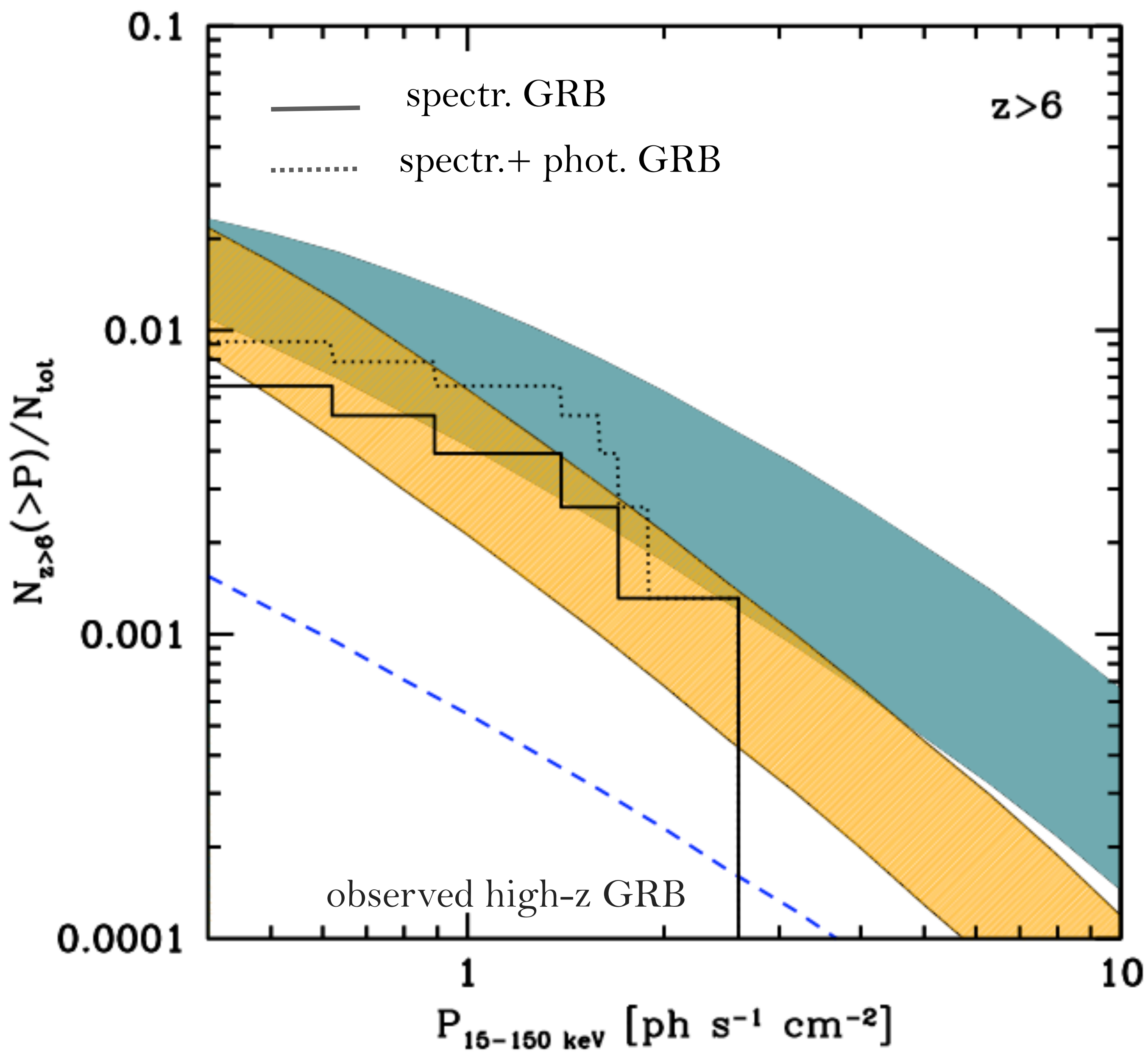
Enlightening cosmic dark ages with GRBs

by R. Salvaterra (INAF/IASF-MI)

why GRBs?

GRBs provide a complementary (sometime unique) tool to study the high-z Universe



Pros:
- high-z events
- very bright
- inside normal galaxies
- power-law continuum
- fade away

Cons:
- fade away
- rare
- inside galaxies

high-z GRBs are 1% of the observed GRBs but ~10% of the entire population

Salvaterra et al. 2012, Ghirlanda et al. 2015

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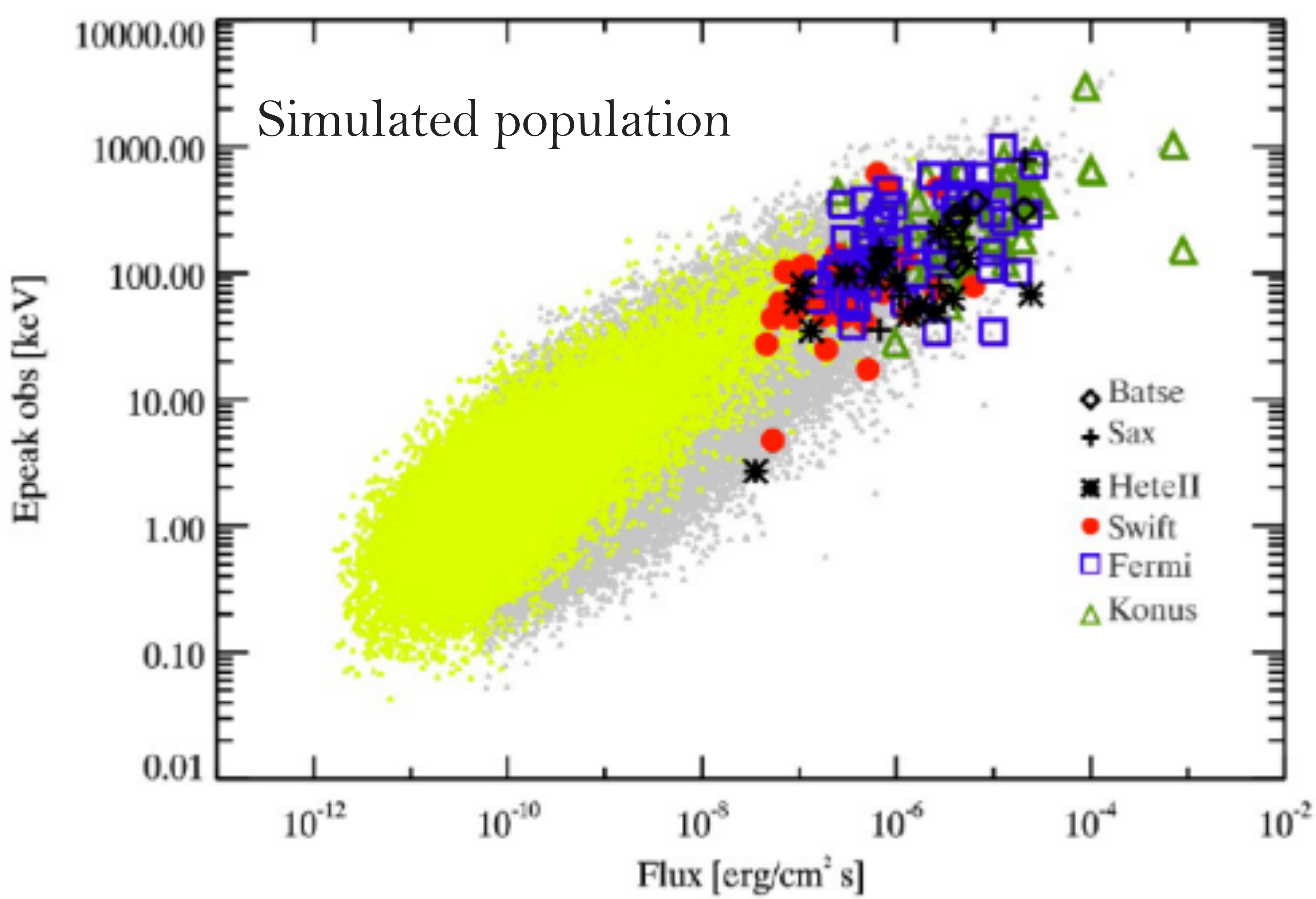

