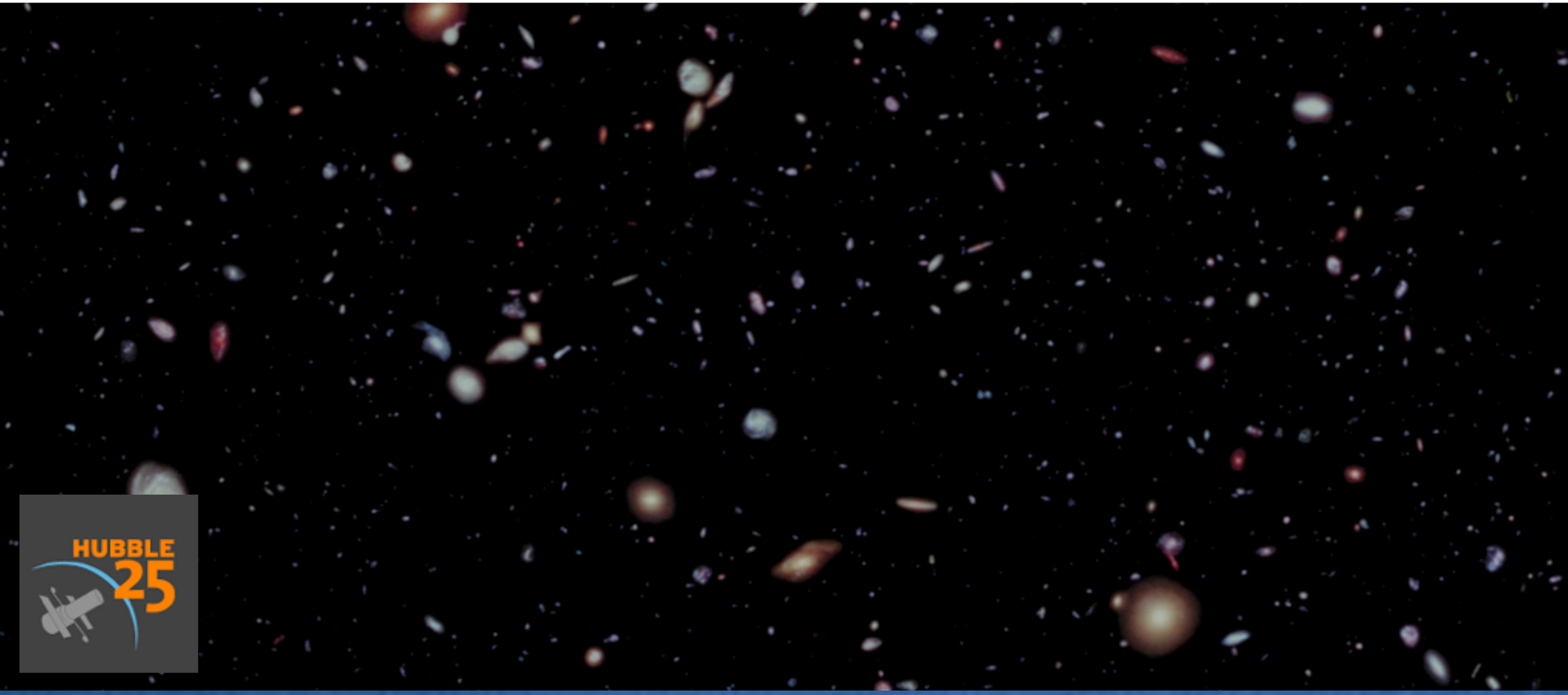
UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

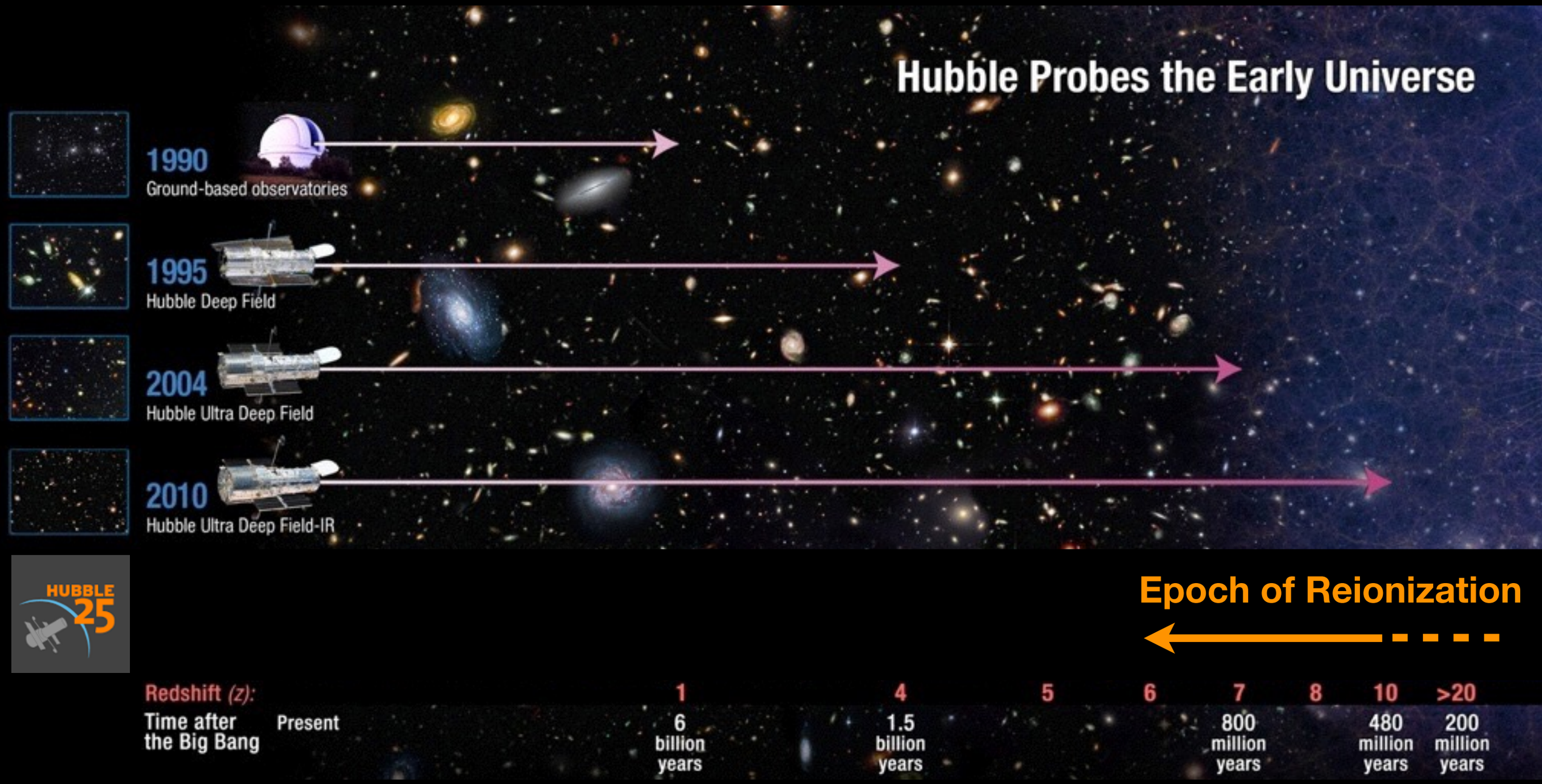
# Spectroscopic Exploration at the Cosmic Dawn

