WFIRST and JWST synergies in the study of First Light

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WFIRST and JWST synergies in the study of First Light

Plan:

- Detecting the First Stars
  - ★ WFIRST-AFTA as an object finder for JWST
- Detection the First Galaxies
- Detecting the First Active Galactic Nuclei
  - ★ WFIRST-AFTA as a follow-up tool to JWST

First Stars

First Light

First Stars

Population III stars : primordial composition

- what are the expect properties?
- how do we find them?
  - direct detection
  - detection of small galaxies made of Pop III stars
  - detection of supernovae

First Stars are faint

For redshift z=10–25 the apparent magnitude is:

m_{1400} ~ 38.5–40 ⇨ too faint for JWST

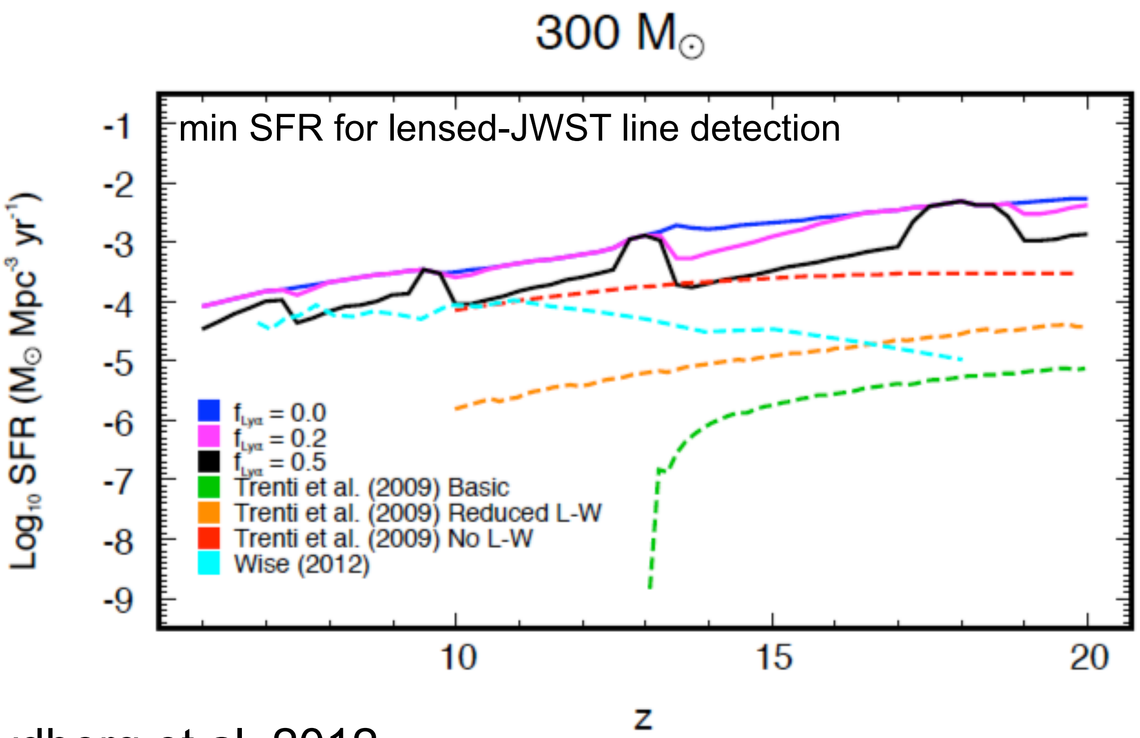
An HII region would have Lymanα emission at:

(5.5–0.7) 10^{-21} erg s^{-1} cm^{-2} which is also too faint.

One possibility could be gravitational lensing amplification by a factor ~100 or more.

First Stars are rare

Lyman-Werner feedback hinders the formation of Population III stars in mini-halos reducing their numbers (e.g. from green to red curve for the Trenti et al. models).



Rydberg et al. 2012

We can expect of the order 0.1-10 per square arcsec per $\Delta z=1$.

