GRBs at z>6: an inside view of re-ionizing galaxies

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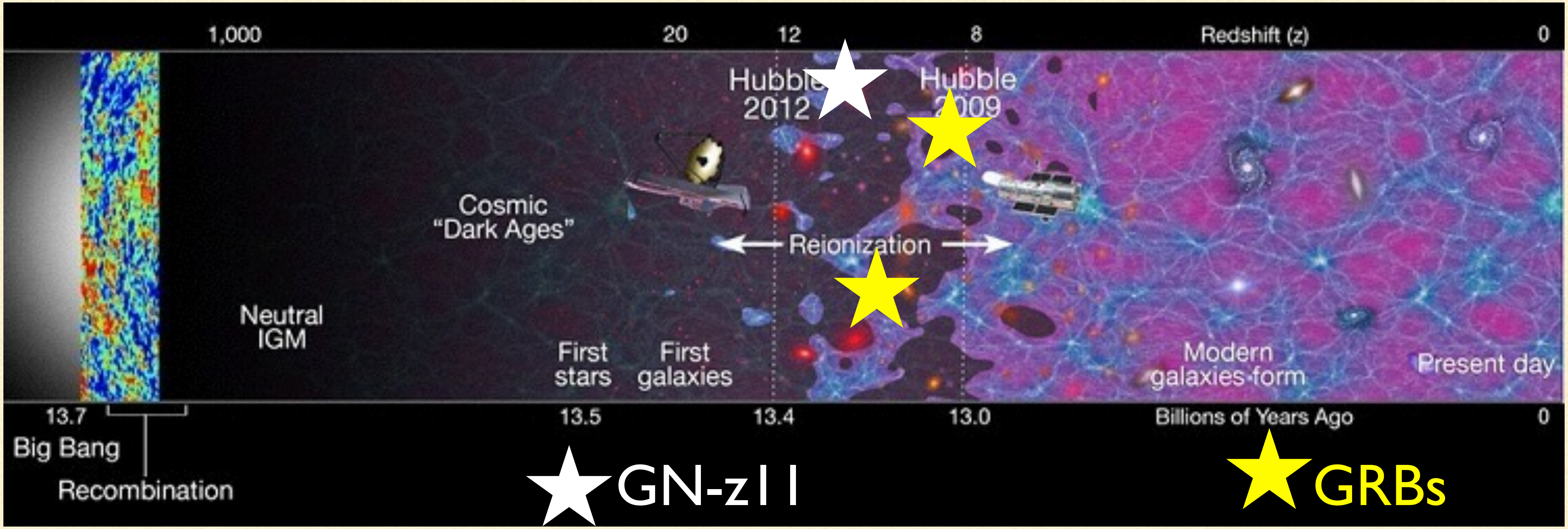
The Universe before JWST

HUDF, Frontier Fields have open a new window in the exploration of re-ionization

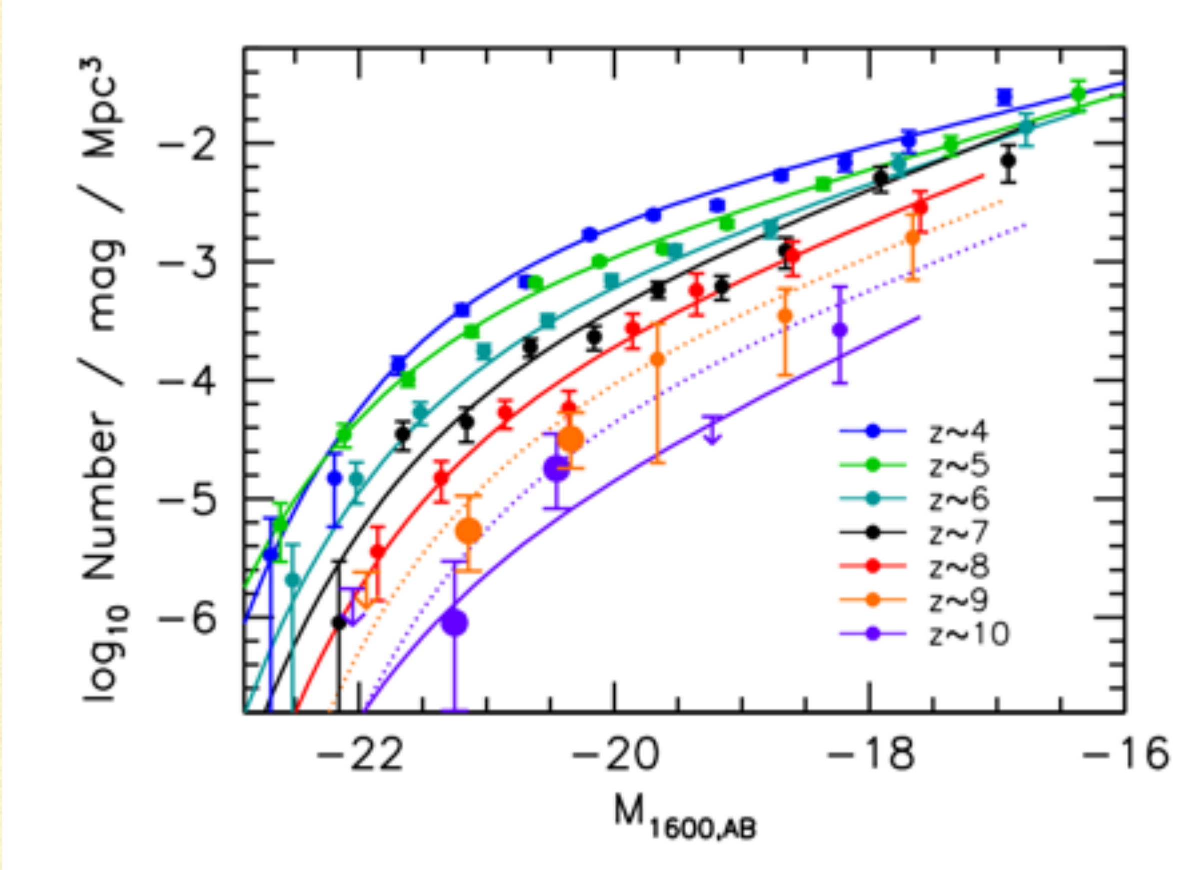


Mainly bright galaxies have been observed….maybe too bright…

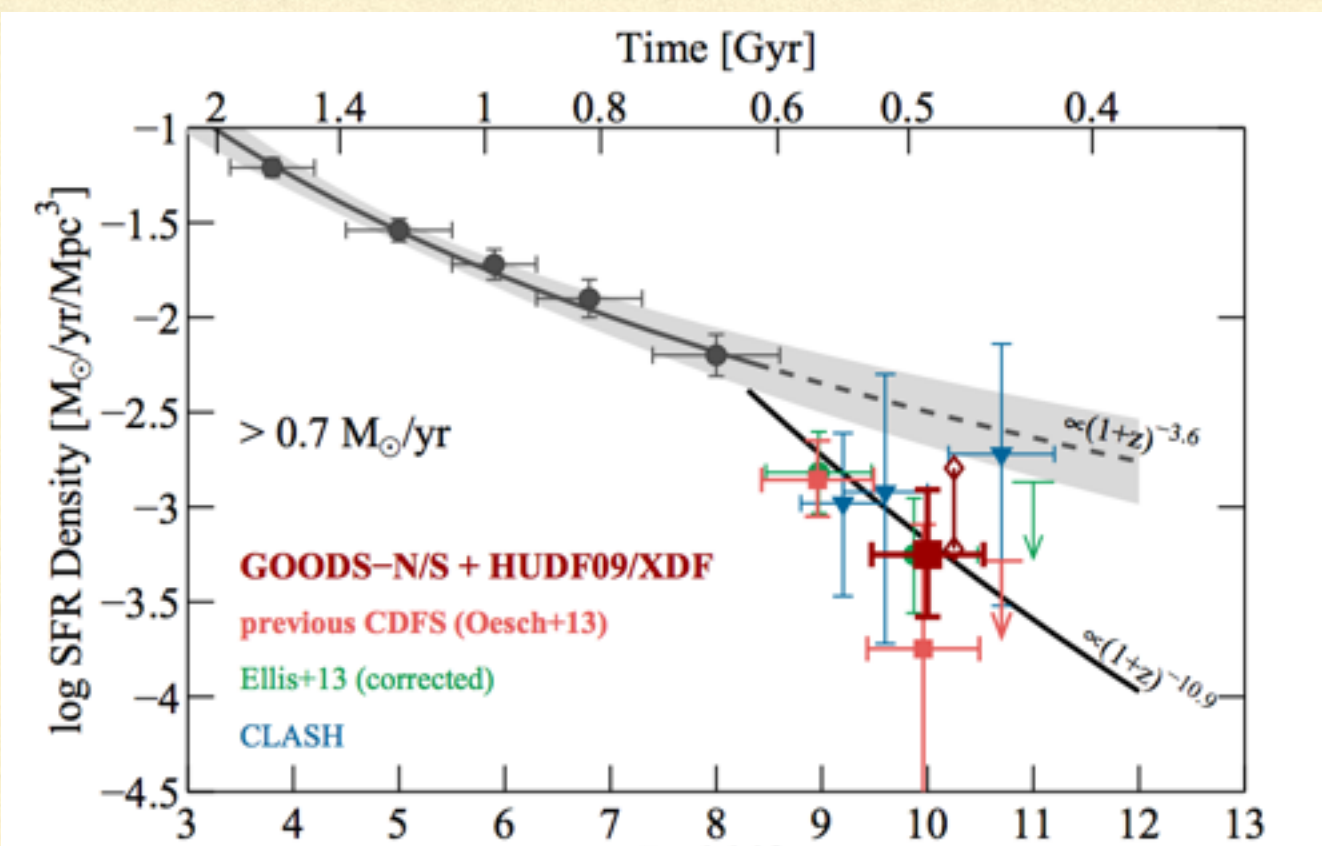
At the same time **Gamma-ray Bursts** have been identified at up to z=8, providing a new tool to identify high-z galaxy and test early epoch star formation

The Universe before JWST

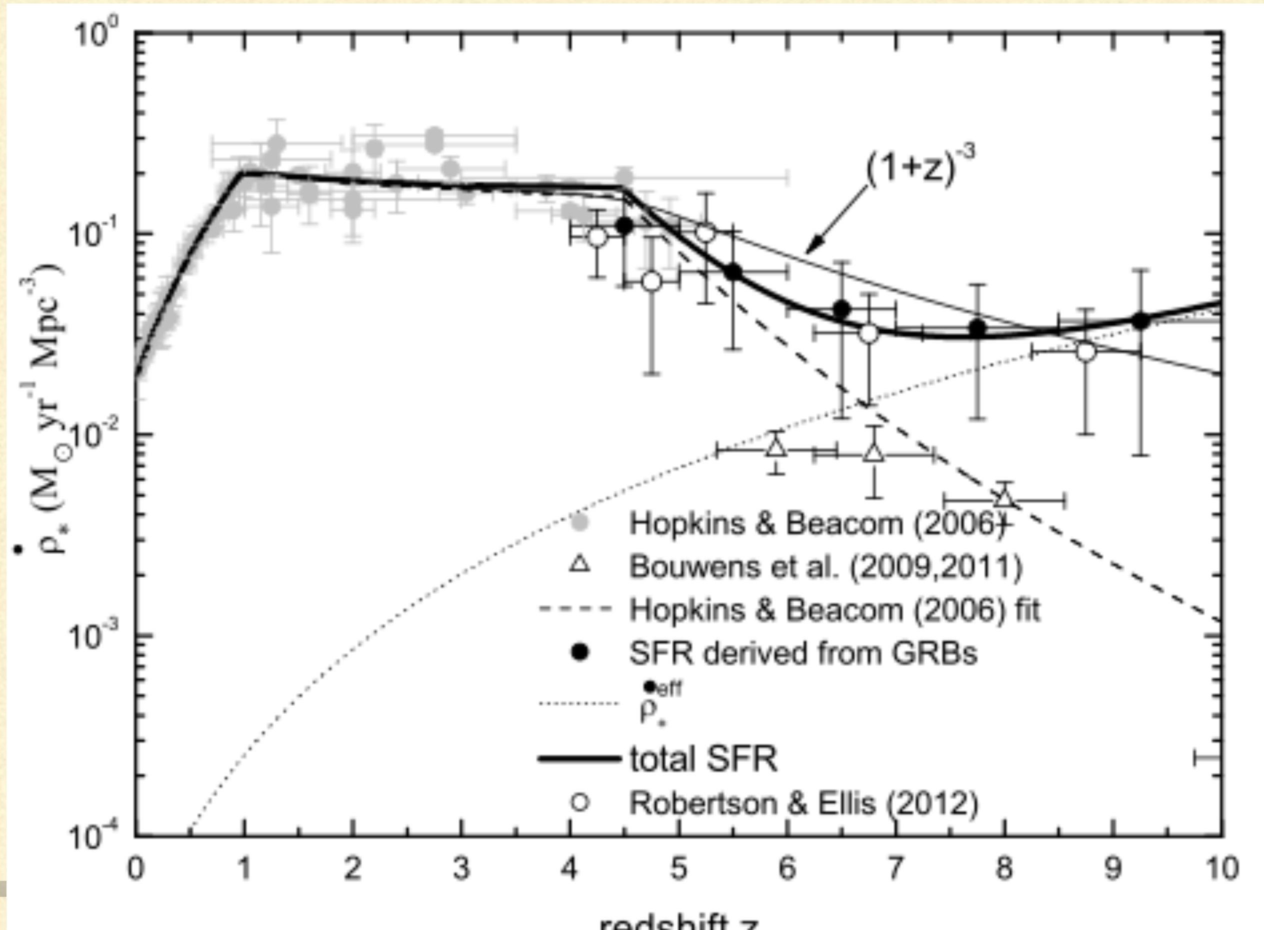
- After 25+ years of HST we are reaching the point of understand the nature galaxies at z>7
- Pushing the luminosity function at z~10
- Testing the SFR density models



Can we test the "behind the scene" actors of Star-formation/reionization?

