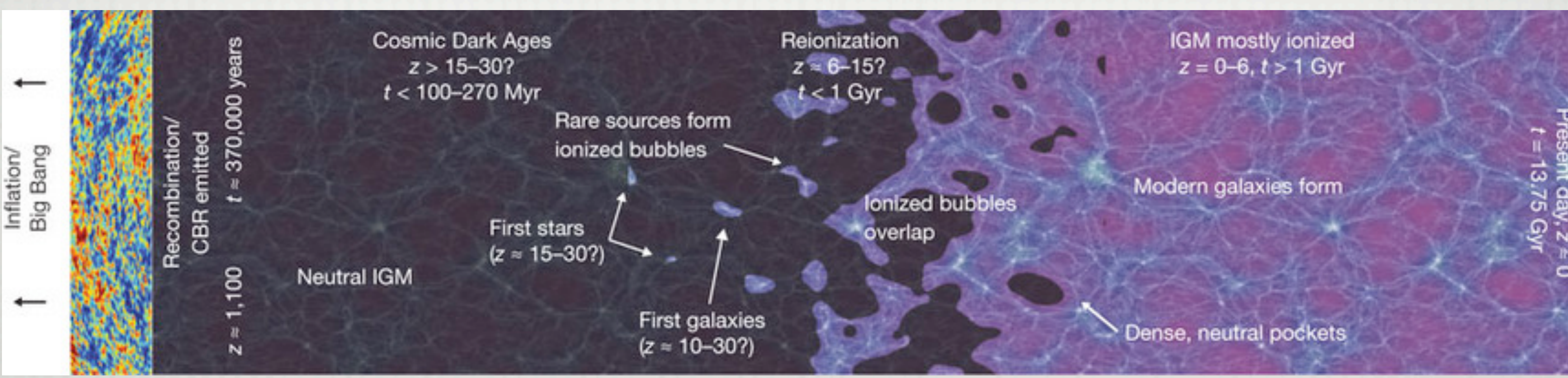
high-z gamma-ray bursts

by R. Salvaterra (INAF/IASF-MI)

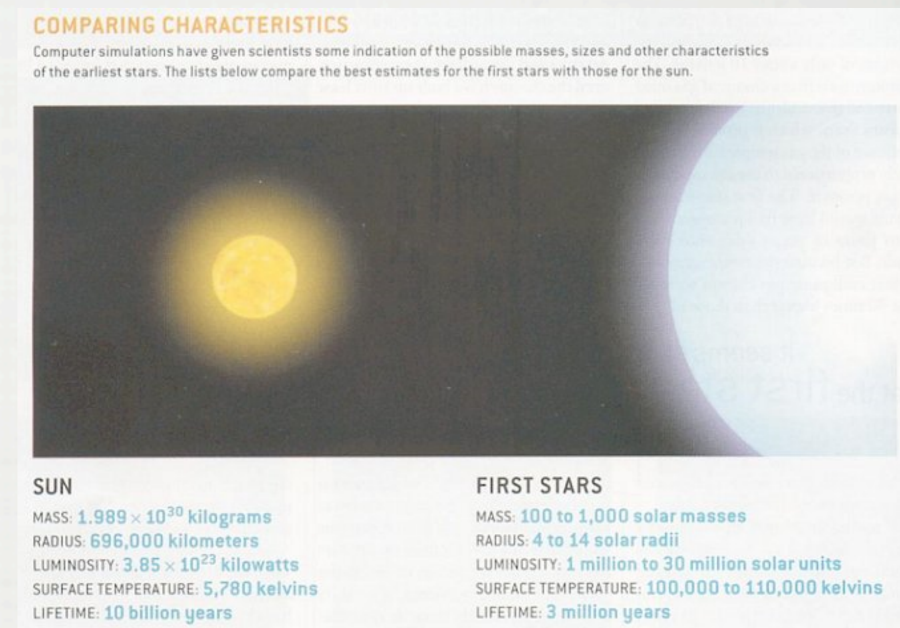
the cosmic dark-ages



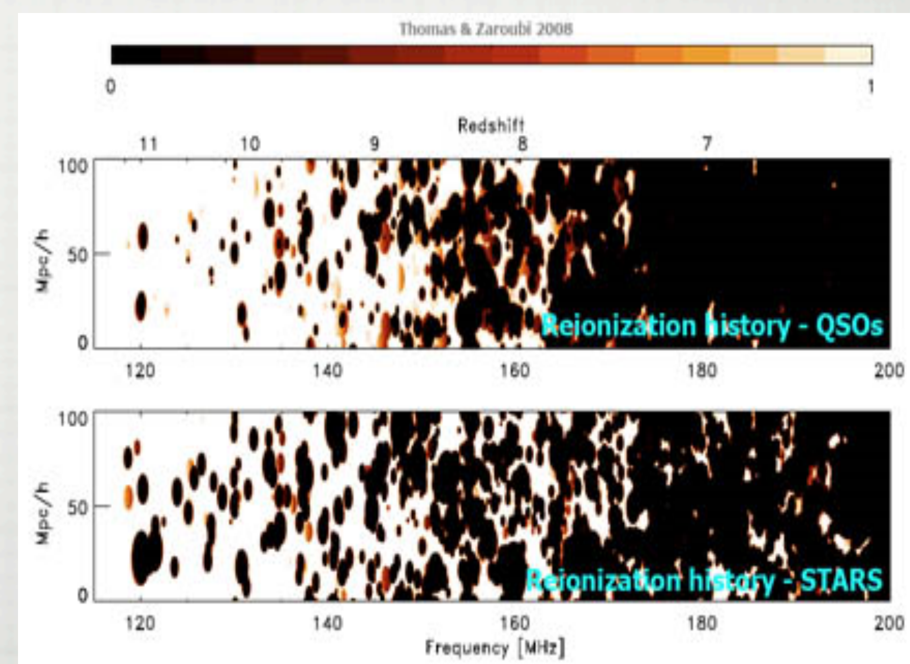
why is it interesting?

the Universe experienced two fundamental transitions:

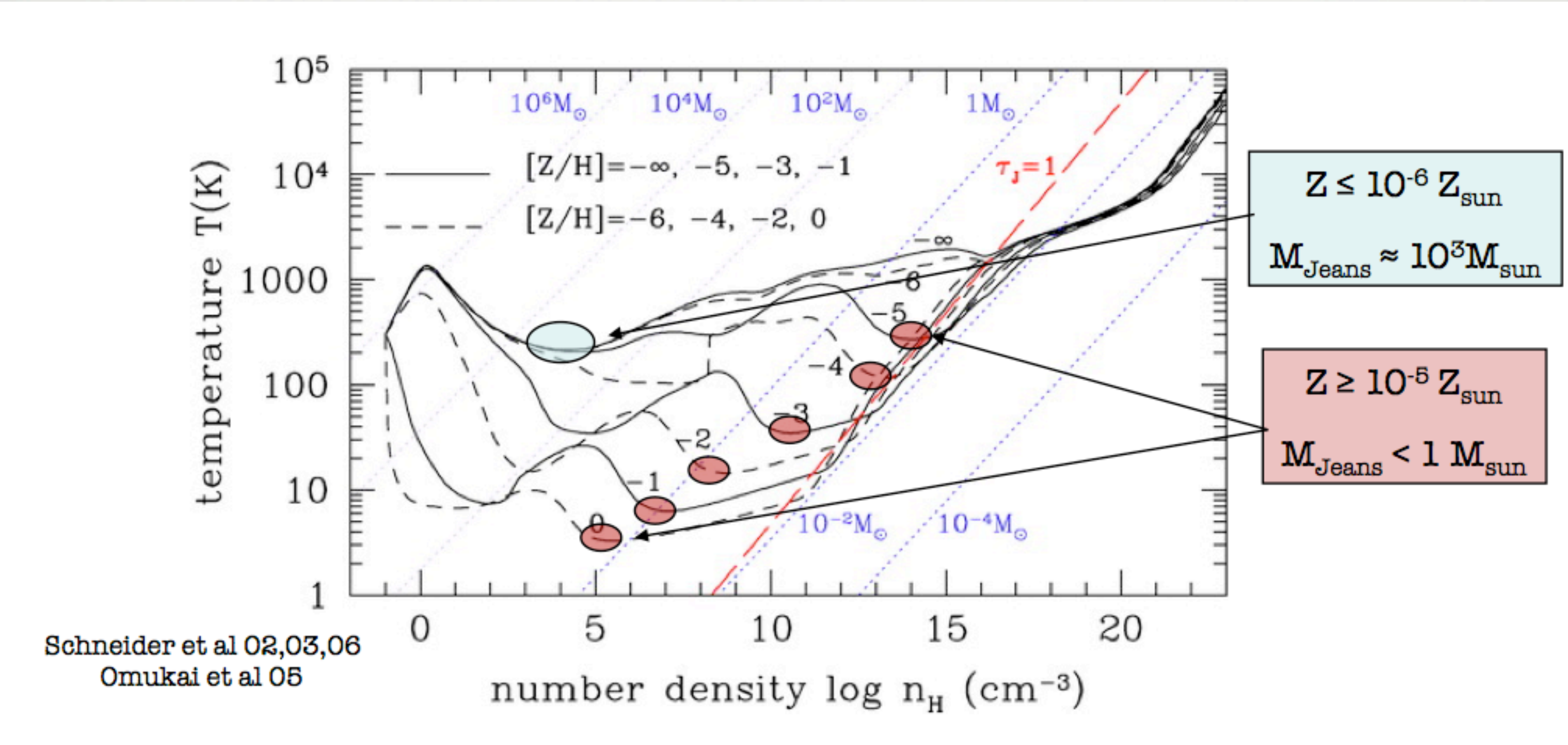
- transition in the star-formation mode:
from massive, metal-free PopIII stars to a normal (Salpeter-like) second generation of stars (PopII)



- transition in IGM state/reionization:
from a neutral to a ionized intergalactic medium



PopIII-PopII transition

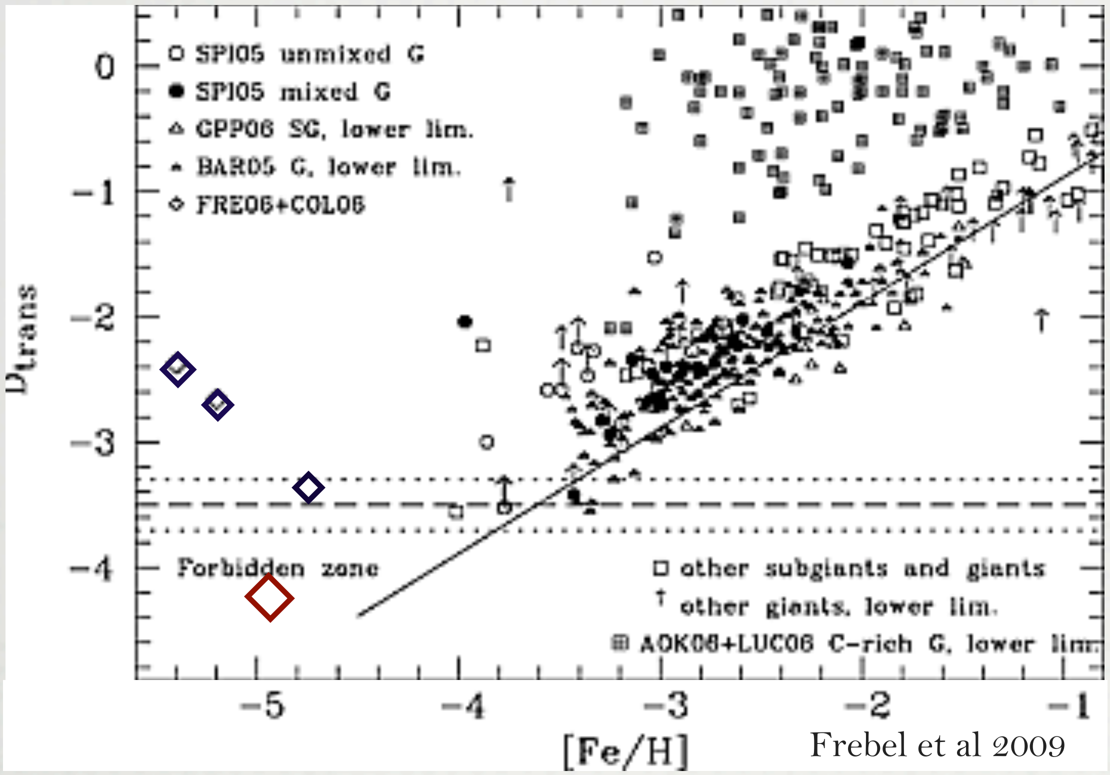


there exists a critical metallicity **Zcrit~10^{-4} - 10^{-6} Zsun**

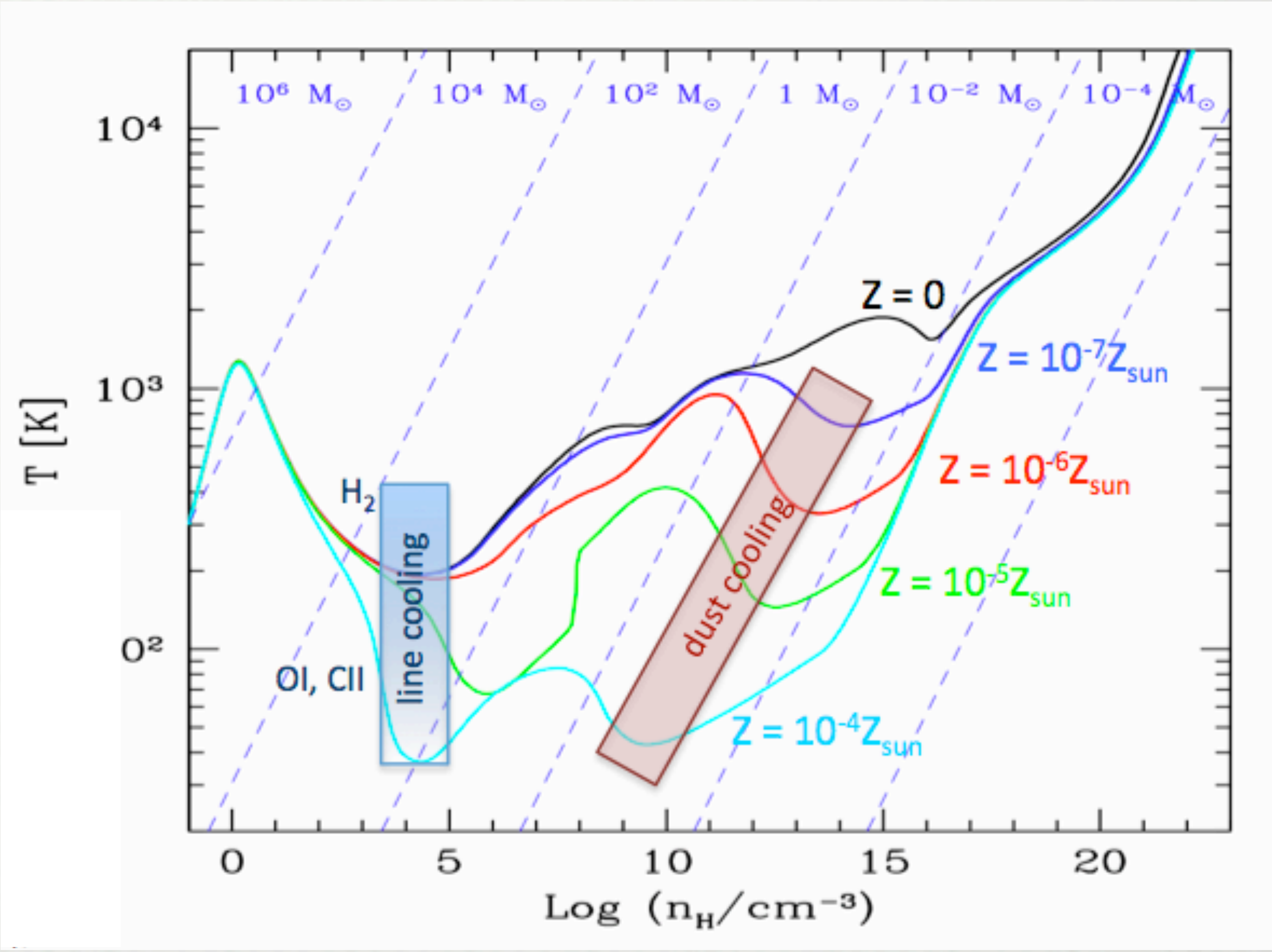
credits: R. Schneider

"the star that should not exist"

Dtrans = Log($10^{[C/H]}$ +0.3 $10^{[O/H]}$) ≥ -3.5



SDSS J1202915+172927 (Caffau+ 2011 Nat.)
iron poor [Fe/H]=-4.99
but also [C/H]<-3.8 [O/H]<-4.1,
i.e. in the forbidden zone

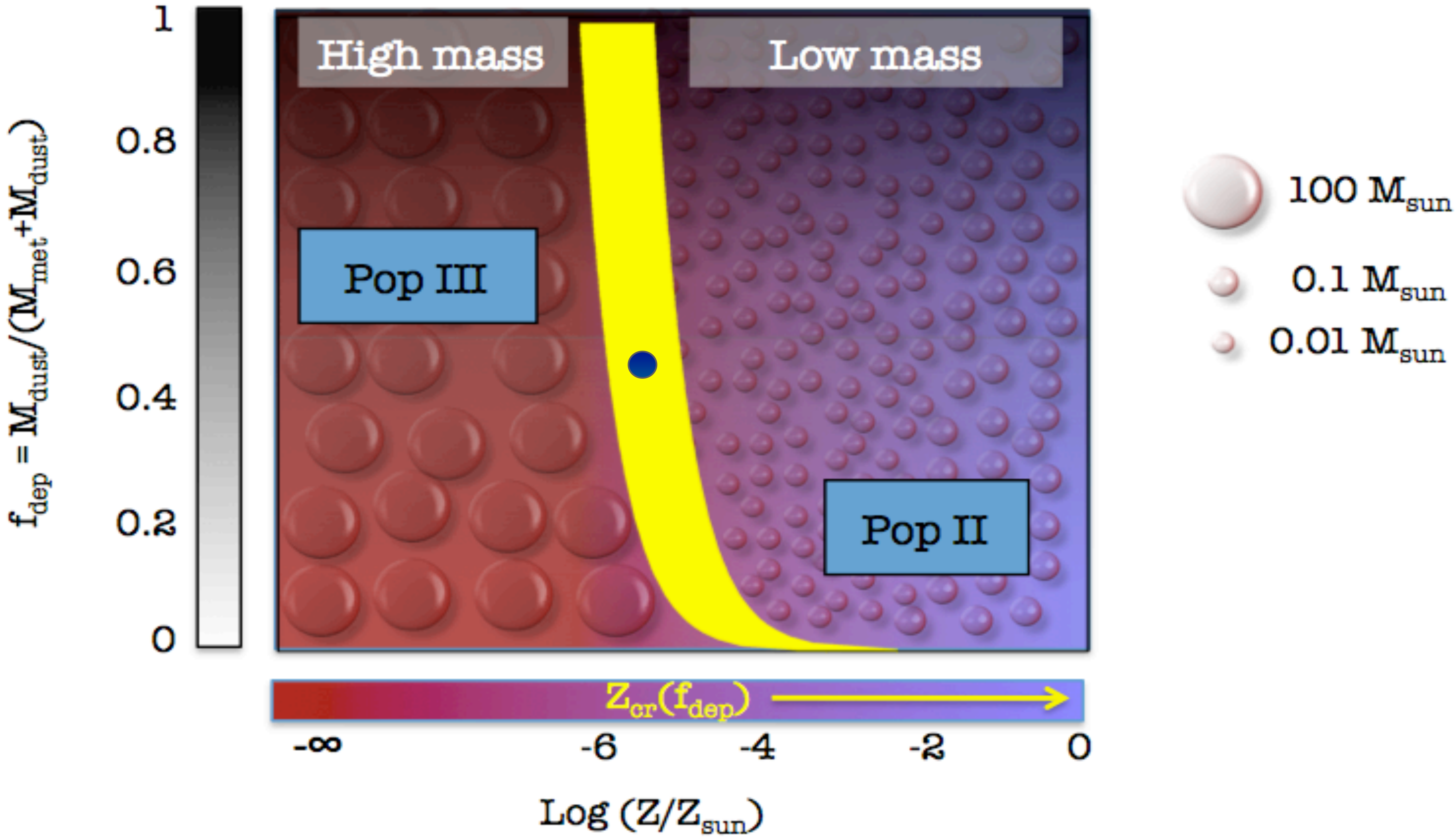


the existence of Caffau's star can be explained assuming it originates from a gas enriched with metals and dust from a massive (30-40 Msun) PopIII ccSN

low mass stars can form even at Z=10^{-5} Zsun if dust is present

Schneider et al. 2003, Nature; Schneider et al. 2012

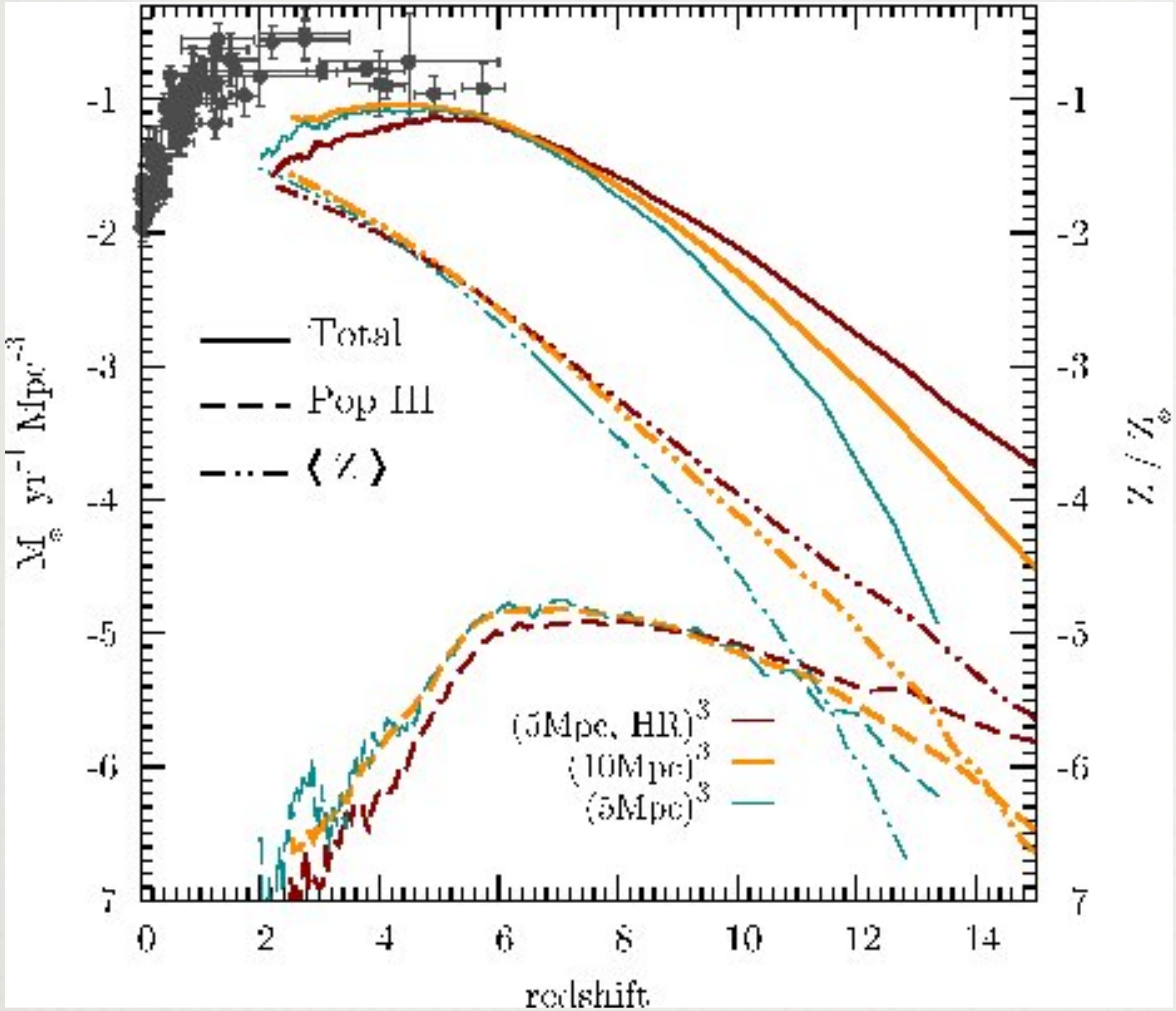
“the star that should not exist”

