theseus

TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

Exploring the early Universe with GRBs
THESEUS Science WG 1

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+ 75 SWG members contributing scientists

THESEUS Science Working Groups
teleconference
June 3-4, 2020

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Niels Bohr Institute
University of Copenhagen

DARK

THESEUS WG1: Key science cases

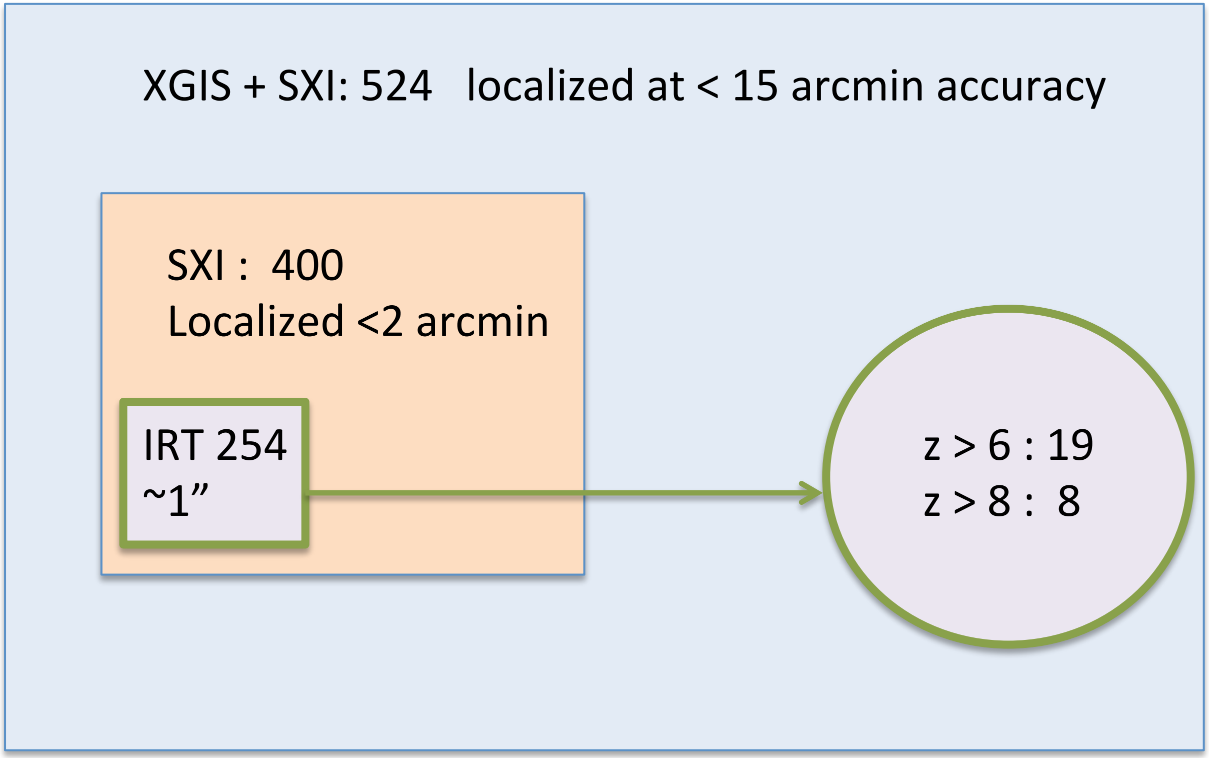
Explore GRBs in the first 1 Gyr lifetime of the Universe

Detect > 50 GRBs at z > 6 over 3 years mission lifetime

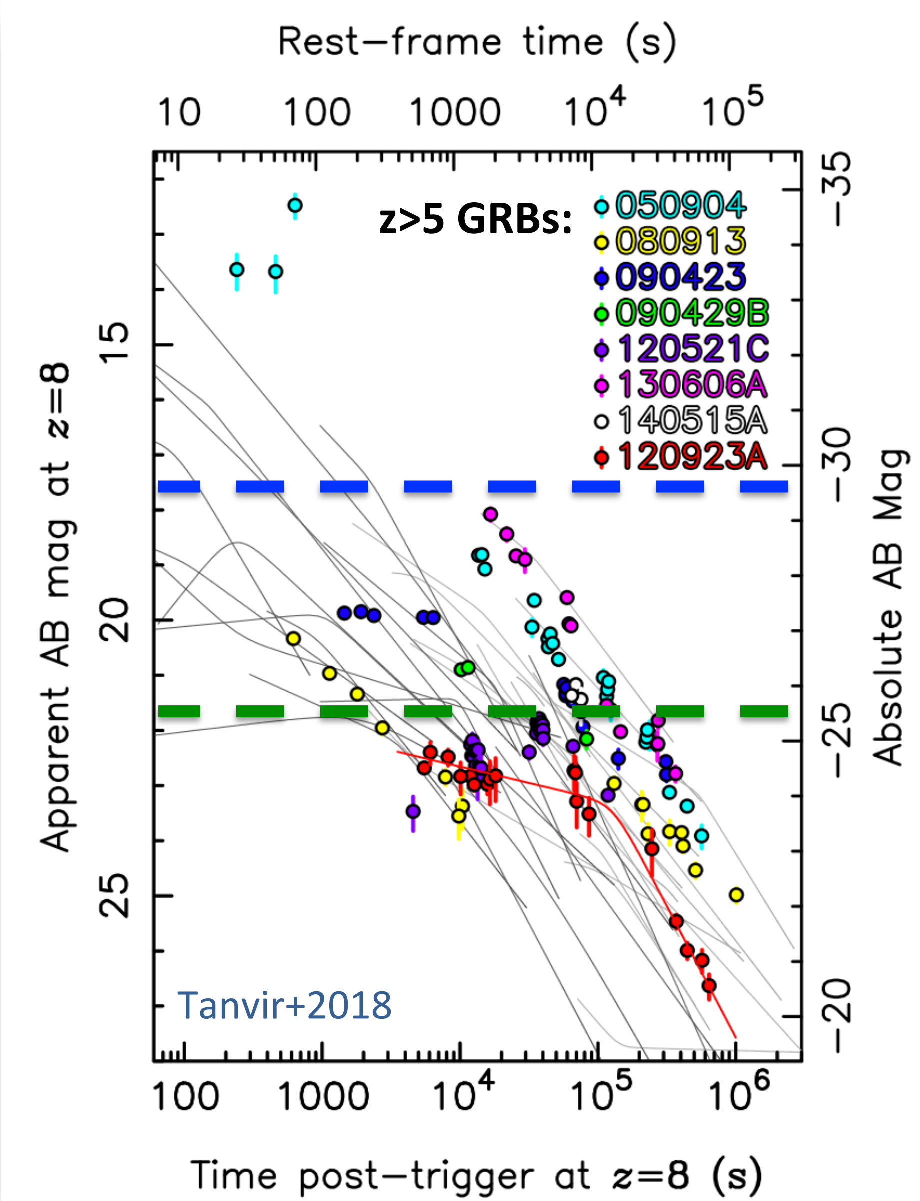
1. Characterize population of z > 6 GRBs
2. Cosmic star-formation density (Tanvir's presentation)
3. High-z galaxies, faint end of luminosity function
4. Epoch of reionization (Tanvir's presentation)
5. Pop III progenitors and metal enrichment
6. Dusty / Dark GRBs

THESEUS detection rates of long-GRBs

Number of detected GRBs in **1 year**
(most recent THESEUS mission operation simulation by ESA – See presentation by E. Bozzo)



High-z afterglow light curves



THESEUS infrared telescope (IRT)

Detection limits:

5 filter IZYJH photometry

- 6 x 25 s / filter
- H_{AB} = 21.7 mag
- Photo-z < 10% uncertainty

Spectroscopy mode

- H_{AB} = 17.5 mag
- T_{exp} = 1800 s
- Resolution R ≈ 400

-> S/N ~ 5 / resolution element

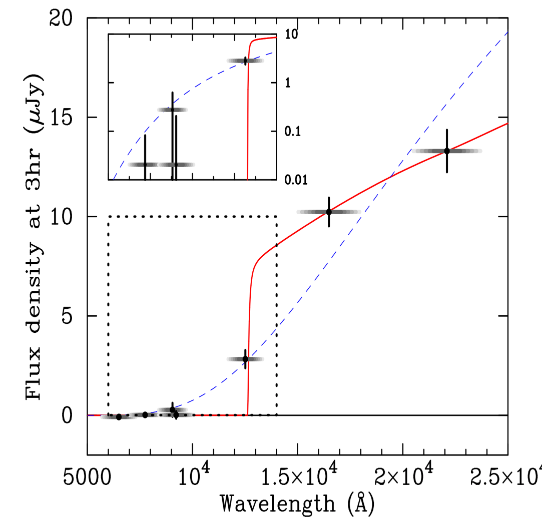
-> Spec-z < 1% uncertainty

Identifying high-redshift GRBs

- Most powerful explosions in the Universe
  - Long-GRBs associated with SN Type Ib/c
  - Beacons to probe the high-z universe
  - Locate star-forming galaxies

- Detectable out to the highest redshifts

E.g. GRB 090429B at z=9.4 (Cucchiara et al. 2009)



