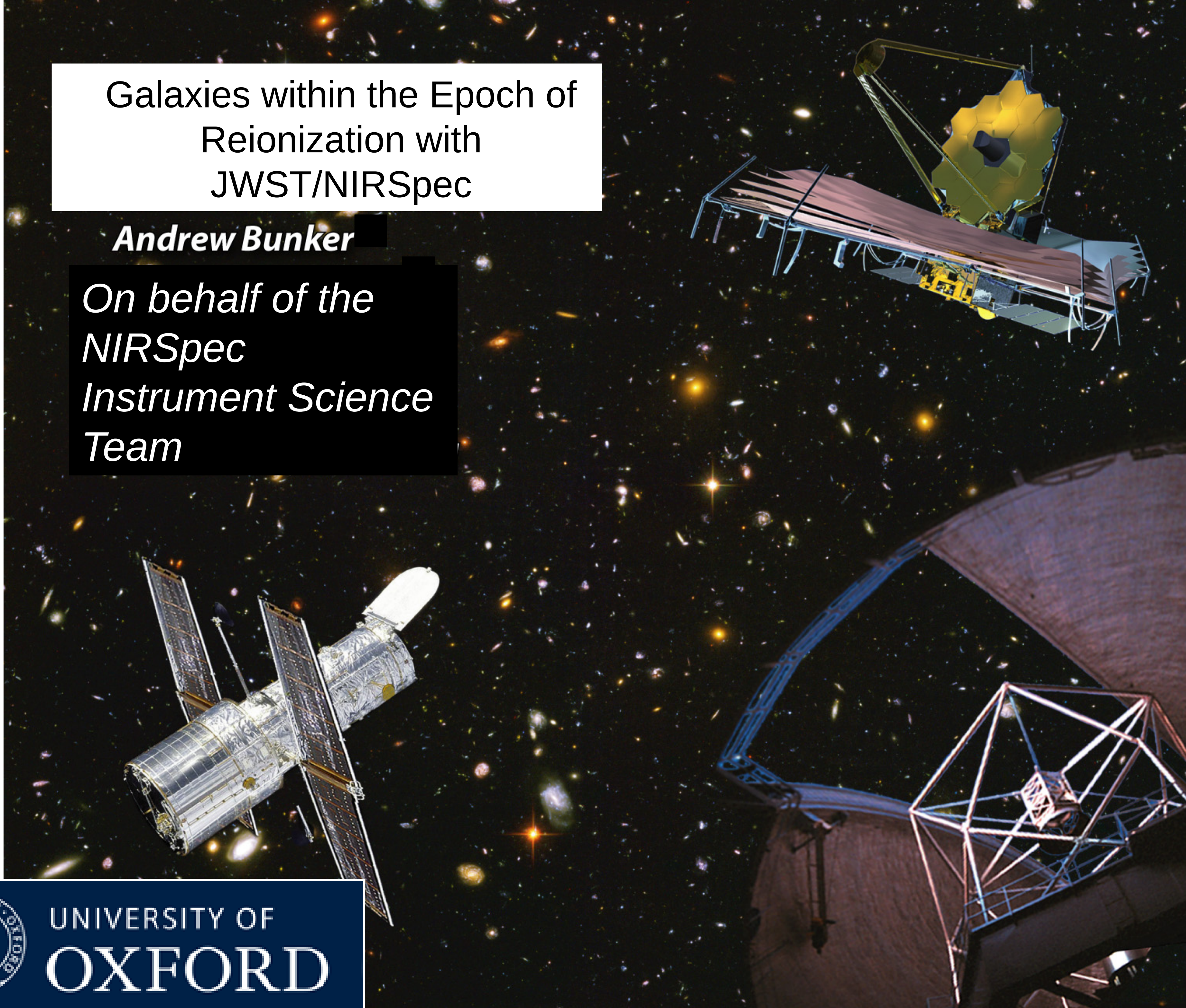
Galaxies within the Epoch of Reionization with JWST/NIRSpec

Andrew Bunker

On behalf of the NIRSpec Instrument Science Team



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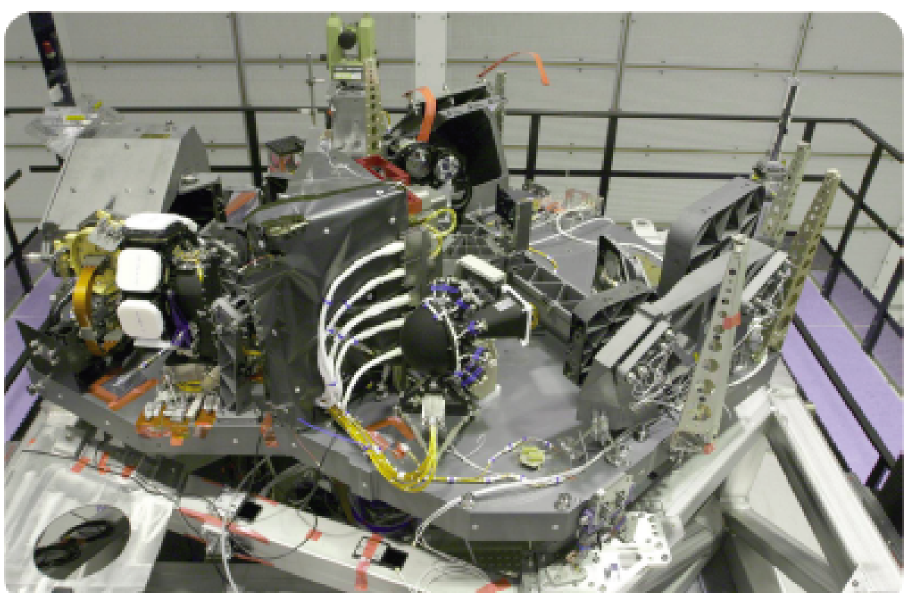
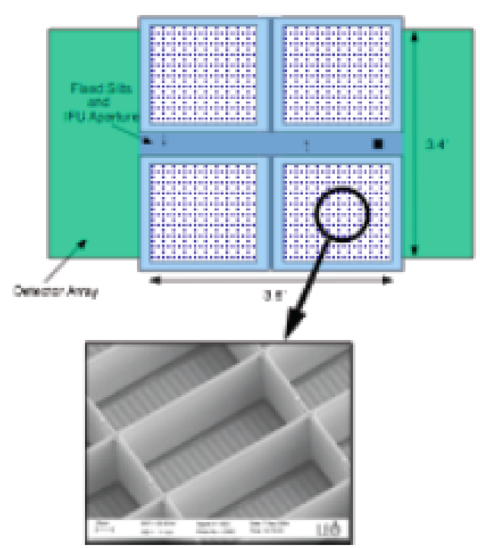
NIRSpec

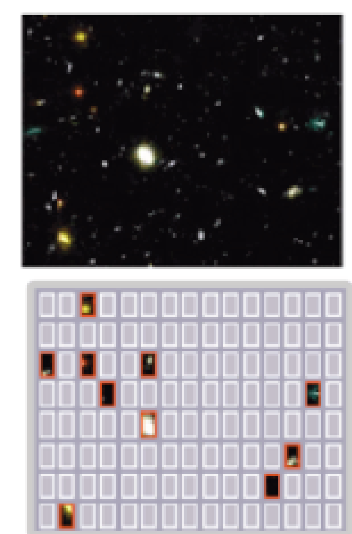
- Developed by the European Space Agency with Astrium GmbH and GSFC
  - ➡ Operating wavelength: 0.6 – 5.0 µm
  - ➡ Spectral resolution: 100, 1000, 3000
  - ➡ Field of view: 3.4 x 3.4 arc minutes
  - ➡ Aperture control: programmable micro-shutters, 250,000 pixels
  - ➡ Angular resolution: shutter open area 203 x 463 mas, pitch 267 x 528 mas
  - ➡ Detector type: HgCdTe, 2048 x 2048 pixel, 2 detectors, T_{op} = 37K (passive)
  - ➡ Reflective optics, SiC structure and optics



