THESEUS
TRANSIENT HIGH ENERGY SKY AND EARLY UNIVERSE SURVEYOR

IRT expected science from very high redshift GRBs

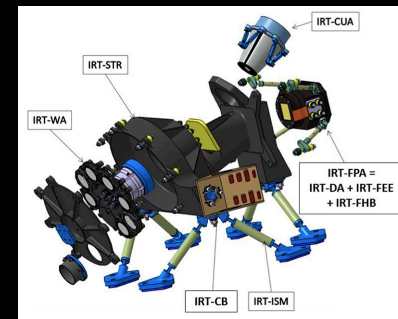
Emeric Le Floc'h (CEA-Saclay)

on behalf of the THESEUS consortium

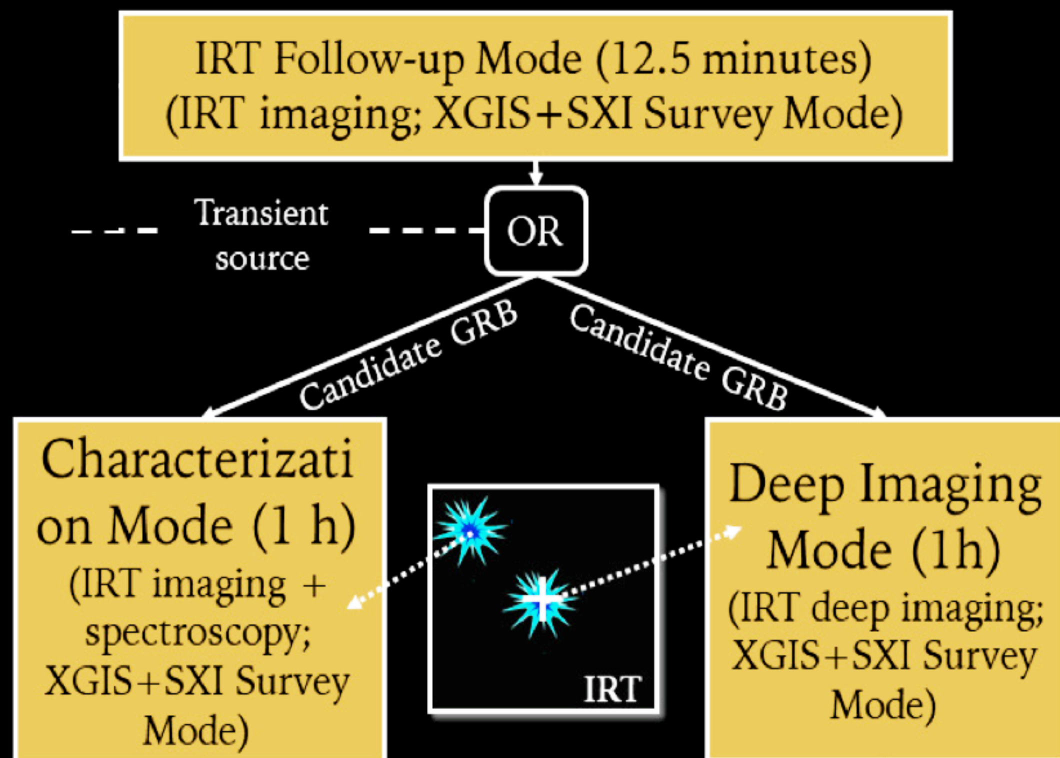
IRT: the IR telescope of THESEUS

THESEUS Infrared Telescope (Götz et al.)

- Wavelength range : 0.7 to 1.8mic
- Imaging mode : I, Z, Y, J, H
- Spectroscopy : R~400



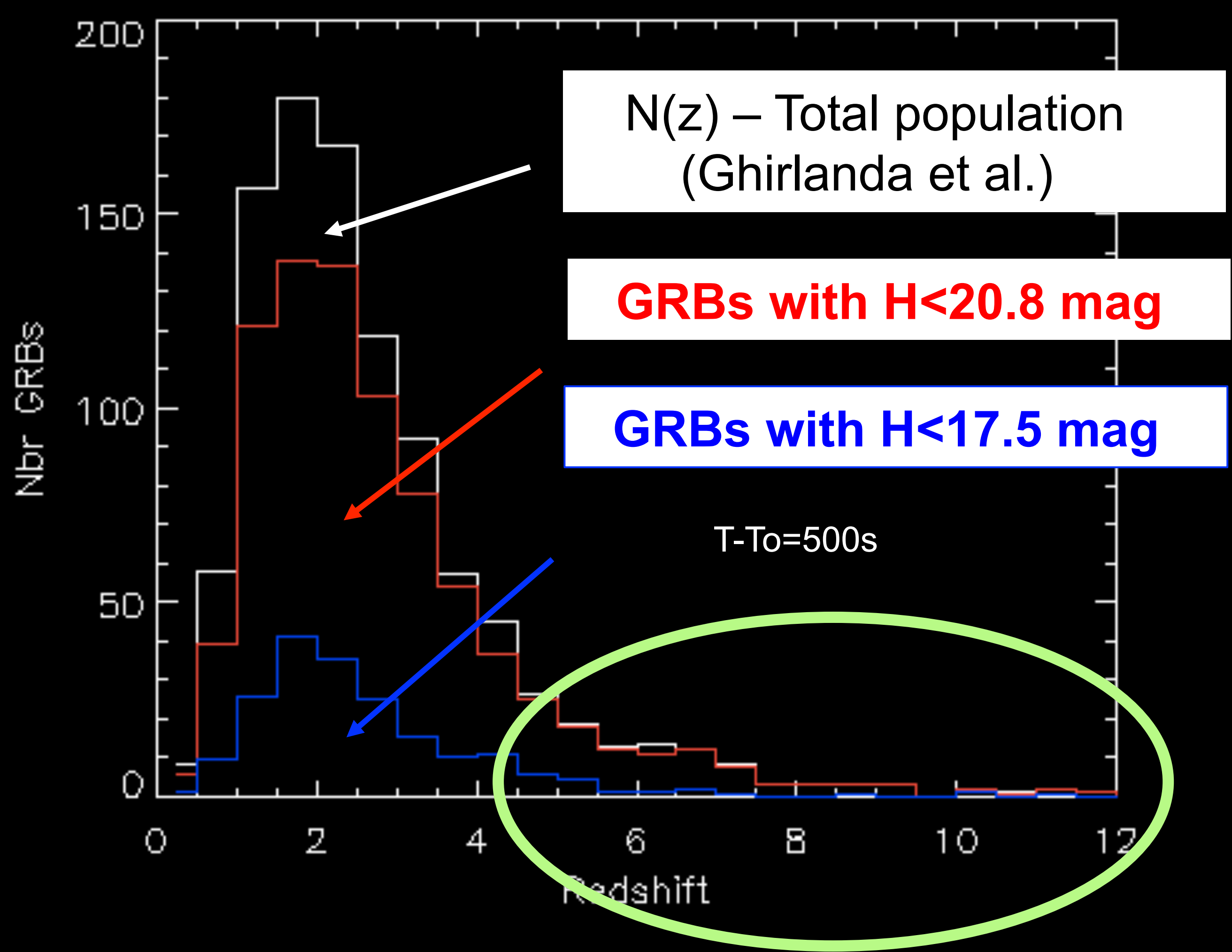
- prompt identification of GRB counterparts
- estimates of photometric redshifts (z>5.5)
- low-resol. spectroscopy for the brightest ones (H < 17.5 mag)
- early AG light-curve characterization



(THESEUS Yellow Book)

GRB redshift distributions

Expected N(z) for 3.4 yrs of THESEUS operations



- ~40-50 GRBs at z>6 (H-band imaging)
- <10 GRBs at z>6 with spectra

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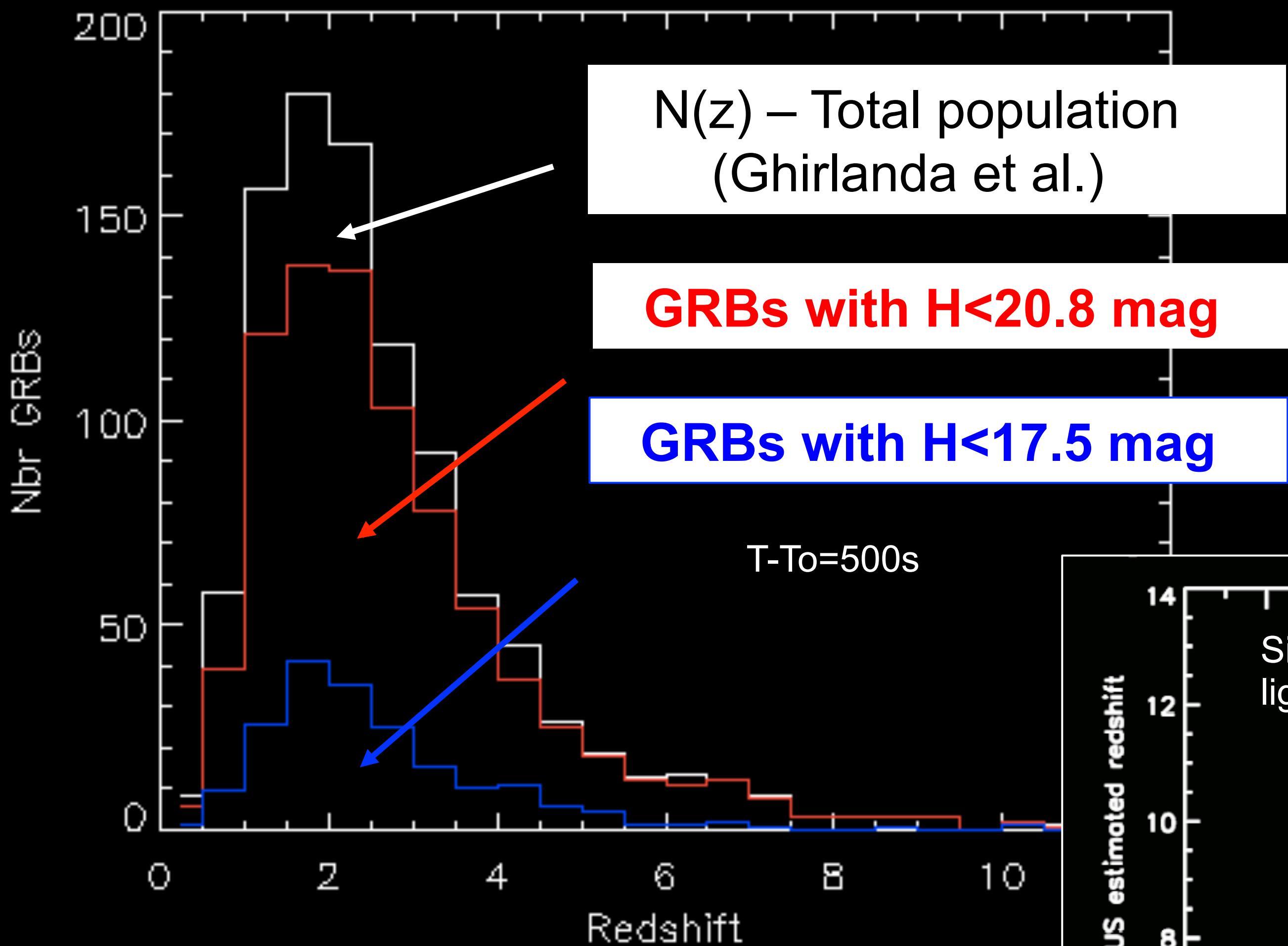