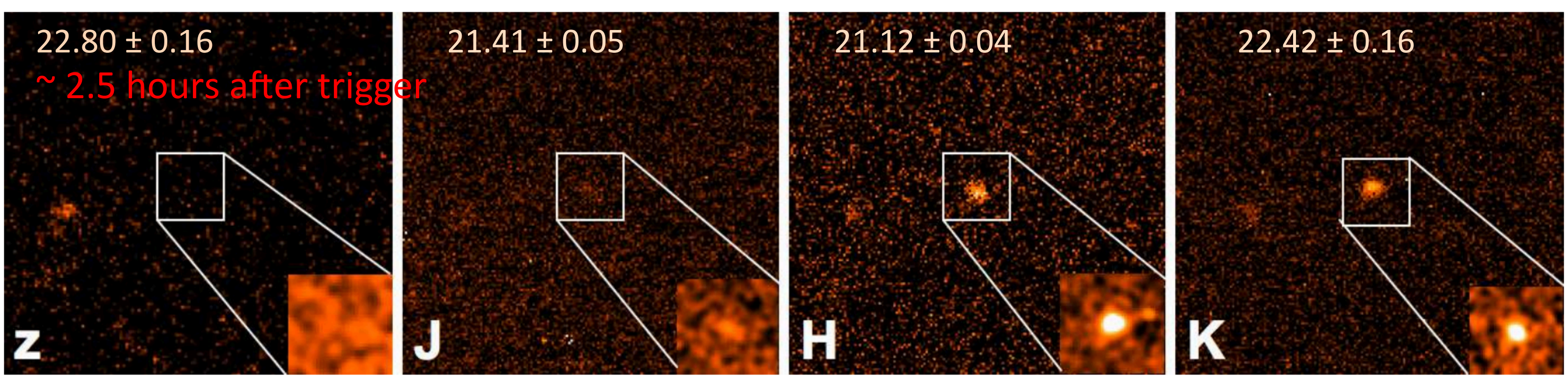
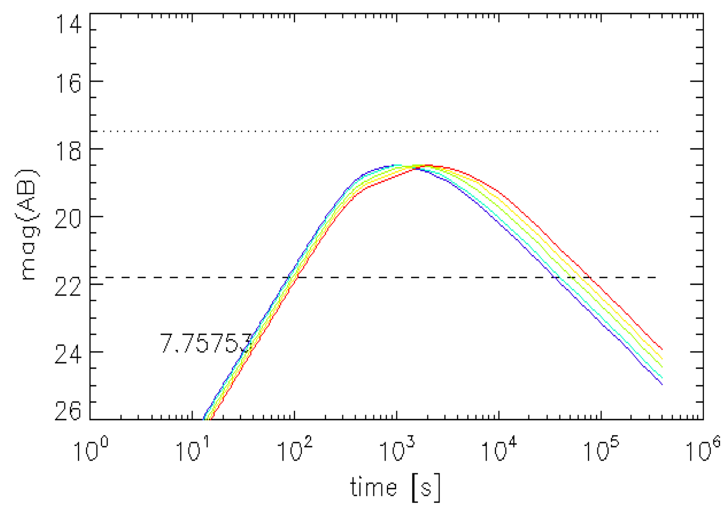


Photo-z estimates

Input : Ghirlanda + Salvaterra models of 2000 afterglows light curves in R, I, J, H, K bands

-> 113 GRBs at z > 6

- No IGM absorption
- No intrinsic GRB host DLA absorption



Post process:

+ Include IGM absorption at z-model

+ Include DLA absorption profile at z-model

+ Convolve with filter transmission curves

(R,I , J, H, K) - > Synthetic mag.

+ Compute S/N detection

(use exact S/N from Theseus ETC)

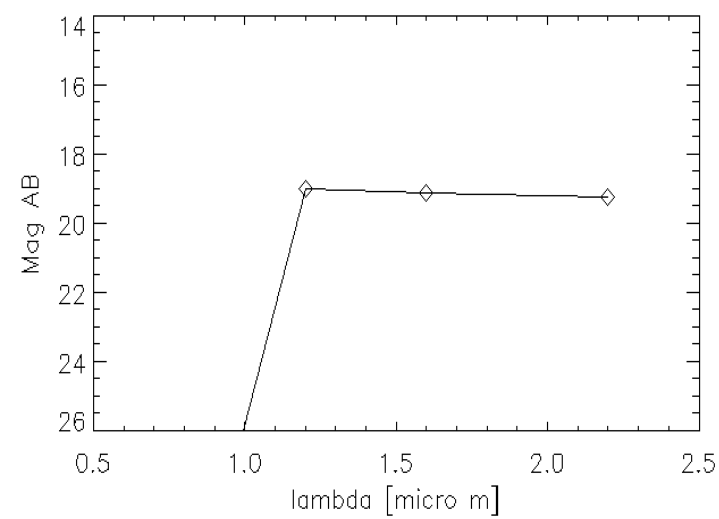
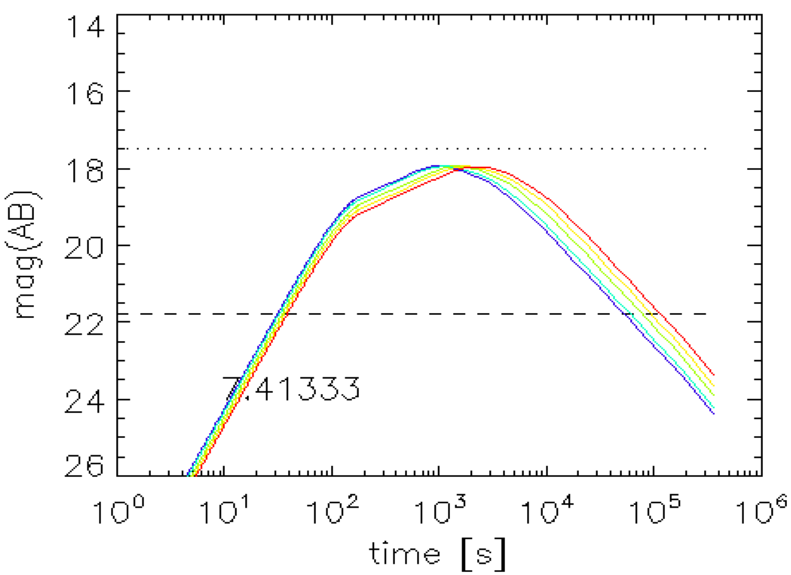


Photo-z estimates

Templates :

- Model GRB afterglow spectrum with slope beta = -0.5
- Compute $$\chi^2 = \sum_{filter} \frac{(mag_{model} - mag_{obs})^2}{\sigma^2_{magobs}}$$



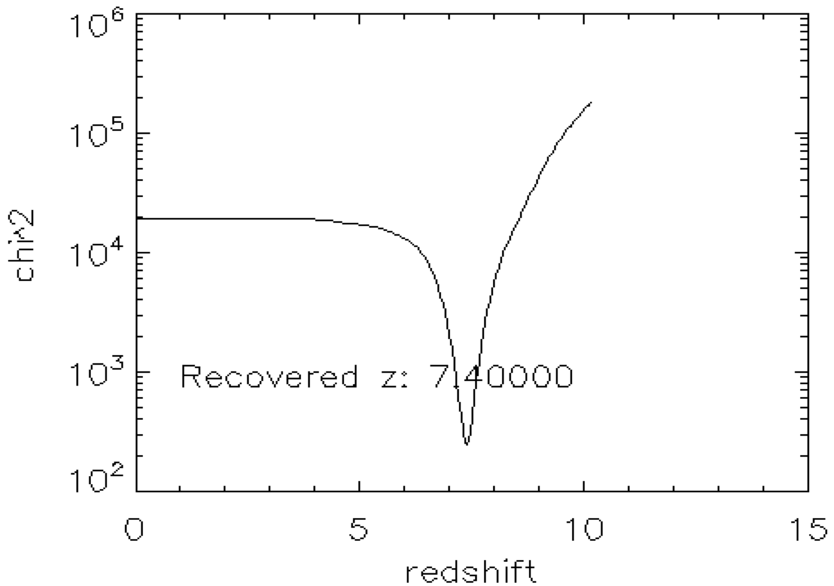


Photo-z estimates

All models with z > 5

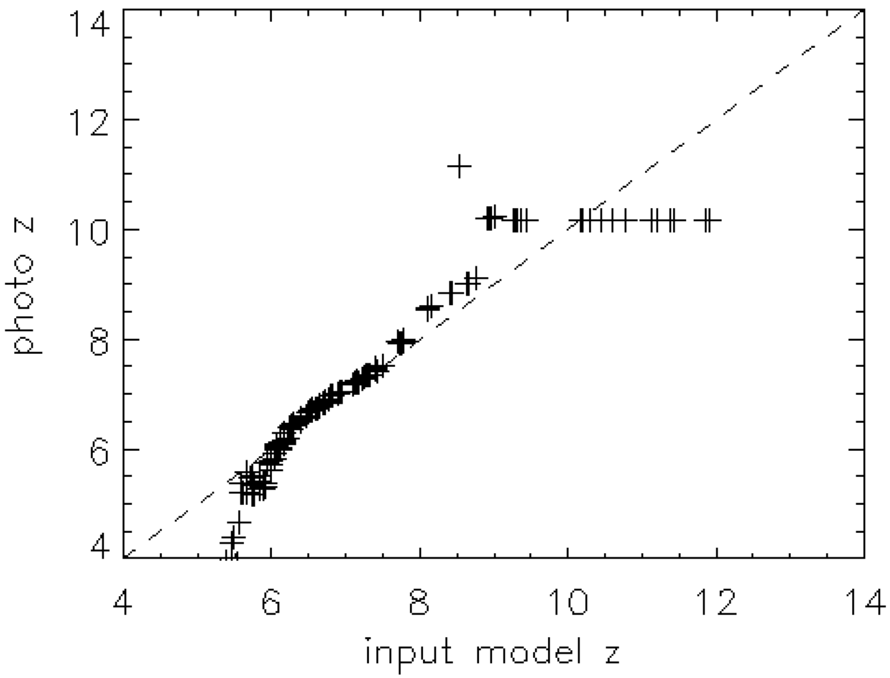
Preliminary results

Accuracy = 0.05

$$\sigma = 1.48 \times median\left(\frac{|z_{model} - z_{phot}|}{(1+z_{model})}\right)$$

