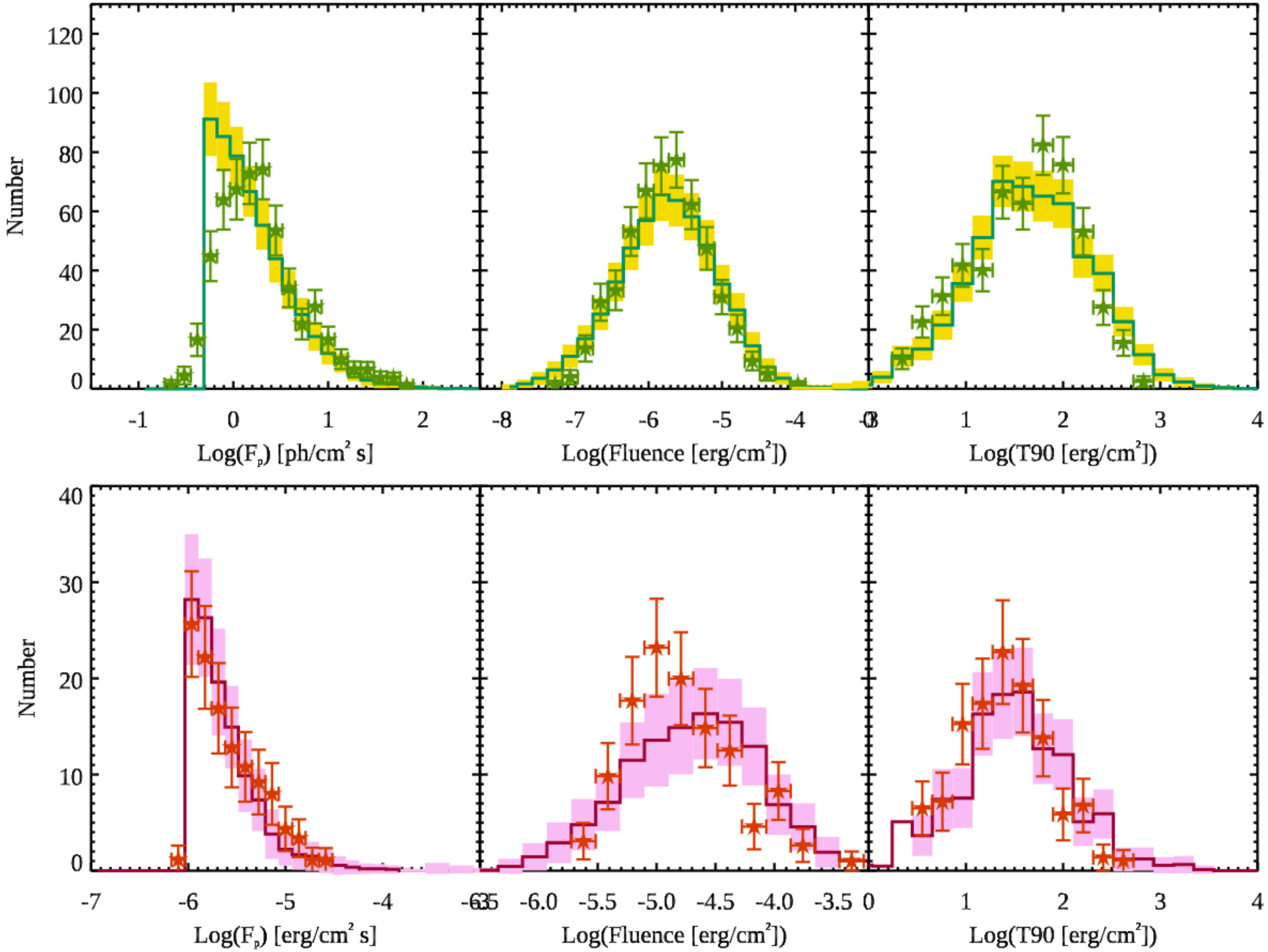
Rest frame multiple constraints



Long GRB population

Ghirlanda & Salvaterra 2022

A posteriori consistency checks

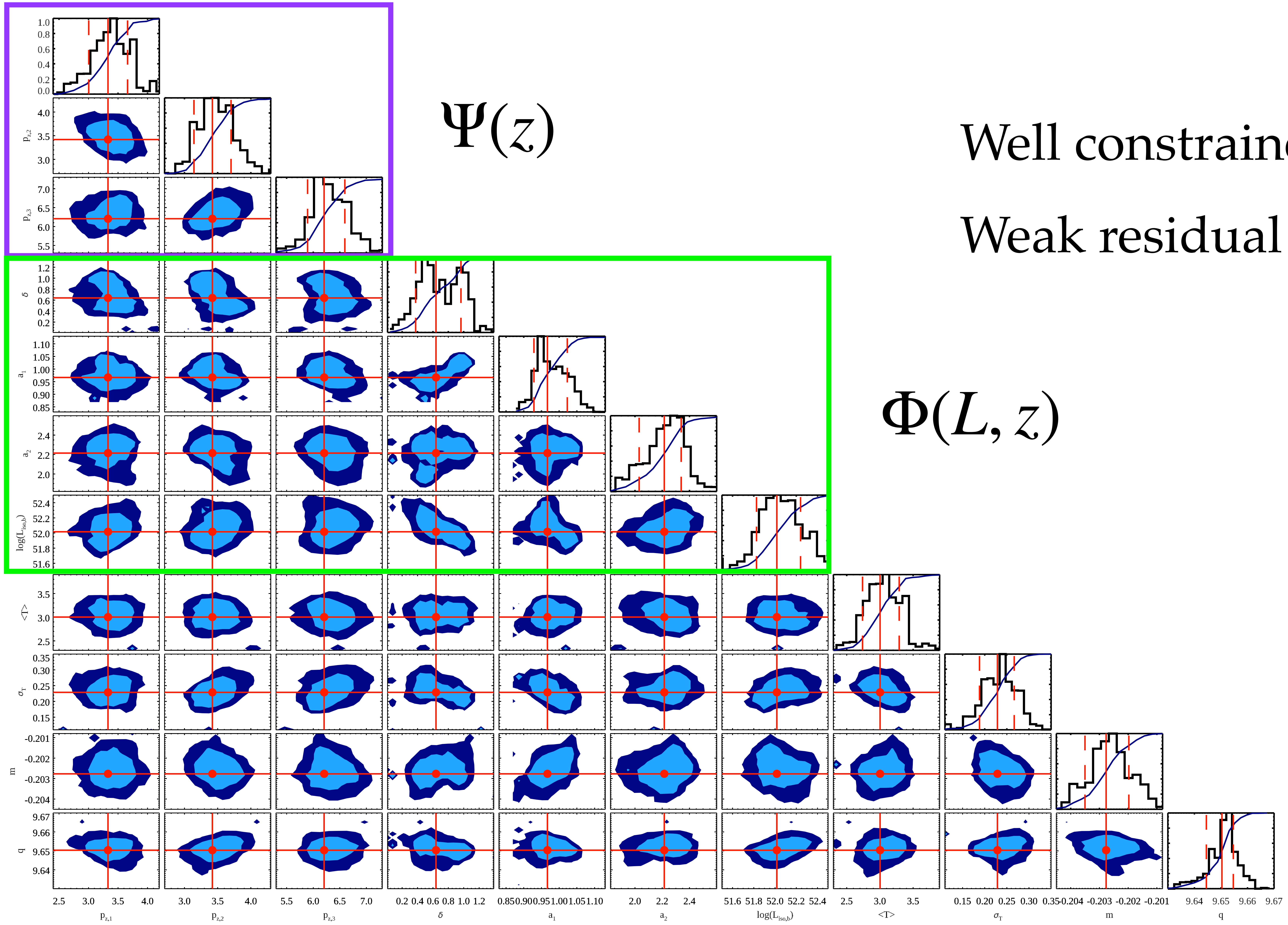


Beppo/SAX

Hete-II

Long GRB population

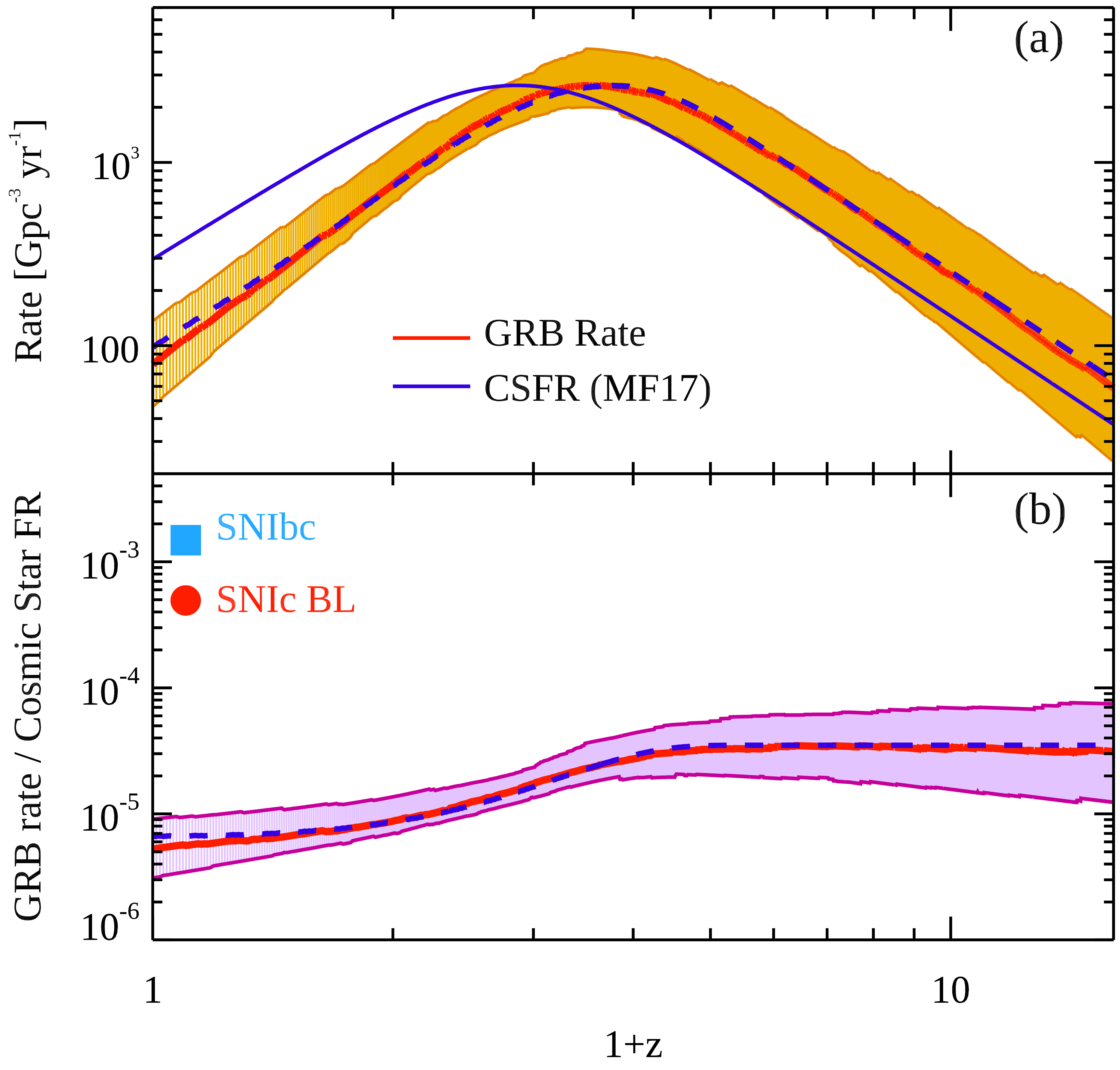
Ghirlanda & Salvaterra 2022



Well constrained parameters

Weak residual parameter correlation

Long GRB population



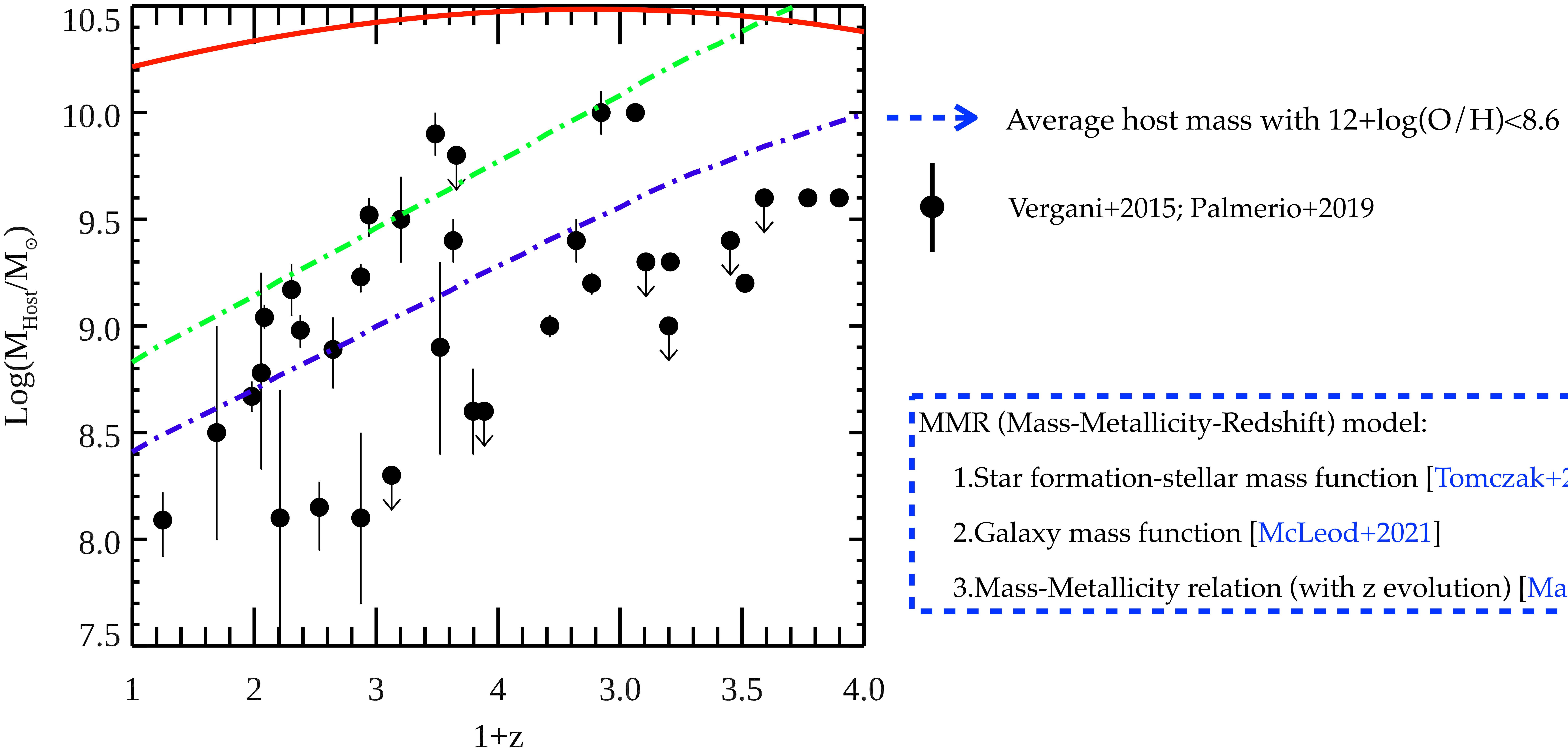
(A) GRB formation rate:

- Peaked at z~3
- Steeper than CSFR at low z and same slope at high z
- (Dashed line) host mass with 12+log(O/H)<8.6
- Local GRB rate (full population) $\sim 80 \pm 30\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$

(B) mild luminosity evolution $L_{\rm break}(z) = (51.0 \pm 0.8) \times (1+z)^{0.6\pm0.3}$

(C) ~1.3% of BL SNIc @ z=0 produce a successful jet (~7% at z>3)