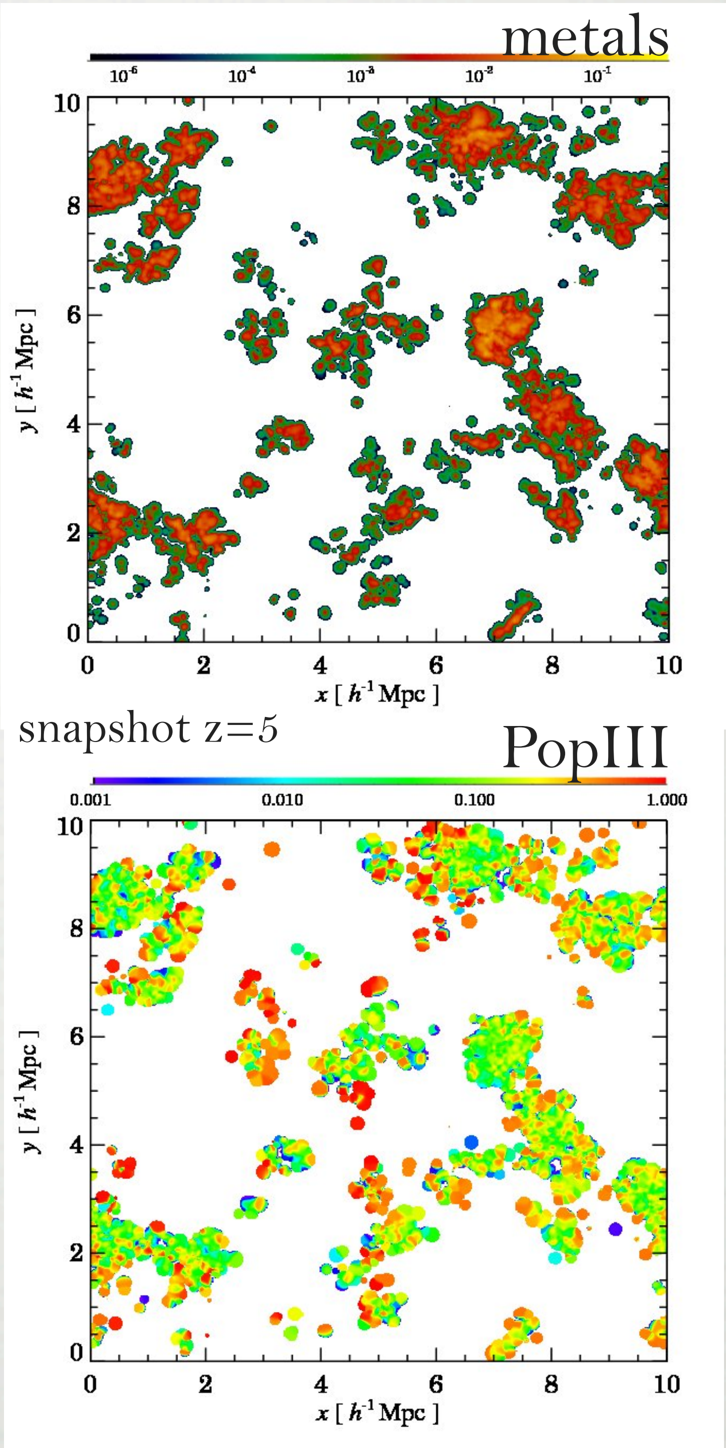


low mass stars can form even at $Z=10^{-5}$ Zsun if dust is present

Schneider et al. 2003, Nature; Schneider et al. 2012

the chemical feedback

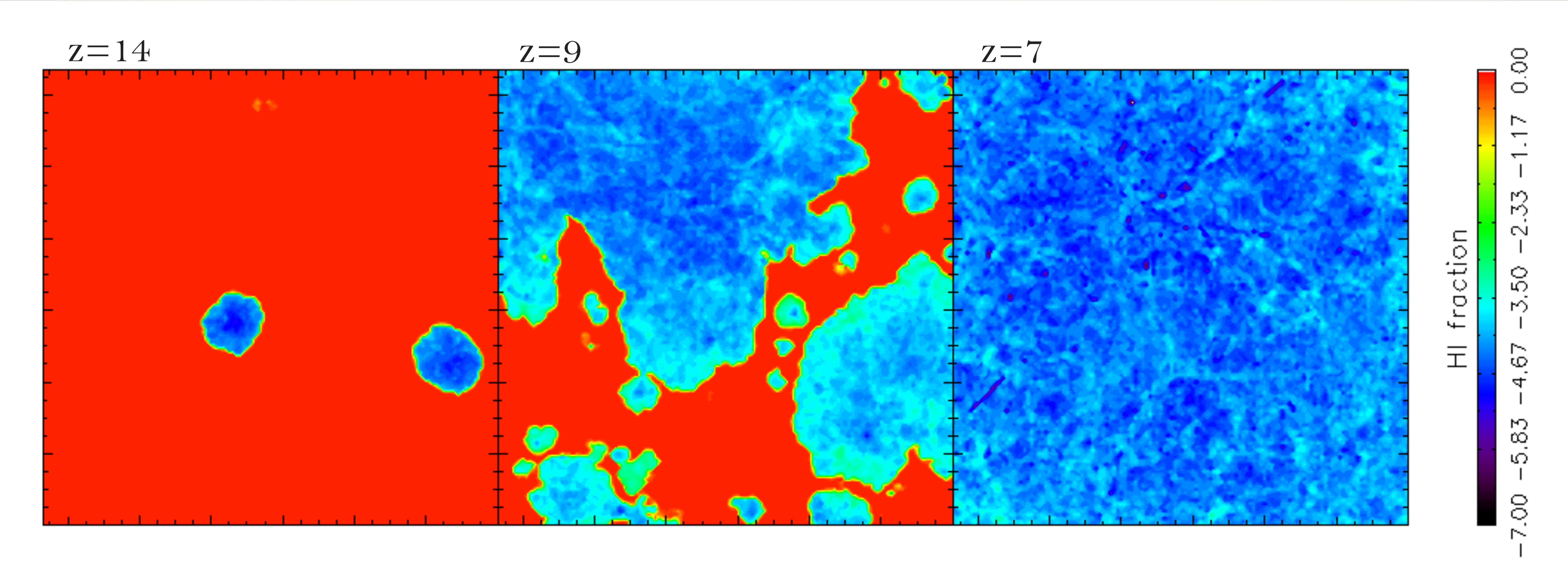




note the recent observation of two gas clouds at z~3 with Z<10^{-4} Zsun (Fumagalli et al. 2011 Science)

Schneider et al. 2006, Tornatore et al. 2007, Maio et al. 2009, 2010, 2011

cosmic reionization

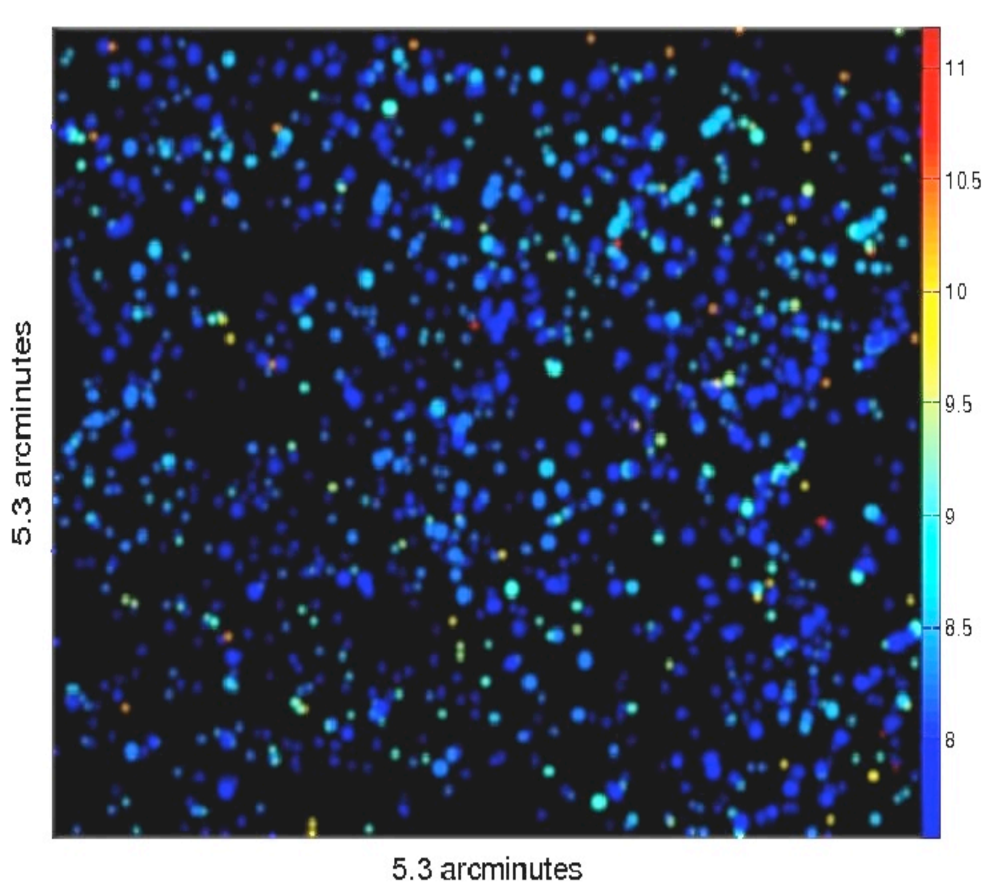


many open questions:

- when did the reionization happen?
- what are the main sources of ionizing photons?
- what is the relative contribution of PopIII/PopII stars?
- what are the feedback effect at play?

credits: B. Ciardi

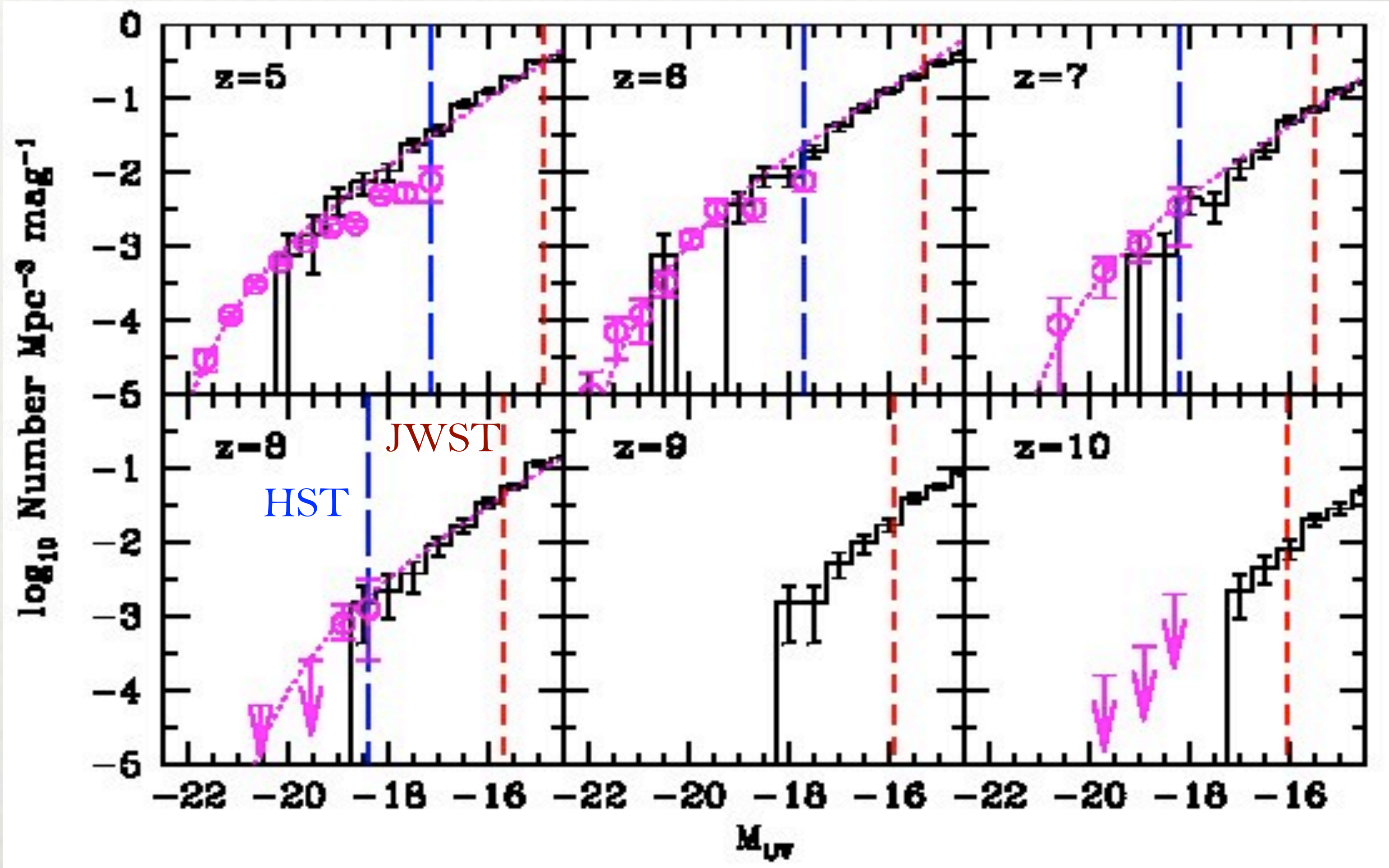
simulating high-z galaxies



simulated JWST H-band sky

cosmological simulaton with GADGET:
L=10 Mpc/h, Np=256^3, Mp= $2x10^6$Msun
with chemical feedback → PopIII-PopII trans.
radiative feedback
mechanical feedback (SNyy and SNII)

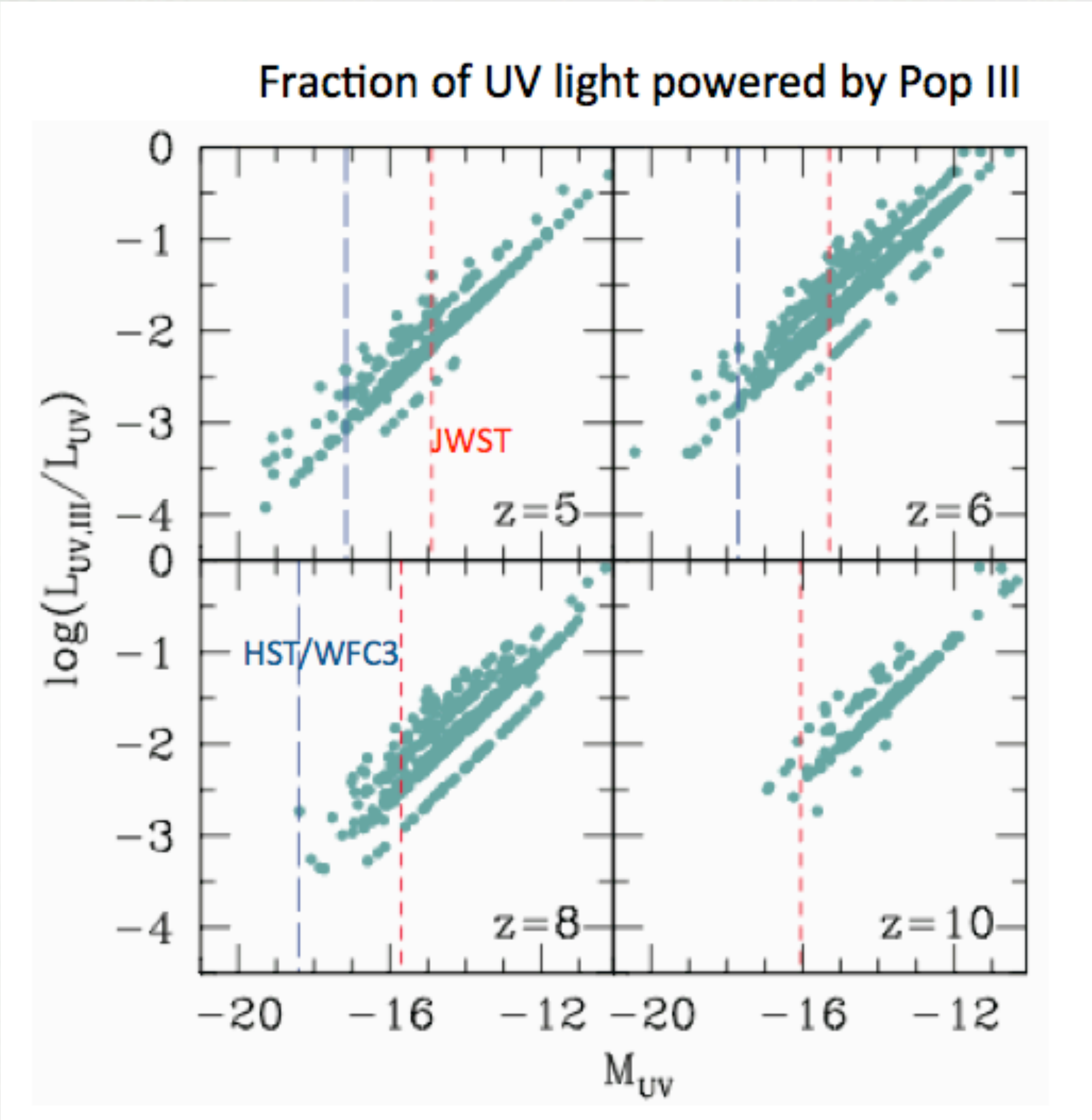
HST/WFC3 dropout LF



the simulation nicely reproduces the HST/WFC3 data without the need of any fine-tuning

