Cosmic Dawn and Reionization

Science objectives chosen by the Decadal Survey committee for the decade 2012-2021 are

- first stars, galaxies, and black holes
- seeking nearby habitable planets; and
- fundamental physics of the universe

Cosmic Dawn with WFIRST

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WFIRST can do high-z science most efficiently

A. Properties of first stars, galaxies, quasars

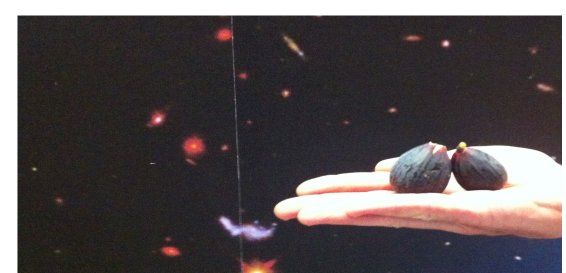
B. Reionization

When: and how long?

Who: quasars, galaxies – big, small?

Where: how inhomogeneous?

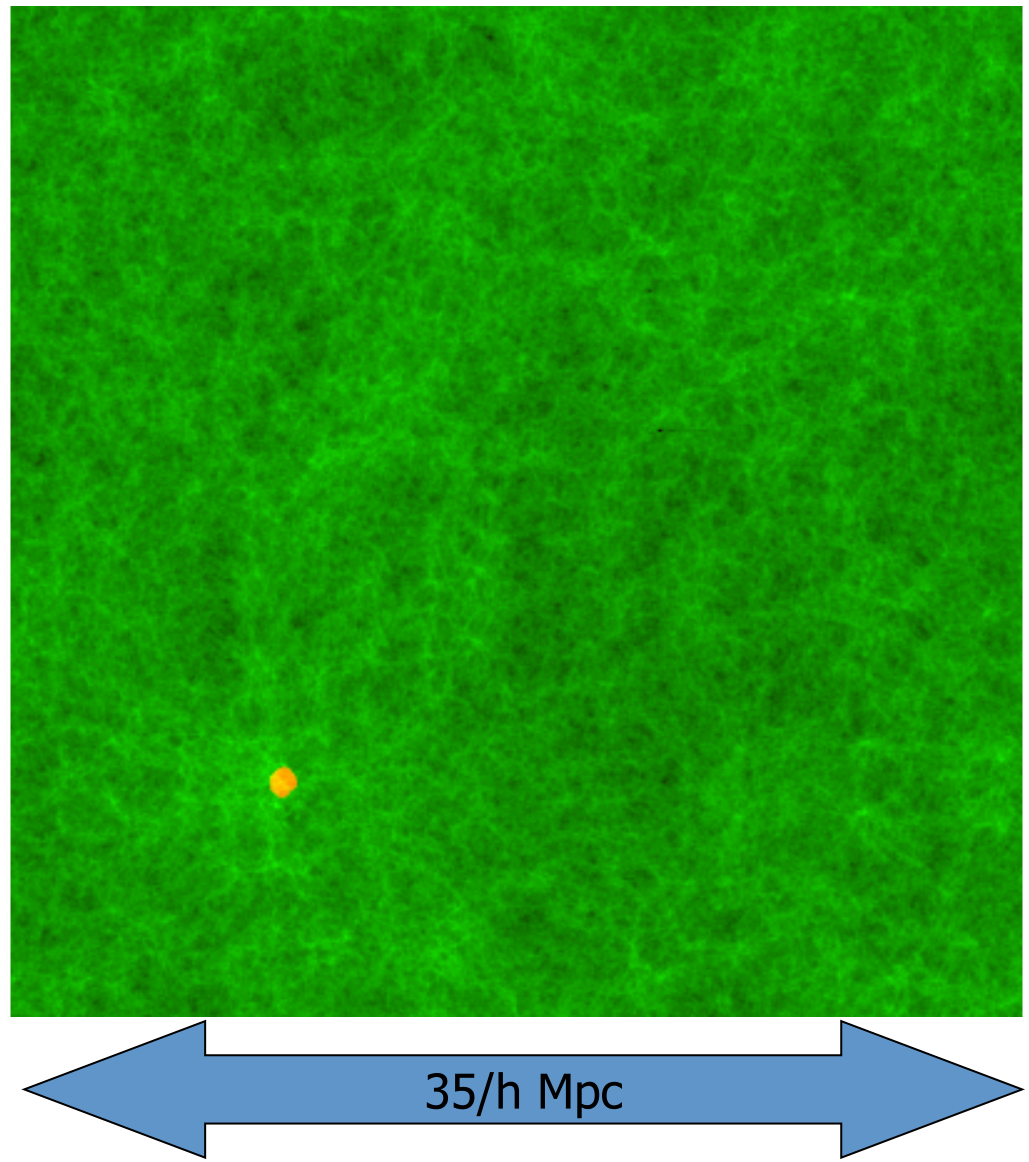
C. High redshift science with slitless grism spectroscopy on HST.



Reionization Simulation (Iliev et al): A picture to keep in mind in this discussion.

- Movie of density field and HII regions
- Green: neutral
- Red: Ionized

- Note: clustering & overlap.
- From start of reionization to nearly its end.
- (z=20 to 10 for WMAP3 parameters).



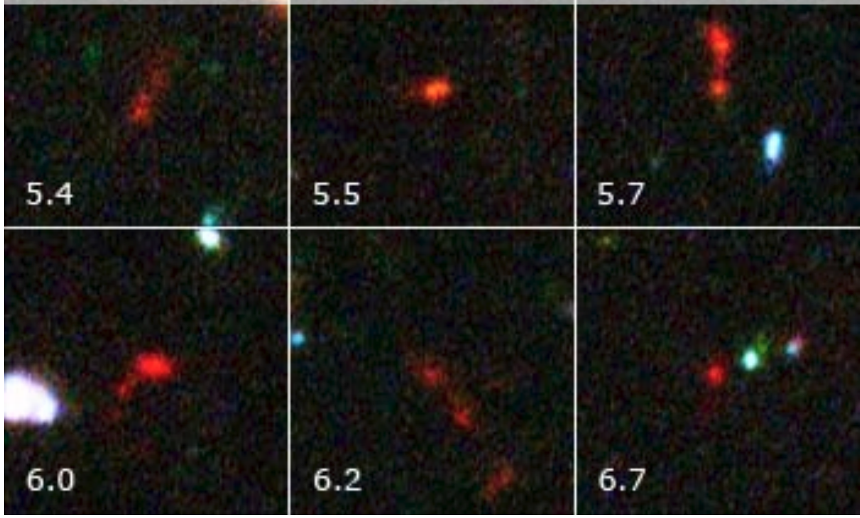
Ways to Study Reionization

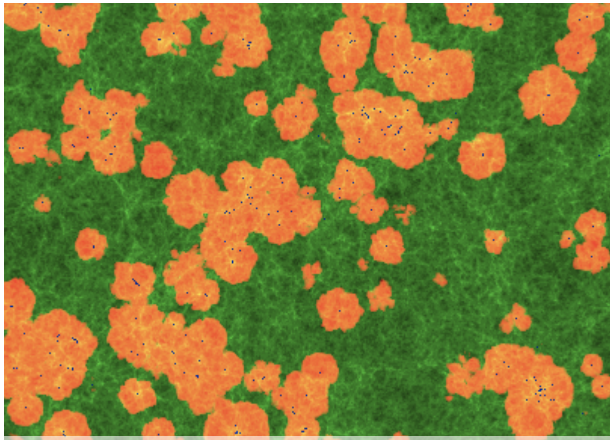
- Look for the ionizing sources, estimate ionizing photon production, and compare to requirements for (re)ionization.
  - Galaxies
  - Quasars [or AGN more generally]

- Look for evidence of neutral gas and/or evidence of free electrons.
  - Lyman alpha galaxy statistics
  - Quasar spectroscopy

- We will explore all of these in detail for WFIRST capabilities.

