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Italiadomani PIANO NAZIONALE DI RIPRESA E RESILIENZA
INAF ISTITUTO NAZIONALE DI ASTROFISICA
UNIVERSITÀ DEGLI STUDI DI MILANO BICOCCA
INFN Istituto Nazionale di Fisica Nucleare

Properties of the populations of Gamma Ray Bursts

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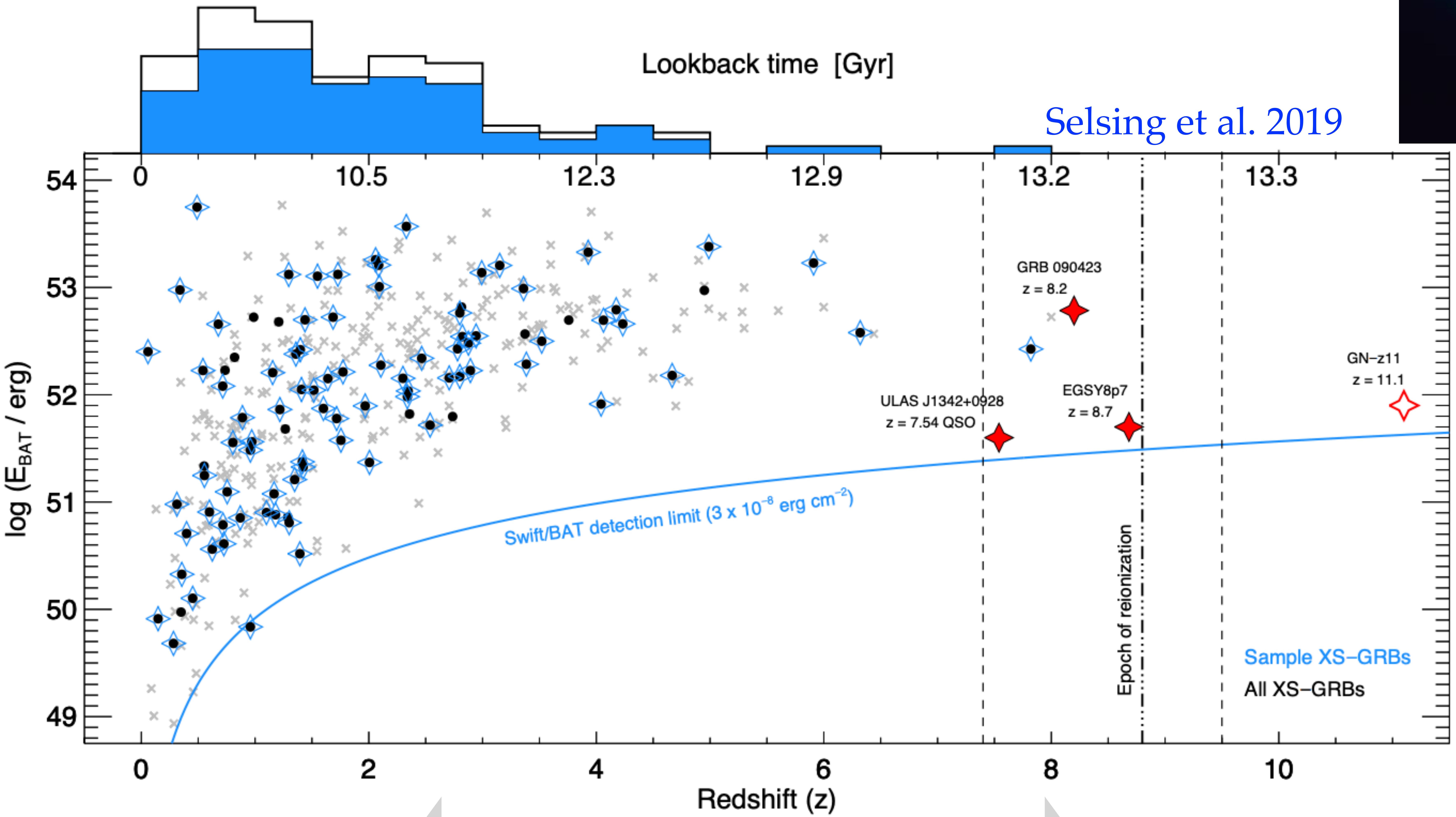
Celebrating 20 years of Swift Discoveries Florence 24-28 March 2024