Salvaterra et al. 2011

PopIII stars contribution

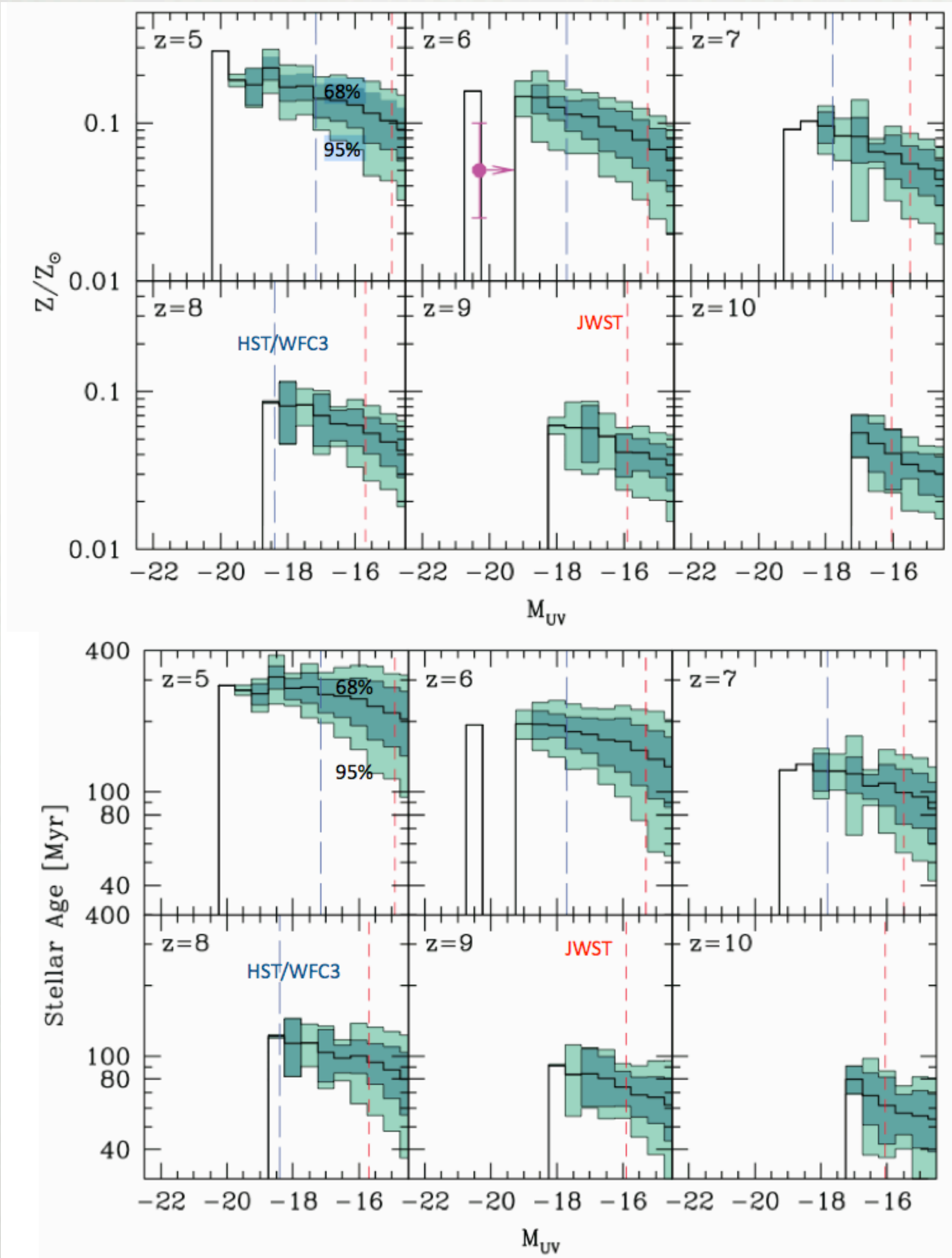


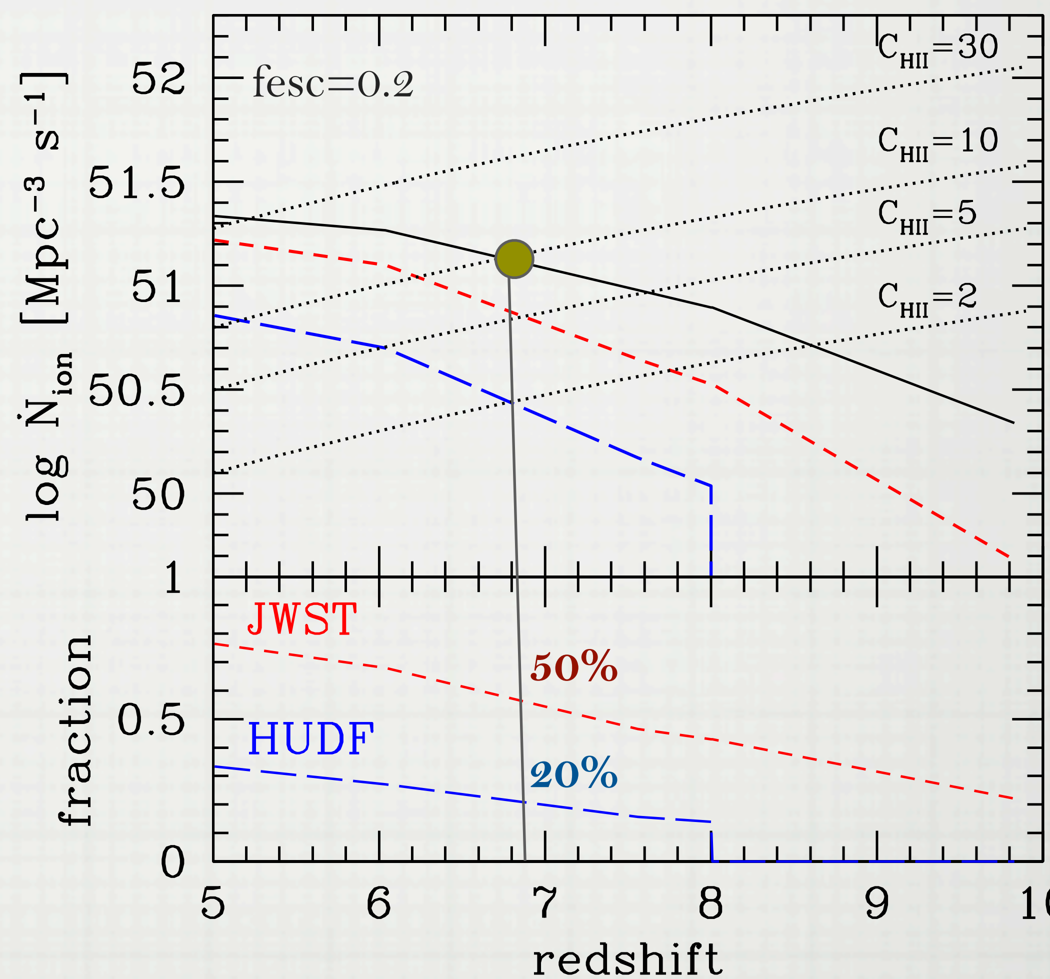
PopIII stars contribute little to the UV light but at the faintest magnitudes at the limit of detection even with JWST

peculiar colors and the HeII emission line can help to identify their signature

Salvaterra et al. 2011

properties of high-z galaxies



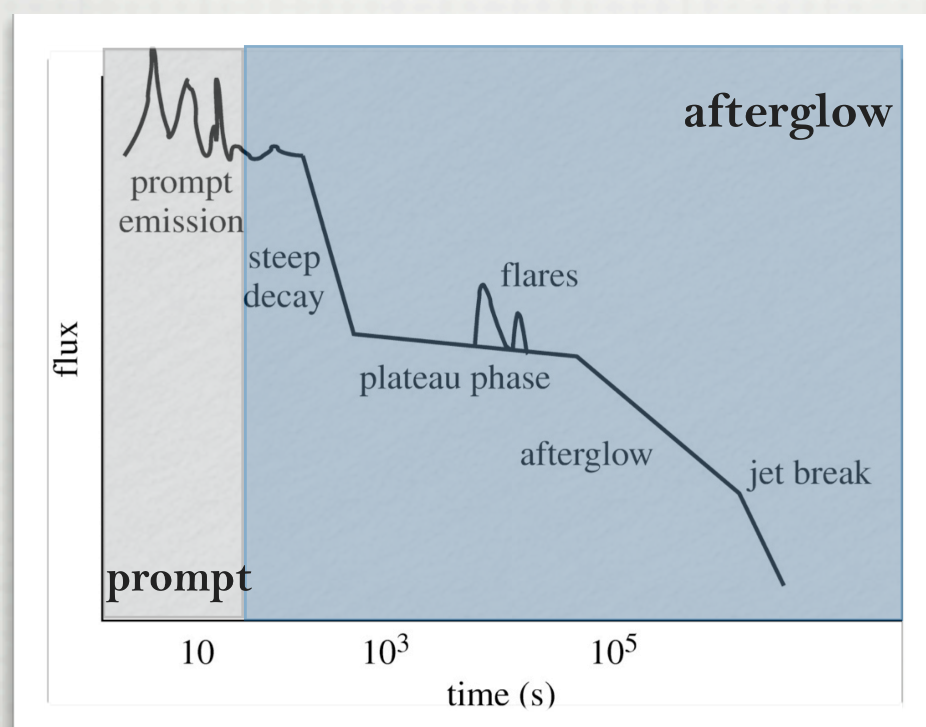


the bulk of ionizing photon production is in galaxies missed even in the deepest HST fields

Salvaterra et al. 2011

the high-z GRB population

GRBs in one slide



long GRBs are powerful flashes of γ-ray radiation originated by the collapse of a massive stars, likely a Wolf-Rayet star

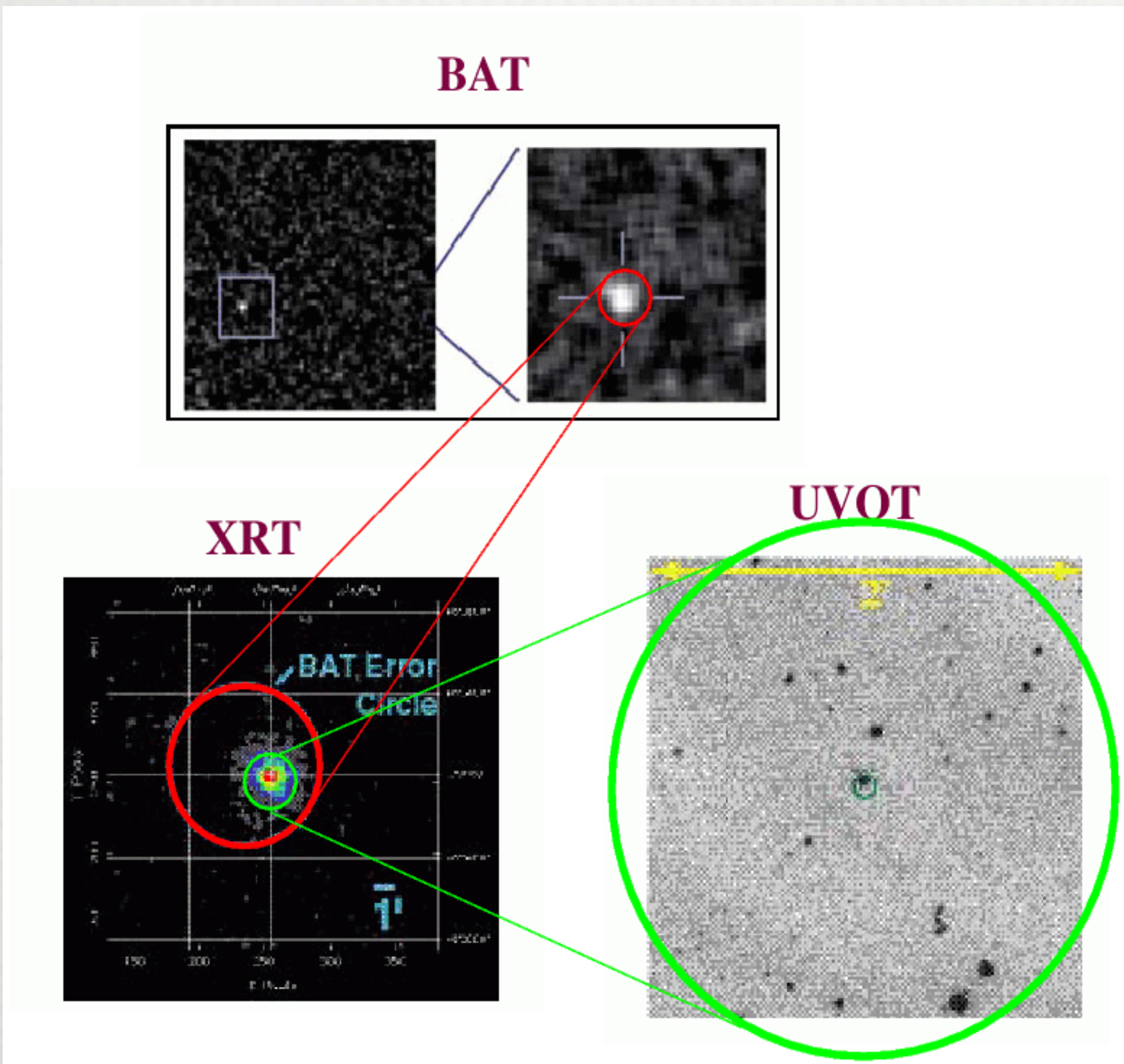
GRB at high-z pros & cons

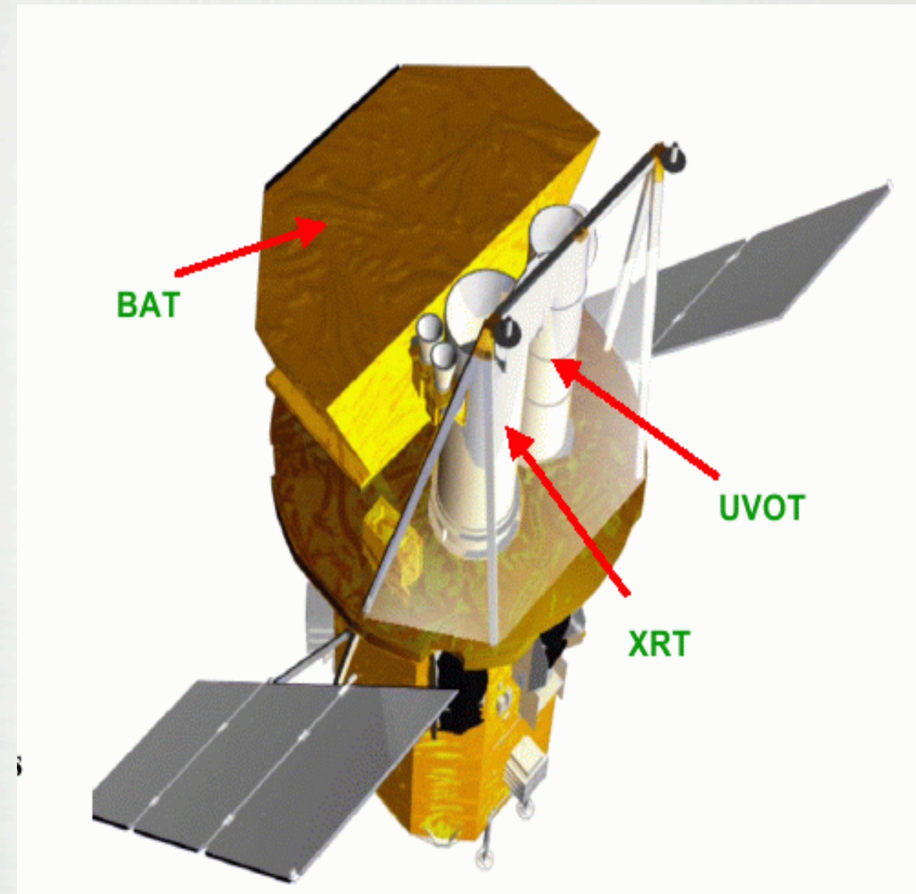
Pros:
- high-z events
- very bright
- inside normal galaxies
- power-law continuum
- fade away

Cons:
- fade away
- rare
- inside galaxies

the Swift satellite

launched in Nov. 2004: ~100 burst/yr

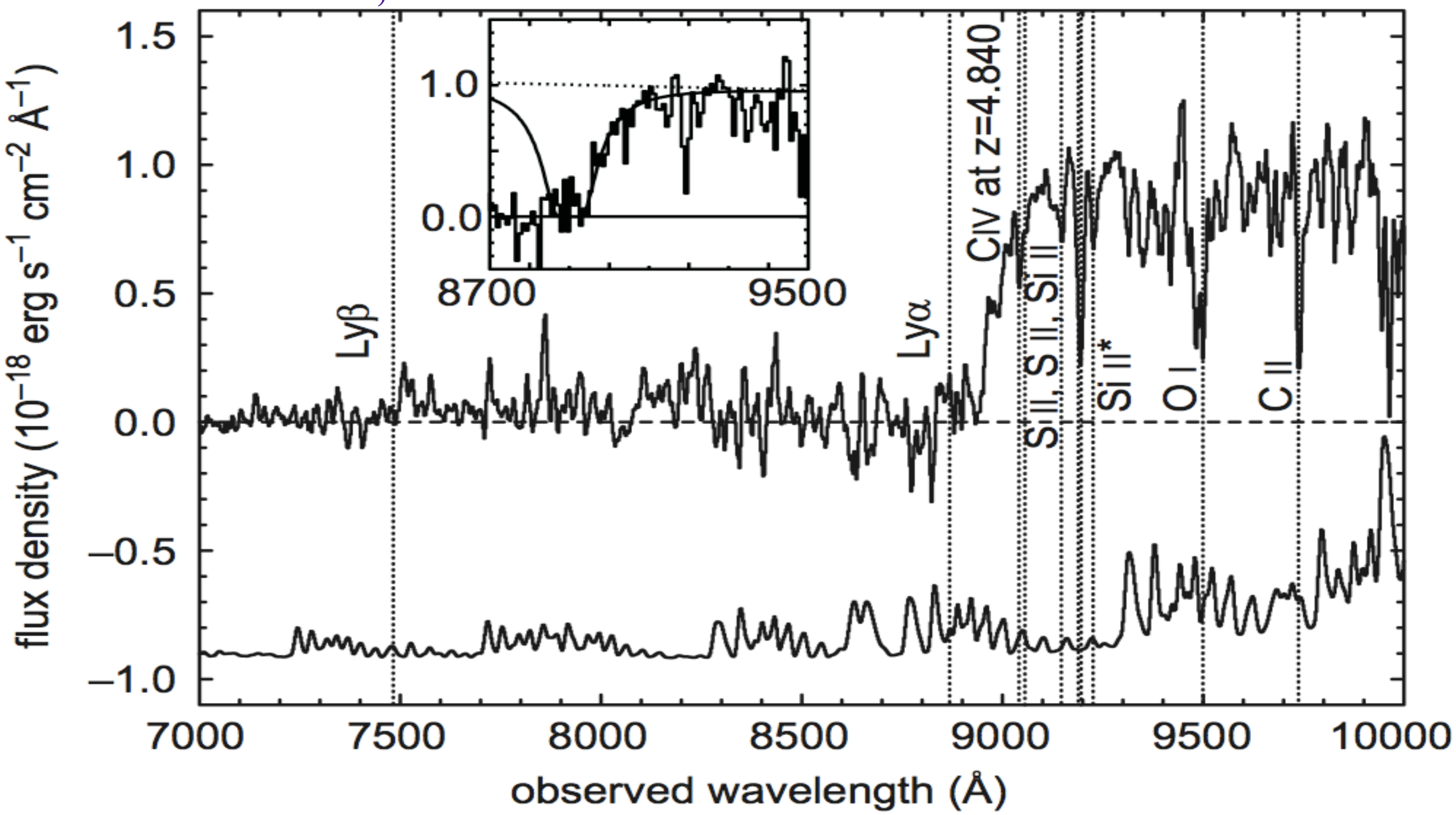


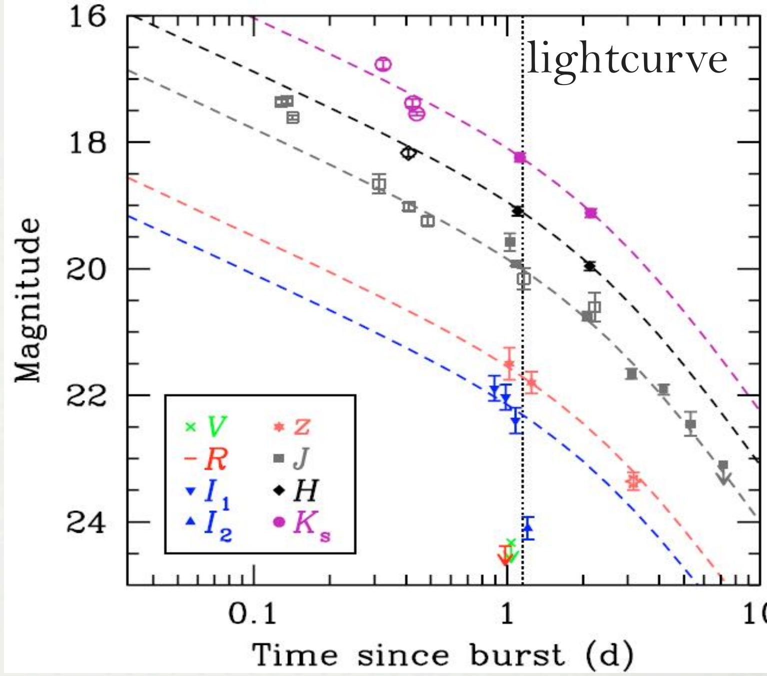


1. BAT triggers on GRB and calculates position to within 4 arcmin
2. Spacecraft autonomously slews to GRB position in 20-70 sec.
3. XRT determines position to within ~5 arcsec.
4. UVOT images field and transmit finding chart to ground