Lyman break galaxies with HST slitless grism redshifts from Malhotra et al 2005

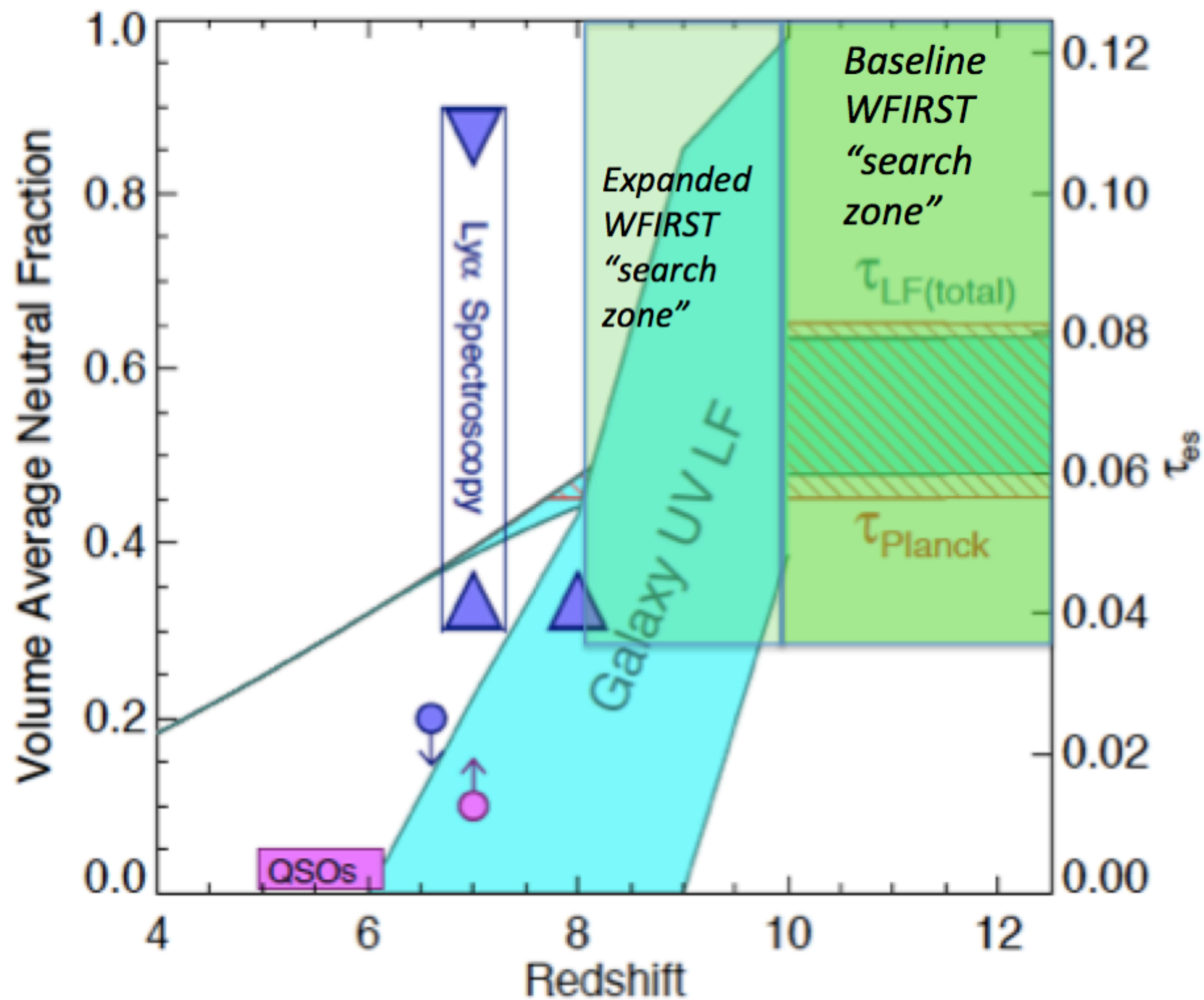




Mellema, Iliev, Pen, Merz, Shapiro, & Alvarez: reionization simulation

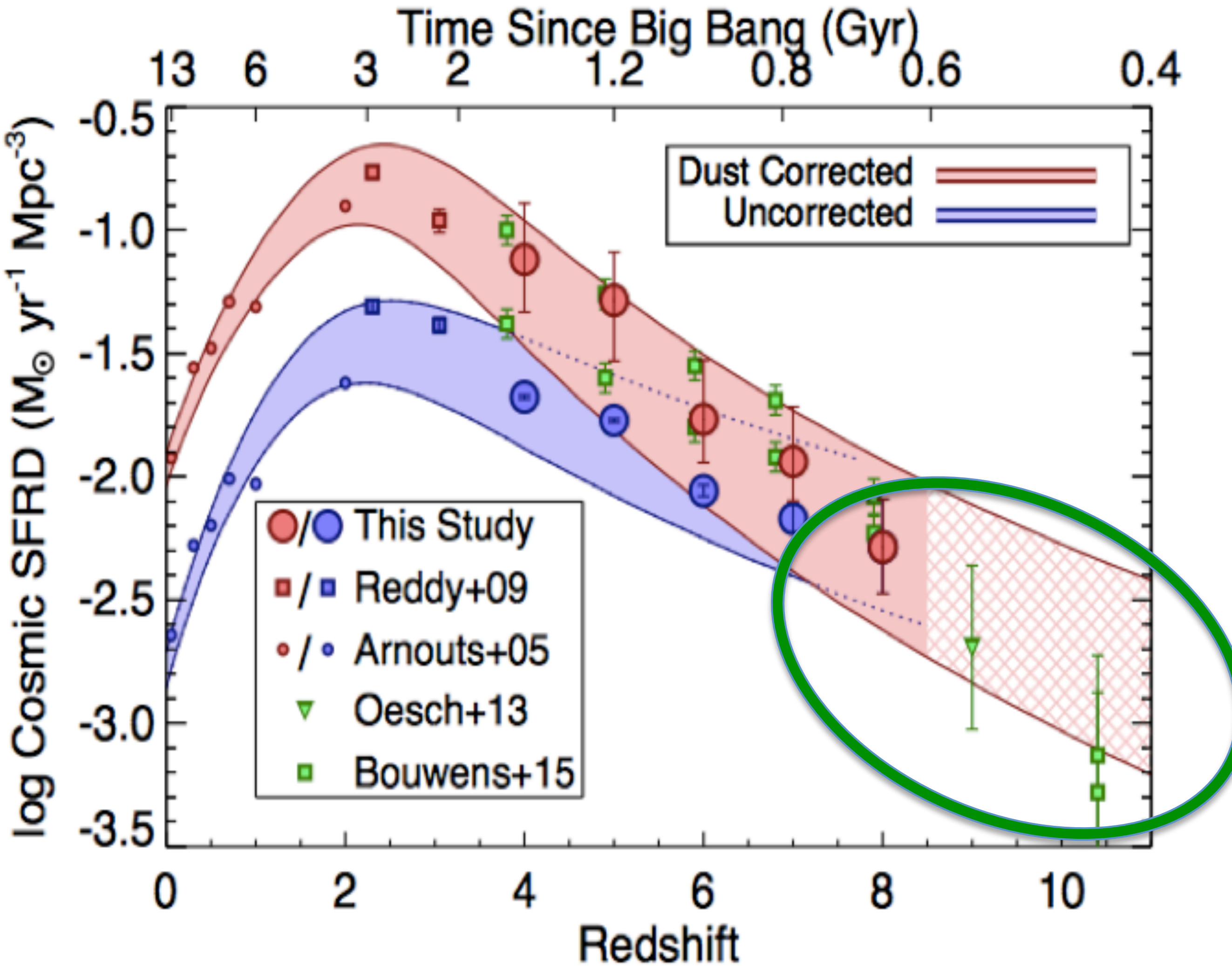
Studying Cosmic Dawn with WFIRST

The volume-averaged neutral fraction as a function of redshift, with constraints from quasars (magenta), Lyman alpha (dark blue), and UV photon production (cyan). The region that can be probed by WFIRST GO spectroscopy is shown in green, both for the baseline WFIRST grism and for a prospective change to the grism's blue wavelength cutoff that we will examine as a trade study.



Hunting the Sources of Reionization: Star Forming Galaxies

- Star formation rate density history from Finkelstein et al 2015.
- WFIRST GO/GI surveys will help fill out the high-z end of this with incredible sample sizes.
- Will complement small but deeper JWST fields.