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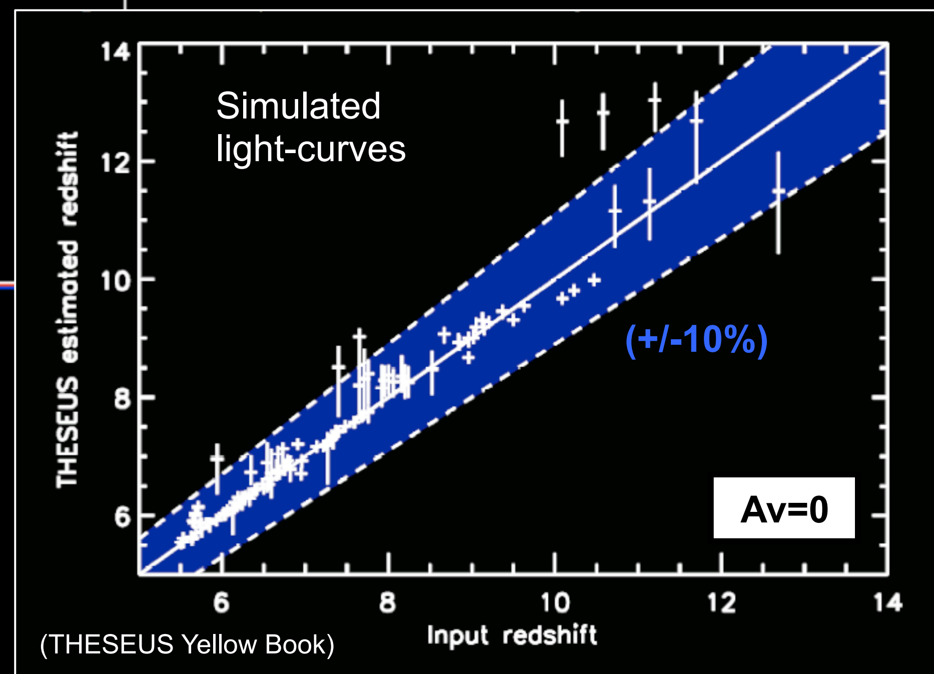

The IRT imaging mode will lead to the largest homogeneous sample of bursts to constrain the GRB N(z) at z>5.5

→ requires accurate photo-z's (<10%)

IRT photo-z simulations

- Afterglow light-curves from the SWG4 GRB population modelling (Ghirlanda et al.)
- IRT observing sequence simulated assuming 150s integration time per filter, starting at T-To=500s, from I to H.
- Noise added assuming IRT ETC
- Photo-z code from Corre et al. (SVOM / COLIBRI) : MCMC approach

Photo-z estimates “in principle” easy,
as relying on the Ly break identification

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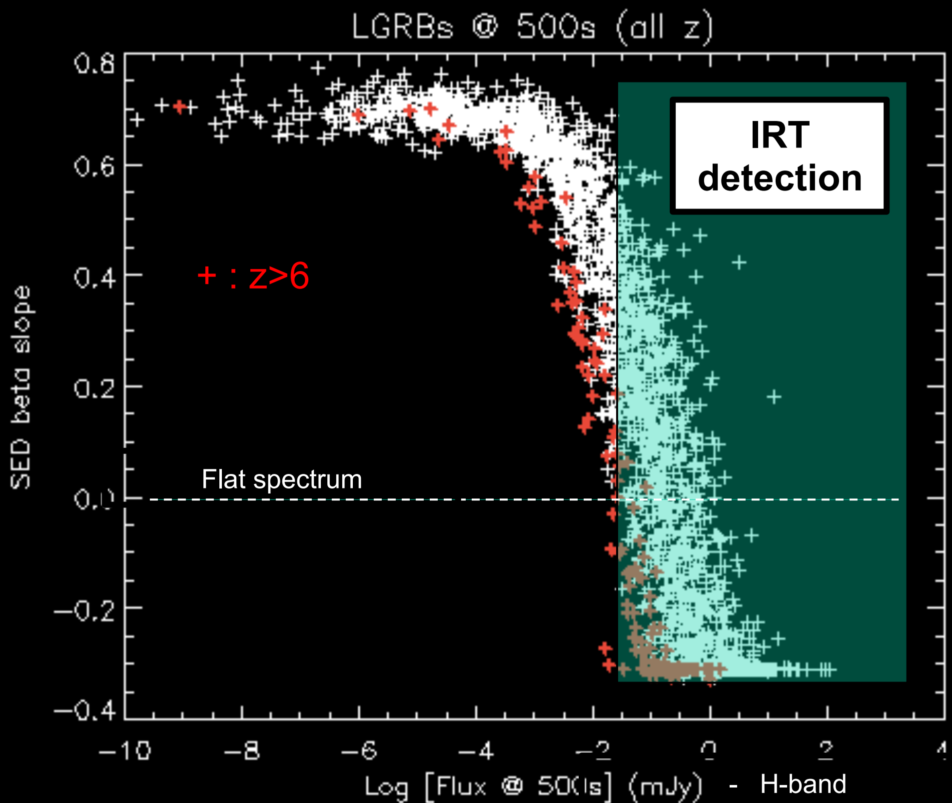
BUT Limited knowledge of AG SEDs at early times

- diversity of spectral slopes



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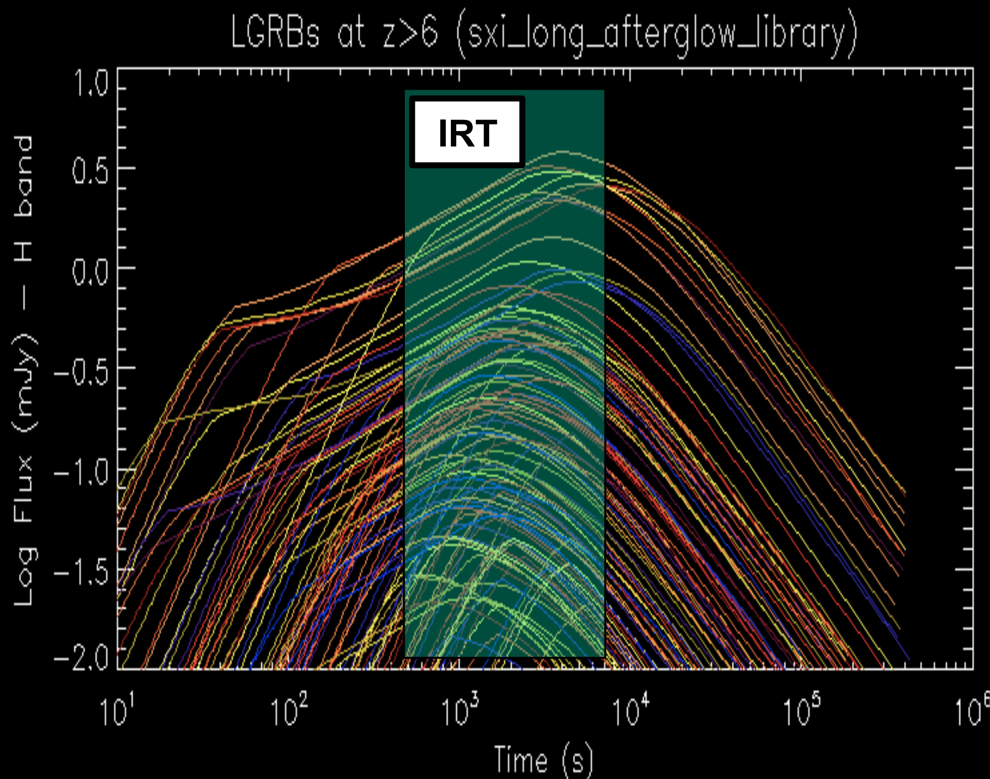
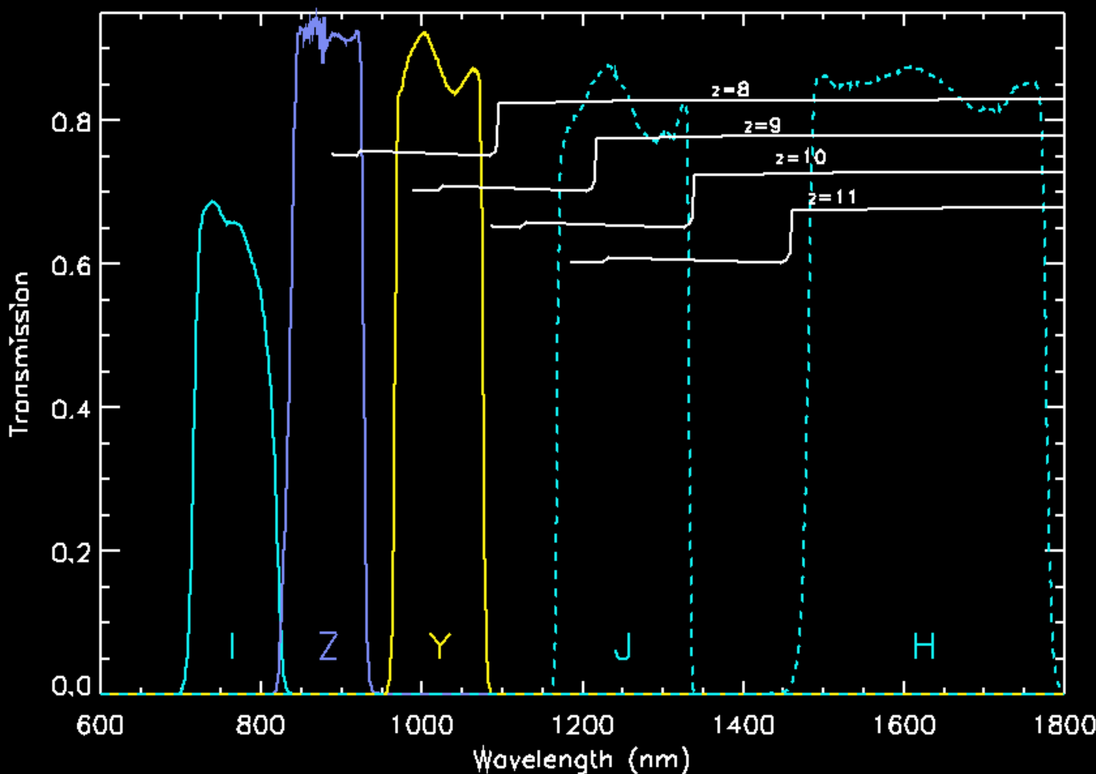
BUT Limited knowledge of AG SEDs at early times