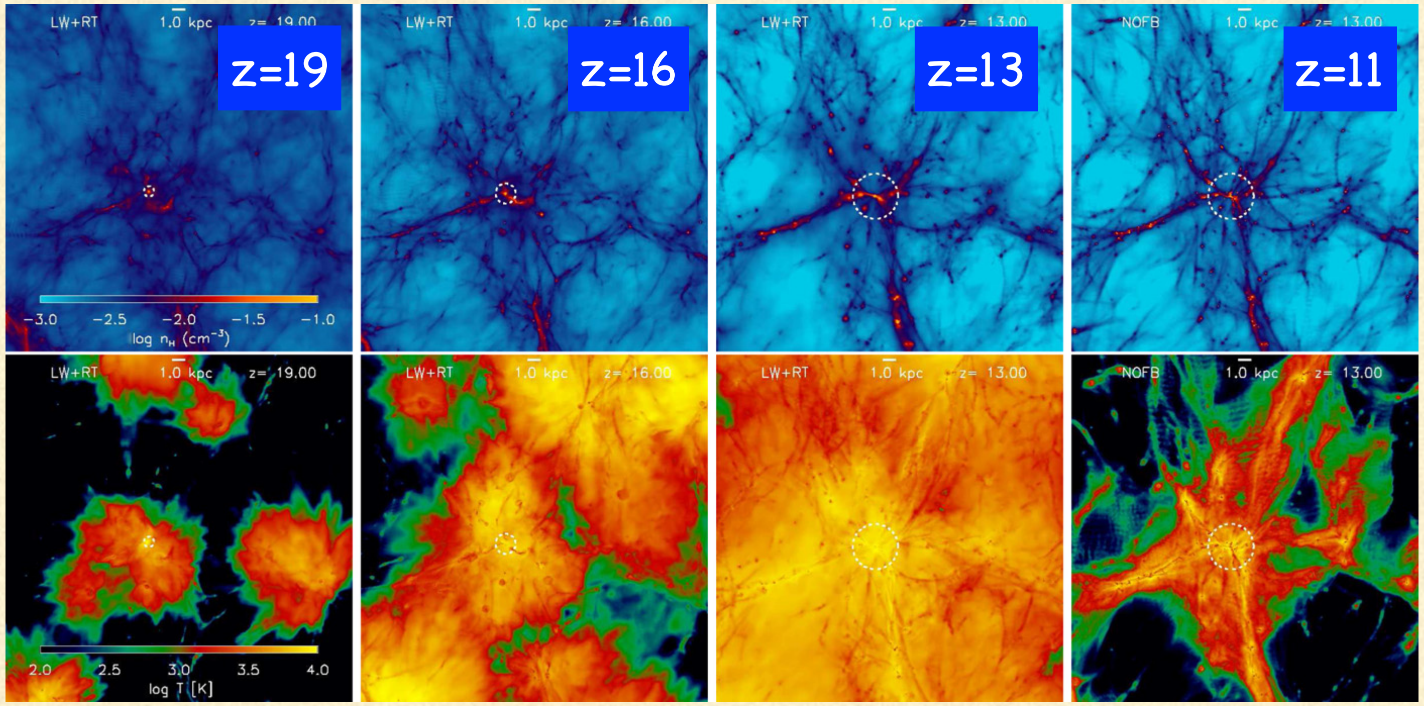


Oesch+13



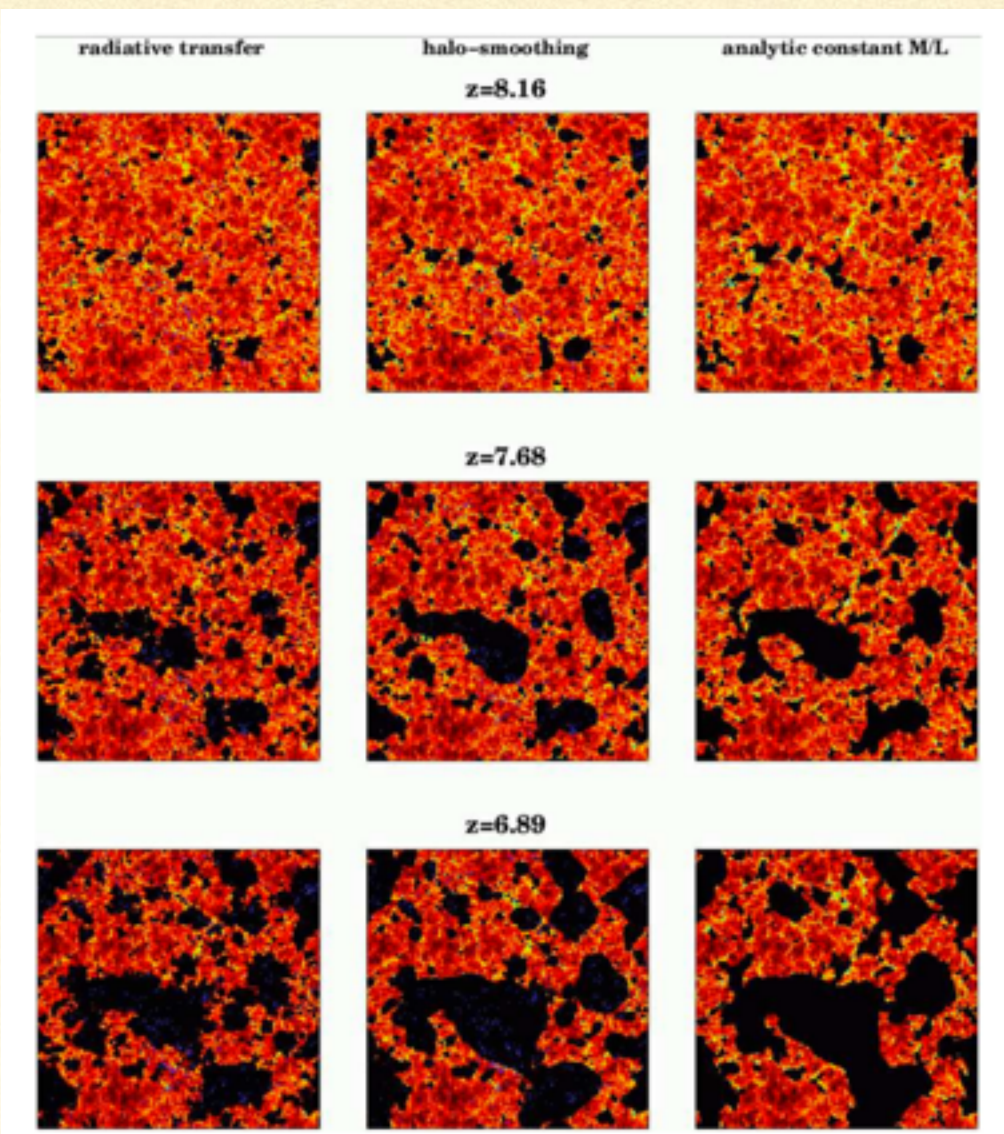
Wang+13

Re-ionization from first principles



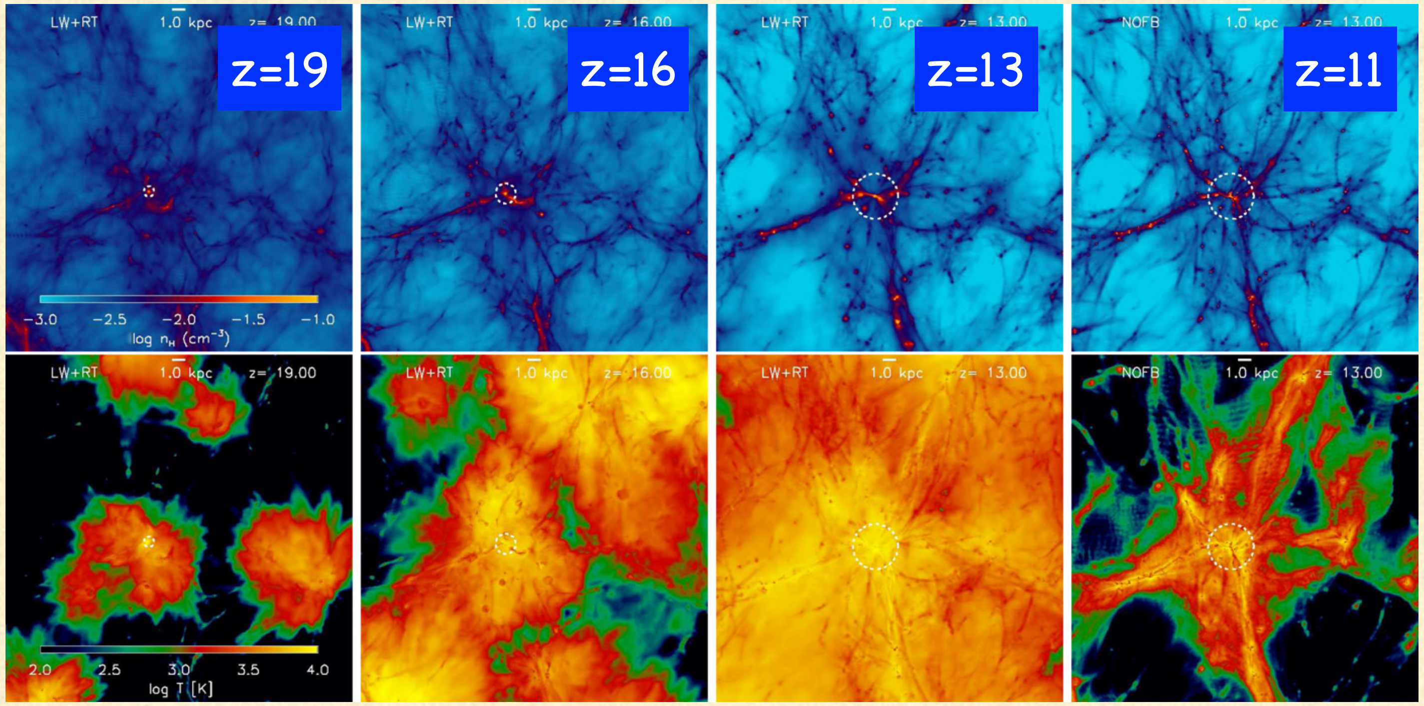
Cosmological simulations allow us to model gas density and temperature of the Universe during re-ionization.

Pawlik et al. 2013
Fumagalli et al. 2011
Boylan-Kolchin et al. 2009



Furthermore re-ionization is likely a patchy process, making hard to identify the exact parameters due to line of sight to line of sight variation (Zahn+06,McQuinn+08).

Re-ionization from first principles



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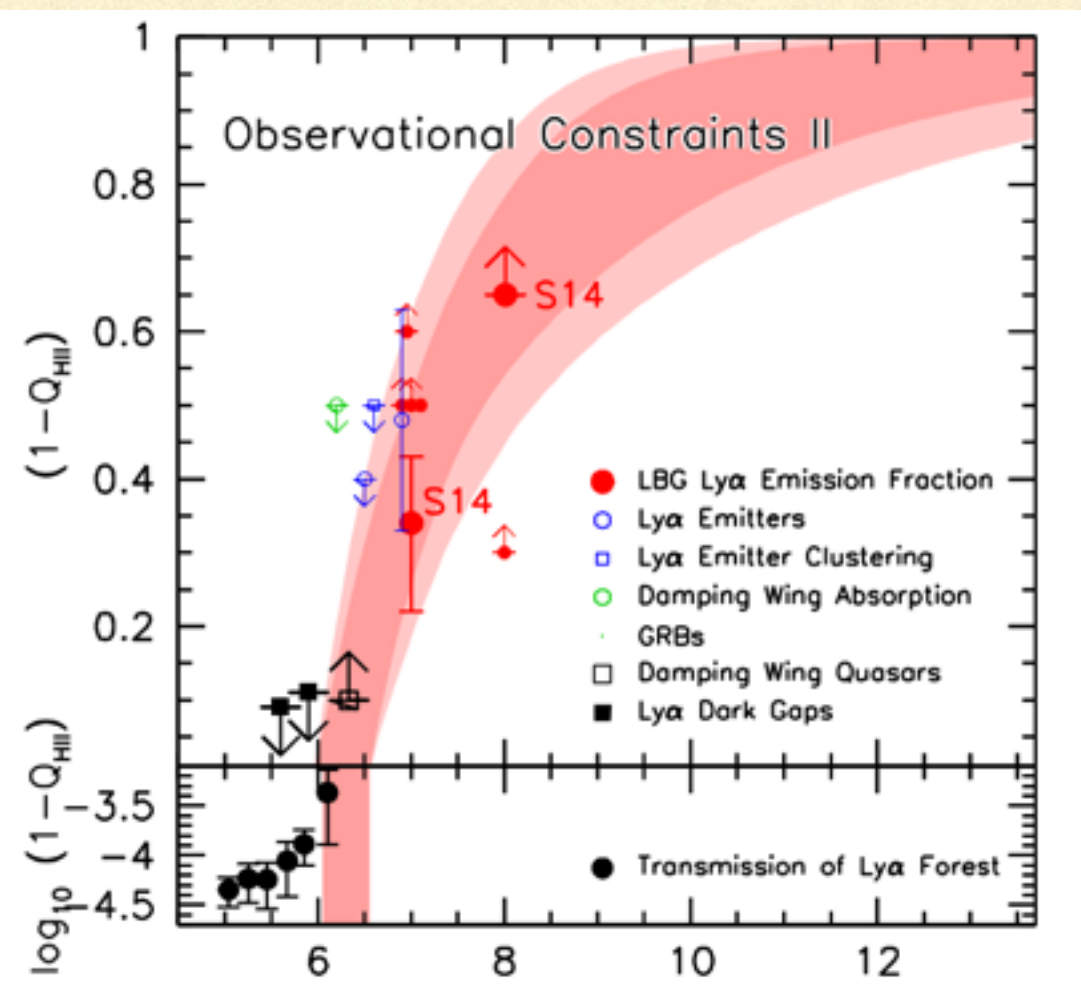

Bouwens+15

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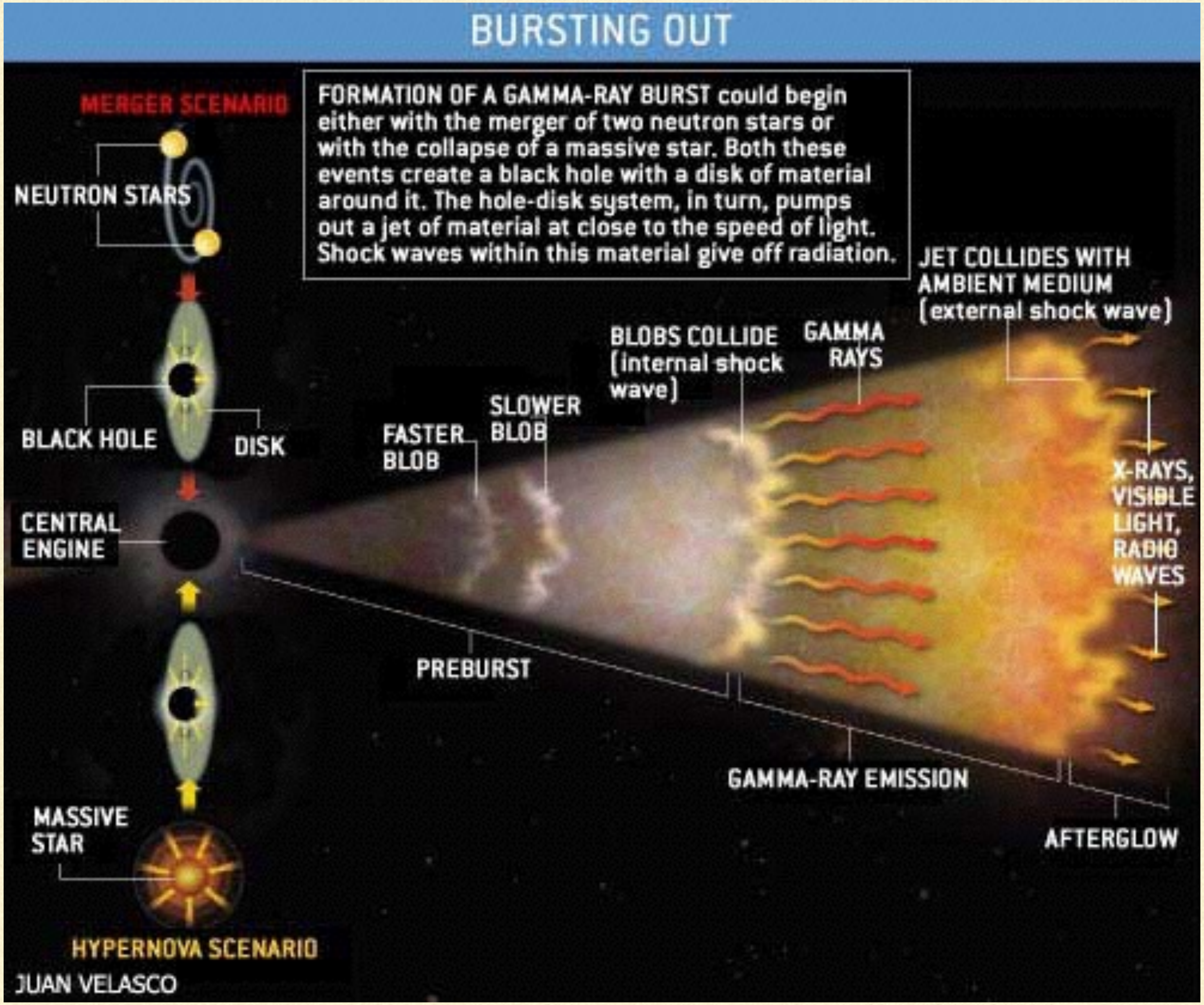
Using LBGs and LAE we can place observational constraints on the neutral hydrogen fraction (Bouwens +15,Robertson+15, McGreer+15, Stark+15).