**Pascal Oesch**
Geneva Observatory



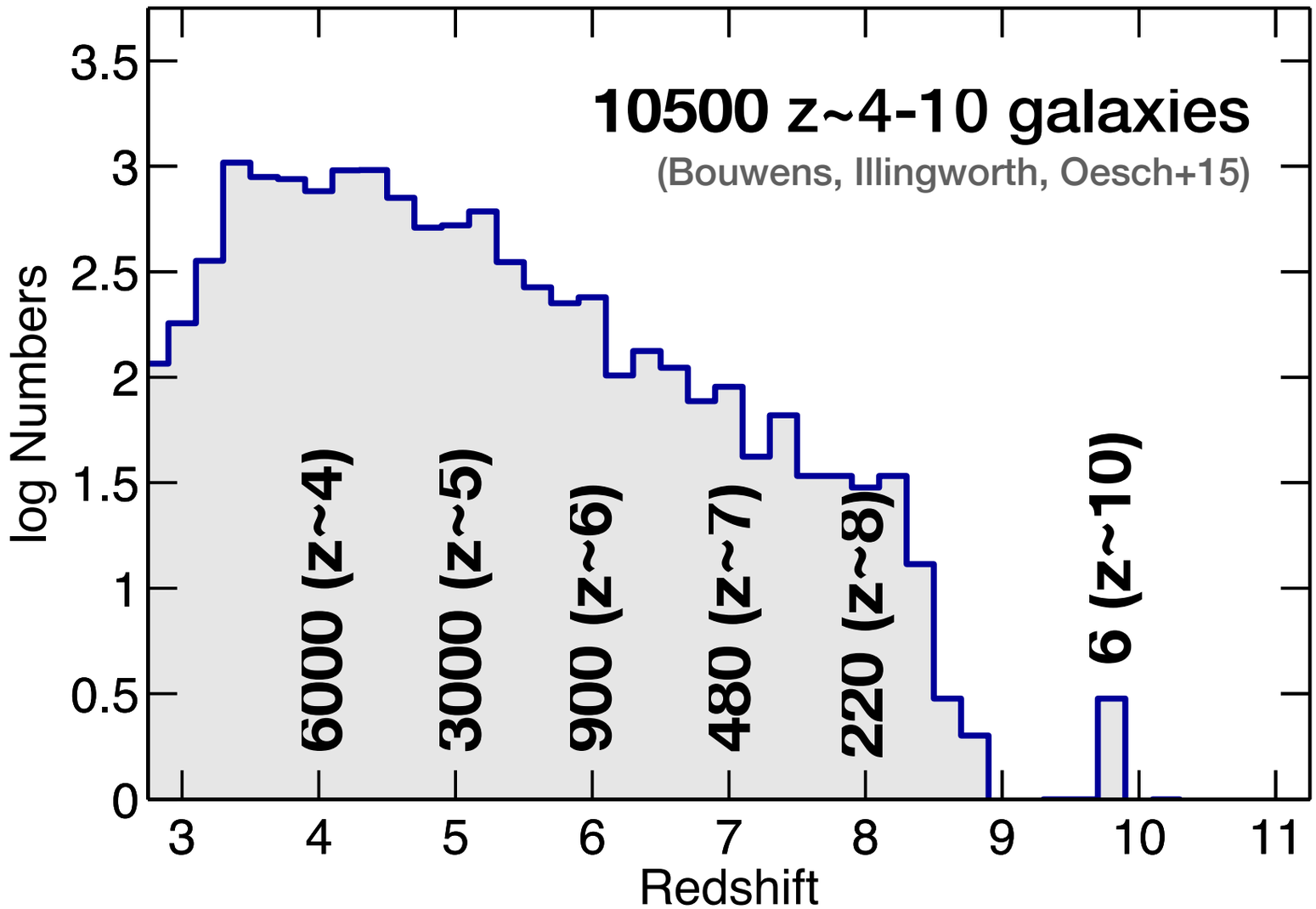
# The history of astronomy is a history of receding horizons.

**E. P. Hubble**



# Unprecedented Galaxy Samples at z>=4

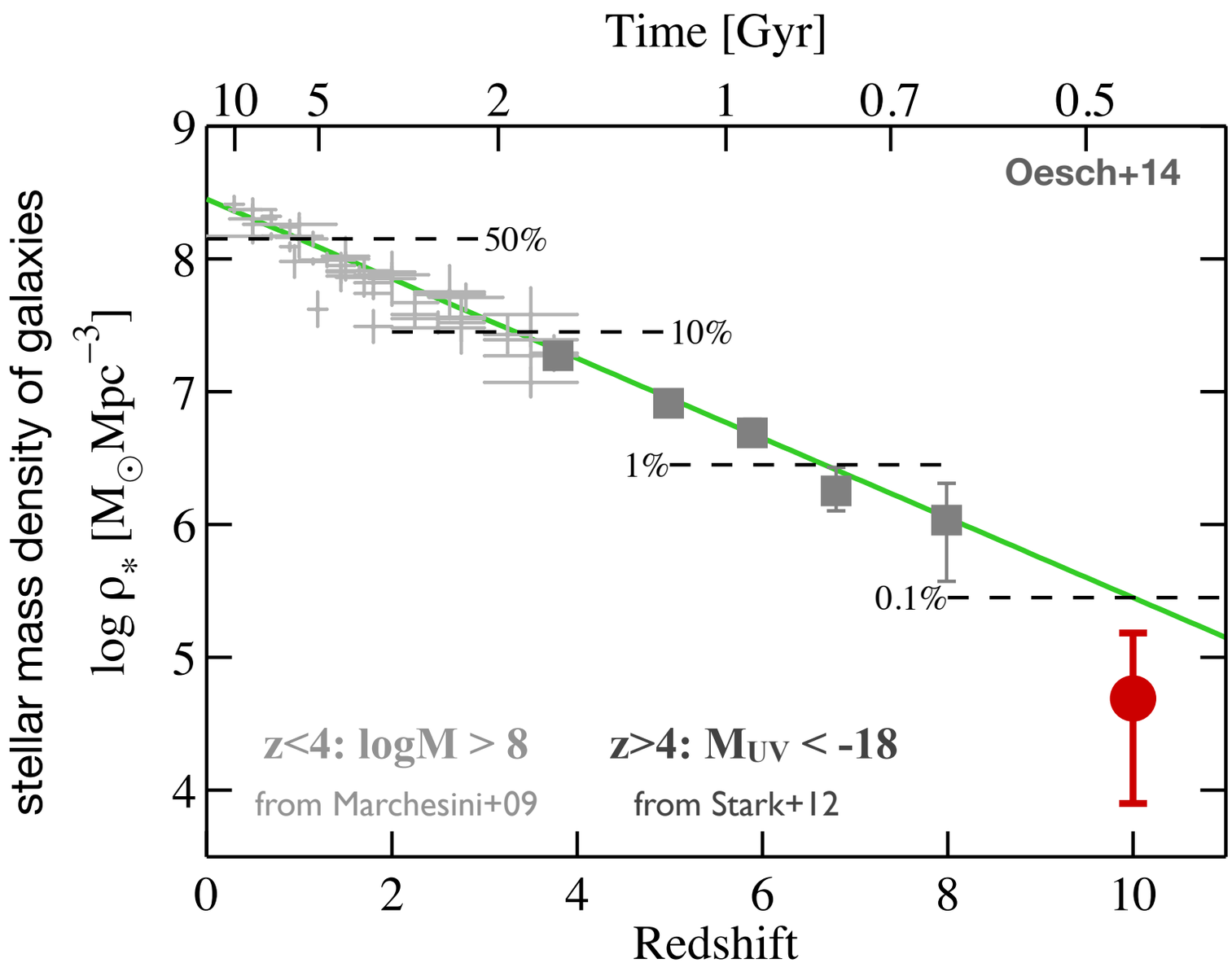
## (from HST's blank fields only)