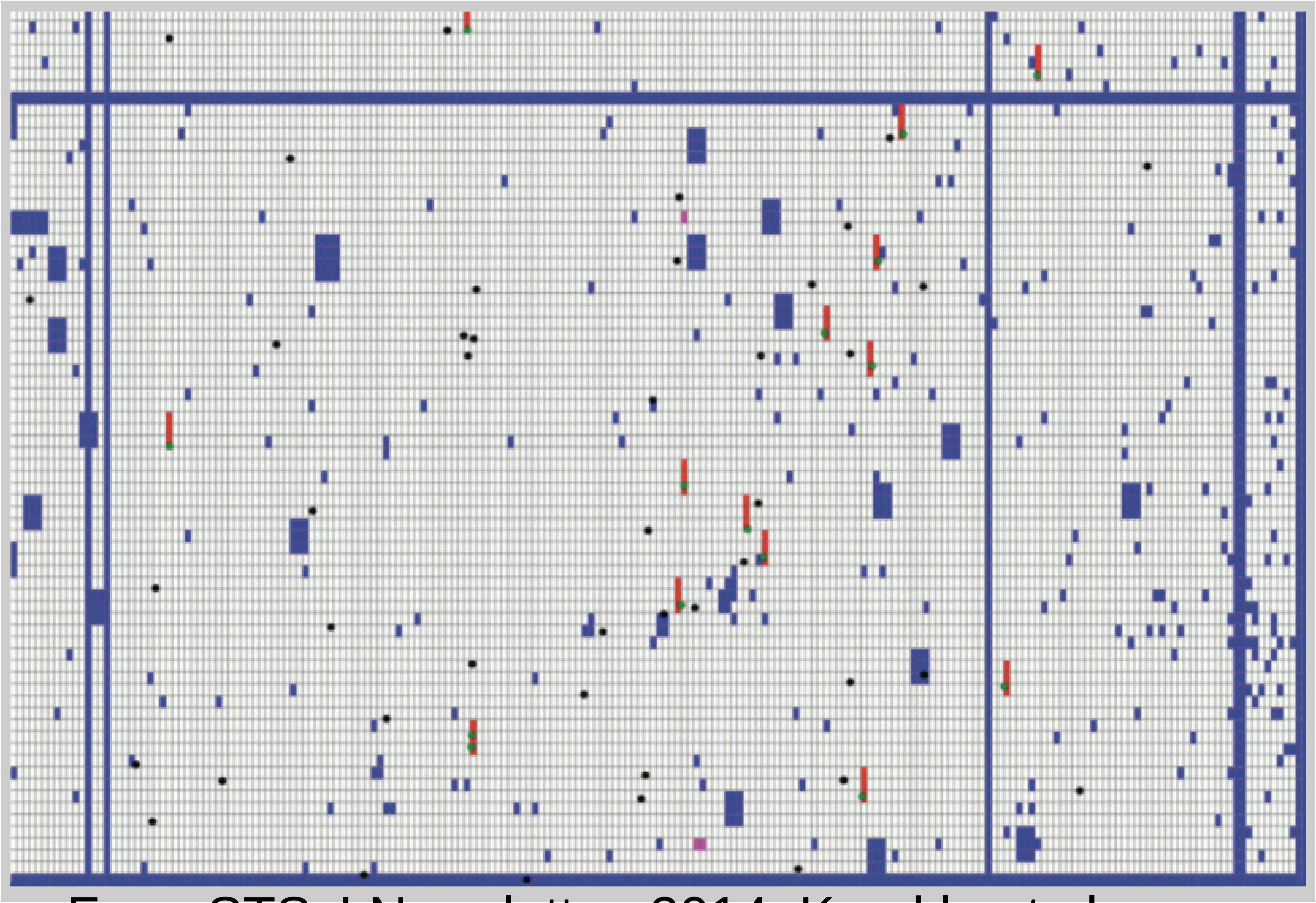
Microshutters



Multiple Objects
≤ 100 objects

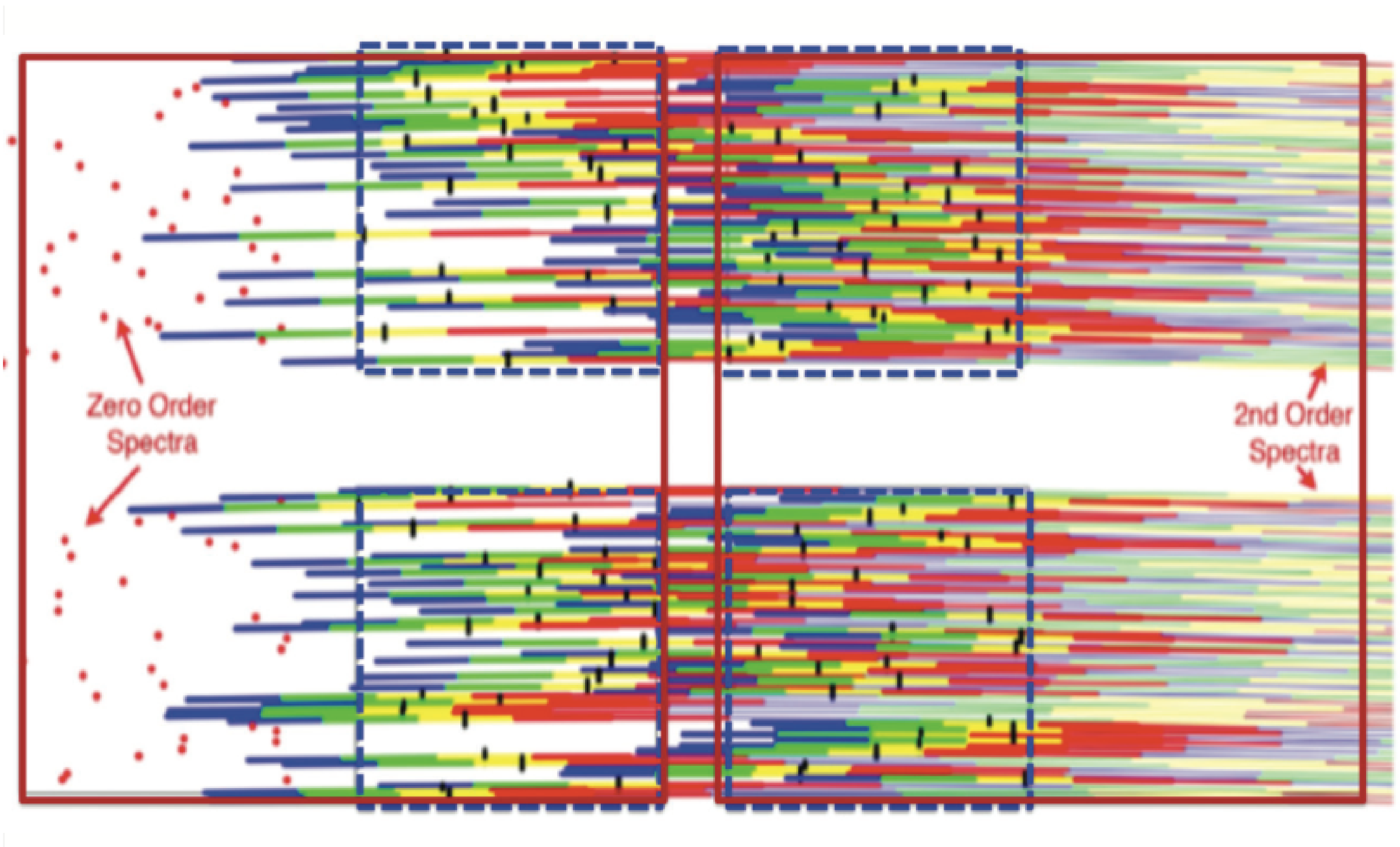


NIRSpec microshutters

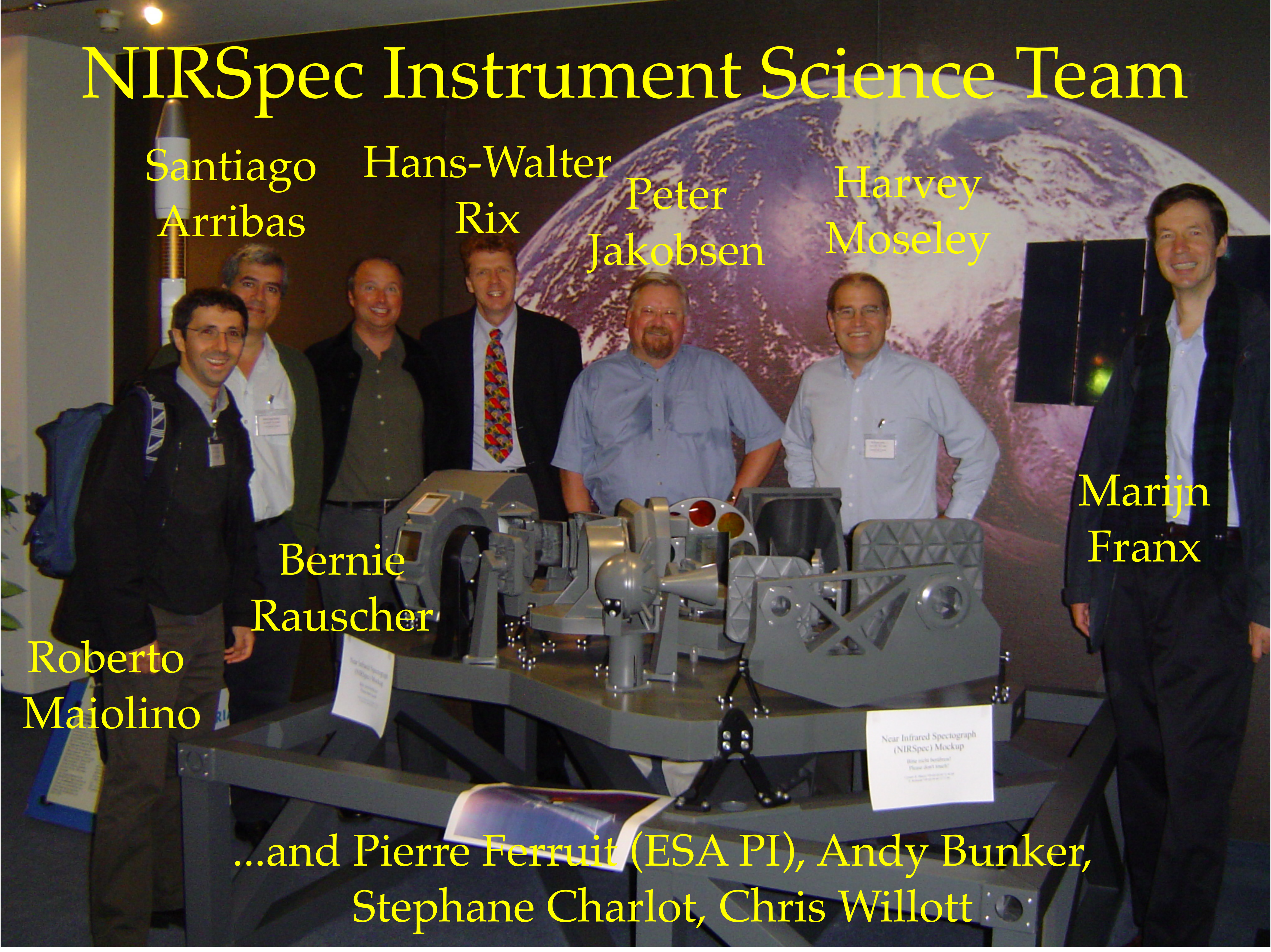


From STScI Newsletter, 2014, Karakla et al.