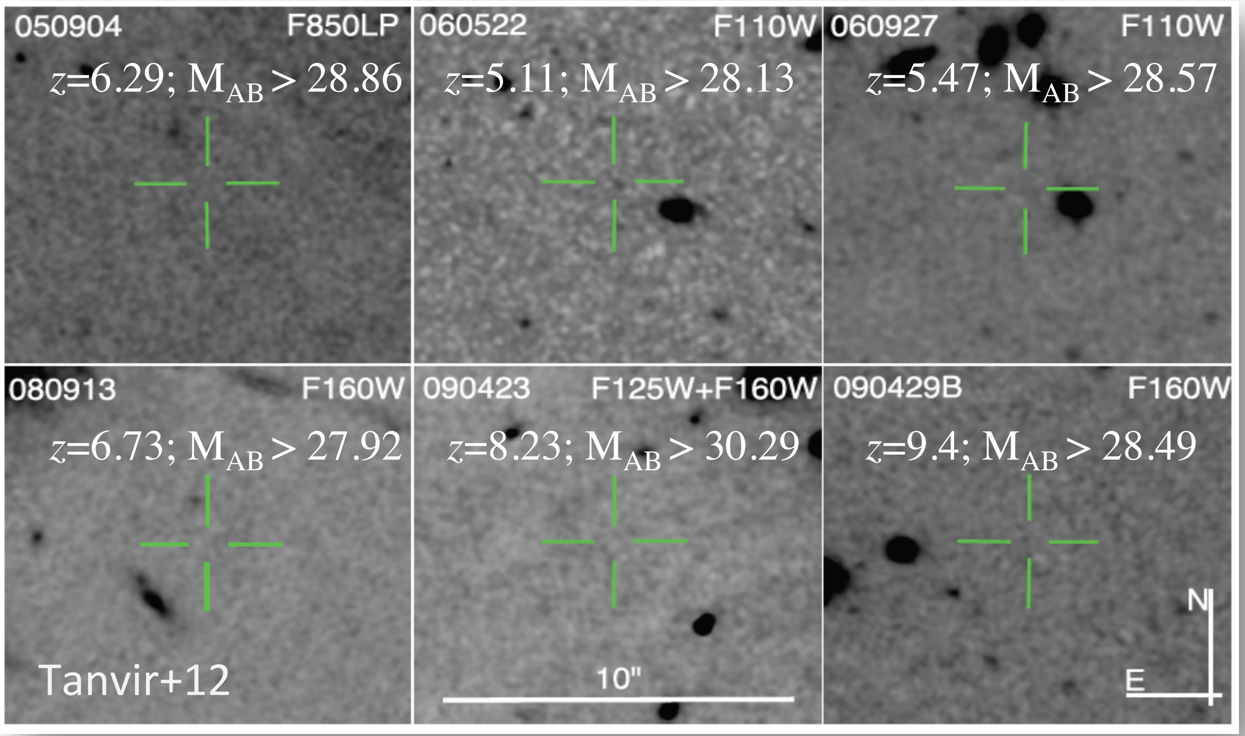
Failure rate: 40 / 163 = 25 %

$$|z_{model} - z_{spec}| > 0.15(1+z_{model})$$



- Assumes simultaneous 5 band filters observations
- RIJHK -> IZYJH
- Use ETC simulations -> correct S/N
- Effects of dust
- z < 5 GRBs identification needs spectra (Susanna Vergani's presentation)

High-z low-luminosity galaxies



Limiting magnitudes (5σ) for :

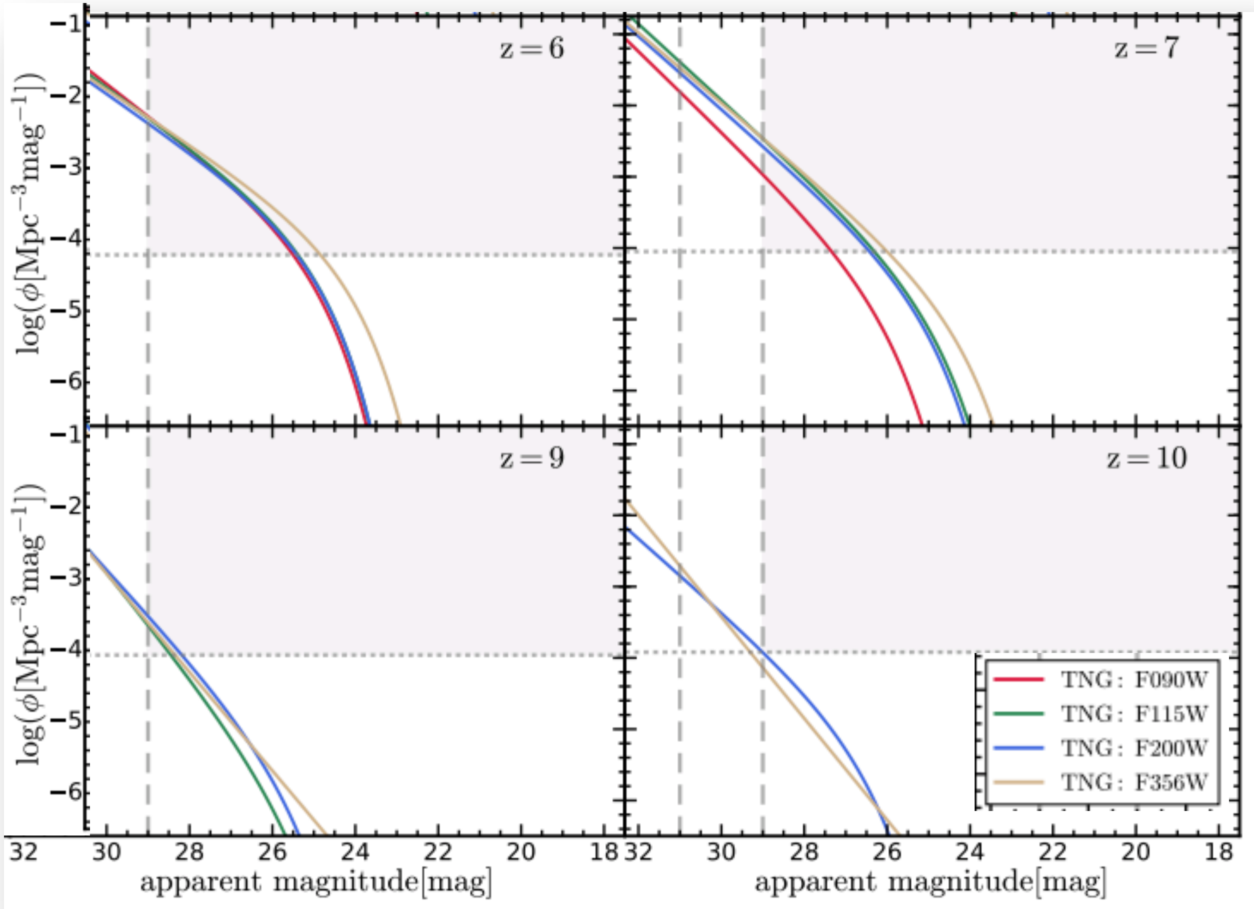
JWST/NIRspec : F150W = 30 in ~30,000 s

ELT/Micado : H_{AB} = 30 in ~30,000 s

- GRB hosts probe the faint end of galaxy luminosity function
- JWST ultra deep fields may detect the faint end z > 7 galaxy lum. function

High-z galaxy luminosity functions

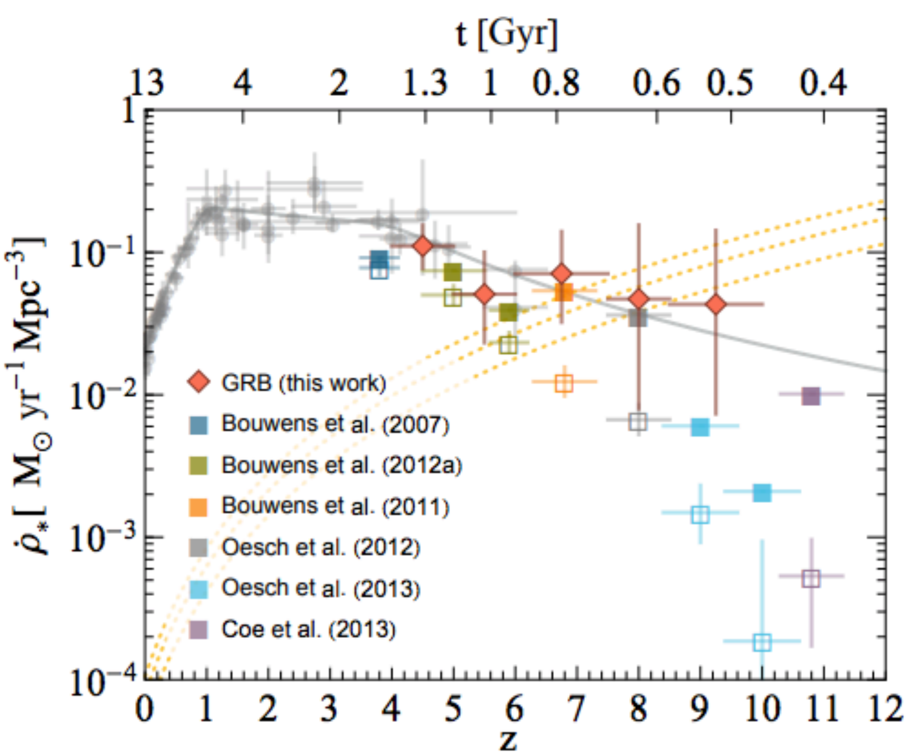
TNG simulations, dashed lines are JWST detection limits (Vogelsberger+2019)



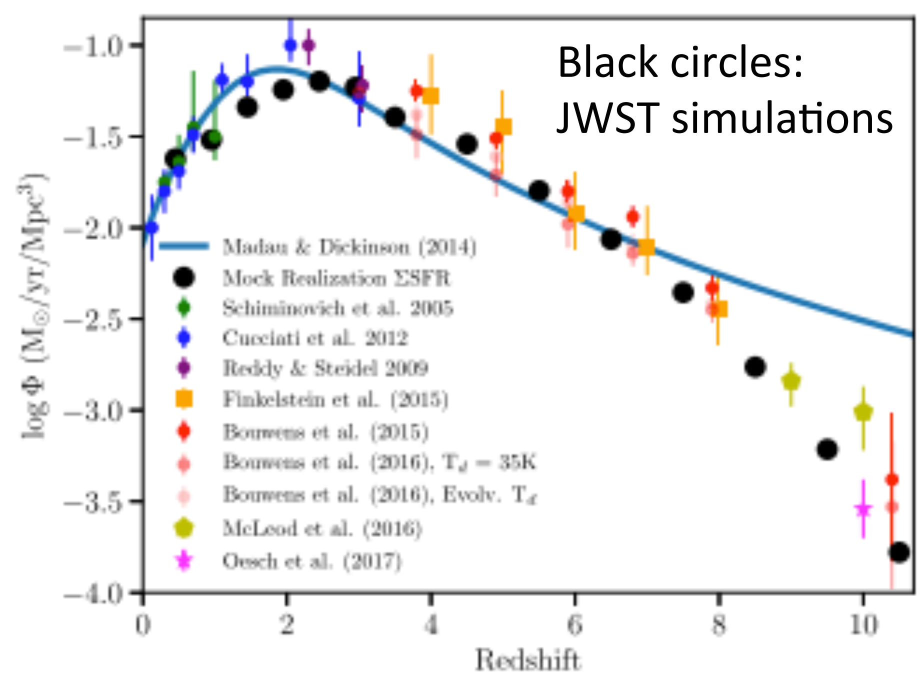
High-z GRBs probe fainter galaxies than in luminosity-limited samples

Cosmic star formation history

See next presentation by Nial Tanvir.