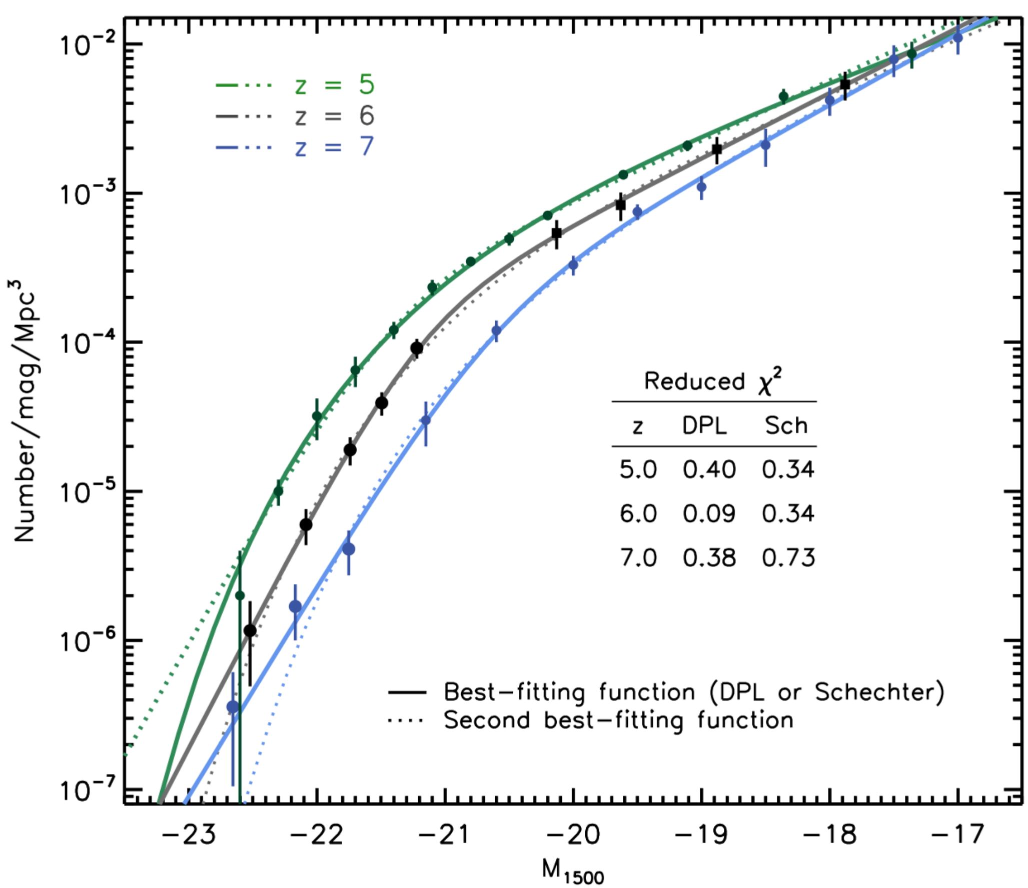


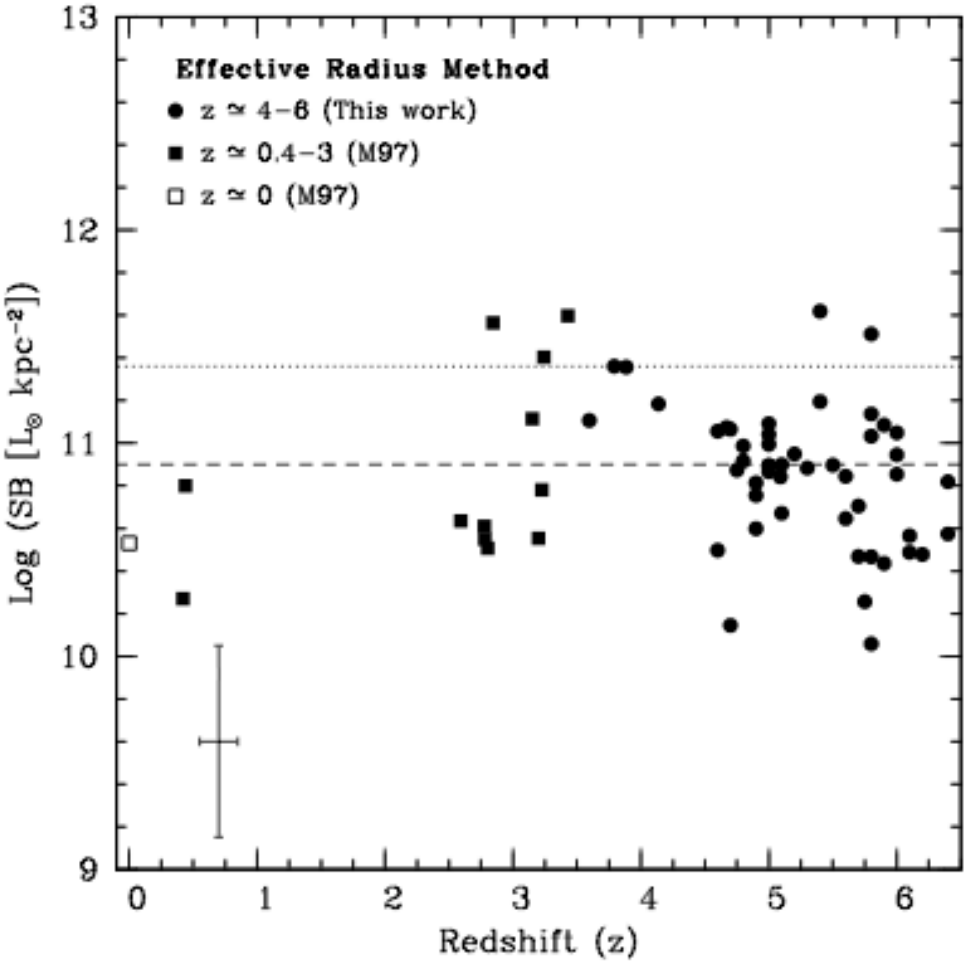
Hunting the Sources of Reionization: Star Forming Galaxies

- When you have this many objects, you can do new things:
- E.g.: Test recent suggestions that the $z \sim 7$ galaxy luminosity function has an excess of bright sources (Bowler et al 2013)
- With WFIRST, we can look for deviations from Schechter functions with high statistical significance.
- Physical implications: Testing feedback...