Long GRB population

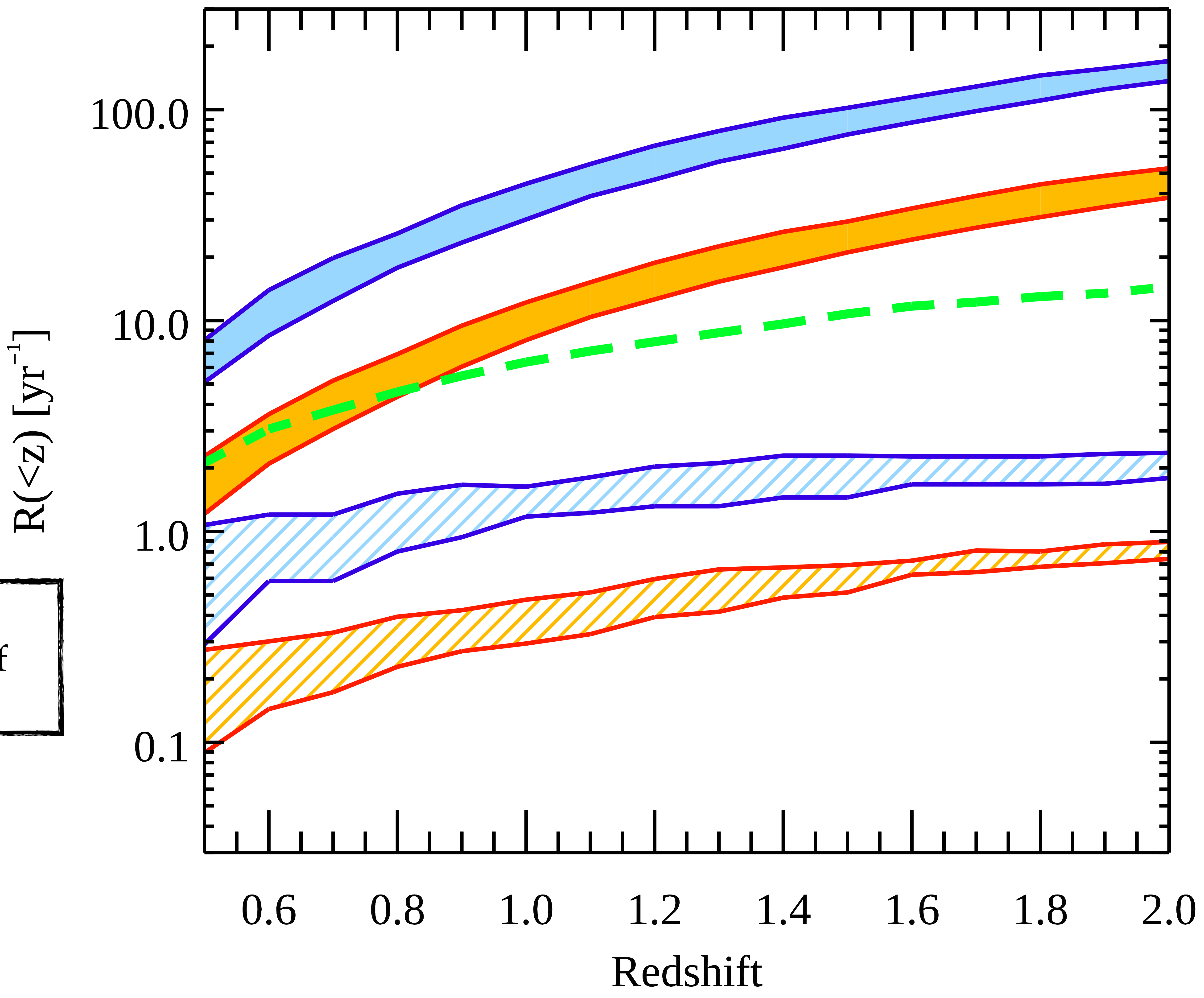


MMR (Mass-Metallicity-Redshift) model:

1. Star formation-stellar mass function [Tomczak+2014]
2. Galaxy mass function [McLeod+2021]
3. Mass-Metallicity relation (with z evolution) [Maiolino+2008]

Long GRB population

Ghirlanda & Salvaterra 2022



~2.5% of Fermi and 1% of Swift detected bursts @ z<2 should be off axis events (conservative estimate).

The redshift retrieval efficiency of Swift detected bursts is slightly decreasing with redshift and ~30% at z=2

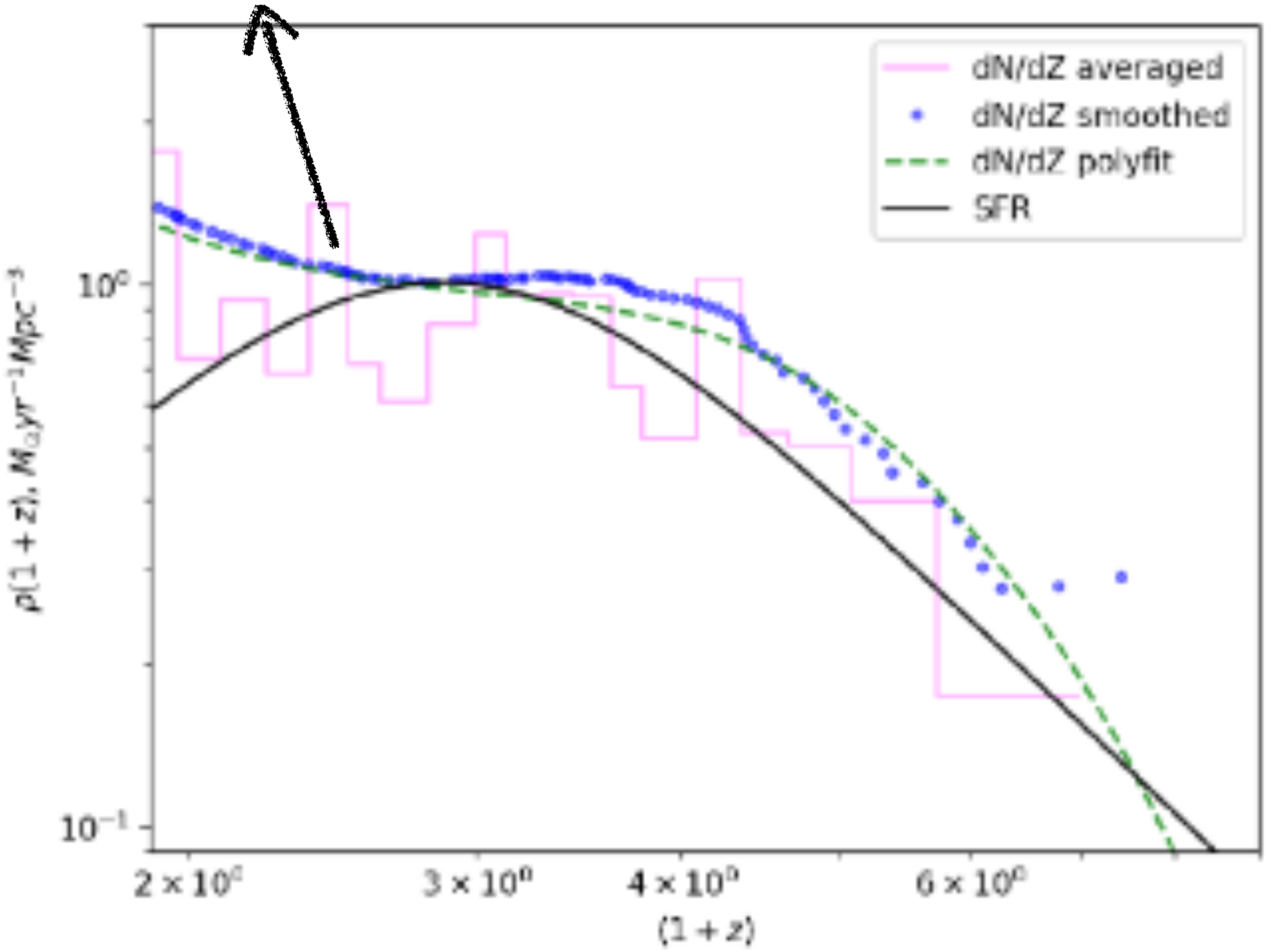
About 14% (Fermi) and 10% (Swift) @ z<0.5 should be off axis events.

Low redshift excess ??

Claim for a low redshift excess of long GRBs with respect to the SFR

Lloyd-Ronning+2019

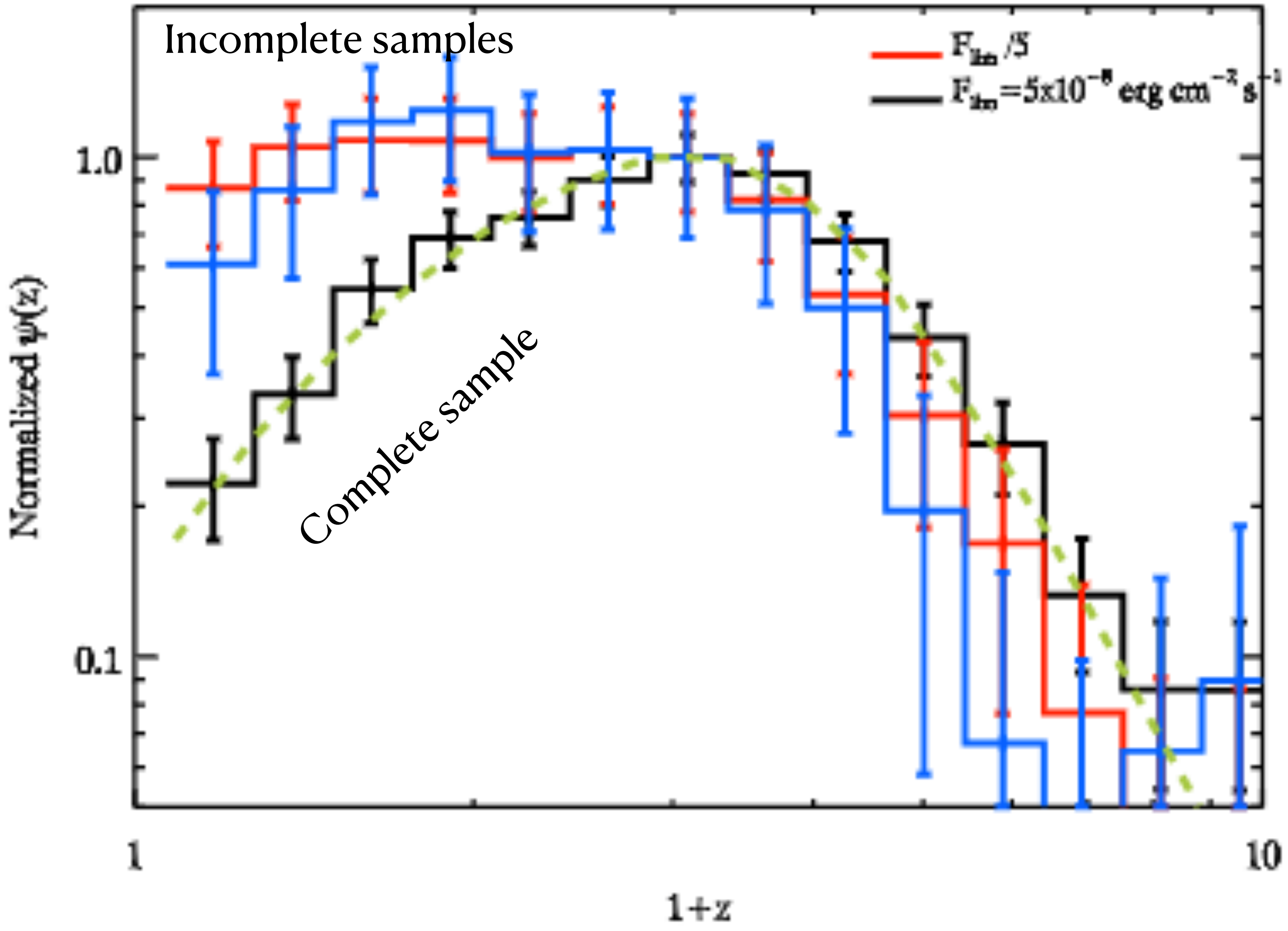
Non parametric method — (L-z plane) [Petrosian+2015; Yu+2015; Tsvetkova+2017; Lloyd-Ronning+2019]