Supersonic streaming (Greif et al. 2011) could decrease these numbers.

Direct detection

It seems unlikely that the combination of rarity and faintness will enable direct detection of Pop III stars even considering lensing. (see also Rydberg et al. 2013).

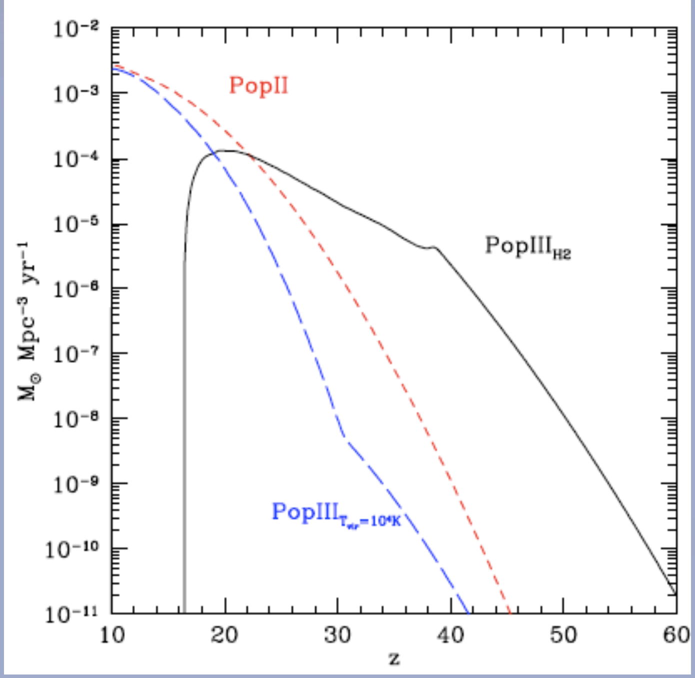
We currently do not expect the formation of significant clusters of Pop III stars (only the total mass in Pop III stars matters as their luminosity is close to Eddington).

Supernovae

The two main issues are supernova brightness and rarity. The brightness is likely not an issue if Population III stars are massive enough to produce pair-instability supernovae (but there is uncertainty on the IMF). Rarity is harder to assess.

PISN Supernovae – expected rates

Weinmann & Lilly (2005) elaborating on previous results suggest densities of 4 $deg^{-2}\ yr^{-1}$ at z~15 and 0.2 $deg^{-2}\ yr^{-1}$ at z~25. The actual numbers will be lower because of negative feedback on mini-halos. However, SNae from atomic hydrogen cooling halos could boost up the rate.

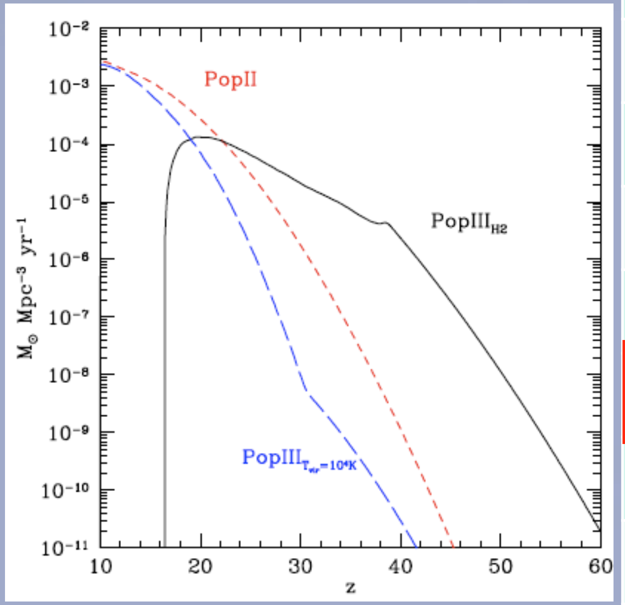


"Optimistic" model by Trenti & Stiavelli 2009. With enhanced formation of Pop III in atomic H cooling halos we could have PISN could be as common as ~1 $deg^{-2}\ yr^{-1}$. A reasonably conservative limit could be ten times lower.