Almost 1000 galaxies in the epoch of reionization at z>6

Current frontier: z~9-10

# Mass and SFR Build-up

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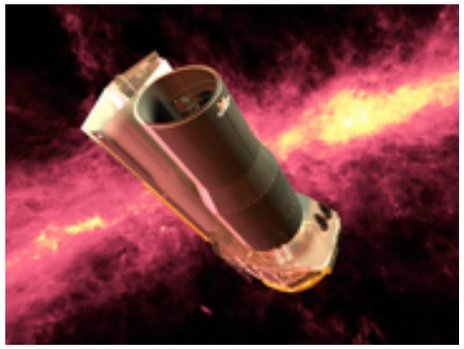
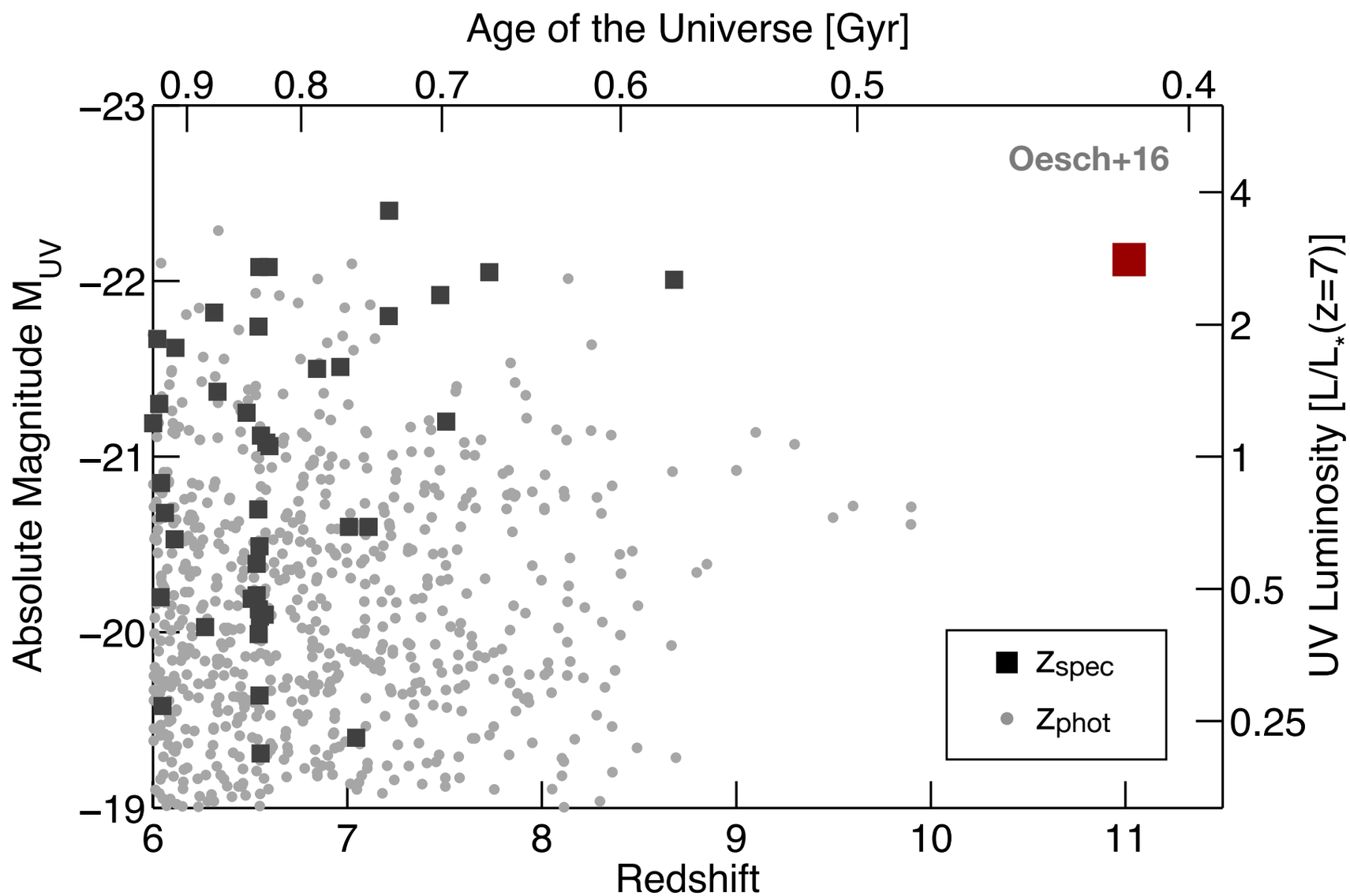


Are witnessing the assembly of the first 0.1% of local stellar mass density at z>8.
The first two Gyr are a very active epoch of galaxy assembly.