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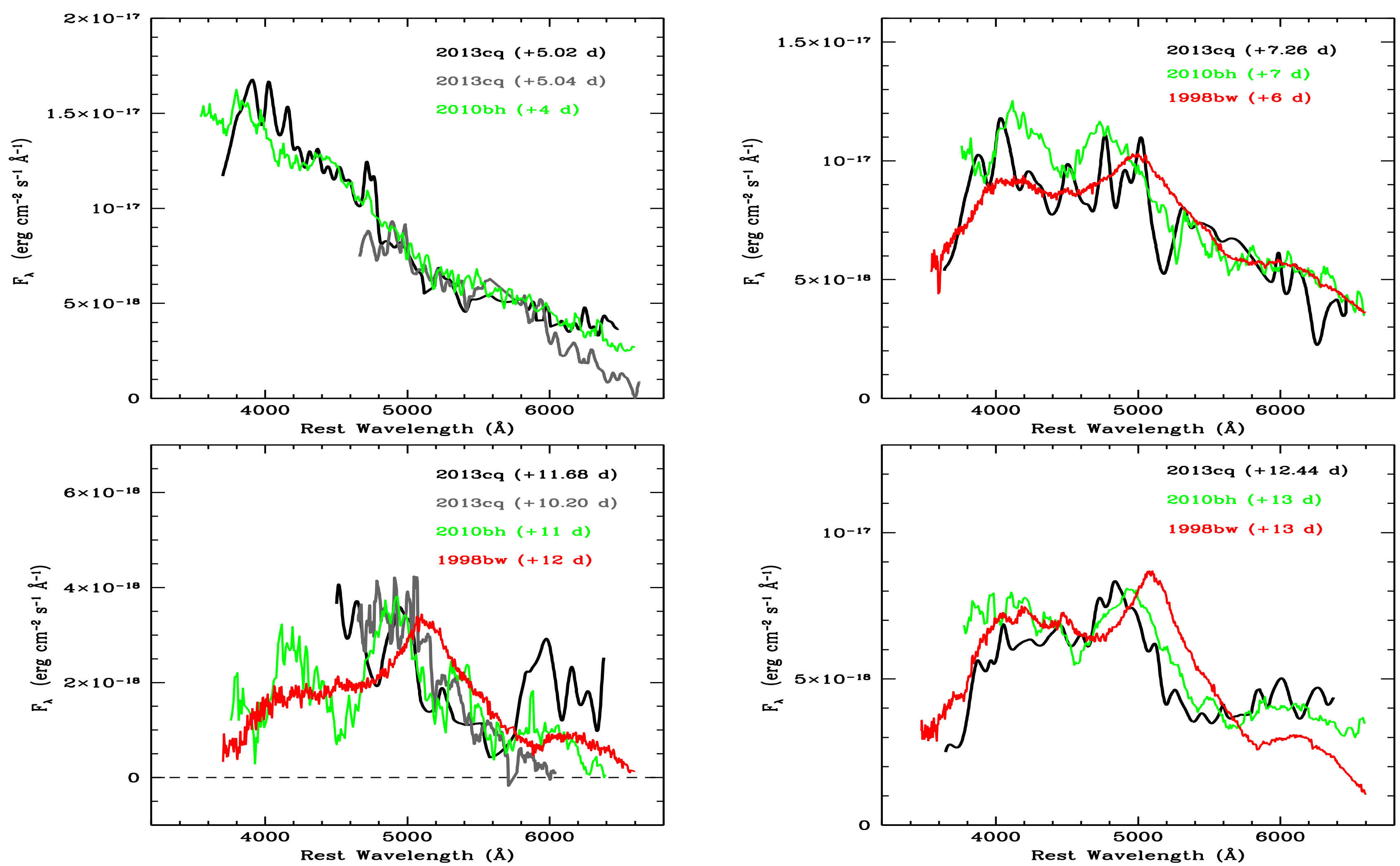
GRBs as a tool… an incomplete list

- ISM metals and dust
- reionization (Gallerani et al. 2008; McQuinn et al. 2008; Xu et al. 2011)
- escape fraction (Chen et al. 2007; Fynbo et al. 2009, Tanvir et al. 2018)
- identify and study high-z galaxies responsible for the reionization
- **constrain the high-z SFR slope and faint-end of the galaxy LF**
- **direct detection of PopIII stars** (Komissarov & Barkov 2009; Mezsaros & Rees 2010; Toma et al. 2011; Campisi et al. 2011; deSouza et al. 2011 …)
- **indirect PopIII detection** (Ma et al. 2015, 2017; Wang et al. 2012)
- probe the intergalactic radiation field (Inoue et al. 2010)
- constraints on DM (Mesinger et al. 2005, deSouza et al. 2013)
- primordial non-Gaussianity (Maio et al. 2012)
- …

see also Salvaterra 2016

GRB-SN connection

Long GRBs are firmly associated with the death of a massive star
by the detection of a type Ib,c SN in low-z events

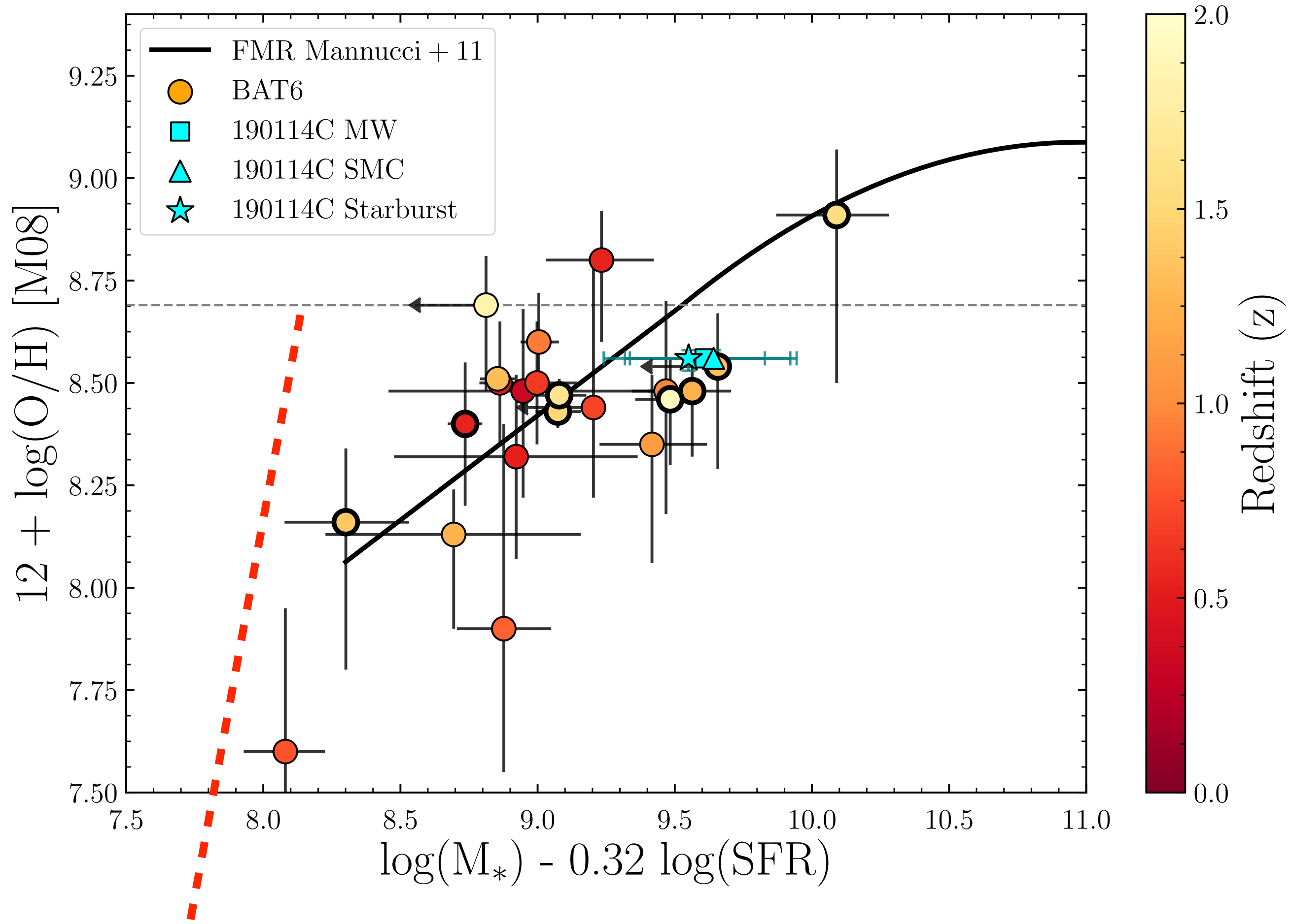


SN2013cq associated to GRB 130427A a low-z analogue to cosmological GRBs
suggesting that GRBs can be used as tracers of SFR