Gamma-ray Bursts (GRBs) 101

Short GRBs
GW
(cool stuff!!!)

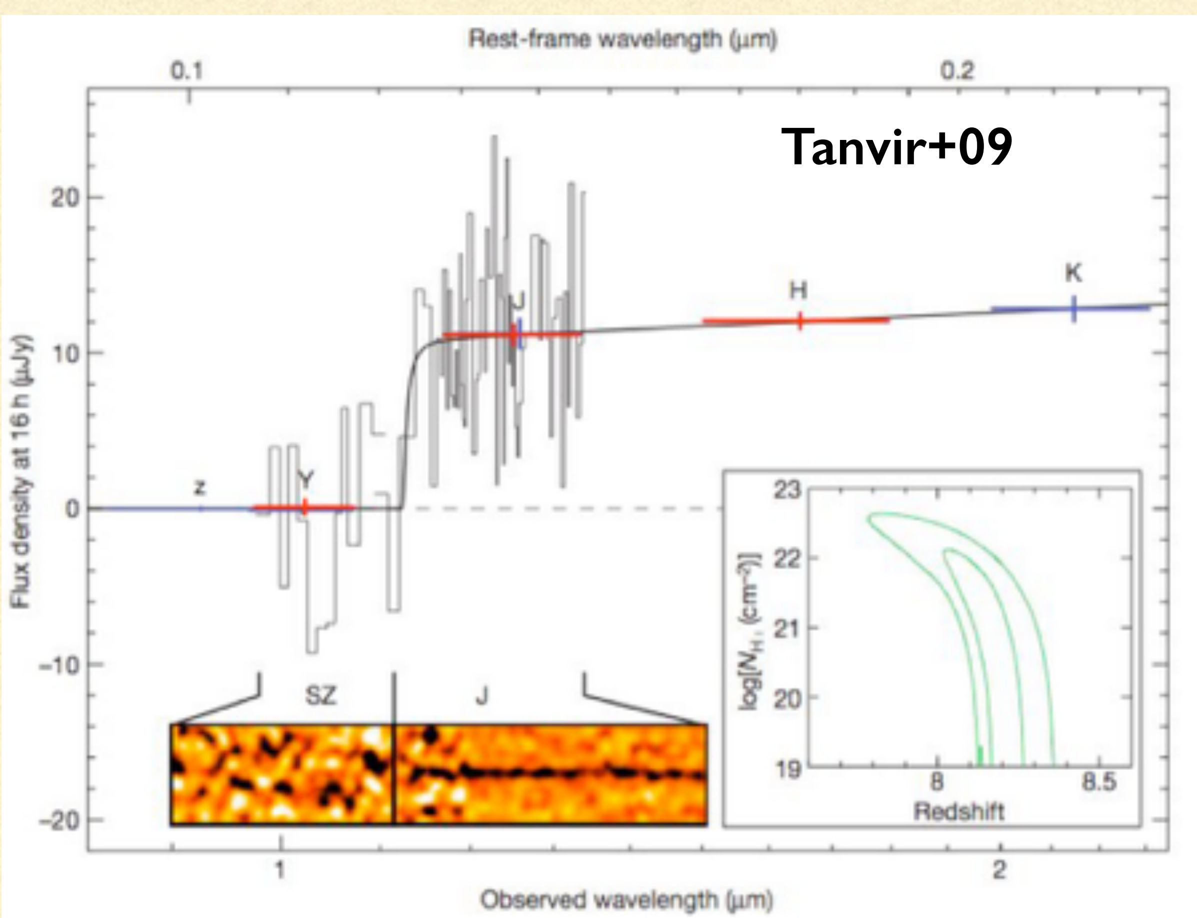


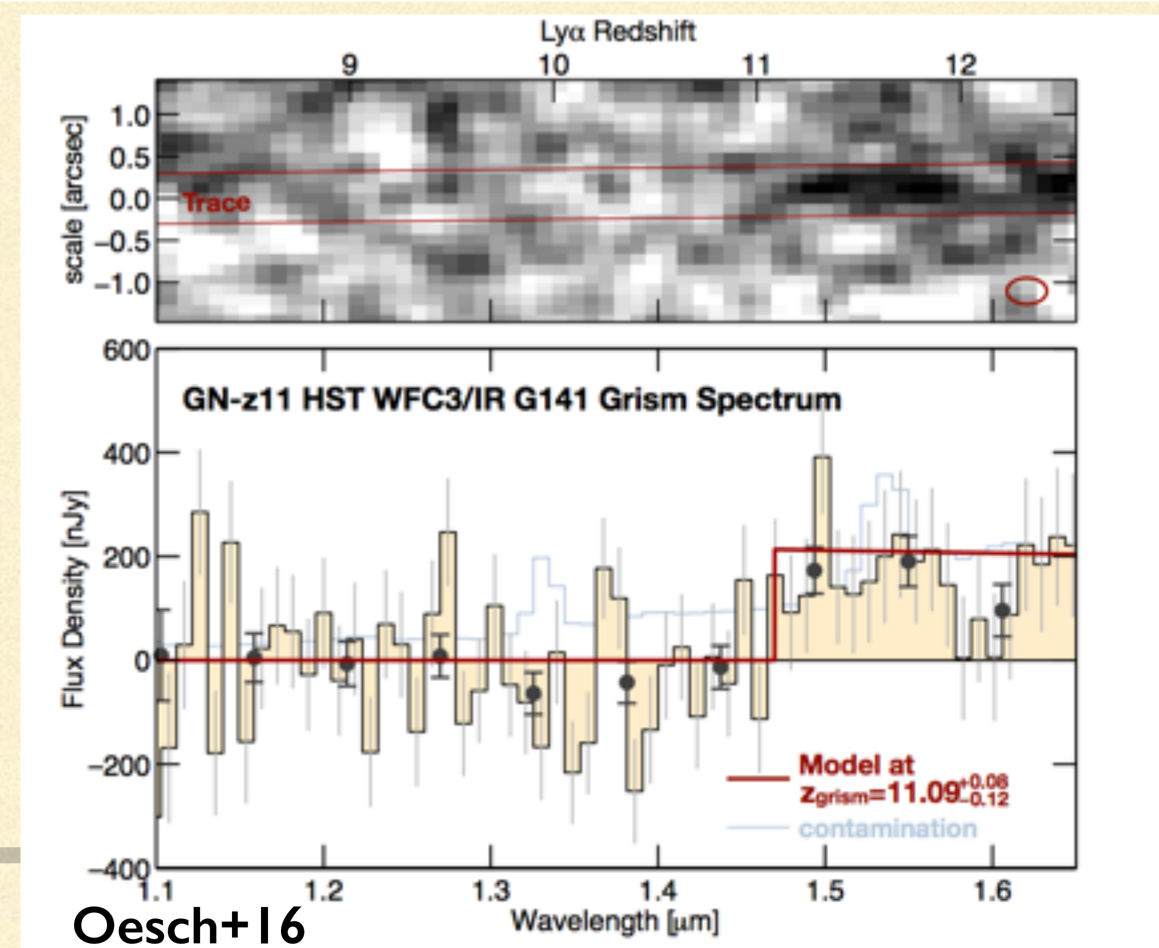
Long GRBs
(also cool stuff!!

GRB 090423 and GRB 090429B

- GRBs occur at z>7
- At discovery they are BRIGHT!
- They are independent of the galaxy luminosity
- Pinpoint high-z "faint" galaxies
- They provide unique insights on star-formation during re-ionization

z	Look-Back Time (Gyr)	GRB	Optical Brightness
9.4	13.1	090429B	K = 19
8.2	13.0	090423	K = 20
~8	13.0	120923A	
7.5	13.0	100905A	H ~ 19
6.7	12.8	080813	K = 19
6.3	12.8	050904	J = 18
6.2	12.8	120521C	
5.6	12.6	060927	I = 16
5.3	12.6	050814	K = 18
5.11	12.5	060522	R = 21





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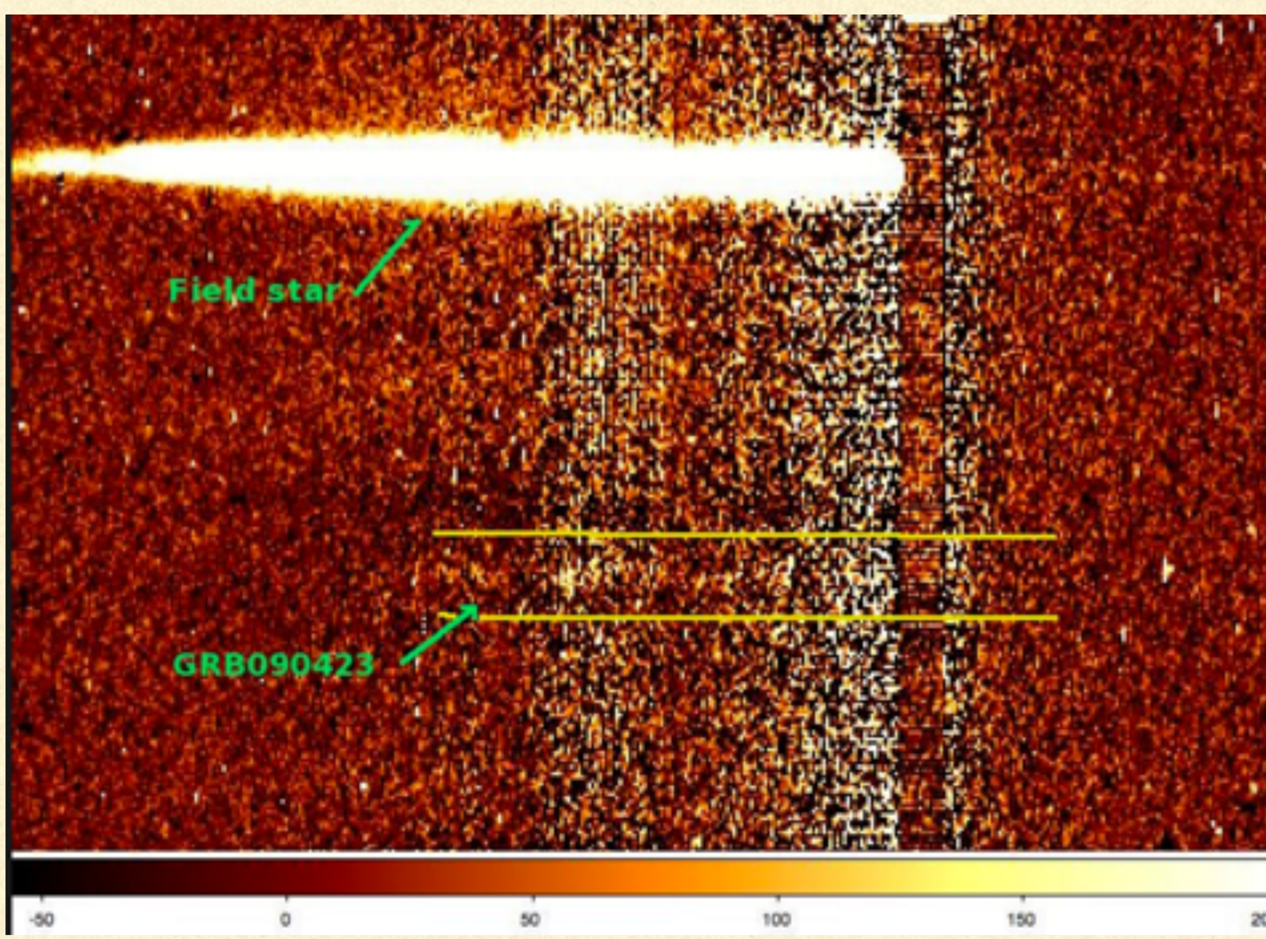
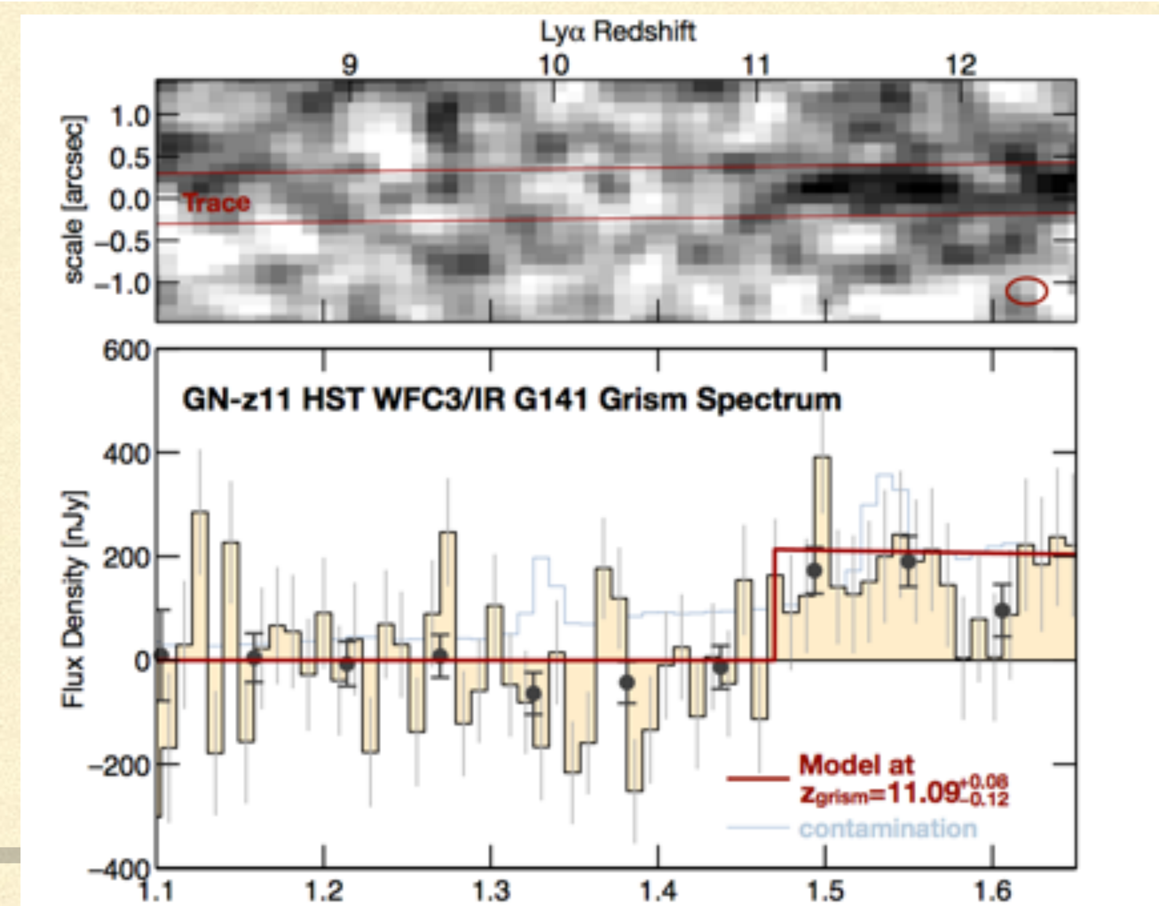
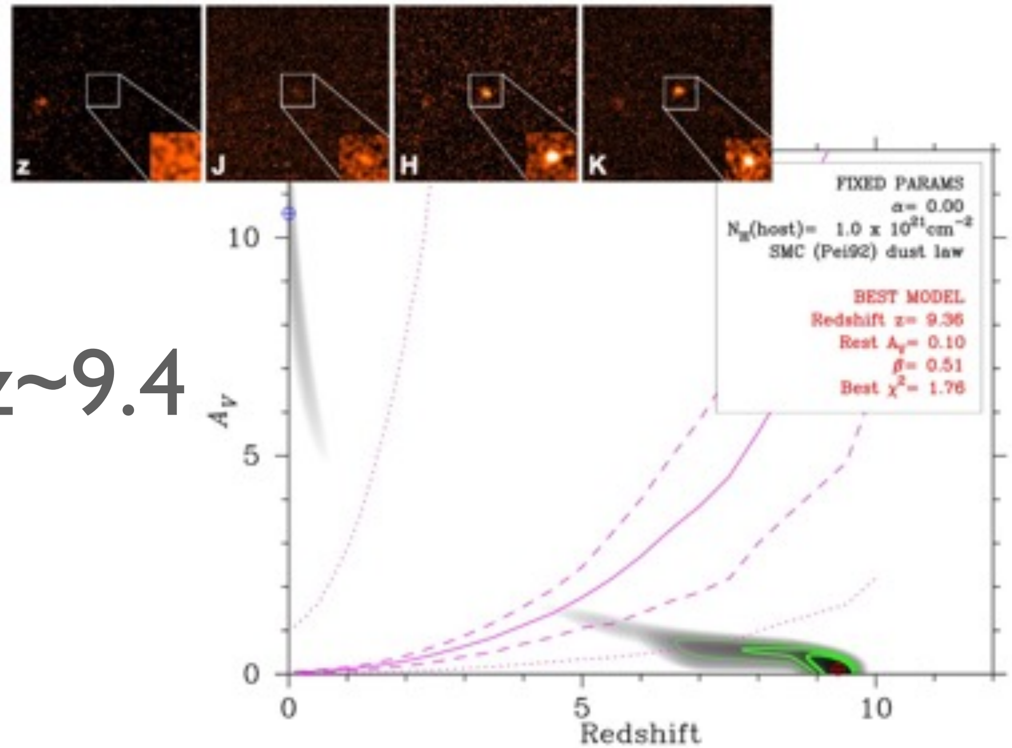