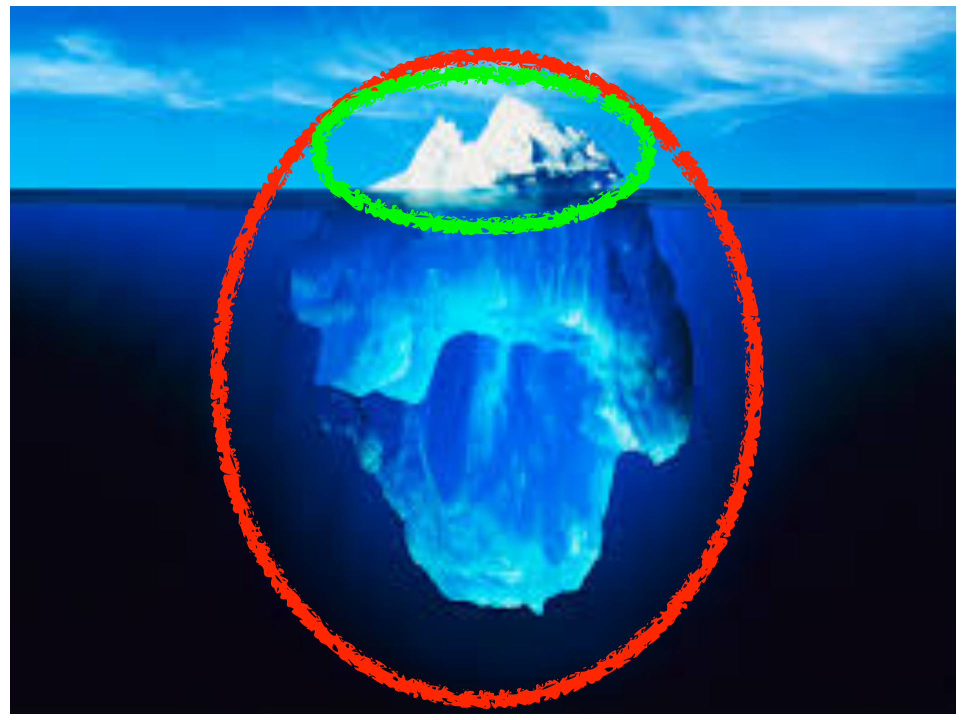
Population properties

$\Phi(L)$

Population luminosity function



Selsing et al. 2019



Event cosmic rate

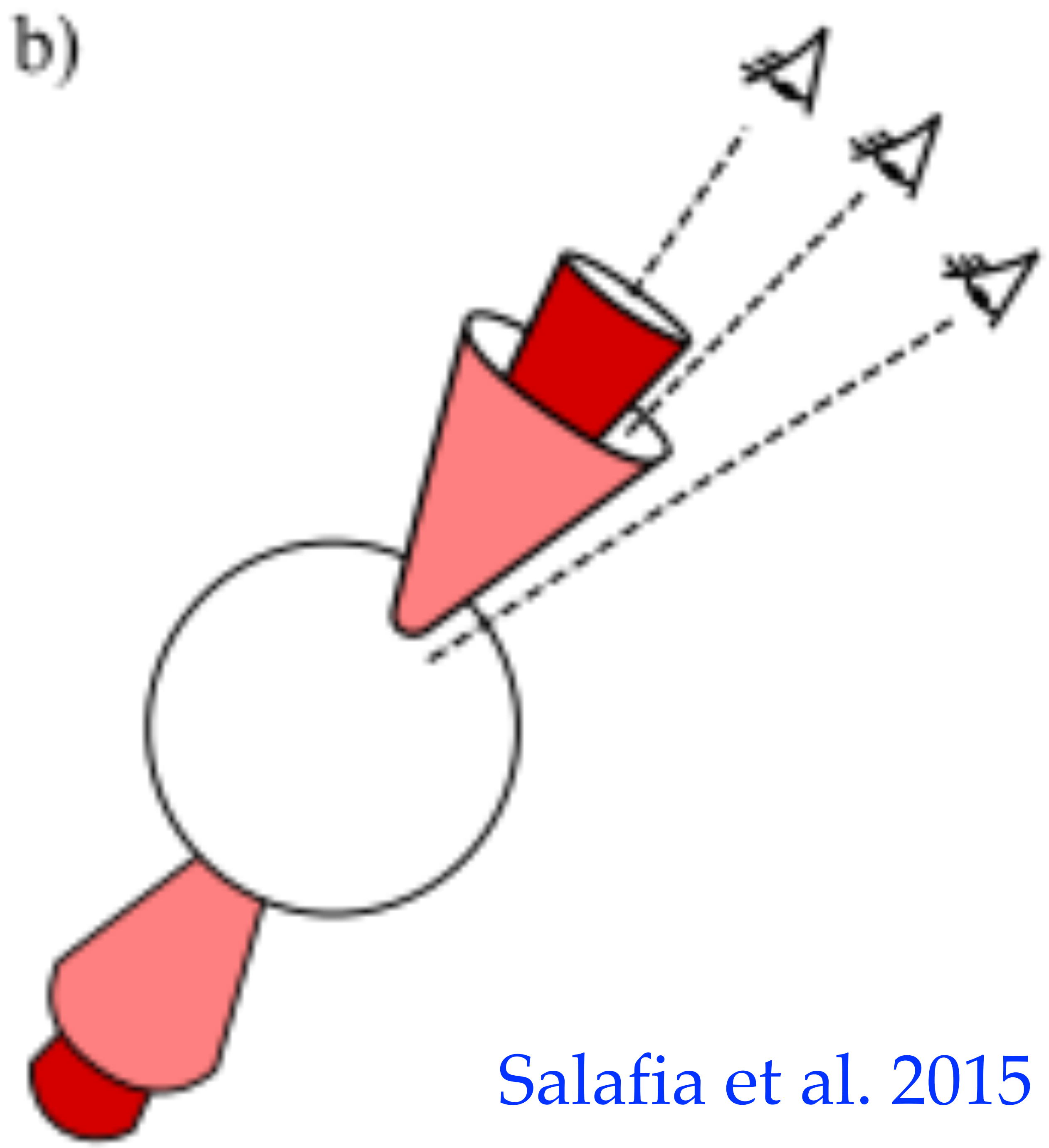
$\Psi(z)$

Physical motivations

Progenitors and ambient

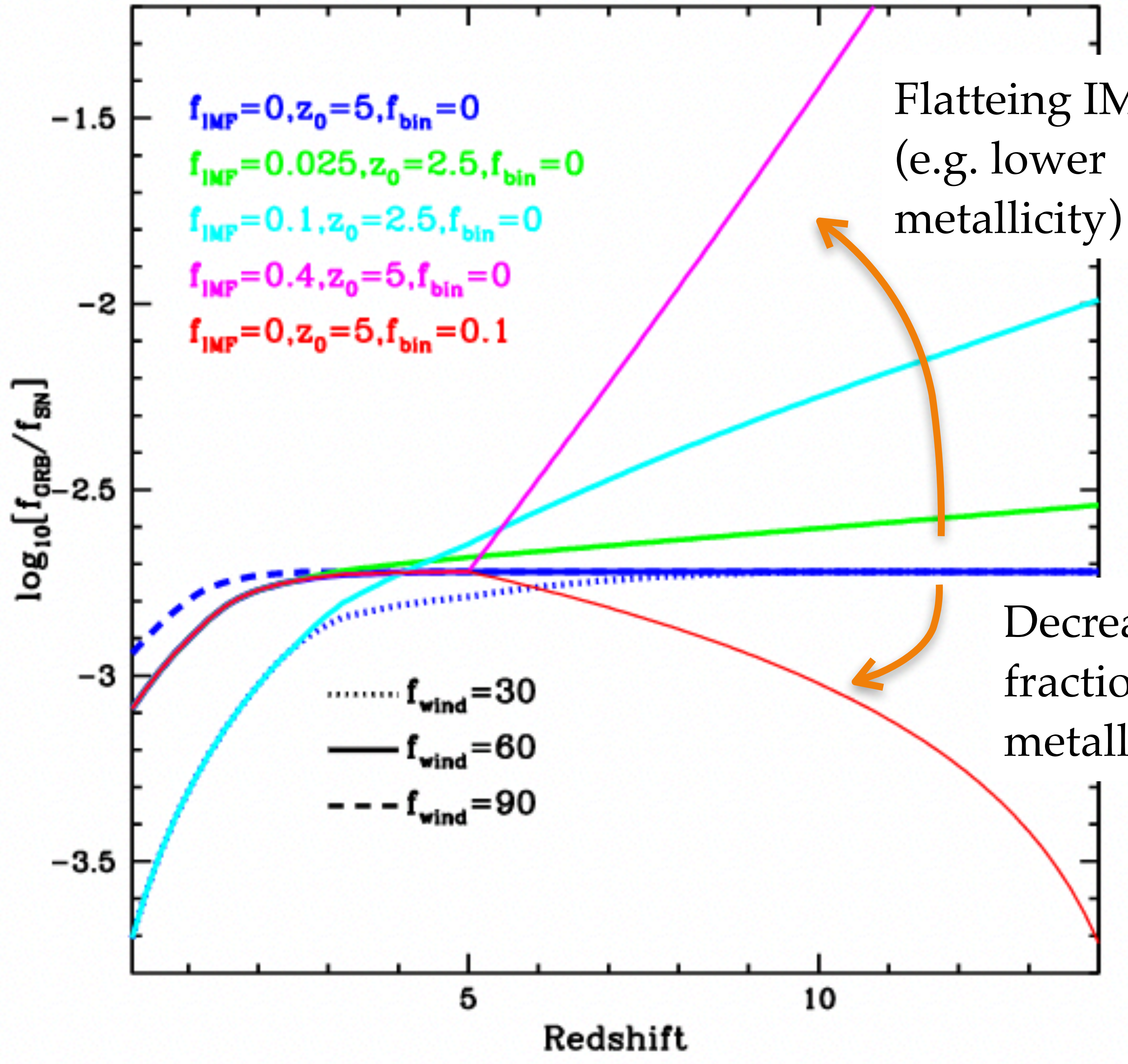
$\Phi(L, [z])$ & $\Psi(z)$

Jet properties



Salafia et al. 2015

Fryer, …, GG, …, RS, … +2022



Methods

Direct (non-parametric)

A Un-binned method - Lynden-Bell 1971
Kocevski+2006; Wu+2012;Yu+2015; Petrosian+2015; Tsvetkova+2017; Lloyd et al. 2019; Petrosian+2023

B 2D binned method - Wanderman & Piran 2010

Parametric (forward folding)