Melandri et al. 2014

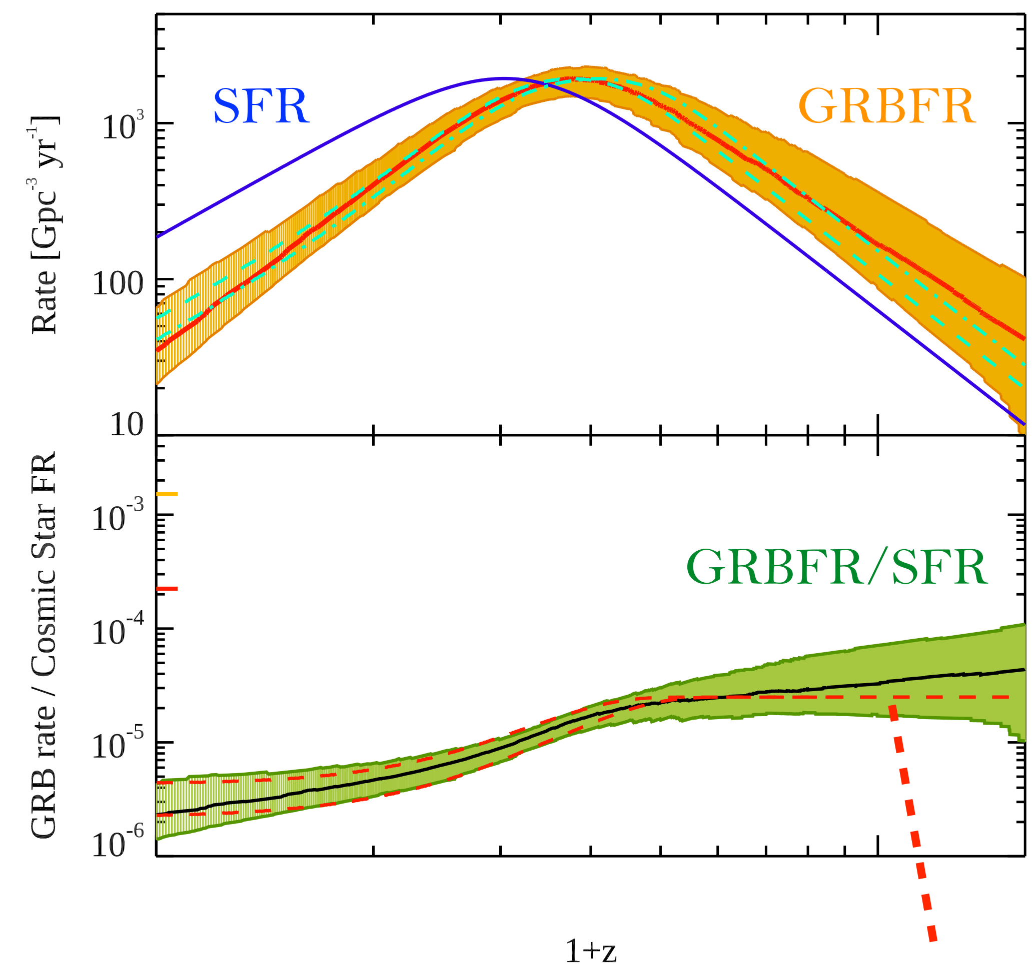
metal bias

Vergani et al. 2017



log(O/H)crit~8.7
[M08 calibrator]

Ghirlanda & Salvaterra 2021

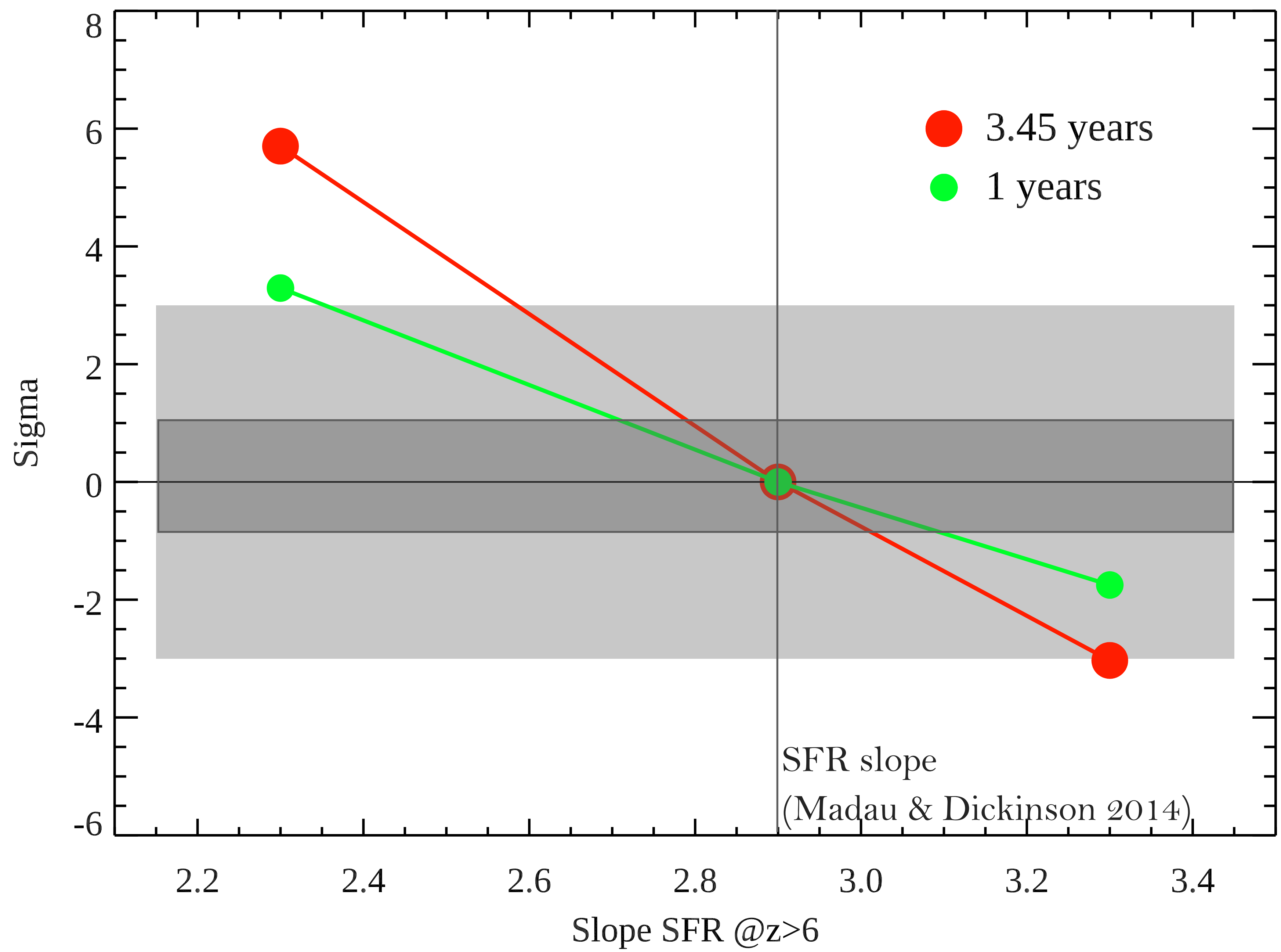


log(O/H)crit~8.5-8.7
[M08 calibrator]

GRB host galaxy properties and population studies suggest a mild metallicity threshold