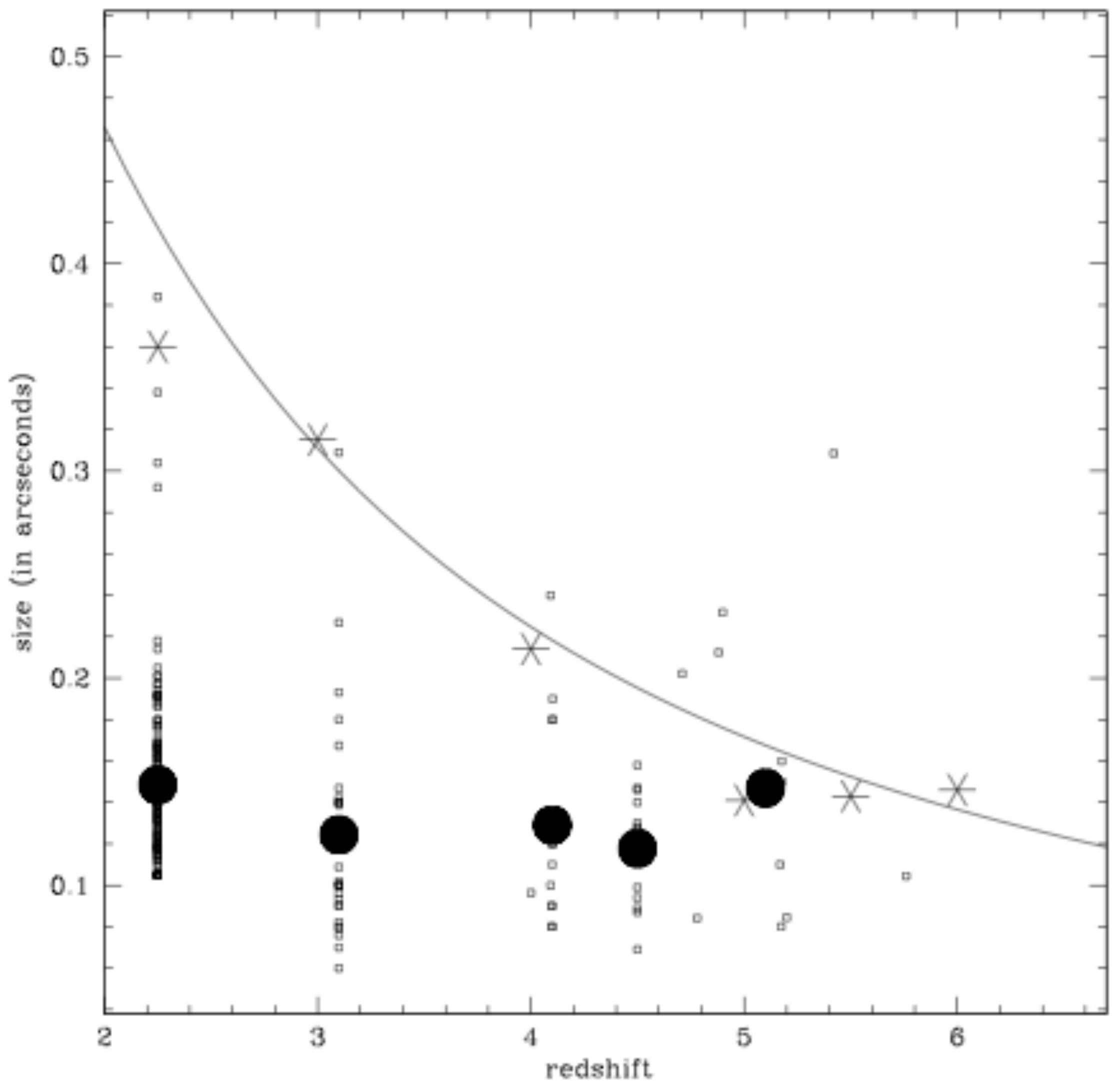
Luminosity functions at z ~7

Bowler et al. 2015





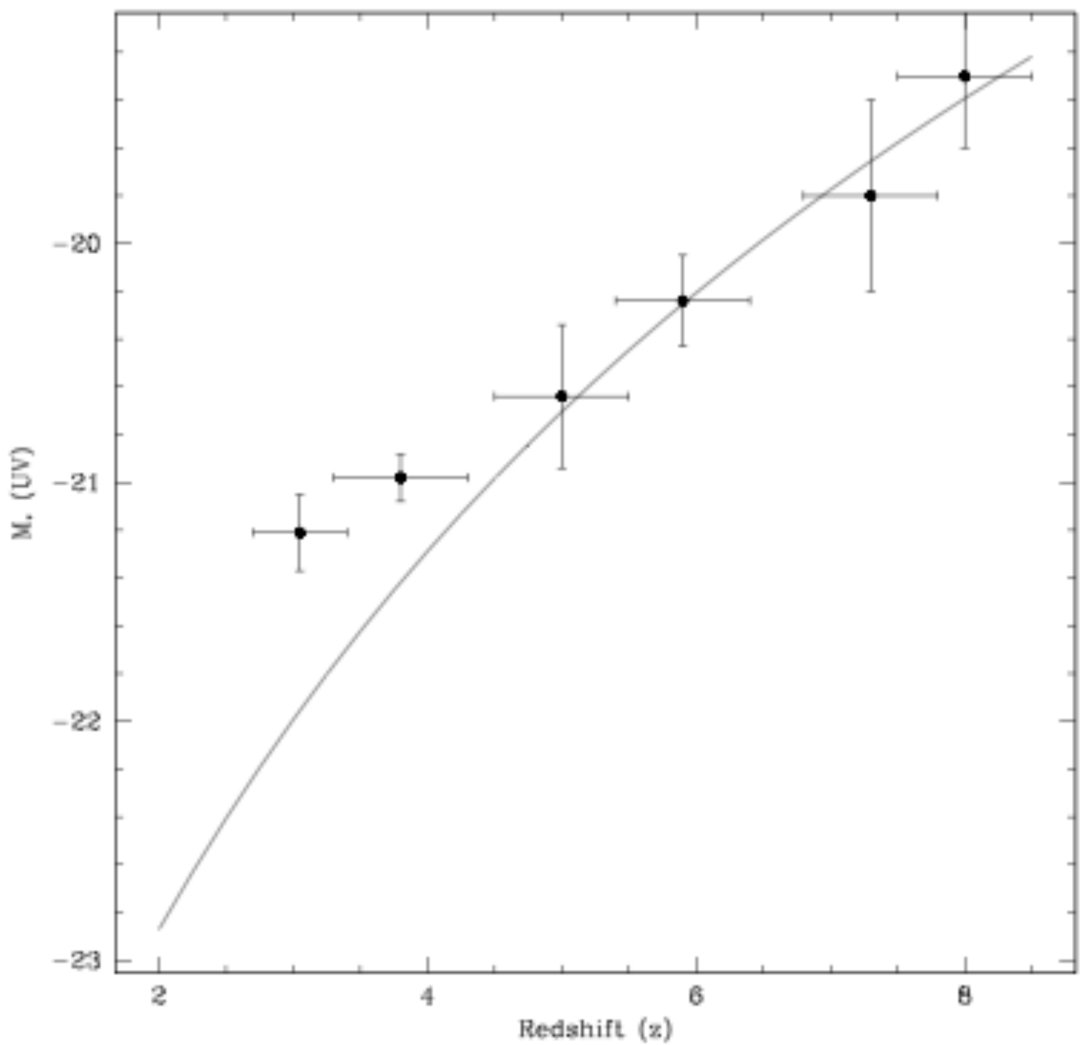
Hathi et al. 2008



Size(radius) vs Redshift: stars are LBG, Dots are Ly-alpha emitters.

Malhotra et al. 2013

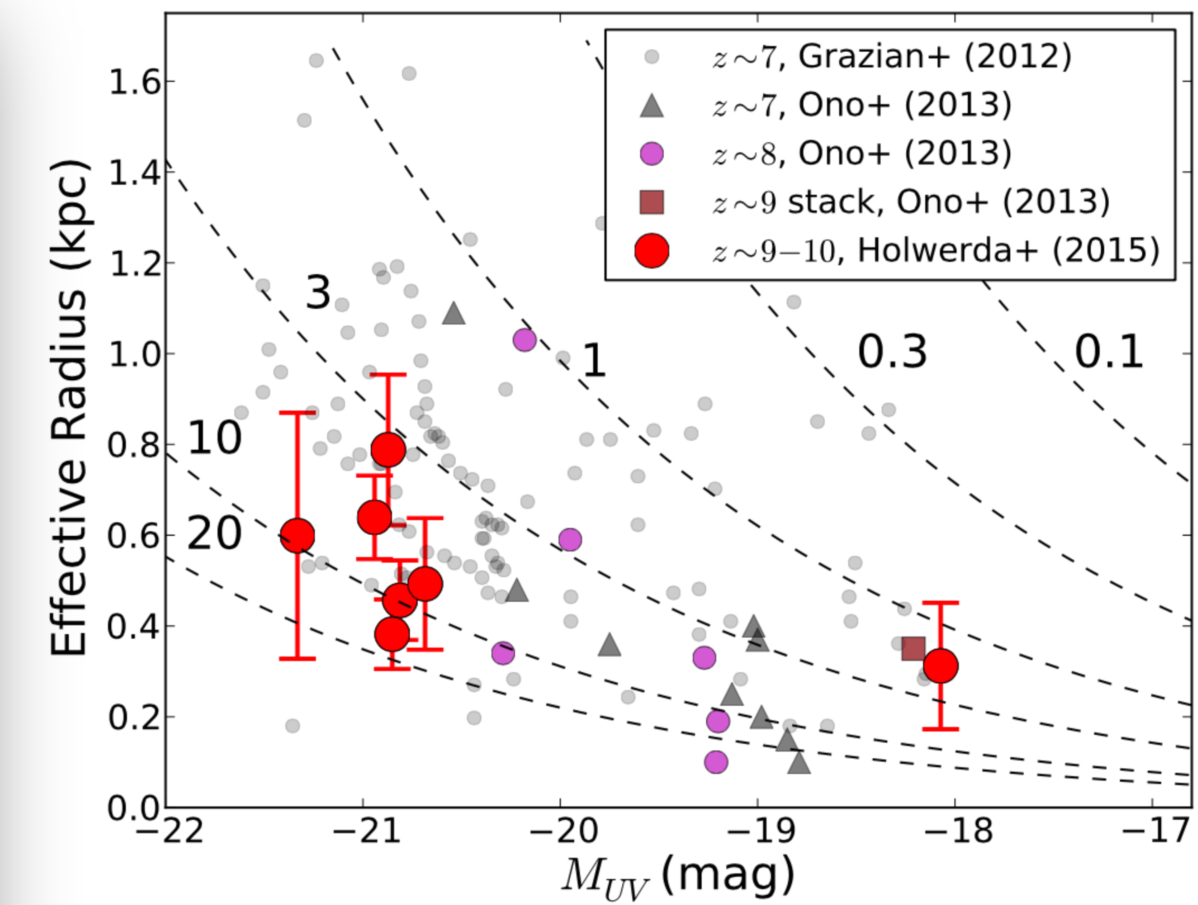
Luminosity evolution due to size?



Malhotra et al. 2013.

