Case Study of the Tunable Filters reaching to 0.95μm

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- (1) Currently planned TF in FGS covers 1.2–5.0 μm .

- (2) There are two etalons each covering no more than an octave in wavelength. There is likely no funds or room for a third etalon.

- (3) There are compelling reasons to have the long wavelength-end go to close to 5.0 μm due to spectral features in brown dwarf/planets.

- (4) There are compelling reasons to have no large gaps around 2.4 μm due to spectral features in starforming regions/stellar pops.

- (5) There are compelling reasons to have the short λ-side of the TF to reach to $\sim$0.95 μm to detect Lyα in the expected numerous faint dwarf galaxies that concluded the reionization epoch around z$\simeq$6–7.

How can we reconcile these issues?

- (1) Getting $\Delta\lambda \simeq 0.30$ dex from a single etalon is hard (Hutchings).

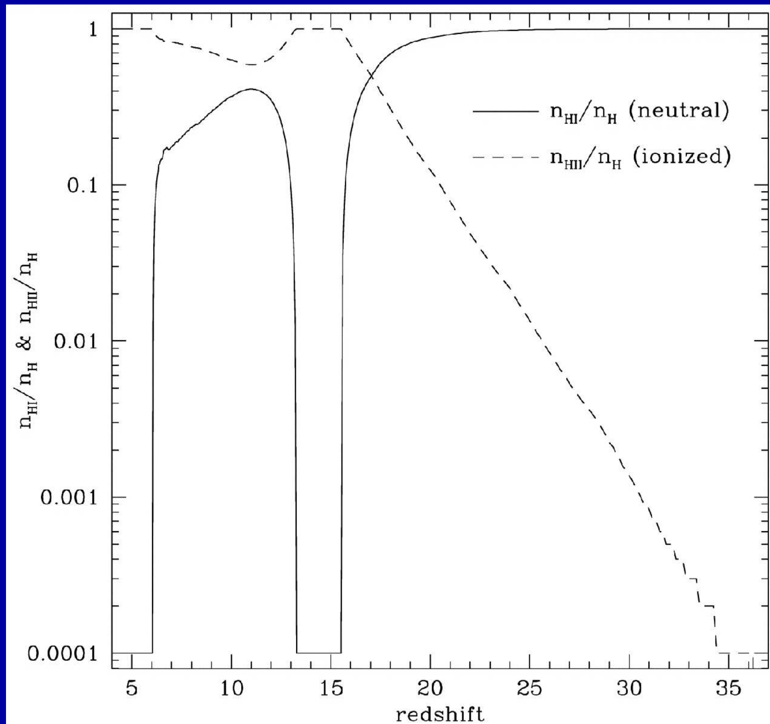
- (2) How far to the red does the reddest etalon need to go when studying spectral features in brown dwarf/planets ($\lambda \gtrsim 4.6 \mu$m; Lunine)?

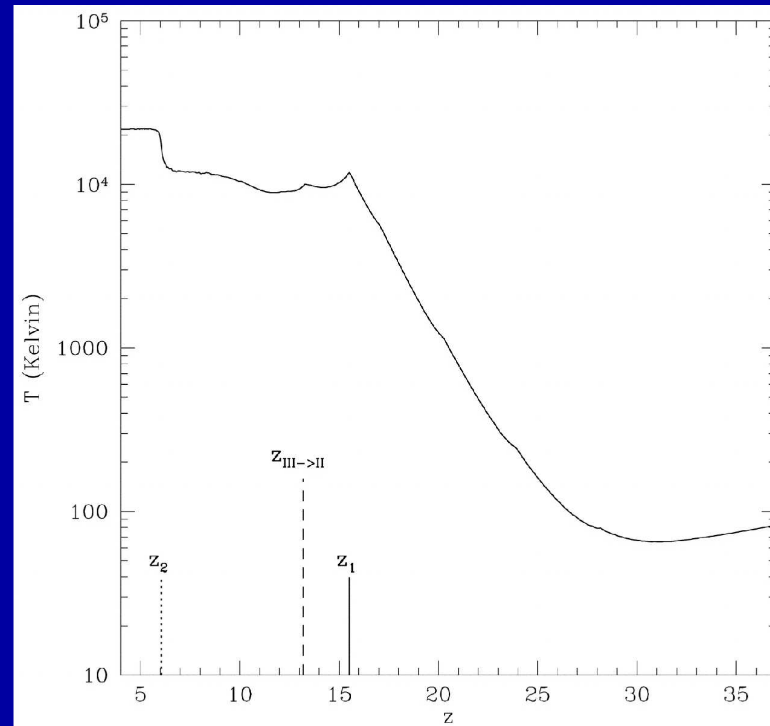
- (3) How large a gap at $\lambda \simeq 2.4$ μm can be tolerated when studying spectral features in starforming regions and stellar populations (McCaughrean)?