Spectra from NIRSpec



From STScI Newsletter, 2014, Karakla et al.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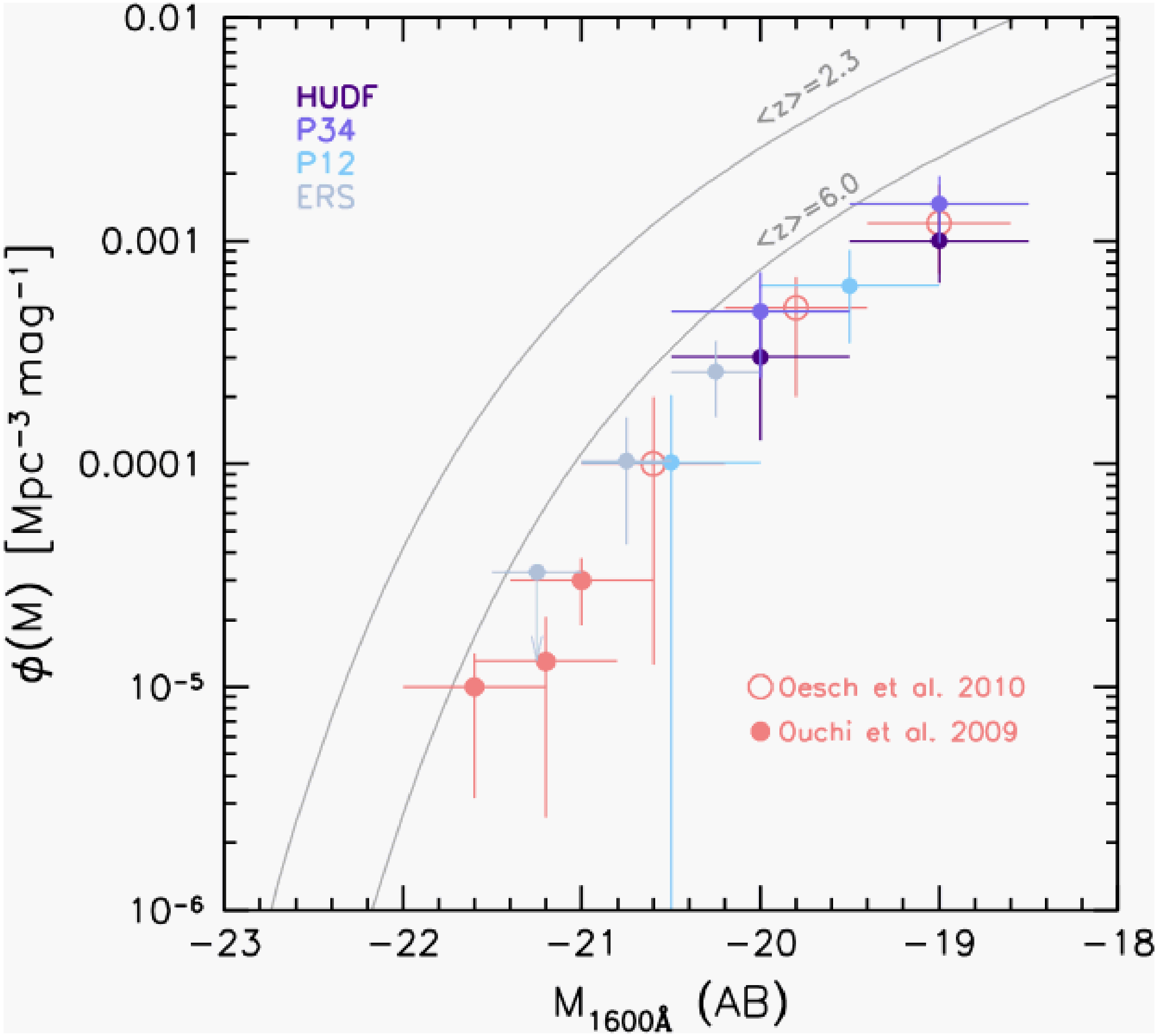
Near Infrared Spectograph (NIRSpec) Mockup
...and Pierre Ferruit (ESA PI), Andy Bunker, Stephane Charlot, Chris Willott

NIRSpec GTO
MSA galaxy assembly program

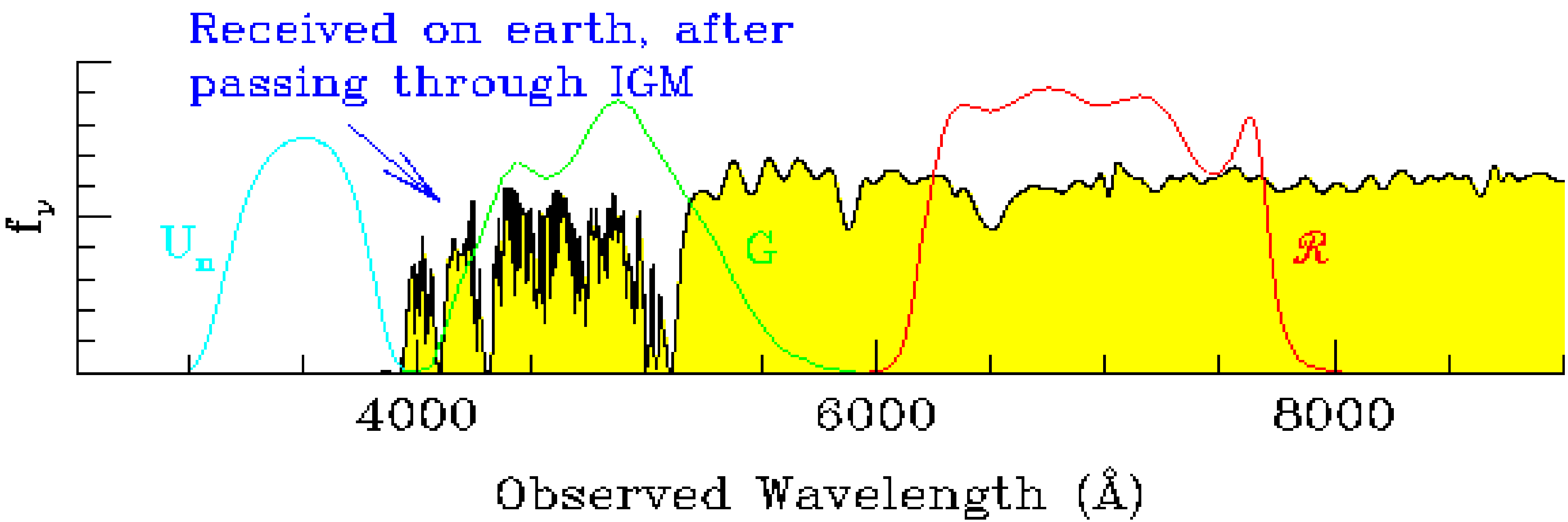
Top priority science cases:

- Spectroscopic confirmation of the most distant galaxies
- Escape of Ly continuum and Lyα photons
- Stellar populations, kinematics and chemical enrichment
- PopIII
- AGNs and their host galaxies
- Large scale structure, environment
- Evolution of the joint distributions



Wilkins et al. (2010) MNRAS The Luminosity Function at z~7

An increasing problem for reionization: requires steep faint-end slope (α<-1.7), large contribution from unobserved faint galaxies, high escape fraction (f_{esc}>0.2) and very smooth IGM (low clumping, C<5)



"Lyman break technique" - sharp drop in flux at λ below Ly-α. First done by Steidel et al. have >1000 z~3 objects, "drop" in U-band. Now with HST/WFC3 in the near-IR pushing “optical dropout” galaxies at z~6-12. At z>6 almost complete Gunn-Peterson absorption below Lyman-alpha.

Overall NIRSpec Galaxy Assembly Plan

- a wedding cake survey at R=100 and R=1000

1) Deep, 20-40 sq arcmin, 1-5 µm, 40-45% of the time, AB≤29-30, $2<z<14$
2) Medium, 100-200 sq arcmin, 1-5µm, 40-45% of the time, AB≤27-28, $2<z<14$
3) Shallow, >400 sq arcmin, 2-5µm, 10-20% of the time, AB≤25-26, 7000+ spectra, $2<z<4$ ($4<z<14$)

≈500 hours

Fields: deep supporting observations (e.g., MIPS, Herschel, ALMA, X-Ray, …): HUDF, HDF, GOODSN,S, CANDELS for shallow, Frontier Fields, Clash,

4) R=3000 IFU spectroscopy of extended objects

≈300 hours

Deep

- Per field: integrations: R=100, 1e5 seconds
  - R=1000, 3settings, total = 1e5 seconds
  - Total integration time=2e5 seconds, with overheads 84 hours/field

- 2-3 pointings following up HST & NIRCAM deep fields

  collaboration between NIRCAM & NIRSpec ISTs

Confirmation Highest redshift sources (1)

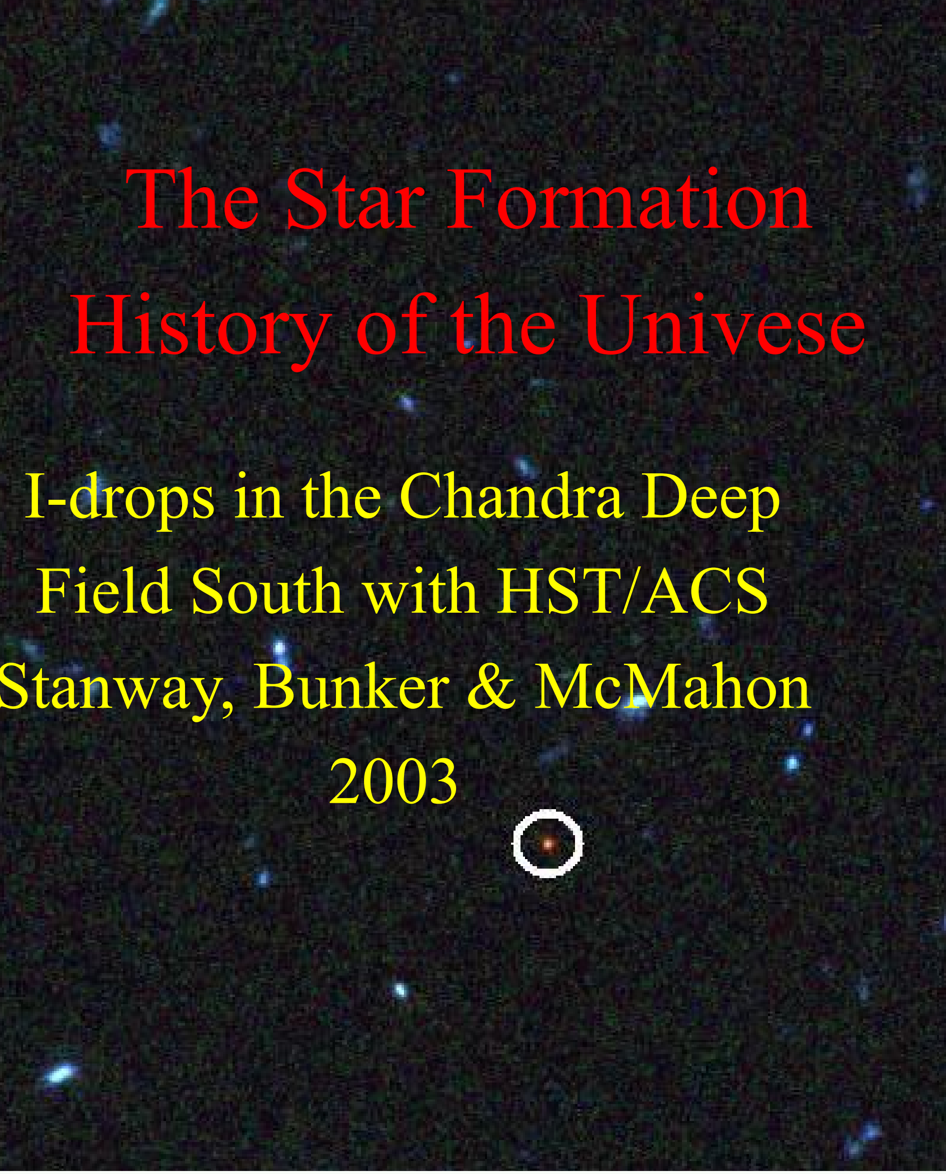
- **Science Objectives**
  - Get spectroscopic redshifts at z>7
  - Initial characterization of spectra