SFI, Sizes of galaxies at z > 7

Holwerda et al. 2015



Hunting the Sources of Reionization: Quasars and AGN

- Accretion onto black holes → hot accretion disks → ionizing photon production.
- Census of AGN used to say, not enough for reionization. Recent changes:
  - Lower redshift of reionization from Planck;
  - New census of AGN from GOODS + CANDELS + 4 Msec CXO observations (Giallongo et al 2015)

AGN and Reionization with WFIRST

- Red: Ionizing photons needed for IGM ionization
- Black: Produced by AGN (Giallongo et al 2015)
- The Willott et al (2010) quasar luminosity function would imply
  - 2500 z ~ 7 QSOs,
  - 600 z ~ 8 QSOs,
  - 130 z ~ 9 QSOs, and
  - A handful up to z ~ 12.
- ***Number of z>7 QSOs today: One!***

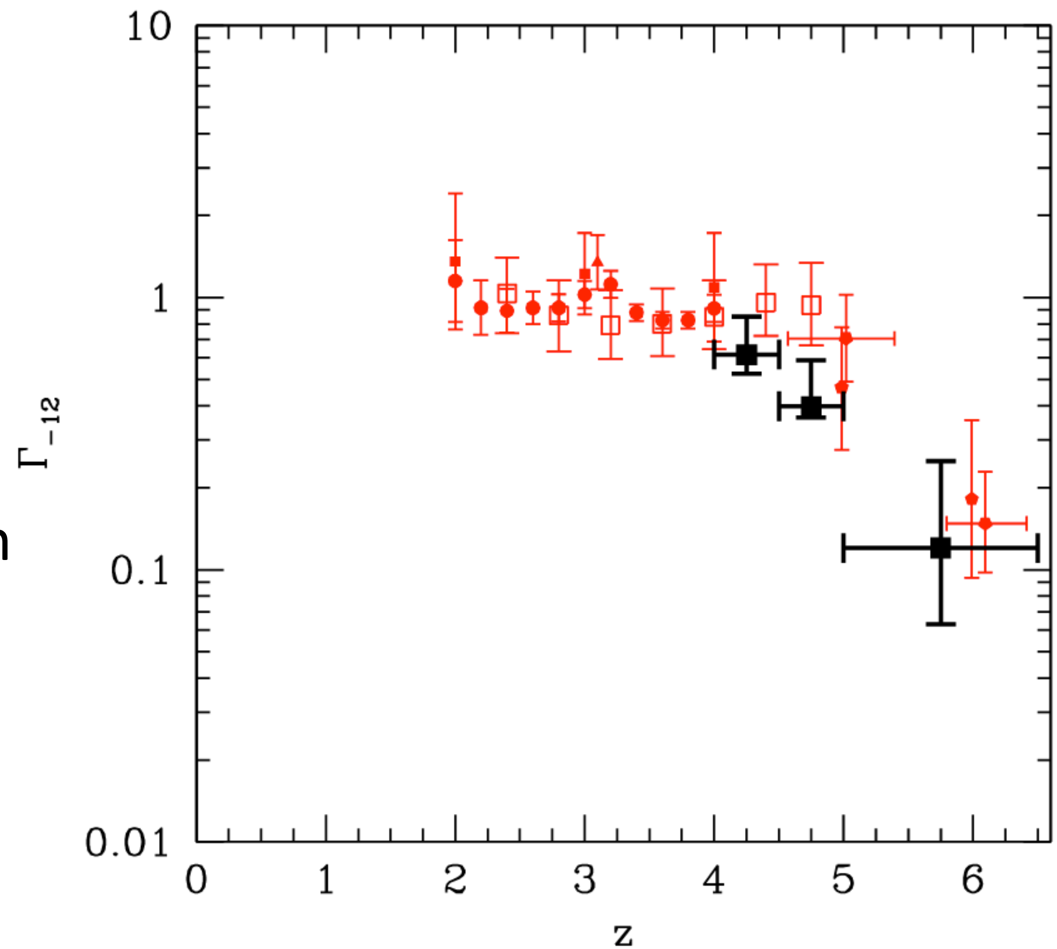
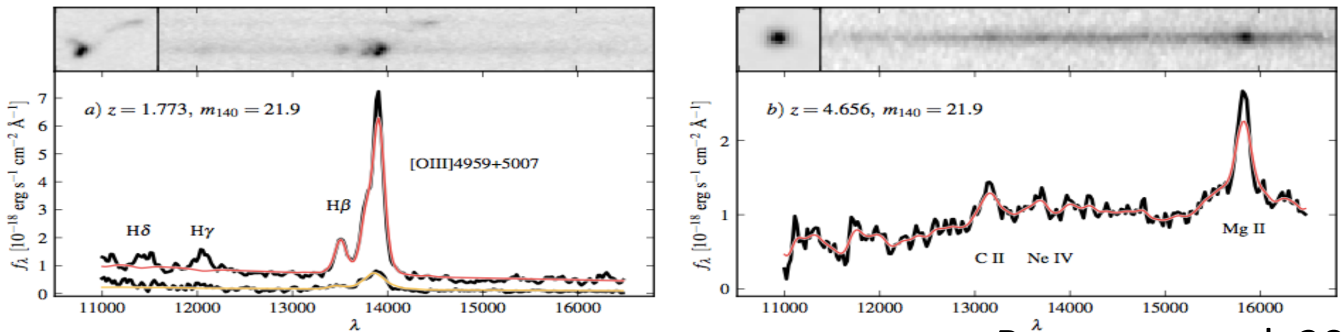


Figure from Giallongo et al 2015

WFIRST Grism is a valuable tool for quasar hunting.

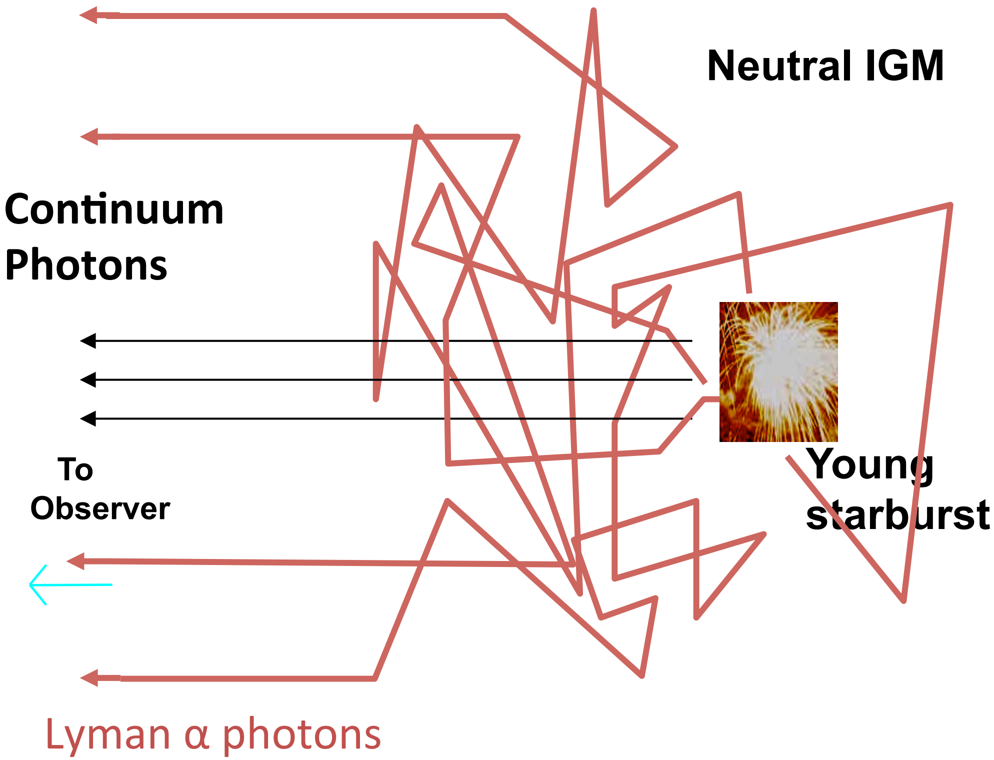


Brammer et al. 2012

- Powerful redshift machine:
  - quasar broad line resolved
  - measure both flux and width
  - for z>5, reaches AB ~24 for detection of average CIV lines

Survey	wavelength	resolution	depth
3d-HST	1.1-1.6	150	5E-17
EUCLID	1.0 -2.0	250	3E-16
WFIRST	**1.35 - 1.95**	**600**	**5E-17**
PFS	0.38-1.26	1900-3500	5E-17
DESI	0.36-0.98	2000-5500	1E-16