GRB 050904 at z=6.29

Kawai et al. 2005; Totani et al. 2006



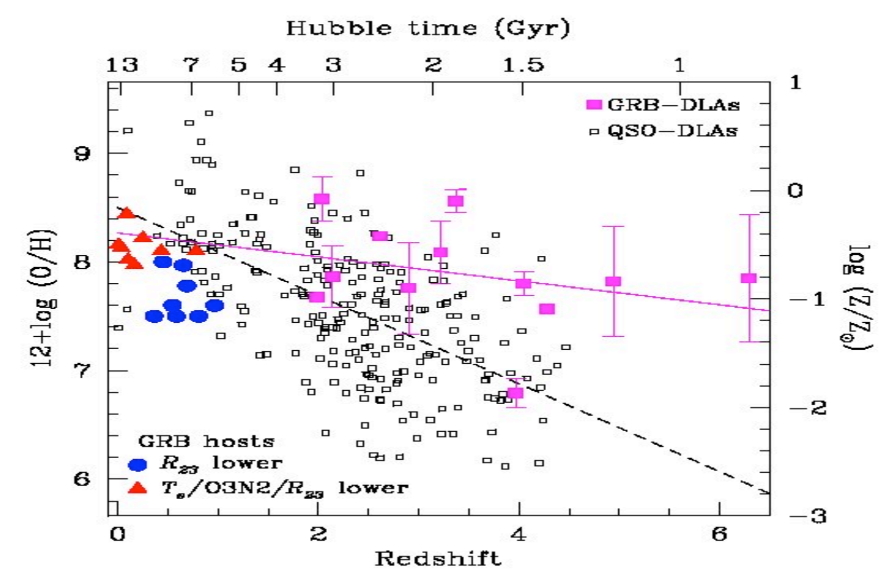


Haislip+2005; Tagliaferri+2005

Subaru 3.4 days after trigger

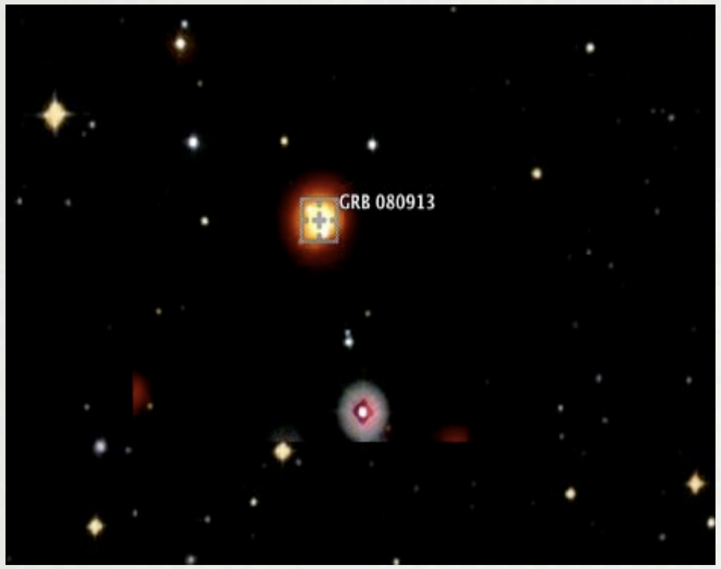
[Si/H]= -1.3 +/- 0.5 Z~0.05 Zsun

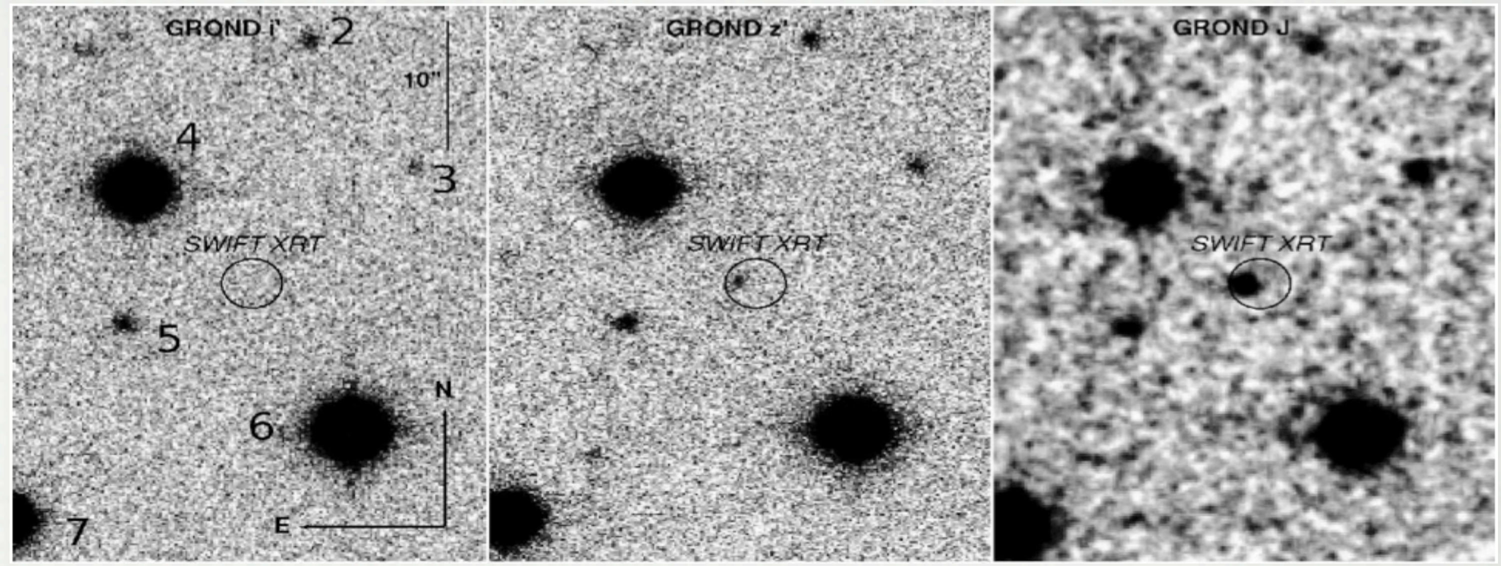
similar to low- and intermediate-z GRBs

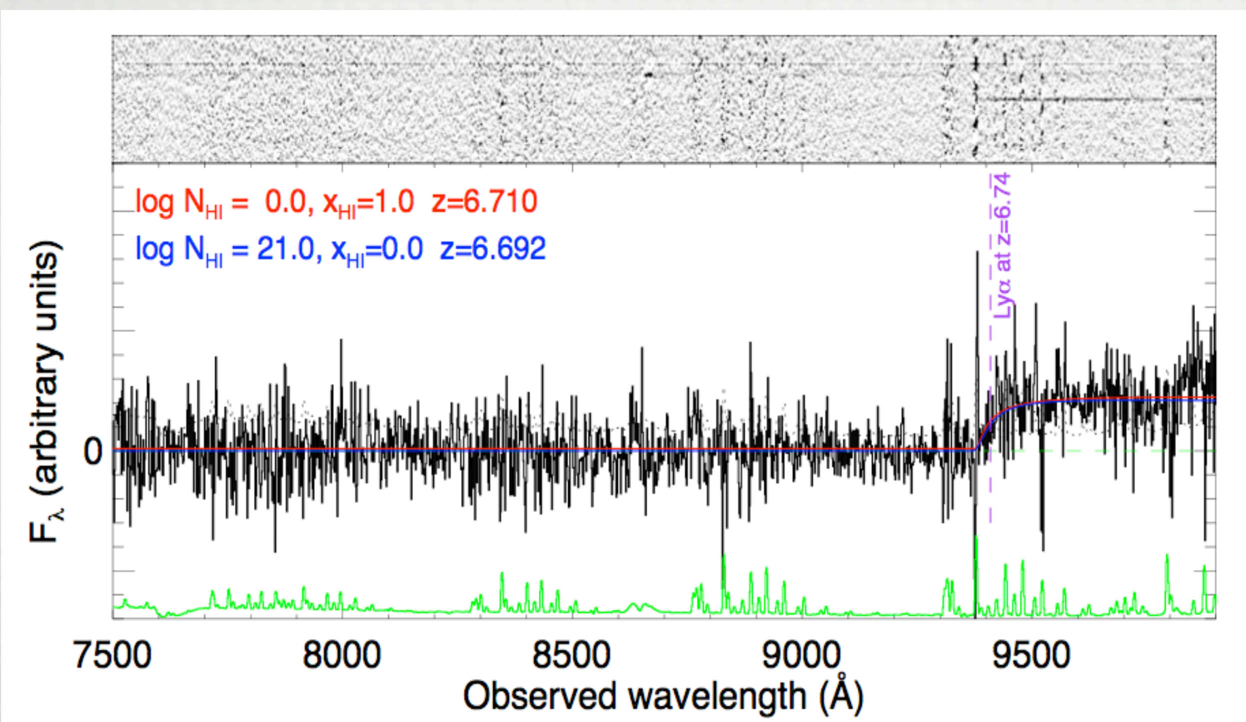


Savaglio et al. 2009

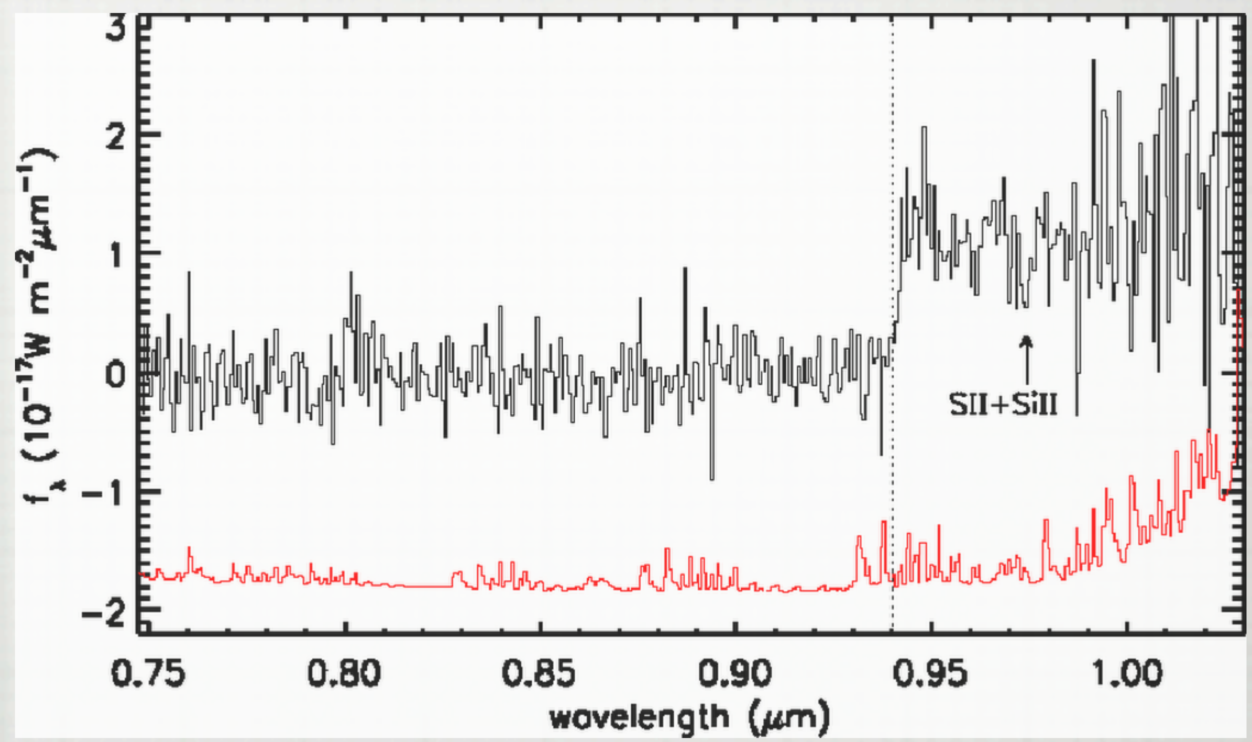
GRB 080913 at z=6.7





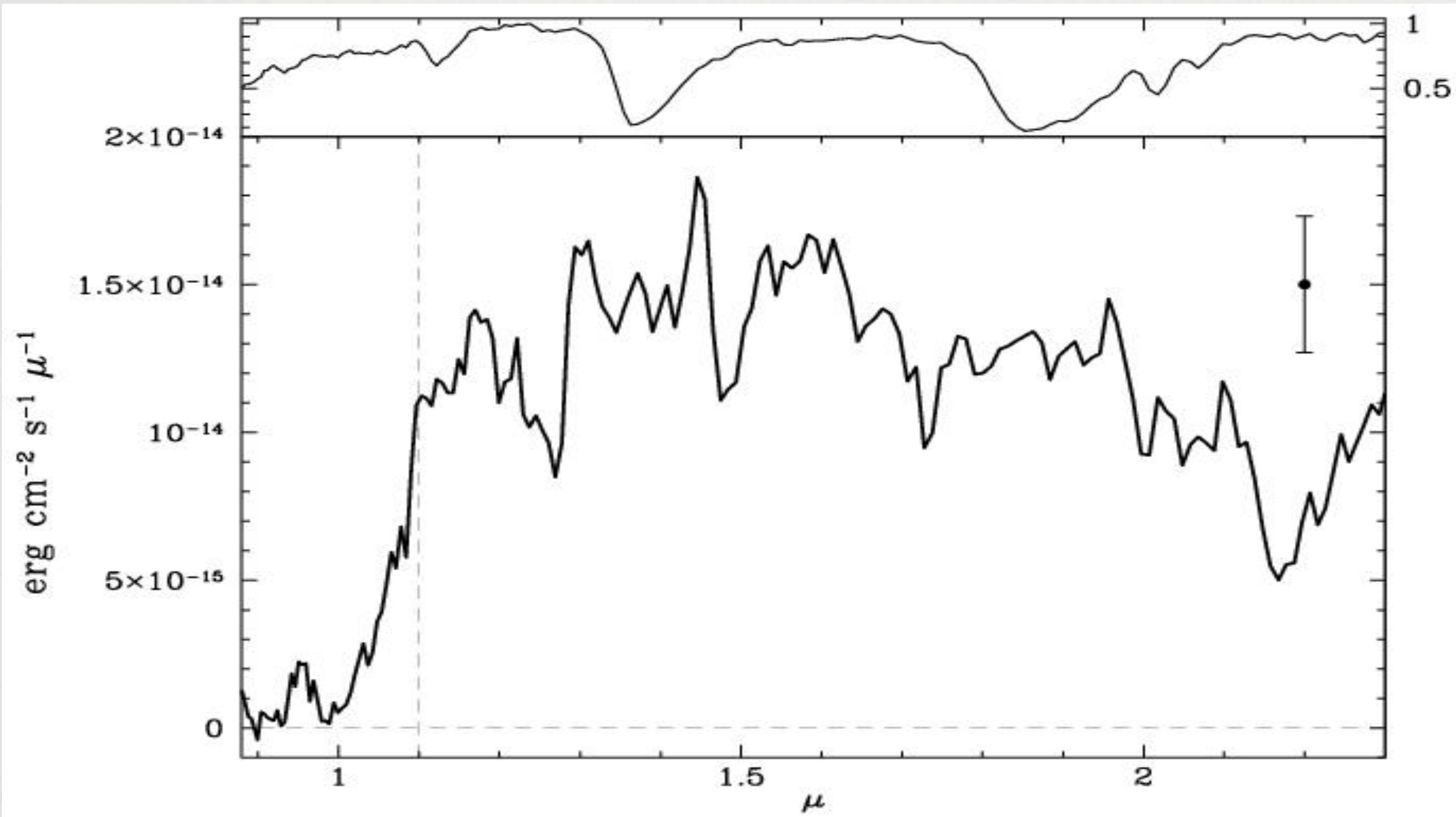


Greiner et al. 2008



Patel et al. 2010

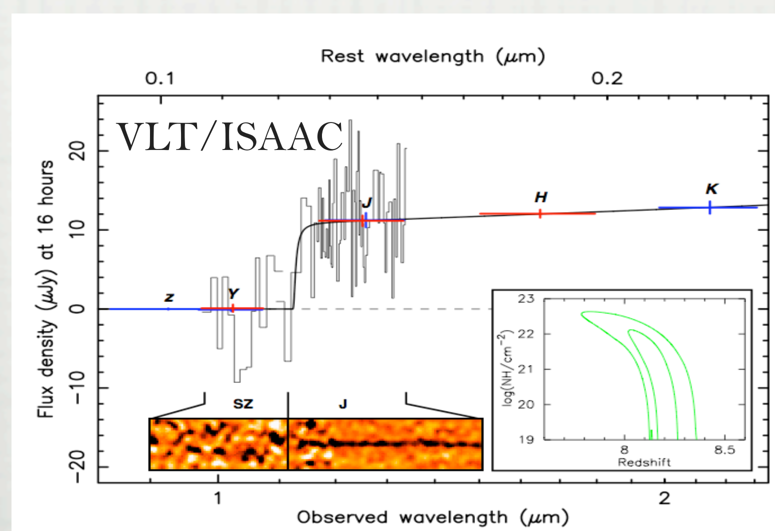
GRB 090423 at z=8.2

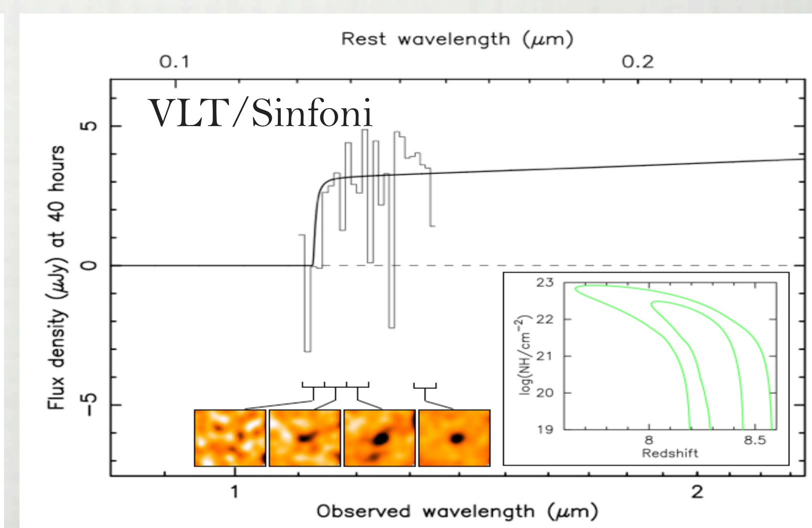


~14hrs after trigger

Tanvir et al. 2009, Nature

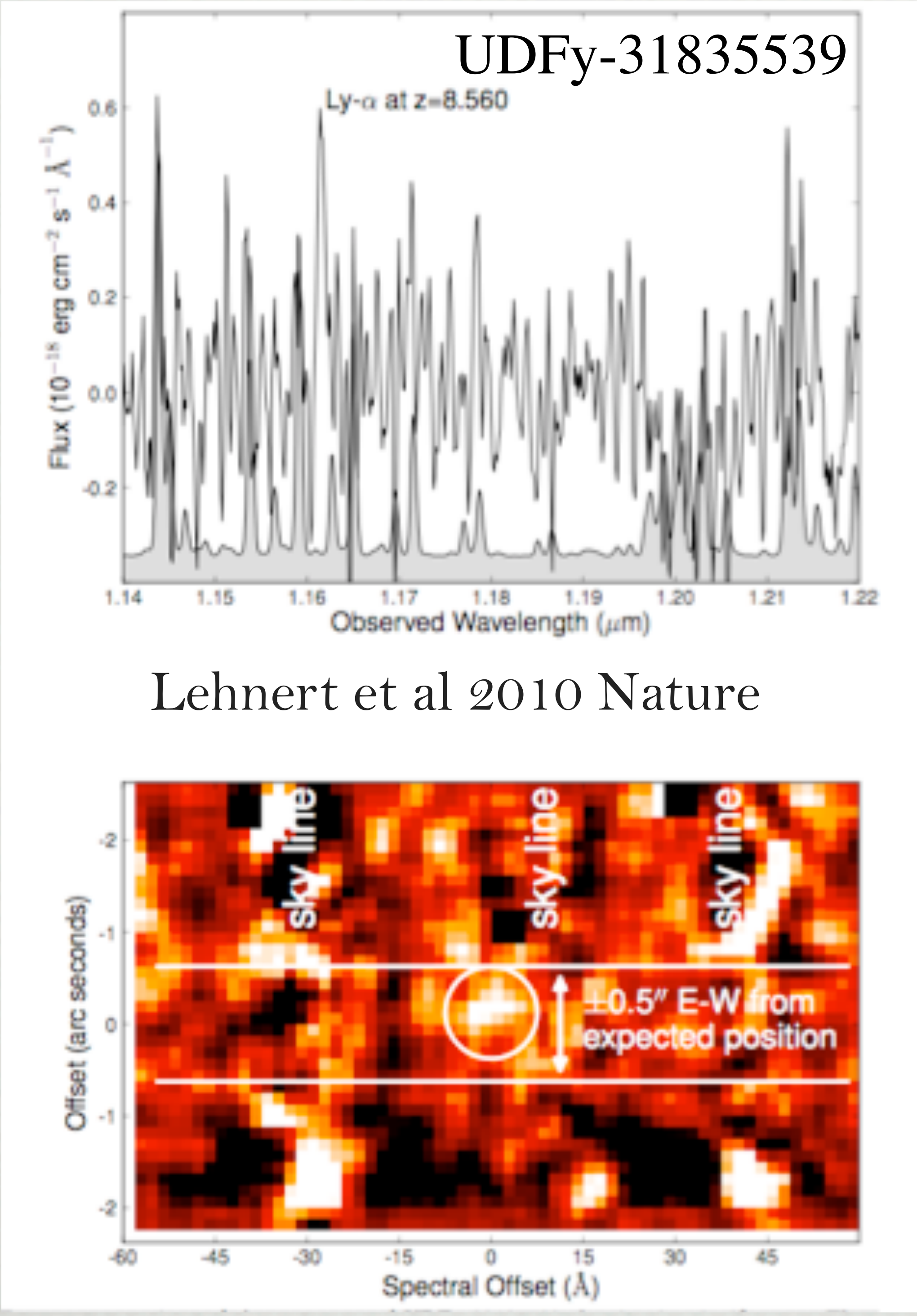
most distant object at that time





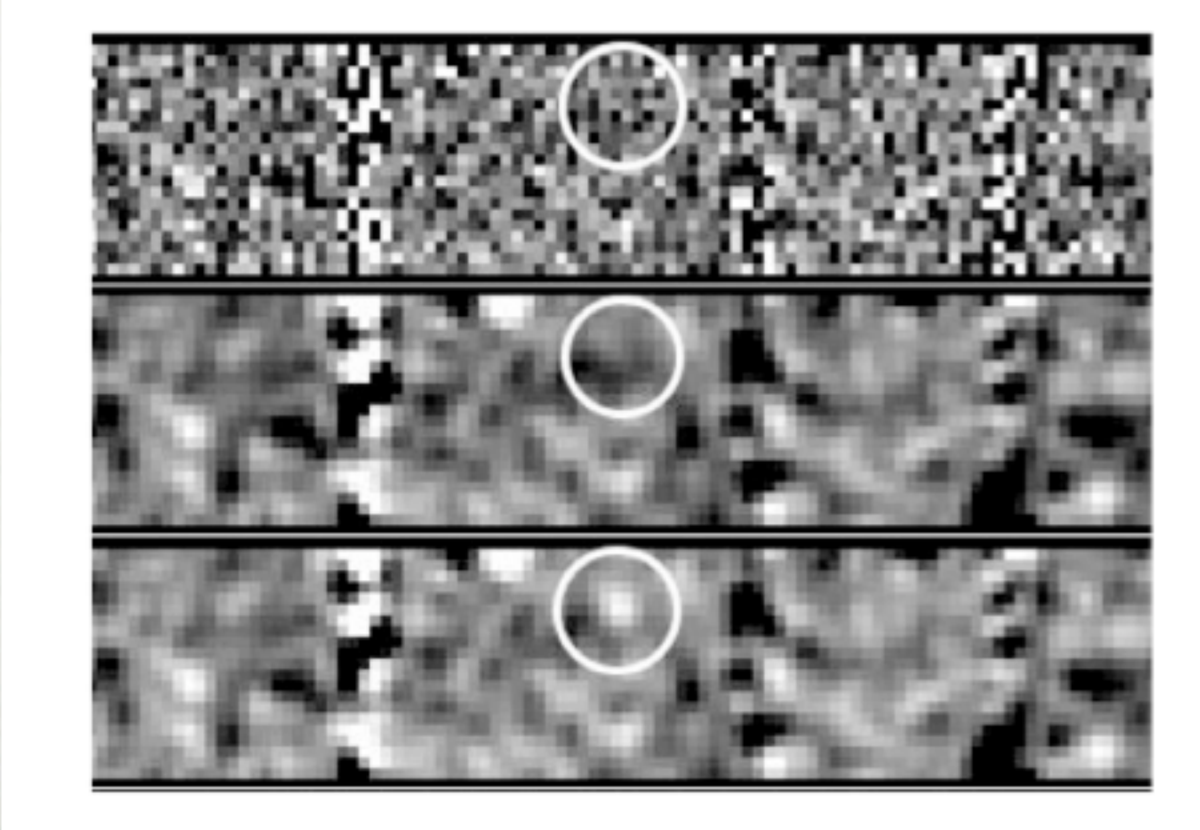
Salvaterra et al. 2009, Nature

still the most distant spectr. object!