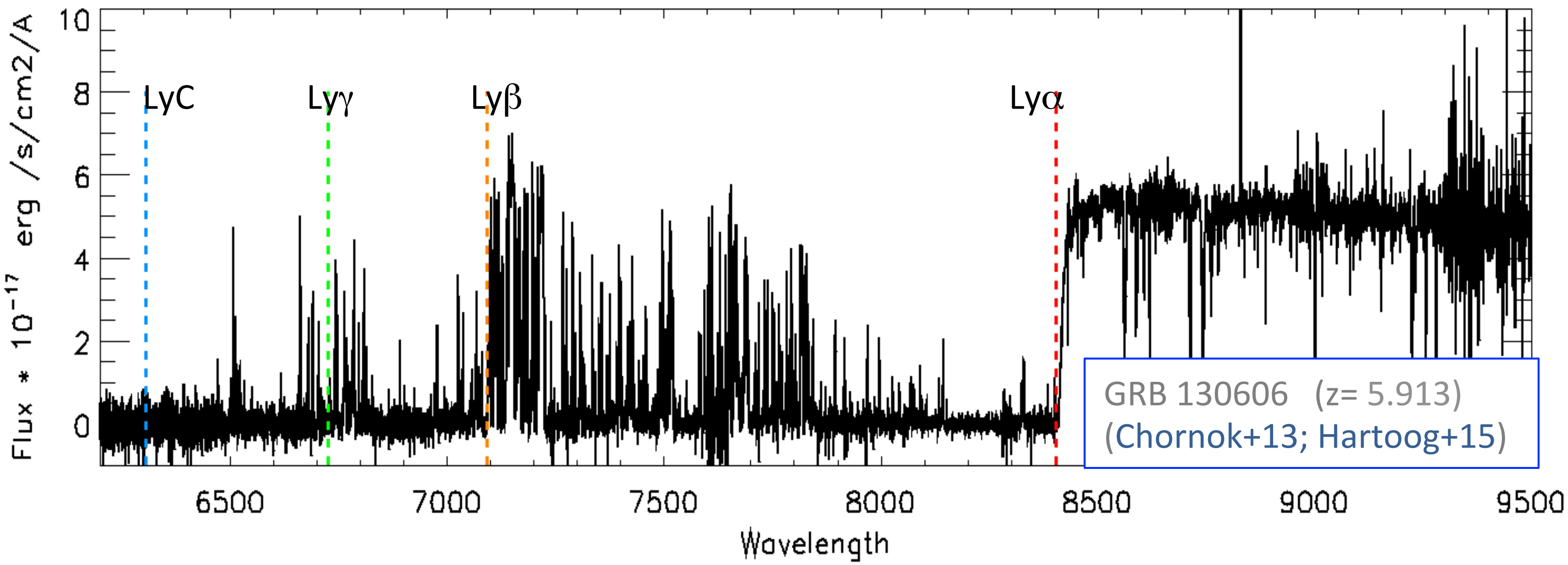


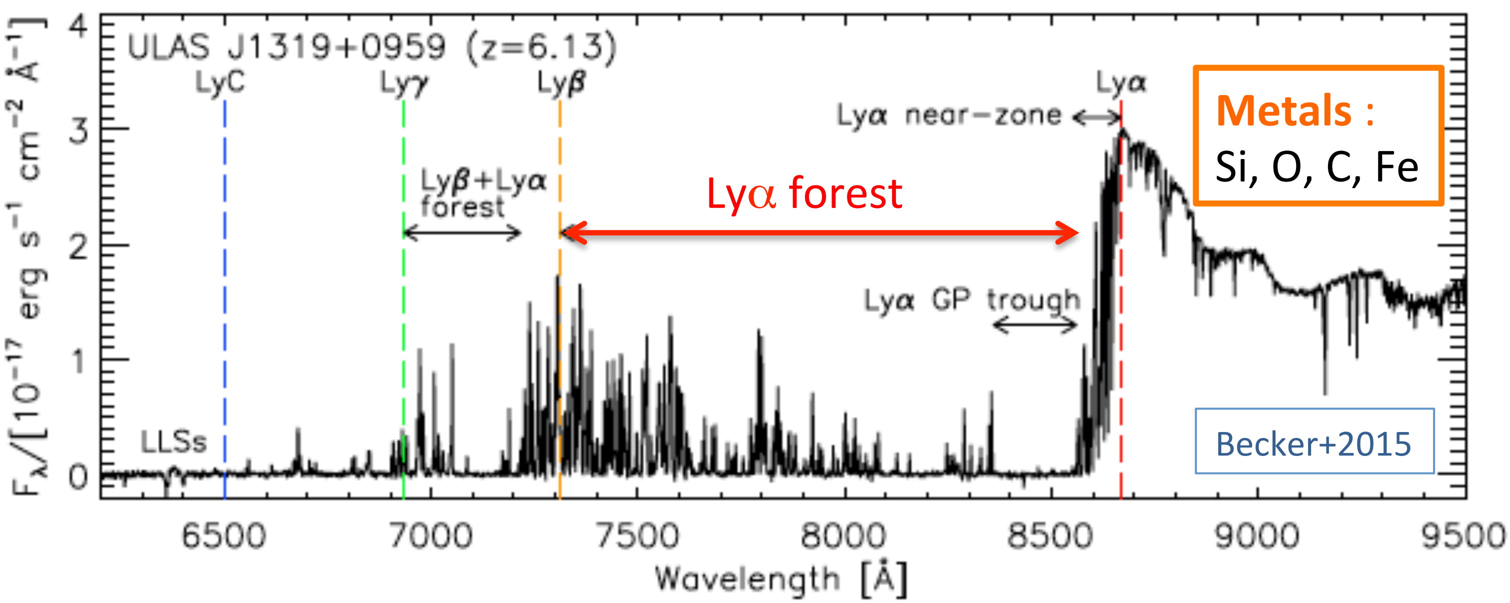
Kistler+2013



Williams+2018

GRB and QSO spectra probing the neutral gas





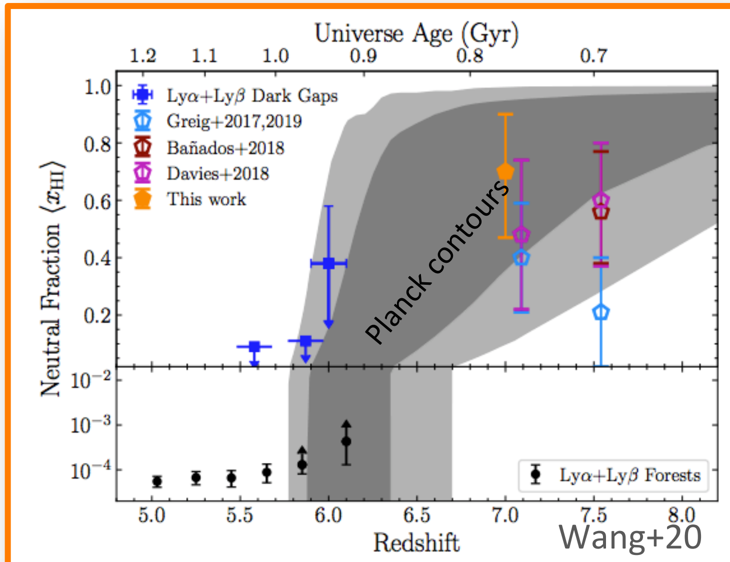
Epoch of reionization

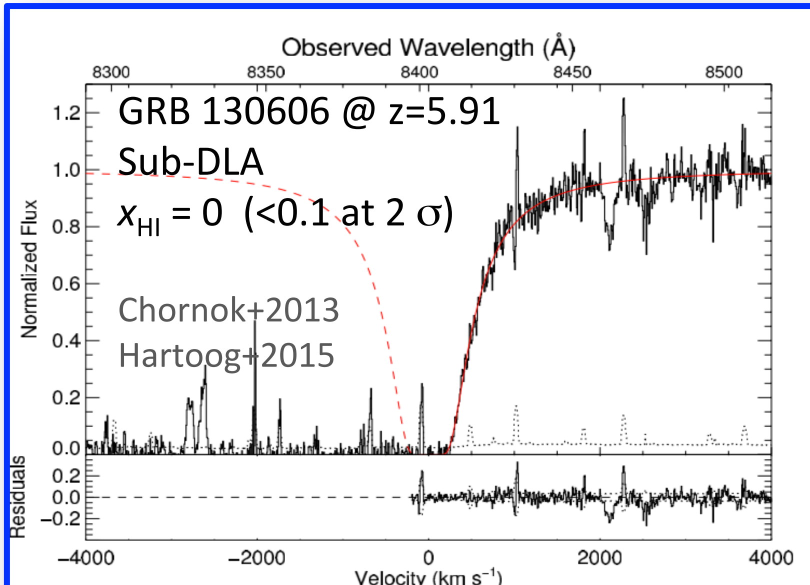
Quasars: **Neutral fraction $\langle x_{HI} \rangle$** sensitive to quasar continuum and Lya emission-line profile