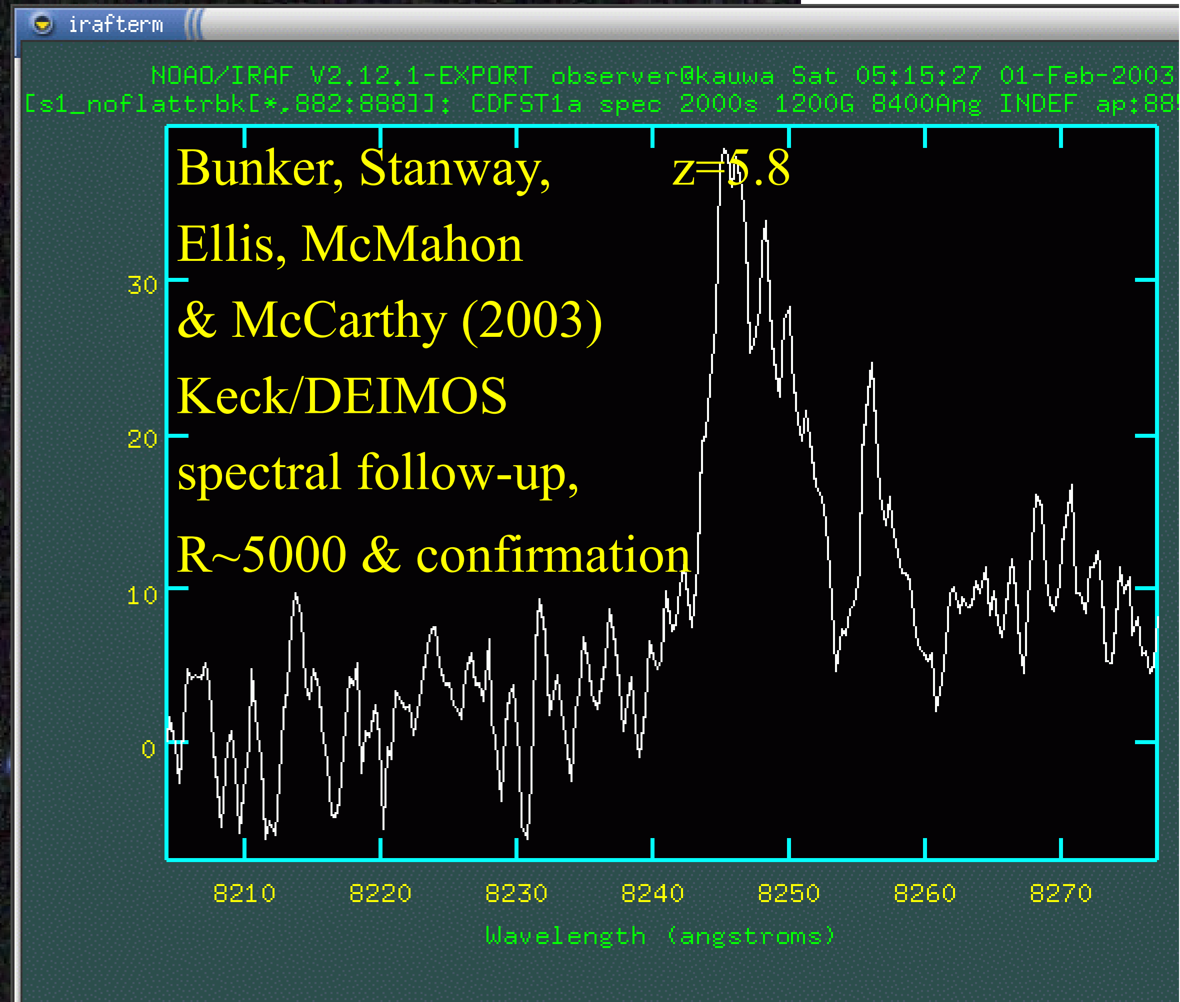
- **Methods**
  - Measure redshift from emission line/continuum features
  - Simple modelling of the spectra (potentially pop III, continuum UV slopes, etc)

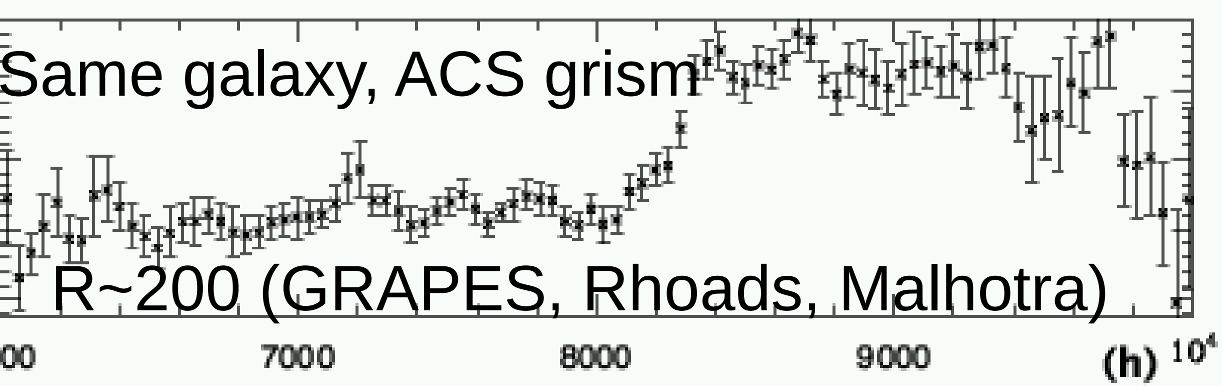
NIRSpec will get very accurate redshifts, and hence determine accurate rest-frame properties;
measure emission lines (Hα, Hβ, [OIII], [OII]), to constrain: attenuation by dust, star formation rate; ionization state and metallicity of the interstellar gas; presence of an AGN;

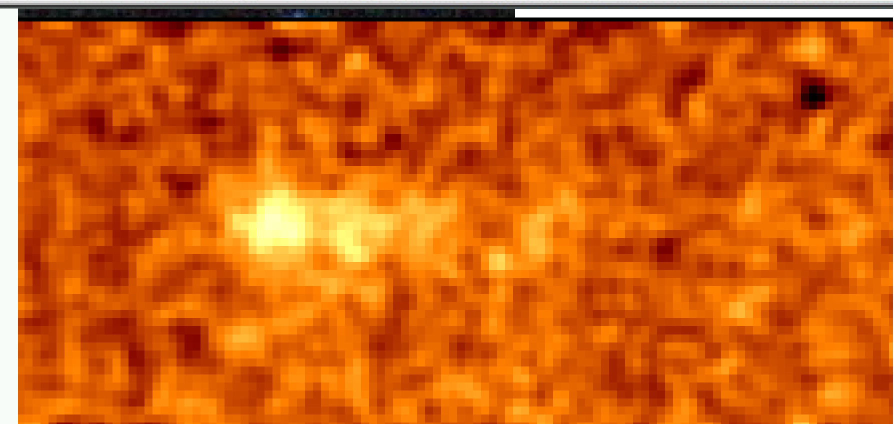
The Star Formation History of the Univese

I-drops in the Chandra Deep Field South with HST/ACS Stanway, Bunker & McMahon 2003