implying that GRBs are good tracer of SF at high-z

recovering the high-z SFR slope

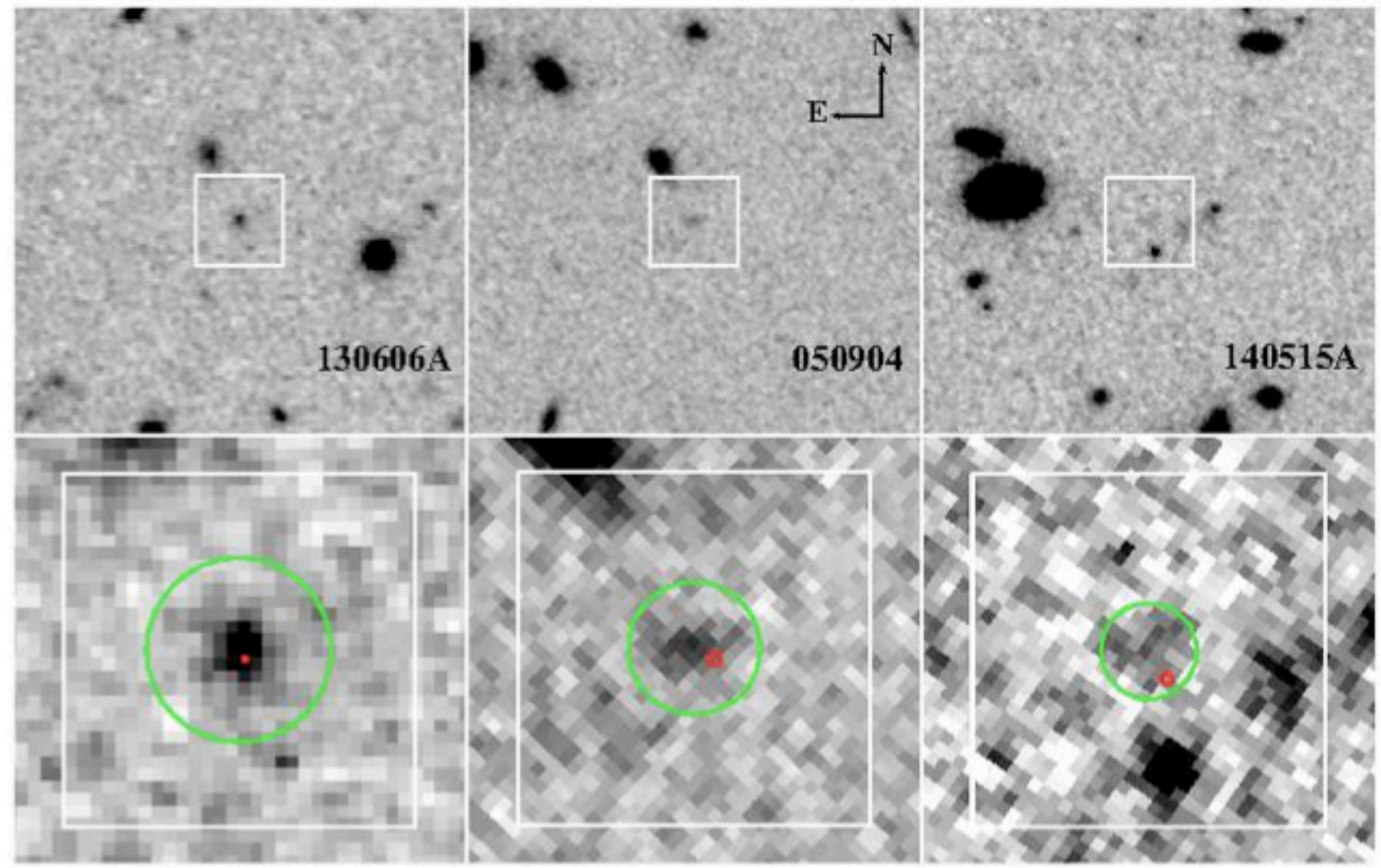


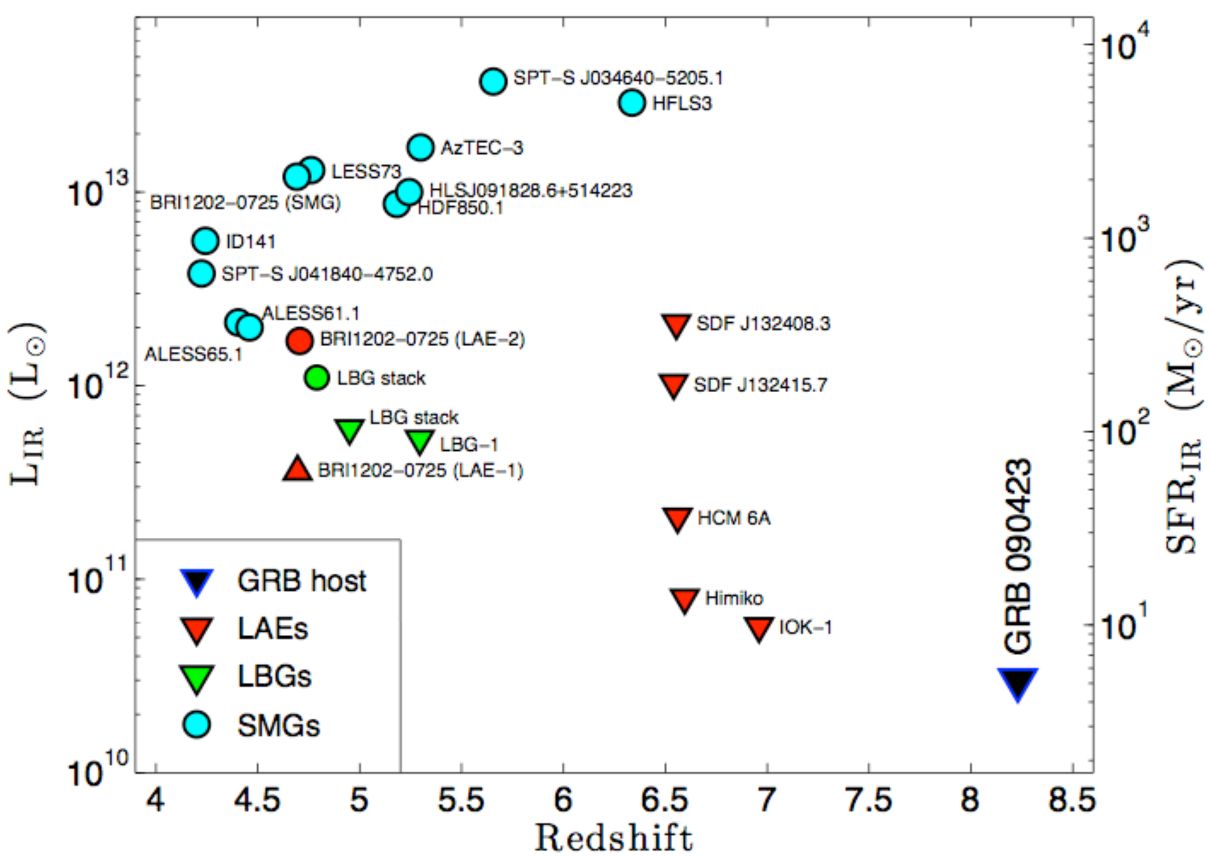
a slope consistent with MD14 can be recovered with an error of ~0.1 (1 sigma)

Tanvir et al. 2021 - Theseus WP

searching for high-z hosts

the knowledge of position and redshift allows very deep search for the GRB host



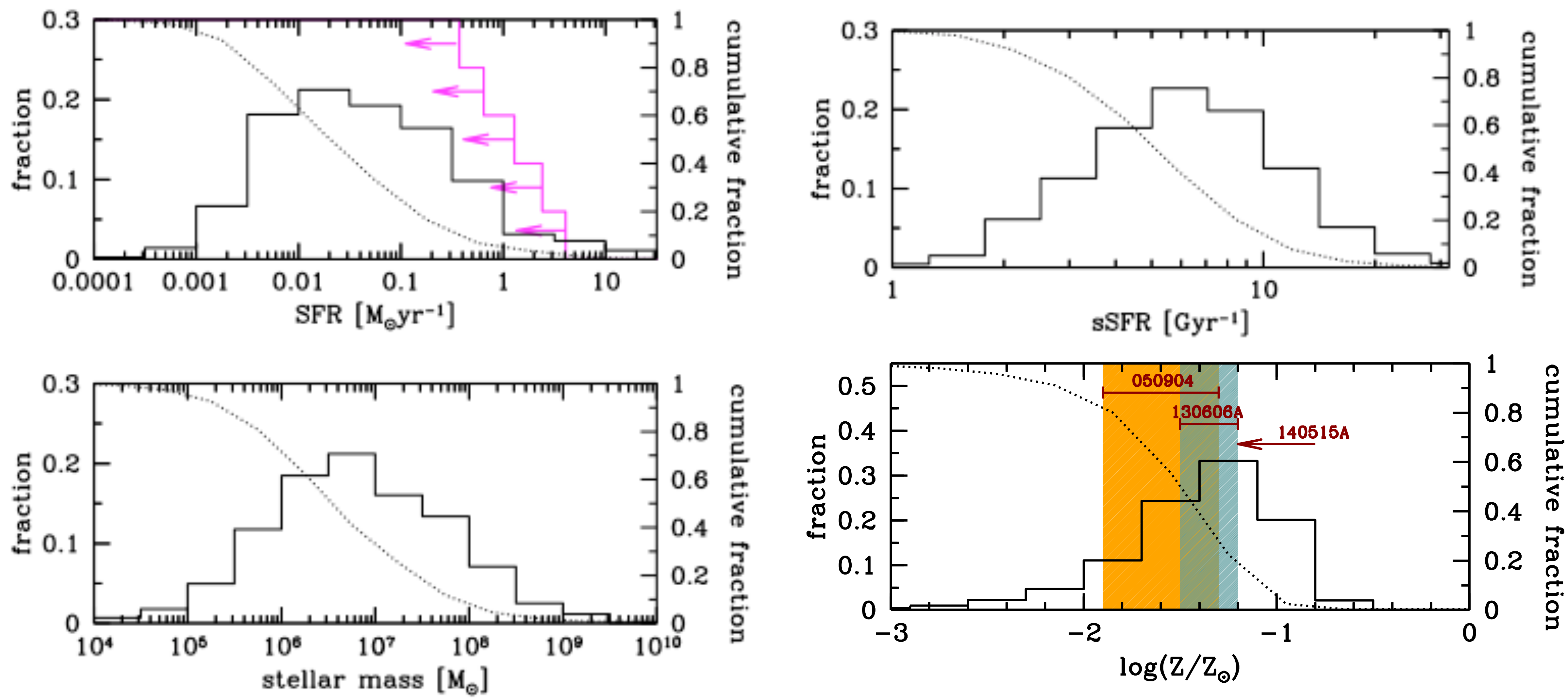


for GRB 090423 at z=8.2 deep HST/ WFC3 (m_J>30.3), Spitzer and ALMA observations provide a strong limit on host brightness and SFR