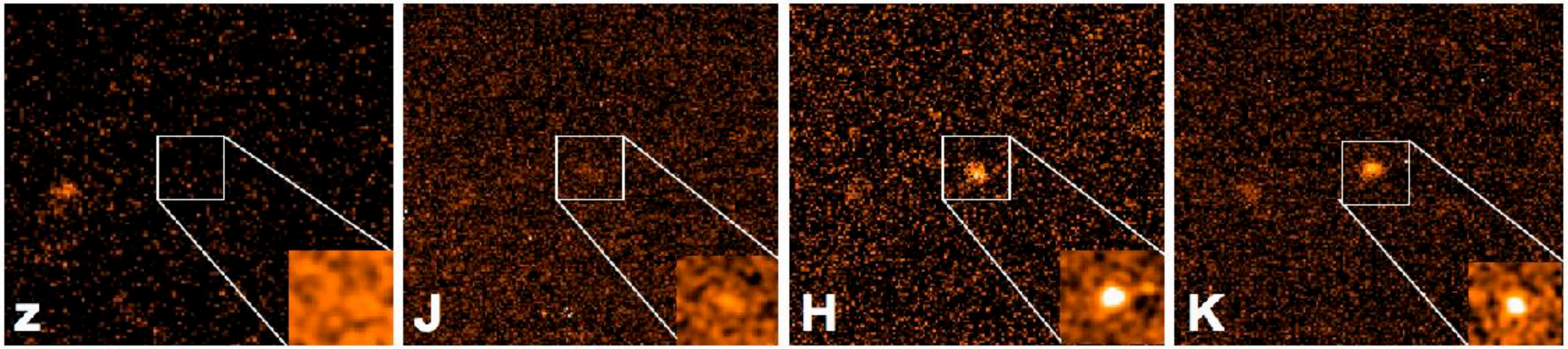
no detection in
5 h with VLT/Xshooter
11 h with Subaru/MOIRCS

Bunker et al. in prep.

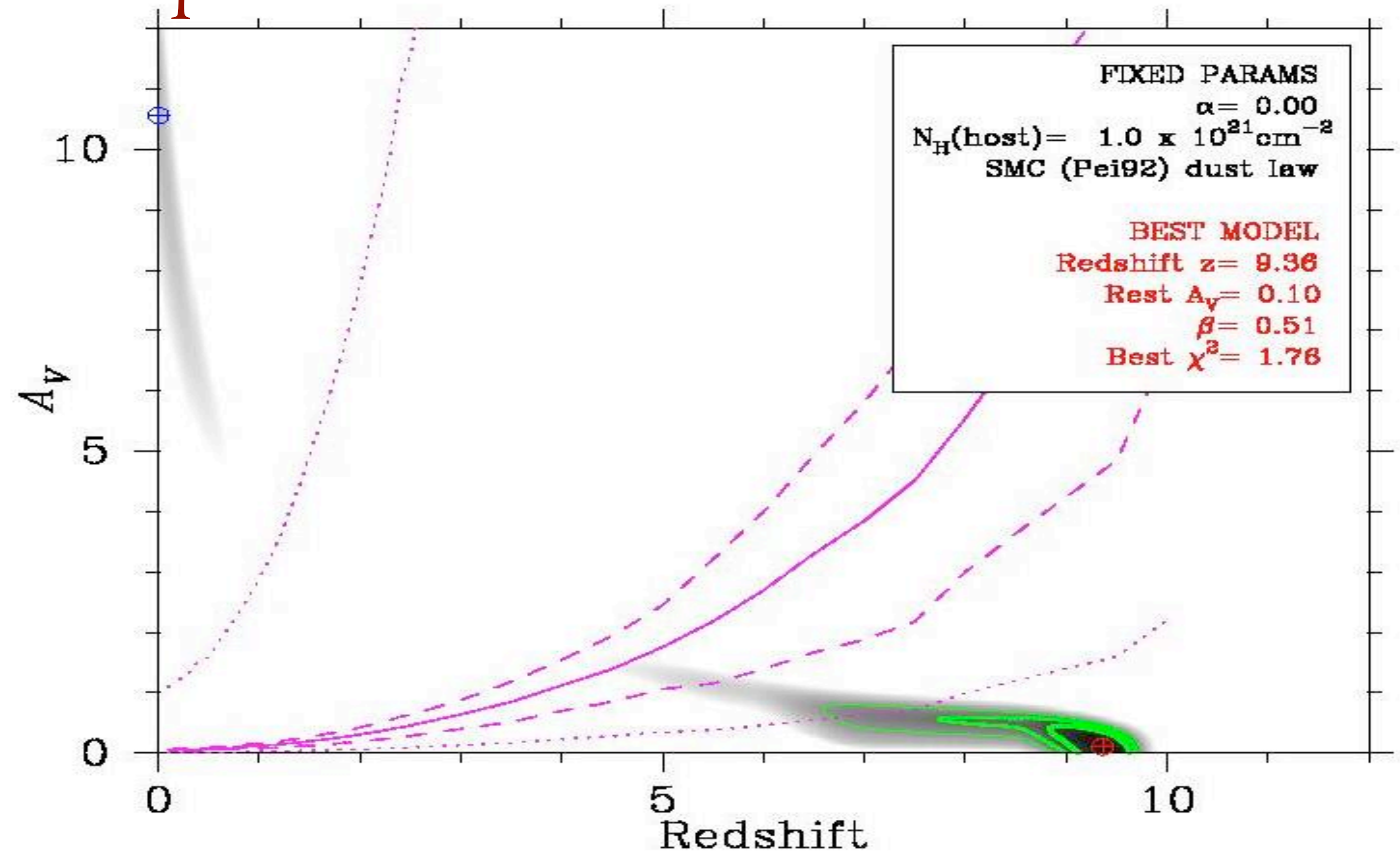


Thursday, May 24, 2012

GRB 090429B at z~9.4



photometric redshift of z=9.4



Cucchiara et al. 2011

what have we learned?

1. they are observable with current facilities even at extreme redshifts

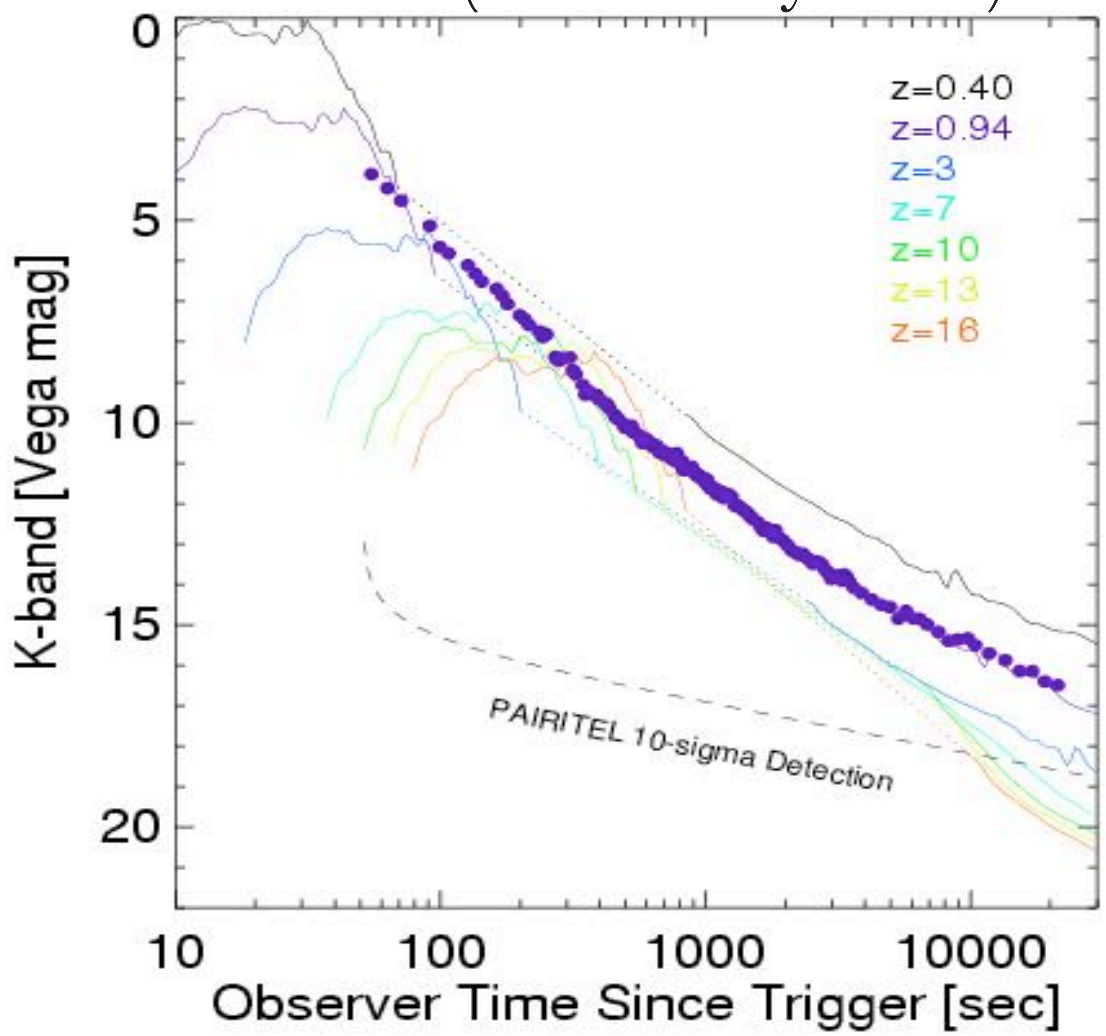
1.a GRB 050904 was firstly imagined by TAROT (25cm)

1.b GRB 050904 spectrum at 3.4 days but has sufficient S/N to measure metallicity at z=6.3. The first night the afterglow was >2 mag. brighter

1.c GRB 090423 spectrum was obtained with a medium class telescope (TNG)

1.d GRB 080913B at z=0.94 reached V~5. In principle observable even at z=20

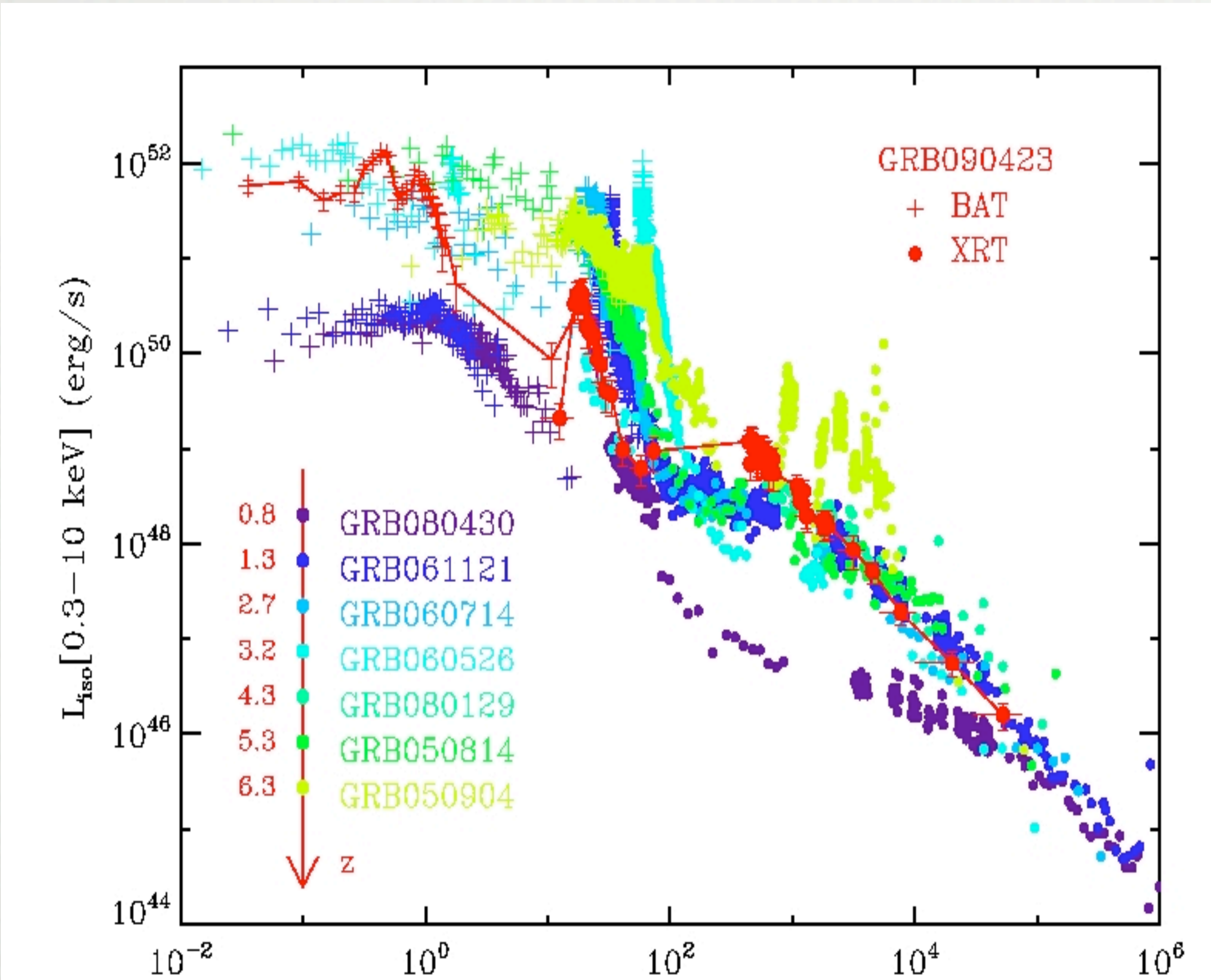
080319B (the naked-eye GRB)



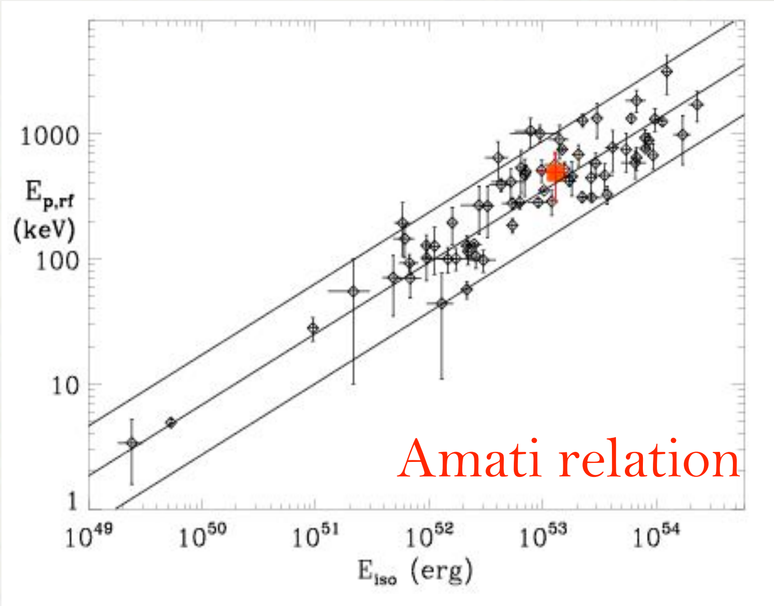
observable with 1m-class telescopes up to z=16

what have we learned?

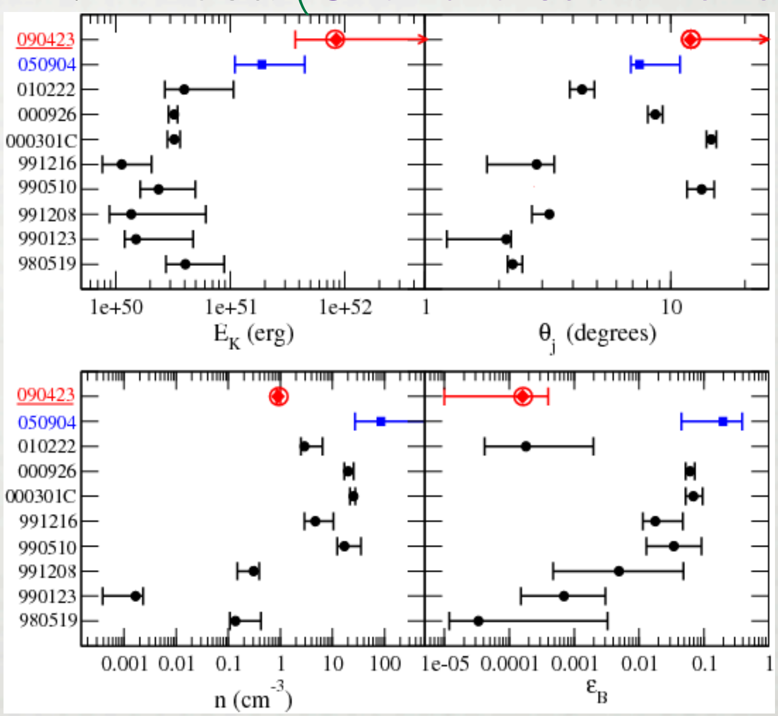
2. high-z GRBs are similar to low- and intermediate-z ones



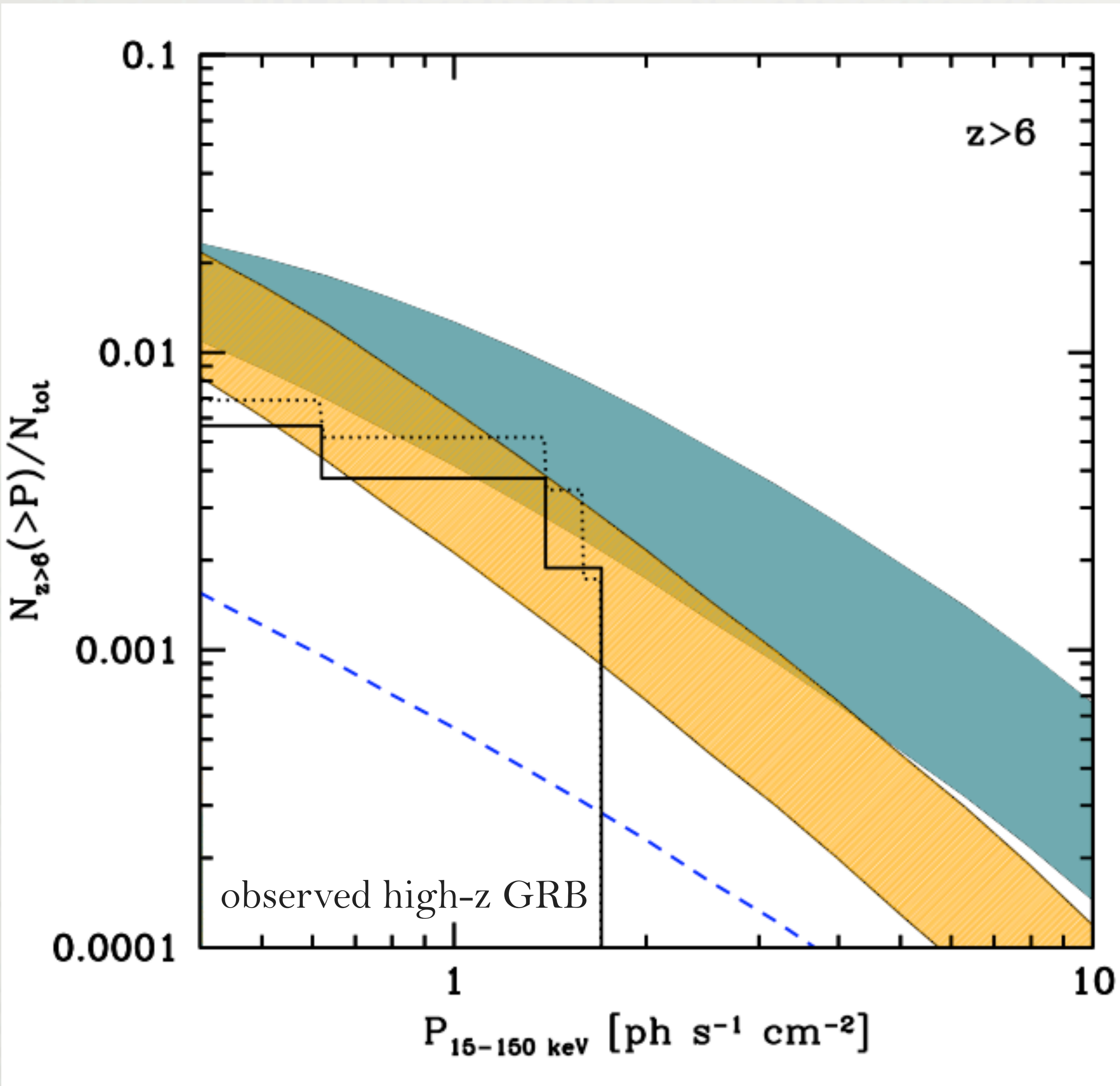
Salvaterra et al. 2009



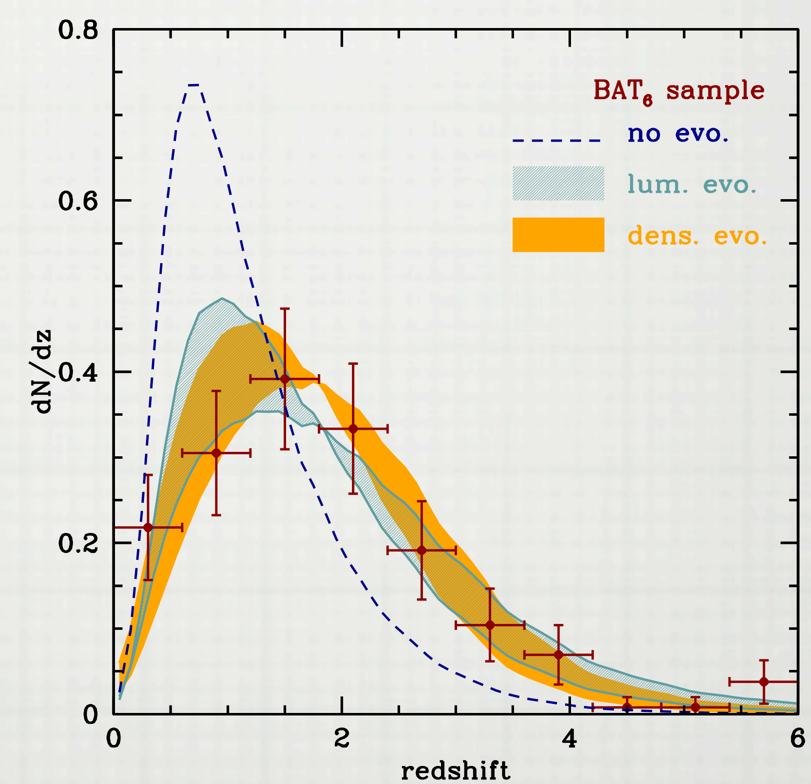
VLA obs. (Chandra et al. 2010)