BUT

Pescalli et al. 2016 demonstrated that the low redshift excess is due to sample incompletesess

Pescalli+2016

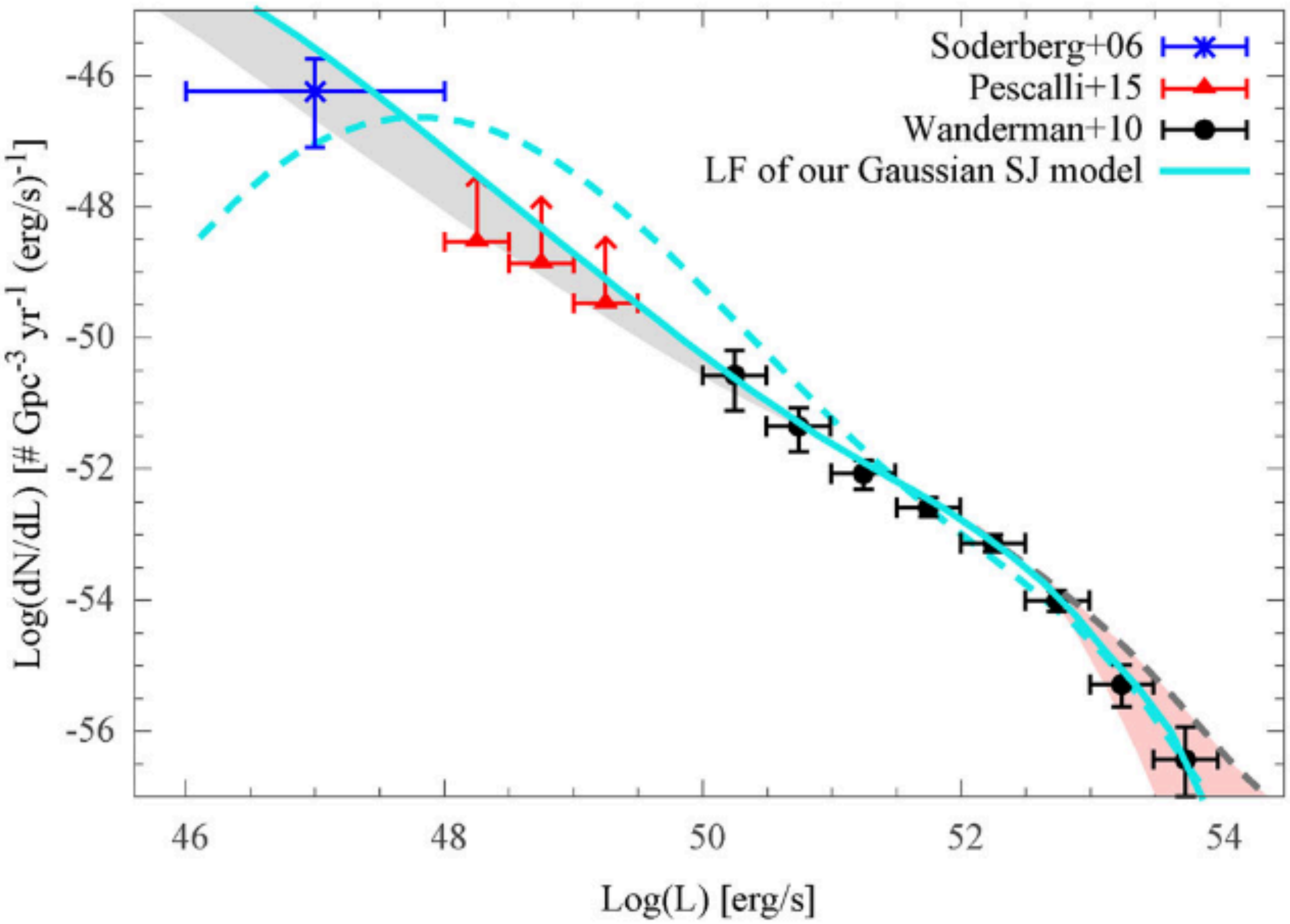


Low redshift excess is EXCLUDED by:

1) parametric studies (GG&RS2022) exclude at $>5\sigma$ low redshift excess (Eq.2 of Lloyd+2019)
2) Pescalli et al. 2016
   (See also Briant+2021 and Le+2020)
3) Host masses (see also Jessie's talk)