- (4) What is the highest redshift where the Lyα line can reasonably be expected to be observable to JWST?

- (5) Can a compromise in the adopted TF wavelength-range be found?

- (6) Or can a few $\sim$3% filters around $\lambda \simeq 1.0 \mu$m be added to NIRCam?



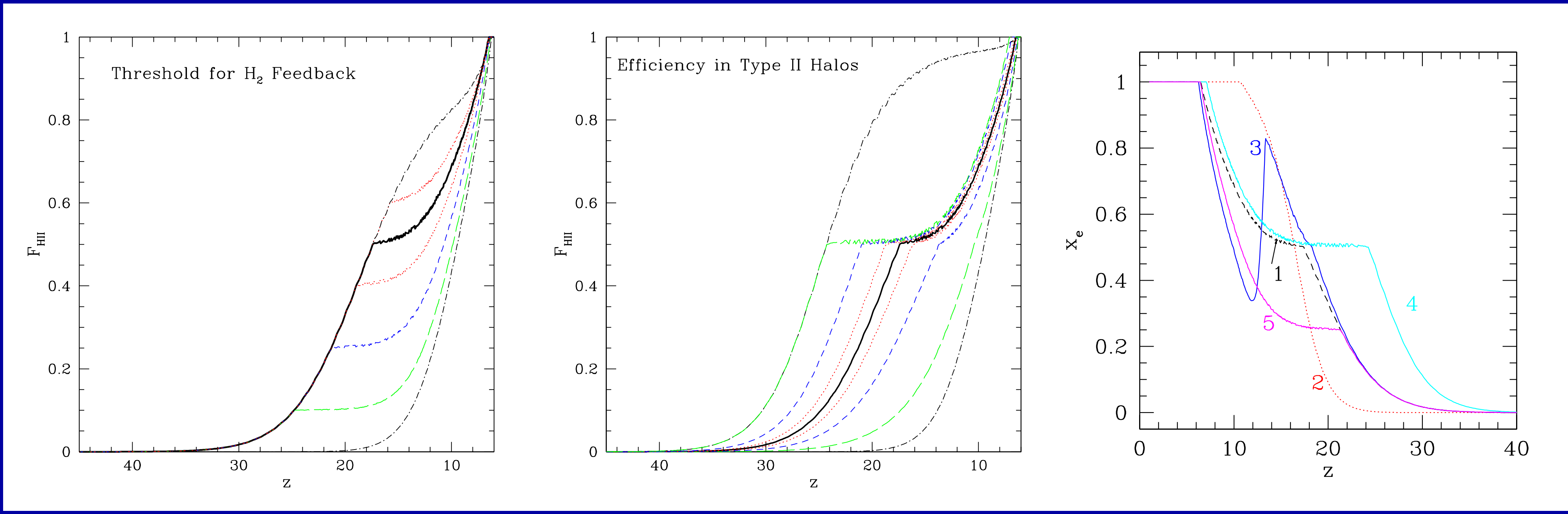


Detailed models based on WMAP results (Cen 2003) suggest that:

- (1) A first epoch of reionization ("First Light") may have been caused by the onset of Population III stars at z$\simeq$15–25. (Other mechanisms have been proposed as well: early AGN, exotic particles, etc.).

- (2) Pop III supernovae may have caused the second Dark Ages at z$=$15$\longrightarrow$10, since they heated the IGM, which could not cool until:

- (3) Pop II stars started to form in dwarf (proto-)galaxies with 10^6–10^9 $M_{\odot}$ at z$\simeq$6–10. These objects concluded the reionization epoch at z$\simeq$6–6.5, as now visible in the GP-troughs of SDSS quasars.