PISN Supernovae – expected rates

There is significant model uncertainty on these rates.

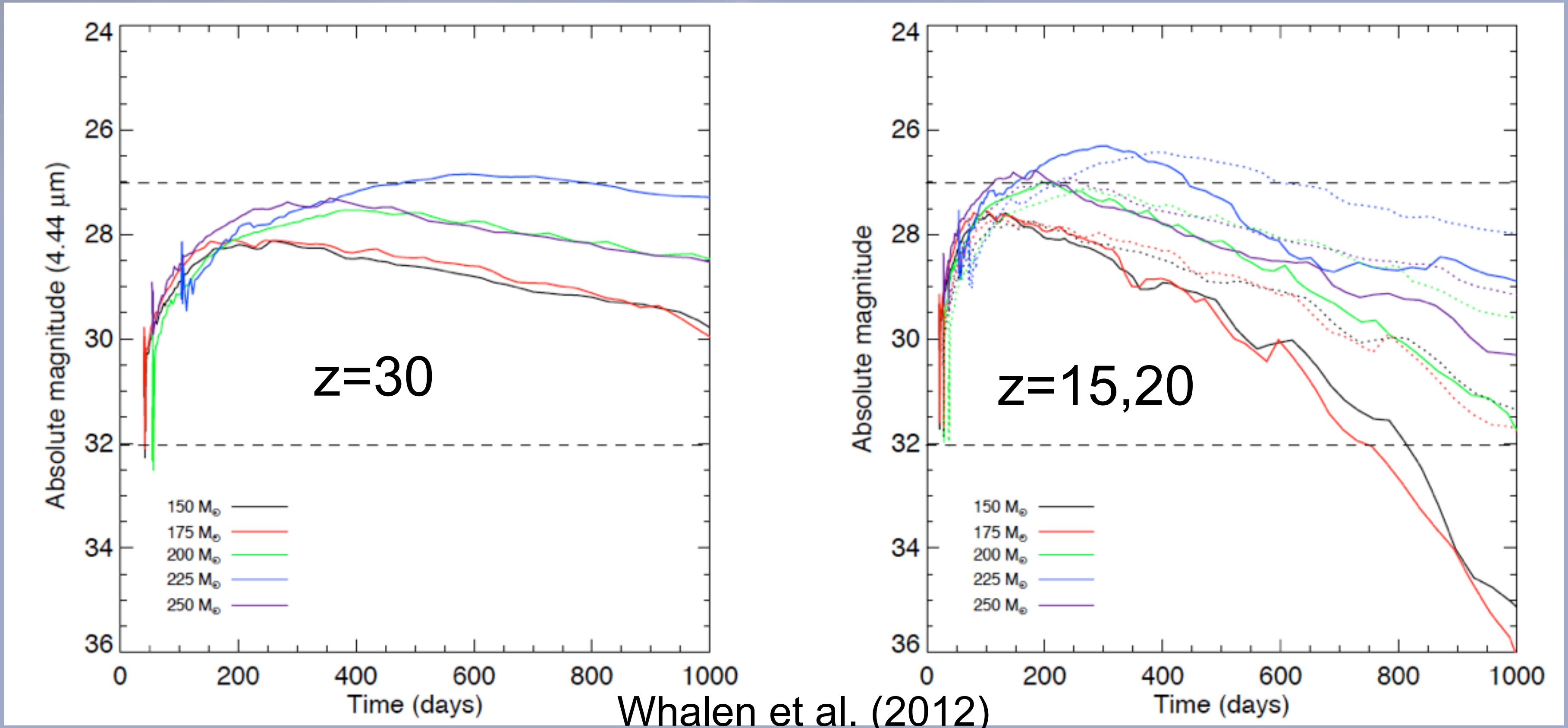
We can track the intensity and redshift of the peak formation of Pop III in mini-halos and the redshift at which Pop III mini-halo formation rate exceeds that of Pop III forming in larger neutral Hydrogen cooling halos as a function of model assumptions (Stiavelli & Trenti 2009).