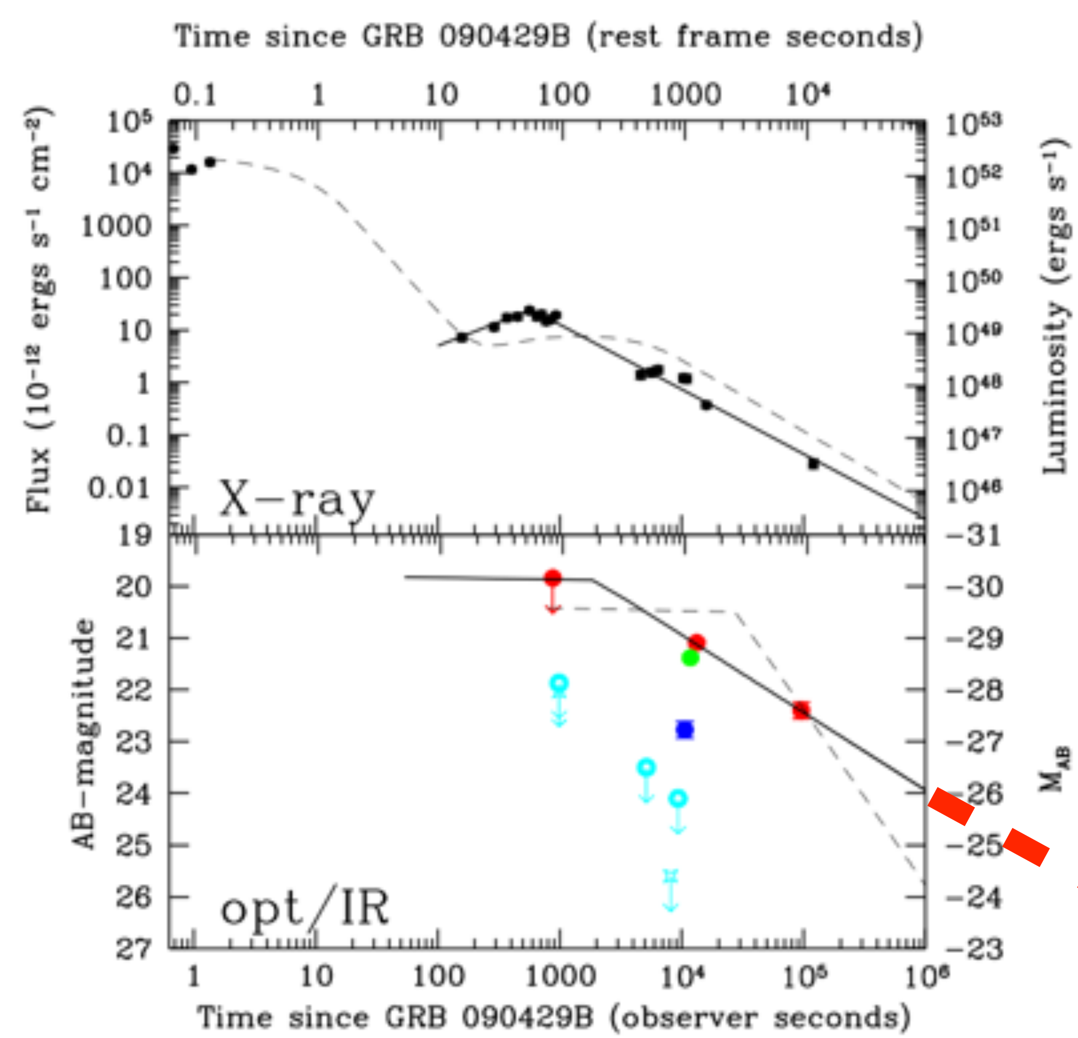
Oesch+16

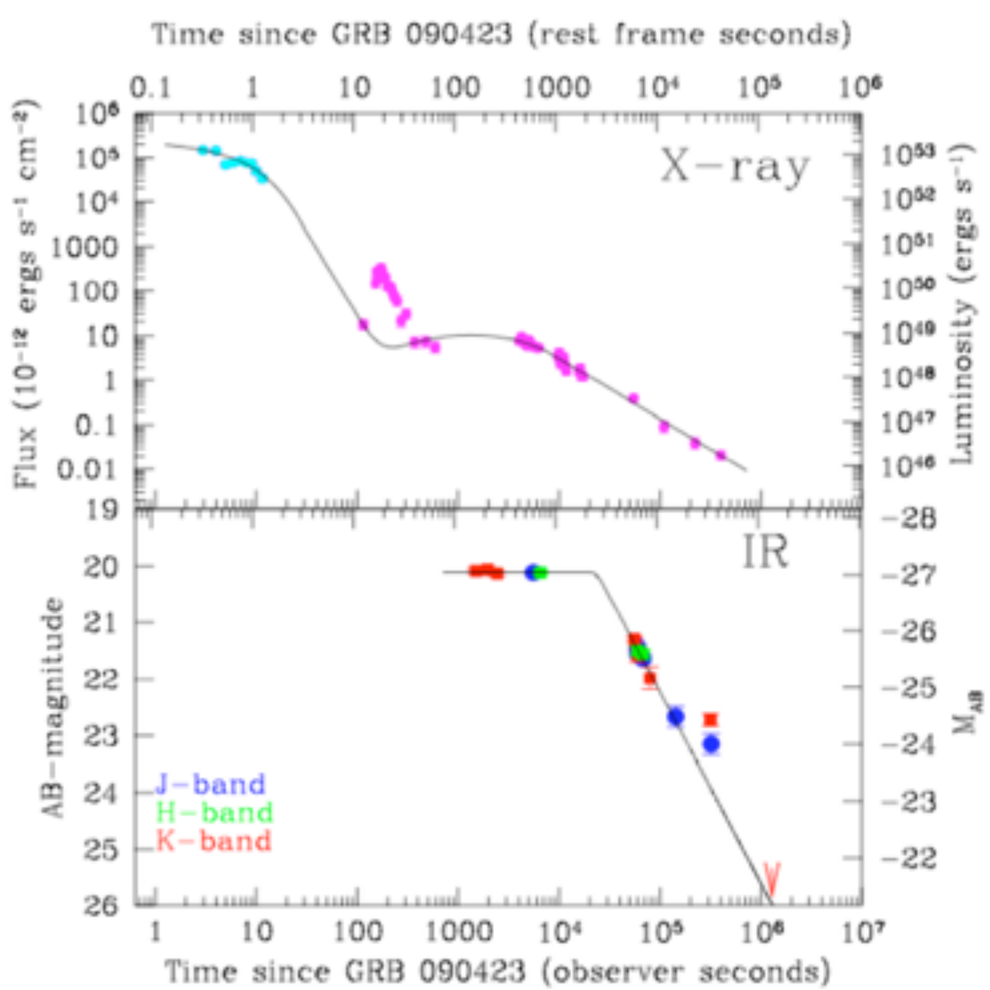
GRB 090423 and GRB 090429B

z~9.4



GRB 090429B: Cucchiara+11

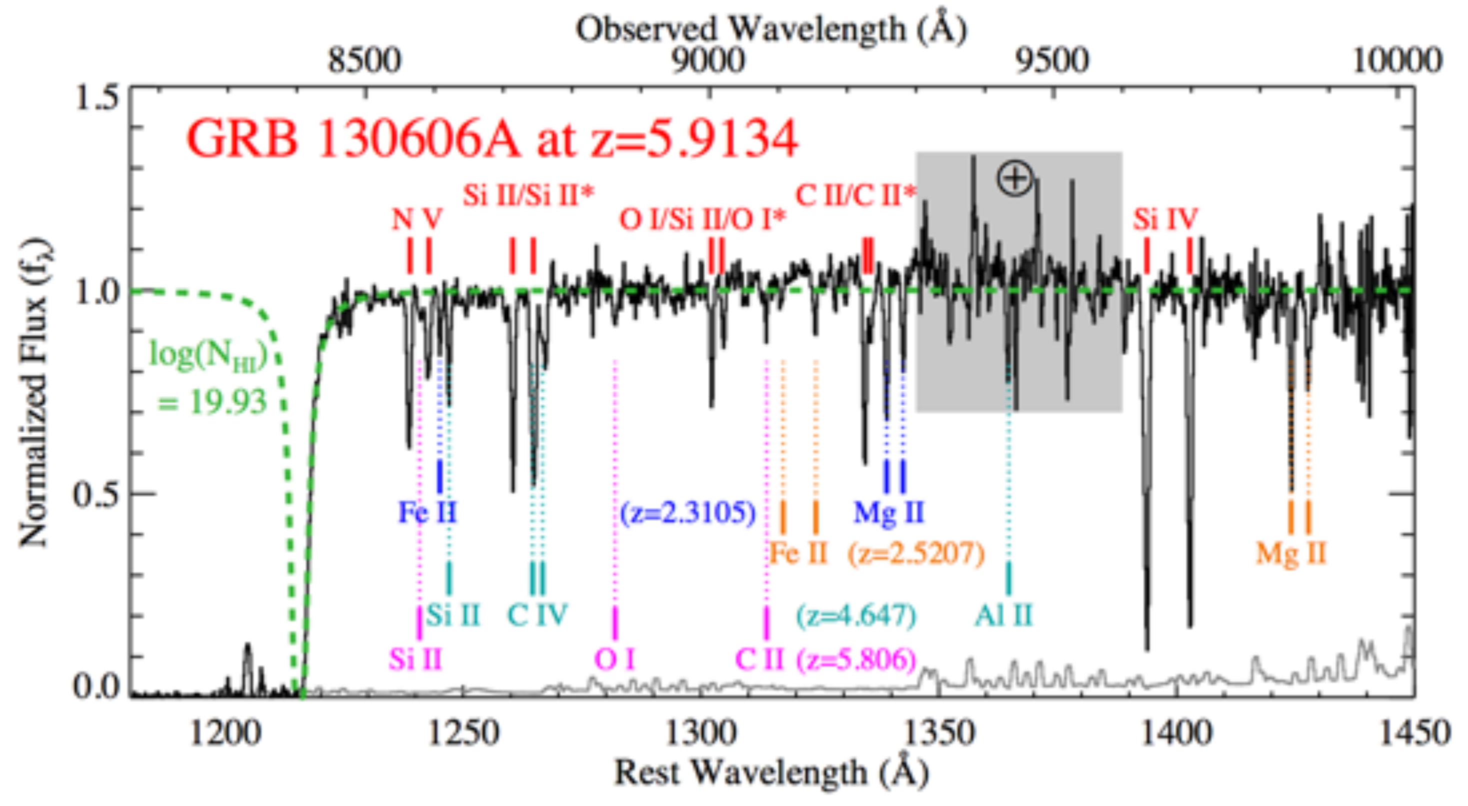




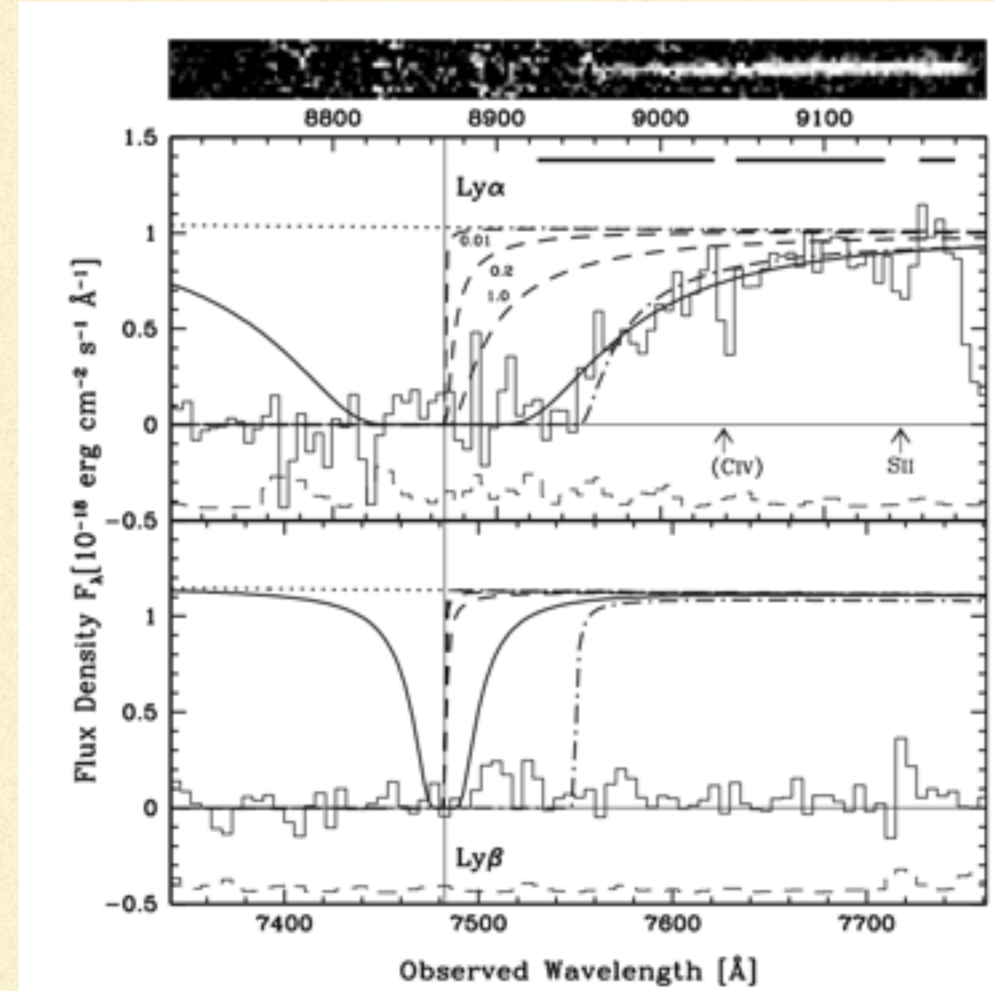
KEY FACT

GRBs at z>7 stay bright for **several days**!!
NIRCAM/NIRSPEC will be able to
obtain photo-z

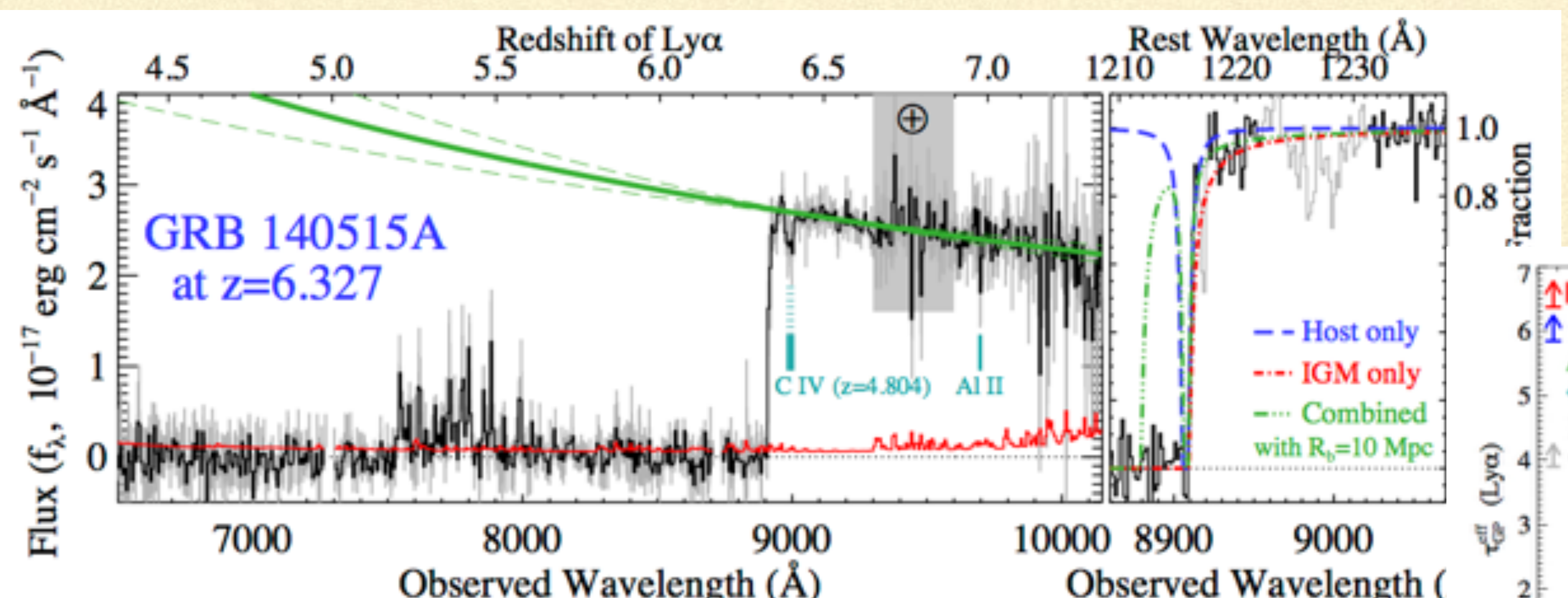