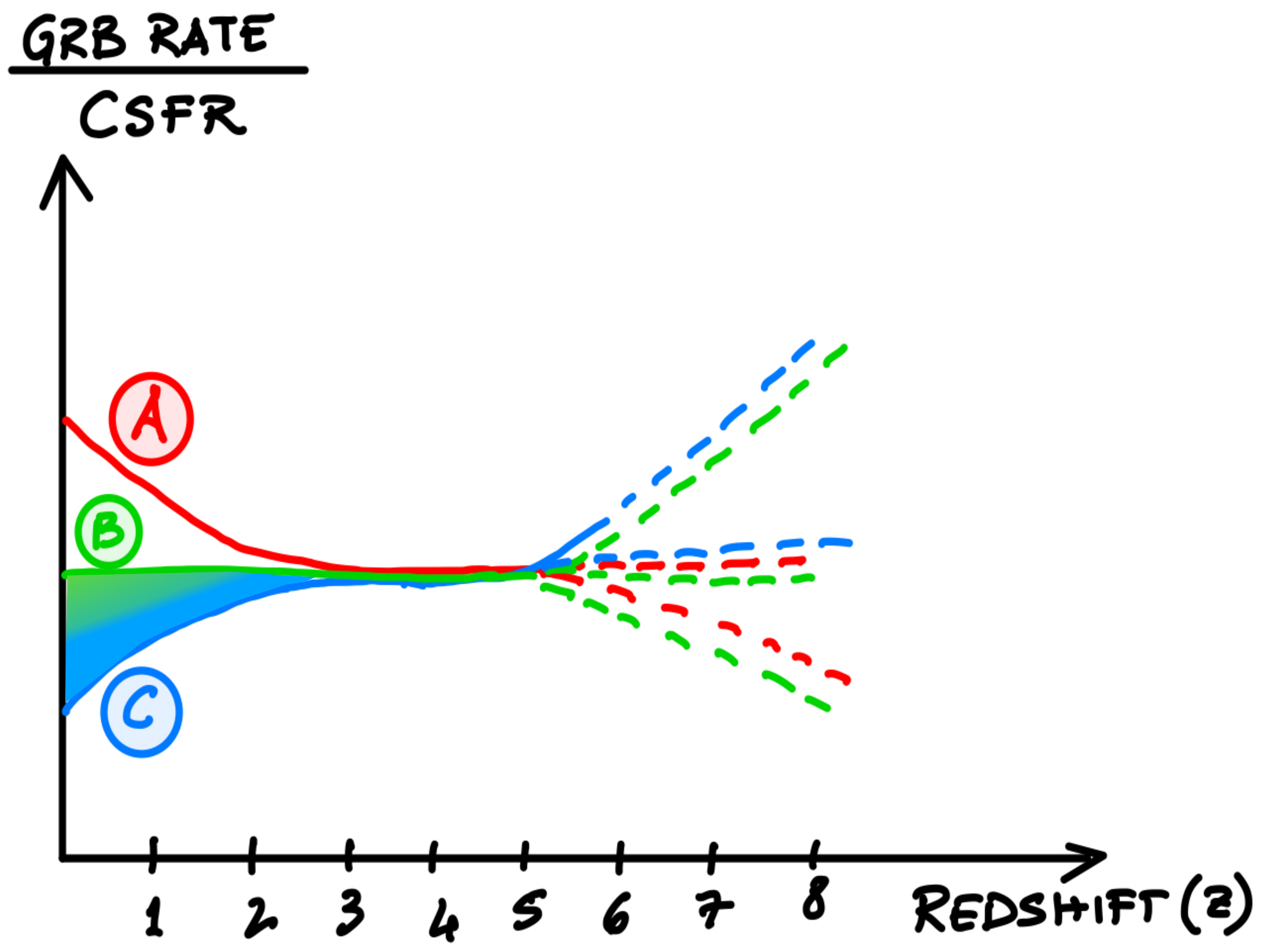
C Constrain model parameters by N(z), N(P) …
Daigne et al. 2006; Salvaterra et al. 2012; Ghirlanda et al. 2015; Palmerio & Daigne 2021; Ghirlanda & Salvaterra 2022; Salafia et al. 2023

Agreement on

$$\Phi(L\,|\,\alpha = 1.5 \pm 0.25,\ \beta = 2.3 \pm 0.5,\ L_b = 10^{52.5\pm0.5})$$

Limitations and issues:

- **Sample incompleteness**
- Extrapolations
- Treat L,z independently
- Jet (not accounted or a-posteriori)



Limitations and issues:

- Degeneracy
- Often treat L,z independently

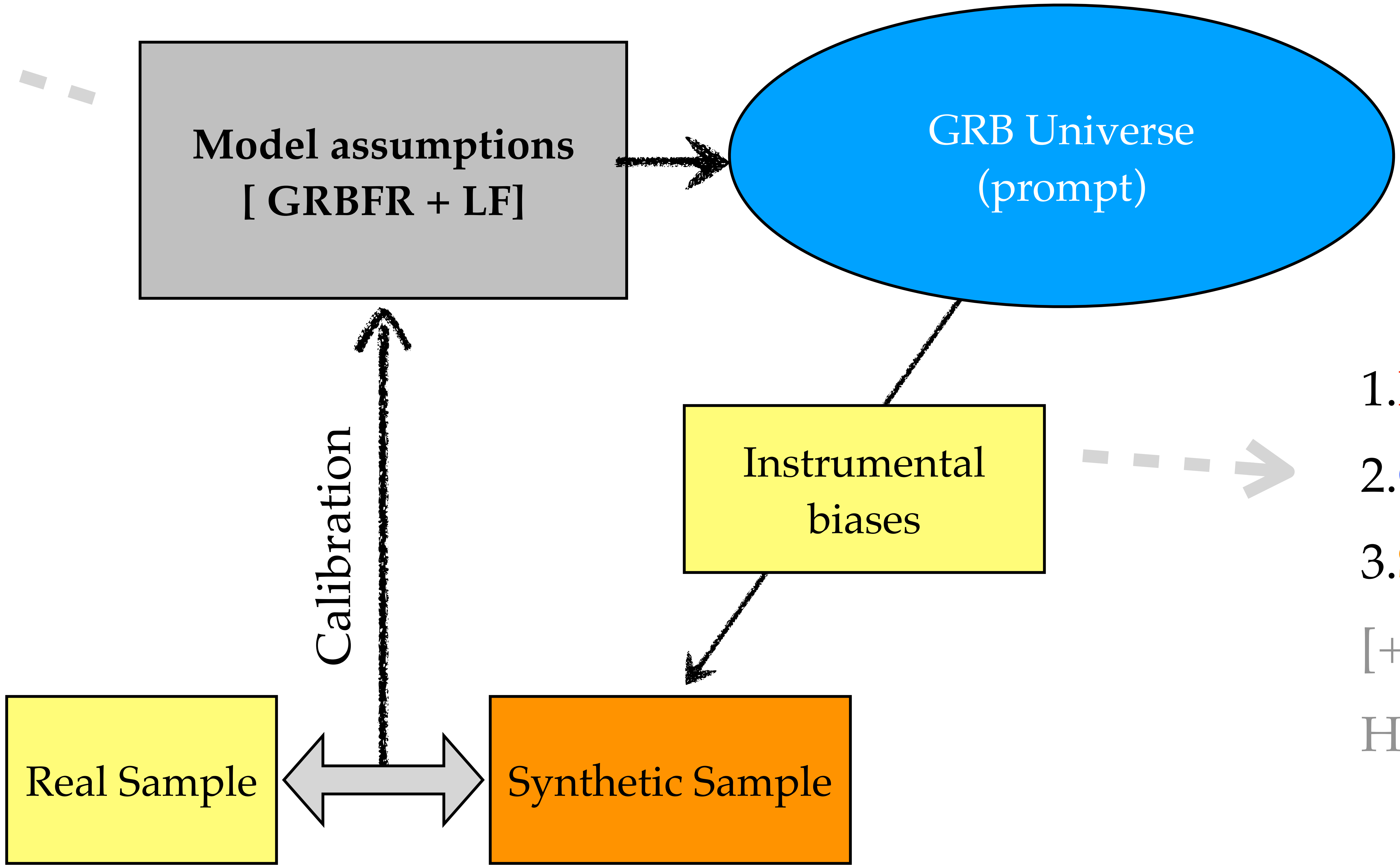
Long GRB population

Ghirlanda & Salvaterra 2022

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

18-D parameter space

(11 free parameters)



1. Fermi/GBM
2. CGRO/Batse
3. Swift/BAT(z)

[+ Beppo/SAX & Hete-II]

14 constraints (Fermi, CGRO, Swift):