model	z(H2 peak)	SFR(H2 peak)	z(H2=HI)
standard	24	10	14.5
less LW	24	4.5x10	<10
no LW	18.5	3x10	N/A
strong external J21	27	8.5x10	18
PS mass f.	22	8x10	13.5
multiple stars	20.5	1.3x10	18.5
multiple stars Hi.Ef.	24	2x10	23.5
multiple stars HI	24	10	20.5

PISN Supernovae – light curves

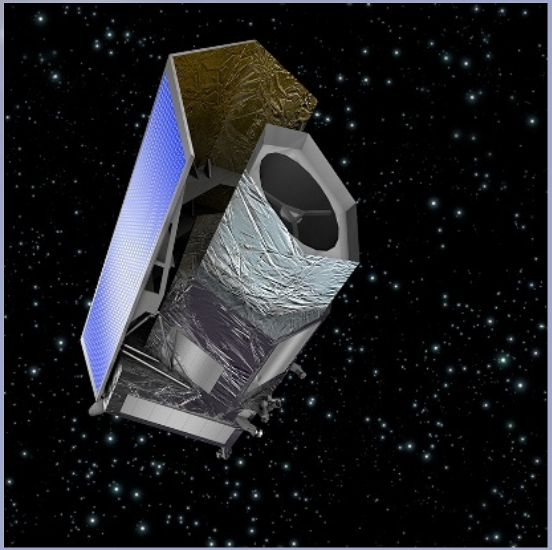
Light curves by Whalen et al. (2012) show that PISN are “easy” for JWST if we know where to look. At lower z they are within reach of WFIRST-AFTA.



Whalen et al. (2012)

PISN Supernovae – finding them

WFIRST has the field of view, sensitivity and wavelength coverage make it ideal to discover PISN up to z~15 (2 μm red limit) or ~20 (2.5μm red limit).



This requires WFIRST-AFTA to fly before JWST end of mission.

Not finding enough Pop III PISN would provide a crucial test for our models or possibly indicate that the dark matter spectrum is not that of CDM → WDM (e.g. few kev Majorana neutrinos) and CDM differ dramatically in their predictions for mini-halos.

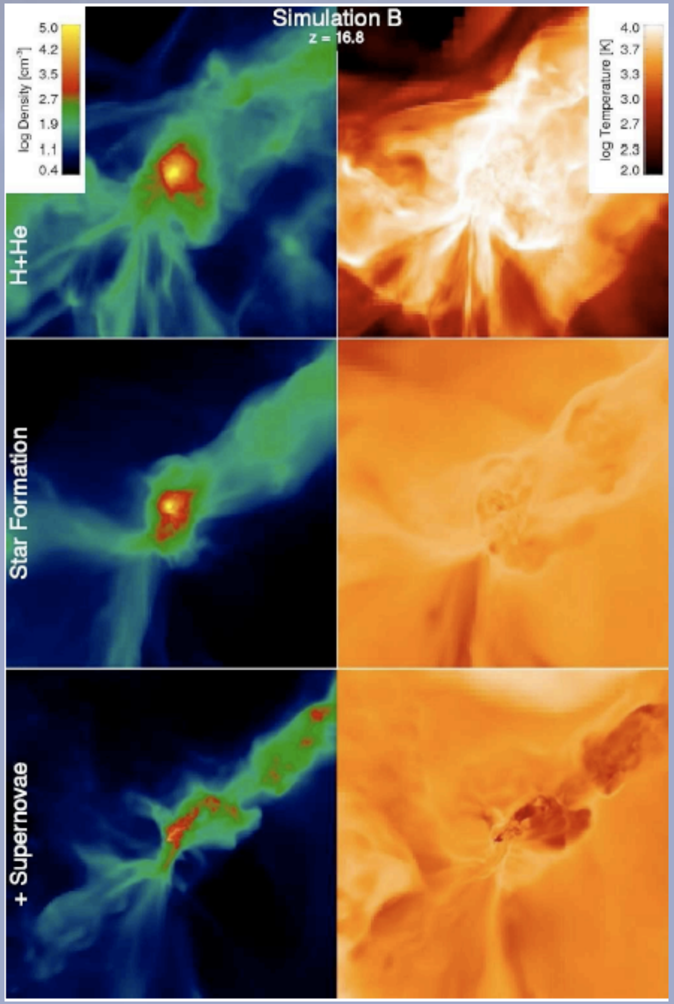
Our models predict that the transition between Pop III formed in mini-halo (probing the DM spectrum) and those from H-cooling halos (DM spectrum independent) could take place at z~13-20 (excluding some of the most unrealistic models).