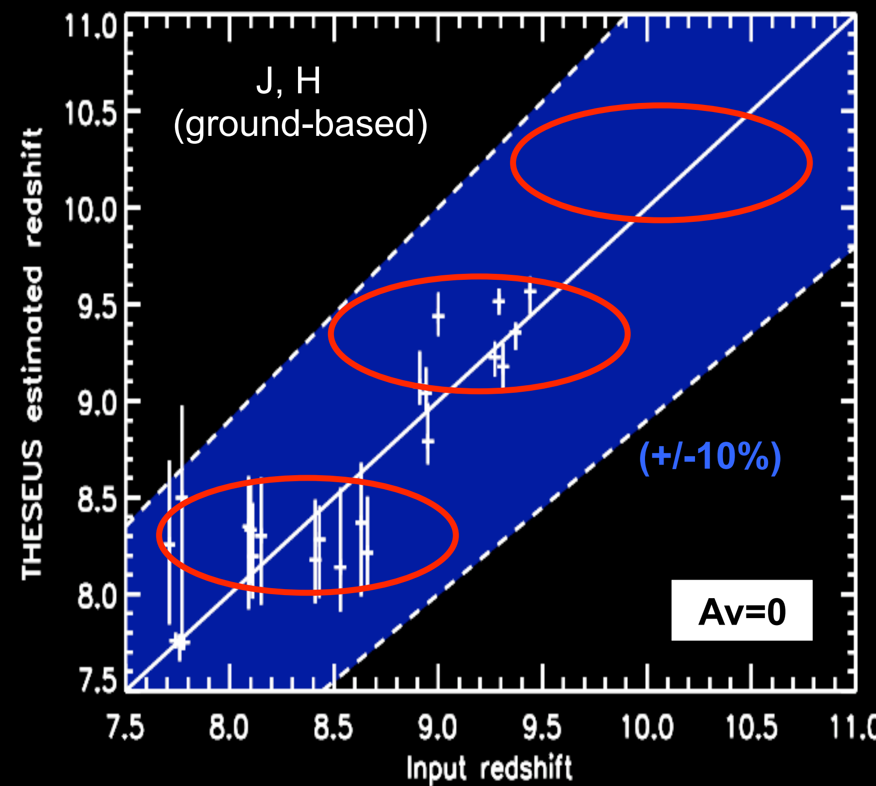
- diversity of spectral slopes
- diversity of LC evolution

IRT bands not imaged simultaneously



IRT: NIR filter definition





J / H ground-based filters : several redshift “sub-ranges” where the position of the Lyman break is poorly constrained → lead to artificial jumps in the N(z) reconstruction

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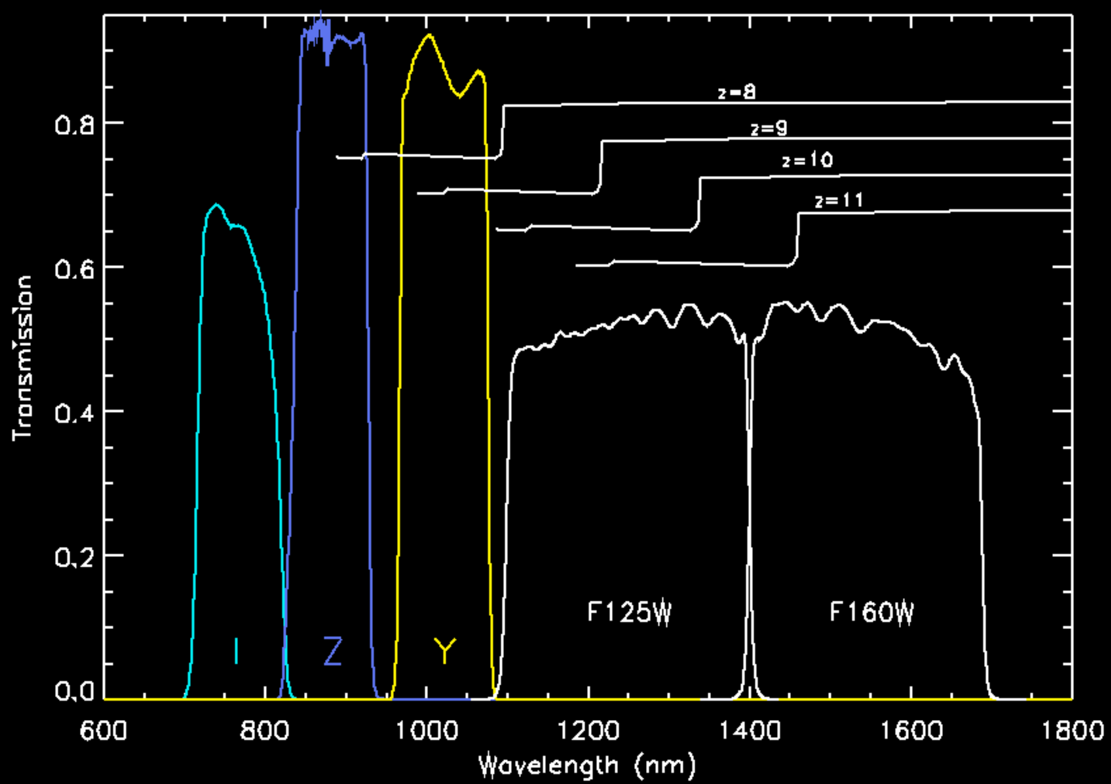
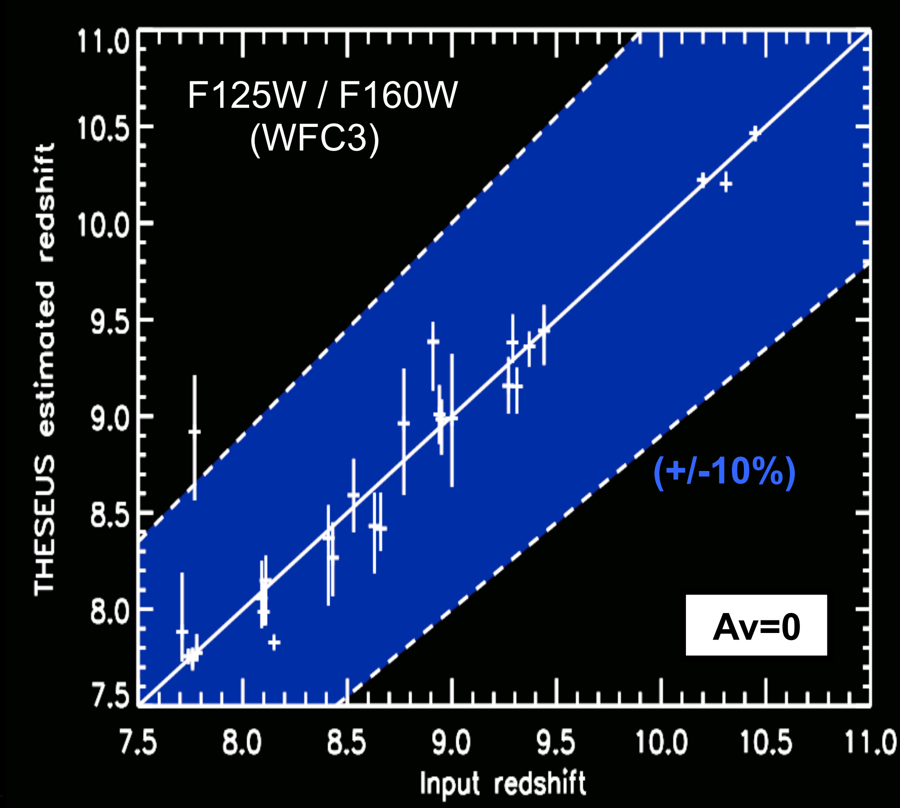