High S/N spectra enable re-ionization studies



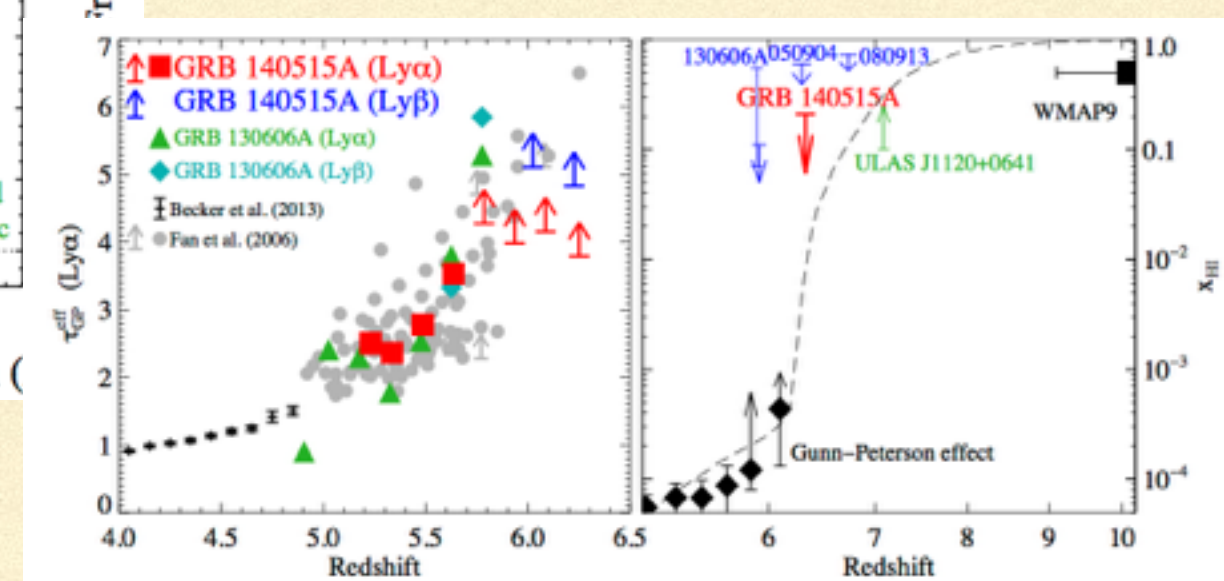
Chornock+13



GRB 050904 (z=6), Totani+05

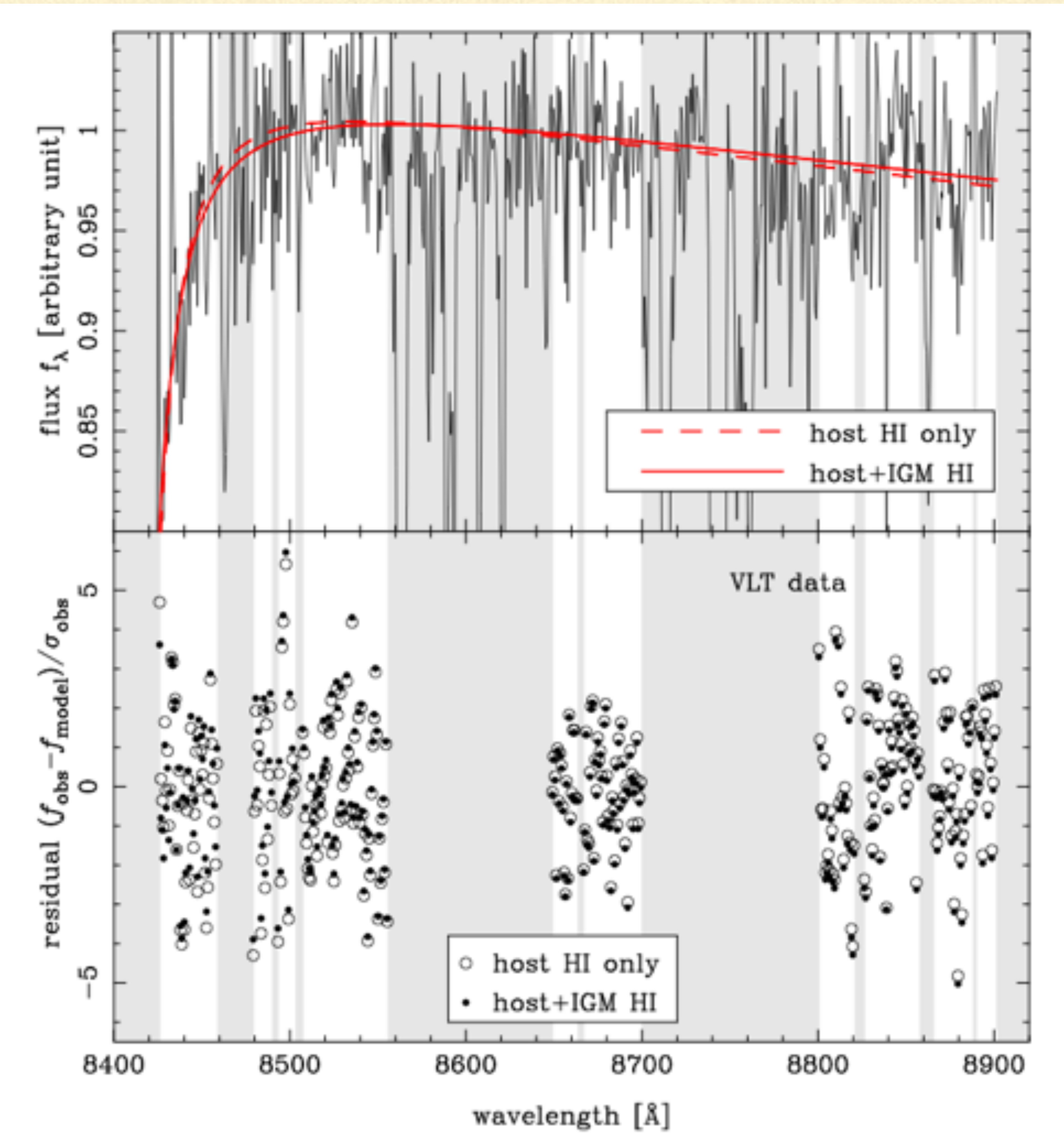


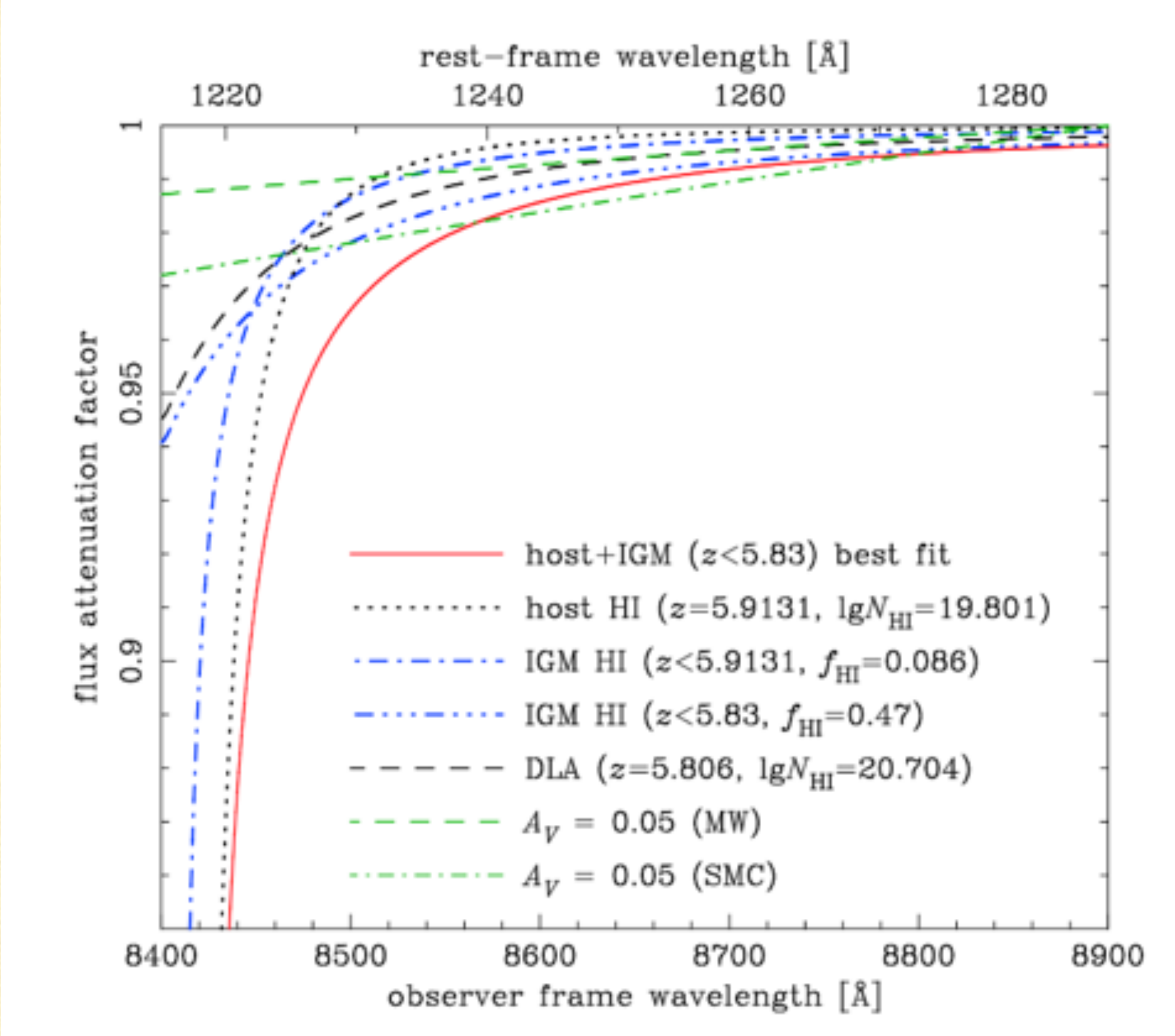
Chornock+14



High S/N spectra enable re-ionization studies

Fitting the red wing of the afterglow spectra allows to measure fundamental parameters of re-ionization. But requires good data (AKA high S/N spectra).