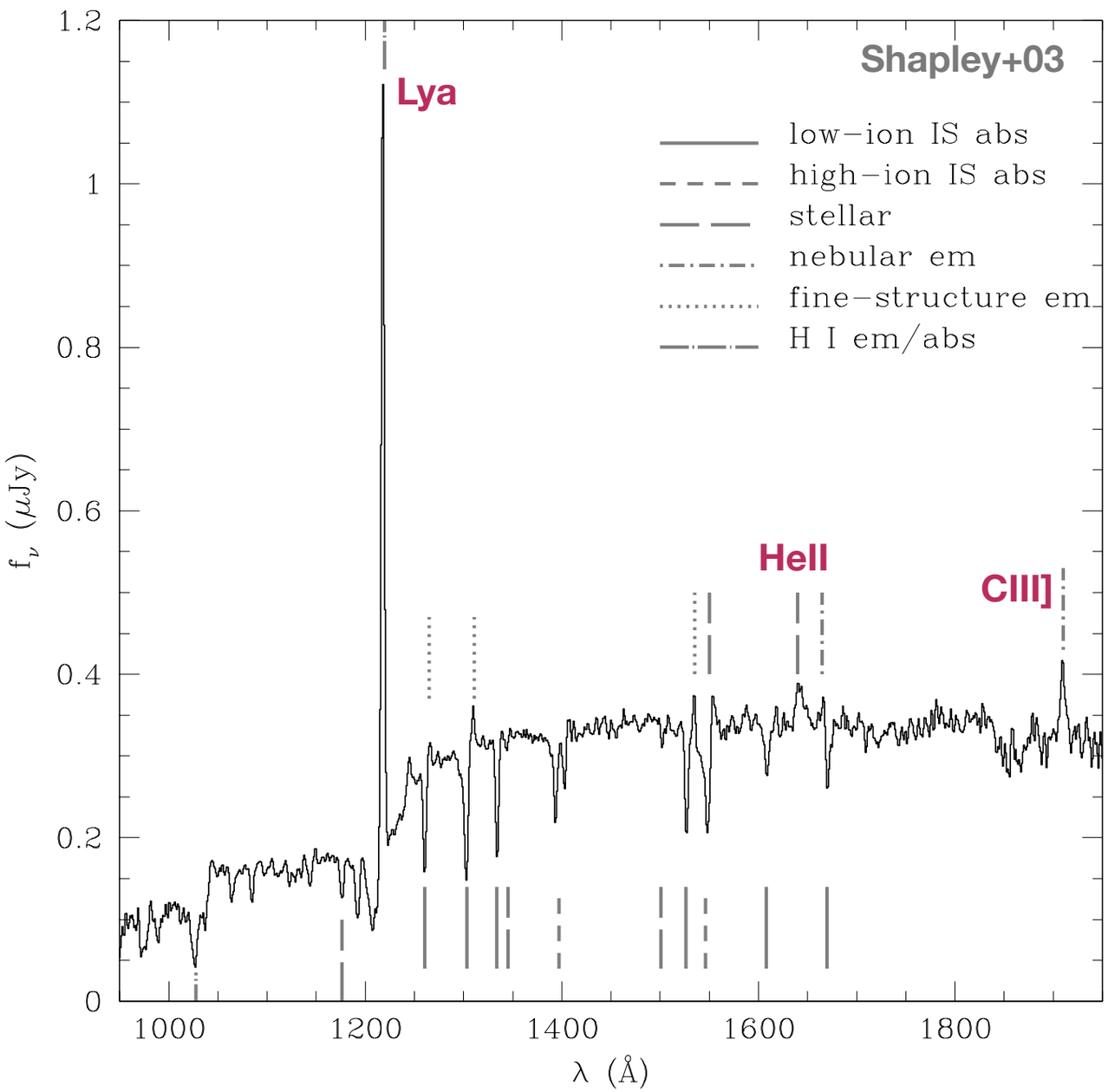
# Our Current Spectroscopic Census




Spectroscopic samples are severaly lagging behind!

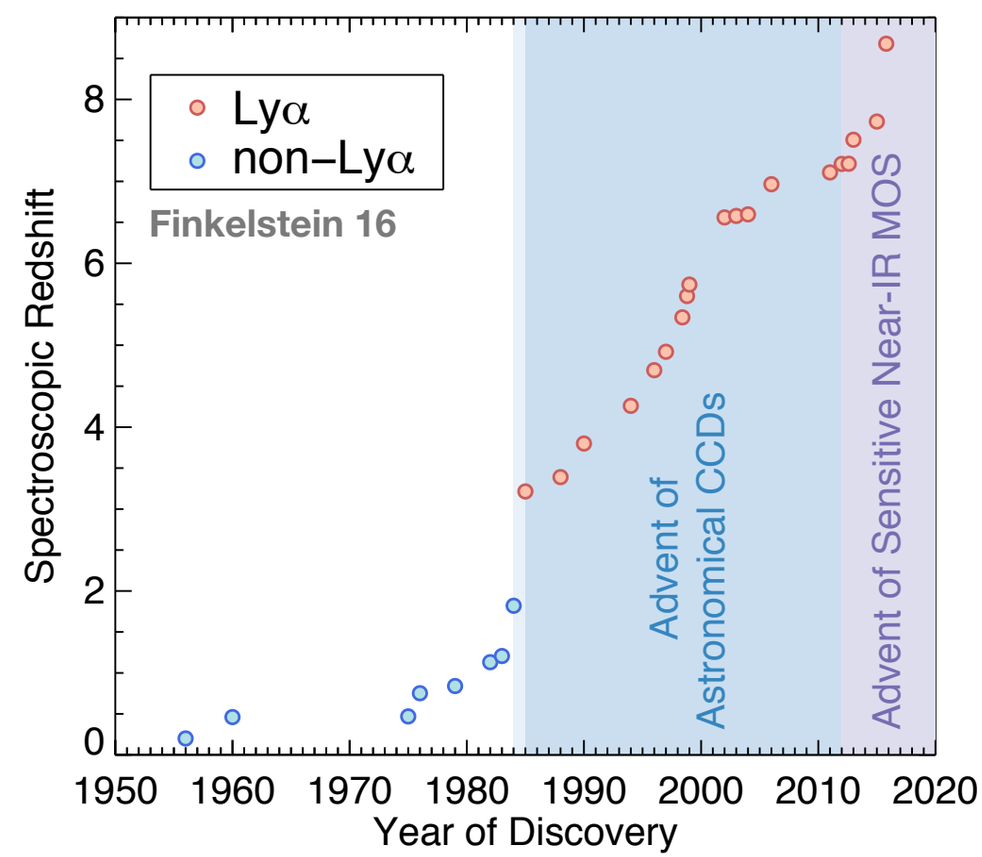
Only a dozen spectroscopic confirmations at z>7 to date.