Tanvir et al. 2012; Basa et al. 2012; Berger et al. 2014, McGuirre et al. 2016, Vergani et al. in prep

high-z host physical properties

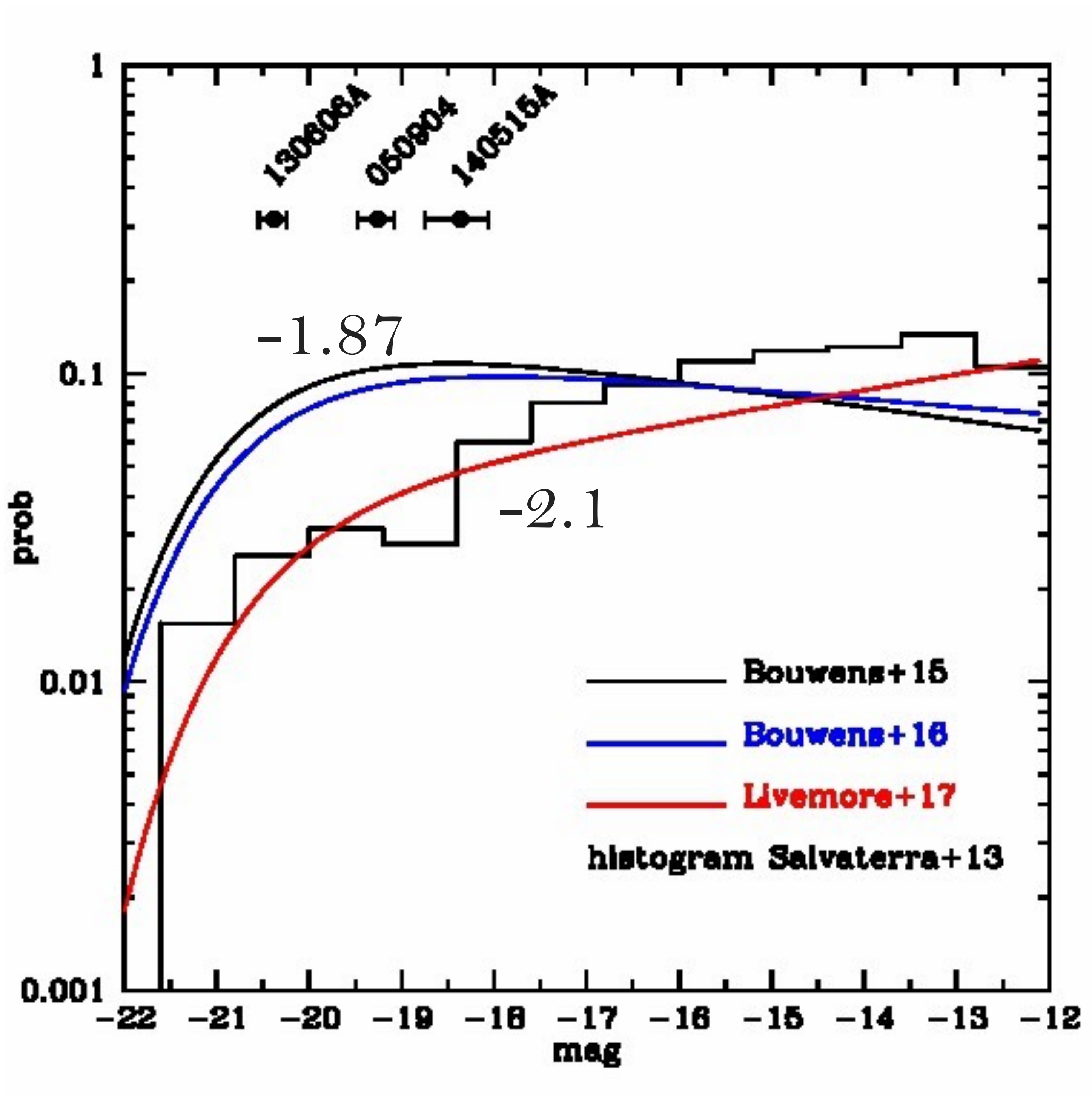
we use the state-of-the art of numerical simulation of structure formation at high-z including all relevant physical process (e.g. chemical, mechanical and radiative feedback)



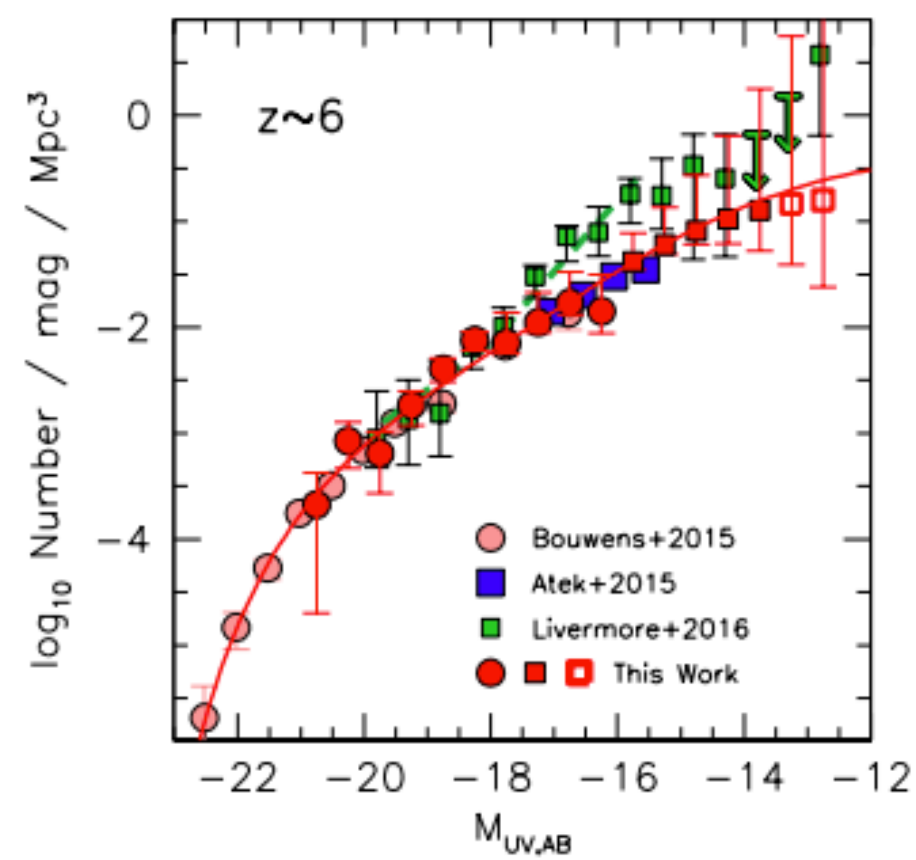
high-z hosts are expected to have low masses (10^6-10^8 M⊙), high sSFRs and Z~0.05 Z⊙