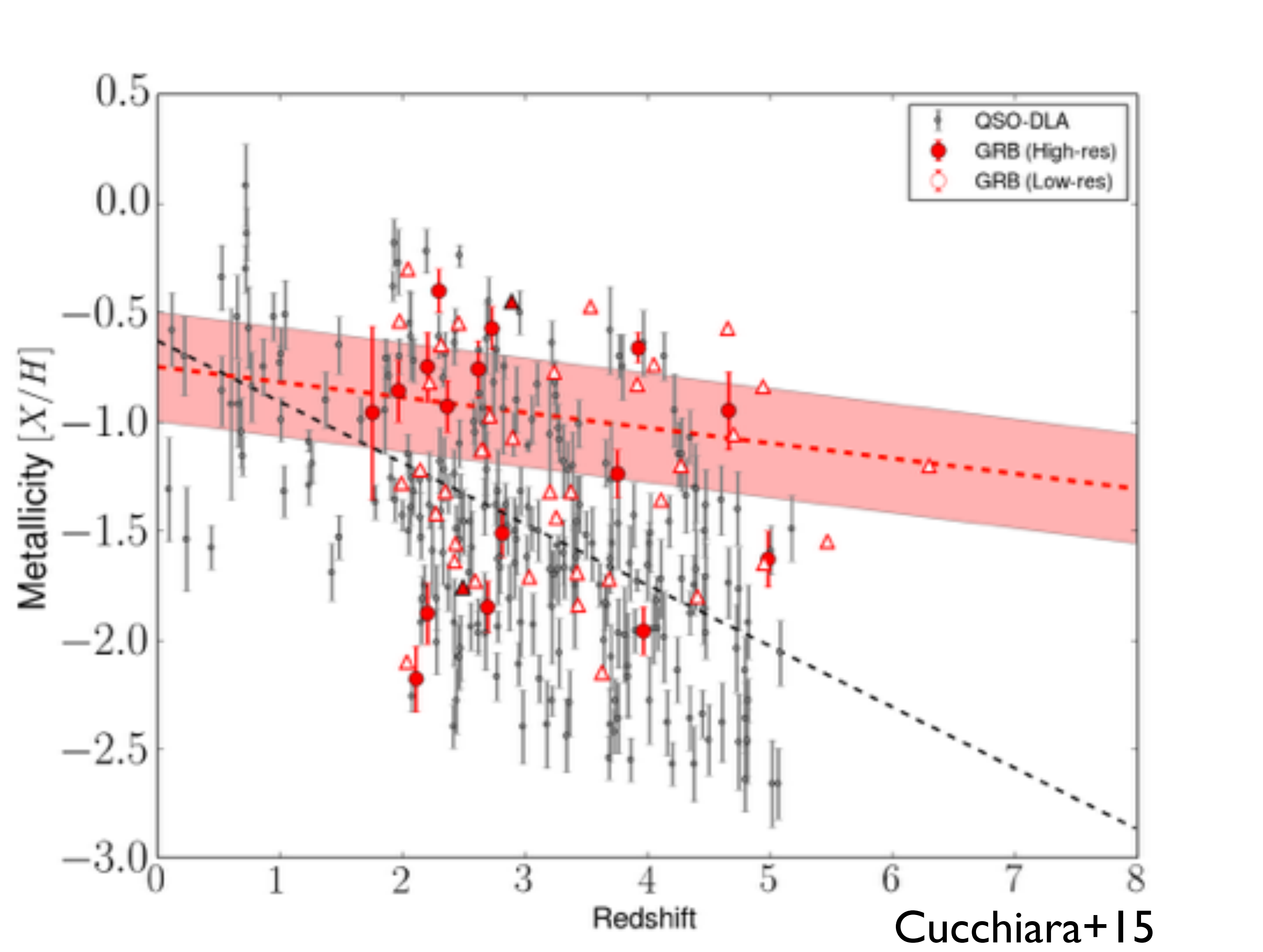




GRB 130606A, Totani+13

GRBs afterglow enable to answers some key questions?

- What is the metallicity of a galaxy at z>8?
- What is the reservoir of HI in these primordial objects?
- Can we constrain the neutral hydrogen fraction?
- Can we constrain the size of the primordial ionized regions?



Cucchiara+15

The perfect recipe (Cucchiara in prep.)

We model a GRB afterglow spectrum including:

- Simple GRB continuum (the beauty of the beast)
- Absorption lines (host+intervening) at $0.01 < Z/Z_{sun} < 1.0$
- $\log(HI) > 17\ cm^{-2}$
- $0.01 < x_{HI} < 1.0$
- A grid of IGM bubble size R_b: 1, 10, 60 Mpc

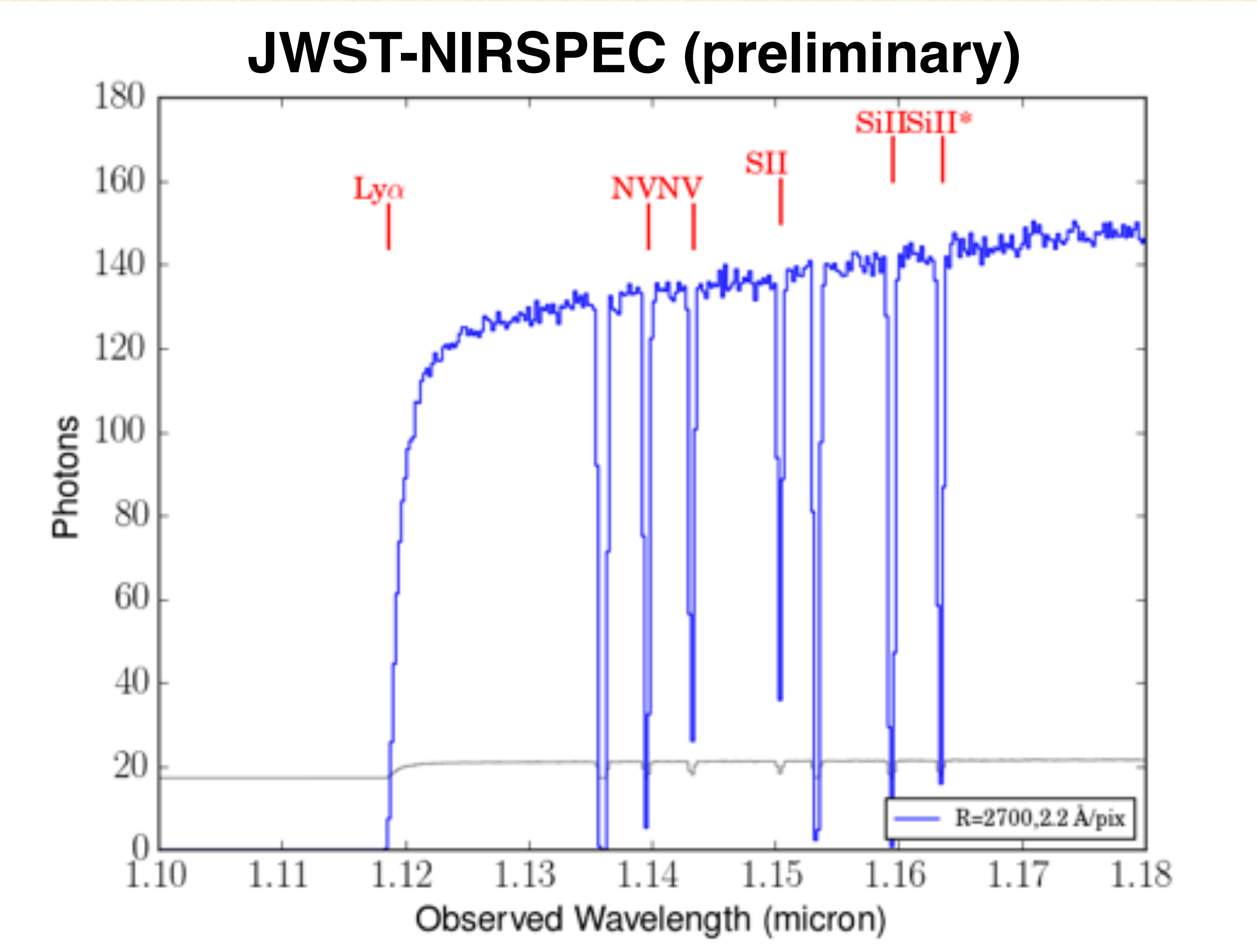
We simulated the following instruments:

JWST+NIRSPEC (not-official tool)

TMT+IRIS (official)

WFIRST-GRISM

DCT+RIMAS (OH lines suppression)



JWST-NIRSPEC

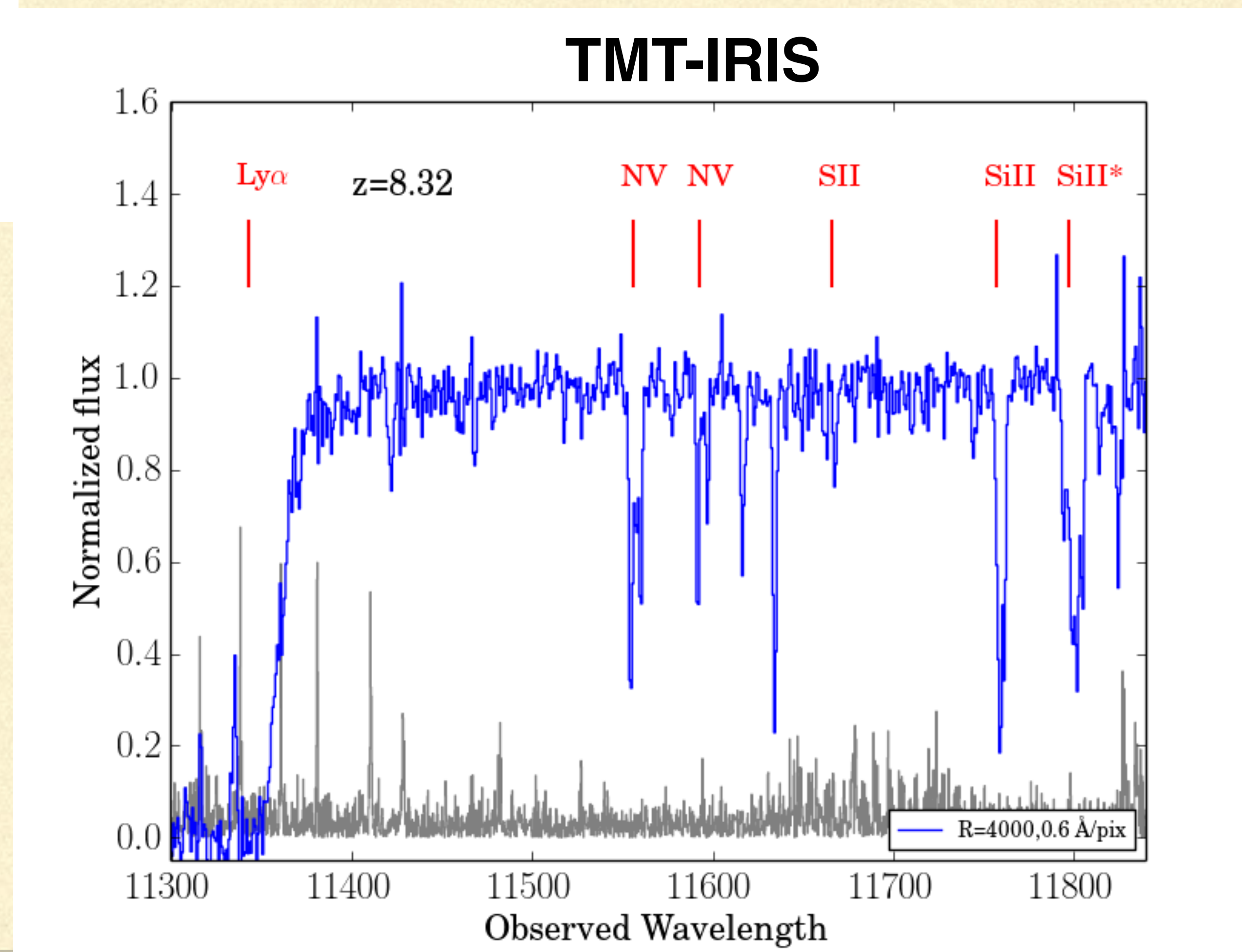
z=8.2

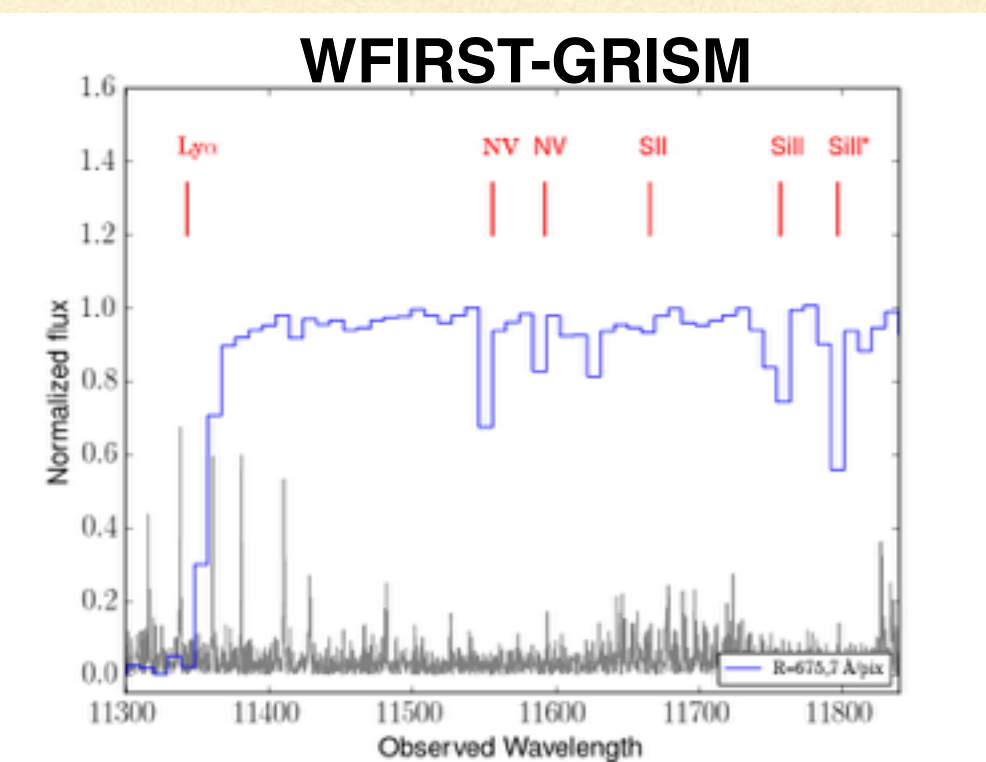
J_{mag}=22 (S/N=10 with T_{exp}=900s)