Luminosity function

Pescalli et al. 2015; Salafia et al. 2015

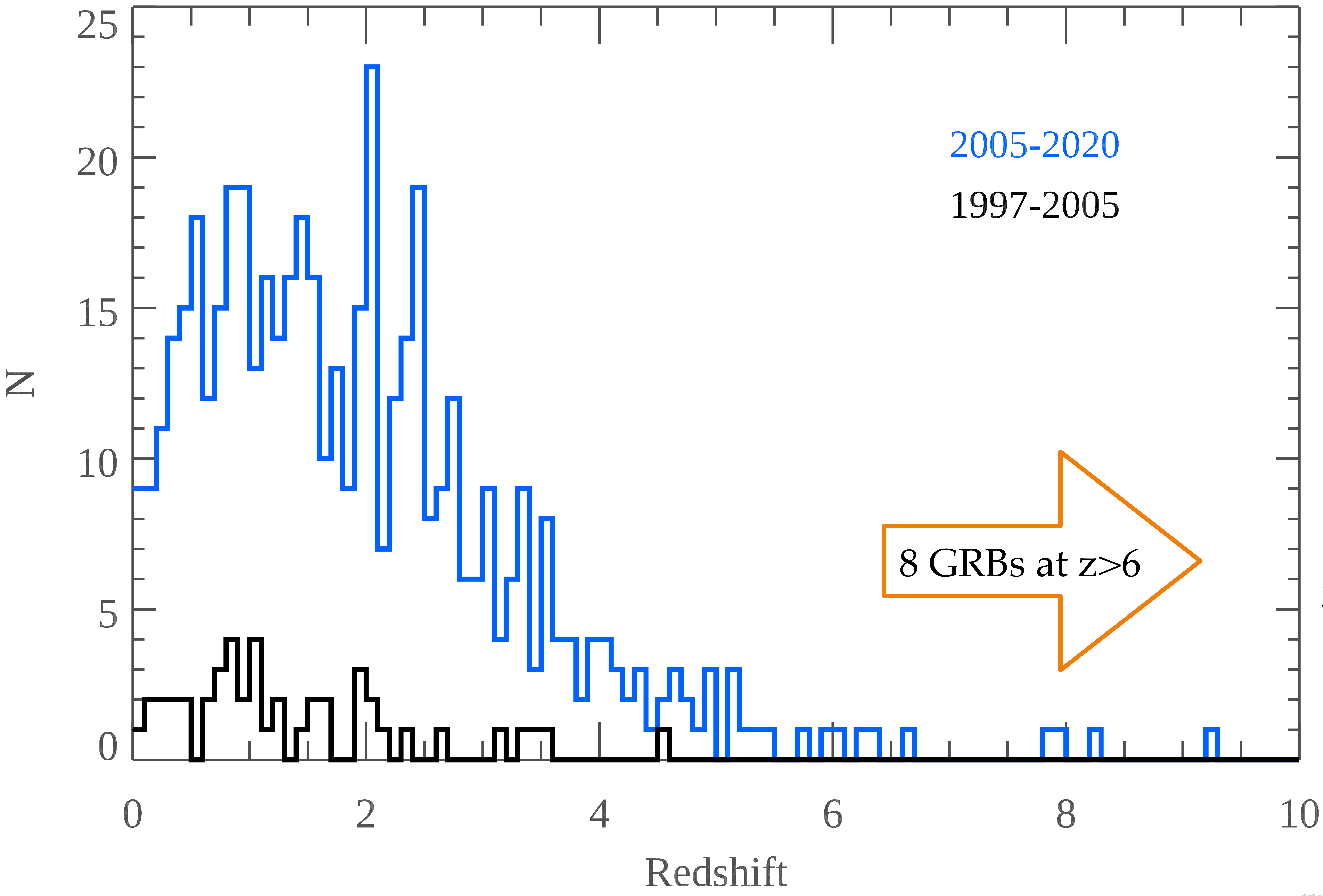


Quasi universal jet structure

Shallower structures —> steeper and "shorter" LF

A powerlaw θ^{-2} is excluded

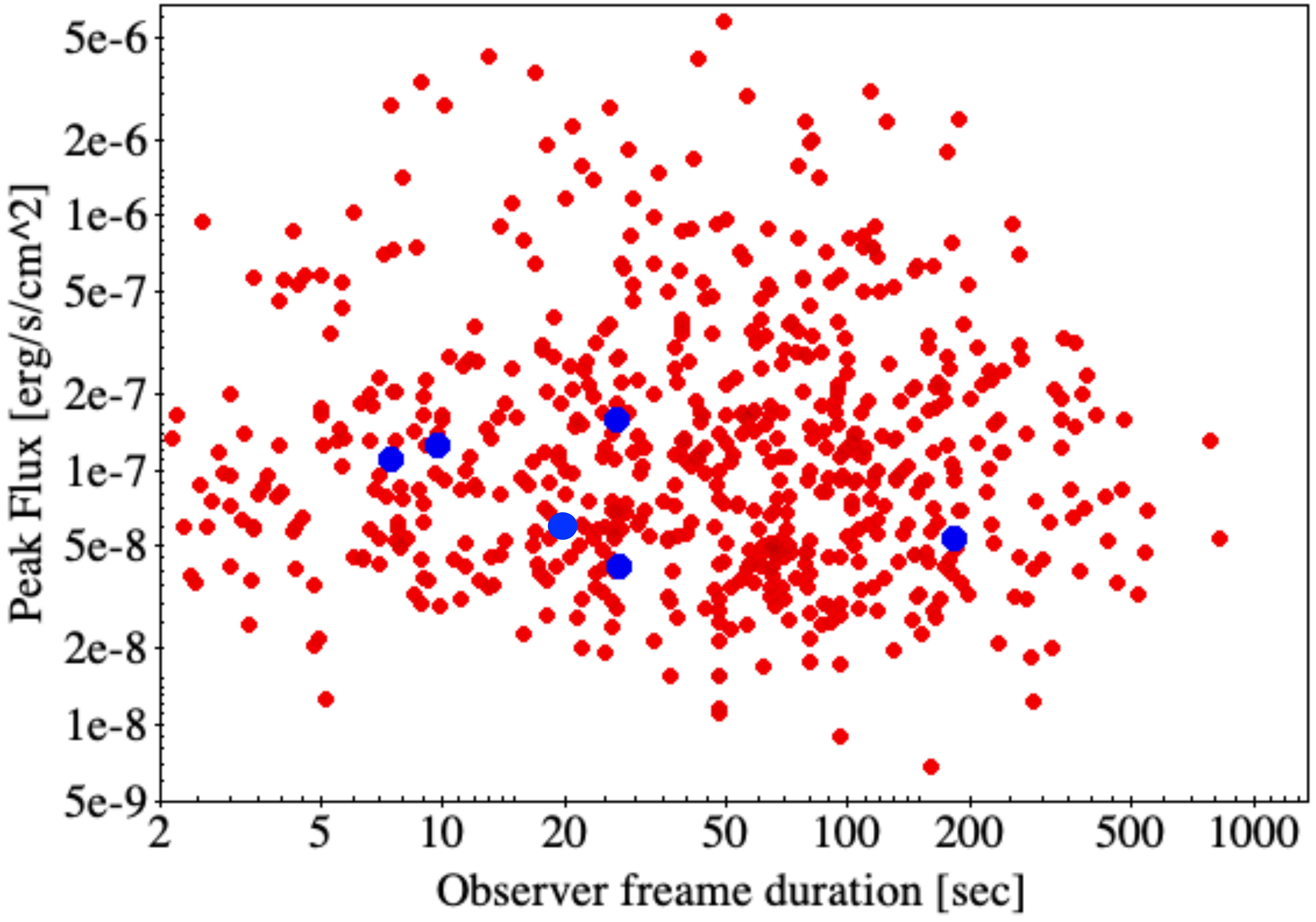
High redshift GRBs



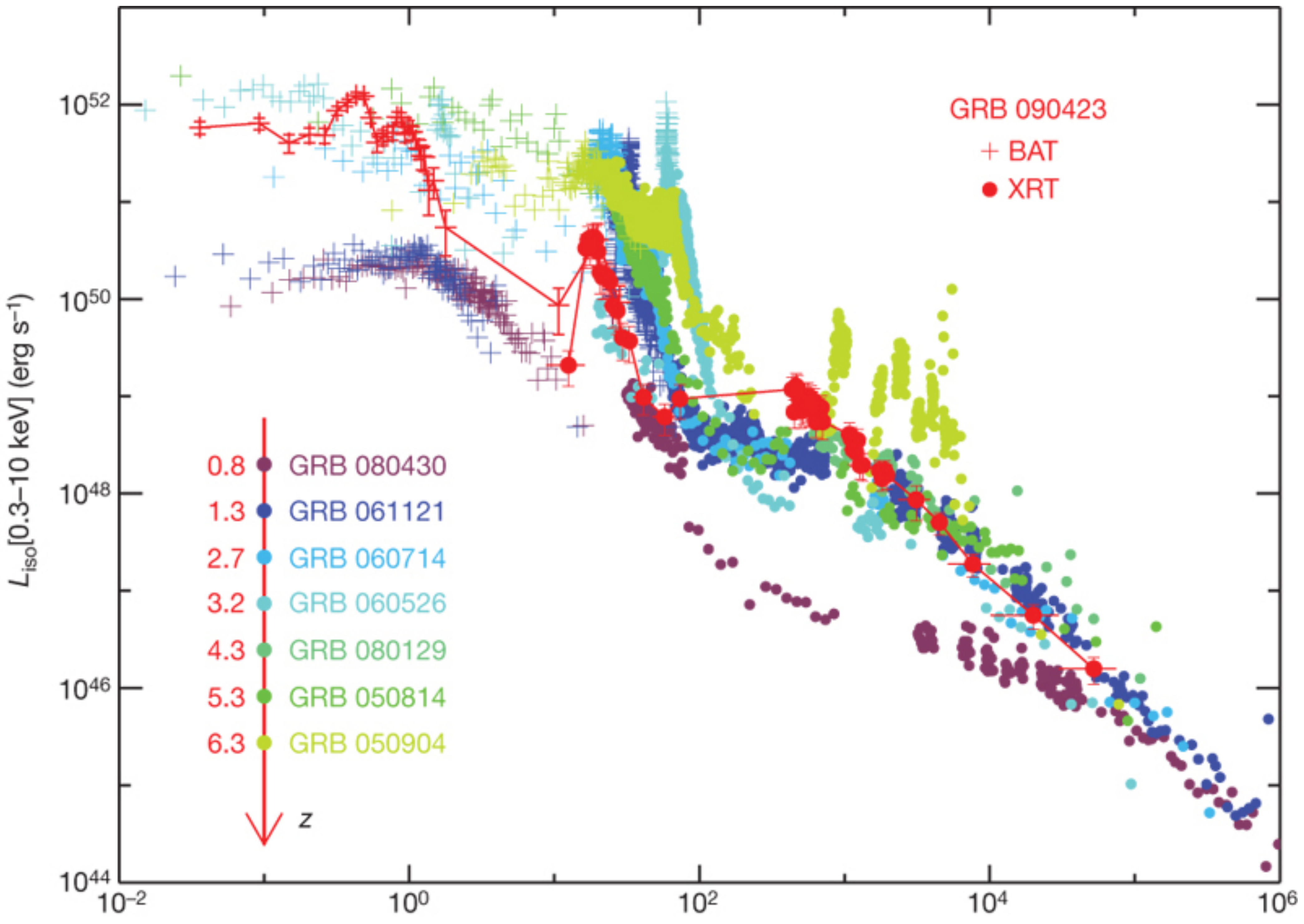
1. Detection rate
2. Redshift measurement efficiency