Salvaterra et al. 2013

constraining the galaxy LF faint-end

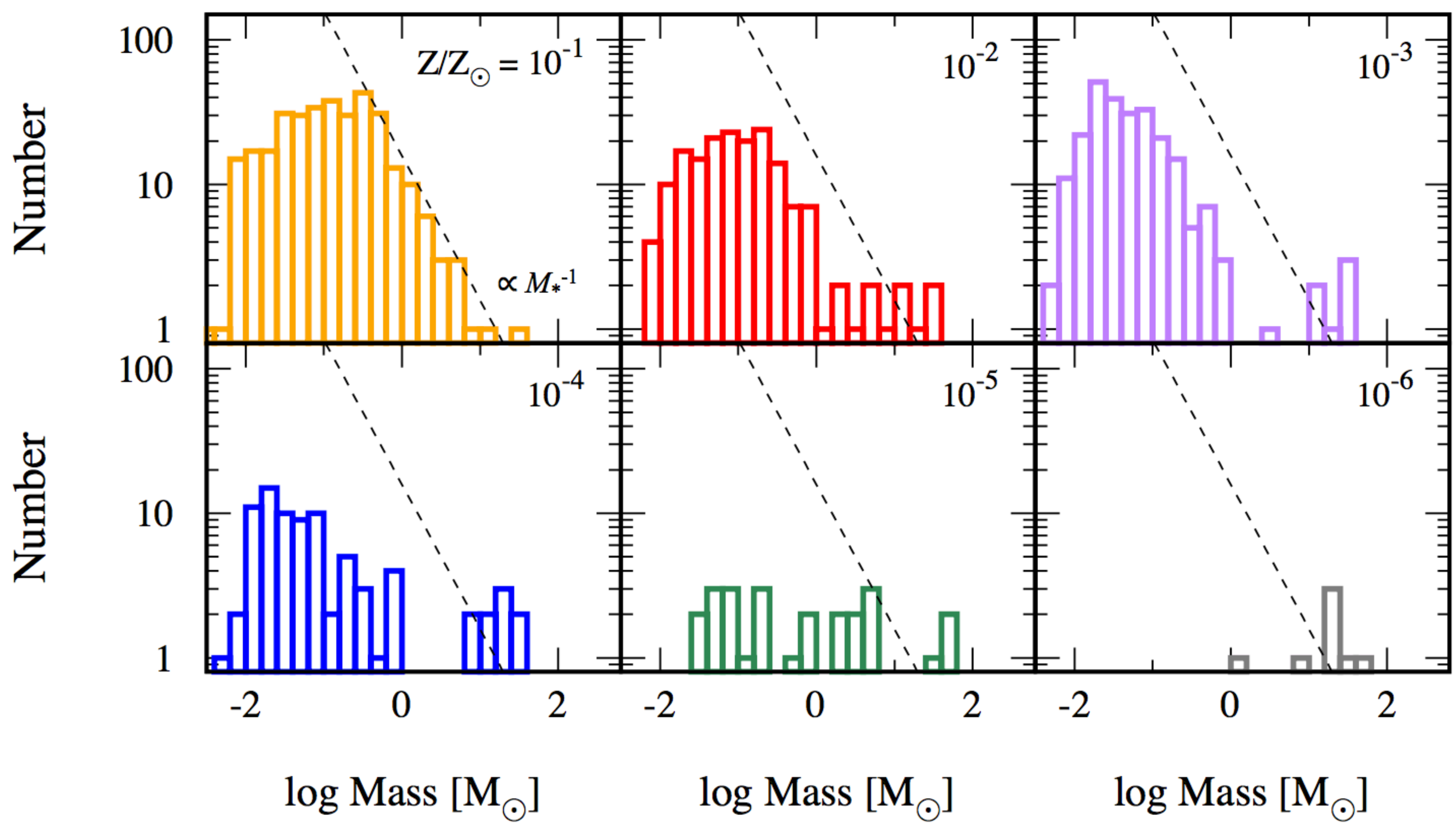


HST Frontier Fields LF



other high-z biases? IMF variation

High-z GRB population results can be compared with other high-z SFR measurements (e.g. JWST) to highlight the existence of other biases.

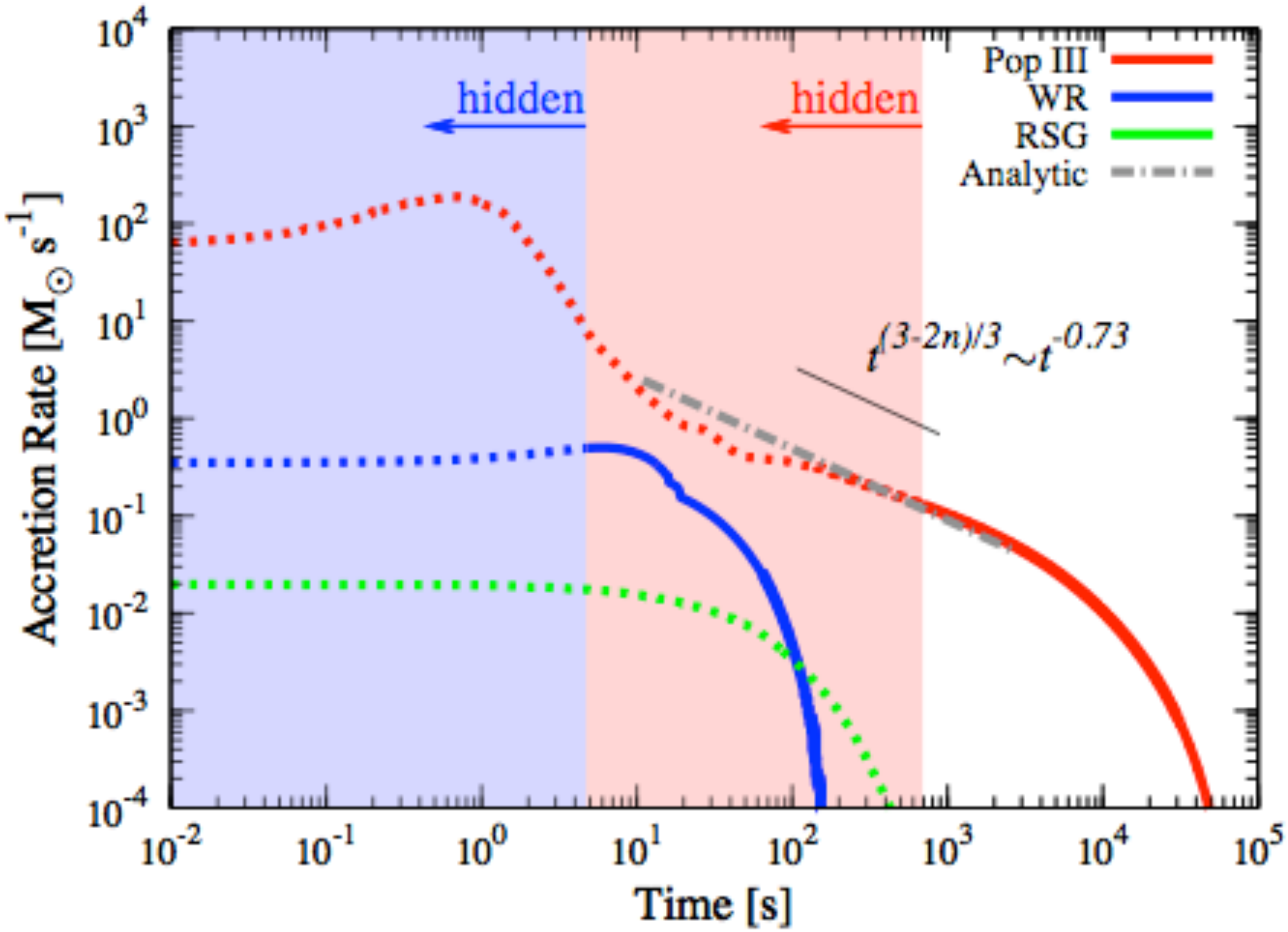


Chon et al. 2021

PopIII GRBs

shock breakout is possible even in a massive, metal-free PopIII stars with a large H envelope thanks to the long-lived powerful accretion onto the forming central BH

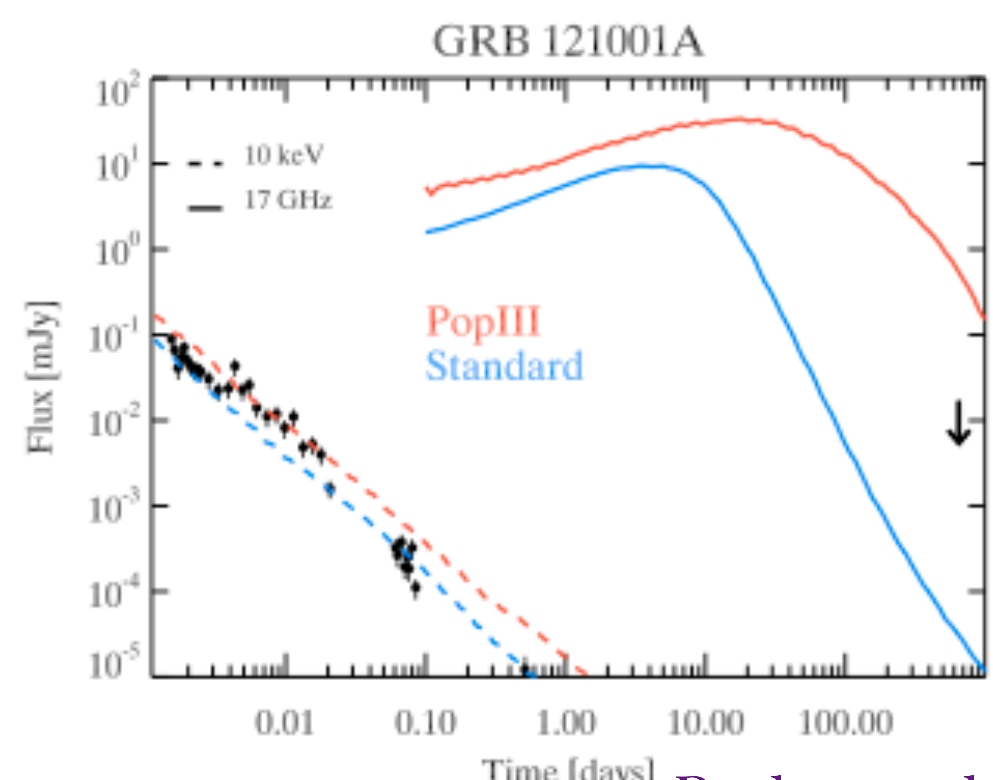
see e.g. Fryer et al. (2001), Heger et al. 2003, Suwa et al. 2007, Komissarov & Barkow (2010), Meszaros & Rees (2010), Suwa & Ioka (2011), Toma et al. (2011), Nagakura et al. 2012, Piro et al. 2014 ...