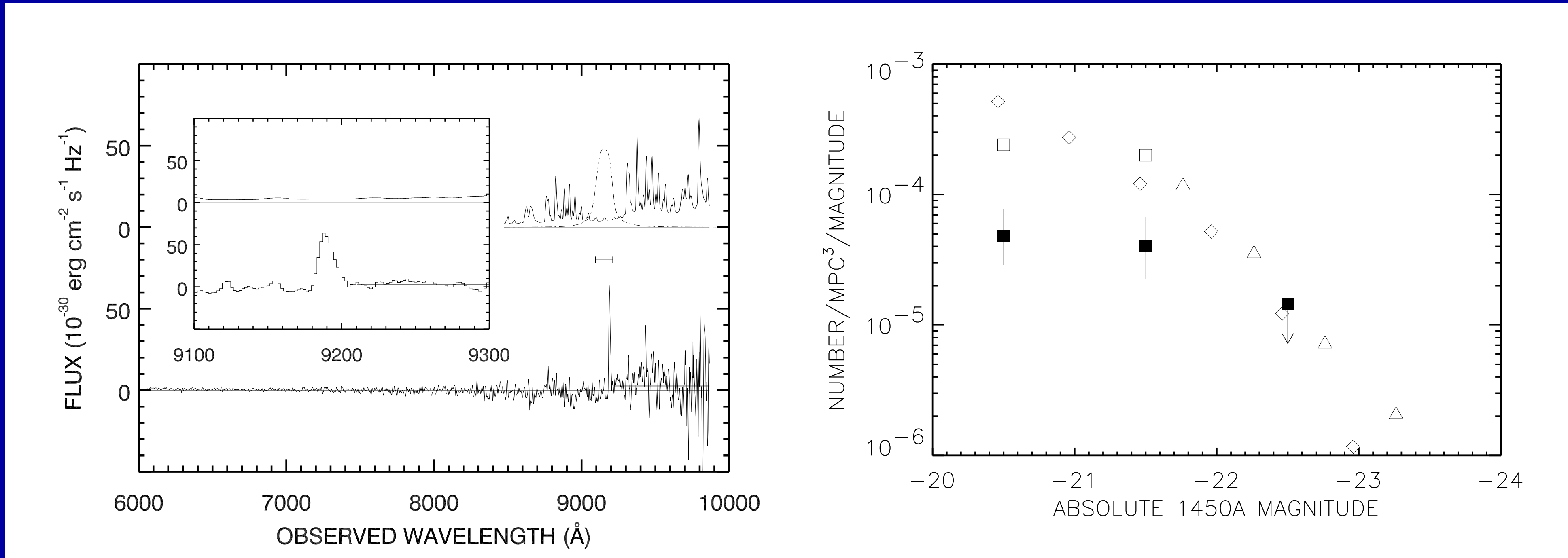


Other models based on WMAP (Holder et al., Haiman et al. 2003) show:

- (1) Widely different reionization scenarios at z$\simeq$25 $\longrightarrow$ z$\simeq$15.
- (2) A general agreement in the increase of HII fraction for z$\simeq$10 $\longrightarrow$ z$\simeq$6, otherwise GP-troughs of SDSS quasars would not be seen at z$\sim$6.

$\Rightarrow$ In most models, a significant increase in the HII fraction is expected in the range z$\simeq$8 $\longrightarrow$ z$\simeq$6.

$\Rightarrow$ Due to foreground HI damping wings, the Lyα line may no longer be visible at z$\gtrsim$7–8, except in some ionized bubbles around transparent objects (Stiavelli 2004). These lines we must try to survey with JWST.