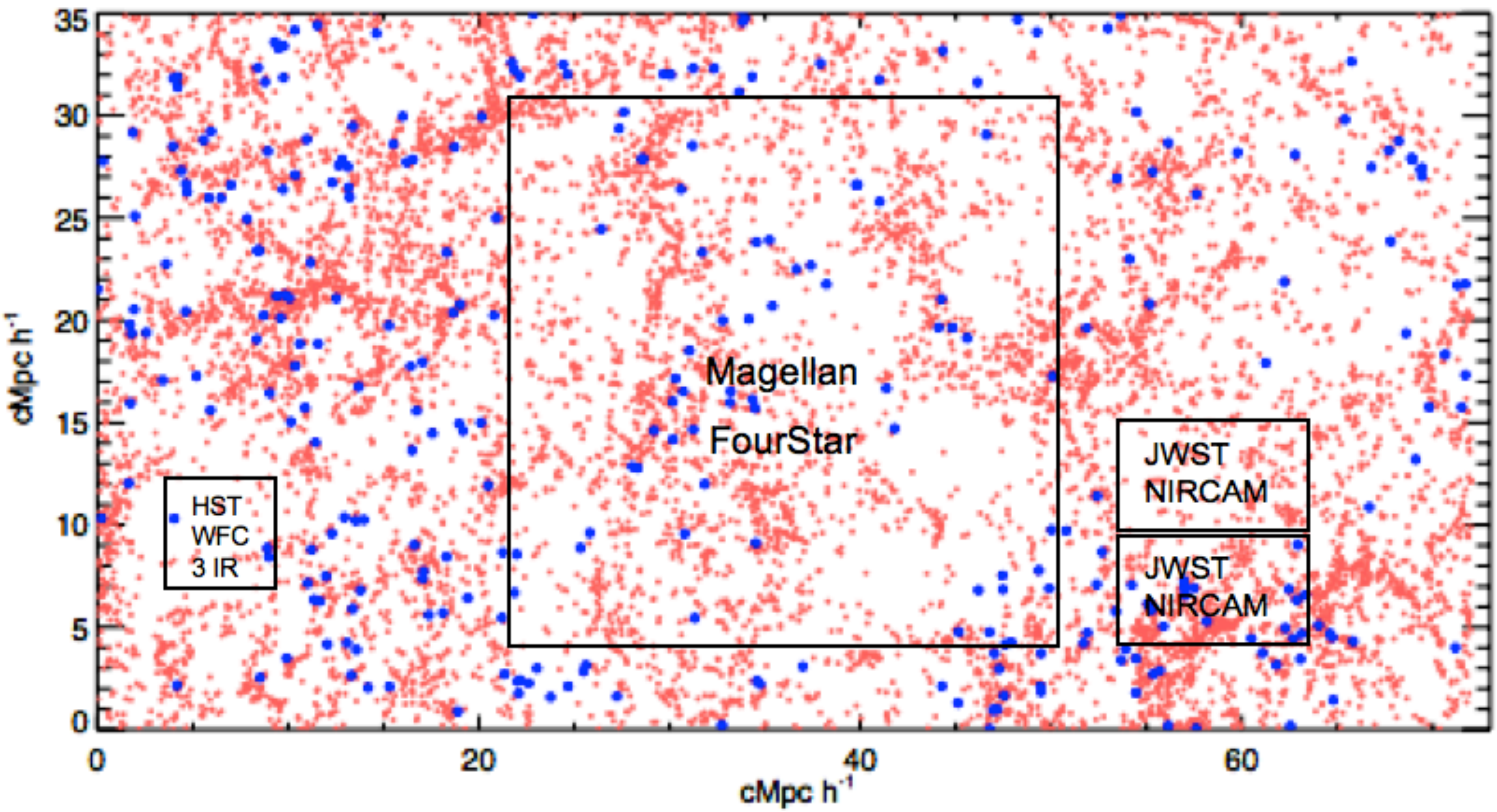
Neutral Fraction Test: Lyman α Galaxies



- Scattering by neutral intergalactic gas hides Lyα from view.
- This affects Lyα luminosity functions and clustering in detectable ways.

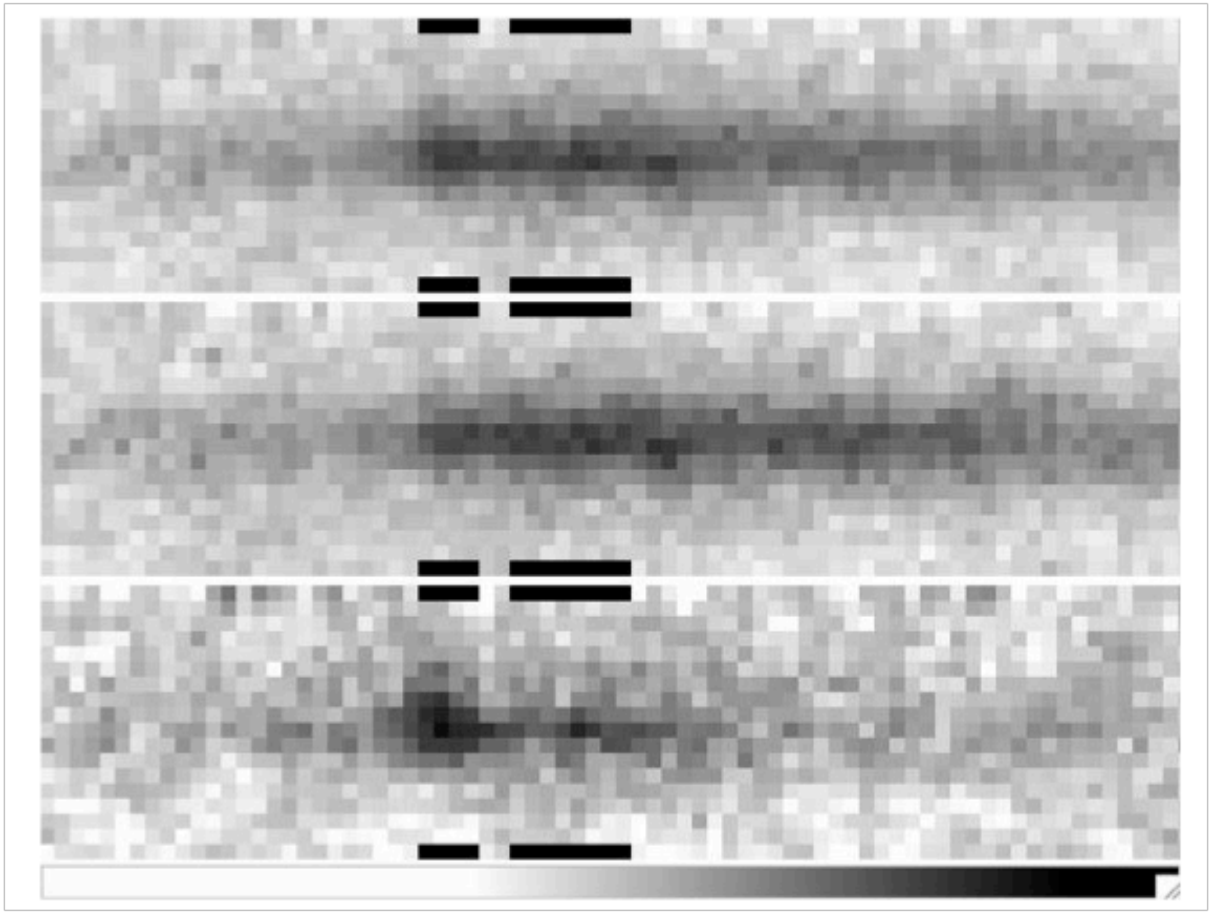
Luminosity function test references: Miralda-Escude 1998; Miralda-Escude & Rees 1998; Haiman & Spaans 1999; Loeb & Rybicki 1999; Santos 2004; Malhotra & Rhoads 2004; Stern et al 2005.

WFIRST can handle "Cosmic Variance":



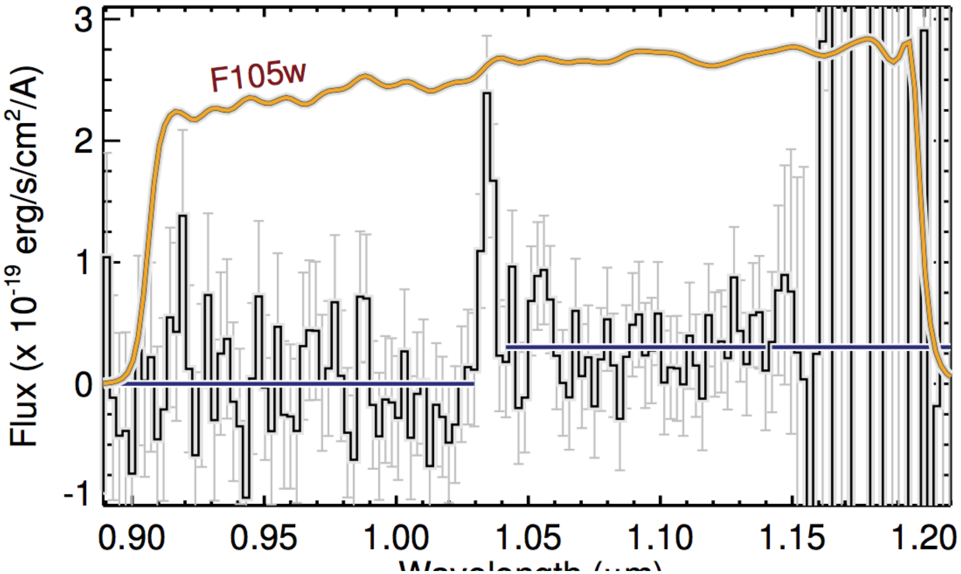
Simulation of dark matter halos (red dots) and Lyman alpha galaxies (blue dots) from Tilvi et al (2009). Two adjacent NIRCAM fields are shown to illustrate the potential impact of field-to-field variations. The WFIRST field of view exceeds the entire plotted area (23'x45'; the FourStar field is 11'x11'.)
Aside: We do not have IGM obscuration of Lyα here; it's just galaxy clustering.