Eiso ~ 10^{55} erg

T90 ~1000-10000 sec

Liso ~ 10^{52} erg/s

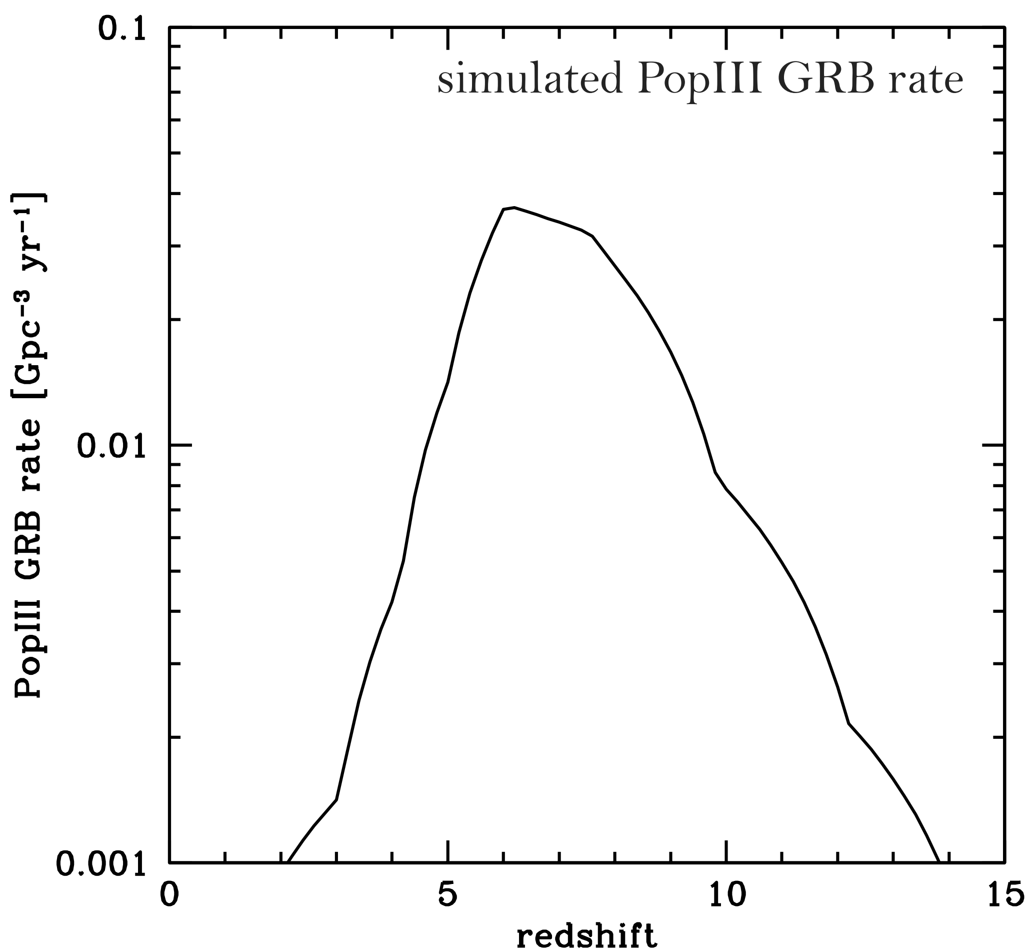


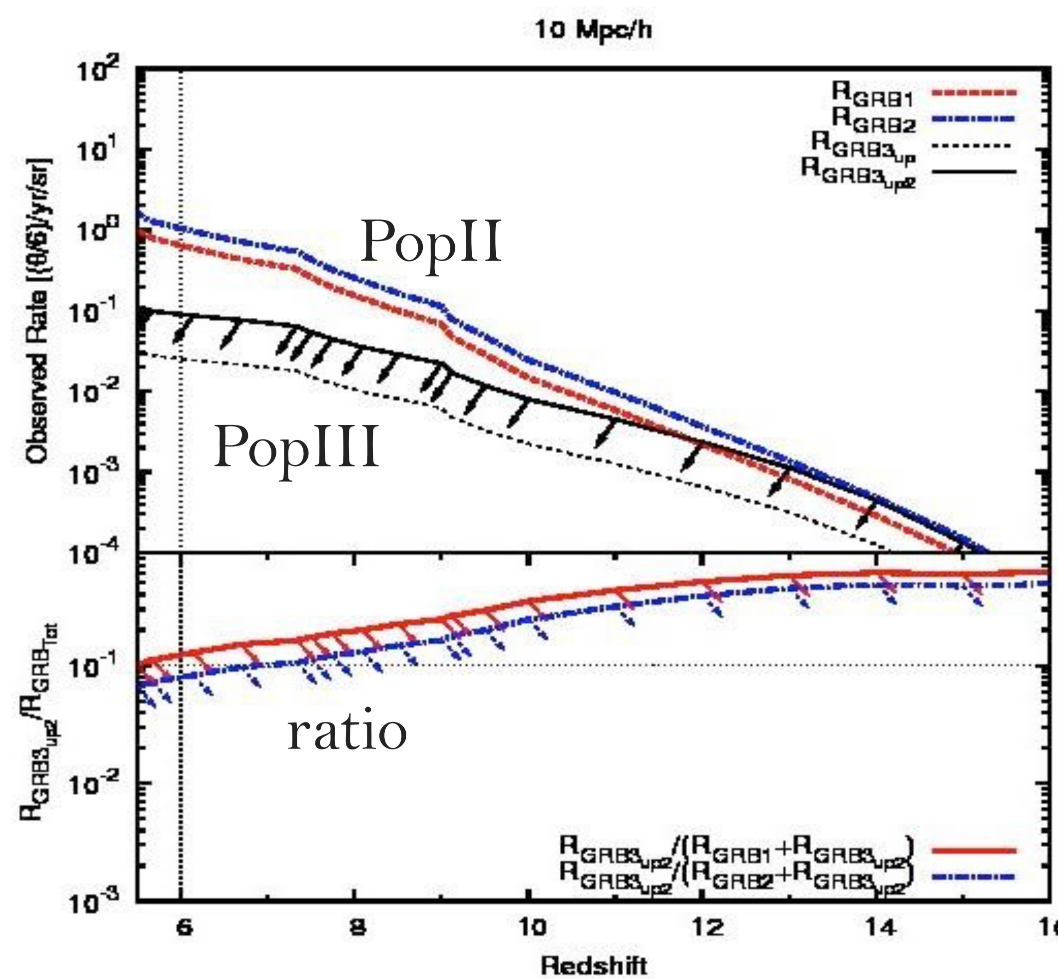
Burlon et al. 2016

Suwa & Ioka 2011, Nagakura et al. 2012

PopIII GRB rate

given that none of Swift detected GRBs is likely to be associated to a PopIII progenitor we can set an upper limit to their rate (assuming that Swift is able to catch them!)





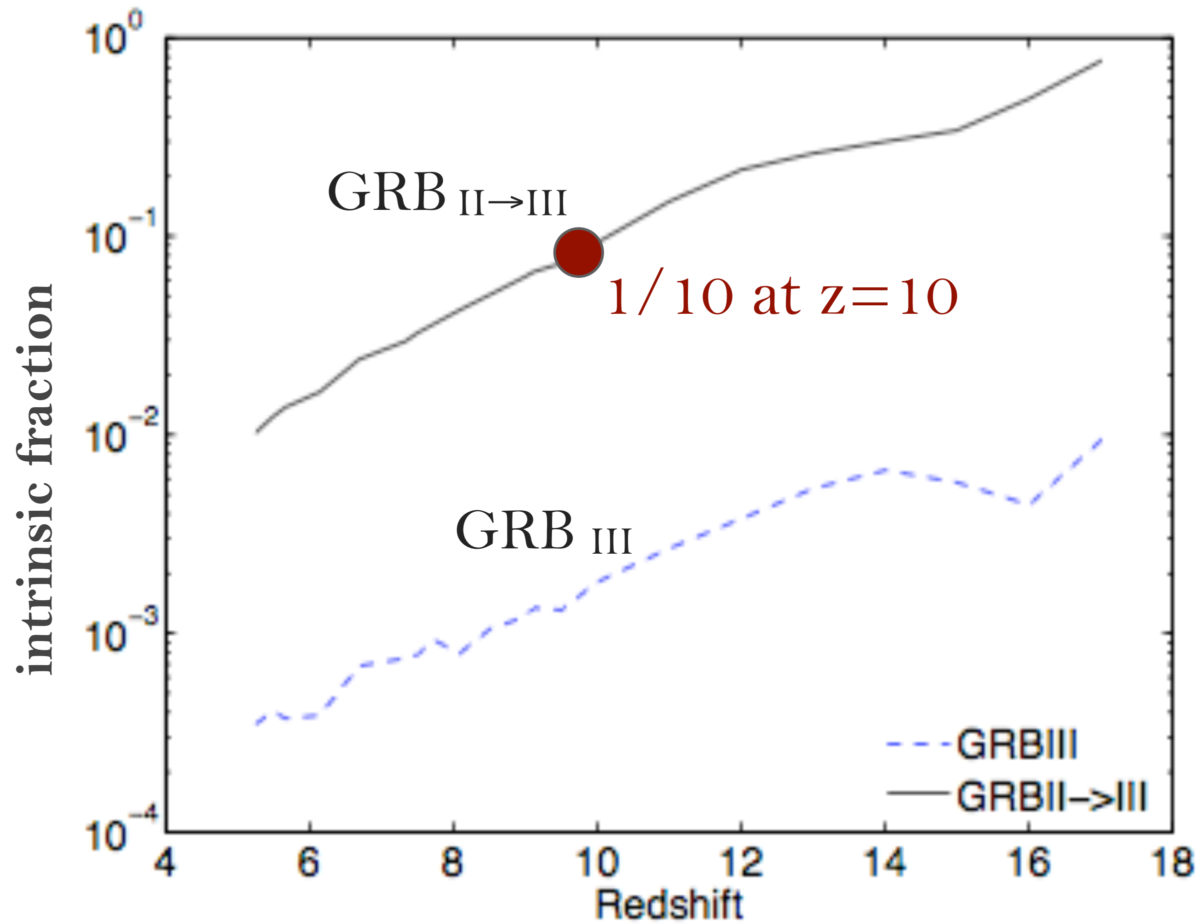
PopIII GRBs are rare (<10% of all detectable GRBs at z=6), i.e. <1 every 500 PopIII stars but they might dominate at z>10-12