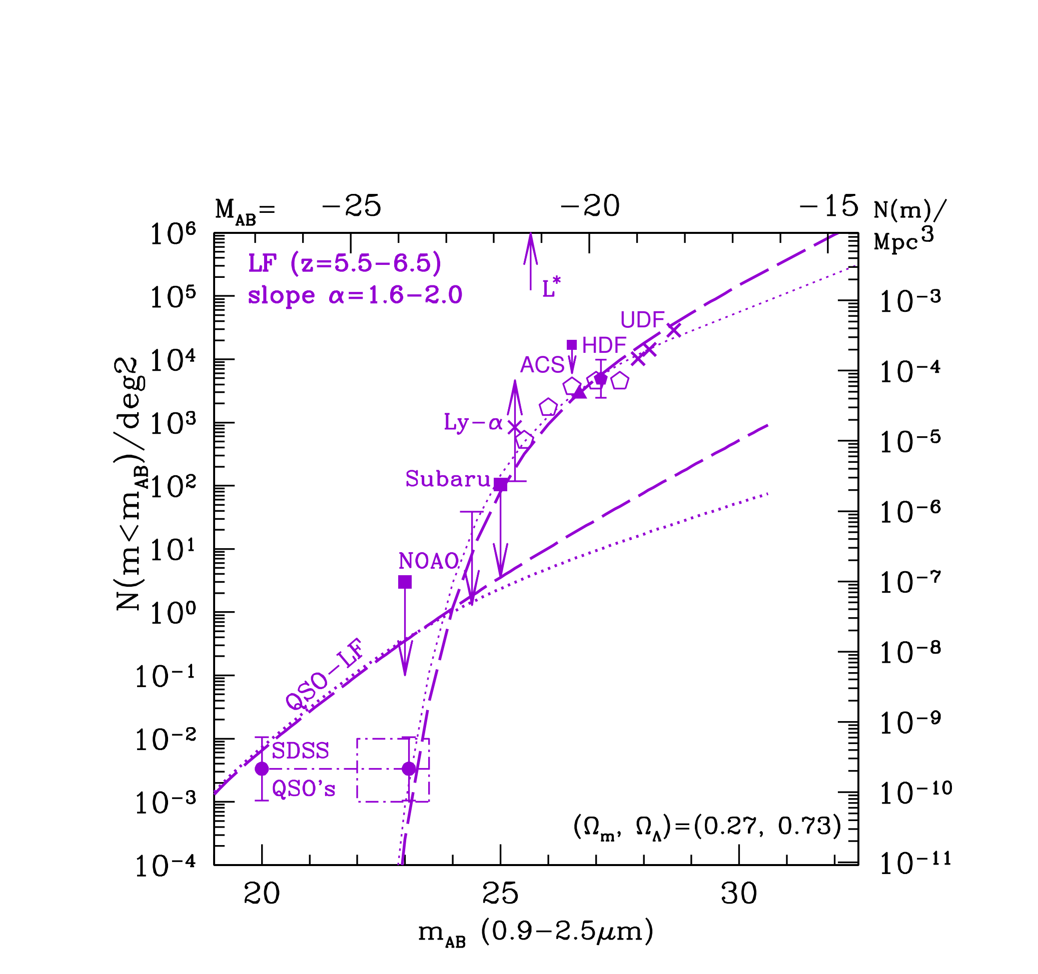


A few narrow-line Lyα objects at $z \gtrsim 6$ are now being seen (Hu et al. 2002).

- (1) From ground-based narrow or medium-band Lyα searches.
- (2) Their LF is likely very steep (Hu et al. 2003, Rhoads et al. 2002)

$\Rightarrow$ We need to prepare to observe Lyα line at the highest redshift where it may be universally observable, i.e. $z \simeq 6.5$–8, which requires the TF to go down to 0.95 μm , or having corresponding filters in NIRCam.