# Spectroscopic Features of High-z Galaxies

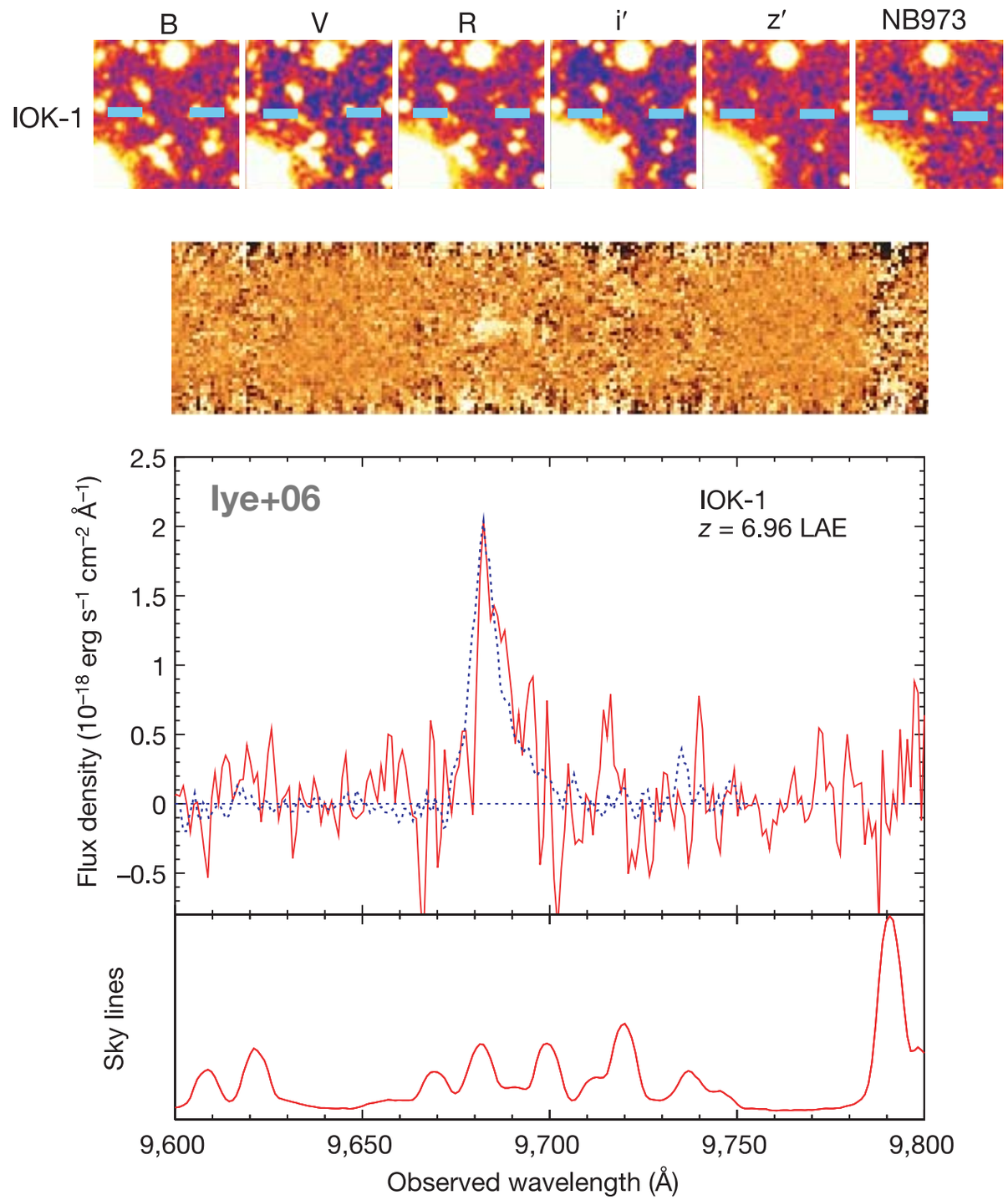



Lyα is the most promising feature of high-redshift spectra

Other emission lines very weak, but possible to detect (e.g. Stark+15)

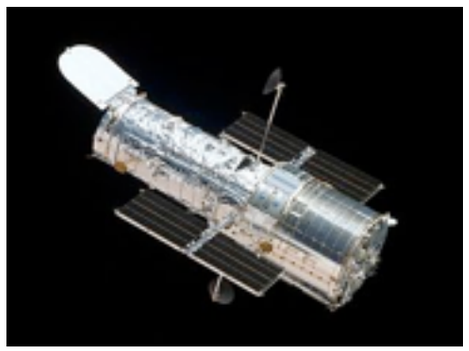


# Long-Term Spectroscopic Redshift Holder



# Lyman Alpha in the Reionization Epoch

Spectroscopic confirmation of sources in the reionization epoch has proven very difficult, even with new efficient NIR spectrographs.