high-z GRB rate



models are calibrated on z-distr. of a complete sample of bright GRBs



predictions are consistent with the detected high-z GRBs

Salvaterra et al. 2012

exploring the high-z Universe with GRBs

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)
- ☐ identify and study high-z galaxies responsible for the reionization
- ☐ direct detection of PopIII stars (Komissarov & Barkov 2009; Mezsaros & Rees 2010; Toma et al. 2011; Campisi et al. 2011; deSouza et al. 2011)
- ☐ enrichment by PISN: indirect PopIII detection
- ☐ measuring the SFRD at very high-z (Yueksel et al. 2008; Kistler et al. 2010; Ishida et al. 2011; Grieco et al. 2012)
- ☐ probe the intergalactic radiation field (Inoue et al. 2010)
- ☐ constraints on DM (Mesinger et al. 2005)
- ☐ …

see also McQuinn et al. 2010 White Paper for the Decadal Survey

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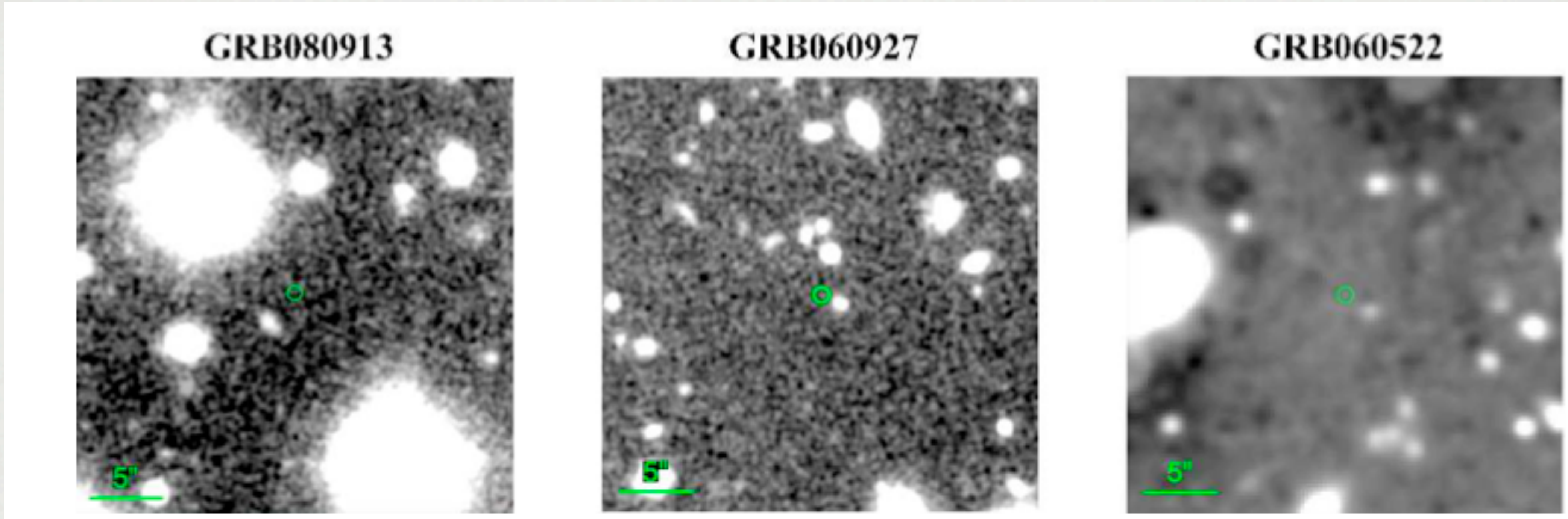
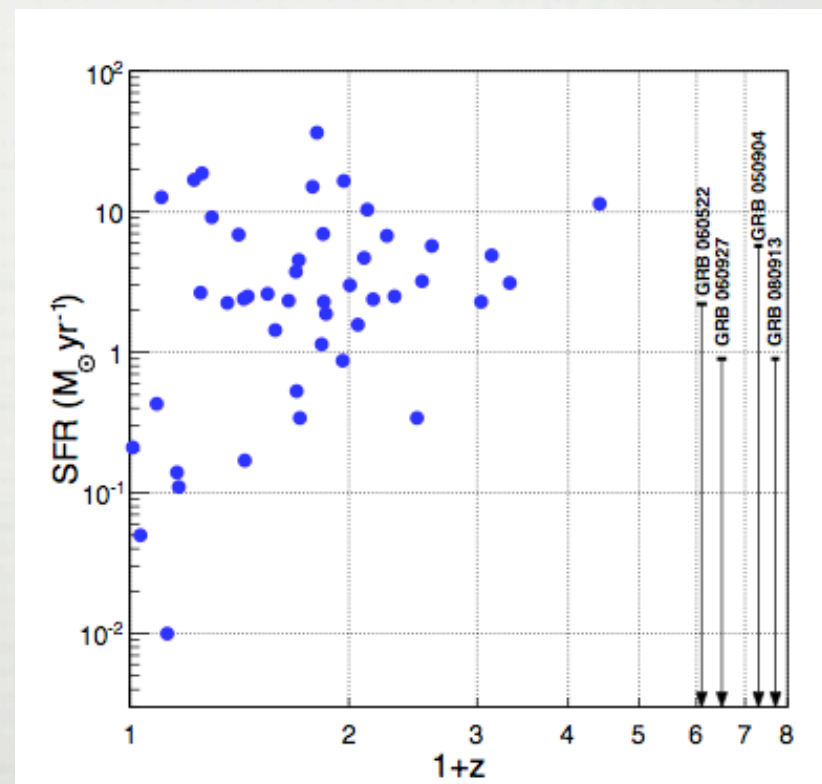
VLT search of high-z hosts



Host galaxy	Redshift	$M_{1500Å}$	SFR
GRB 080913	6.7	> -19.4	< 0.9 $M_{\odot}\ yr^{-1}$
GRB 060927	5.5	> -19.6	< 0.9 $M_{\odot}\ yr^{-1}$
GRB 060522	5.1	> -20.5	< 2.2 $M_{\odot}\ yr^{-1}$
GRB 050904[a]	6.3	> -20.7	< 5.7 $M_{\odot}\ yr^{-1}$

[a] From Berger et al. (2007).



only 6% probability for simultaneous non detection of the four high-z targets if they were similar to z<1 hosts

Basa et al. 2012

HST search of high-z hosts

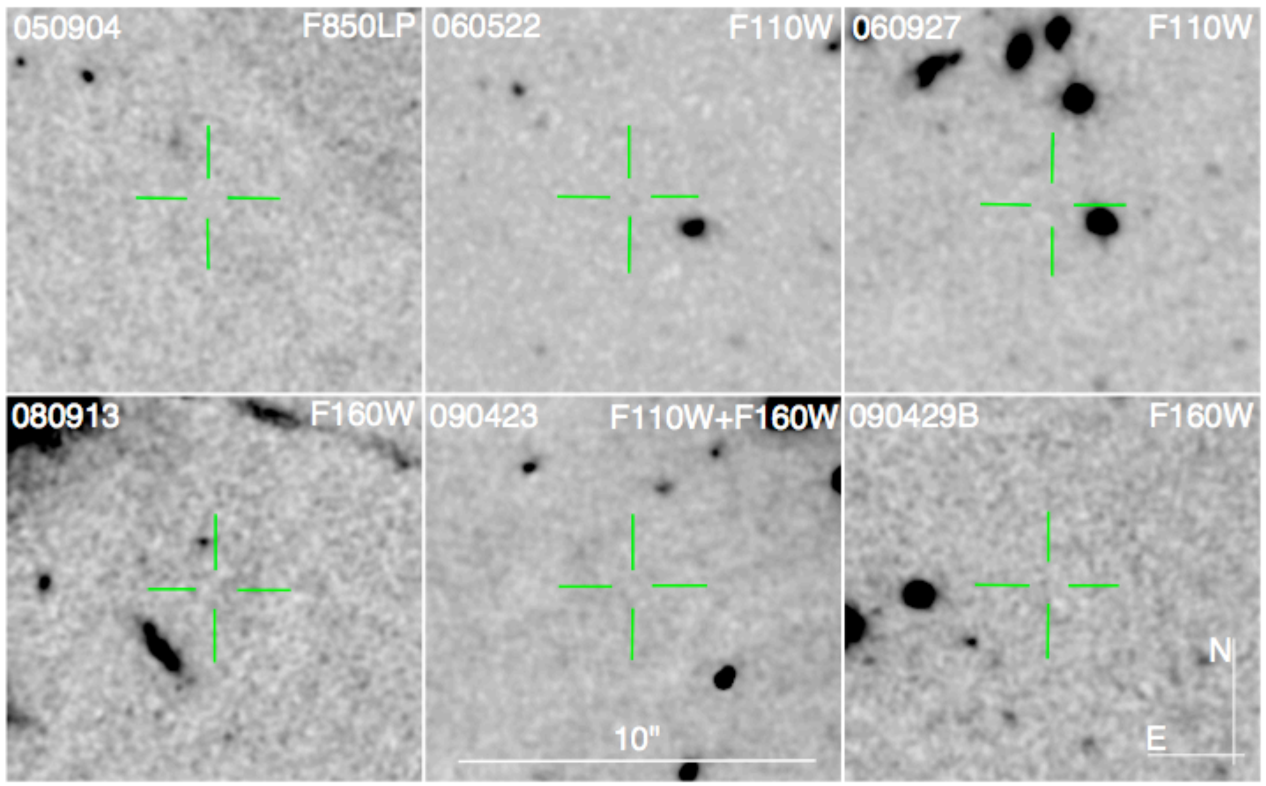
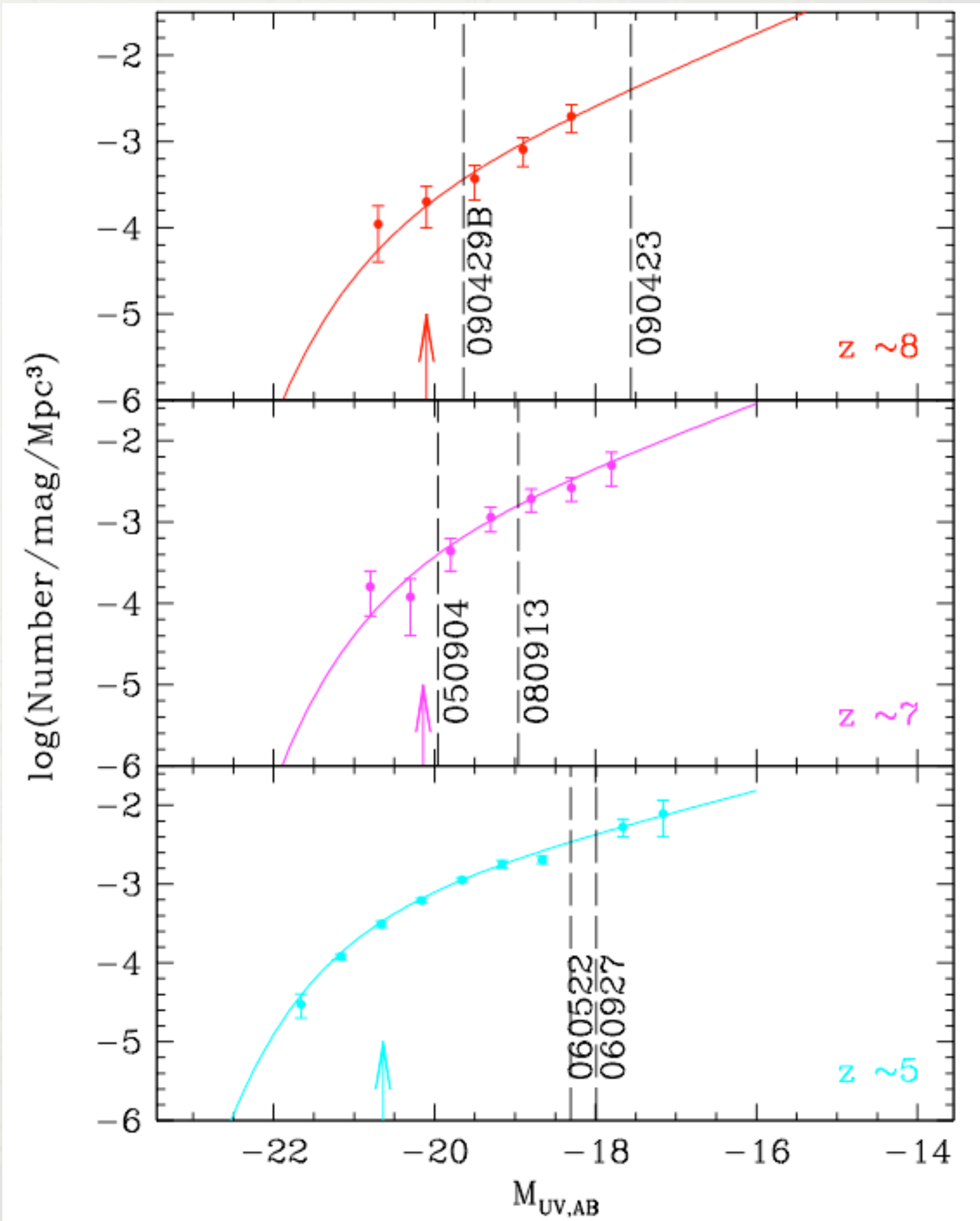


TABLE 2
LOG OF *HST* OBSERVATIONS OF THE HOST GALAXIES OF GRBS AT $z > 5$

Date	UT Time	Filter	$\lambda_{\rm rest}$(Å)	Exp (s)	$F_{\rm obs}$ (nJy)	AB mag limit	$M_{\lambda/(1+z)}$
060522							
17 Oct 2010	10:30	F110W	1888	8395	7 ± 4	> 28.13	> −18.35
060927							
29 June 2007	11:30	F160W	2396	10240	7 ± 5	> 27.75	> −18.84
25 Sept 2010	14:30	F110W	1783	13992	4 ± 3	> 28.57	> −18.02
050904							
26 Sept 2005	21:03	F850LP	1279†	4216	-9 ± 30†	> 26.86	> −19.95
080913							
30 Nov 2009	16:10	F160W	1996	7818	3 ± 6	> 27.92	> −19.00
090423							
24 Jan 2010	11:34	F160W	1665	13029			
25 Jan 2010*	14:44	F160W	1665	13029	4 ± 3	> 28.36	> −18.88
26 Jan 2010*	13:06	F125W	1353	13029			
27 Jan 2010*	13:04	F125W	1353	13029			
22 Oct 2010	18:23	F125W	1353	13029			
27 Oct 2010	16:36	F125W	1353	13029	-2 ± 2	> 30.29	> −16.95
090429B							
22 Feb 2010	19:22	F160W	1480	2412	7 ± 5	> 27.78	> −19.65



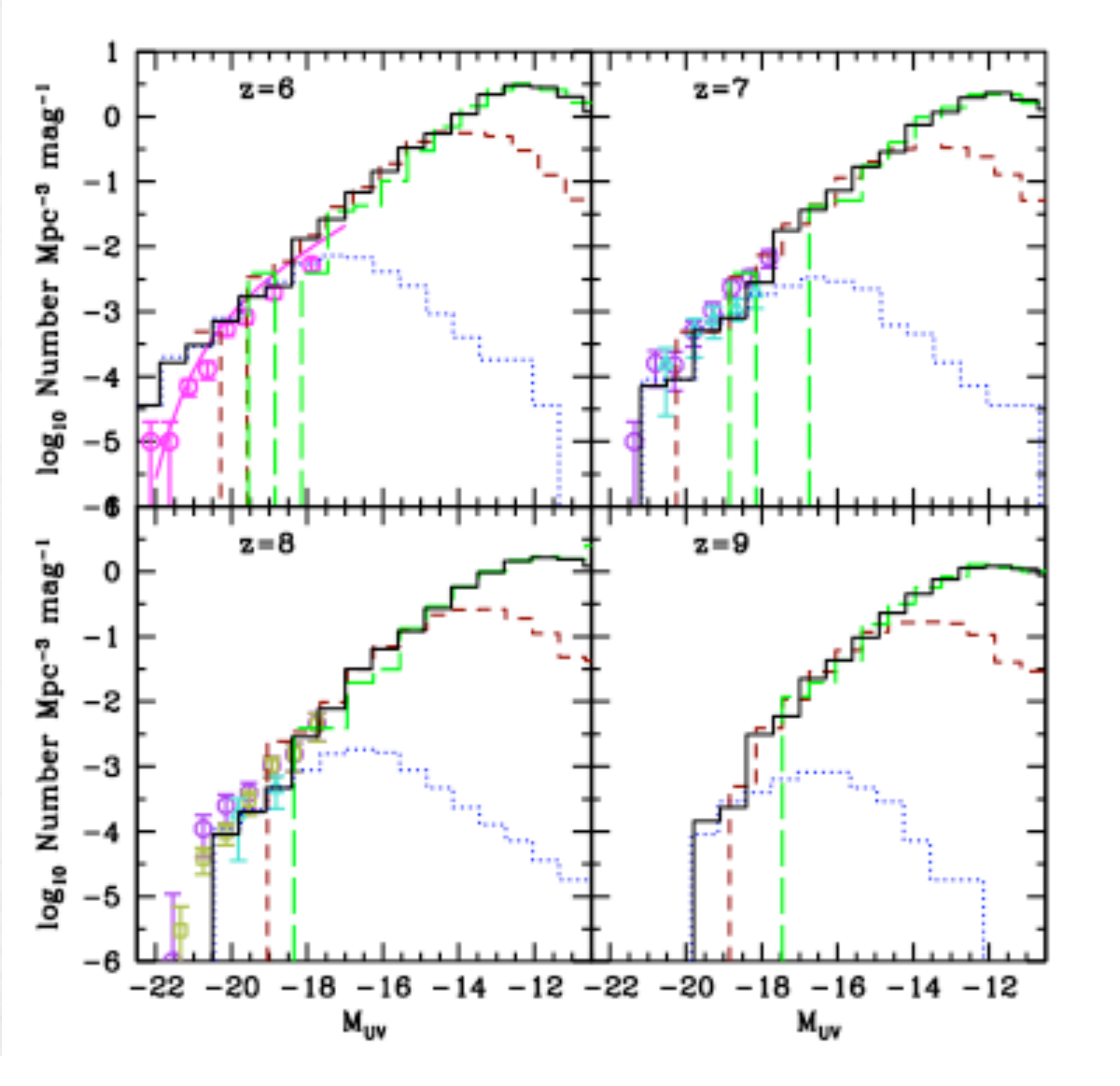
Tanvir et al. 2012

simulated high-z GRB hosts

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)

the simulation provides a good description of the galaxy LF at all redshift without any fine-tuning of the parameters

the probability to host a GRB is assumed to be proportional to the young stellar mass content $t_{age}<10^7$ yr