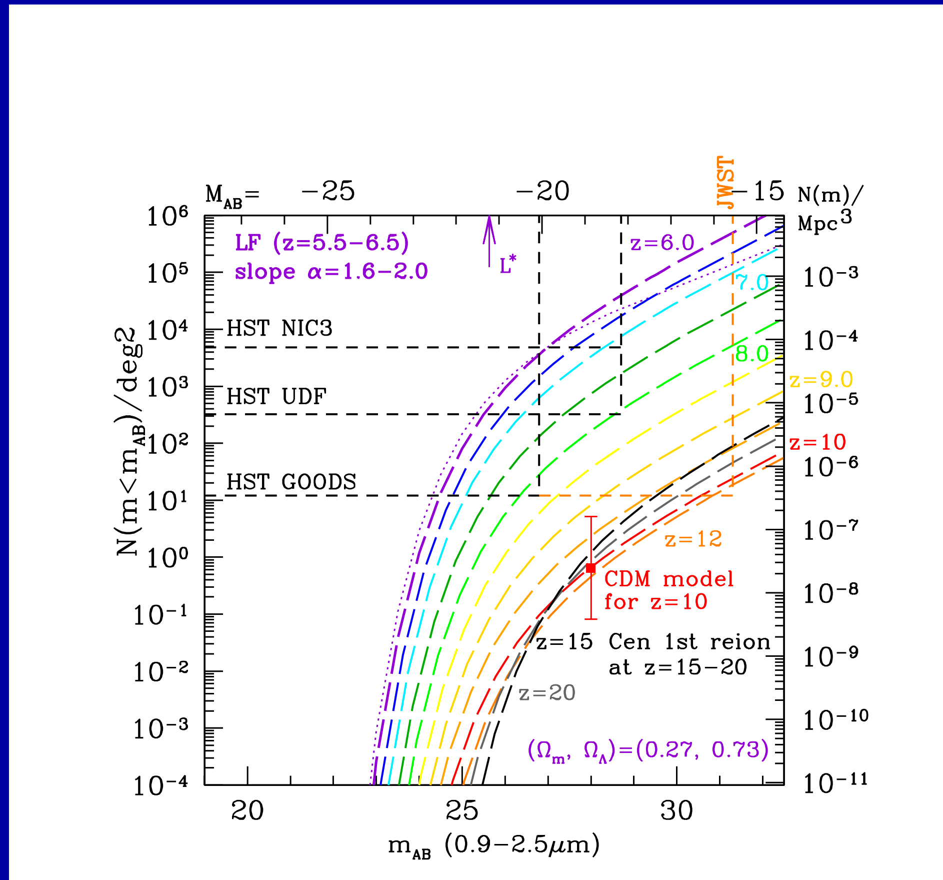
Large numbers of dropouts and Lyα emitters are expected for z$\simeq$6–8.



The luminosity function ("LF") of z$\simeq$6 objects (Yan et al. 2003a, b) is possibly extremely steep. Preliminary UDF points from the released z$\simeq$6 UDF dropout list confirm this (but wait for the final UDF early March).

- Their LF almost violates Olbers' paradox with faint-end Schechter slope $|\alpha|\simeq$2.0. Equal octaves contribute equally to the reionizing background.

⇒ Must probe AB$\gtrsim$27 mag to measure the LF slope for z$\gtrsim$6.5.



• The stars in dwarf galaxies, not quasars, provided enough UV flux to complete the reionization of the universe by z$\simeq$6 (Yan et al. 2003b; Yan & Windhorst 2004). This is what JWST will observe in detail.

• The ionizing OB-stars must have formed between z$\simeq$6.5 and z$\simeq$8 (ages $\tau\simeq$30–200 Myr), but they cannot have pervasively filled the universe at z$\gtrsim$8, or no GP-troughs would be seen in SDSS quasars at z$\simeq$6.

• We must seriously count on the possibility that the dwarf galaxy LF ramps up significantly in amplitude between z$\simeq$8 and z$\simeq$6, or Gunn-Peterson troughs in the spectra of SDSS quasars would not be seen at z$\sim$6.

• The epoch z$\simeq$8 $\rightarrow$ z$\simeq$6 is likely when the first significant and pervasive Population II star-formation took place, where the normal IMF first developed, or the "actual beginning of the galaxy assembly epoch".

$\Rightarrow$ In order to probe this epoch, JWST must be able to observe the Lyα line at z$\simeq$6.5–8 or $\lambda\simeq$0.95–1.1 μm .

$\Rightarrow$ **Faint** flux levels (AB$>>$27 mag) must be reached in order to measure the faint-end slope of the LF.