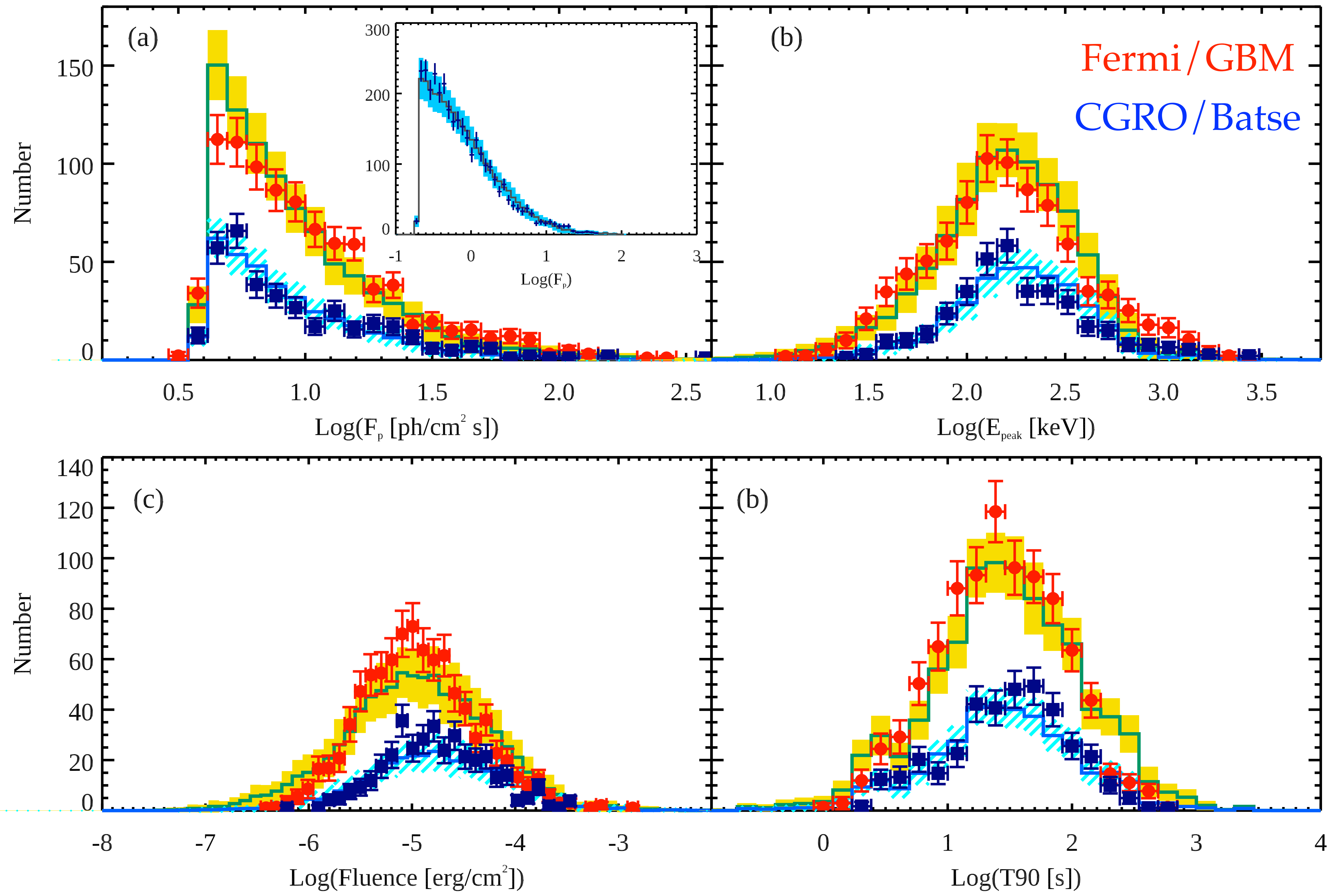
- Observer frame (e.g. Peak flux, Fluence, duration …)
- Rest frame (Energy, Luminosity, Redshift)

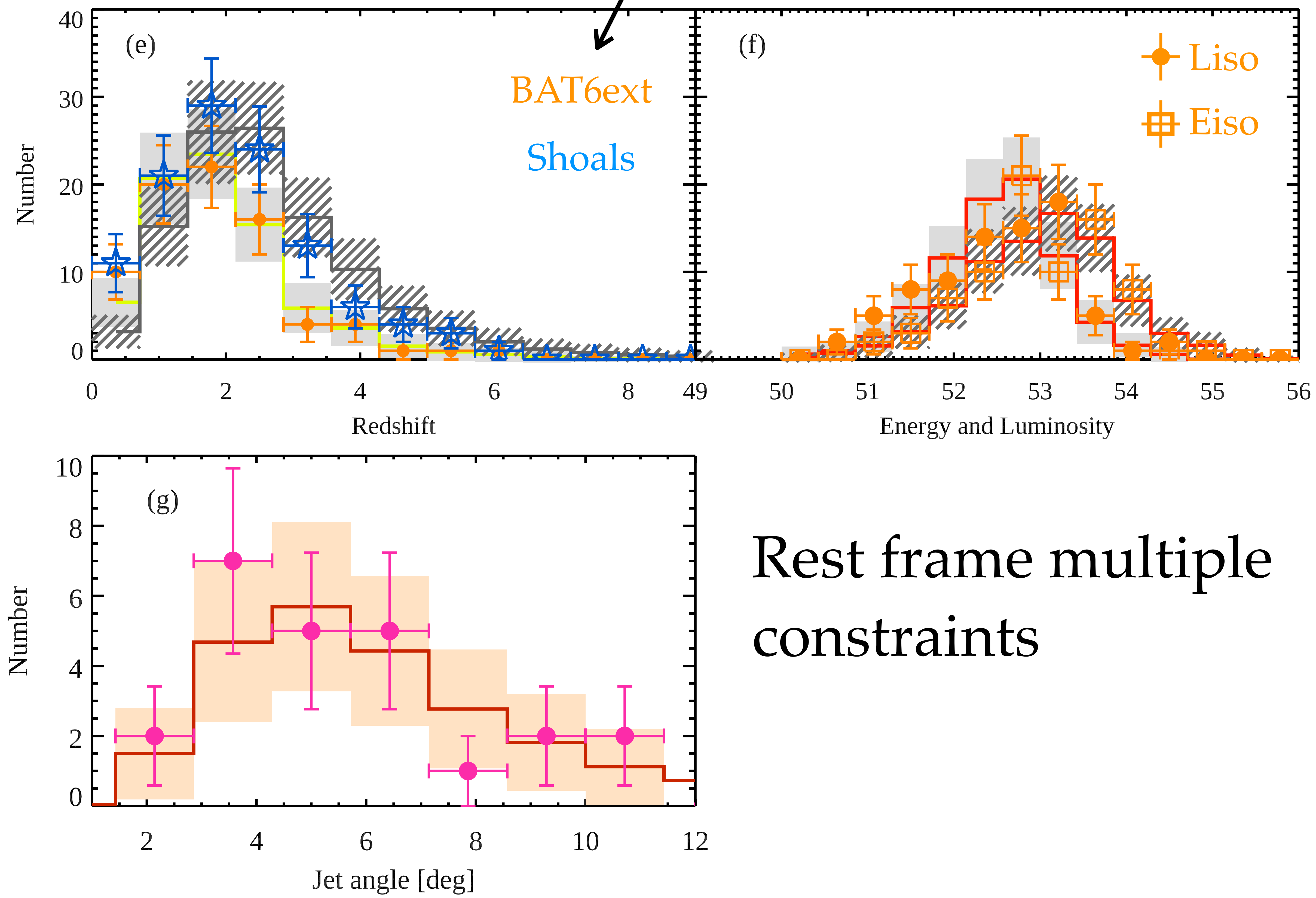
Method: MCMC + parallel stretch move

Long GRB population

Particularly relevant Swift/BAT complete sample (z, Eiso, Liso) - see Salvaterra et al. 2012