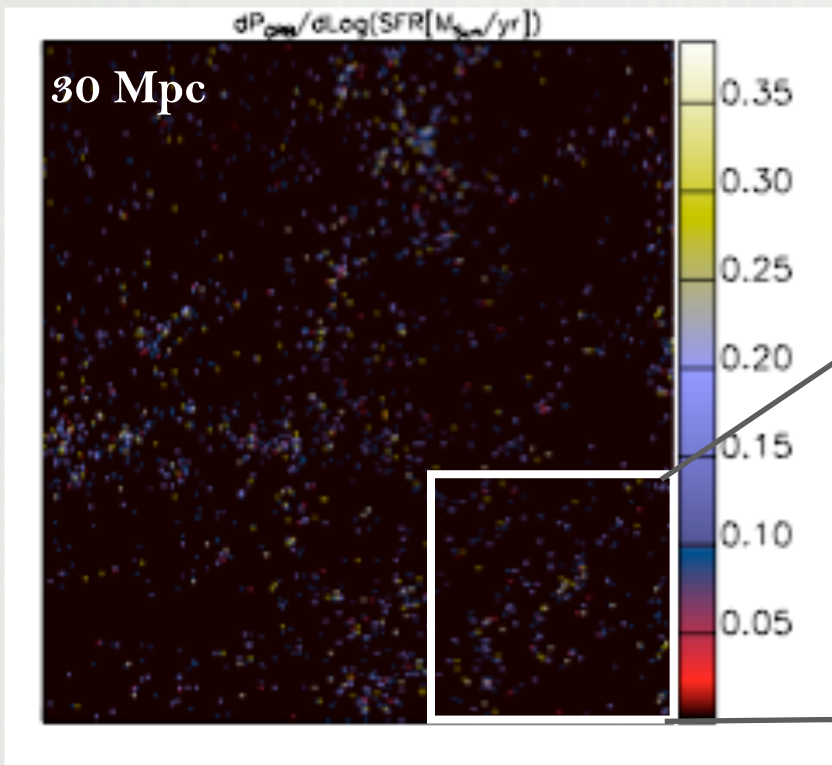
simulation parameters

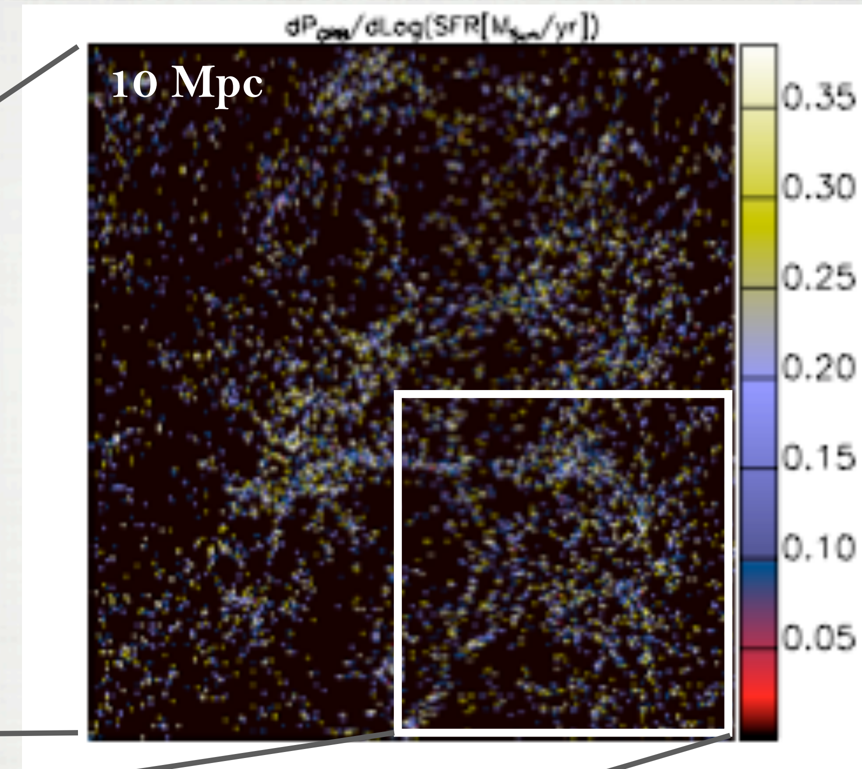
Box side [Mpc/h]	Gas particle mass [$M_\odot/h$]	Dark-matter particle mass[$M_\odot/h$]	Physical softening [kpc/h]	Log(SFR) [$M_\odot yr^{-1}$]
30	9×10^6	6×10^7	4.7	> 0
10	3×10^5	2×10^6	1.0	$[-1.5, 0]$
5	4×10^4	3×10^5	0.5	< -1.5

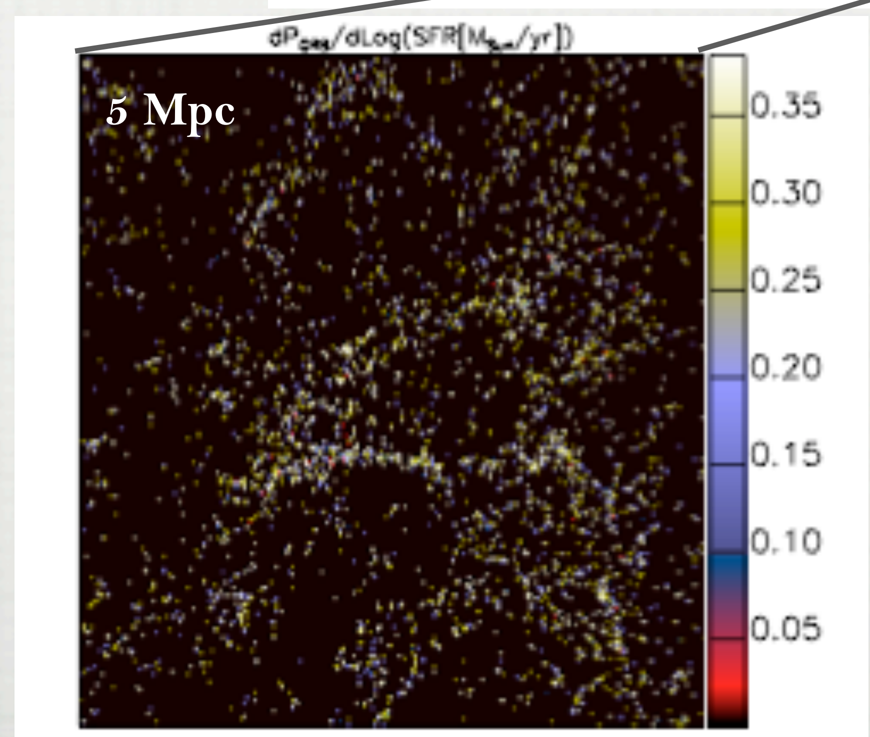
Maio et al. 2009, 2010, 2011

Salvaterra et al. in prep.

simulated high-z GRB hosts



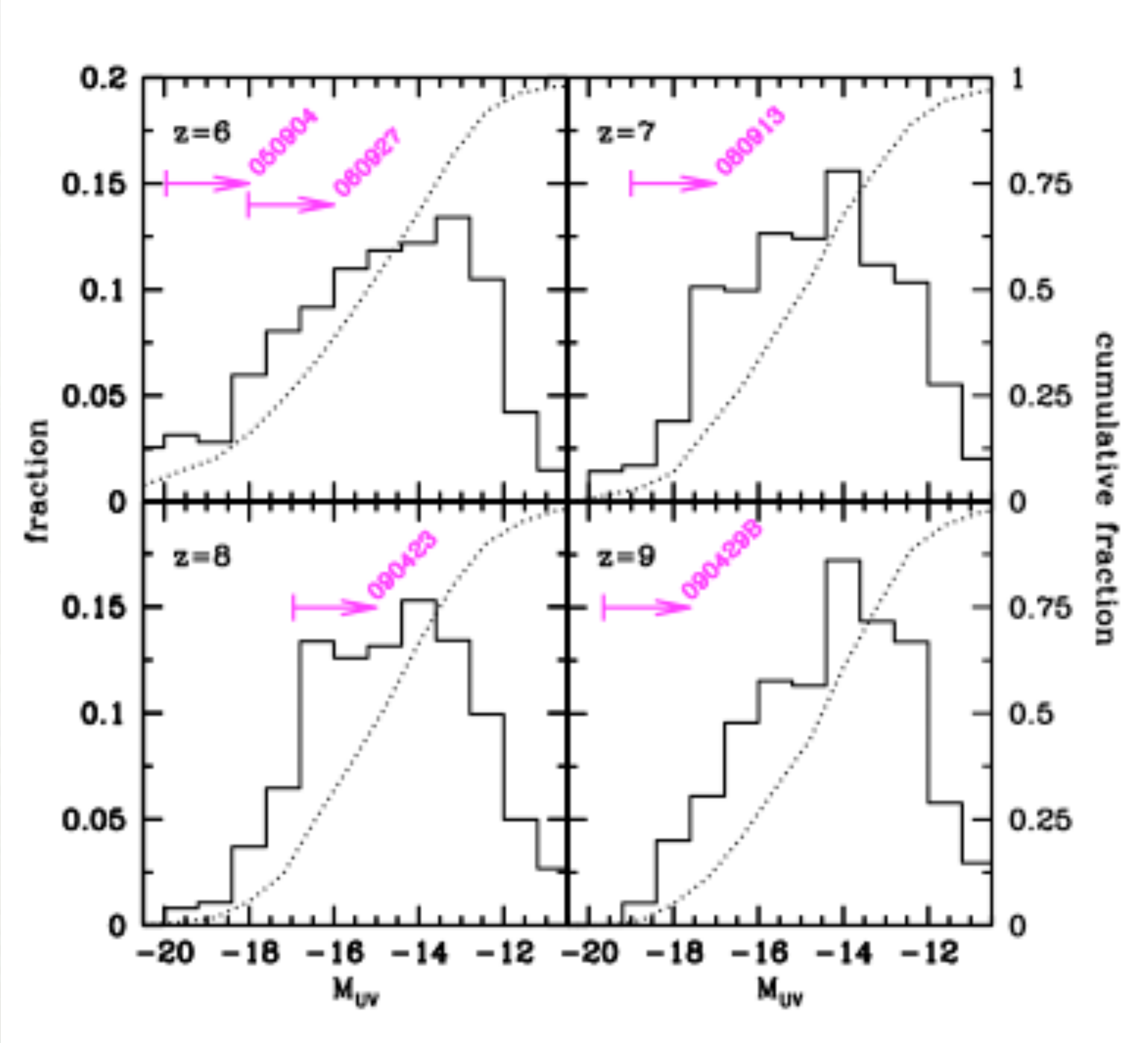




the color scale refers to the global probability to find a GRB hosted in a galaxy of given Muv from red (low prob.) to yellow (high prob.)

Salvaterra et al. in prep.

simulated high-z GRB hosts

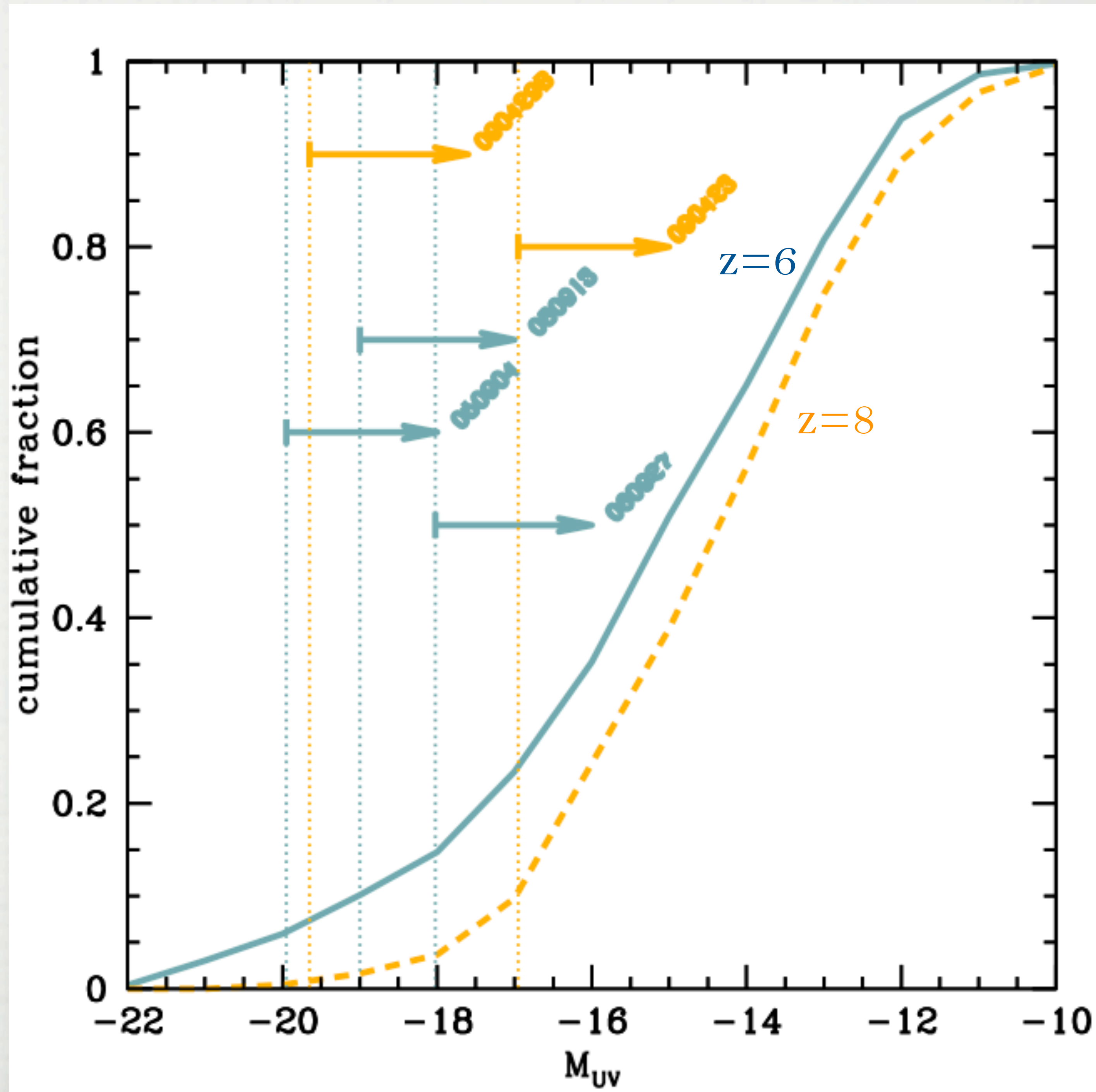


simulations are consistent with non detection of high-z GRB host with HST/VLT

Salvaterra et al. in prep.

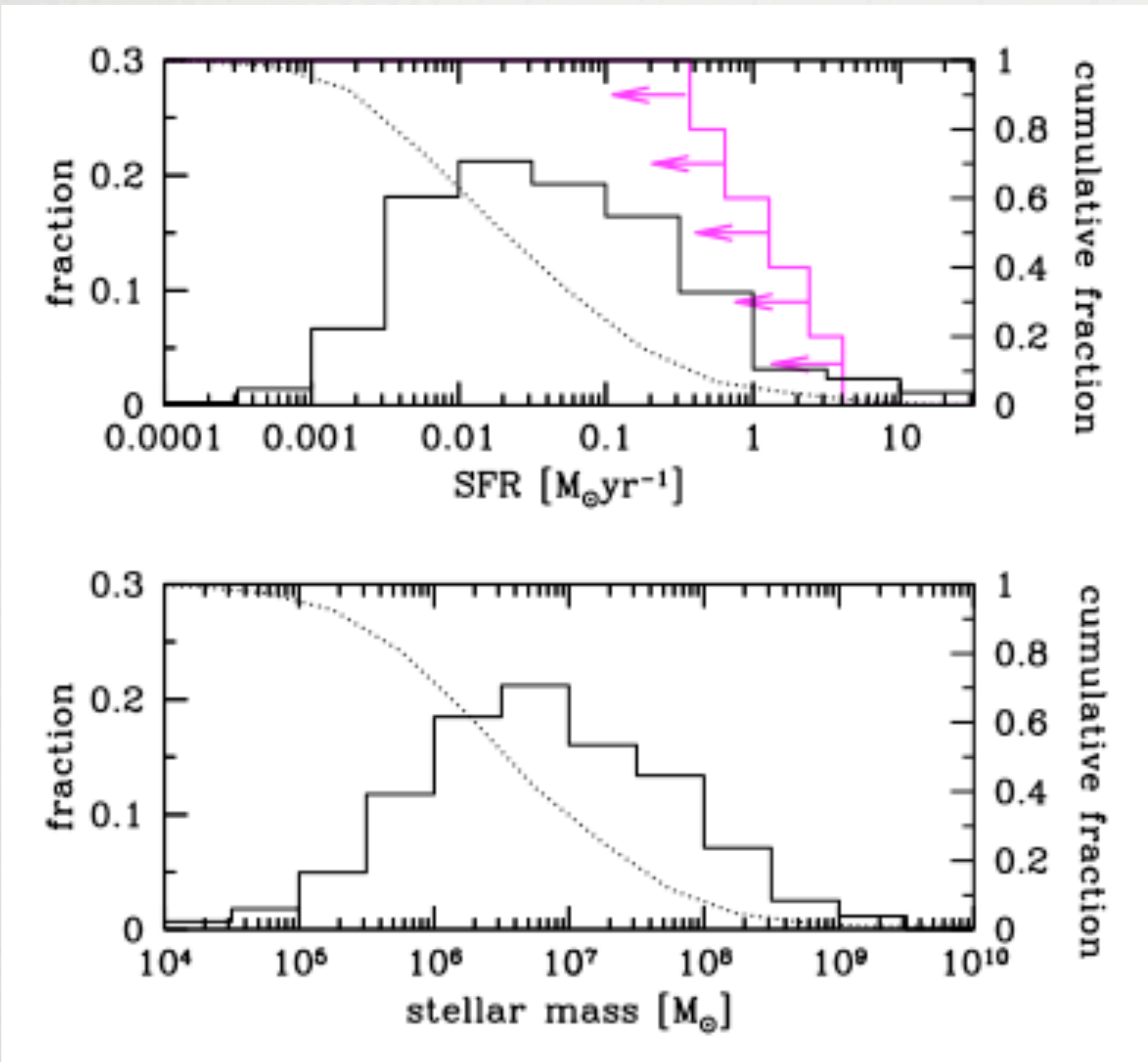
high-z hosts: reionization sources

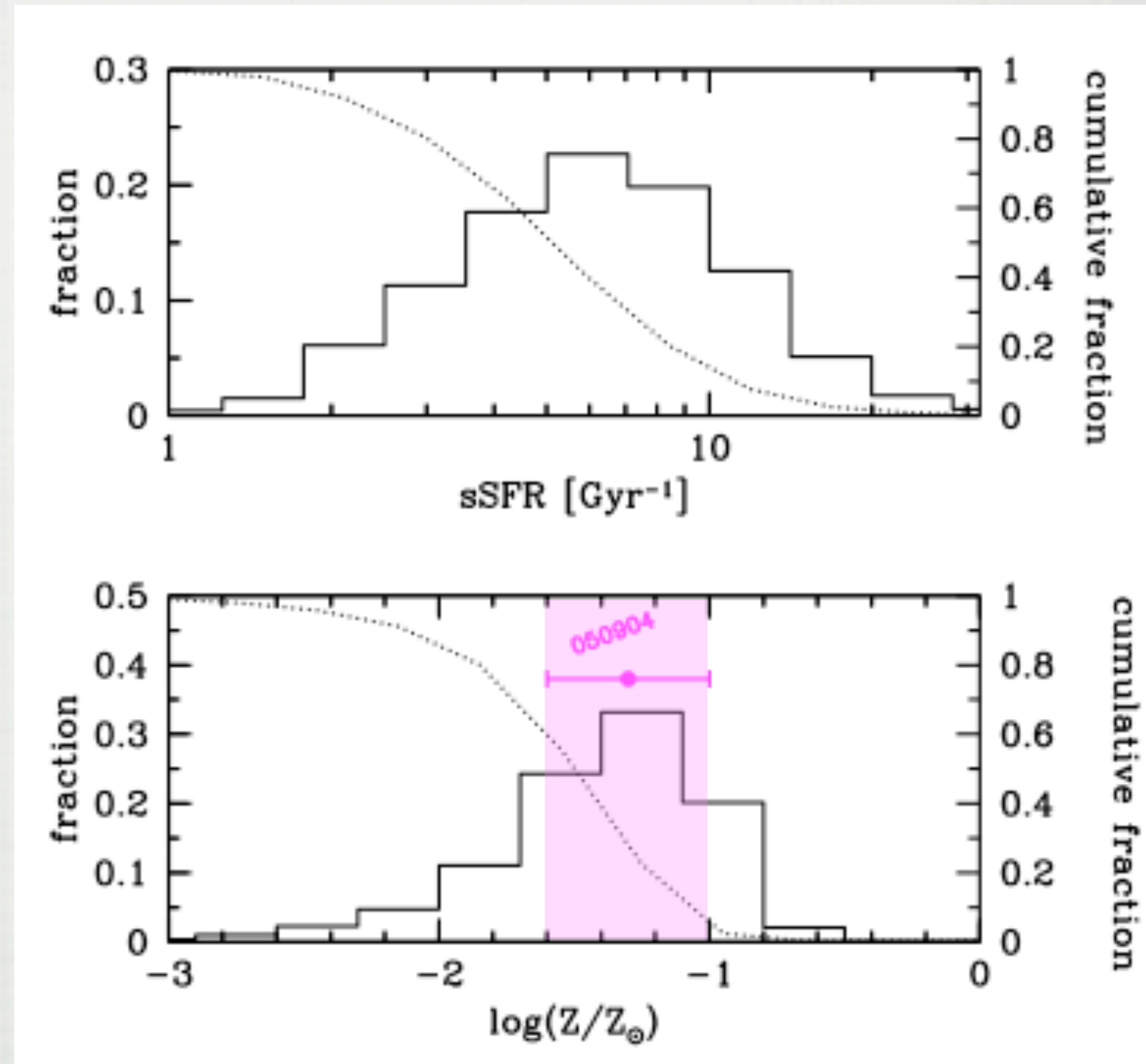
normalized production of ionizing photons from galaxies brighter than M_{UV}



Salvaterra et al. in prep.

high-z host physical properties

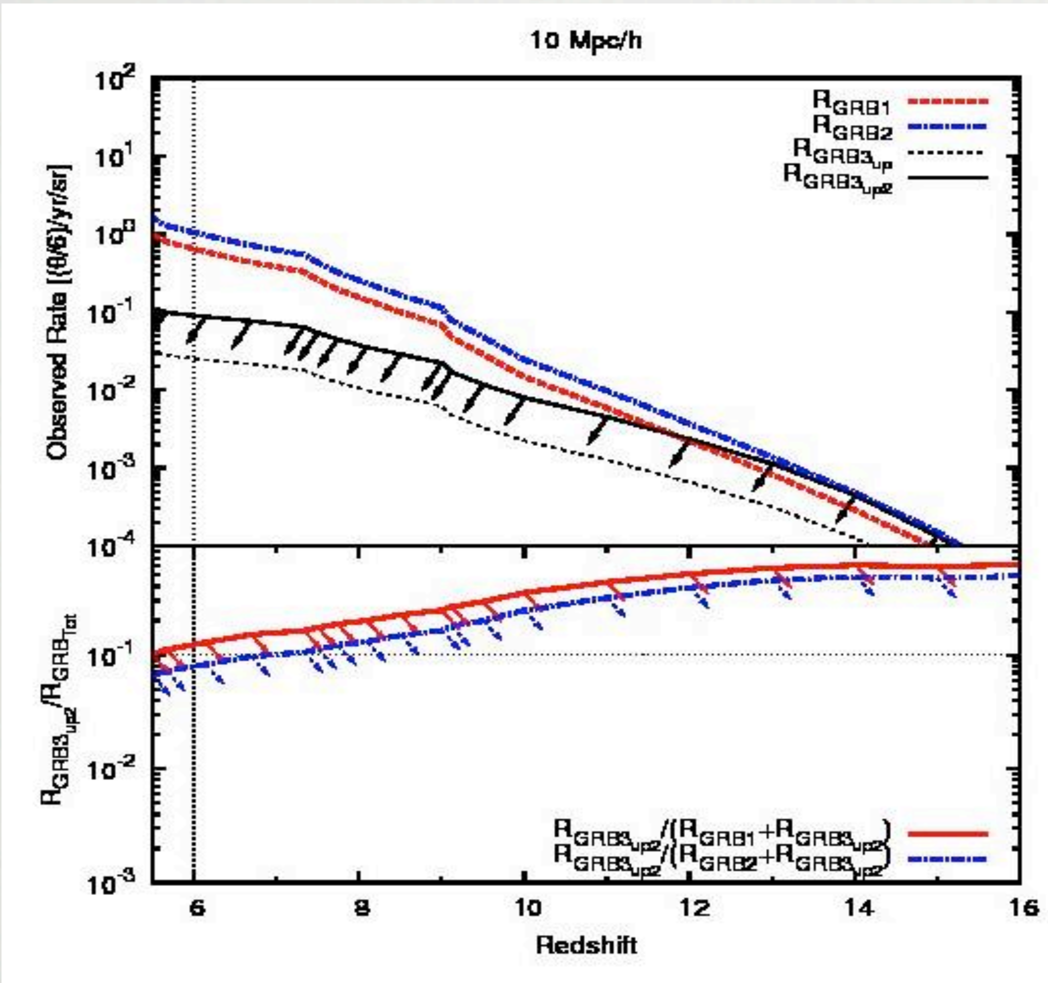




typical GRB hosts at z=6-10: SFR~0.01-0.3 Msun/yr, stellar masses $M_* \sim 10^6$-10^8 Msun, sSFR~3-10 Gyr^{-1} and Z~0.01-0.1 Zsun

Salvaterra et al. in prep.