G140H (R~2700)

Pixel scale: 2 Ang/pix

Z/Z_{sun} = 0.1





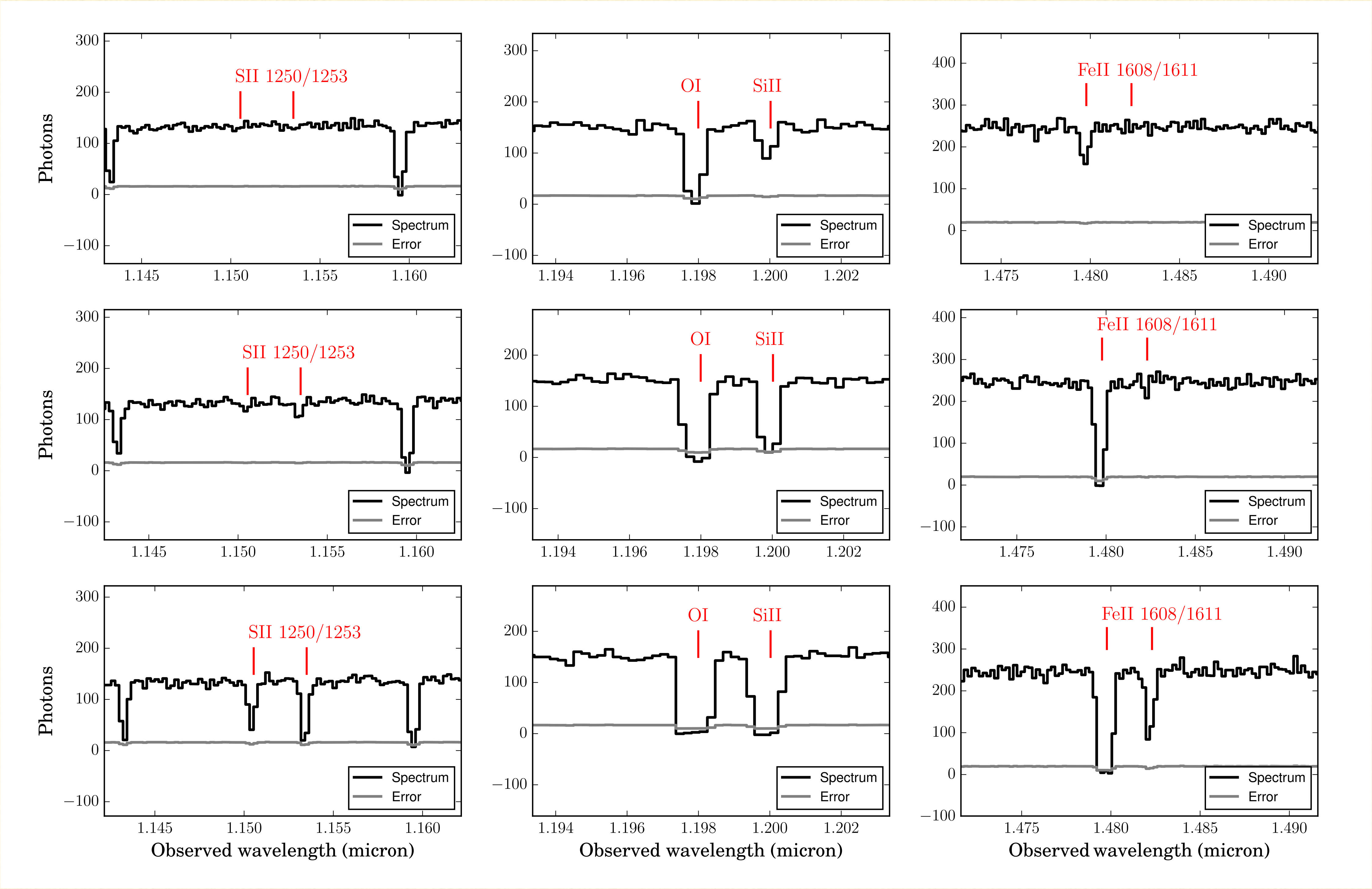
Determine the ISM metallicity of z>8 galaxies

At Z/Z_{sun} = 0.1, G140H= 900s , S/N 10 (J_{mag}=22)

log(HI)= 19.5

log(HI)= 20.5

log(HI)= 21.5



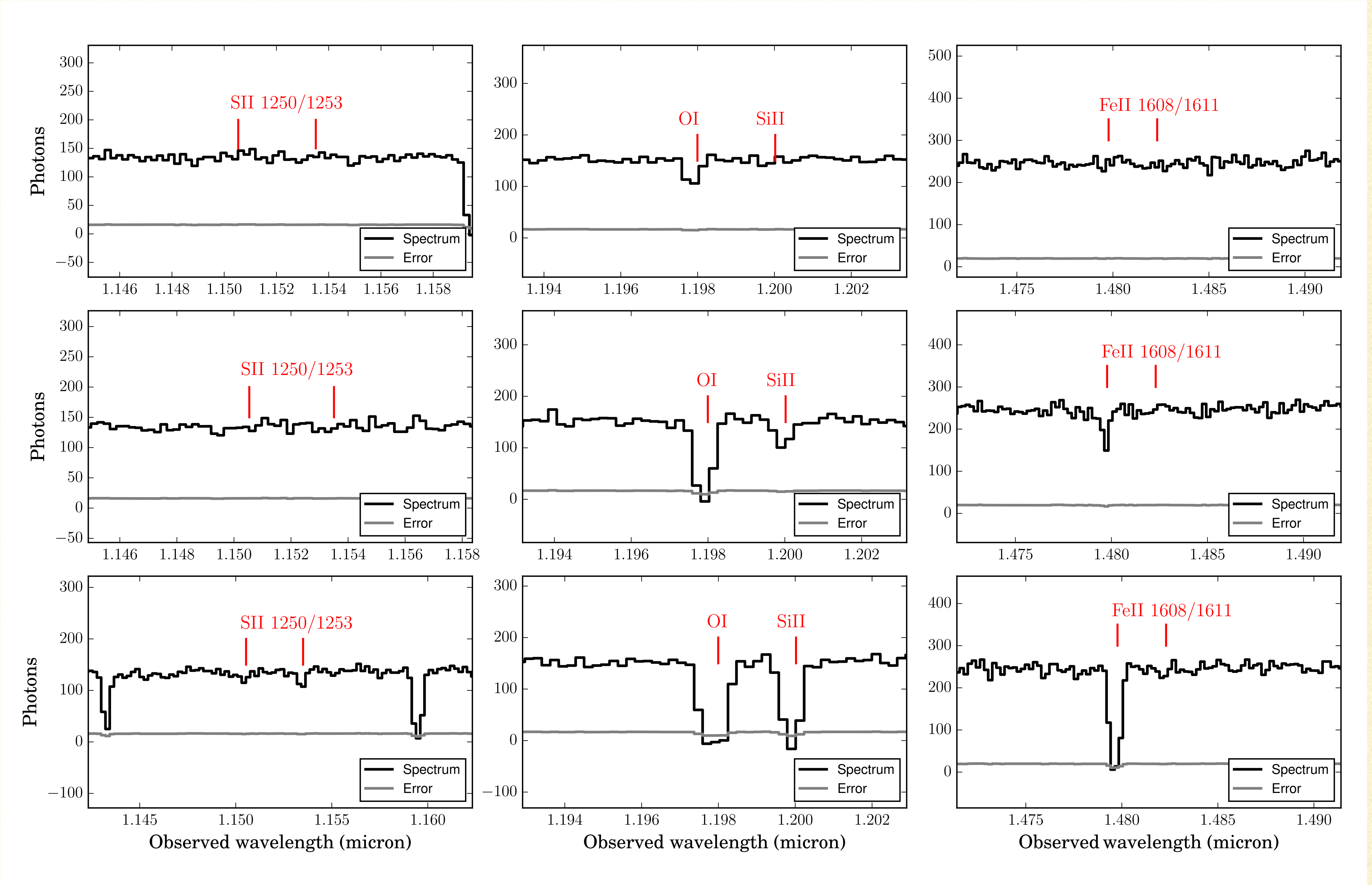
The future, JWST+NIRSPEC

At Z/Z_{sun} = 0.01, G140H= 900s , S/N 10 (J_{mag}=22)

log(HI)= 19.5

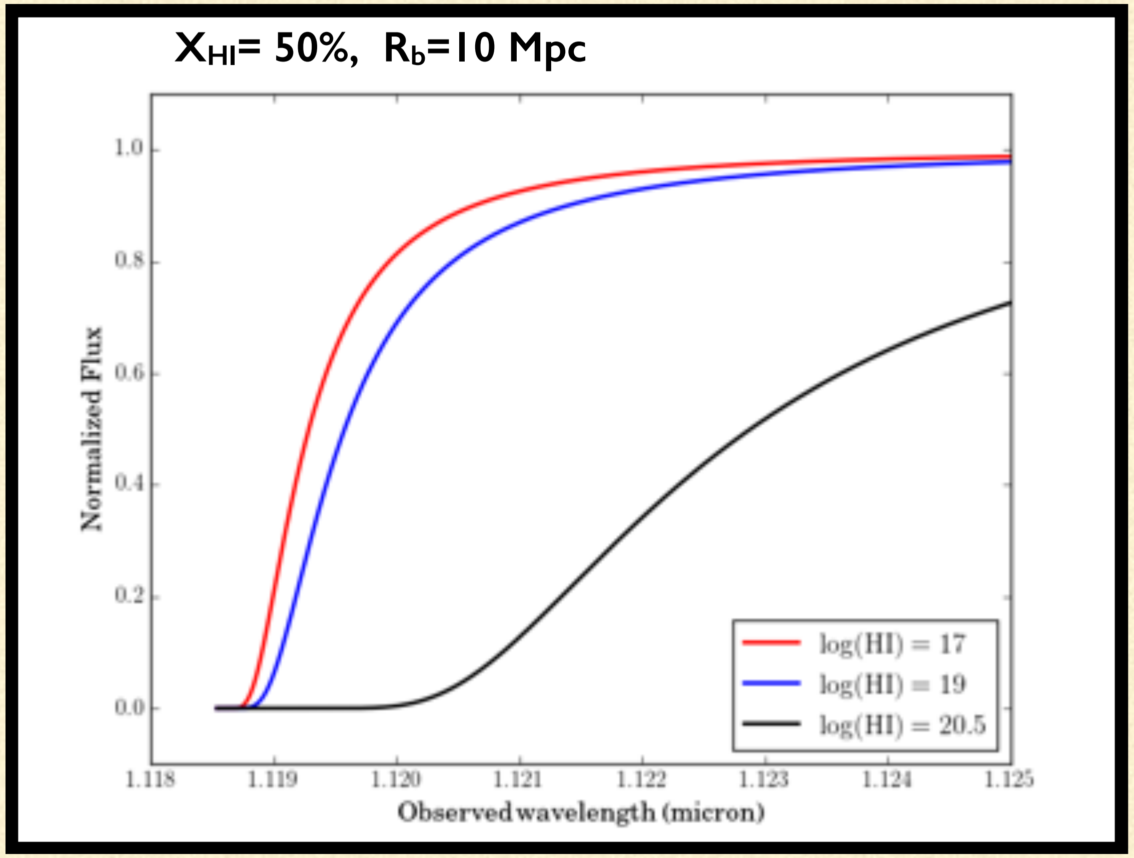
log(HI)= 20.5

log(HI)= 21.5

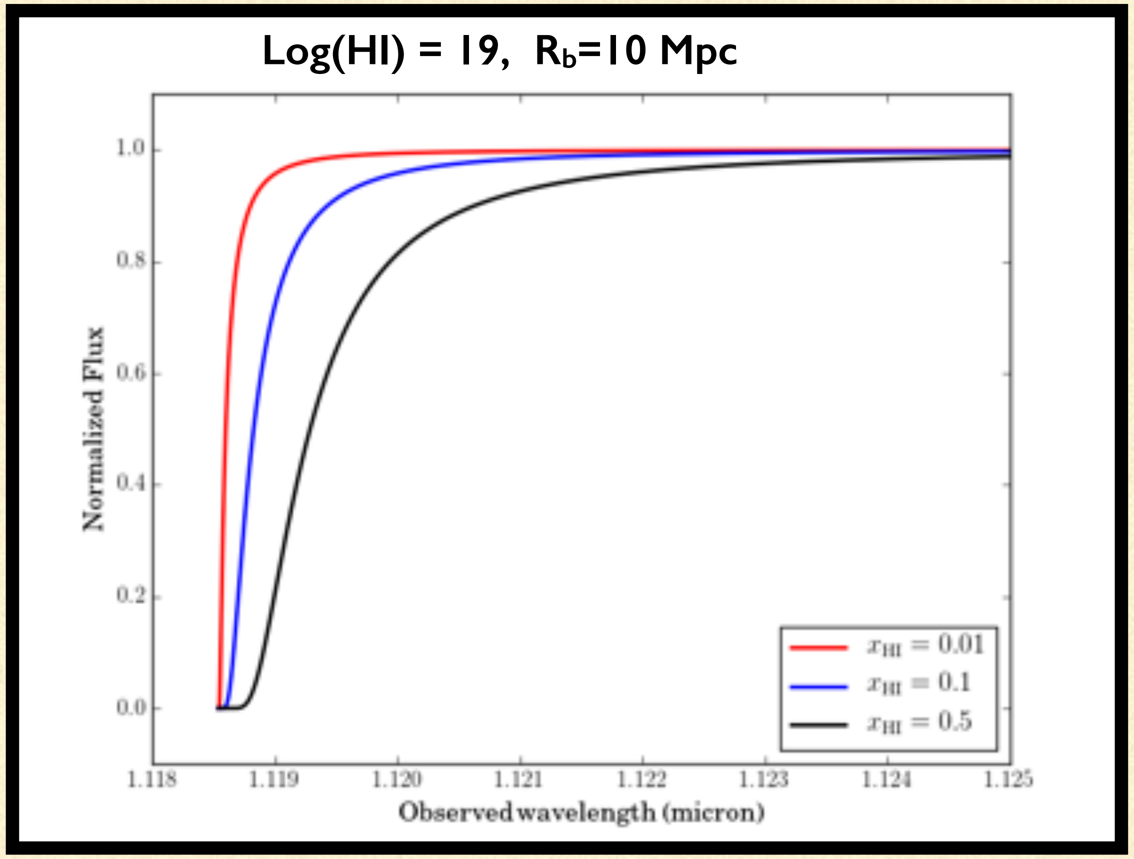


Re-ionization (preliminary)