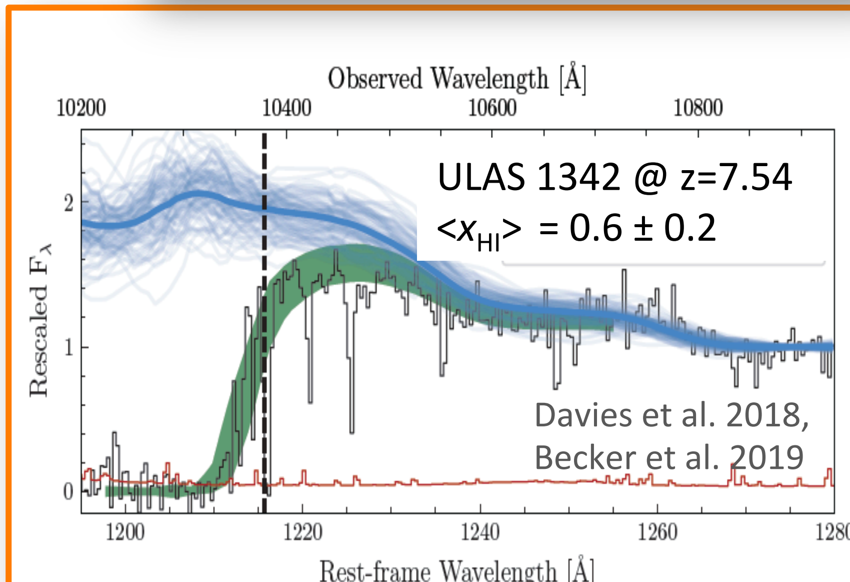
- Proximity zones
- ~10 QSOs at z > 8 may have been discovered in the optical/near-IR in 2020+

GRBs : + Simple power-law slopes

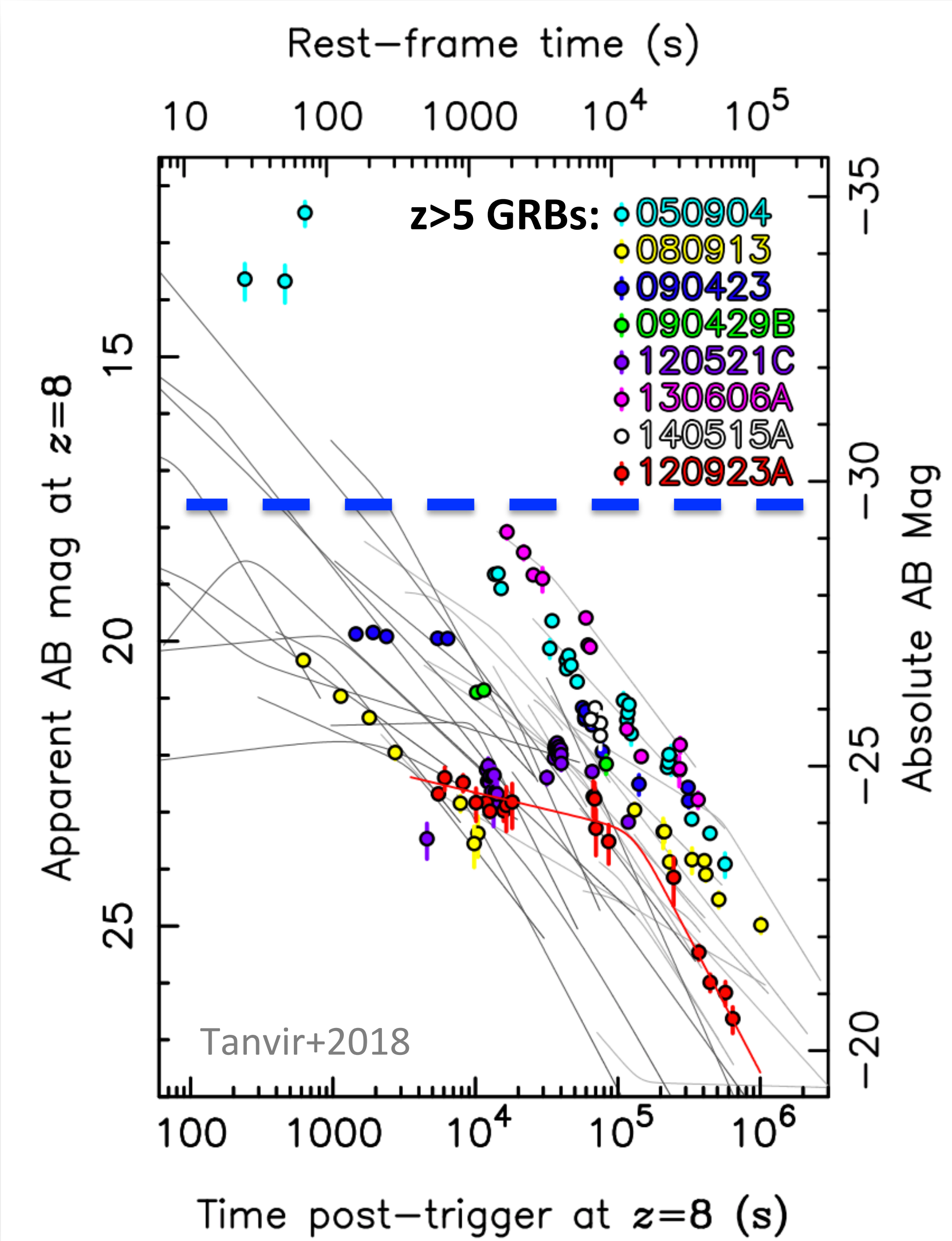
+ No host luminosity dependence
- Need fast, R > 5000 NIR spectra
- Host DLA contamination







High-z infrared afterglow light curves



THESEUS infrared telescope (IRT)

Detection limit:

Spectroscopy mode

- H_{AB} = 17.5 mag
- T_{exp} = 1800 s
- R~ 400

-> S/N ~ 5 / resolution element

-> Spec-z < 1% uncertainty

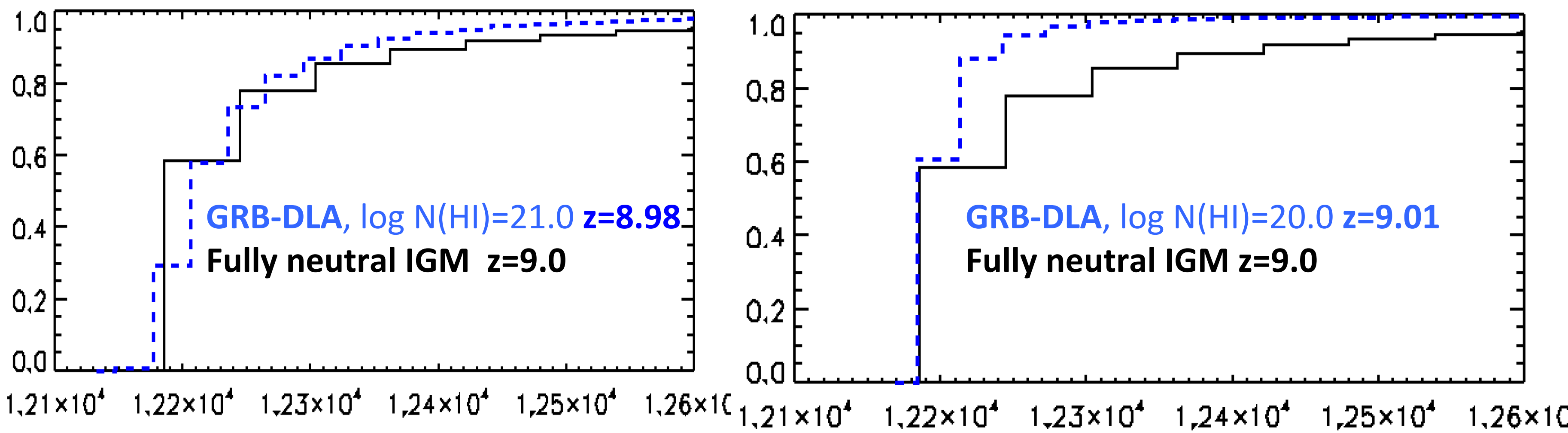
Epoch of reionization

- Higher *R* needed to measure neutral gas fraction, x_{HI}
  -> synergy with ELTs/VLT

- log N(HI) **can** be measured with THESEUS IRT spectroscopy to within ±0.2 dex

- Distinguishable when GRB DLA log N(HI) ≠ 21.0
  - Line profile
  - Exact redshift known (Δz = 0.02 from DLA -> IGM absorption)

Resolution = 400 (**THESEUS IRT spectroscopy**)

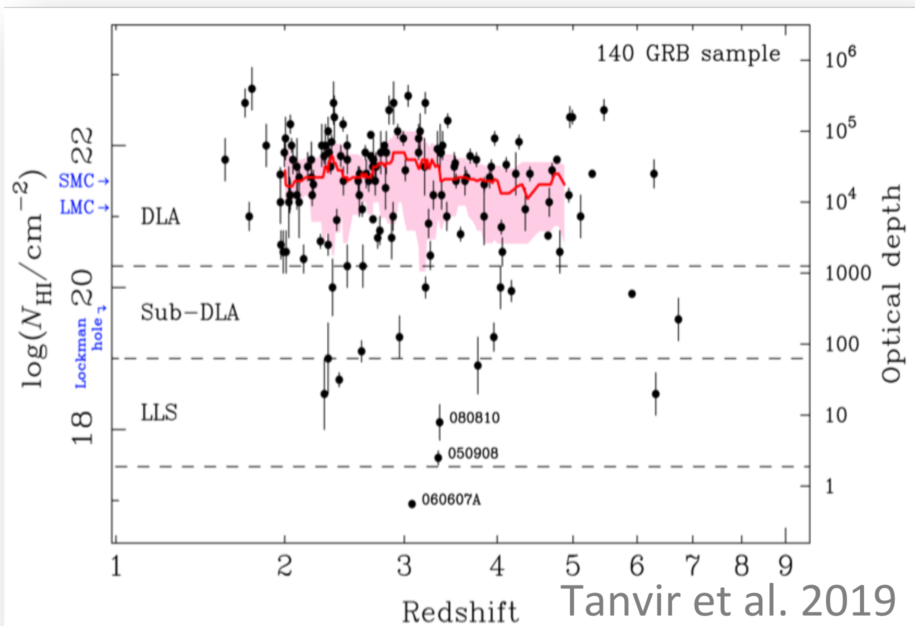


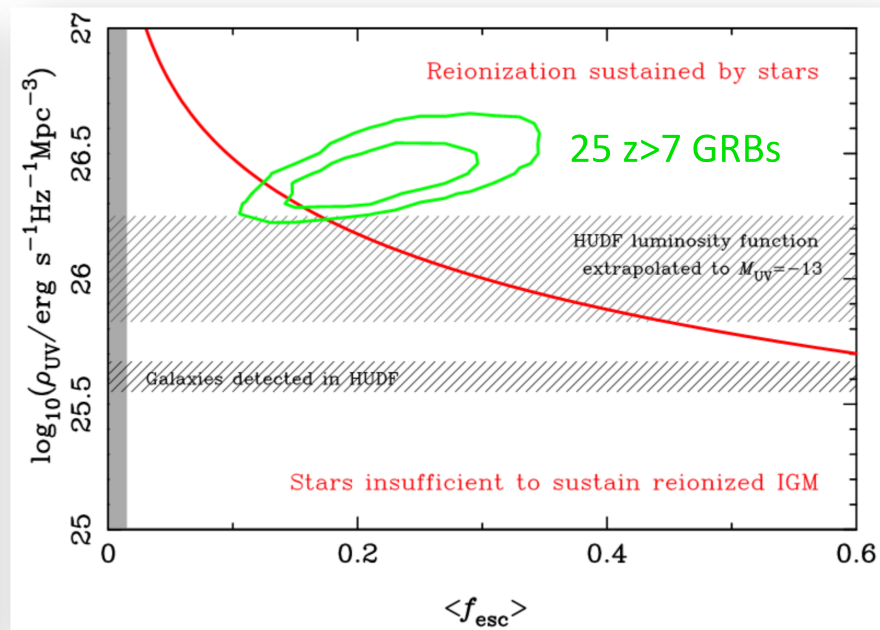
Epoch of reionization

Evidence for escaping ionizing flux?