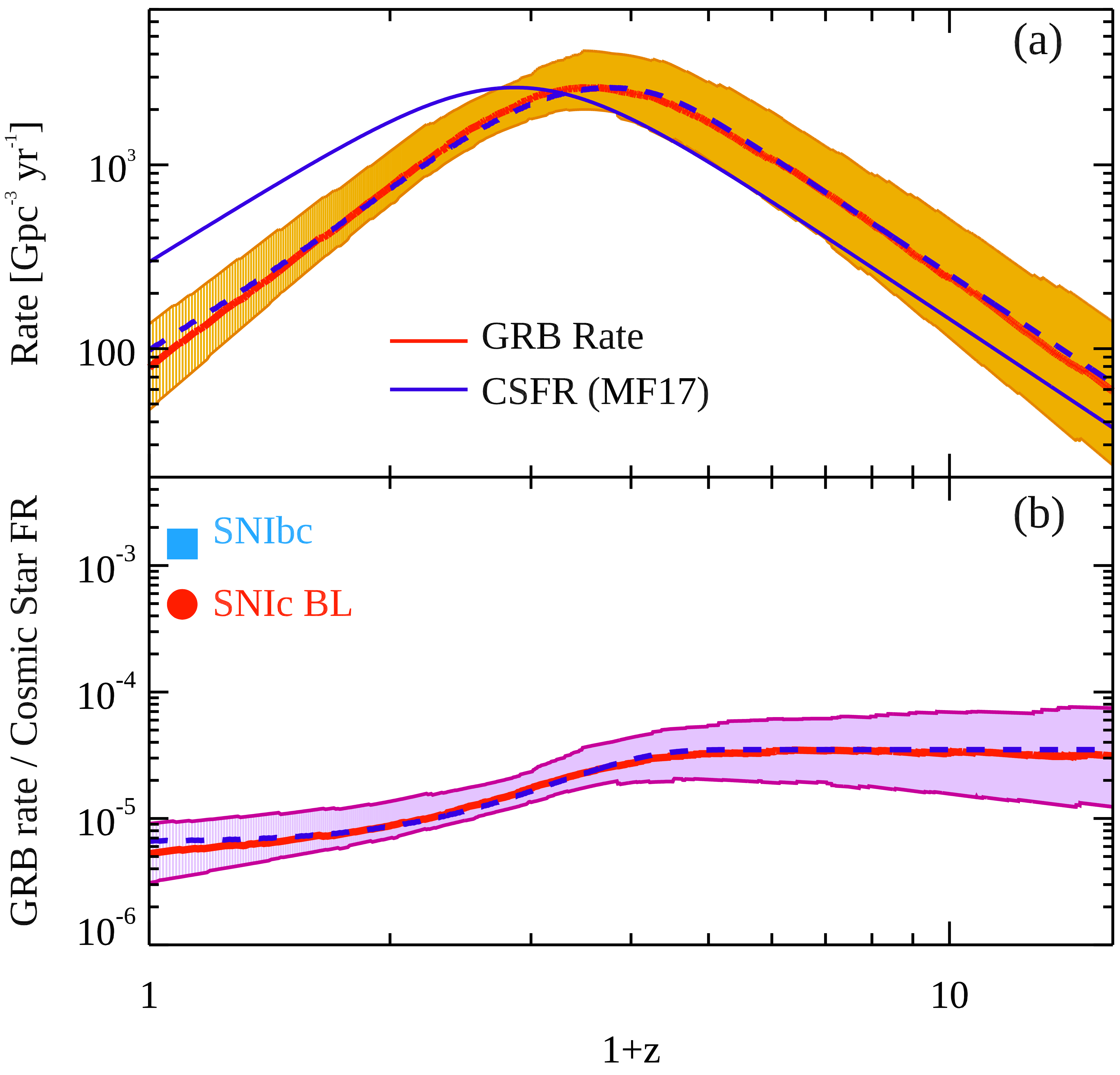
Observer frame multiple constraints





Rest frame multiple constraints

Long GRB population



GRB formation rate:

- Local GRB rate (full population) $\sim 80 \pm 30\,\mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$
- Peaks at z~3
- Steeper than CSFR at low z and same slope at high z
- Dashed line: 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]

Metallicity < 12+log(O/H)<8.6 [consistent with hosts, e.g. Palmerio+2019, Vergani+2015]

IMF slope (see also F. Gabrielli, ... GG, ... et al., 2024)

But a few GRB hosts with super-solar metallicities (See Briel, … GG, … et al., 2025)

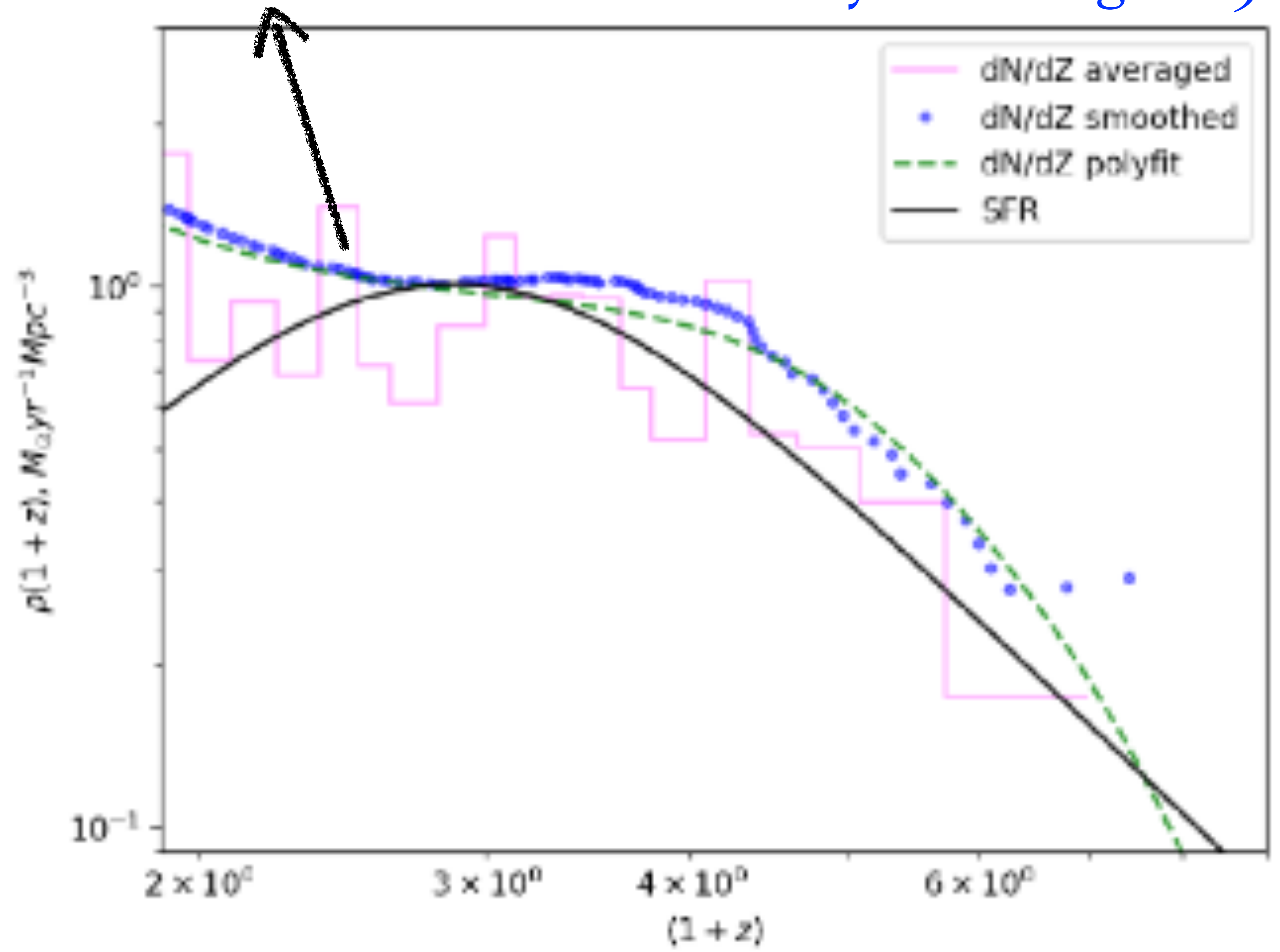
- ~1.3% of BL SNIc @ z=0 produce a successful jet (~7% at z>3)

There is no low redshift excess !