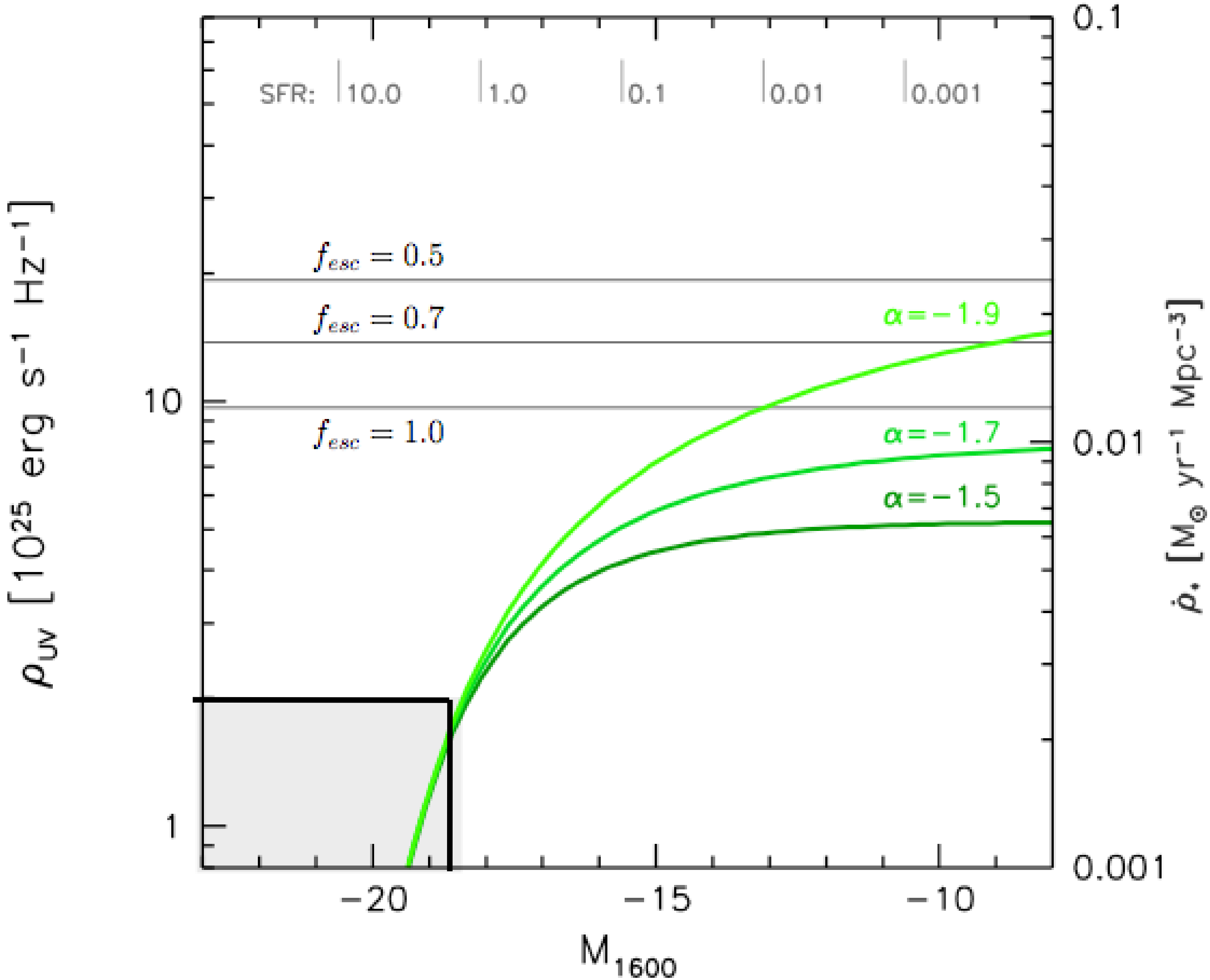


Confirmation of highest redshift (2)

- **Are the blue spectral slopes real?**
- **Is the suggested severe contamination of broad-band magnitudes (e.g. Spitzer/IRAC) by hugh EW line emission real?**

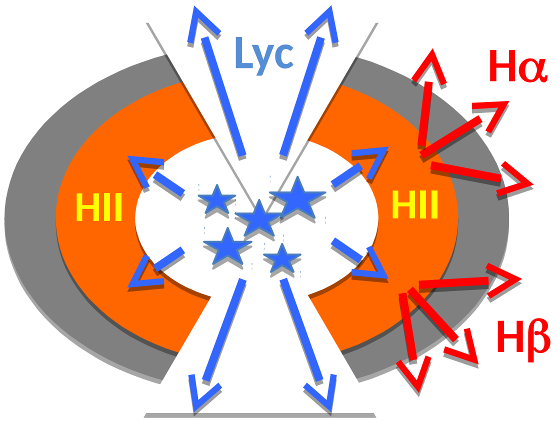
- **Link to the program at large**
  - part of Deep UDF, Deep, Medium, Shallow;
  - R=100 and R=1000 to get emission lines

- **Ancillary Data:** HST UDF, NIRCam imaging
  - Target selection (based on SED (photoz), dropout, etc, magnitude, size)
  - Morphological information (sizes)
  - photometry for accurate SED



Wilkins et al. (2010) – Photon budget for reionization @z=7.
Deeps on ionizing escape fraction, clumping factor

The Lyman continuum escape fraction (1)

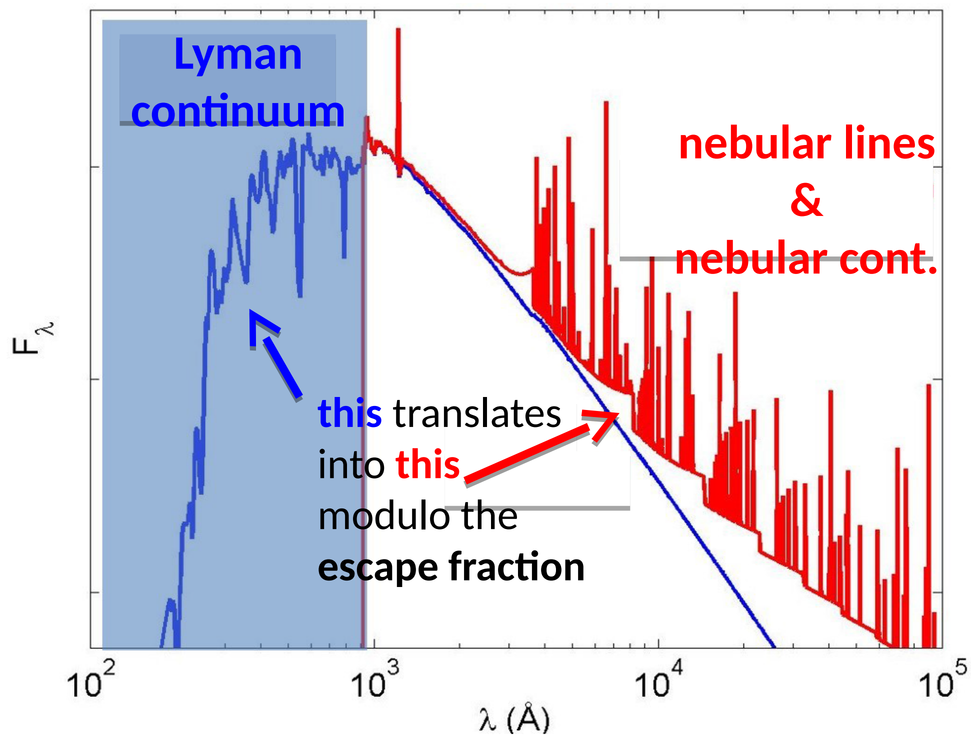


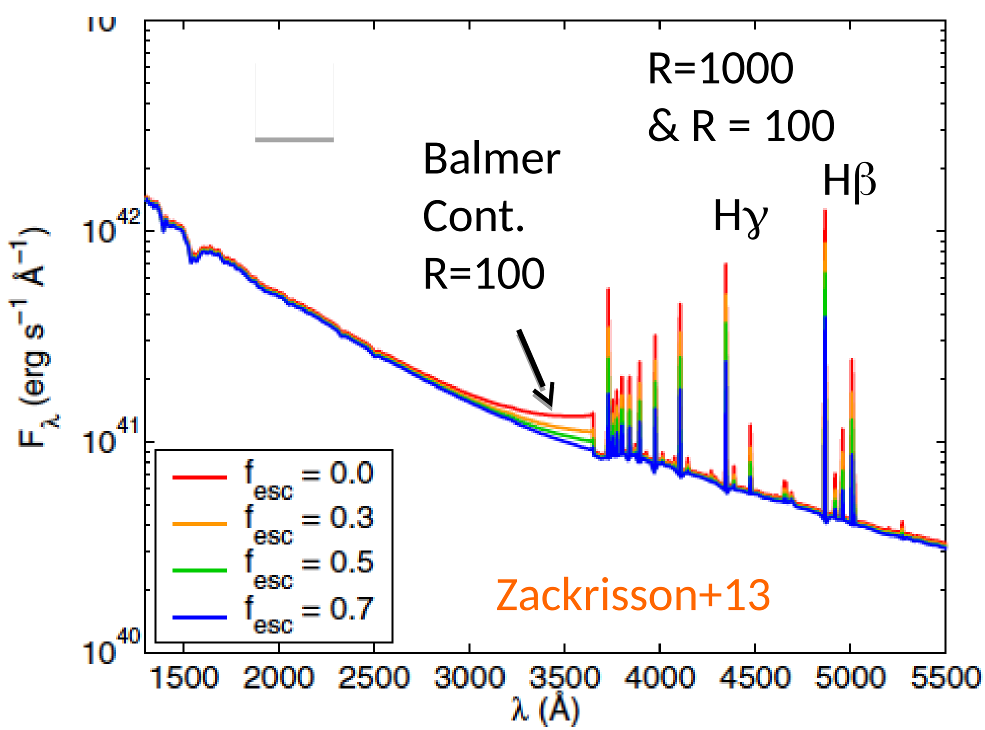
Science goals

- Escape fraction of Lyman continuum as a function of galaxy properties (mass, SFR, z,….)

Methods

- Balmer lines compared with UV continuum
- Balmer decrement and UV slope -> dust extinction + age
- HeII/HeI/H line ratio -> shape of ionizing continuum
- R = 1000 (R=100 for Balmer break)