The First Galaxies

Numerical simulations for the formation of the first galaxies has been focussed so far on the early evolution of halos with mass $\lesssim 10^8 M_\odot$ (e.g. Wise & Abel 2008, Greif et al. 2008).

These objects are too faint to be observable with JWST. However, they are already enriched to $\sim 10^{-3} Z_\odot$.

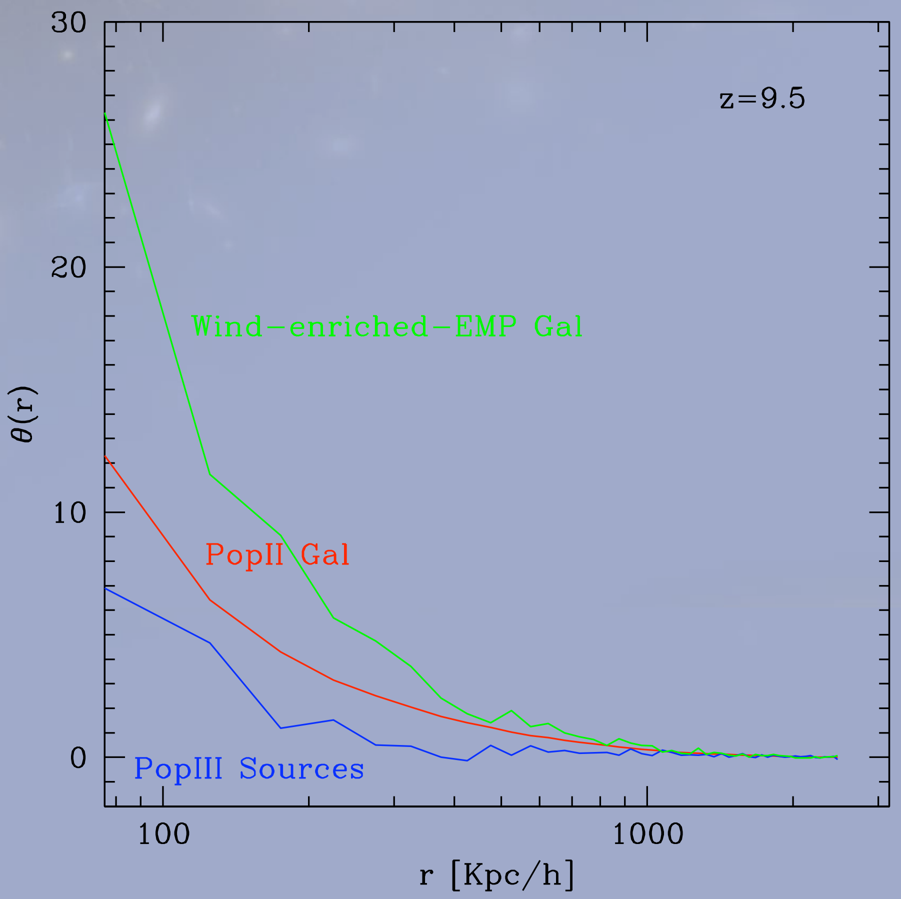
For this chemically enriched population see talks by Brant, Pascal, Rychard.



Clustering and metallicity

It is possible to form a dwarf galaxy of Population III stars in a late forming halo that has been kept pristine by the Lyman-Werner background set up by the early generations of Population III stars.