Non parametric method — (L-z plane)
[Petrosian+2015; Yu+2015; Tsvetkova+2017; Lloyd-Ronning+2019; Petrosian 2024]

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

Lloyd-Ronning+2019

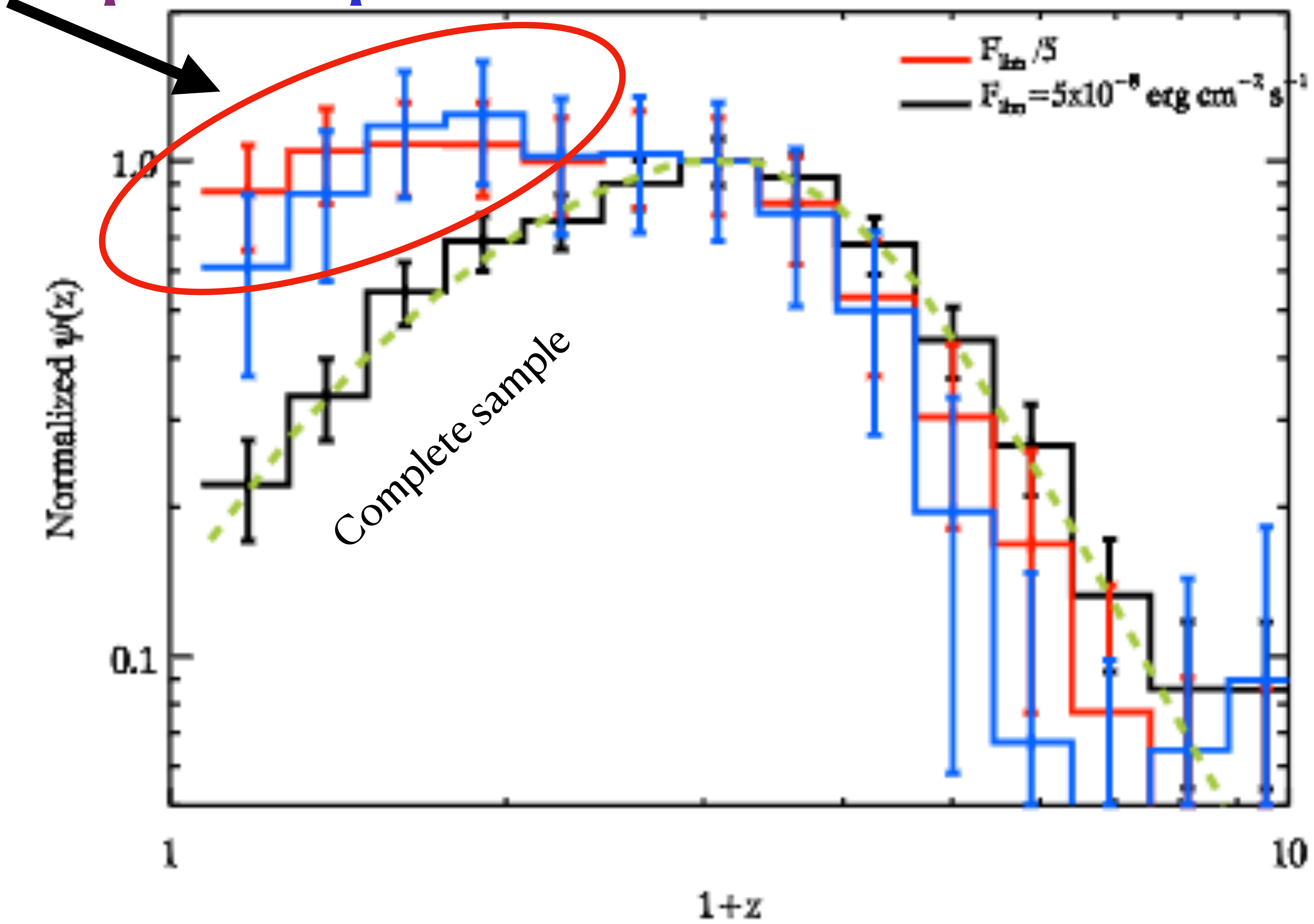


BUT

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

Incomplete samples

Pescalli+2016



Low redshift excess is **EXCLUDED** by:

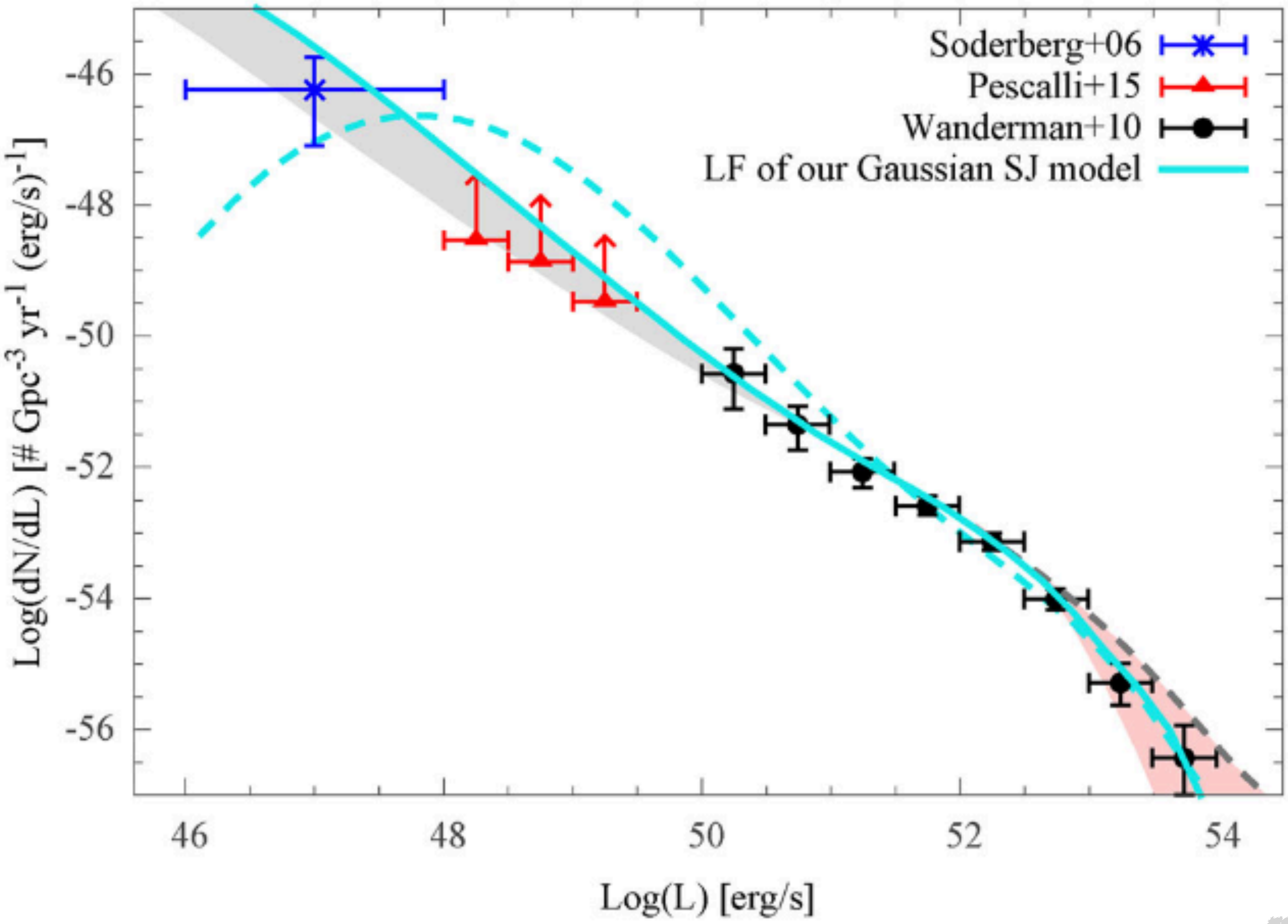
1) at $> 5\sigma$ (GG&RS2022)

2) Pescalli et al. 2016 (real complete data and simulations)

(See also Briant+2021 and Le+2020)

3) Host masses (e.g. Palmerio+2019; Vergani+2015)

Luminosity function



Salafia et al. 2015

Quasi universal Gaussian jet structure

A powerlaw θ^{-2} is excluded

[For QSJ in short GRBs see Salafia et al. 2023]