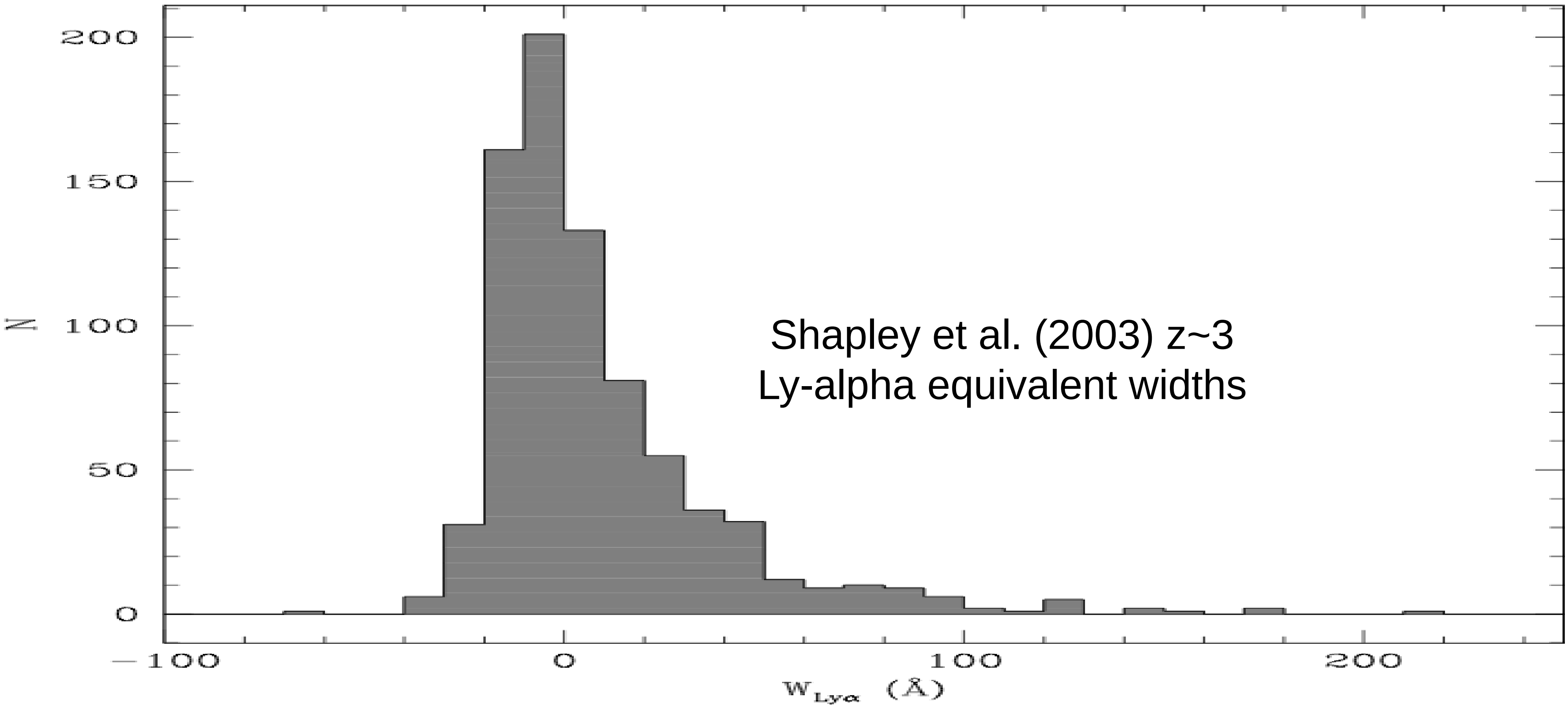
JWST-NIRSpec – Escape Fraction and Reionization

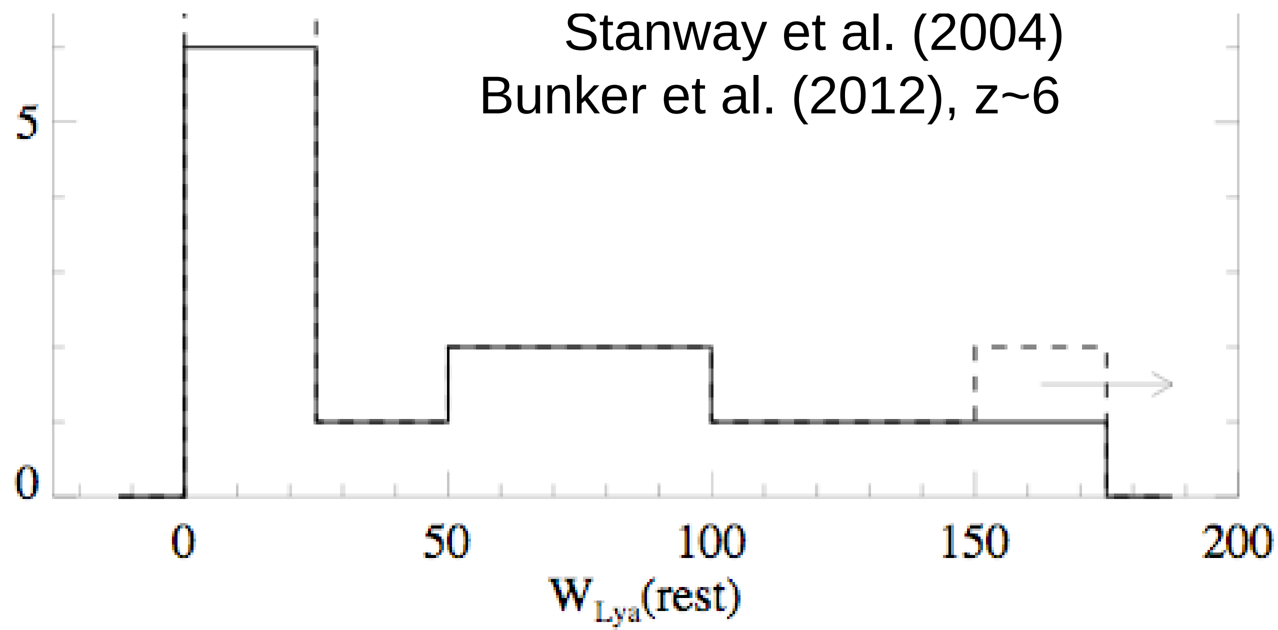
Escape fraction (from Balmer lines compared with UV) (dependence on mass, SFR; compare with Lya flux and profile)

The comparison of the H-alpha or H-beta photons with the UV continuum should provide a good constraint - a simple photon budget governed by well known photoionization and recombination physics.

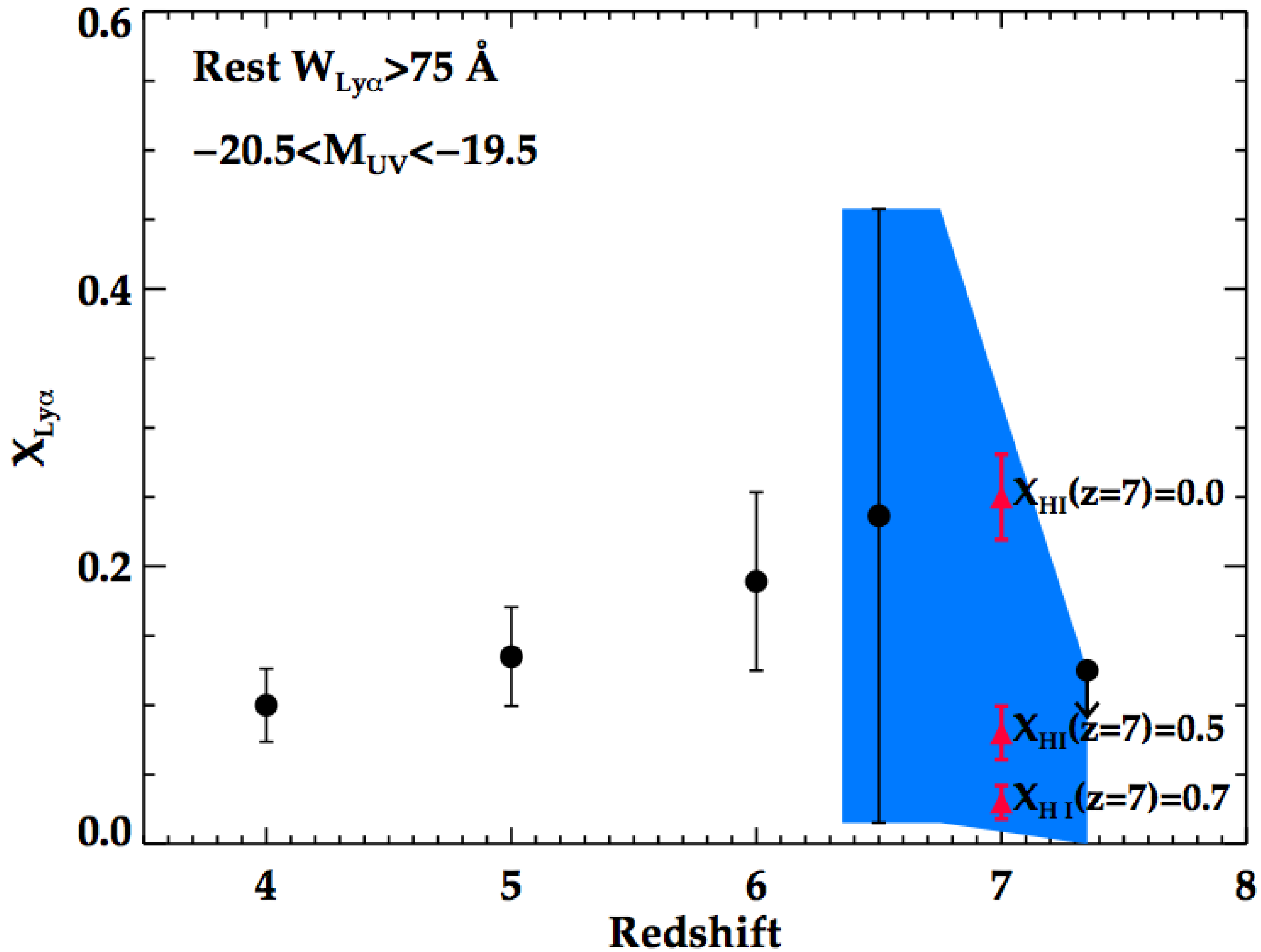
[Modulo the UV extrapolation beyond Lyman-alpha, which may be model dependent, but can be constrained by the HeI/H ratio, or even HeII/HeI/H.]