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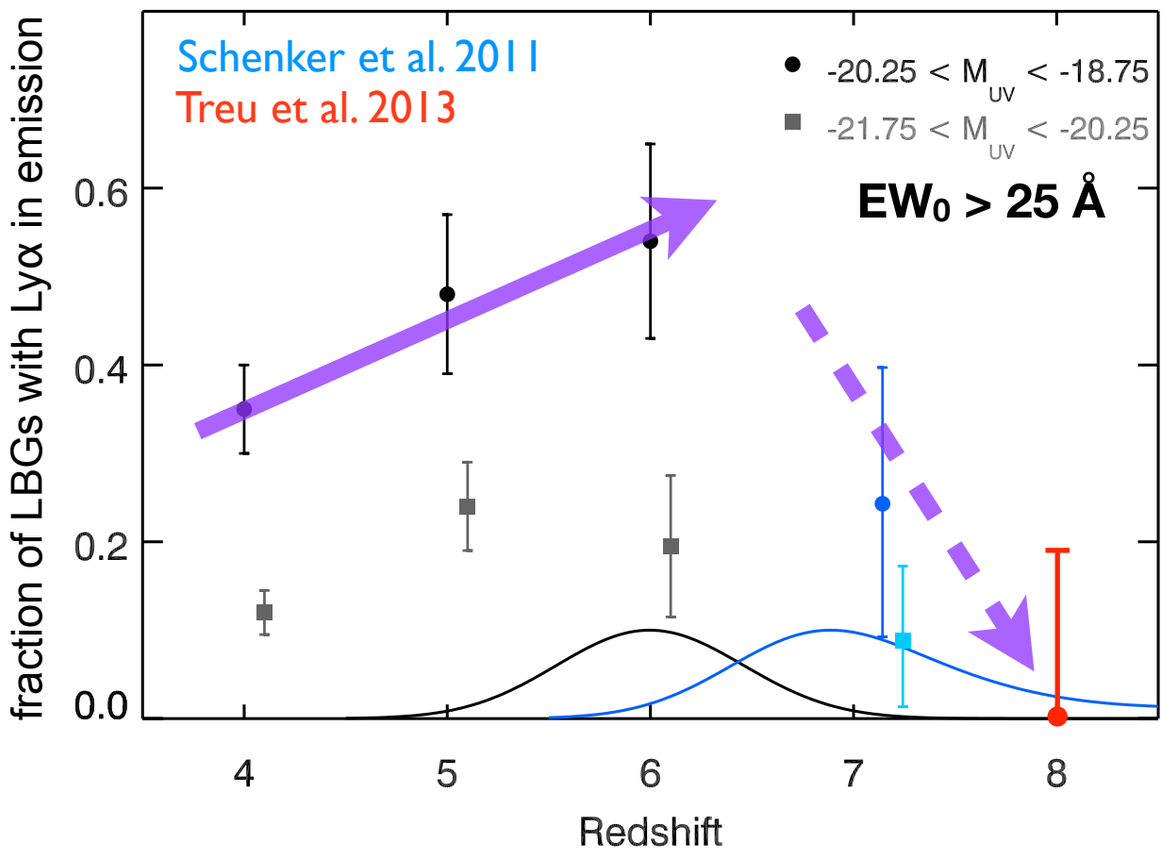
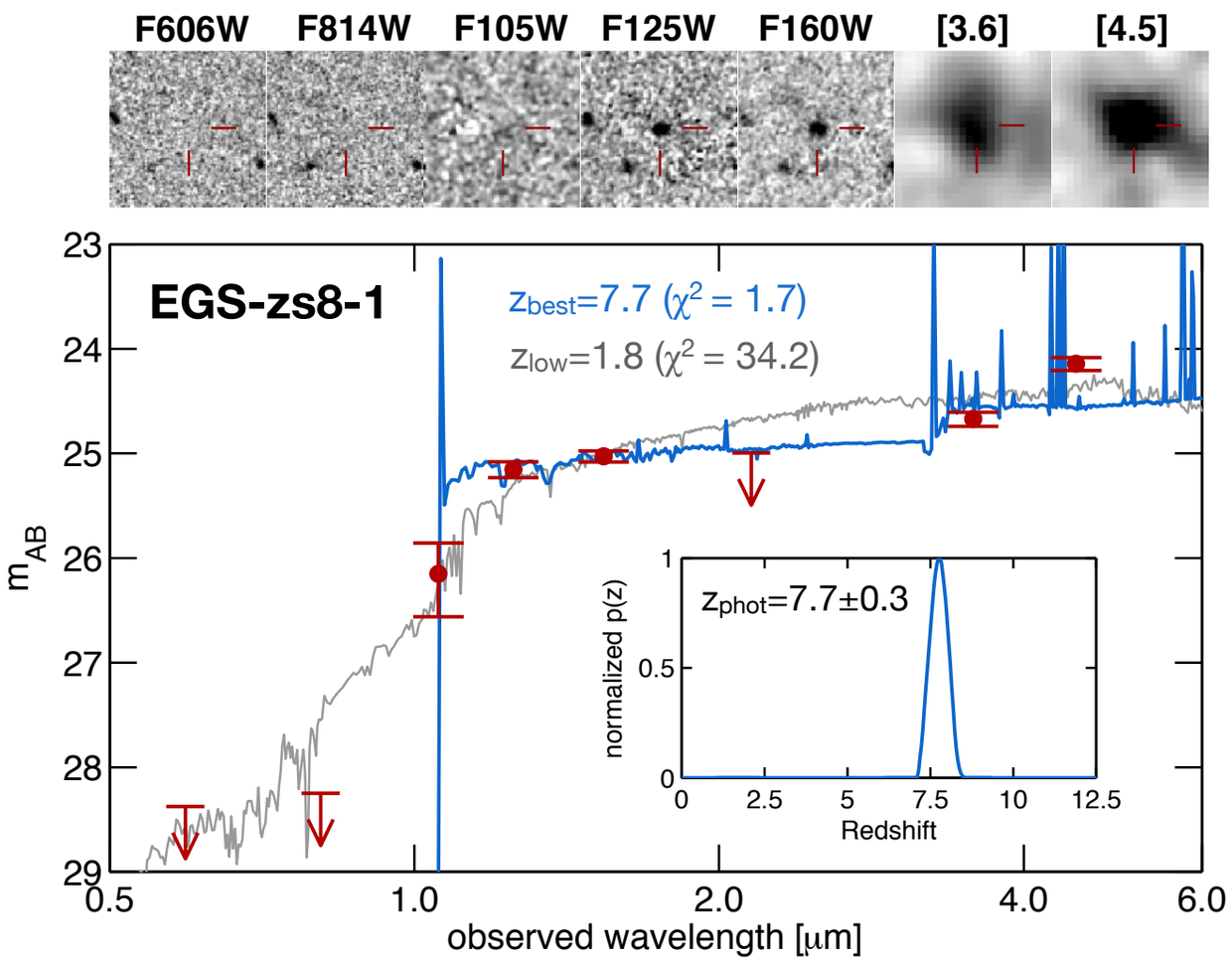
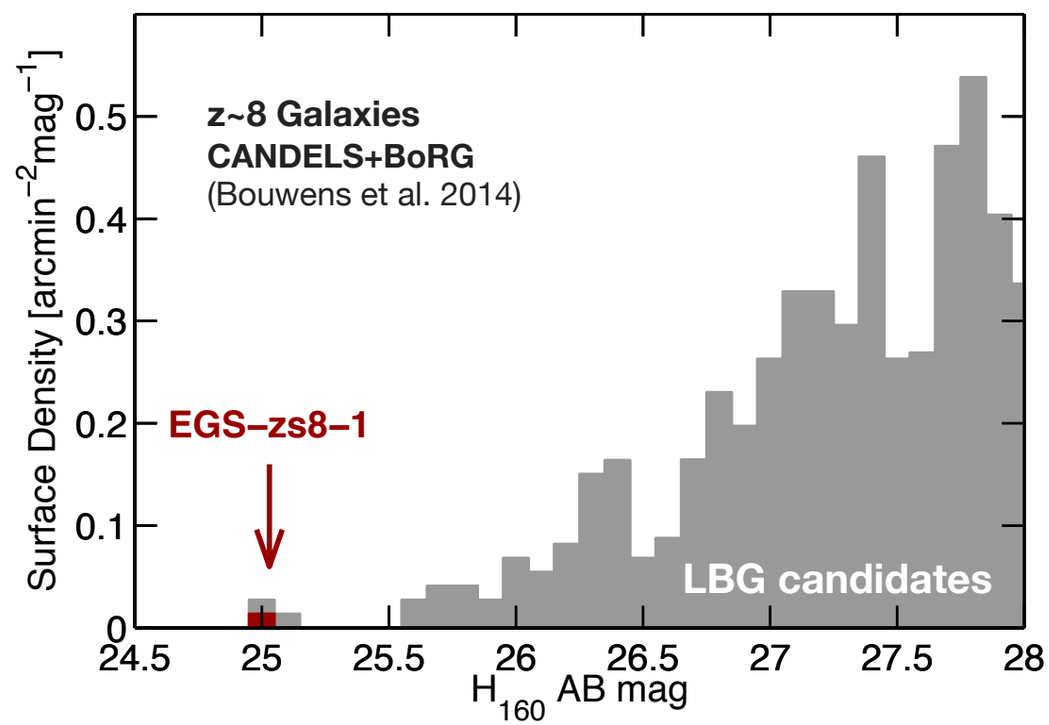



Fraction of Lyα line emitters drops across z=6.5 to z=7:
***imprint of cosmic reionization?***

# Bright z~8 Galaxies with Spectroscopic Redshifts




Small sample of four IRAC excess sources from CANDELS/WIDE
**(see Roberts-Borsani+15)**