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Conclusions

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

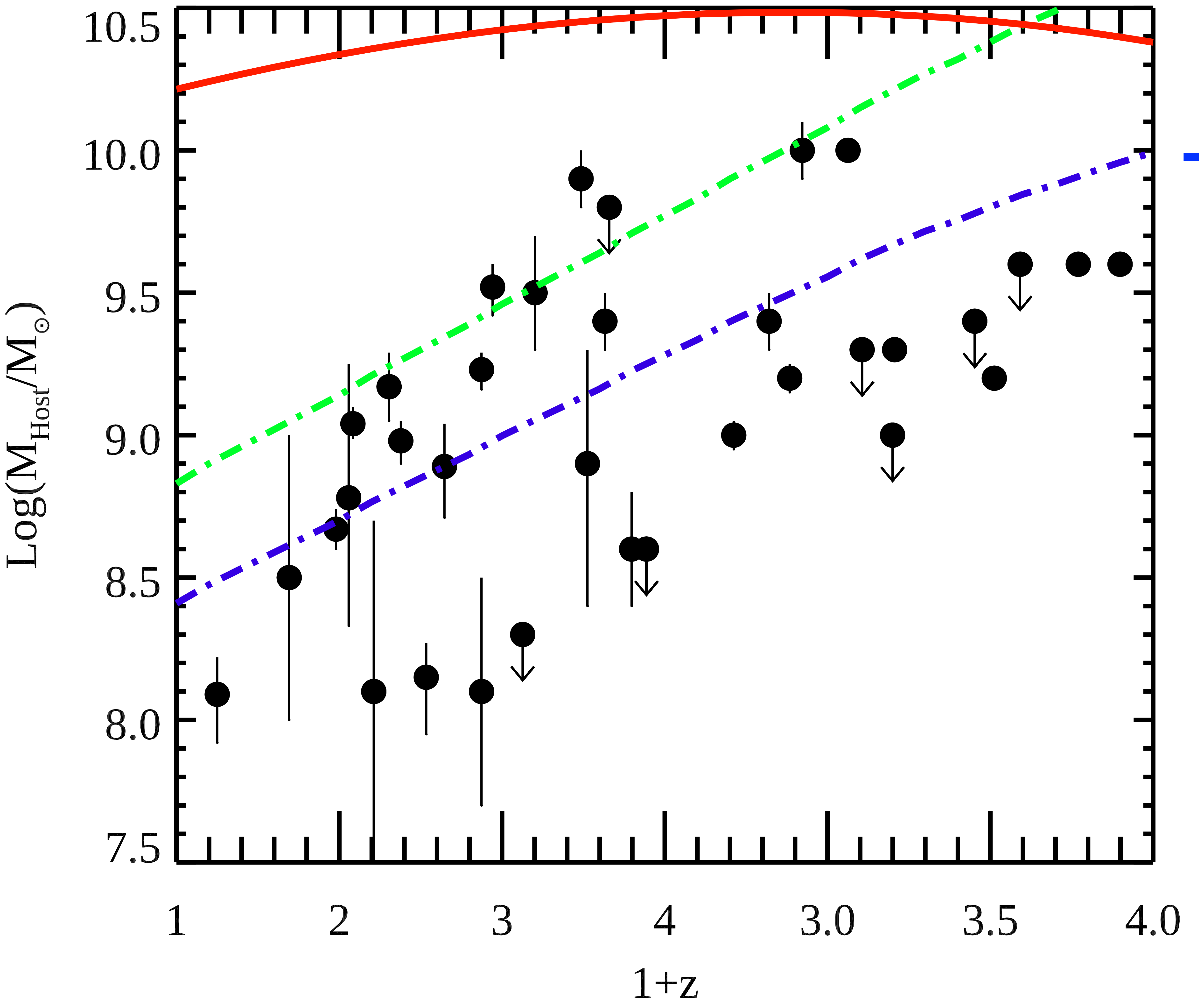
Parametric approach

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 ~80(+-30) yr^-1 Gpc^-3
- Luminosity function slope and extension consistent with Gaussian quasi universal jet

Long GRB population



Average host mass with 12+log(O/H)<8.6

Vergani+2015; Palmerio+2019

Role of metallicity (Fryer, ... GG, ... et al. 2022)

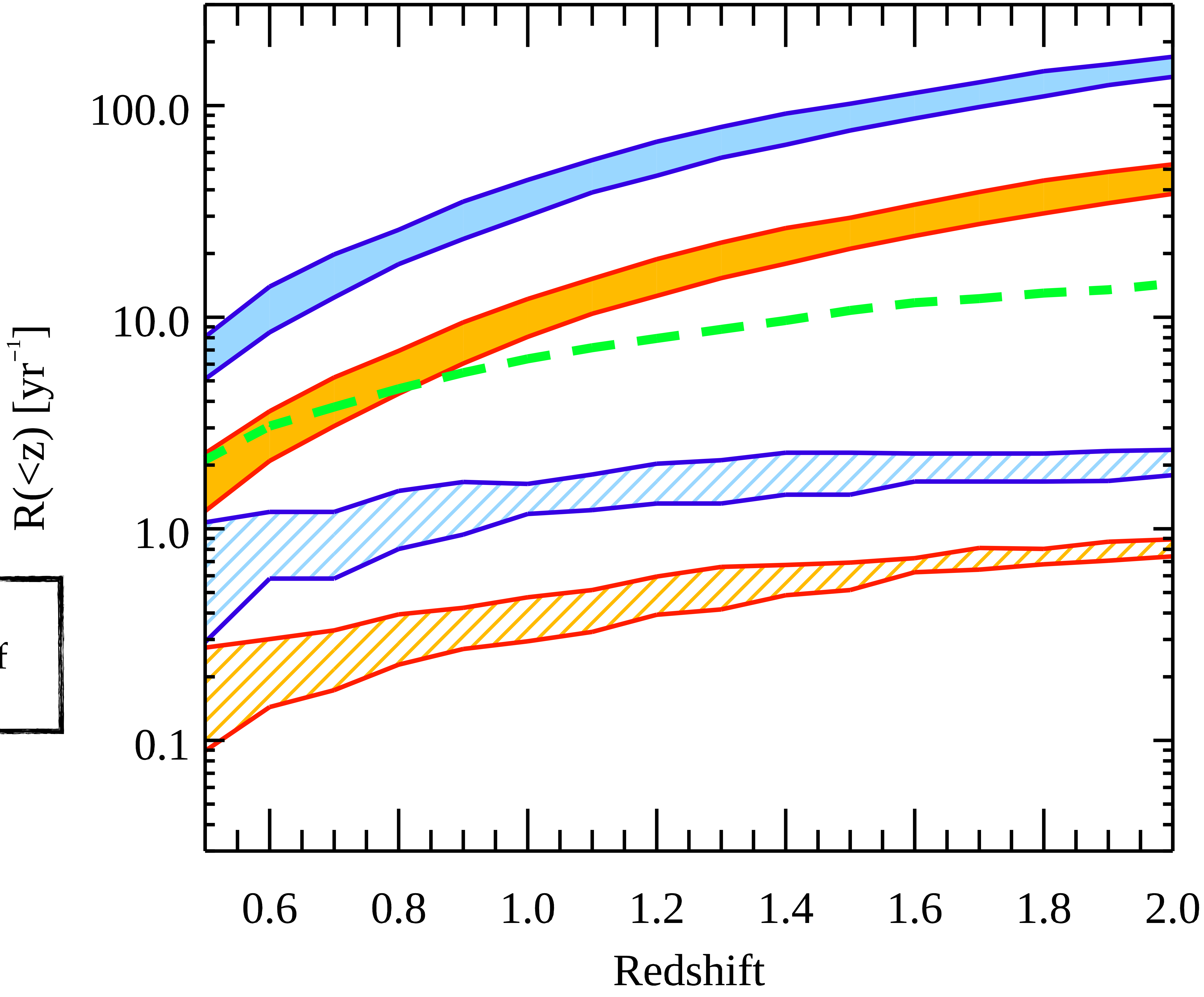
- Mass and angular momentum loss (Yoon et al. 2001)

IMF slope (see also F. Gabrielli, ... GG, ... et al., 2024)

But a few GRB hosts with super-solar metallicities
(See Briel, … GG, … et al., 2025)