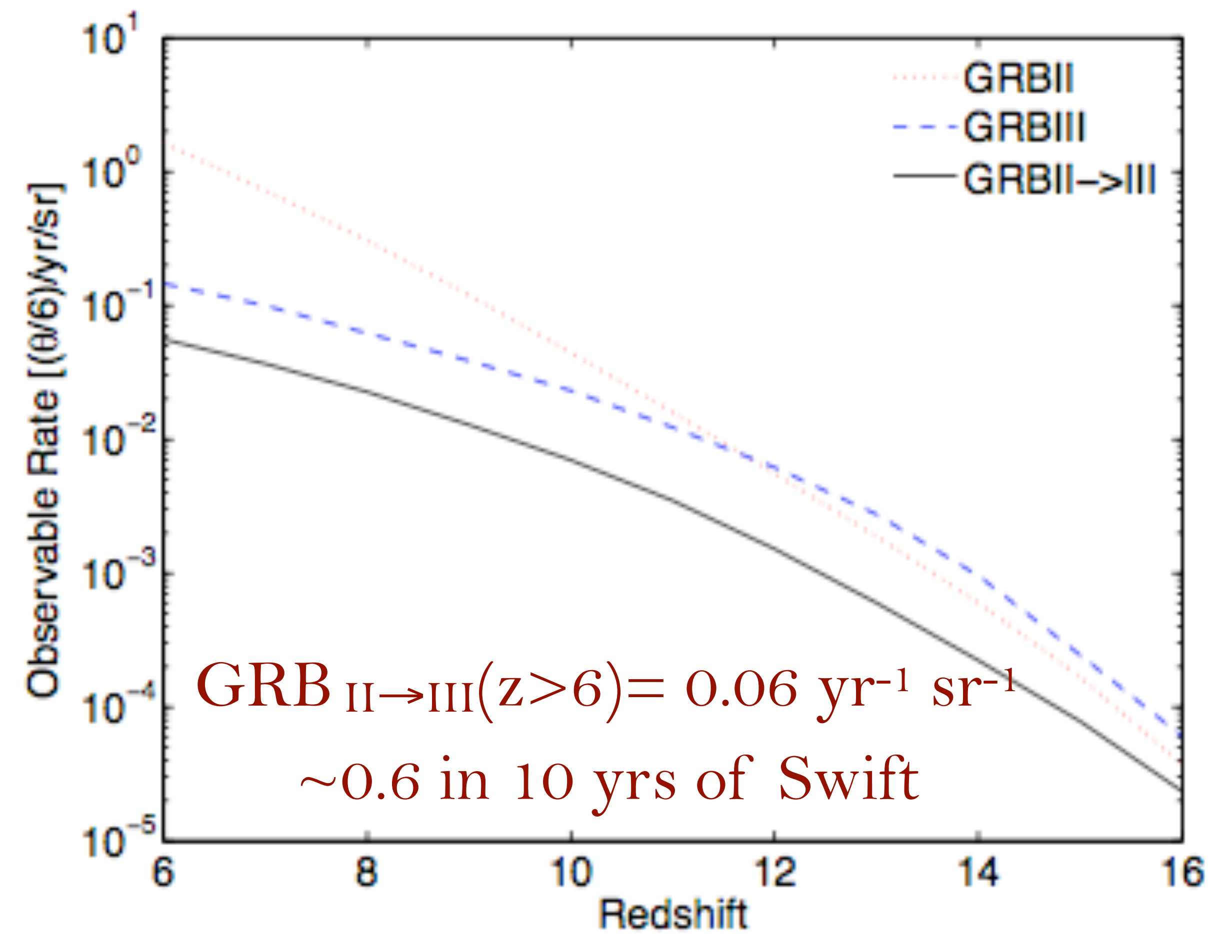
[vs 1 PopII/I GRB every 300 SNIb/c (Ghirlanda et al. 2013a)]

Campisi et al. 2011, Kinugawa et al. 2018

indirect search for PopIII stars

we compute the expected rate of PopII GRB exploding in a gas enriched by PopIII stars

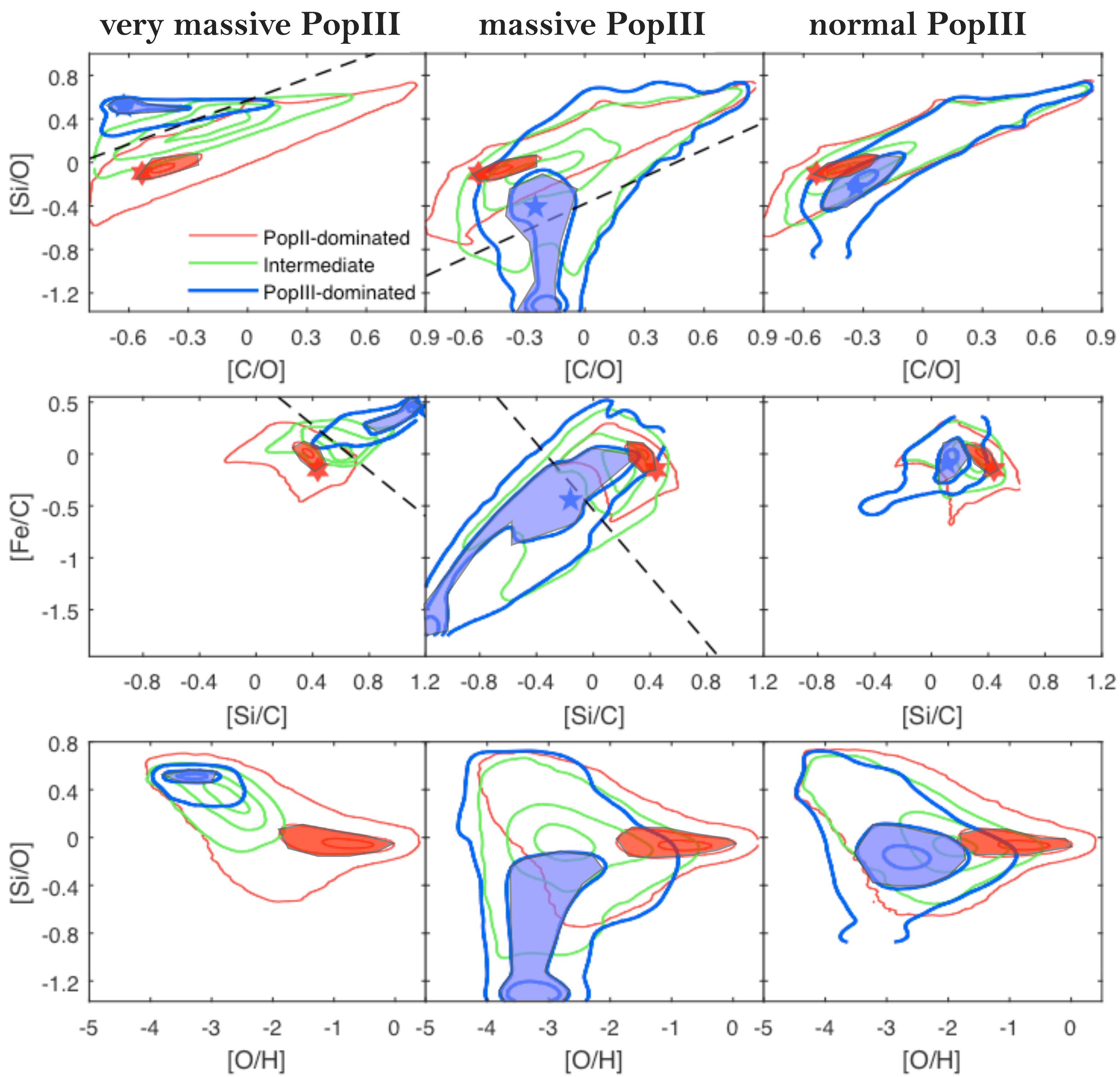




we expect GRB $_{II \rightarrow III}$ to be ~10% of z=10 PopII GRBs

Ma et al. 2015

inferring PopIII IMF



GRB 050904 and 130606A abundance ratios are consistent with PopII SN enrichment

Ma et al. 2016

conclusions

the future of cosmic dark ages is bright