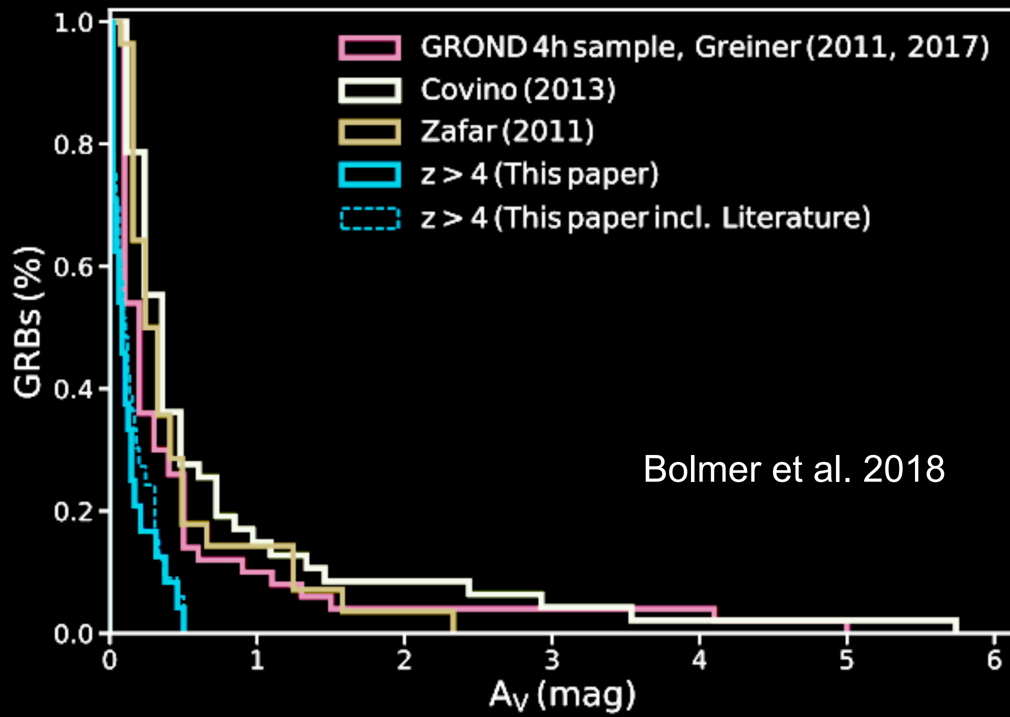
J / H ground-based filters : several redshift "sub-ranges" where the position of the Lyman break is poorly constrained → lead to artificial jumps in the N(z) reconstruction

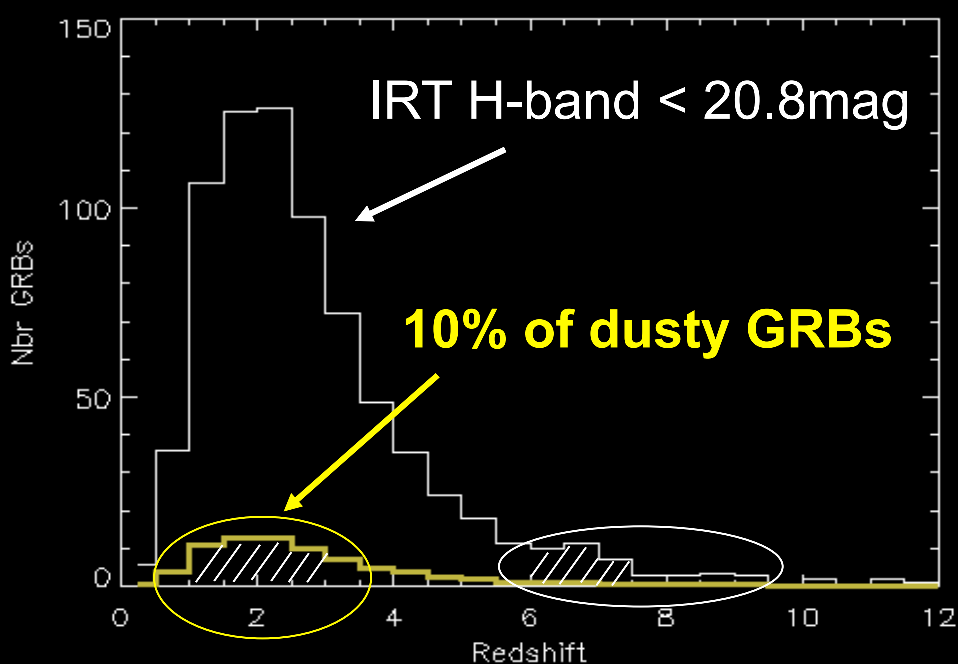
F125W / F160W WFC3 filters provide substantial improvement (NMAD reduced by 3 at 7.5<z<11)

Interlopers from low-z dusty GRBs

It is not "*unreasonable*" to assume that GRBs at z>6 will not be too much affected by dust

But ~10-15% of afterglows at intermediate z do show substantial extinction (Av > 1 mag)

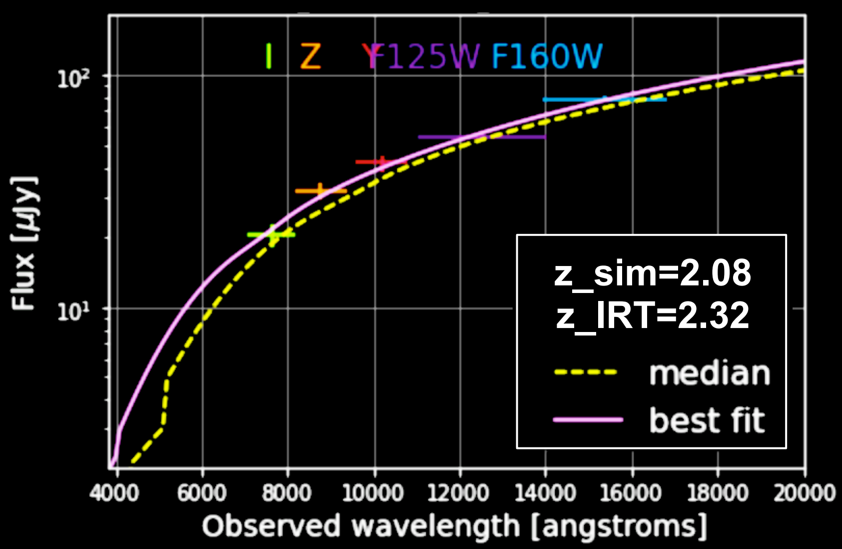




→ Number of low-z bursts with Av > 1mag comparable to the total number of GRBs expected at z>6

Interlopers from low-z dusty GRBs

"Joint" simulation mixing the THESEUS high-z GRB population with Av=0mag and a 10% fraction of GRBs at 1<z<4 with Av=1mag



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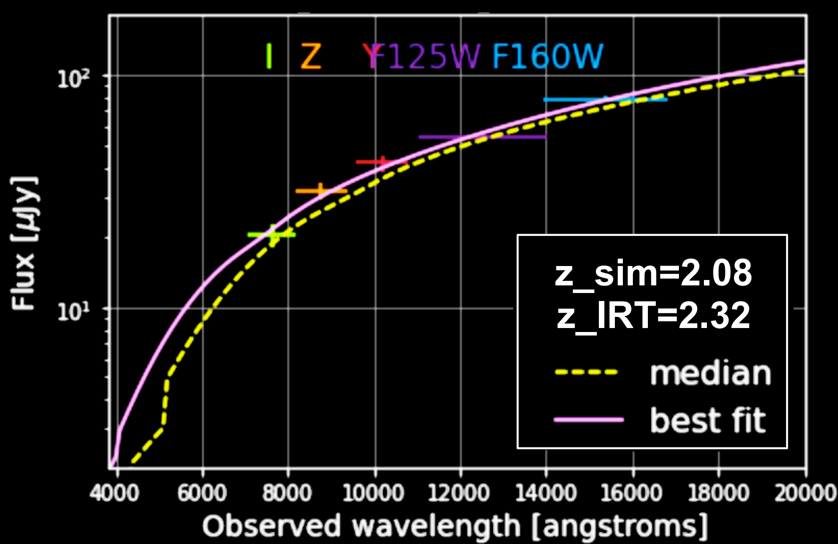
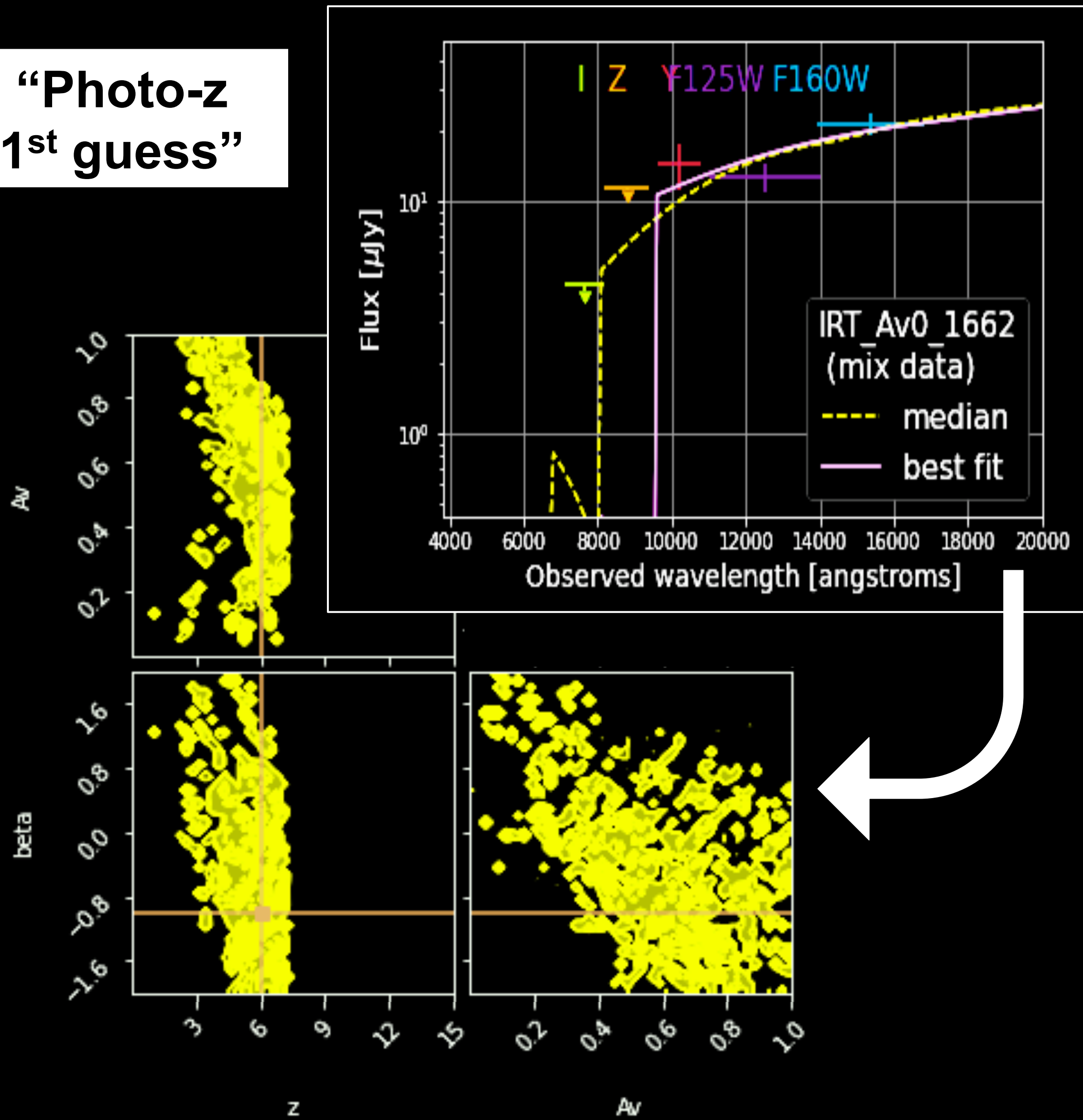