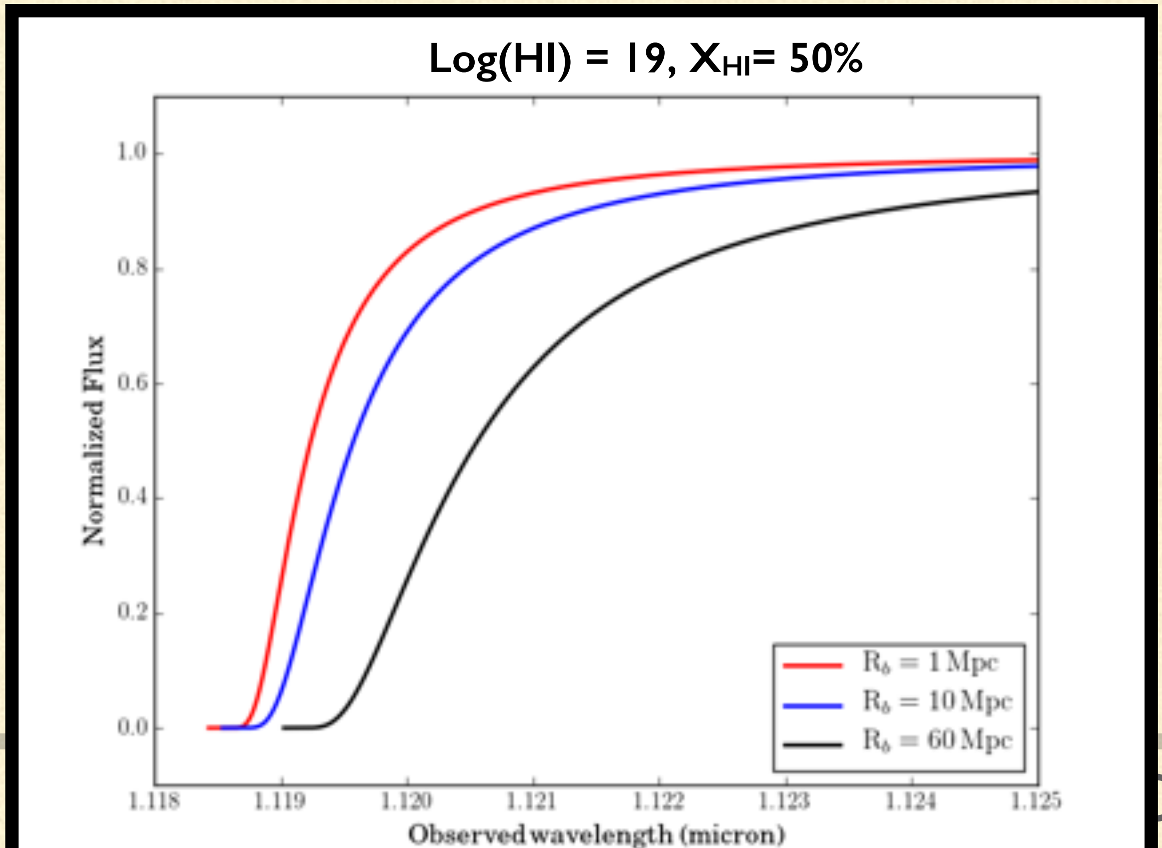
Effect of pure HI column on the red wing



Effect of X_{HI} on the red wing



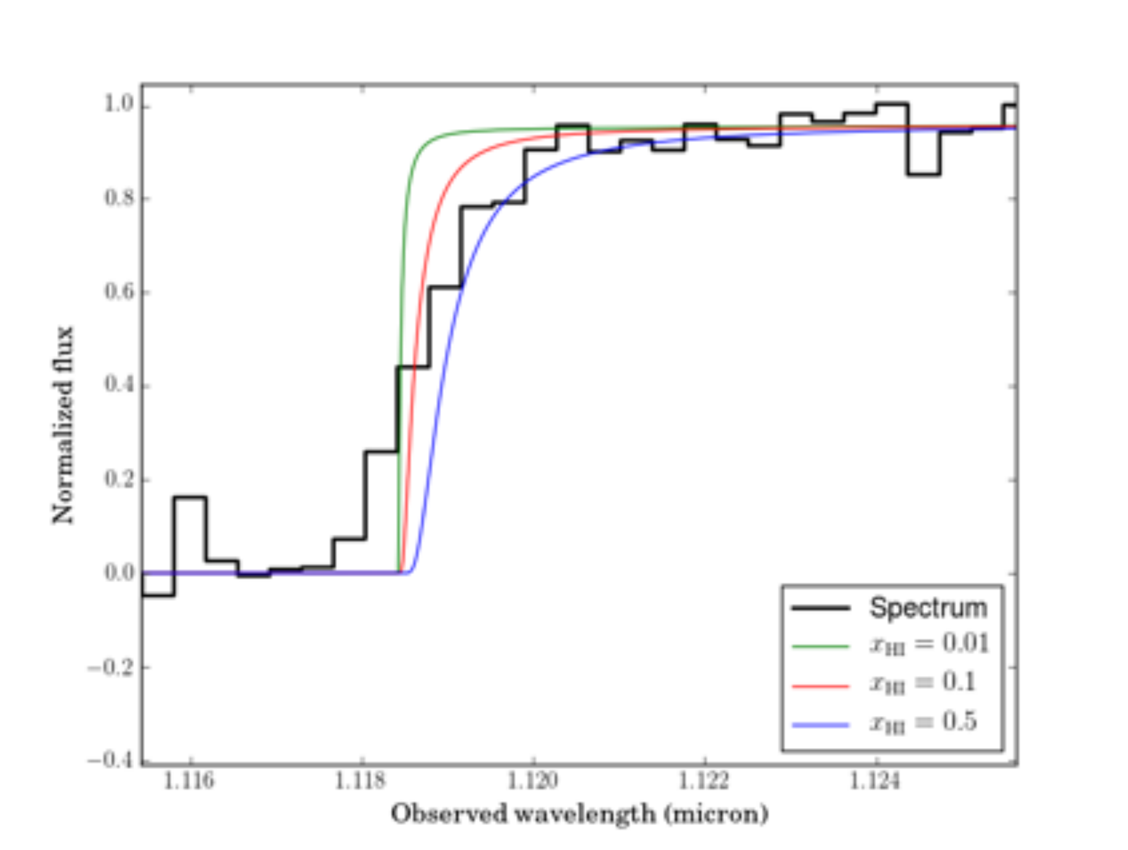
Effect of R_b on the red wing

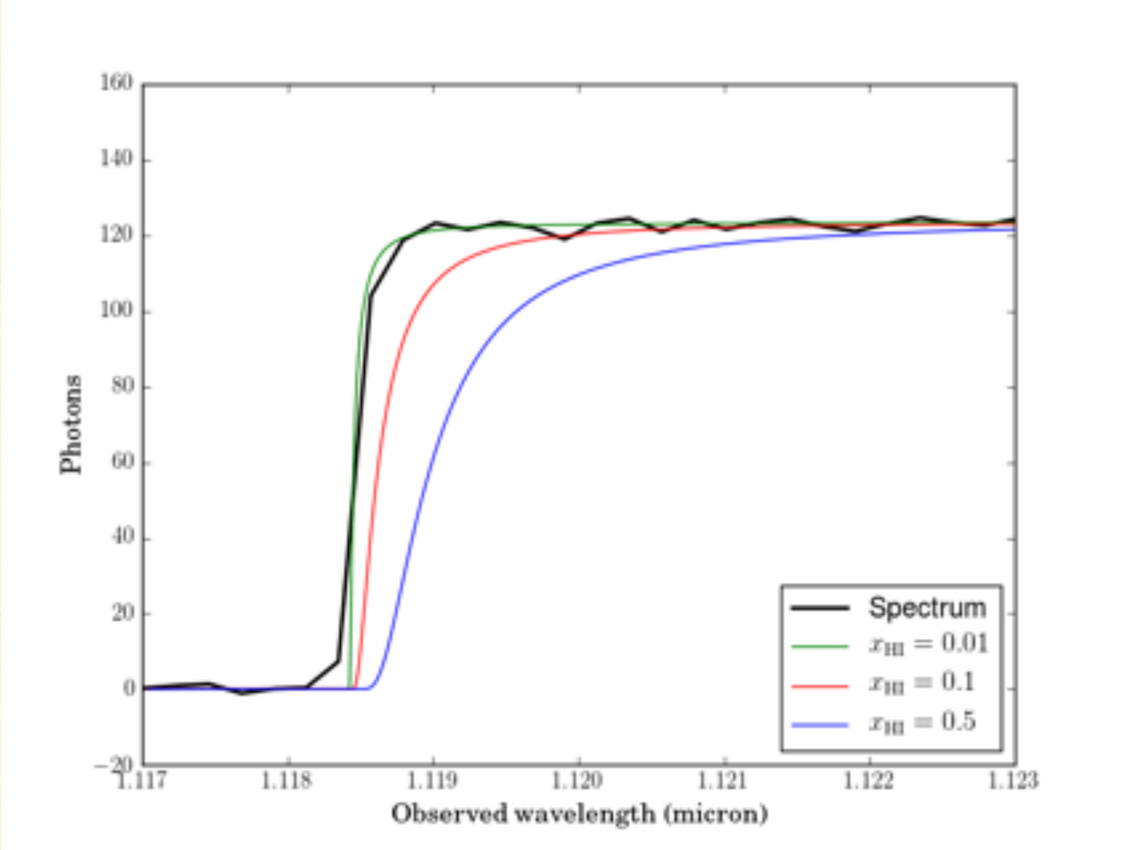


Re-ionization (preliminary)

TMT+IRIS (R~4000) spectrum of GRB130606A shifted at z=8.2 (HI=19.9)

JWST+NIRSPEC (R~2700) simulated spectrum of a at z=8.2, with HII size 10Mpc, HI=19.5 x_{HI}=0.01





Work to do

- Understand the error budgets (instrumental)
- Including sky transmission (IRIS)
- Perform observing strategies (slew response time for JWST)
- How many GRBs do we need to be sure we can constrain IGM

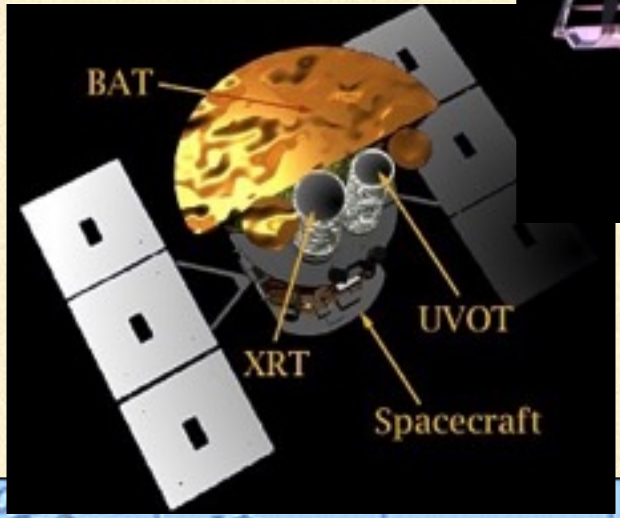
Conclusions

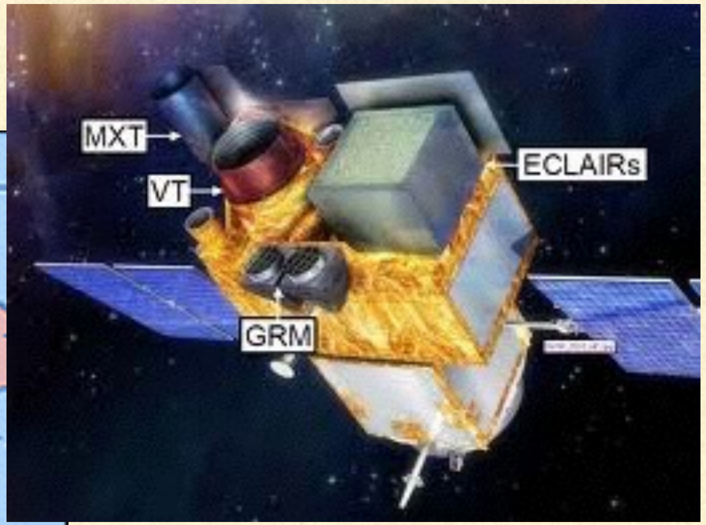
In the era of JWST and beyond (TMT, GMT, E-ELT) we will be able to move from stars to gas (ISM, IGM)

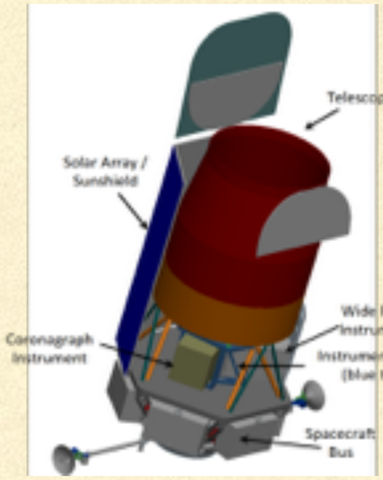
- GRBs a unique addition to the exploration of re-ionization
- Absorption lines analysis (OI, SII, FeII) will probe the ISM of primordial star-forming regions (ionizing bubble around first galaxies)
- High S/N spectra will help constraining the key ingredients of re-ionization (x_{HI} , HI, HII regions size).
- Rapid follow-up of z>8 GRBs is critical: combining space triggers (Gamma-ray) with ground based facilities (1-4m telescopes) + JWST/30m telescopes (spectroscopy)….**promise 1-10 z>8 GRBs!!**

2017-2023:

Exploring the re-ionizing Universe







Direct access

Collaborators