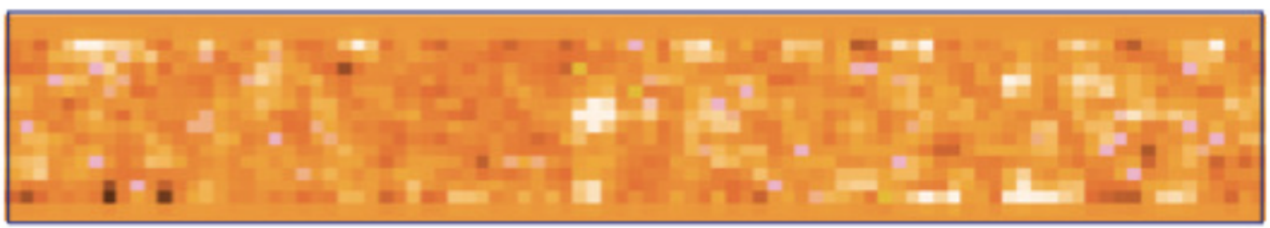
Finding Lyman α: Signal is detectable.



Real HST grism spectra from the GRAPES and PEARS projects. Composite z ~ 5 LBG spectra for the full GRAPES sample (top), and those without LyA (middle) and with LyA (Bottom). [Rhoads et al 2009].

Faint Infrared Grism Survey (FIGS)

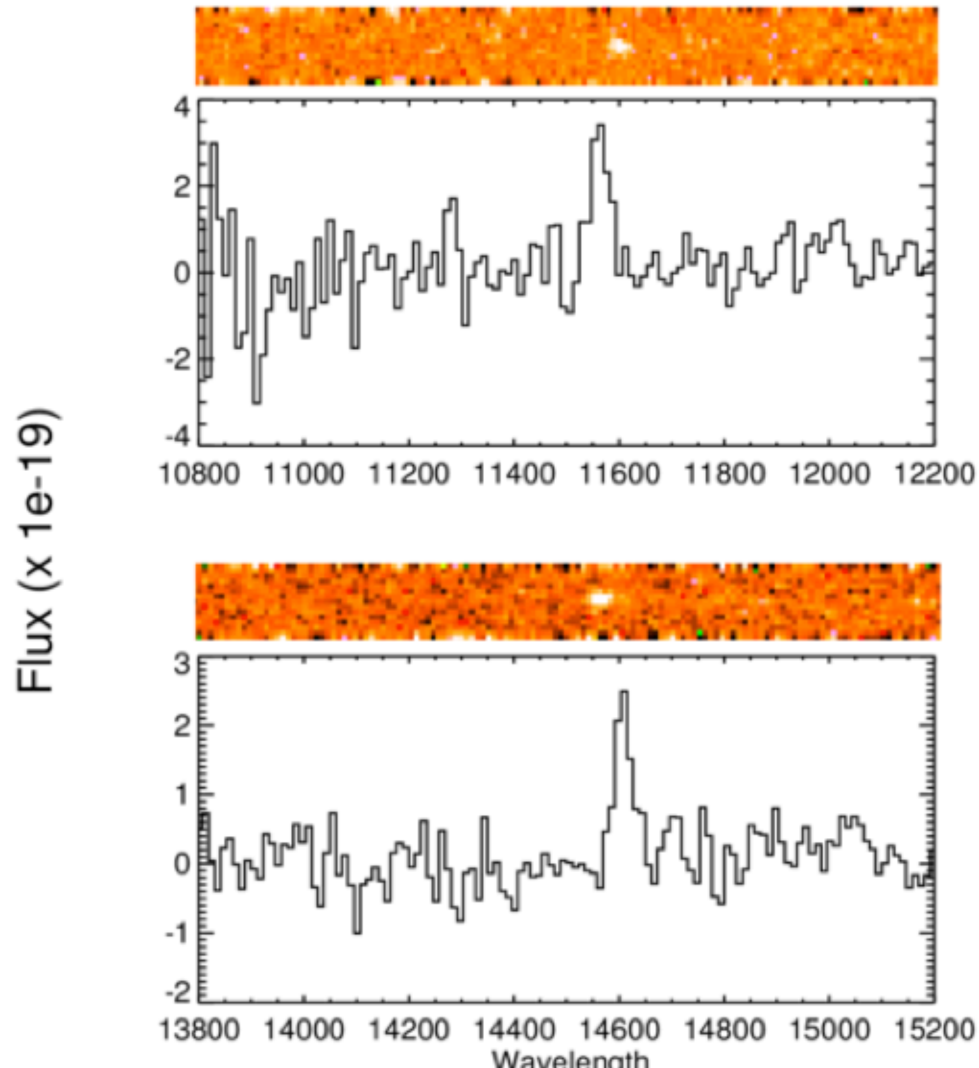




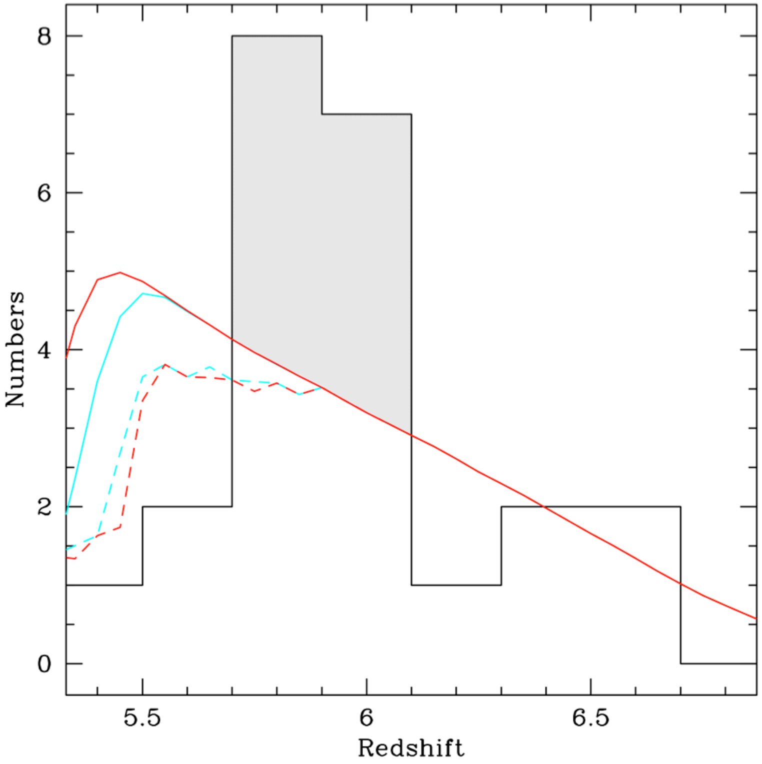
Tilvi et al. 2016, also poster at this meeting.

Finding Lyman α: Signal is detectable.

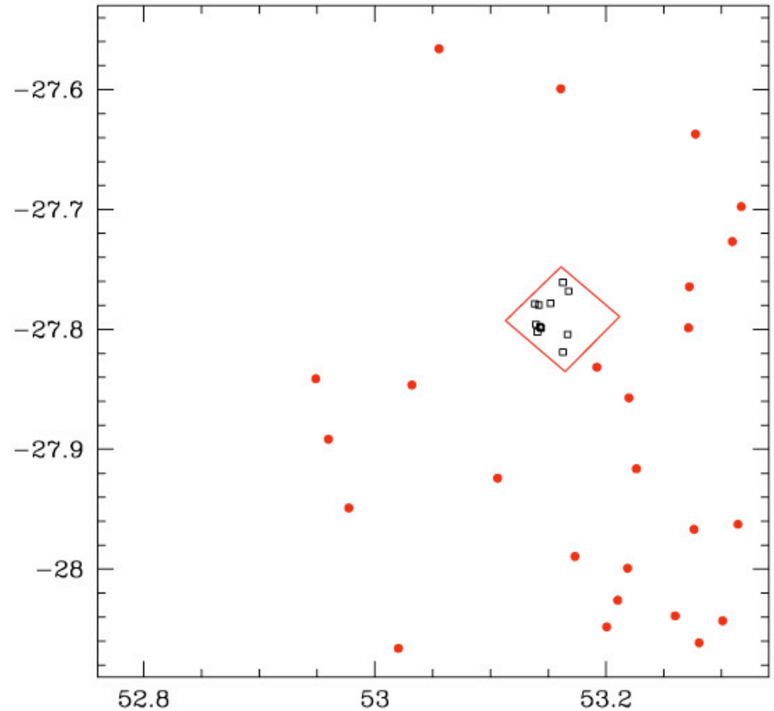
- Right: Simulated 30 hour WFIRST spectra for a source with AB=26.0 and f=1.3e-17 erg / cm2 / s at z=8.5 (top) and z=11 (bottom).