"Photo-z 1st guess"



Strong degeneracy between z, Av and AG power-law index, especially at low S/N

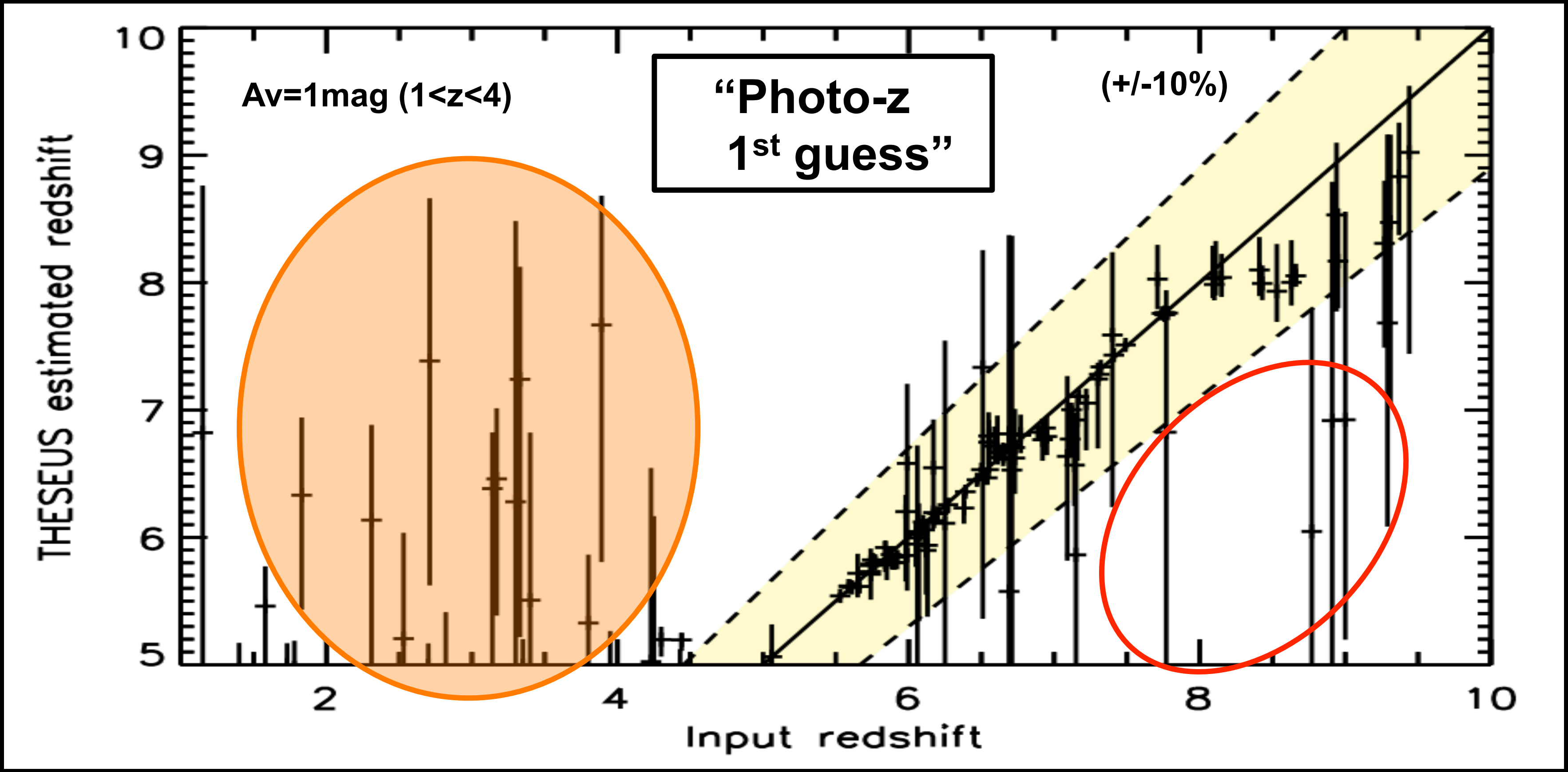
→ Quality of photo-z degrade at z>6

→ Low-z GRBs contaminate the high z sample

Interlopers from low-z dusty GRBs

After the 1st IRT imaging sequence :

- low-z contaminants misidentified as high-z GRBs: 10% of the genuine high-z sample
- high-z "outliers" (i.e., outside requirements) : 5-10%

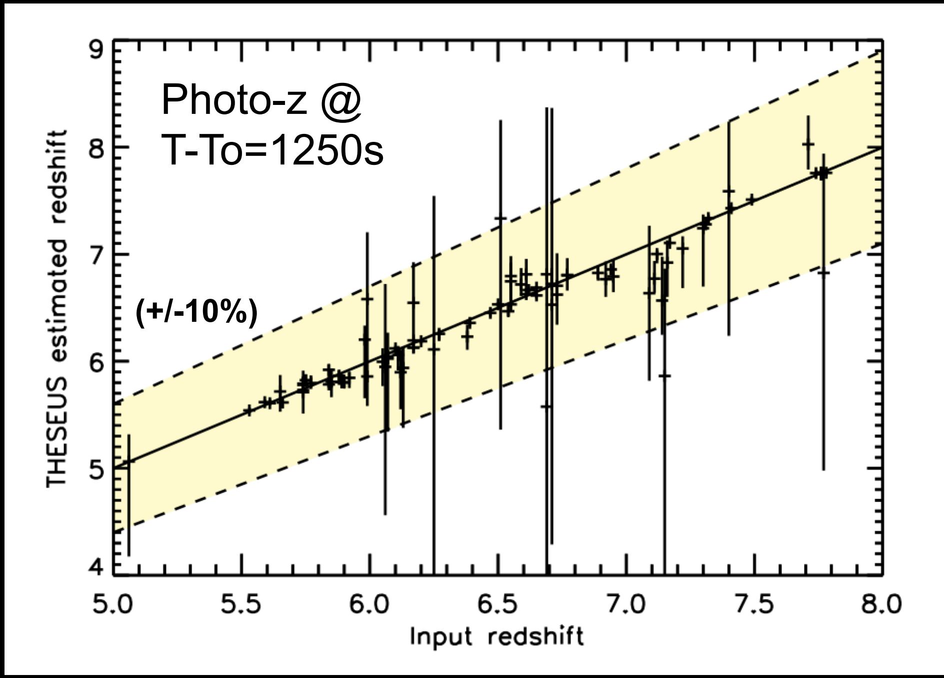


Fortunately, still a large fraction at z>5.5 with small photo-z uncertainties (probably the main criterion to trigger "high-z follow-up" with other facilities)

Interlopers from low-z dusty GRBs

IRT imaging sequence (T-To=500s)

- I (150s)
- Z (150s)
- Y (150s)
- F125W (150s)
- F160W (150s)



Interlopers from low-z dusty GRBs

IRT imaging sequence (T-To=500s)