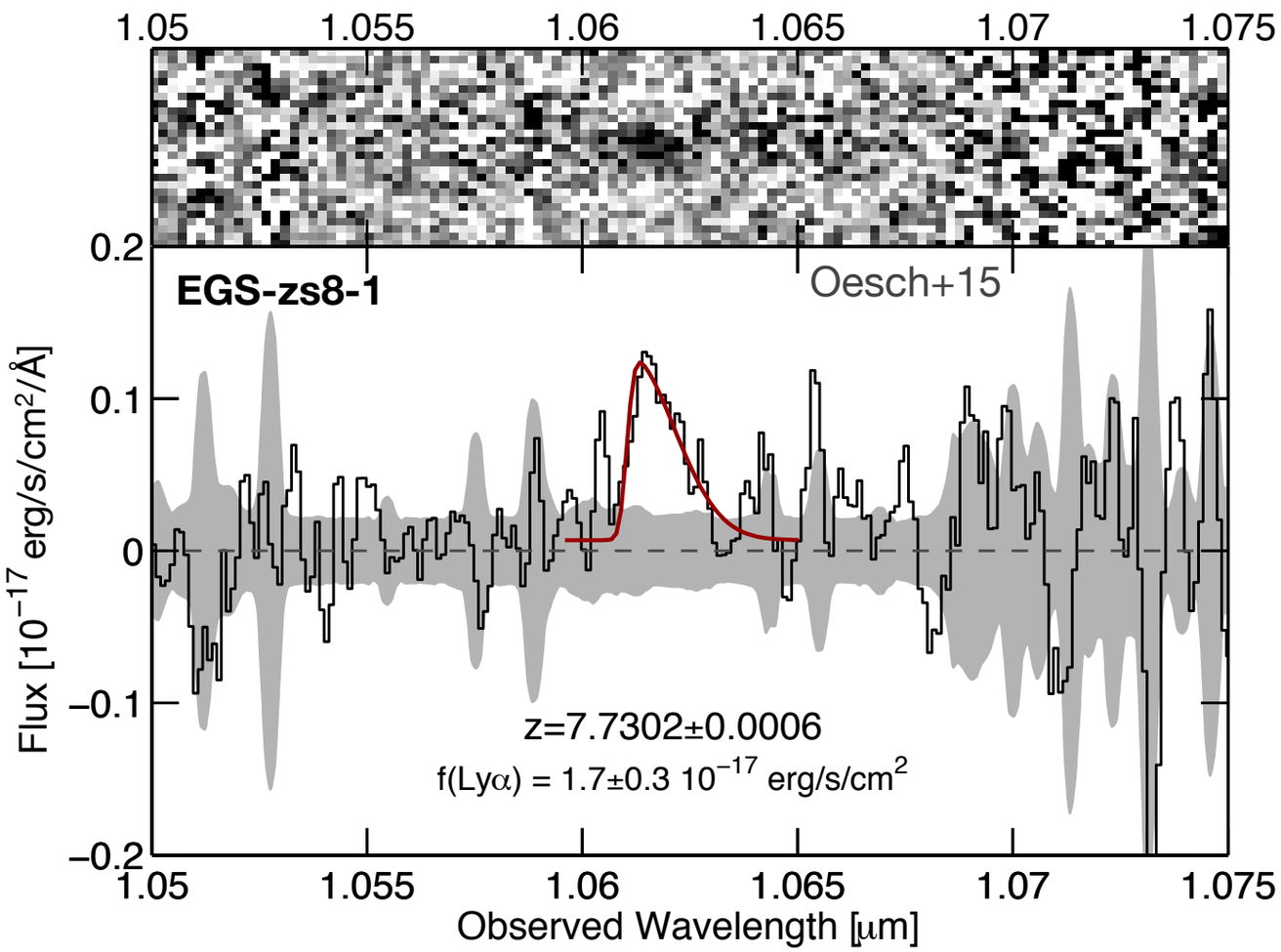


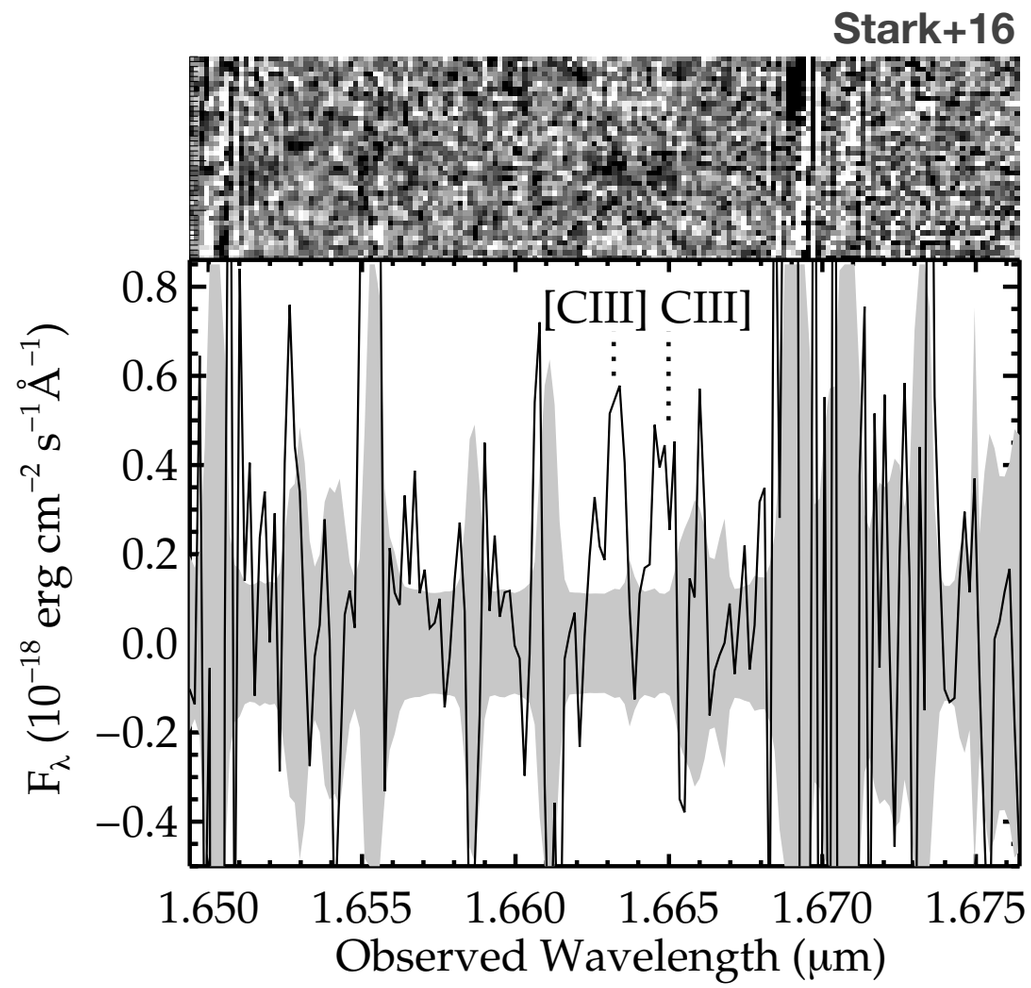

Spitzer/IRAC colors allow us to exploit very wide area imaging data to search for rare, ultra-luminous z~8 galaxy candidates with robust photometric redshifts