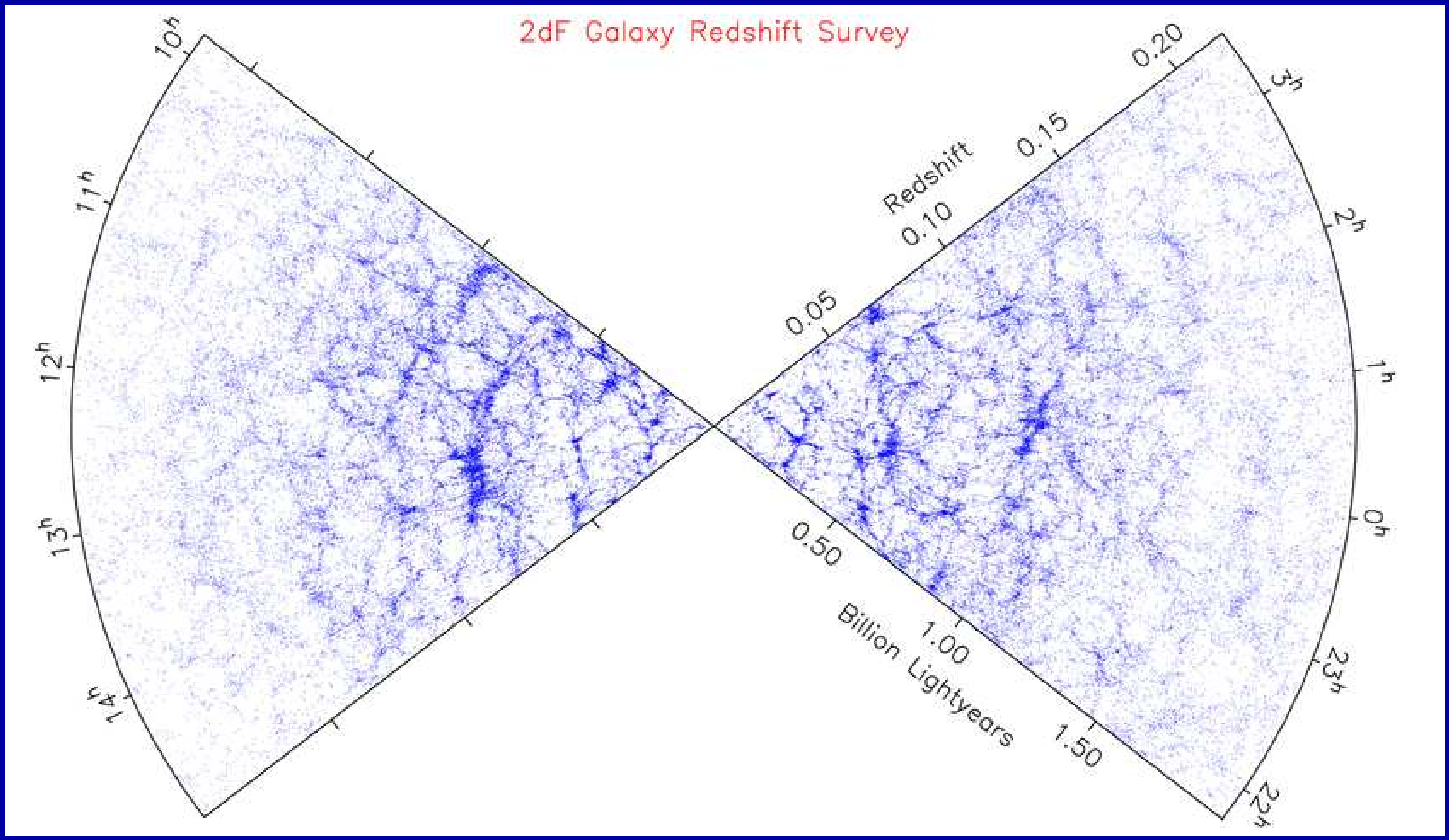
• This cannot be done from the ground because of a subtle conspiracy of observational and cosmological reasons. In summary, these are:

(a) Gaps in the redshift distribution N(z) of galaxies are typically seen at co-moving separations of 60-120 Mpc (Great Walls, etc). Faint redshift surveys with rich statistics reflect this in spikes in N(z) typically $\Delta z \simeq 0.03$ apart locally, and at $\Delta z \simeq 0.03 \times (1+z)$ at higher redshifts.

(b) While there are some gaps between the near-IR OH night-sky lines, these are not wide enough to efficiently sample Lyα over the entire required redshift range.

(c) The relative width of the filters needed to do the corresponding ground-based images increases the night-sky brightness by 3–5 mags, voiding the advantage of a larger ground-based telescope. OH-suppressing spectrographs don't solve this, since they don't cover wide fields for imaging.