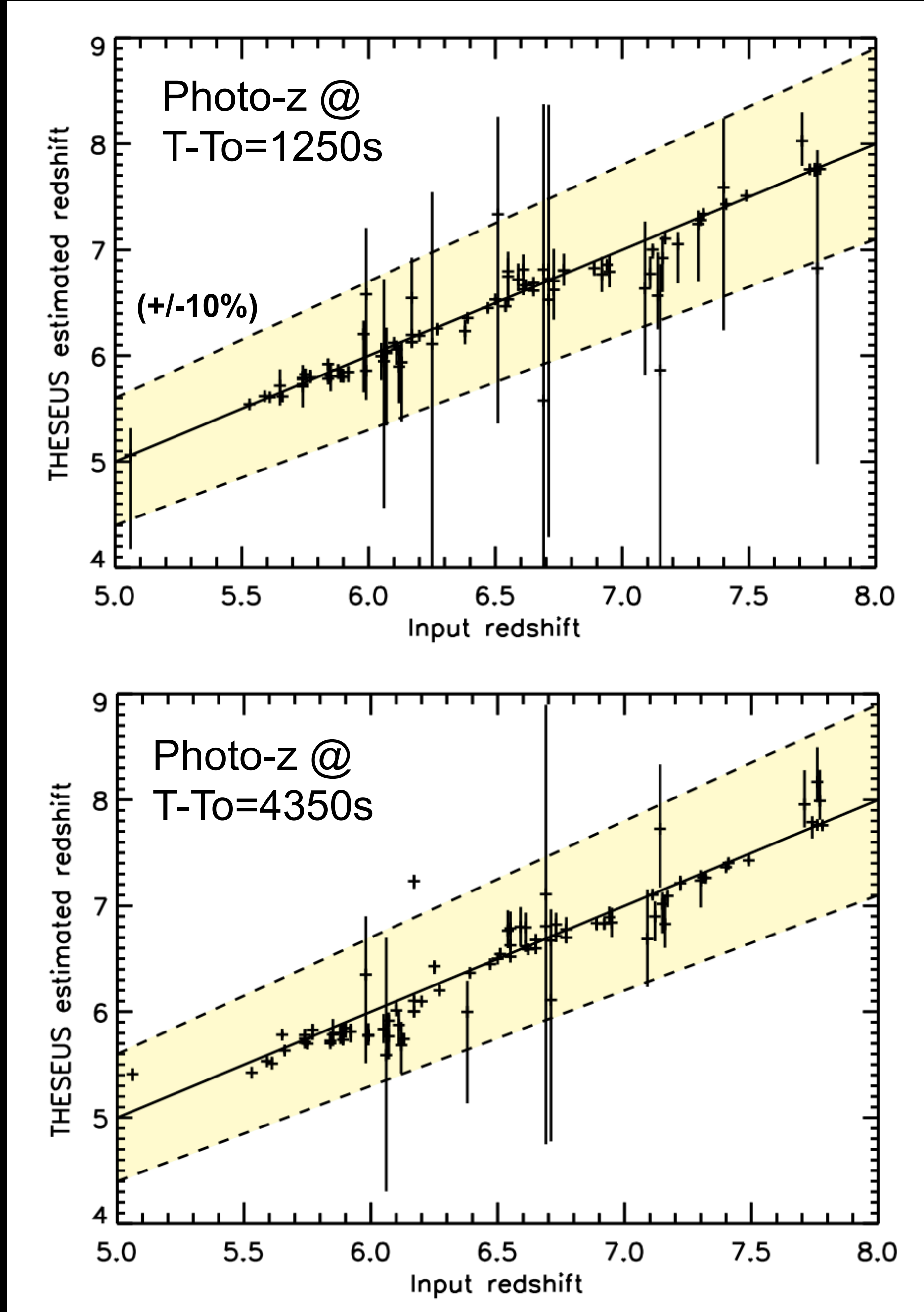
- I (150s)
- Z (150s)
- Y (150s)
- F125W (150s)
- F160W (150s)

F160W < 17.5 mag ? (T-To=1250s)

Yes → spec mode (1h)

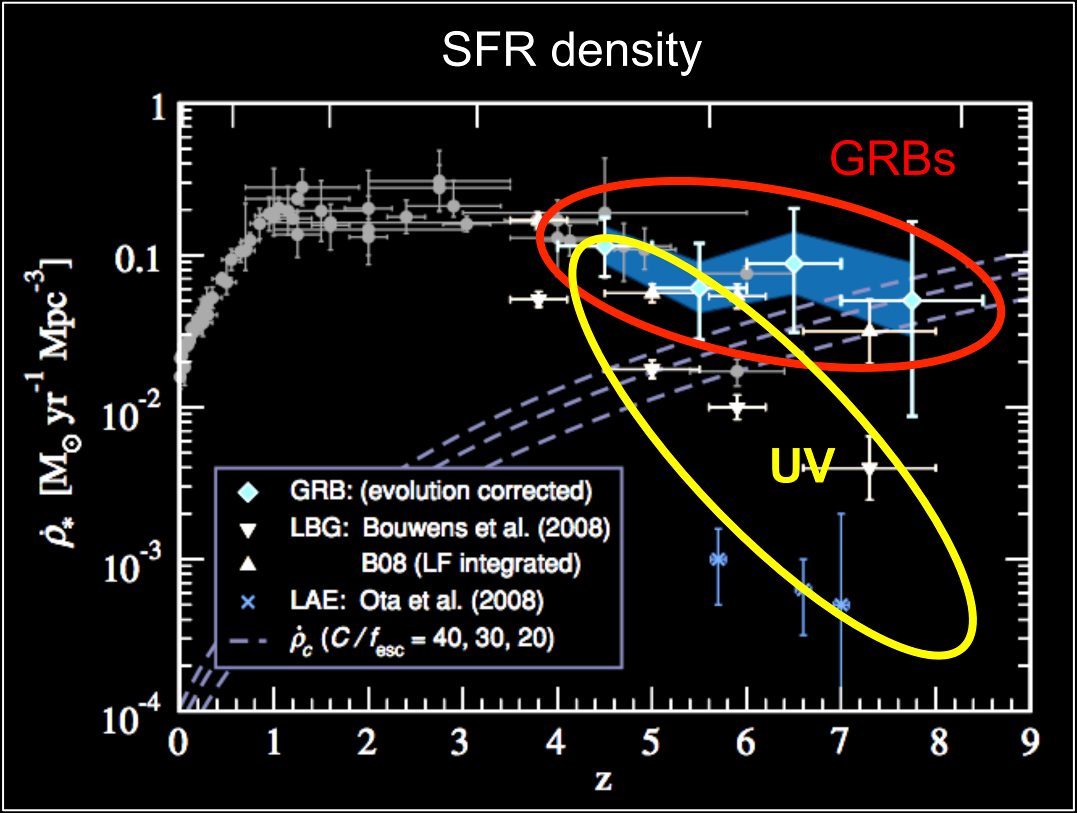
No →

- I (360s)
- Z (360s)
- Y (360s)
- F125W (360s)
- F160W (360s)



Outliers / low-z interlopers reduced by ~50%

Cosmic Star Formation history at z>5



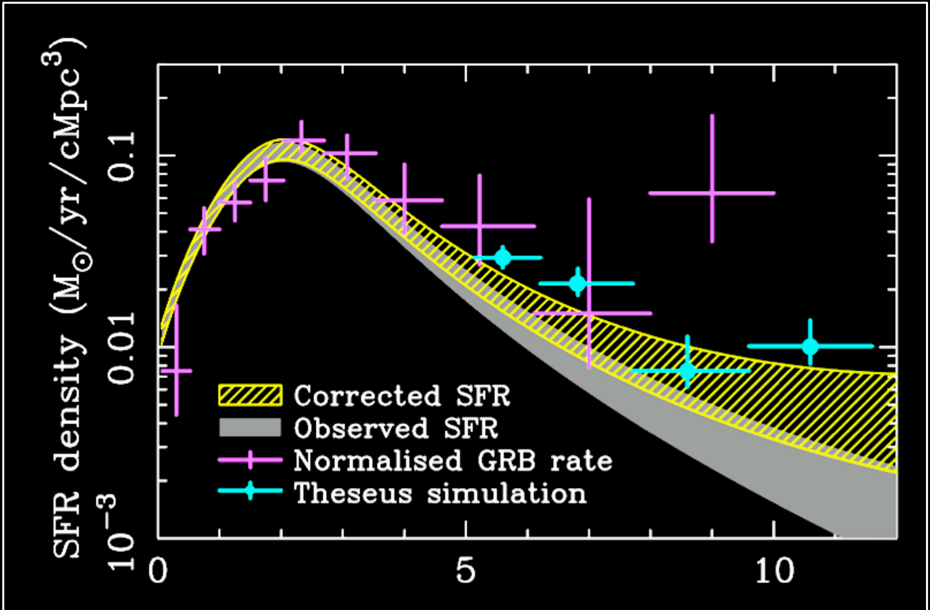
Probing cosmic SF density at z>5 with GRBs. Tension with UV-based galaxy surveys

- IMF departure ?
- Metallcity cut ?

Kistler+09, Robertson+12, Perley+16, …

Current GRB samples at z>6 still too limited, remedied by THESEUS in 3.4yrs of operations

But need to control the conversion from GRB rate to stars….