These Pop III galaxies would not be clustered because clustered objects are chemically polluted. (Stiavelli&Trenti 2010).

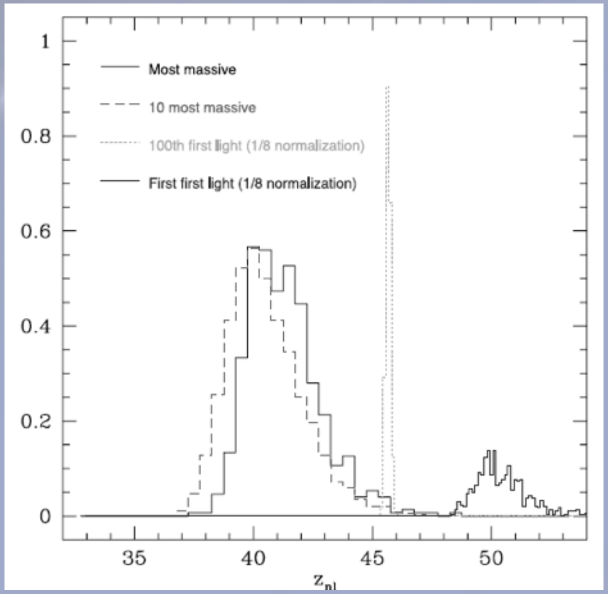


We might be able to observe these Pop III galaxies if lensed. We expect ~80 $arcmin^{-2}$ per unit z. With 1% star formation efficiency they would be AB~32. Modest lensing would make them detectable by JWST

The First AGNs

Early Black Hole growth

We do not know how the SDSS z=6 QSO black holes form. Direct growth from stellar mass seeds is made difficult by merger kicks and by the need for constant Eddington limit accretion. However, there are tens of thousands of seeds available for each QSO so an unlikely combination might still work.



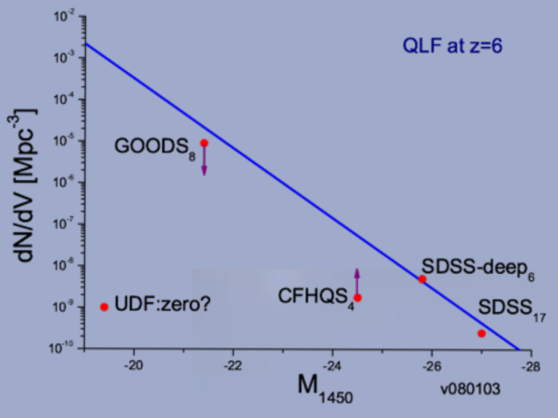
Direct collapse in 10^8 M$_\odot$ halos (Bromm&Loeb 2003, Begelman et al. 2006) forming ~10^4 M$_\odot$ black holes requires halos that are not pre-enriched by mini-halos. This leads to anti-biased QSOs → z~6 QSOs should not be in overdensities.

Direct discrimination → detecting 10^3 M$_\odot$ black holes

First Active Galactic Nuclei

The stellar mass black hole remnants of Pop III stars are not directly observable. The star is already at the Eddington luminosity so the mini-AGN is not any brighter.

The Eddington luminosity of a $10^4\ M_\odot$ black hole is $\sim 3\times10^8\ L_\odot$. At z~10 with a typical QSO spectrum this corresponds to H_{AB}~31. Thus, discriminating between the growth from stellar seeds and direct collapse by the presence or absence of $10^3\ M_\odot$ black holes is problematic.



The z=6 QSO LF is in principle measurable to low luminosities. It would be useful to predict what it should be in the various models (figure from Jian Su).

Environment of AGNs

If direct discrimination is hard, can we learn something from AGN environment?