Low vs high redshifts

Prompt emission



Afterglow emission

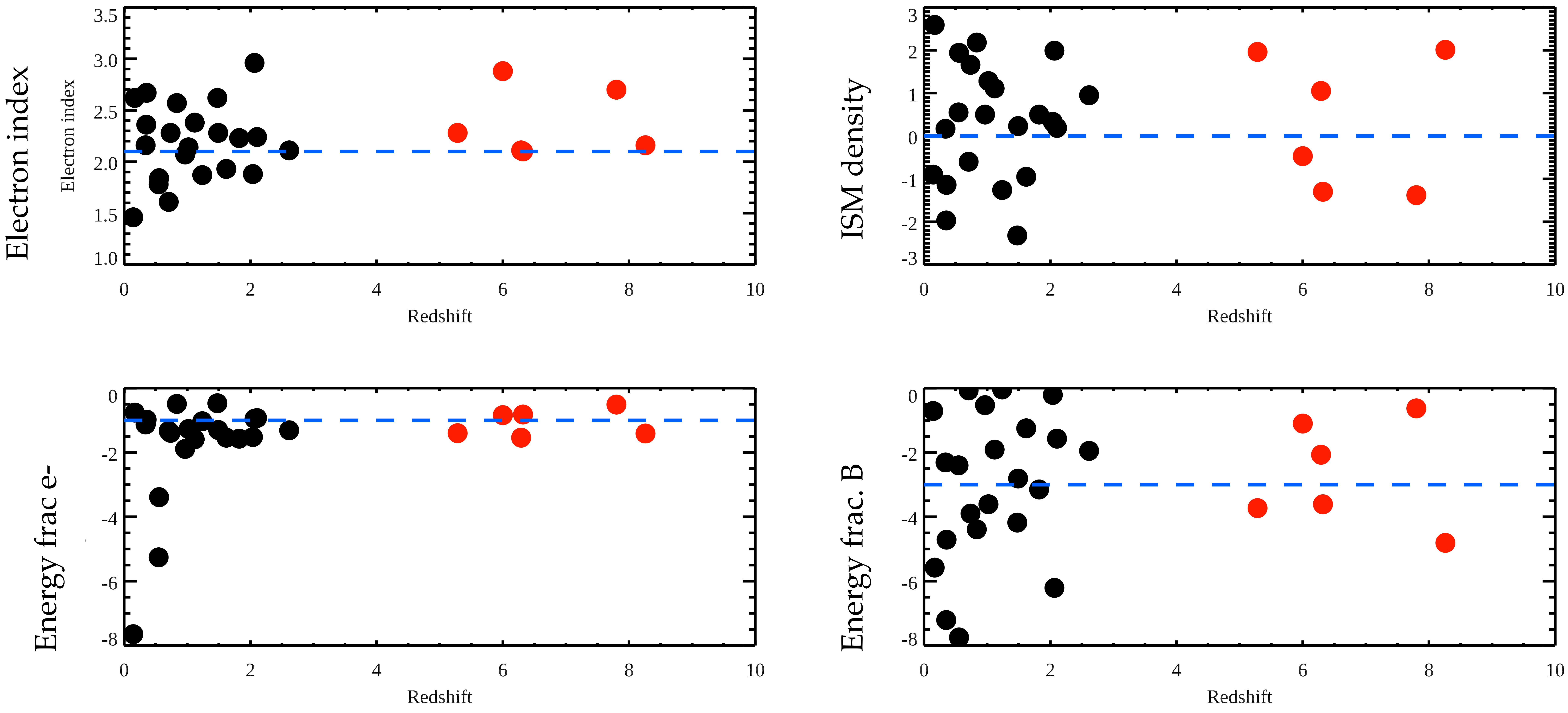


Salvaterra 2009

High-z GRBs similar properties of low redshift siblings

Low vs high redshift afterglow

Afterglow MW modelling

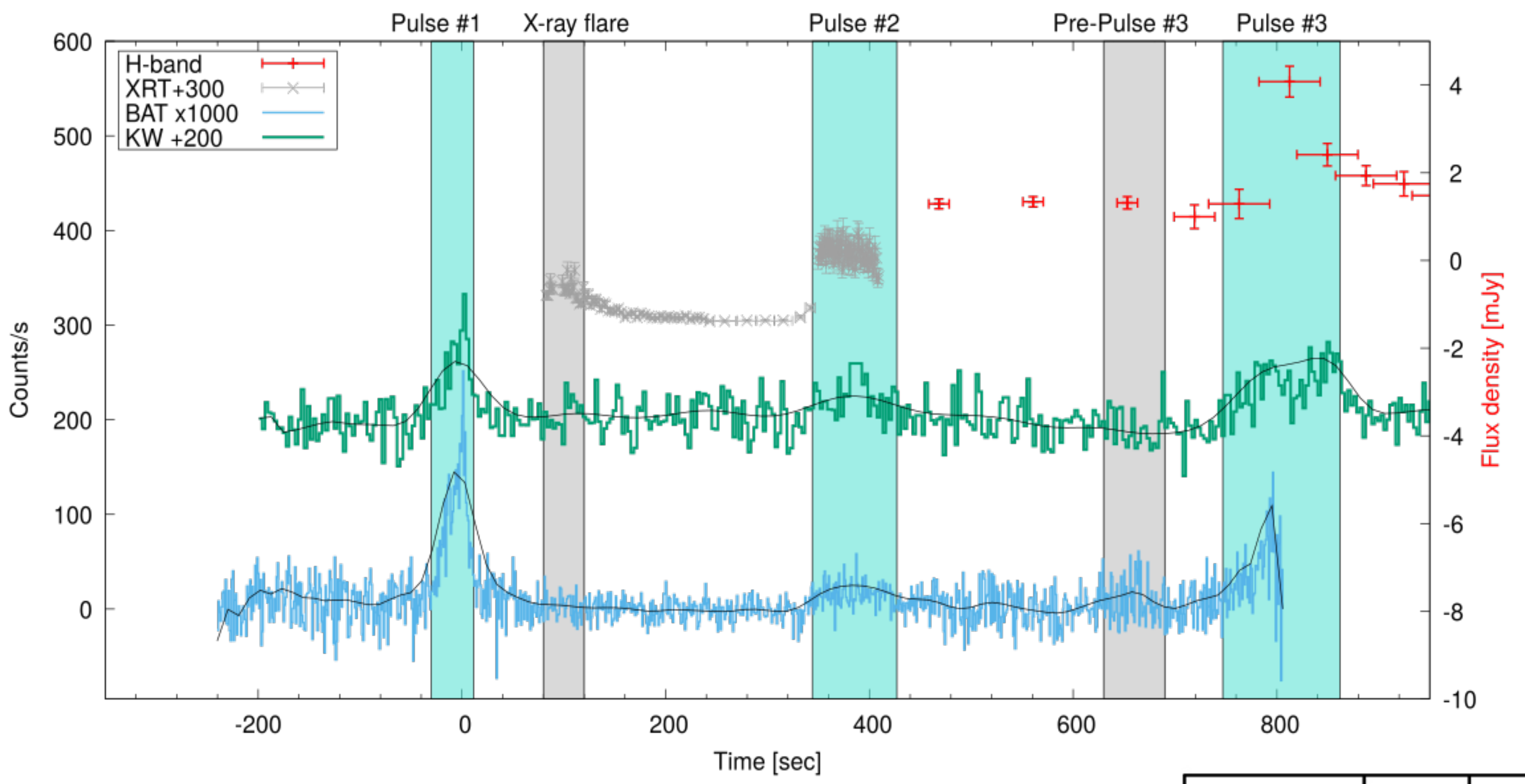


GG in prep.