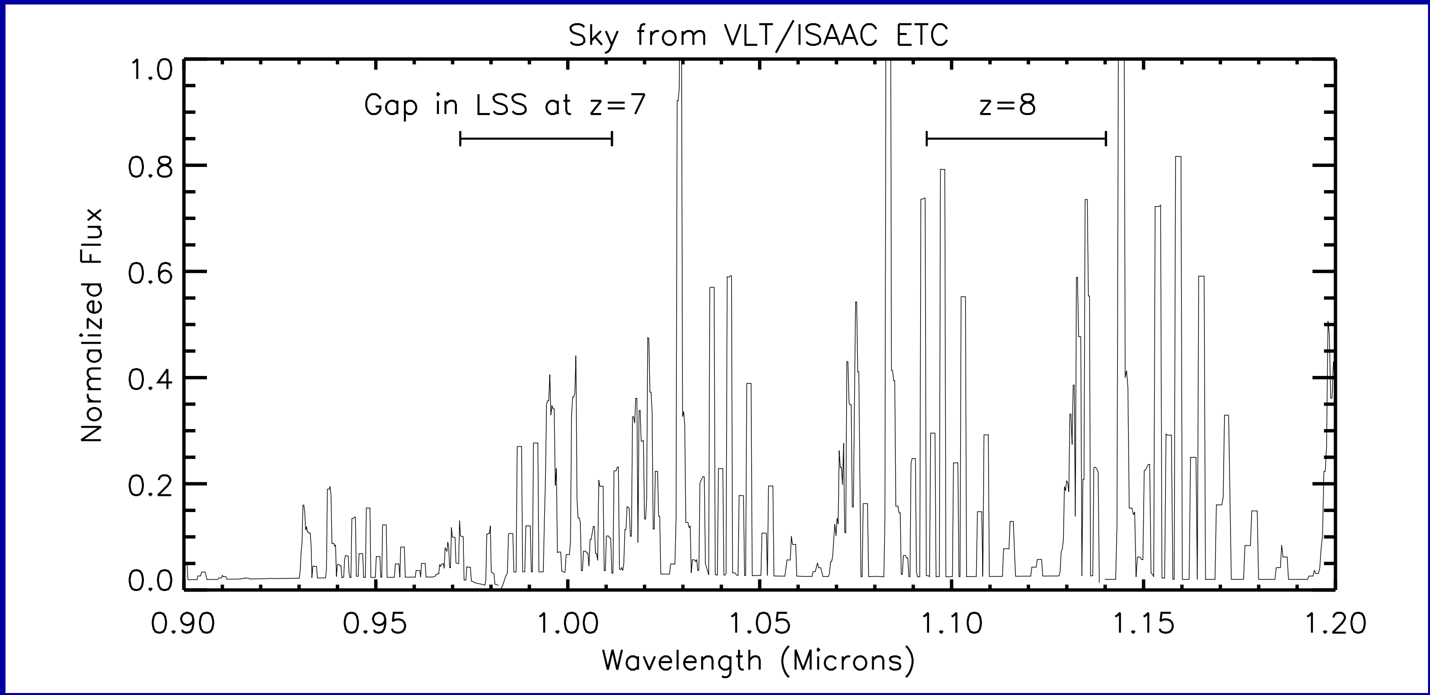
Lyα from AB$\gtrsim$27 objects can't be observed from ground for z$\gtrsim$6.5.



• Large Scale Structure (LSS) has typical spacings in the redshift distribution ("foam") in between which fewer objects are seen in a given LOS.