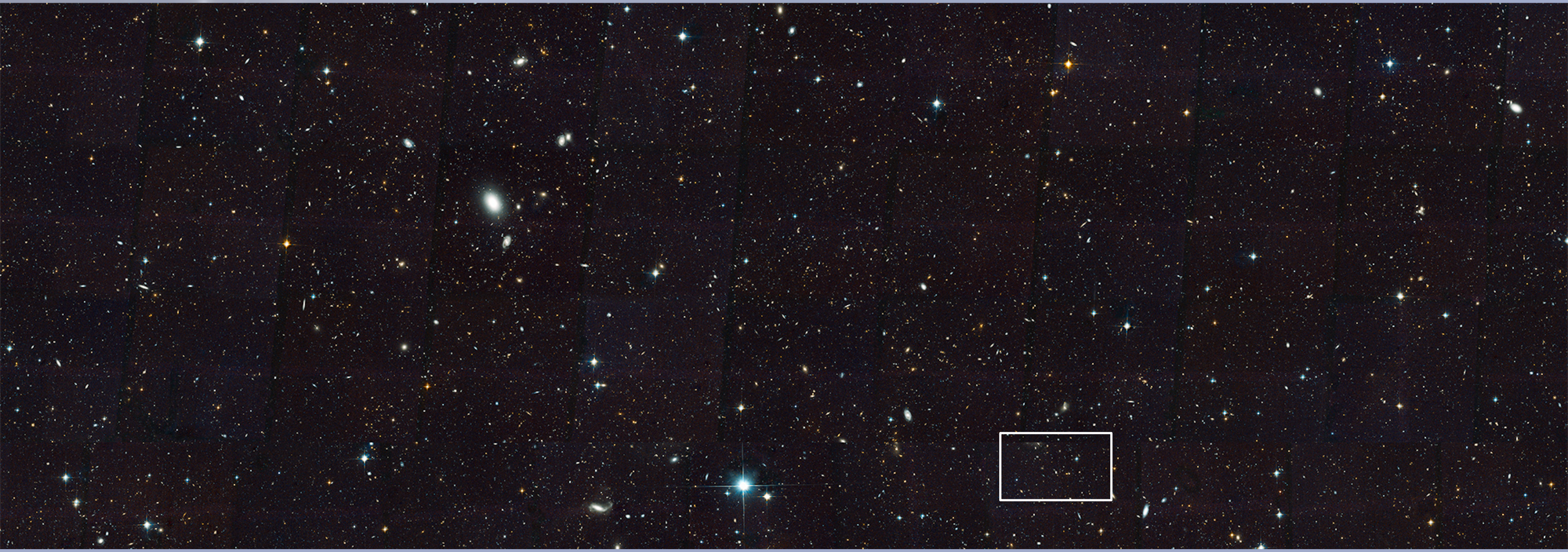
Results on z~6 QSO are not conclusive. From HST imaging of 5 z~6 QSO fields Kim et al. (2009) found only 1 to be overdense at a statistically significant level (Stiavelli et al. 2005).

Utsumi et al. (2010) find an overdensity at large radii around a z~6.4 QSO. No galaxies are found within 2 Mpc of the QSO. Thus, this field would not be recognized as overdense in Kim et al. (2009). "Holes" in the immediate vicinity of the QSO could be cause by negative radiative feedback.

No overdensity is seen with HST around the z = 7.0842 quasar ULAS J112001.48+064124.3 (but again could be due to a "hole" due to QSO negative feedback).

Environment of AGNs

Need to look at z~6-7 QSOs environment at least as faint as 27-28 AB and over a large field of view → **WFIRST-AFTA**



Comparison of the HST WFC3 IR F.O.V. with that of WFIRST

Environment of AGNs

In addition to large radii one will want to study also the near environment of high-z AGN. JWST coronographs provide ~10^{-6} suppression while those on WFIRST will reach much higher contrast enabling the study of fainter companions/substructure in the AGN vicinity.

Conclusions

- Detection of Population III stars is best done through identification of PISN. These objects are rare and would require WFIRST-AFTA to find them.
- Understanding the origin of the first AGNs needs probably to rely on studying early AGN environments as the two leading scenarios differ in their predictions on AGN overdensities. WFIRST-AFTA would follow-up complement JWST studies by enabling the study of the environment over a larger area and for fainter sources in the AGN vicinity.