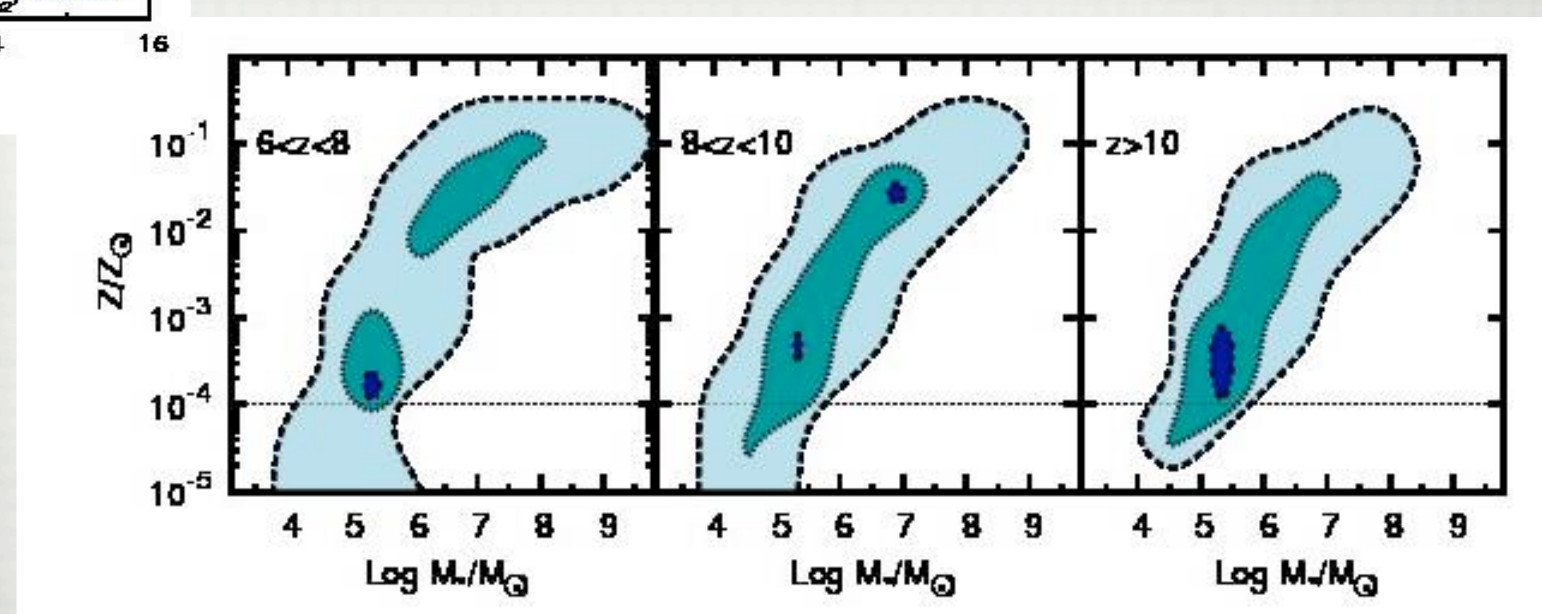
PopIII GRBs



assumes Lp~$10^{53\text{-}54}$ erg/s (Fryer et al. 2001, Komissarov & Barkov 2009, Mezsaros & Rees 2010, Toma et al. 2011, Suwa et al. 2011)

PopIII GRBs detection probability goes from 10% at z=6 to 50% at z=10

expected hosts

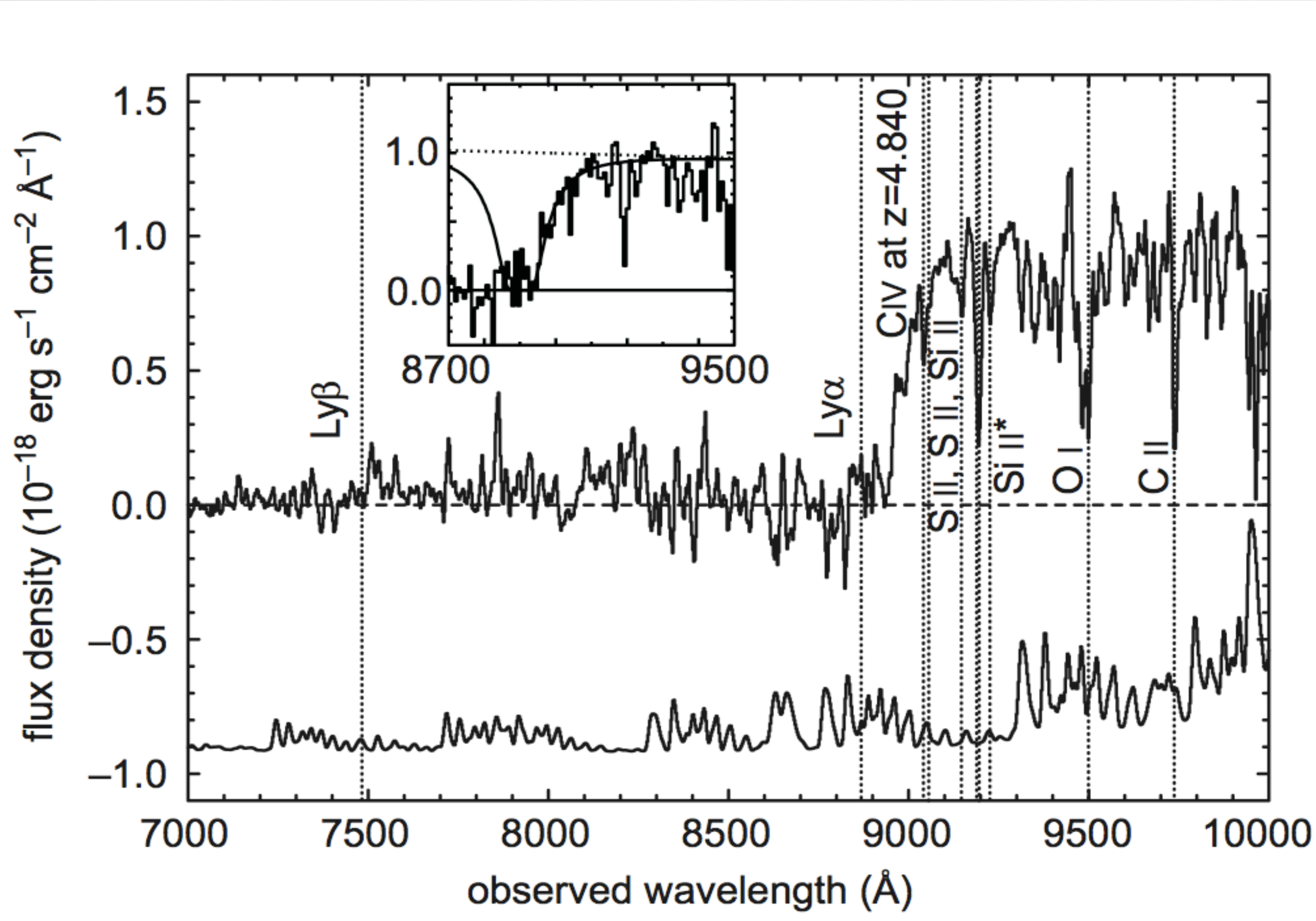


how can we distinguish between PopIII and PopII GRBs?

Campisi et al. 2011

constraining reionization

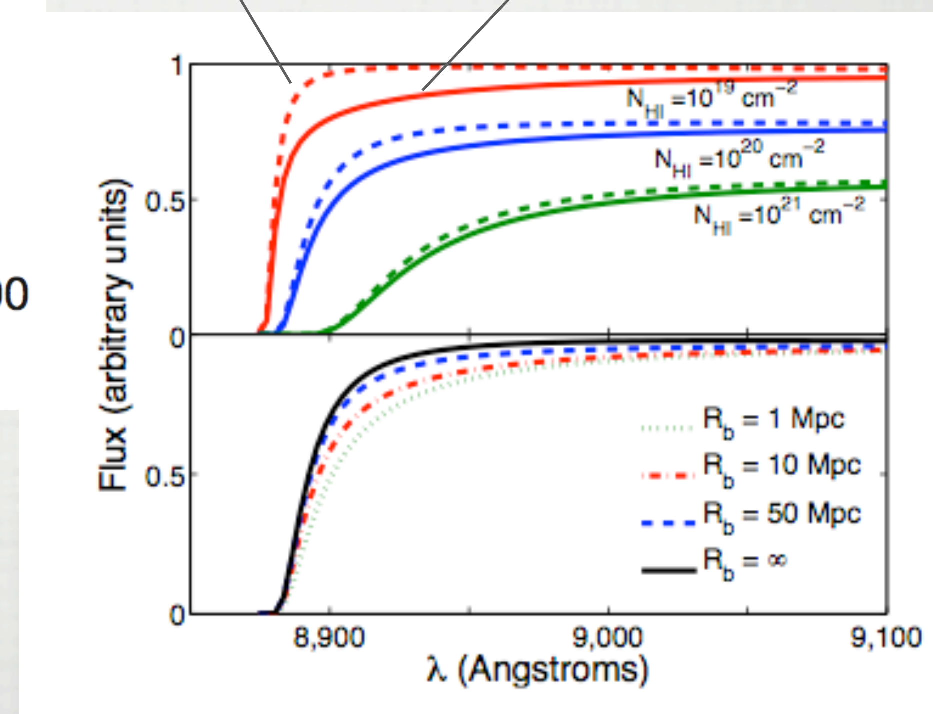
constraining the reionization history I



Kawai et al. 2005; Totani et al. 2006

x_{HI}<0.17

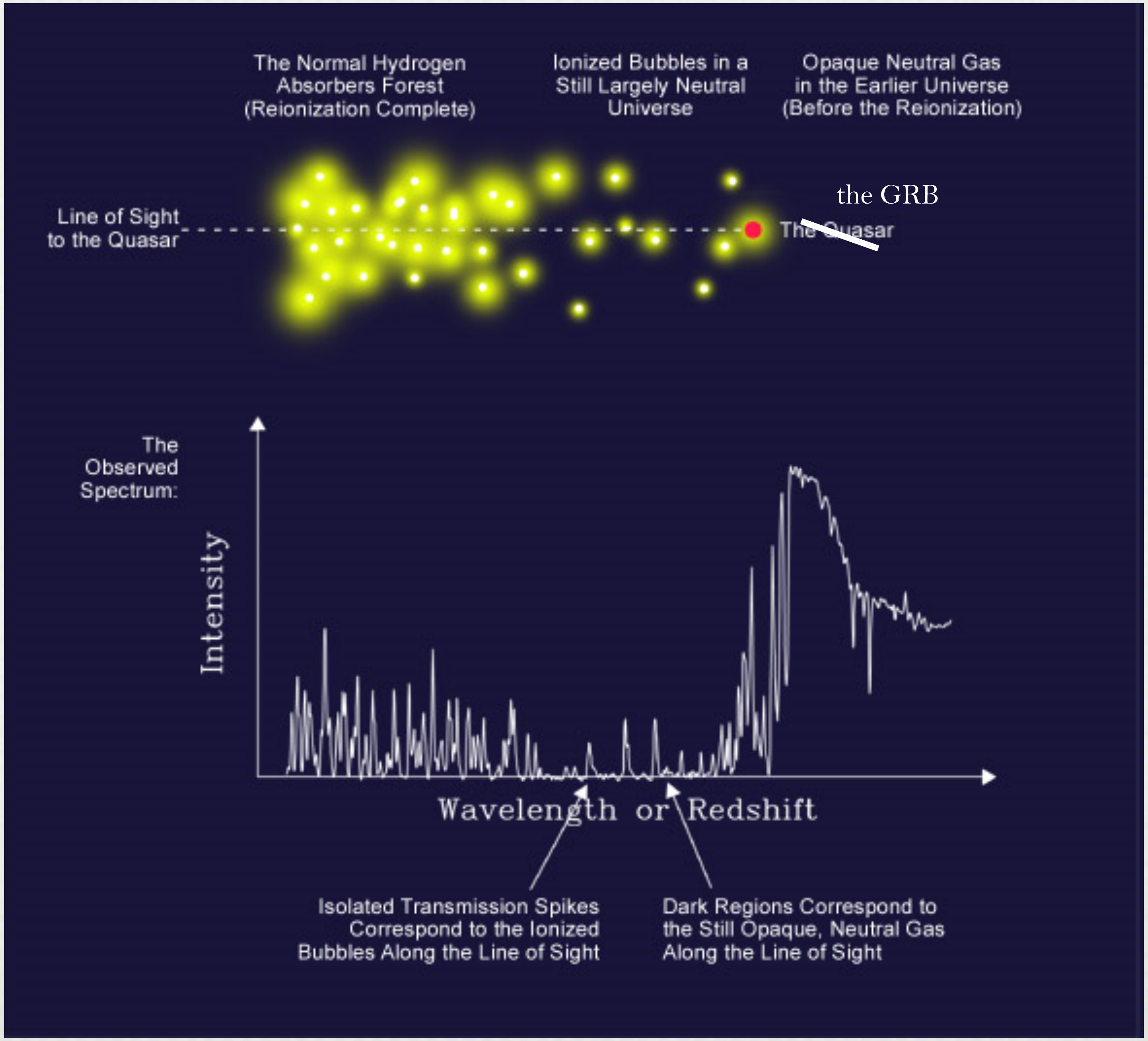
half ion. fully ion.



McQuinn et al. 2009

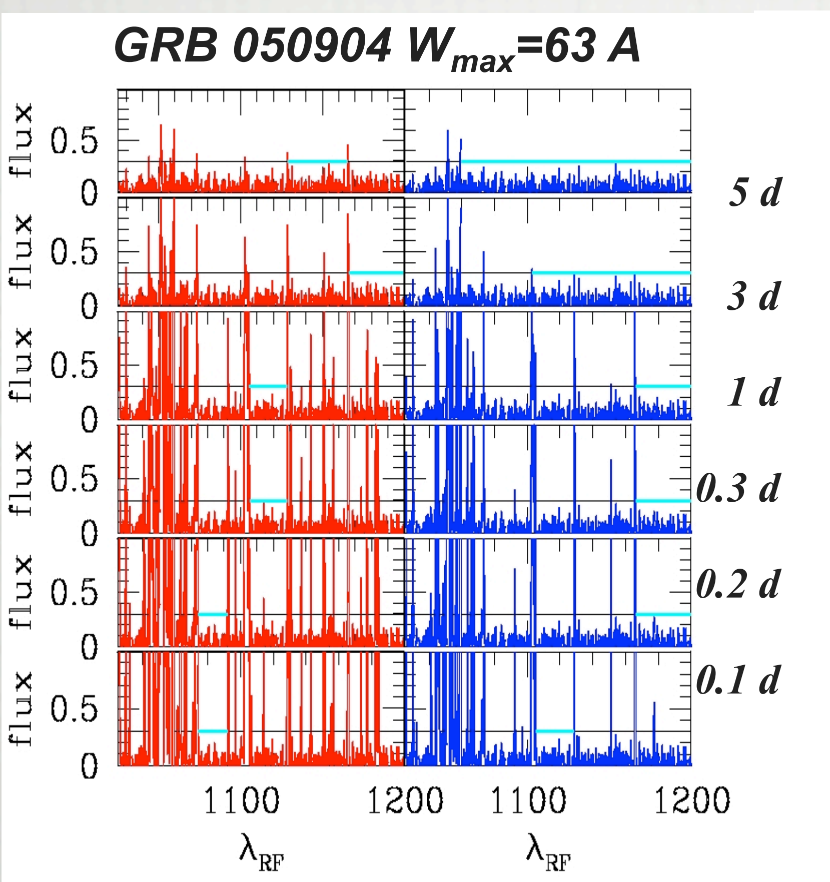
~20-30% of DLAs have log(N_{HI})<20 cm^{-2}
small enough to provide reliable constrains
to the IGM HI neutral fraction

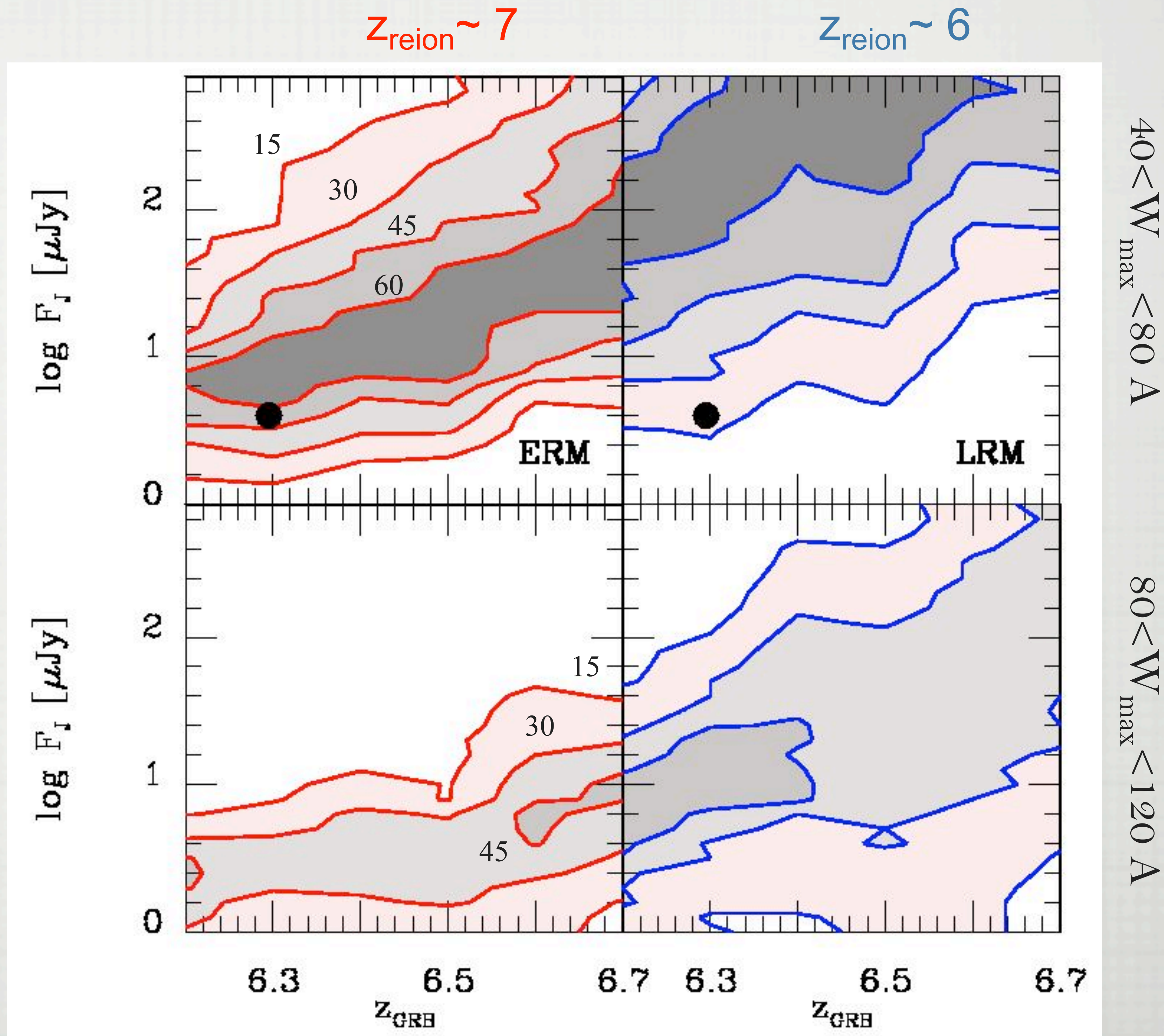
constraining the reionization history II



constraining the reionization history II

The dimension of the largest dark gap in the afterglow spectrum between Lya and Lyb can help to constrain the reionization history





Gallerani et al. 2008

conclusions

- three spectroscopically confirmed z>6 GRBs + one photometric
  - detectable at extreme high-z and similar to low-/intermediate-z ones
- 1-3% of all GRBs detected by Swift should be at z>6
- high-z GRBs are a fundamental tool to study the high-z Universe and the fundamental transition expected to occur in the cosmic dark-ages
  - GRB hosts are the signpost of galaxies responsible of the re-ionization process missed even in deepest HST/WFC3 observations
  - simulated hosts: typically SFR=0.01-0.3 Msun/yr, $M_*=10^{6-8}$ Msun, sSFR=3-10 Gyr^{-1} and Z=0.01-0.1 Zsun in lines with available constraints
  - PopIII GRBs are one of the most promising way to detect the first stars
  - similar to quasar, GRBs can be used to constrain the reionization redshift