GRB210905A

Rossi et al. 2022

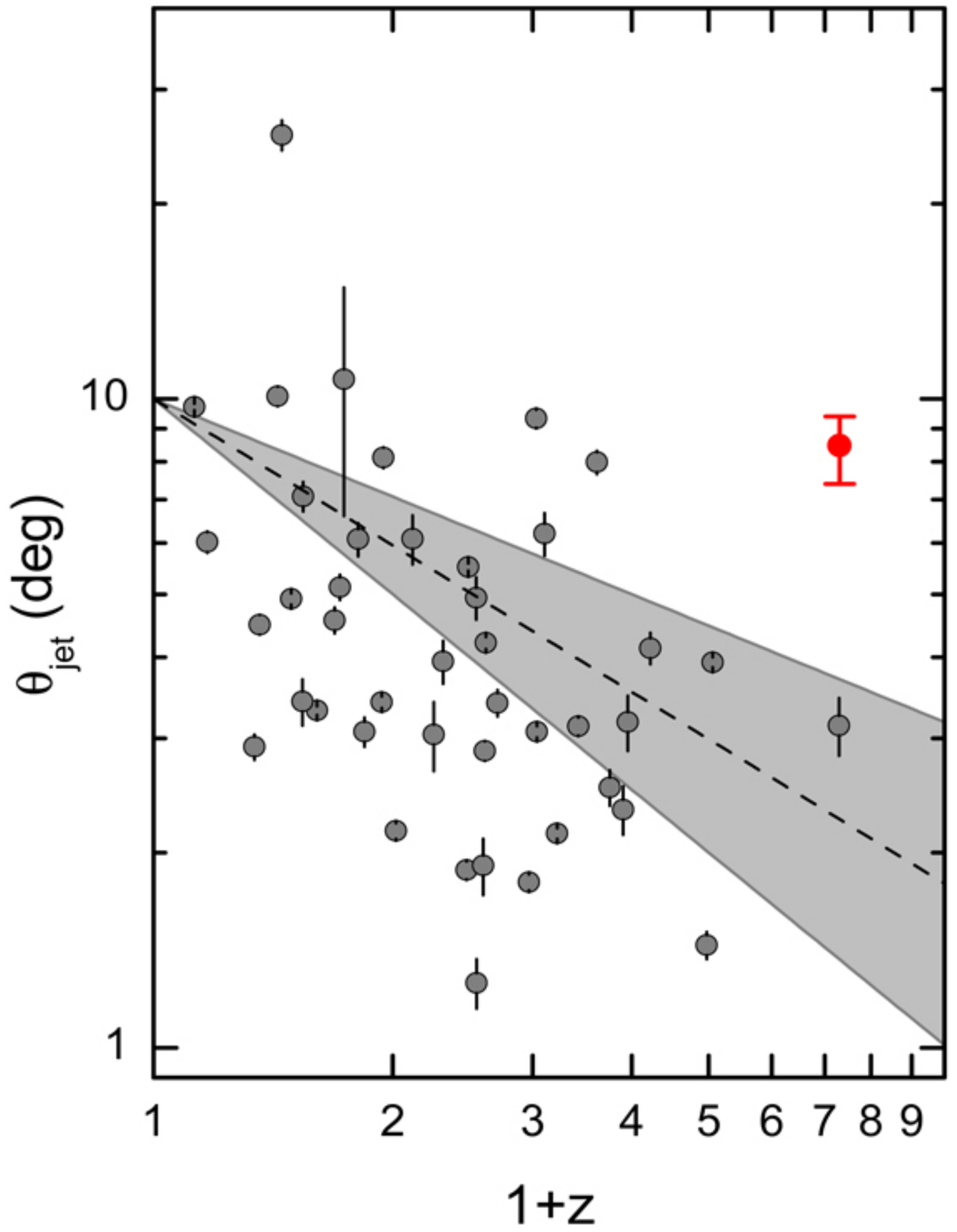
@ z=6.3

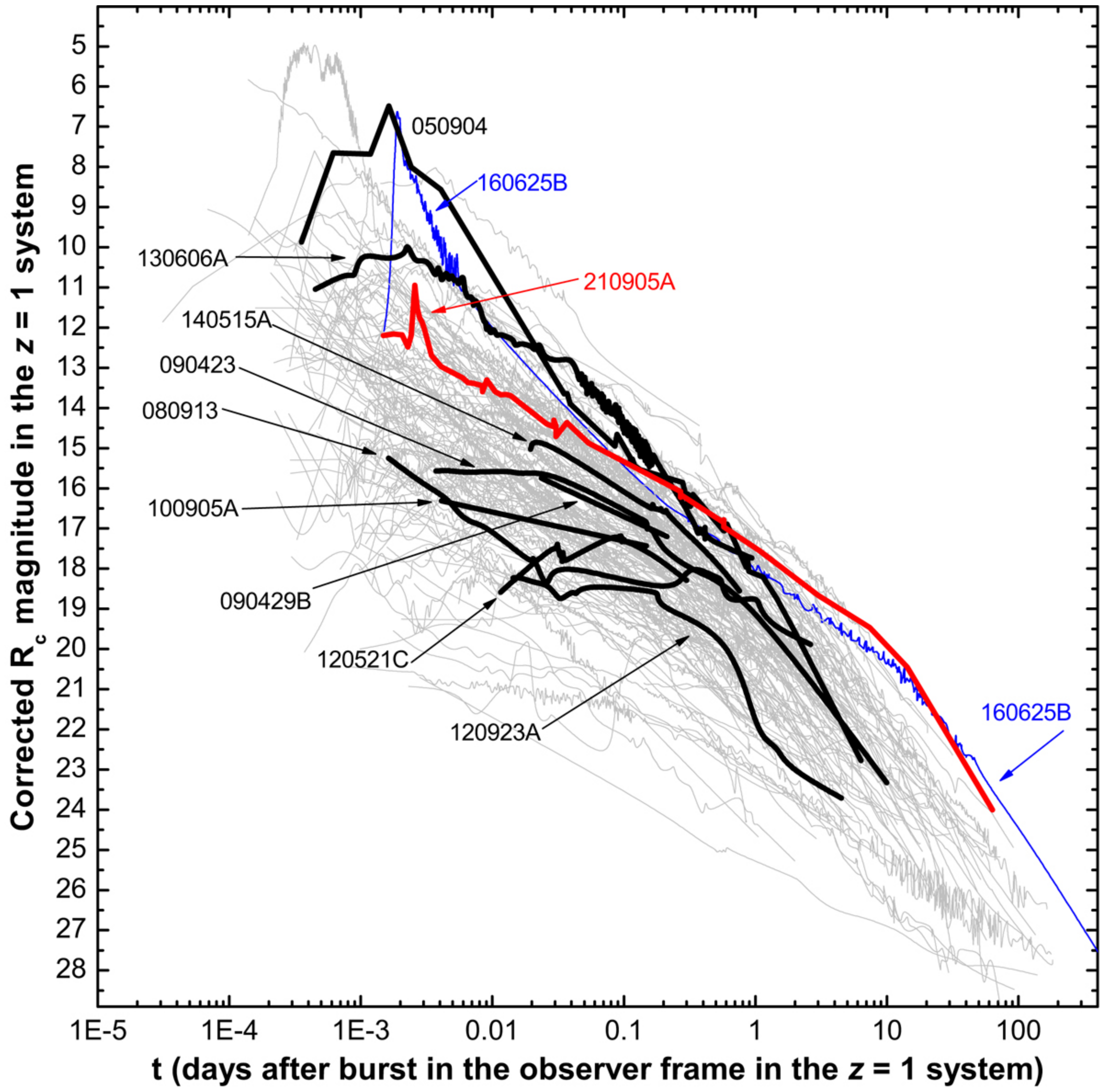


(Lloyd-Ronning+2019, 2020) Jet - redshift evolution

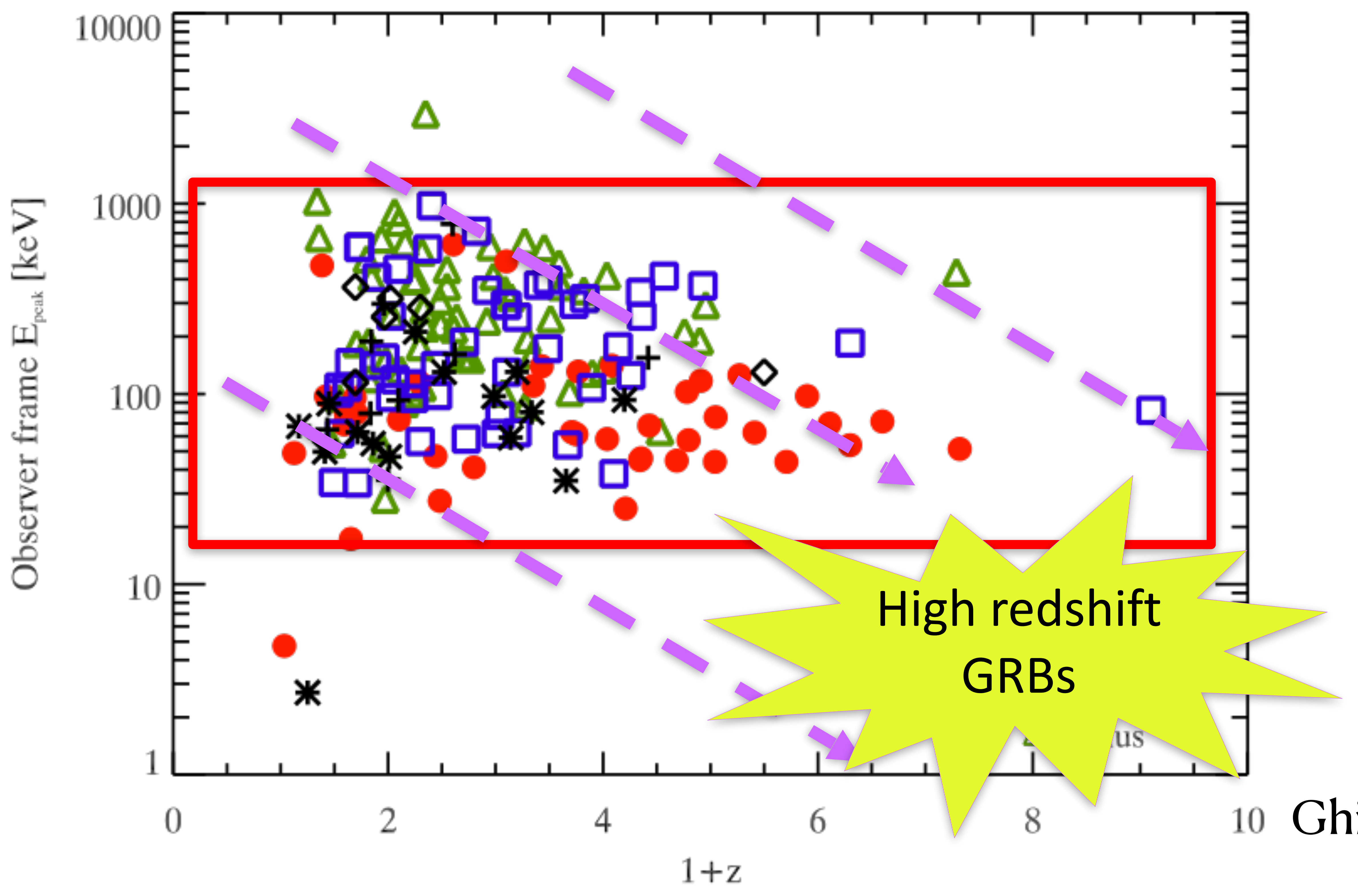
BUT

1) no statistical support from well defined sample of jet breaks (GG in preparation)
2) 210905A
3) Strong selection bias