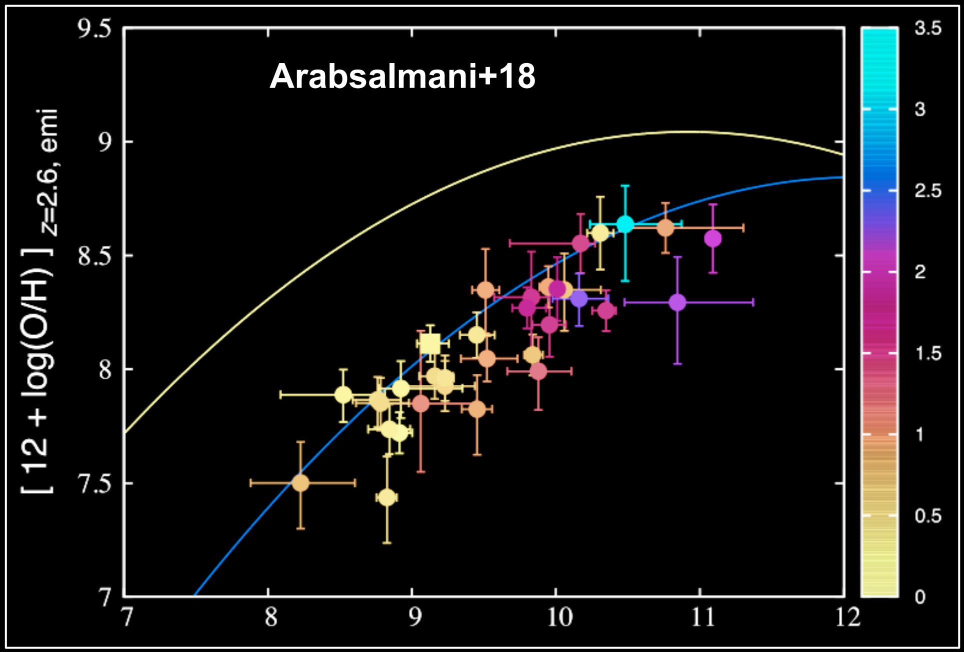


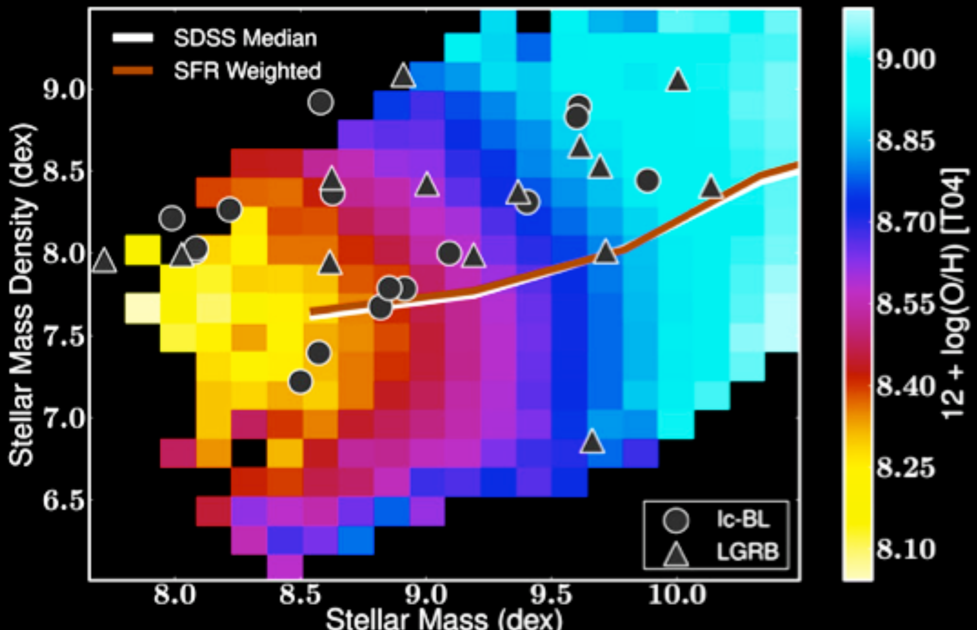
Tanvir et al.

Long GRBs as SF tracers

LGRB bias : long standing debate since the 2000s

- Low metallicity cut
  - ok at low z (Modjaz+, Graham+, Vergani+, Palmerio+, ..)
  - less critical at higher-z (massive dusty hosts, mass-metallicity relation (Perley+, Arabsalmani+, …)





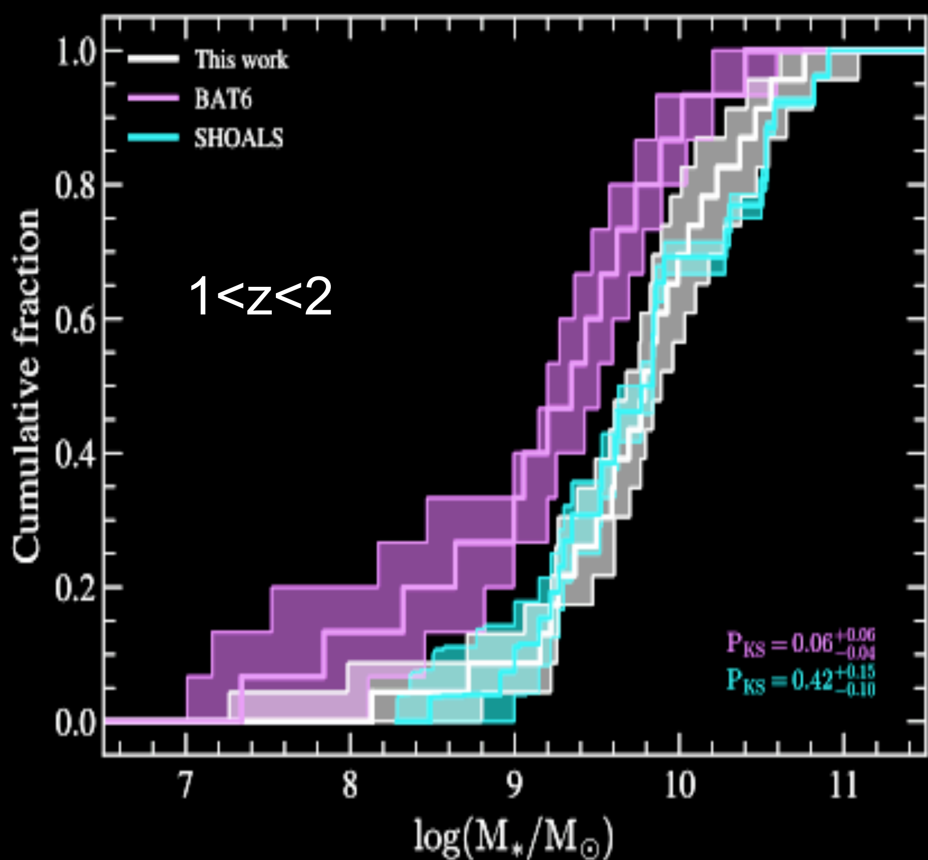
Kelly+14

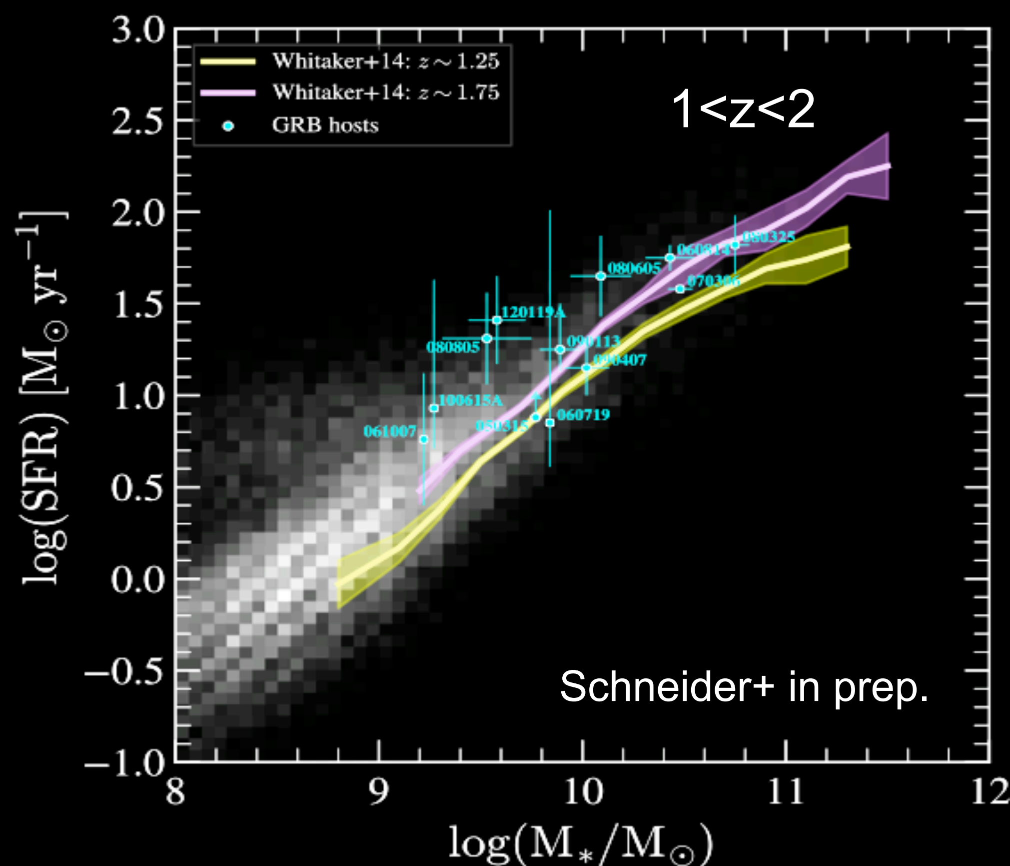
- Specific SFR : e.g. Bjornson 2019
- SF / mass surface density & gas compression (e.g, Kelly+14, Arabsalmani+19, 20)

LGRBs: impact of stellar mass density ?

Stellar mass and SFR surface density of LGRB hosts compared to field galaxies at 1<z<3   (Benjamin Schneider PhD work)

- LGRBs with HST/WFC3 imaging, ~40 sources (complicated selection function !)
- Stellar mass distribution follows BAT6 / SHOALS
- Follow the SF galaxy main sequence, albeit sSFR slightly higher