- f_{esc} < 2% at z< 5
- At z > 5 : lower HI column densities – higher f_{esc} ?

High-z events detected with THESEUS allows analysis of f_{esc} from afterglow N(HI)

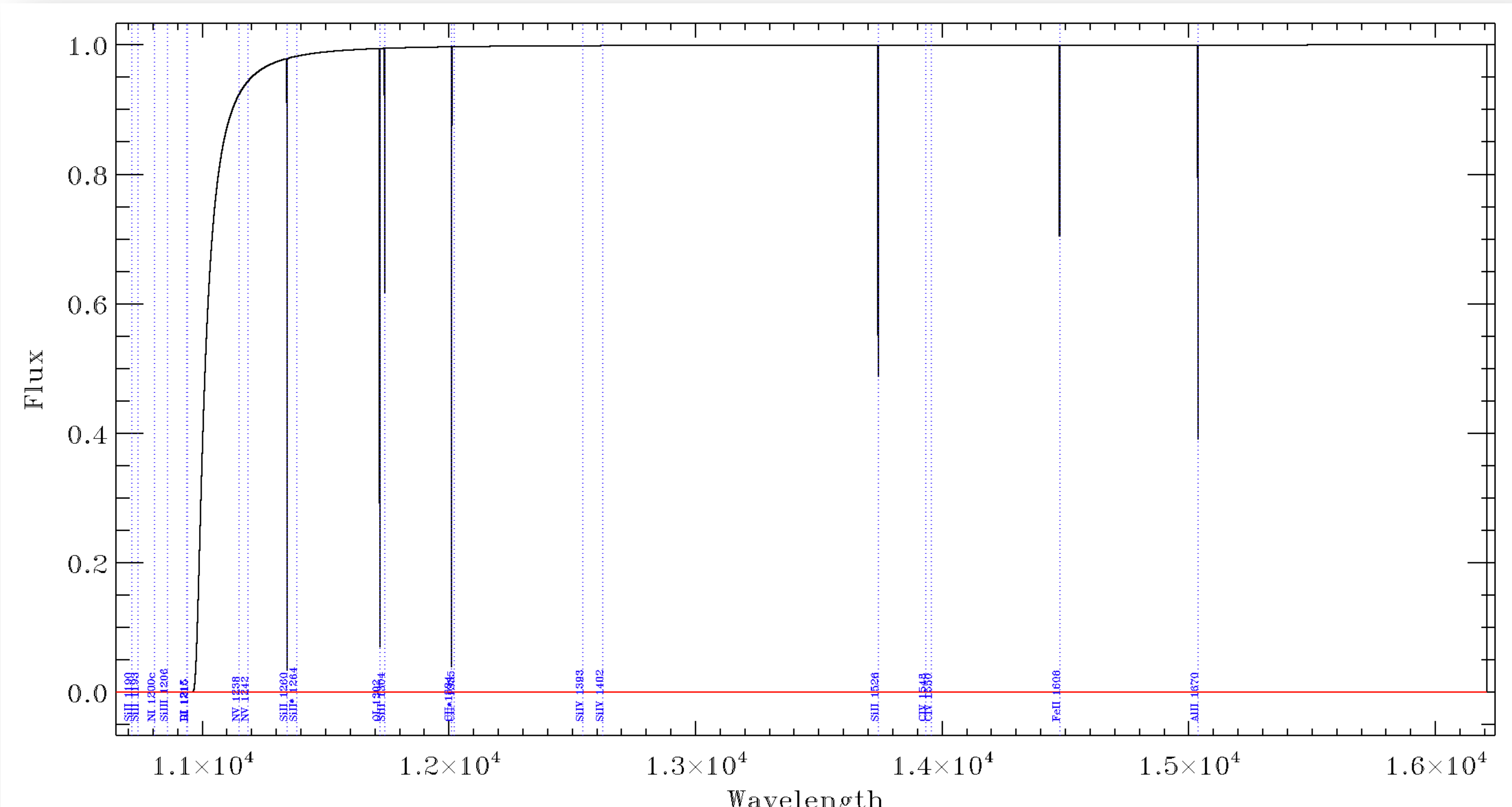




Simulated GRB-DLA spectrum

Input

- z_{DLA} = 8.0 (range 6-11)
- log N(HI) = 21.0 (range : 18-23)
- log Z = -3 (0 to -4) , solar abundance pattern, + HI, Si II, O I, C II, and FeII transitions

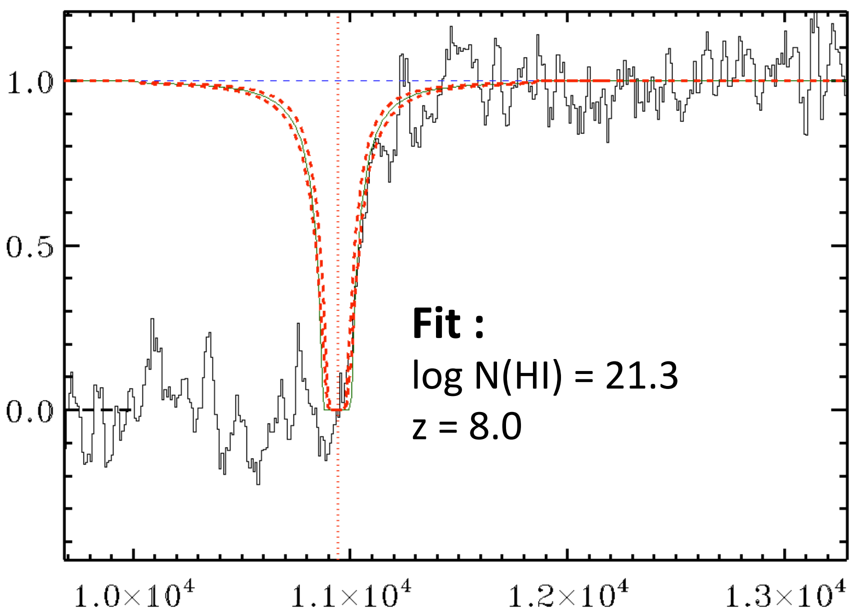


Simulated GRB-DLA with **THESEUS IRT**

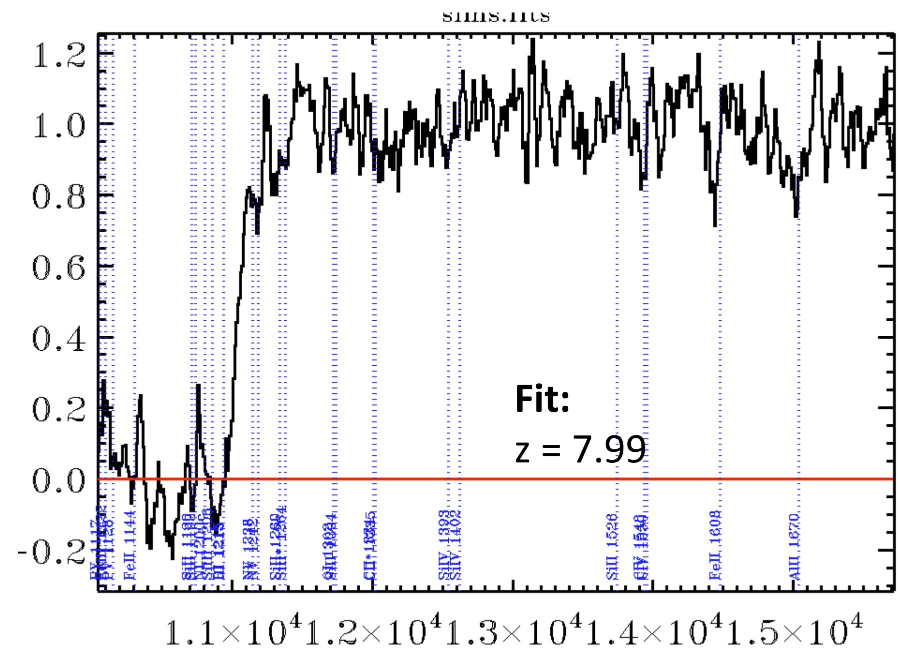
Input

- z(DLA) = 8.0
- log N(HI) = 21.2
- Metallicity = 0.01 solar
- S/N=5
- Resolution = 400