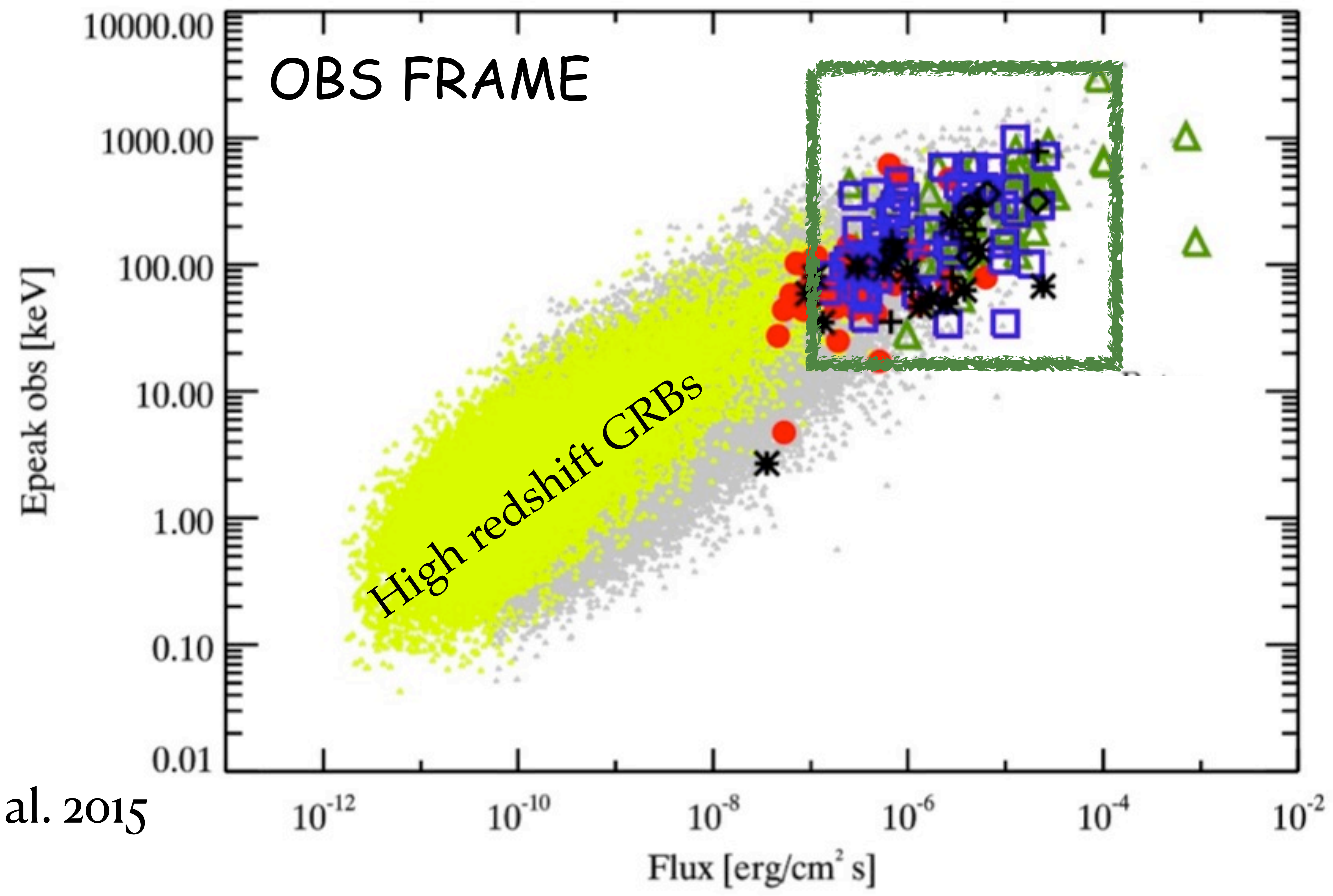




Catching high redshift GRBs



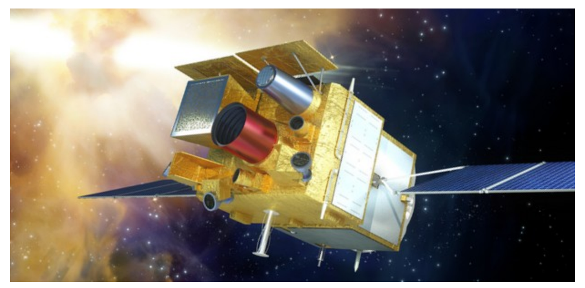
Ghirlanda et al. 2015

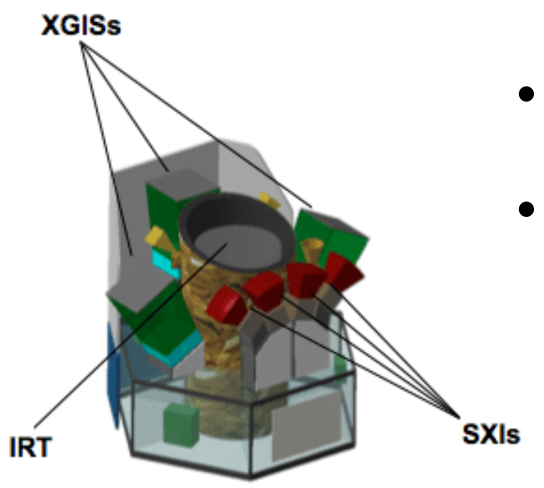


Softer

Deeper

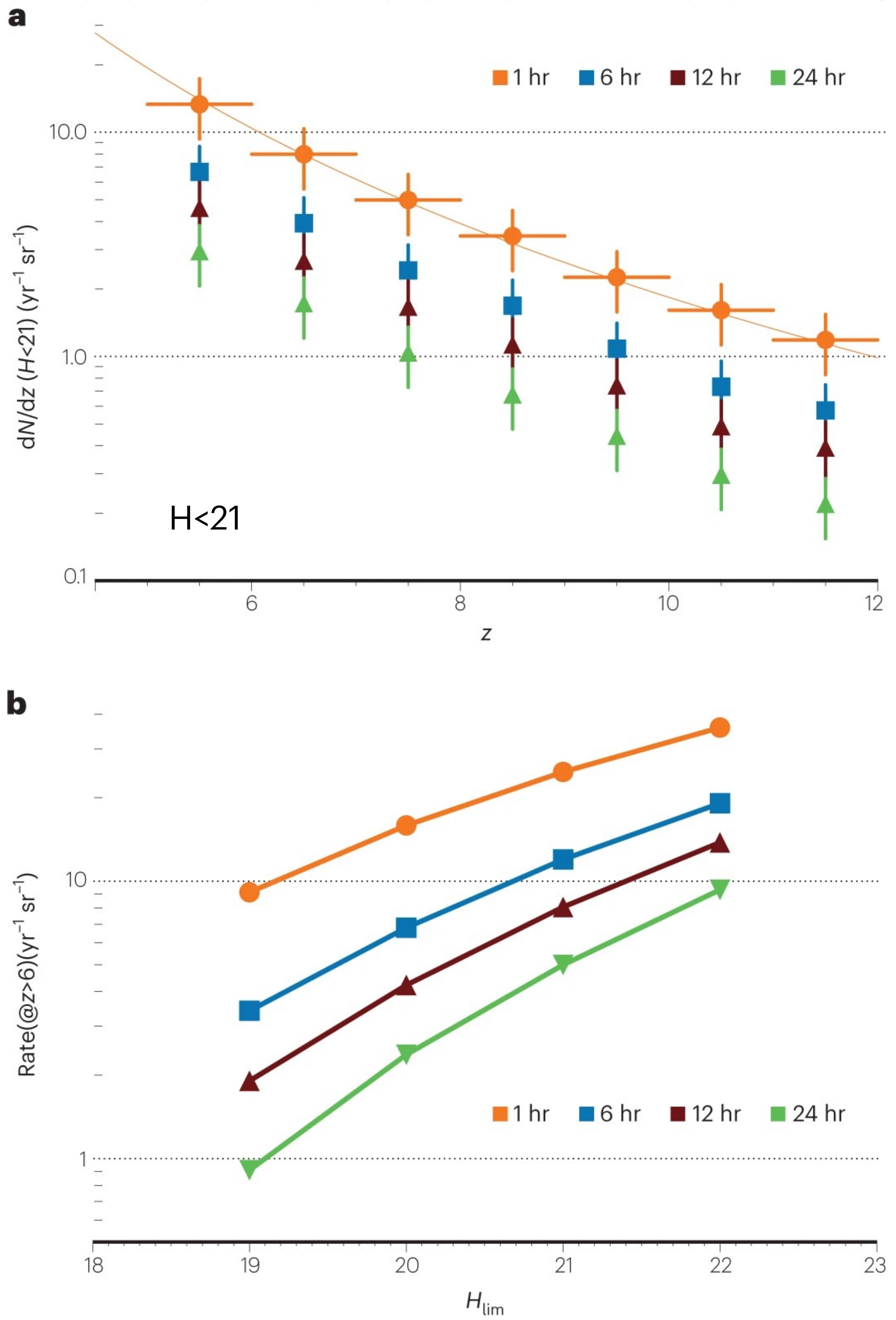
SVOM





- THESEUS
- Gamow

Catching high redshift GRBs



Campana et al., 2022

A dedicated NIR telescope, slave of VR to select high-z GRB candidates.

- NIR telescope (1320-1940 nm)
- 9.6 deg2 FoV slave of Vera Rubin
- H=21 (30s exp, SNR=5)

- ~ 11 yr^-1 @z>6 candidates H-r>3.5

Conclusions

Long GRB intrinsic properties $\Phi(L, z); \Psi(z); \rho_0 \ldots$ (GG&RS2022)

Parametric approach

Largest set of obs/rest frame constraints (CGRO, Fermi, Swift + SAX, HeteII)

Account for jets

- Long GRB formation rate shaped by a (low) metallicity bias
- Low redshift excess excluded at >>5σ
- Mild evolution of the characteristic luminosity
- Local (beaming corrected) rate
- Luminosity function slope and extension consistent with Gaussian quasi universal jet

Low vs high redshift GRBs

- No clear evidence for evolution of micorphysical parameters.
- No statistical evidence for jet-z evolution (but 210905)

Need more events: high energy dedicated satellite or nIR dedicated telescope (but prompt)