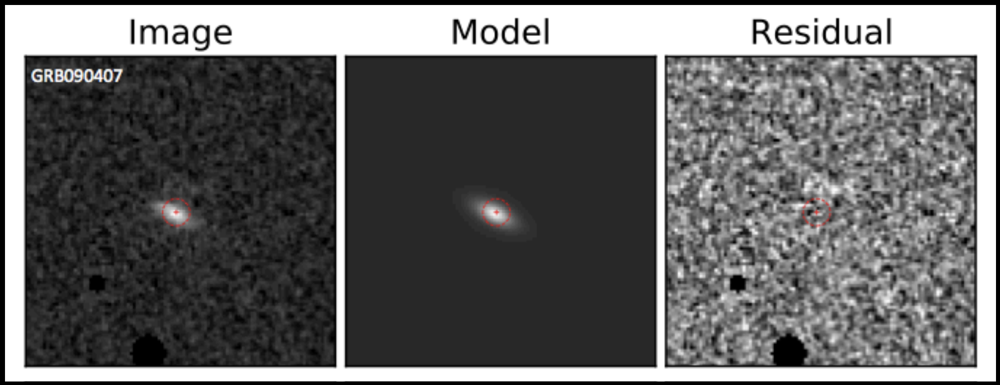




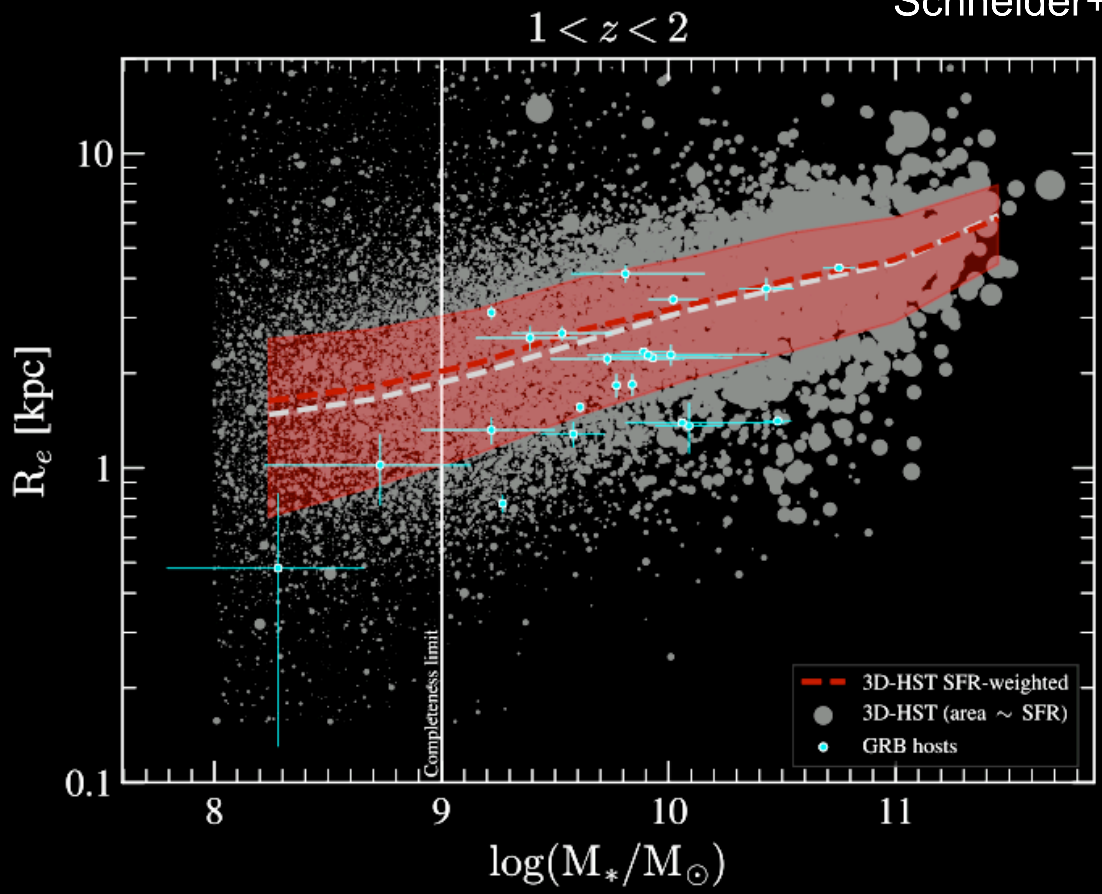
LGRBs: impact of stellar mass density ?

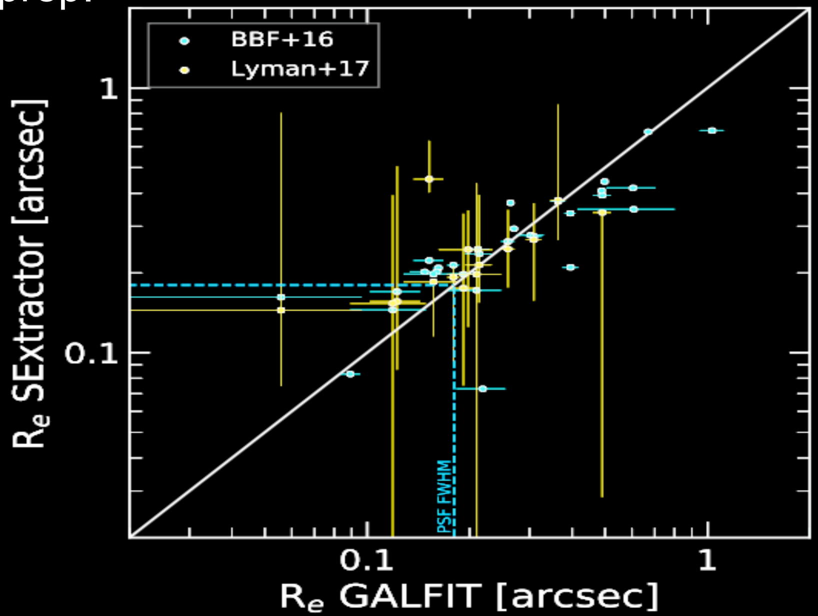
GALFIT (surface brightness fit)
→ provide Sersic index, Re, axis ratio

Detailed comparison with the field
(3D-HST & CANDELS)



Schneider+ in prep.

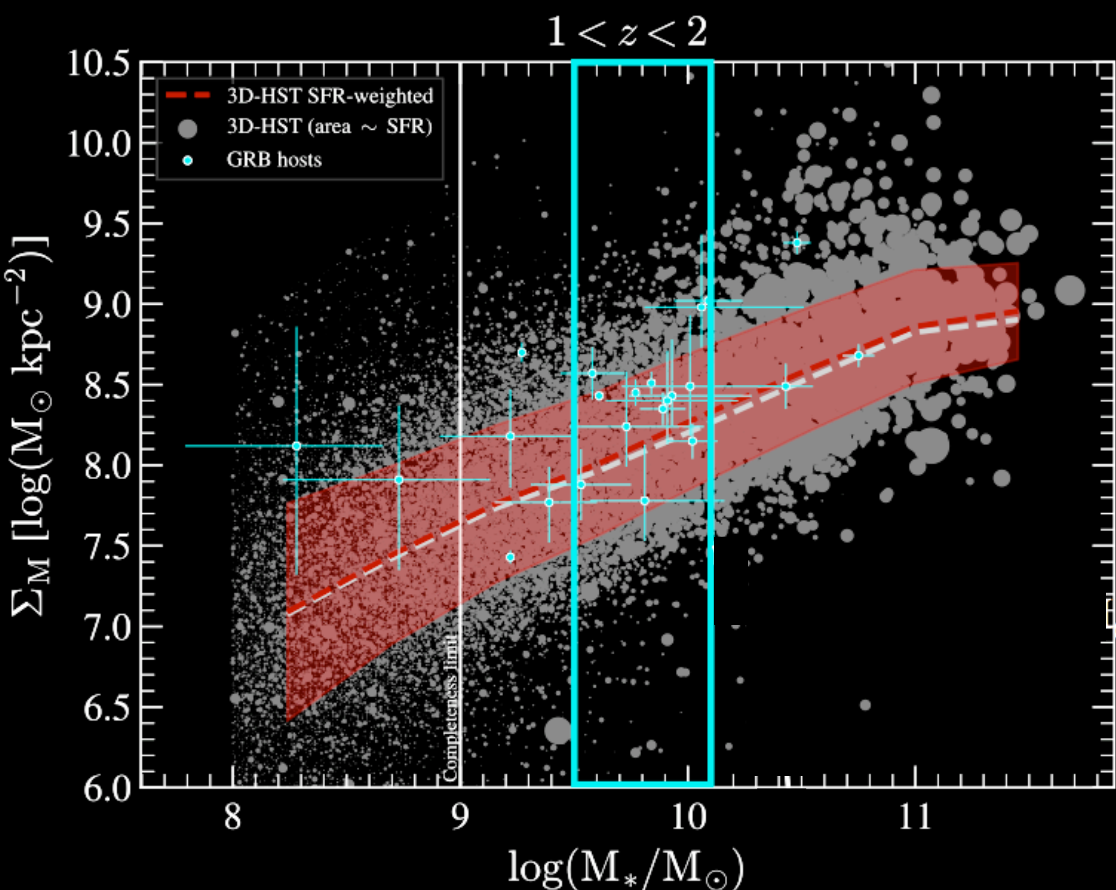




LGRB host globally follow the
mass-size relationship of SF galaxies

But exhibit smaller half-light radii

LGRBs: impact of stellar mass density ?



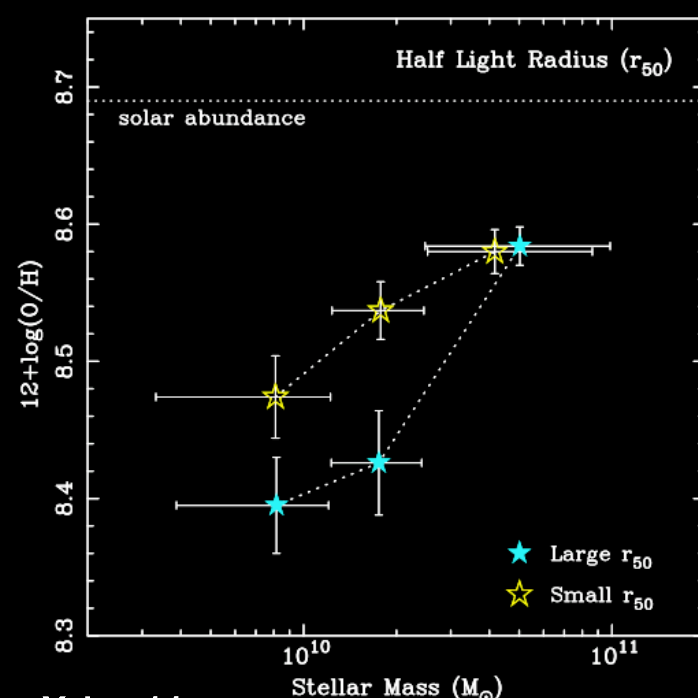
Schneider+ in prep.

1<z<2 : stellar mass surface densities of GRB hosts *slightly* larger than field galaxies at similar mass

Offset statistically robust (KS, p-value), can not be explained by systematics on mass and Re estimates.

Tension with the metallicity bias, given the anti-correlation between size and metallicity (Ellison+07, Yabe+12, 14)

2<z3: bias not seen, although statistics is likely too low



Yabe+14

Summary / Prospects

- Understanding of LGRB host environments still progressing

  → converges to a picture where the "low-z bias" may vanish with increasing redshift

  → promising for constraining cosmic SFR density at redshifts where THESEUS will be key

- IRT / THESEUS will provide photo-z's accurate within 10% at z>5.5, leading to ~50 GRBs to constrain N(z)

- Reddening by dust should not be neglected !!!

  → contamination of the high-z sample by low-z dusty interlopers might reach ~10%