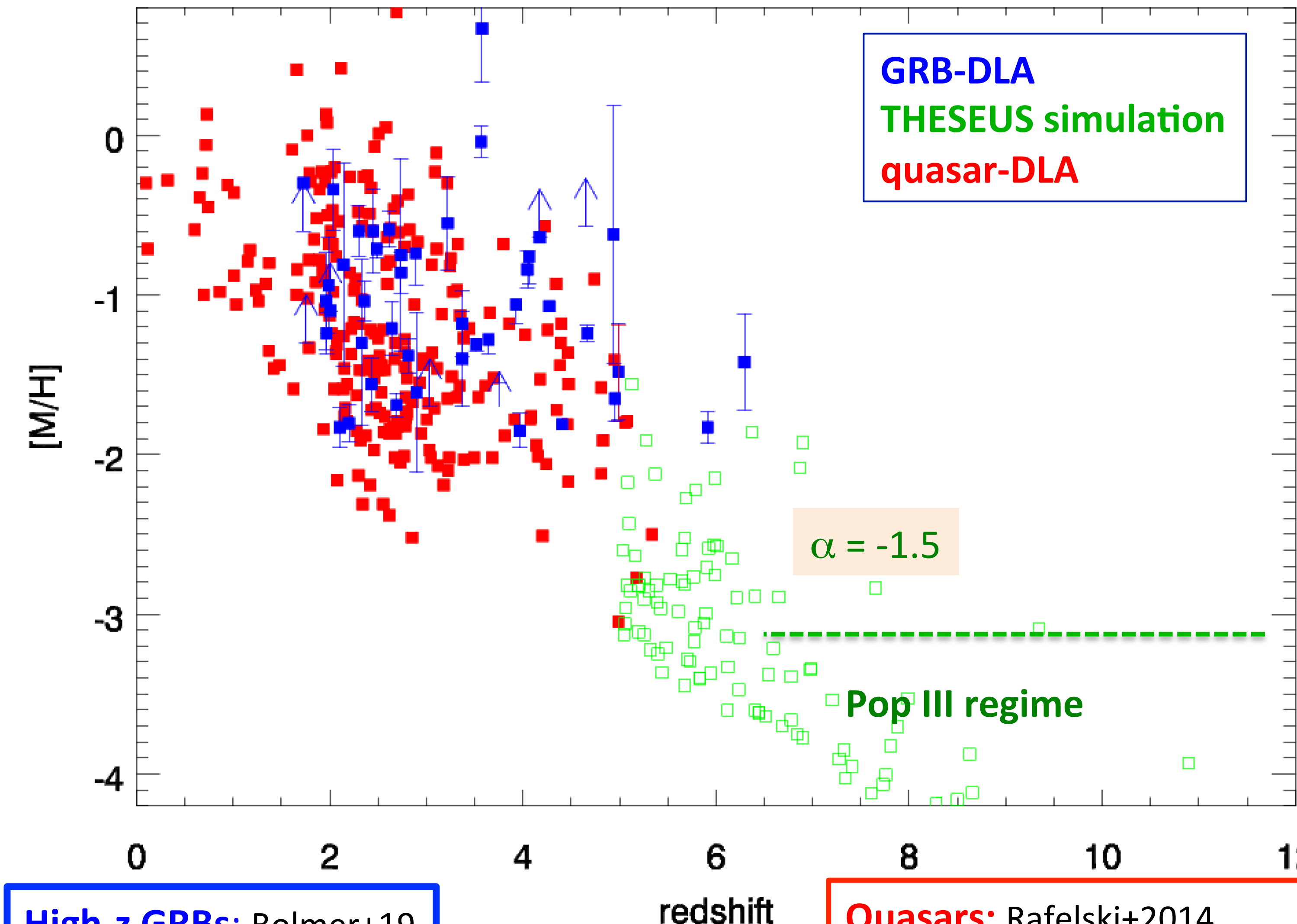
log Z ≥ –2 detectable when S/N > 5
log Z ≥ –3 detectable when S/N > 20
Log Z= -3 : Can have a pop III progenitor (Campisi+2011)



Observed wavelength (Å)



Quasar- and GRB metallicities



High-z GRBs: Bolmer+19
Hartoog+15, Sparre+15

Quasars: Rafelski+2014,
Neeleman+13, Jorgenson+13,
Quiret+16, De Cia+18

GRB metallicities signatures of galaxies

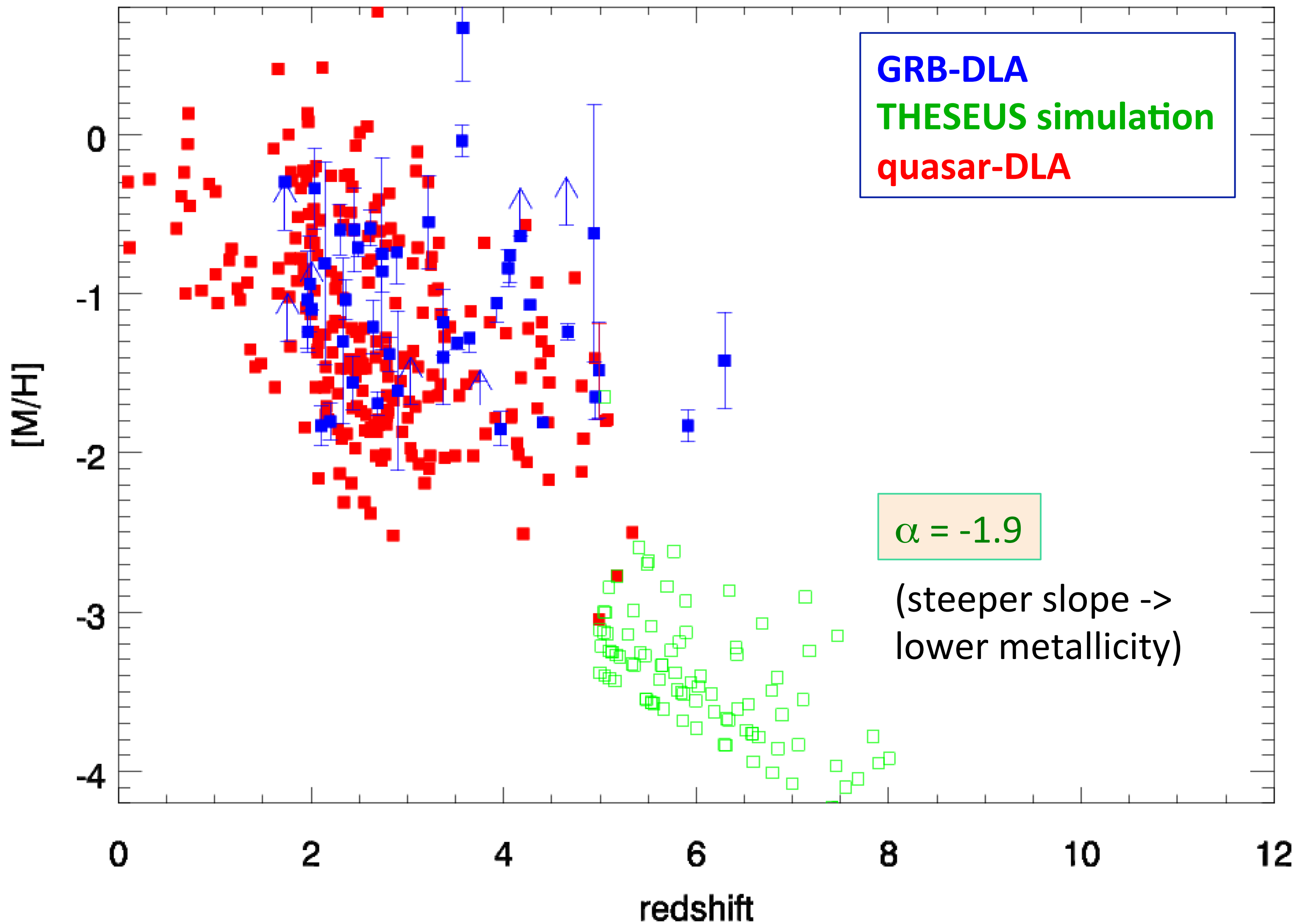
1) Assume a Schechter luminosity function (mass function)

2) Draw a set of galaxies based on mass/luminosity weighted probability function

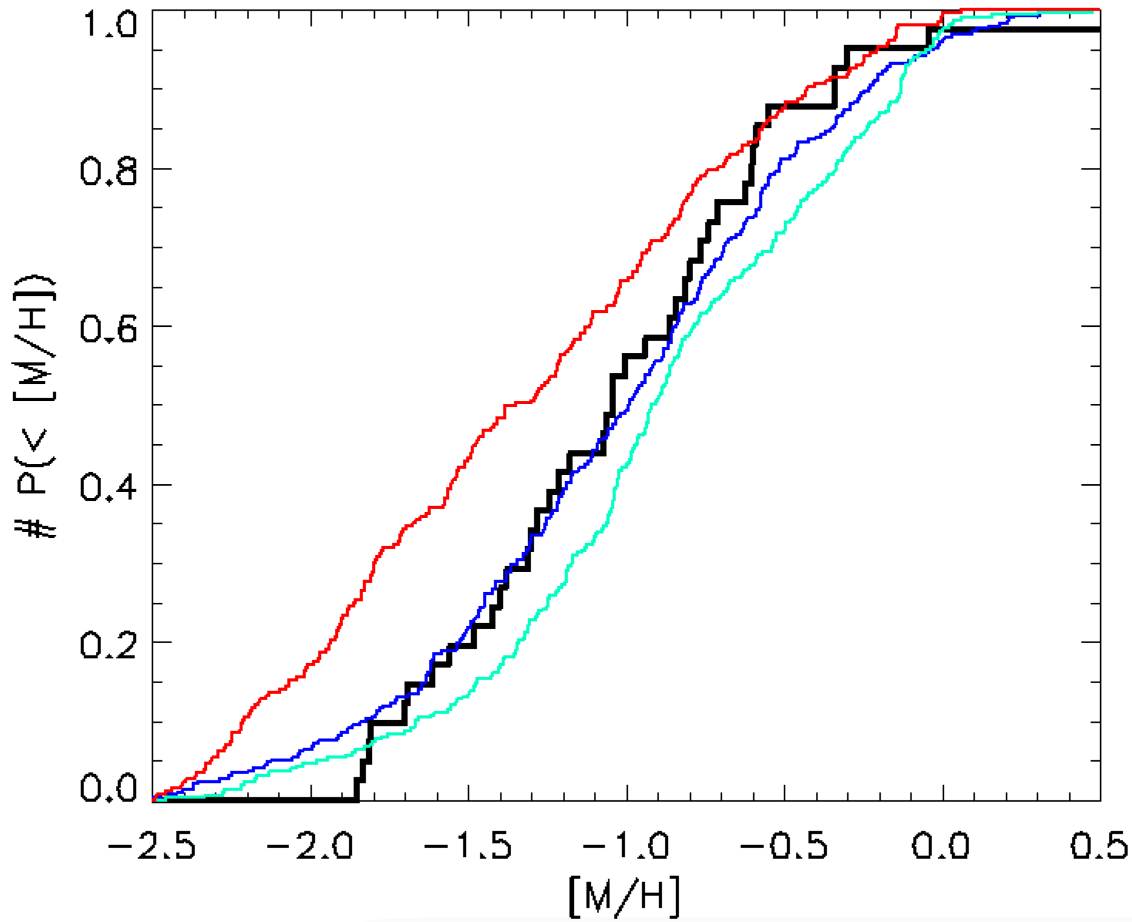
3) Compute GRB metallicity from redshift dependent galaxy mass-metallicity relation (Møller et al. 2013)