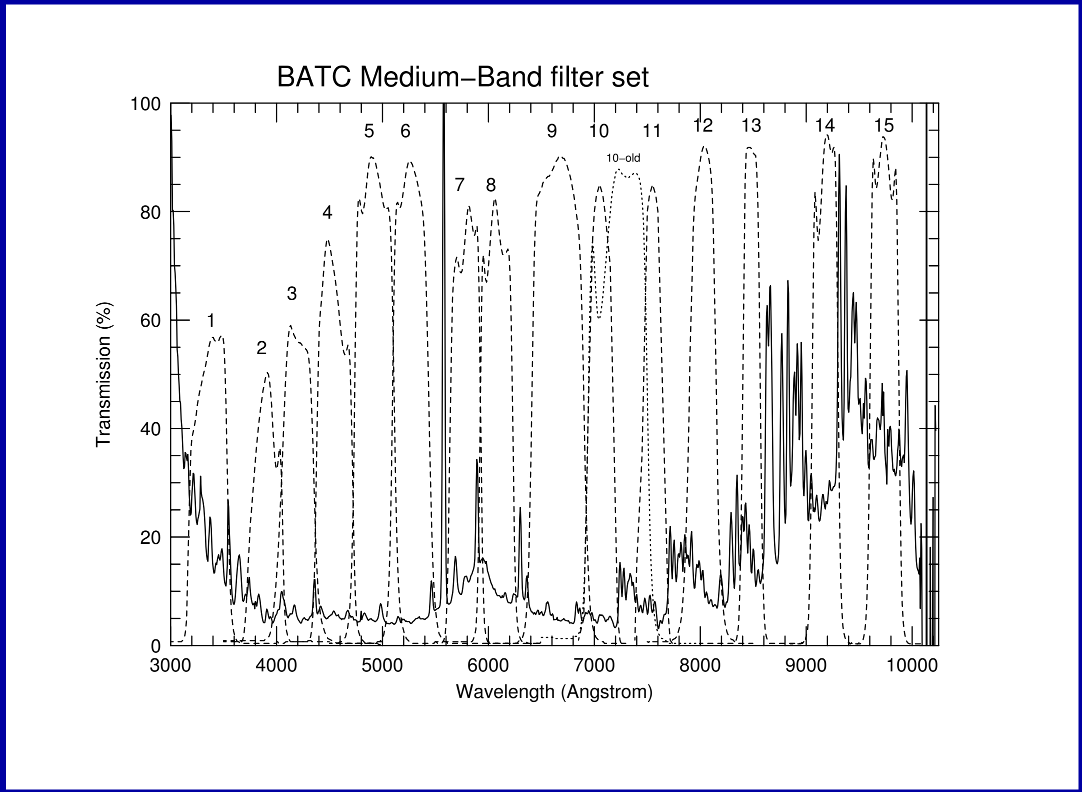
• These structures or "Great Walls" are typically 60-120 Mpc in size and separation.

Gaps in LSS at high-z are larger than any windows in NIR sky-spectrum.



- At z$\simeq$7, 60–120 Mpc corresponds to $\boldsymbol{\Delta\lambda}$ $\simeq$0.02–0.04 μm .
- There are no windows in the near-IR night-sky large enough to counter these effects from LSS $\Rightarrow$ Atmospheric OH-lines limit efficiency of medium (or broad-)band observations from the ground.
- The deepest VLT J–band image reached $J_{AB}$$\simeq$26.8 in 33.6 hours (Labbe et al. 2003). We require $AB$$\gtrsim$27–31 mag.
- The required medium-band imaging for 0.95$\lesssim\boldsymbol{\lambda}\lesssim$1.2 μm can only be done from space. It would require 100's of nights on 8-10 m telescopes.

Ground-based medium-band imaging/spectroscopy between the sky-lines.



- Some imaging has been done on ground-based 4-8 m telescopes (Wolfe et al. 2001; Rhoads et al. 2002; Yan et al. 2002; Kodaira et al. 2003). Modest numbers of $z \simeq 5.7$–6.6 objects were found to AB=24-25.5 mag.
- The near-IR sky in between the brightest sky-lines is not completely dark, neither is the transparency (mag/sec(z)) necessarily small (7600Å !).
- The best search technique uses a grism filtered between the sky-lines with multislit follow-up (Lilly et al. 2003). Possibly $\gtrsim$0.1 sq. deg. has to be surveyed to AB$\gtrsim$25 mag to get a significant sample at $z \gtrsim 6.5$.

In conclusion:

• Very deep medium-band TF searches at z=6.5–8 will see enormous numbers of faint Lyα emitters, an extremely efficient use of JWST survey time.

• We must try to find a solution to let the TF cover 0.95–1.10 μm , without jeopardizing the brown dwarf/planetary science at the long wavelength end or the star-formation science around 2.4 μm .

• Failing to do so may result in JWST missing out on:

(1) The end of the reionization era;

(2) The beginning of the galaxy assembly line; and

(3) The development of the first Pop II stars and their Initial Mass Function.