Long GRB population

Ghirlanda & Salvaterra 2022



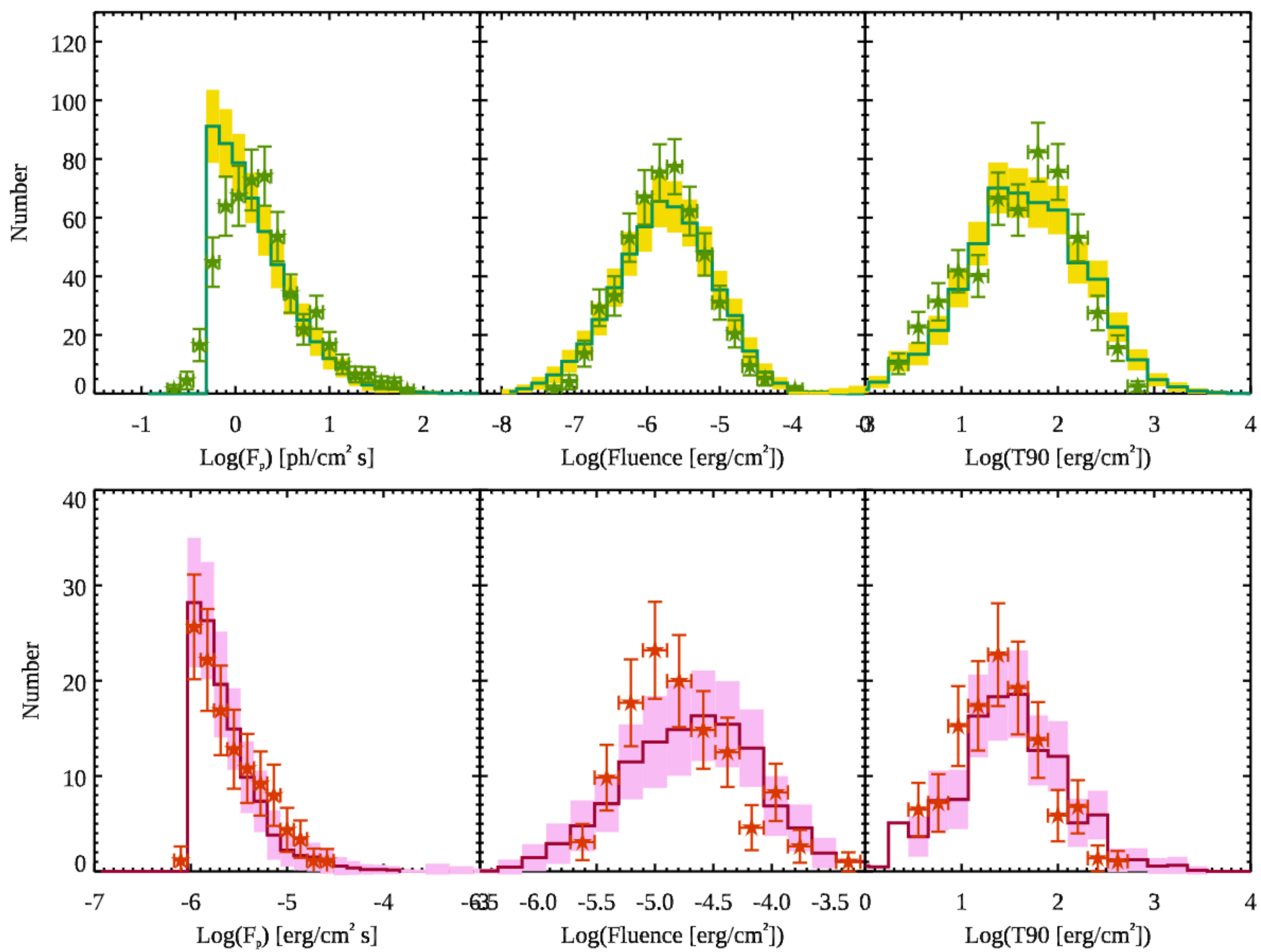
~2.5% of Fermi and 1% of Swift detected bursts @ z<2 should be off axis events (conservative estimate).

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.

Long GRB population

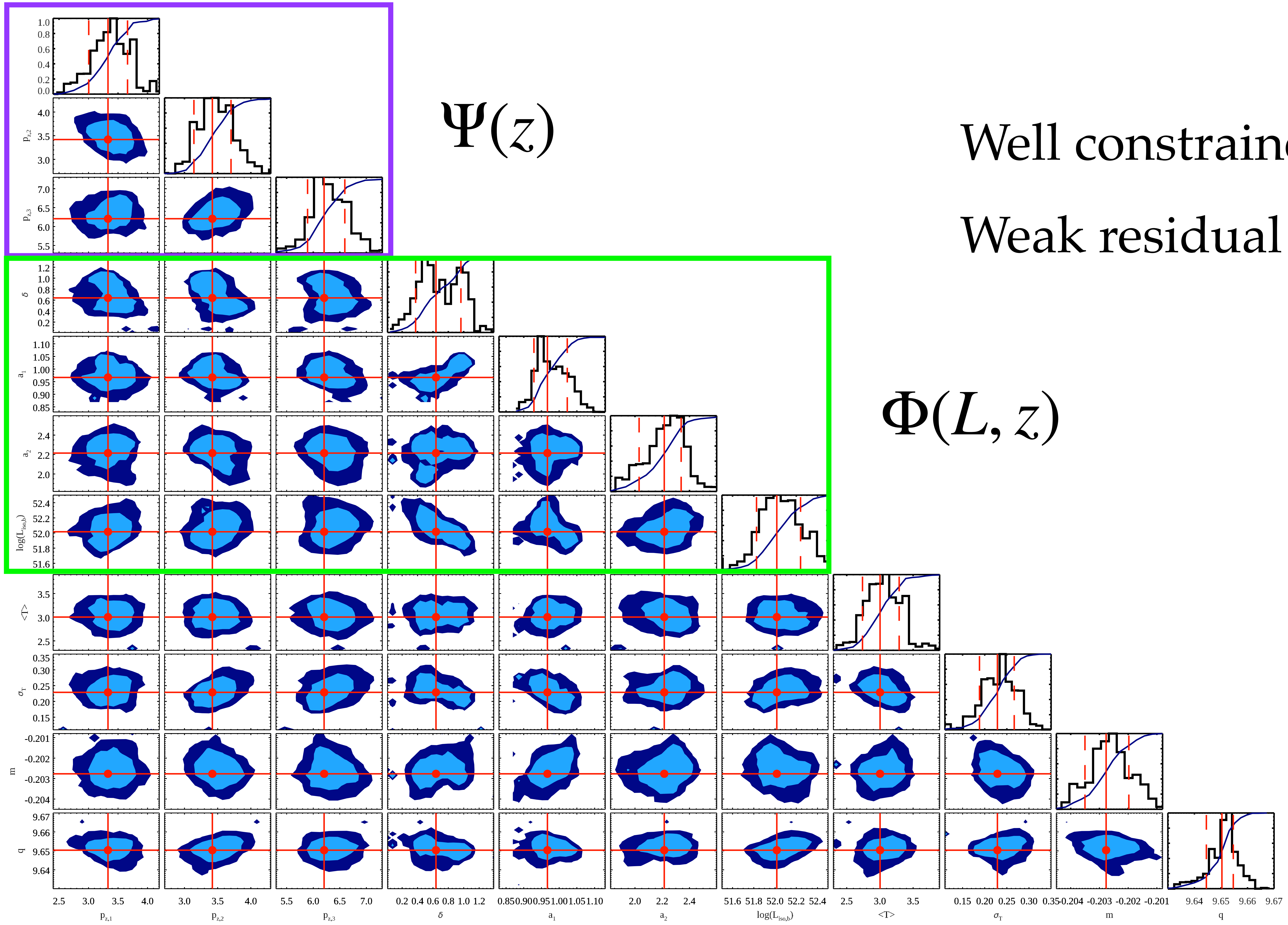
A posteriori consistency checks



Beppo/SAX

Hete-II

Long GRB population



$\Psi(z)$

$\Phi(L, z)$

Well constrained parameters

Weak residual parameter correlation