Also: searches for PopIII – HeII 1640Ang

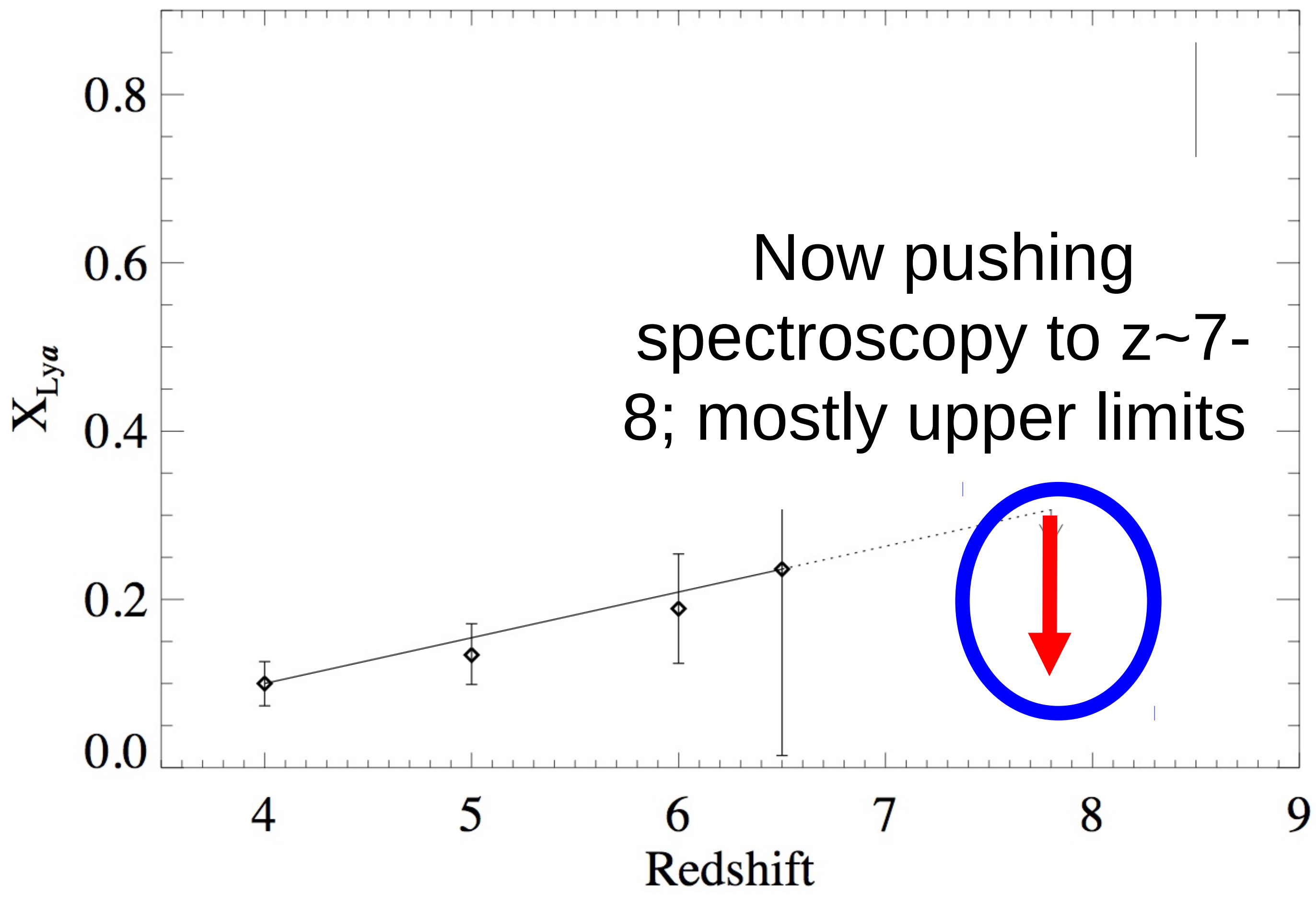

200
150
N
100
50
0
−100
0
100
200
$W_{Ly\alpha}$ (Å)
Shapley et al. (2003) z~3
Ly-alpha equivalent widths


Stanway et al. (2004)
Bunker et al. (2012), z~6
5
0
0
50
100
150
200
W_{Lya}(rest)

Ly-alpha fraction (Stark et al. 2010)



Lyman alpha equivalent width distribution as a function of redshift for patchy or not reionization scenarios. Also, measuring Lyman alpha line shape evolution into the reionization epoch with systemic redshifts determined from nebular lines.

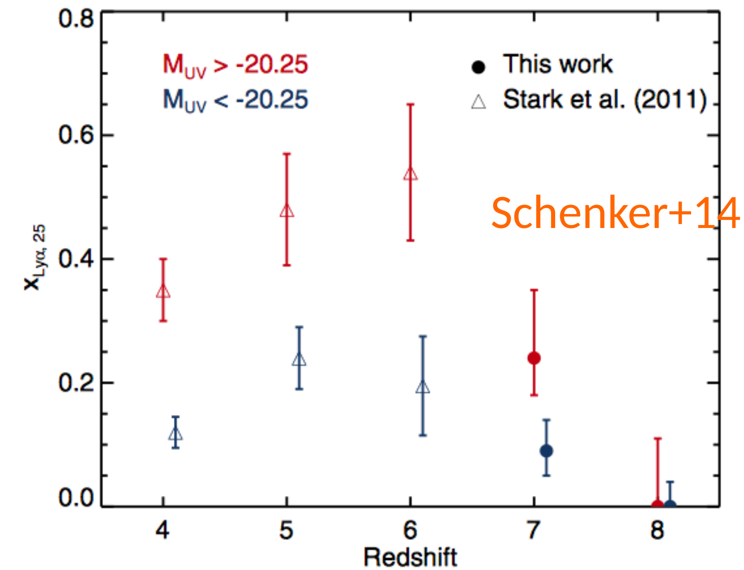


Stark et al. (2010) Caruana et al. (2012, 2014). Ly-alpha suppressed in mostly-neutral IGM

Observability of Lyman α emission: the ionization state of the IGM (1)

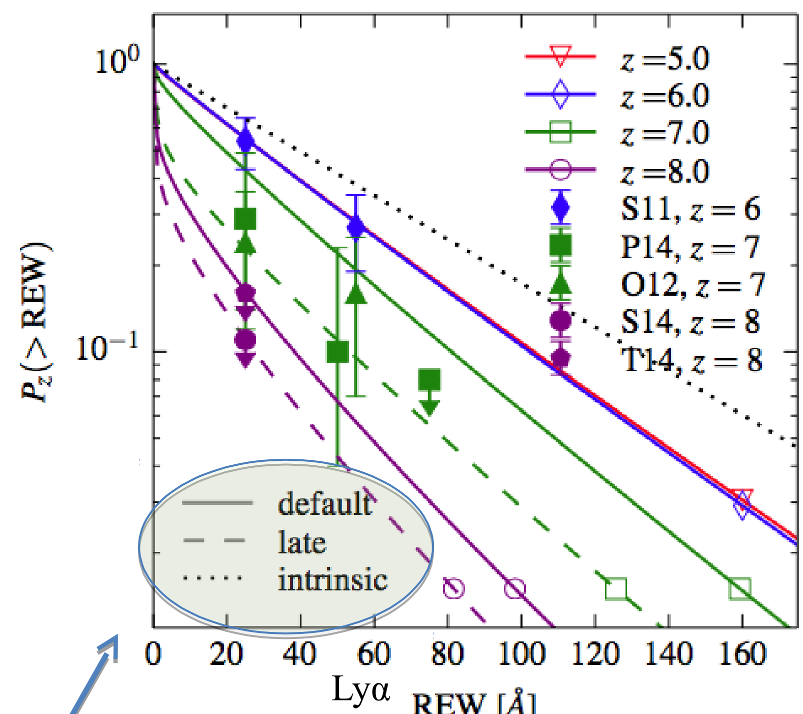
Science goals

- Lyman-α photon escape fraction as a function of redshift and galaxy luminosity
  ➔ constraints on reionization scenarios.



Methods

- Continuum (R=100) for all z>6 gals
- Lyα equivalent width or limit (R=1000/100)
- Line centroid and shape (R=1000)
- Other nebular lines (R=1000) ➔ fix systemic z
- Determine P(>REW) distribution as fn of z and L_{UV}
- Photon radiative transfer in outflowing gas
- Constrain reionization models ($f_{HI}(z)$, patchiness, bubble sizes)



Reionization models

Choudhury+15

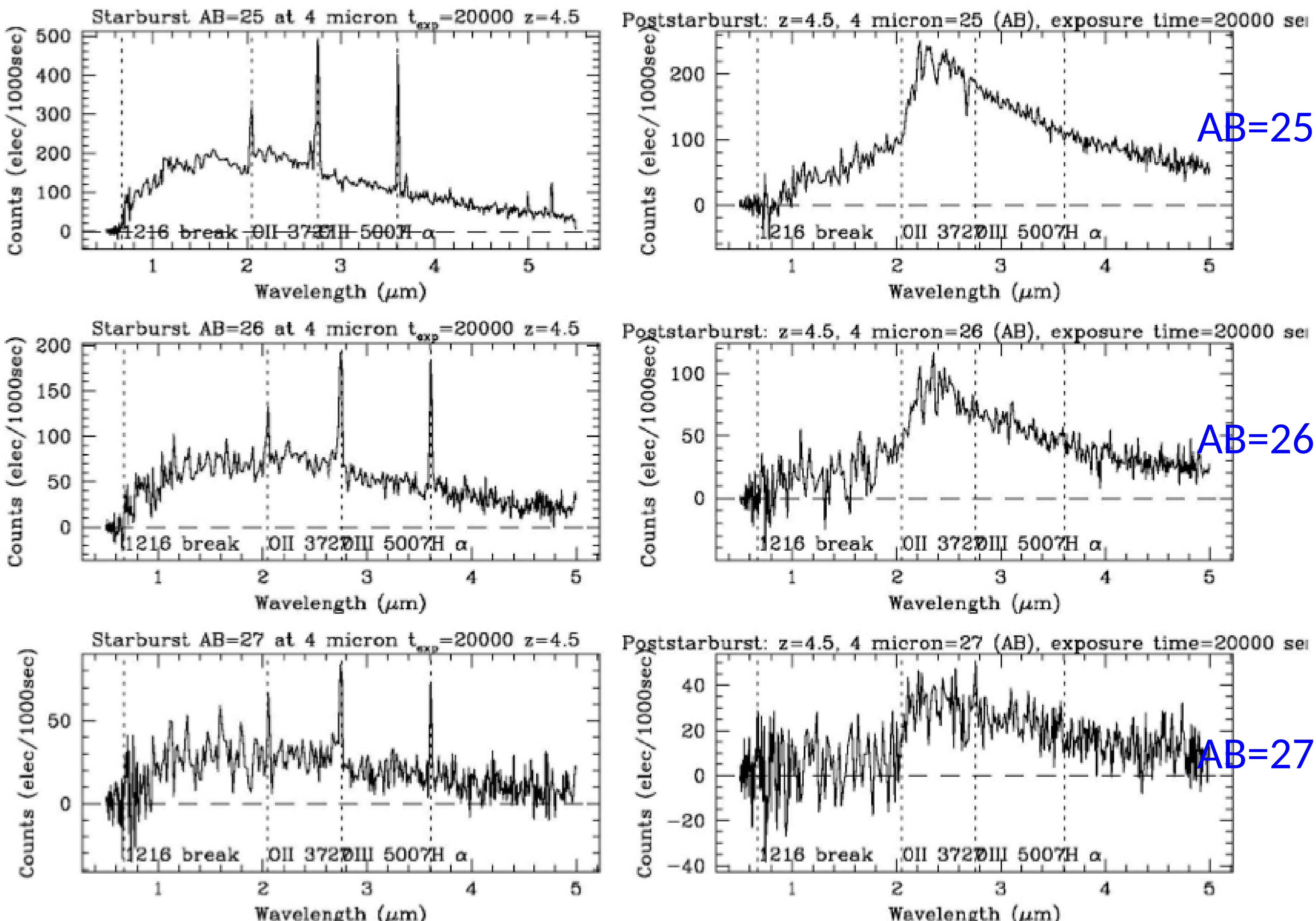
Quantities to be measured:

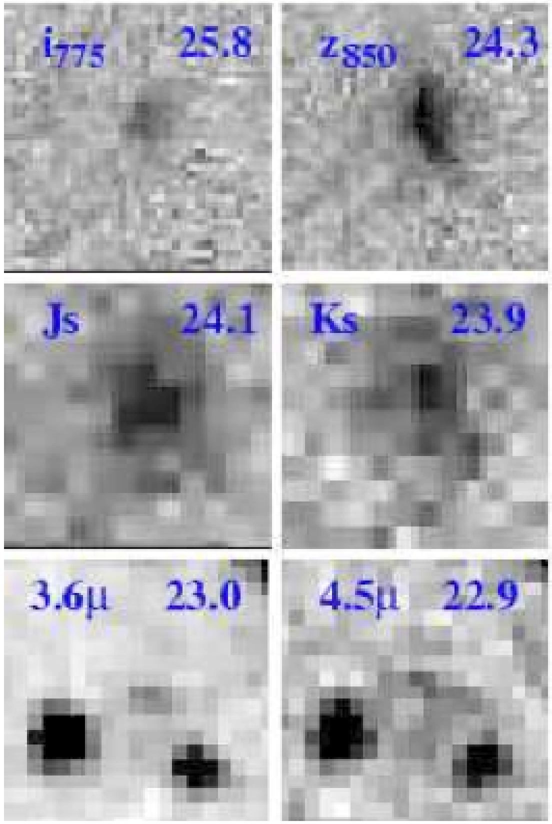
- Stellar mass
- Galaxy age and star formation history
- Star Formation Rate
- Stellar metallicy
- Gas metallicity
- Attenuation by dust
- Presence and power of AGN
- Black hole masses
- Presence of shocks
- Outflows
- Dynamics

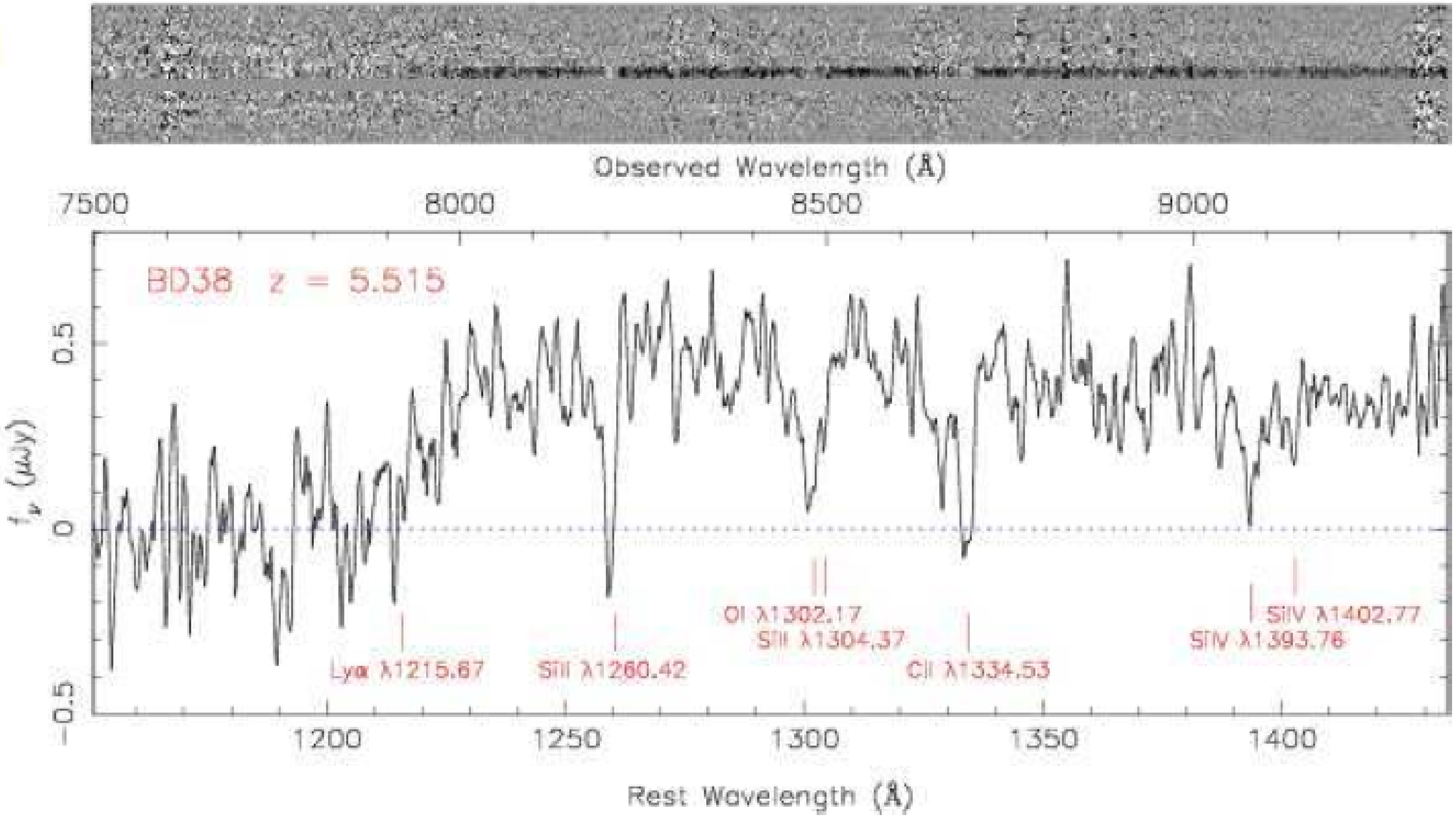
NIRSpec MSA simulations; T_exp = 20,000 sec z=4.5 with R100

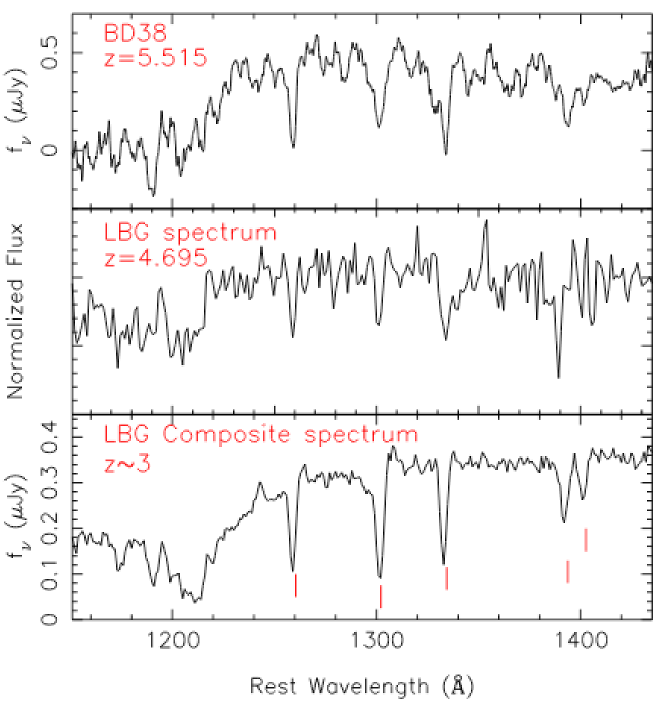
NIRSpec team (Franx, Bunker, Ferruit, Maiolino, Arribas, Charlot, Rix, Willot, Jakobsent)

Starburst Post-starburst









Absorption lines at z>5 - a single v. bright Lyman break z=5.5 galaxy, Dow-Hygelund et al (2005), AB=23-24, VLT spectrum (22 hours). R=1000 mode with NIRSpec to probe z>6 rest-UV absorption lines

Synergies with other JWST instruments

NIRCAM:

- imaging (and slitless spectroscopy), target selection
- morphological parameters
- correction for slit losses
- calibration of physical parameters inferred from broad band photometry (e.g. photo-z calibration)

MIRI:

- mid-IR diagnostics of star formation and AGN
- complementary tracers of dust

NIRISS: complementary survey

- larger statistics for line emitters
- diagnostics limited to lower redshifts (blue part of the spectrum)

Conclusions

- Have found star-forming galaxies at z=6-10 (Lyman breaks), and spectroscopic confirmation at z~6; not much Ly-alpha emission beyond z~7 (due to Gunn-Peterson absorption?)
- However, z>7 number counts from HST/WFC3 imply the newly-discovered galaxies would struggle to reionize the IGM
- Many of these have very blue rest-UV spectral slopes
- High escape fraction/Steep faint end slope/low metallicity/smooth IGM?
- JWST spectroscopy will get Hα, Hβ, [OIII], [OII] to high redshift, Getting REAL redshifts for luminosity functions
- will determine escape fractions, star formation rates, metallicities...

Program plan – Medium Survey (100-200 sq. arcmin)

- 9 NIRSpec pointings x 2 fields (test cosmic variance)
- (9arcmin x 9arcmin per field; possible fields include
- GOODS/CANDELS, Frontier Fields –
- complementary data, X-ray, UV, sub-mm....)
- ~3000 galaxies at 2<z<6 (150 galaxies per pointing)
- AB < 27
- R=100: 20ksec per pointing (continuum)
- R=1000: 10ksec per pointing in each of three bands
  ? (emission lines)
- total of ~ 230 hours

- Shallow survey (200-400 sq. arcmin, 48 pointings)

- AB<25, 7000+ galaxies, R=100 for 1000s
- R=1000 at 2-5microns for 1000s (2 settings)
- Total of ~50 hours