4) Evaluate best fit Schechter faint end slope (α) by comparing with **observed GRB metallicities**

Quasar- and GRB metallicities



Faint-end galaxy luminosity function with GRB metallicities



Observed GRBs at 1<z<5 with measured absorption metallicities

Predicted from lum.func:

α = -1.6

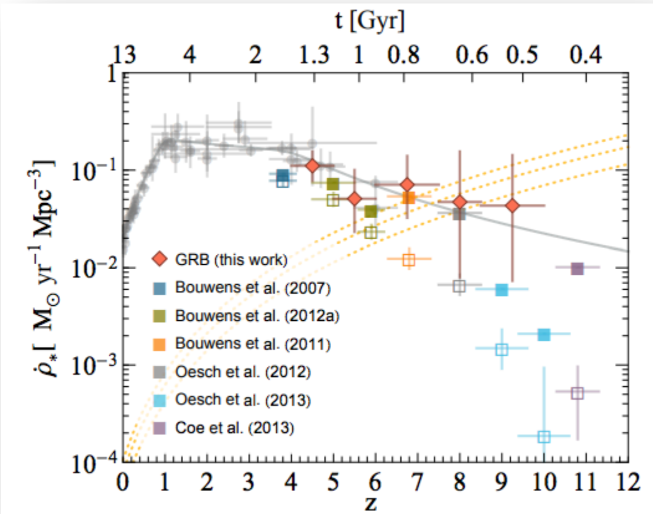
α = -1.4

α = -1.9

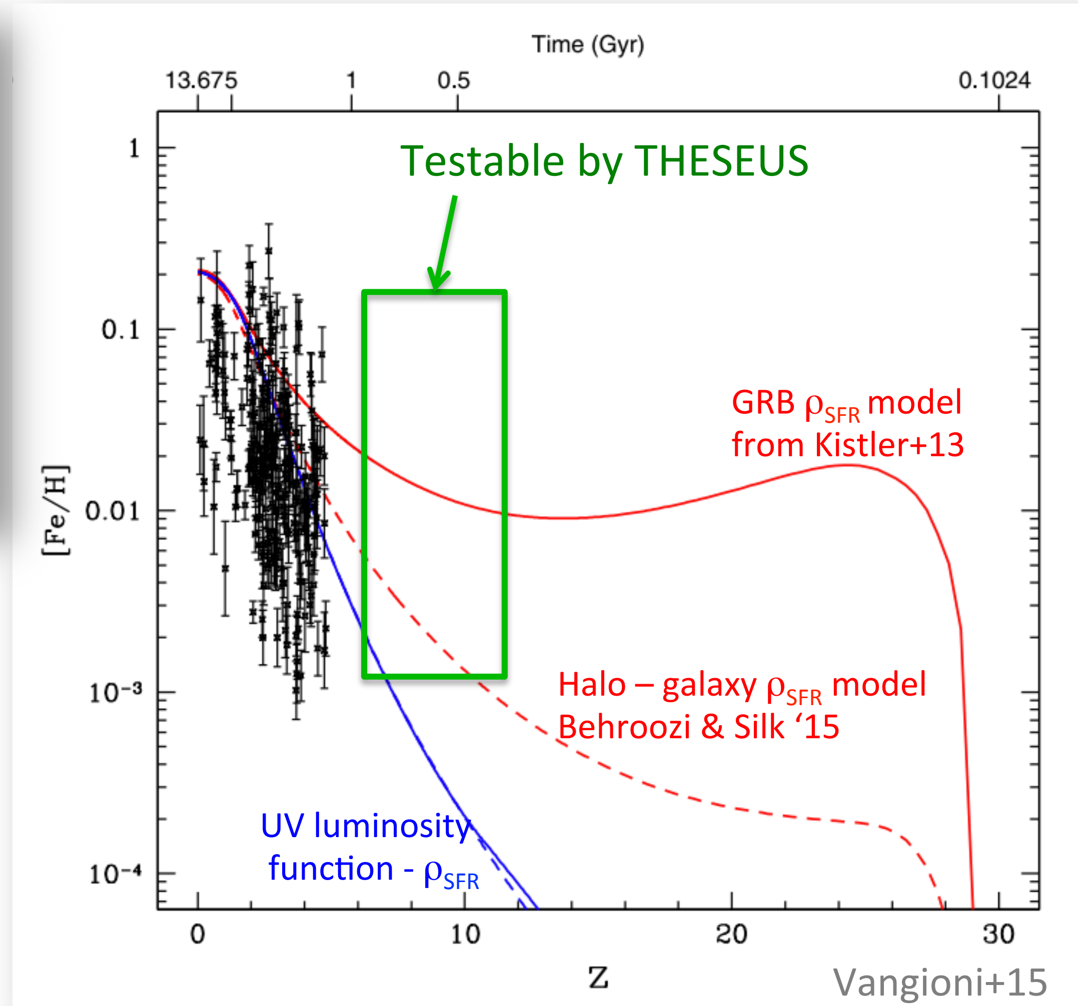
Dependence on:

- Assumed M-Z relation
- High-z dependence
- L* in the lum. function
- GRB metallicity threshold

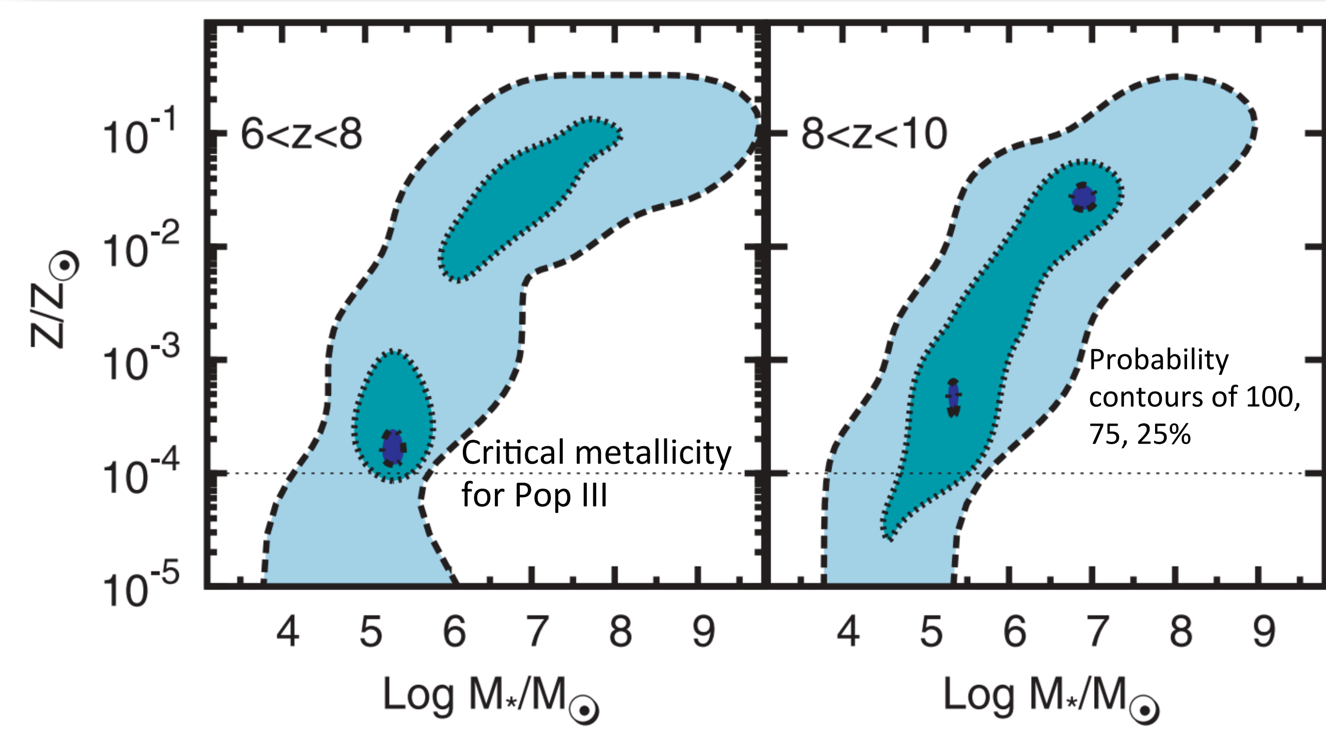
GRBs tracing star-forming galaxies



Consequence for metallicity evolution



GRBs tracing Pop III (hosts)



- Predict host galaxy stellar mass and metallicity
- Pockets of pristine gas produce pop III

(Campisi+2011)

A log M* ≈ 5 (7) its host galaxy has M_{UV} ≈ −12.0 (−16) (FIRE simulations, Ma+2018)

At z=8, the observed magnitude would be H_{AB} ≈ 35 (31) mag

(31 is *just* reachable with ELT/MICADO)

THESEUS will provide a unique probe of the early universe:

- z_{GRB} better than 1% (spectroscopy)   5-10% (imaging photo-z)
- Accurate log N(HI):   constrain f_{esc}
- x_{HI} at z > 6 through joint fit for DLA+IGM absorption

  knowing z accurately is essential
- Metal absorption lines detectable at 0.001 solar
- Trace faint-end star-forming galaxy population at z = 6-12

  Direct host emission, cosmic SFR density, reionization, GRB metallicities
- Transmit accurate localization within 30 sec (2 arcmin precission)

  –> max. 20 min with IRT (1" accuracy)

Provide essential triggers for key science cases with ELTs, VLT, Athena, ALMA, SKA, …