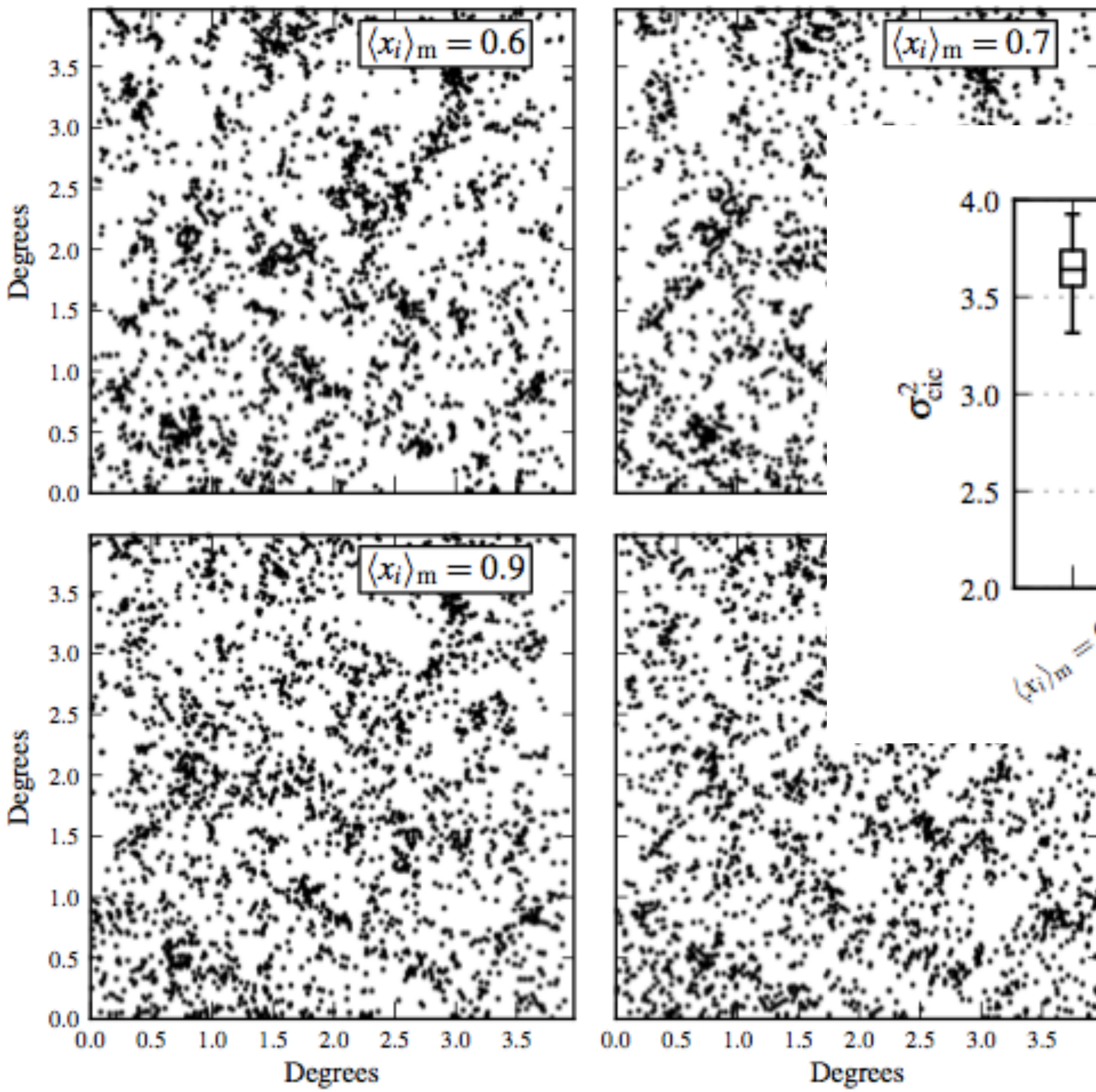
Ionizing sources (Malhotra 2005)

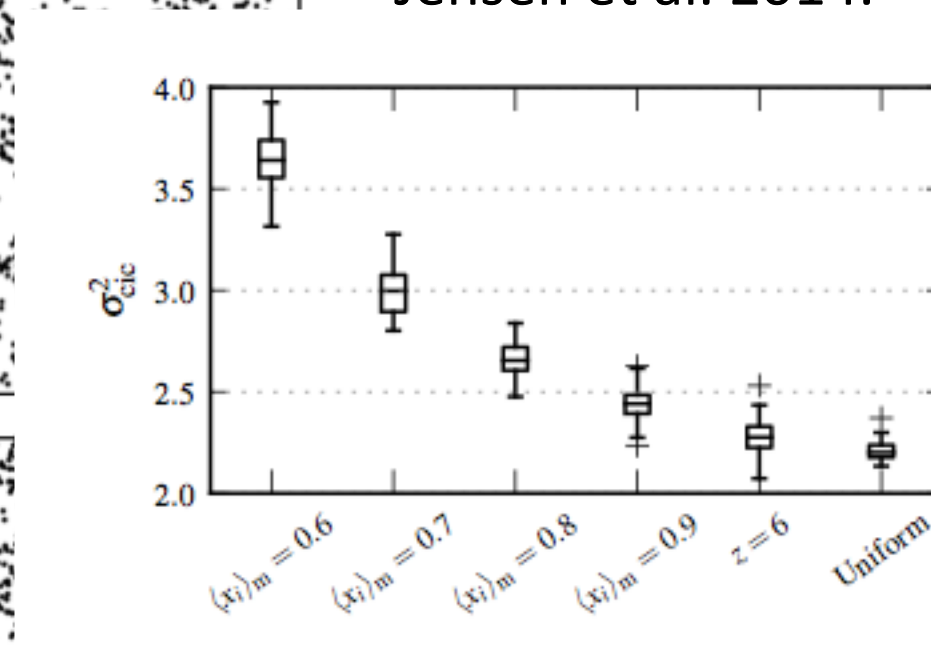


Overdensity > 4 at z=5.8



Topology of Reionization:





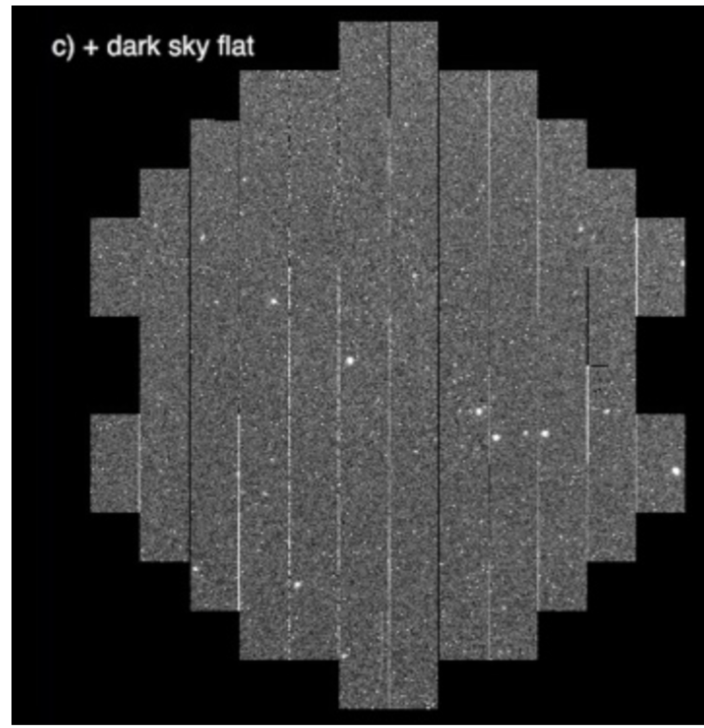
Simulations by Jensen et al. 2014.

Synergies with LOFAR, MWA studies of 21 cm.

Lyman-Alpha Galaxies at End of Reionization (LAGER)

Z=6.9 Lya Survey at DECAM(CTIO)

-- Zhenya Zheng, James Rhoads, Alistair Walker, Junxian Wang, L. Infante, Linhua Jiang.



Neutral fraction test: Quasar Spectra

- The ionized “near zones” of quasars have a size that depends critically on ambient neutral fraction.
- Given a statistical sample of high-z quasars, we can use this to learn about neutral fraction evolution.
- These will be bright targets for high resolution follow-up with large ground based telescopes or JWST.

Science Summary

- WFIRST will find unprecedented samples of Lyman break galaxies, Lyα galaxies, and quasars in the epoch of reionization.
  - This will test luminosity function evolution and provide key data on the ionizing photon budget at $z>7$.
- Both quasars and Lyα galaxies from WFIRST can be used to directly study the neutral fraction during reionization.

Galaxy Environment and Reionization

- Environment may affect galaxy properties.
- WFIRST will be our first opportunity to test this in the epoch of reionization, offering galaxy samples in Coma-cluster-progenitor environments and in void environments.
- Studying clumpiness of ionizing photon production will help understand inhomogeneity of reioinization (which we may see directly with Lyα and quasar tests.)