# Bright z~8 Galaxies with Spectroscopic Redshifts

**100%** spectroscopic success rate via Lyα detection in luminous galaxies!

**see: Roberts-Borsani+15 (z=7.48), Zitrin+15 (z=8.68), Stark+16 (z=7.15)**



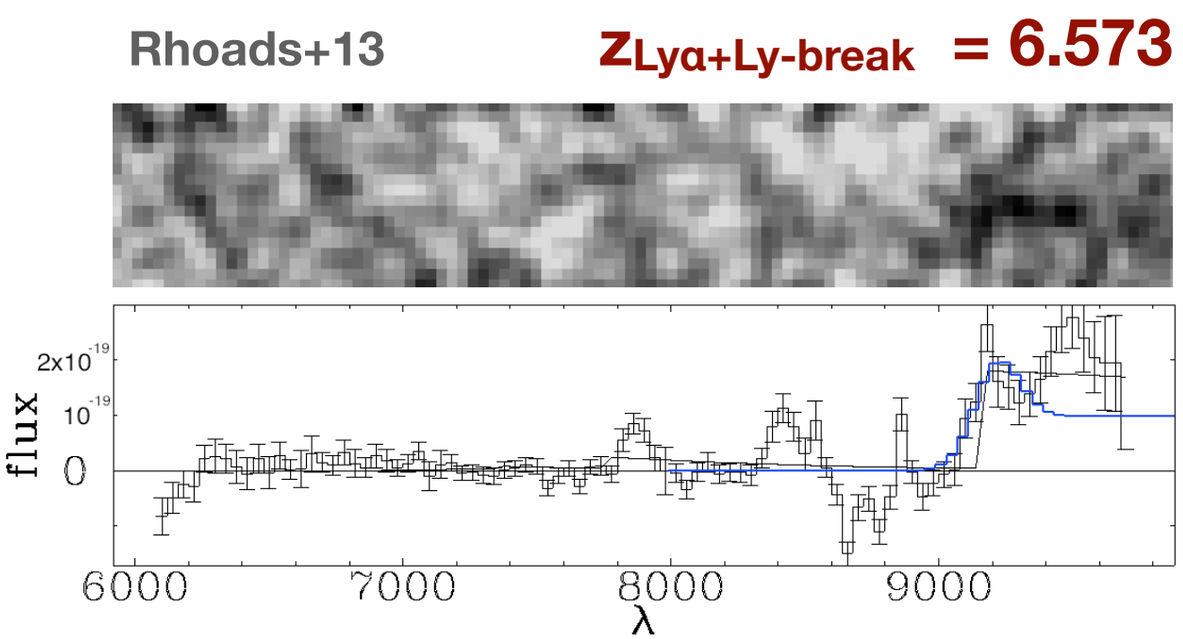

EGS-zs8-1 now has a three line redshift z=7.73.

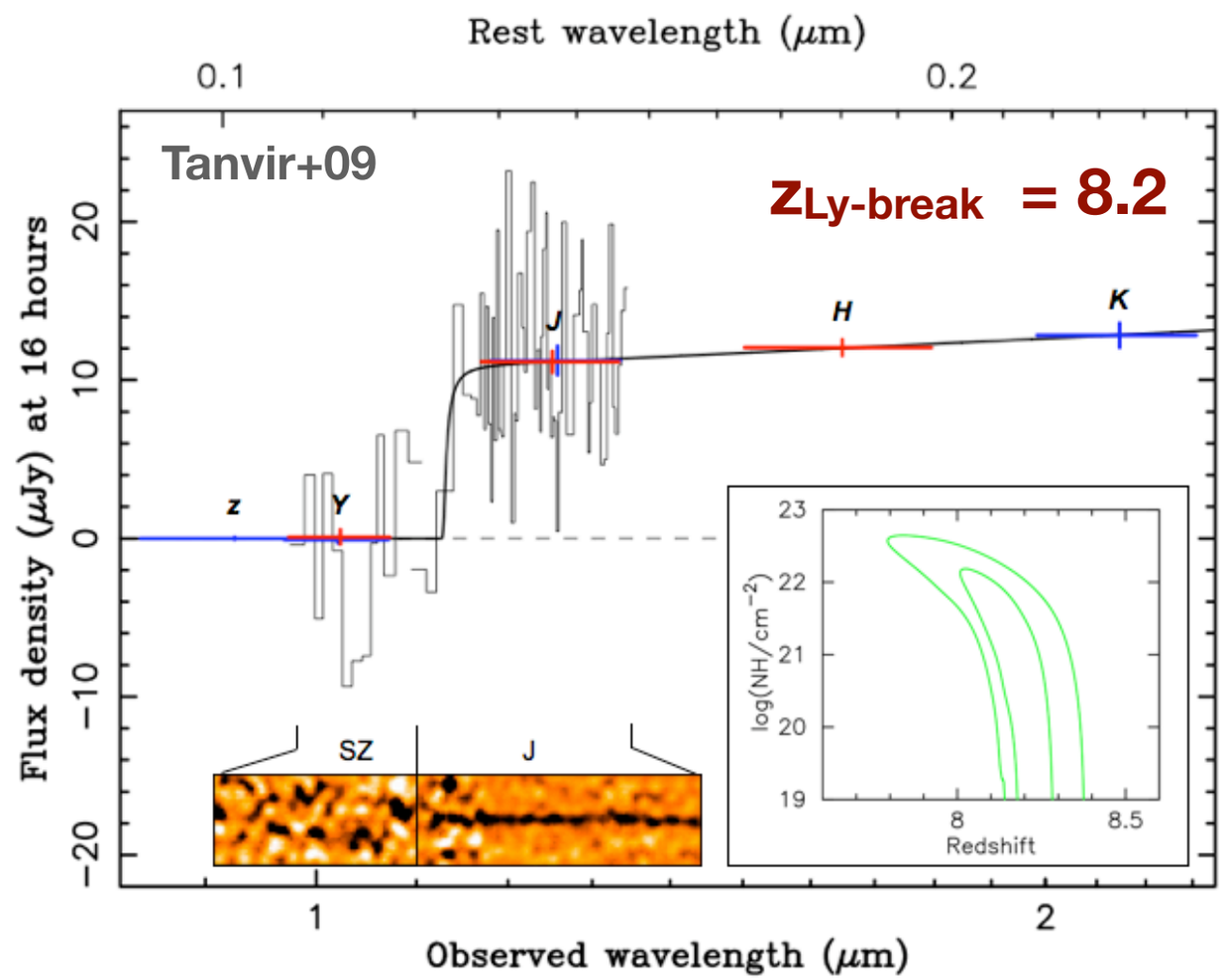
Very high EW CIII] emission ($W_0$=22+-2 Å),
implies strong radiation field and low metallicity

# Different Way Forward: Continuum Break Redshifts

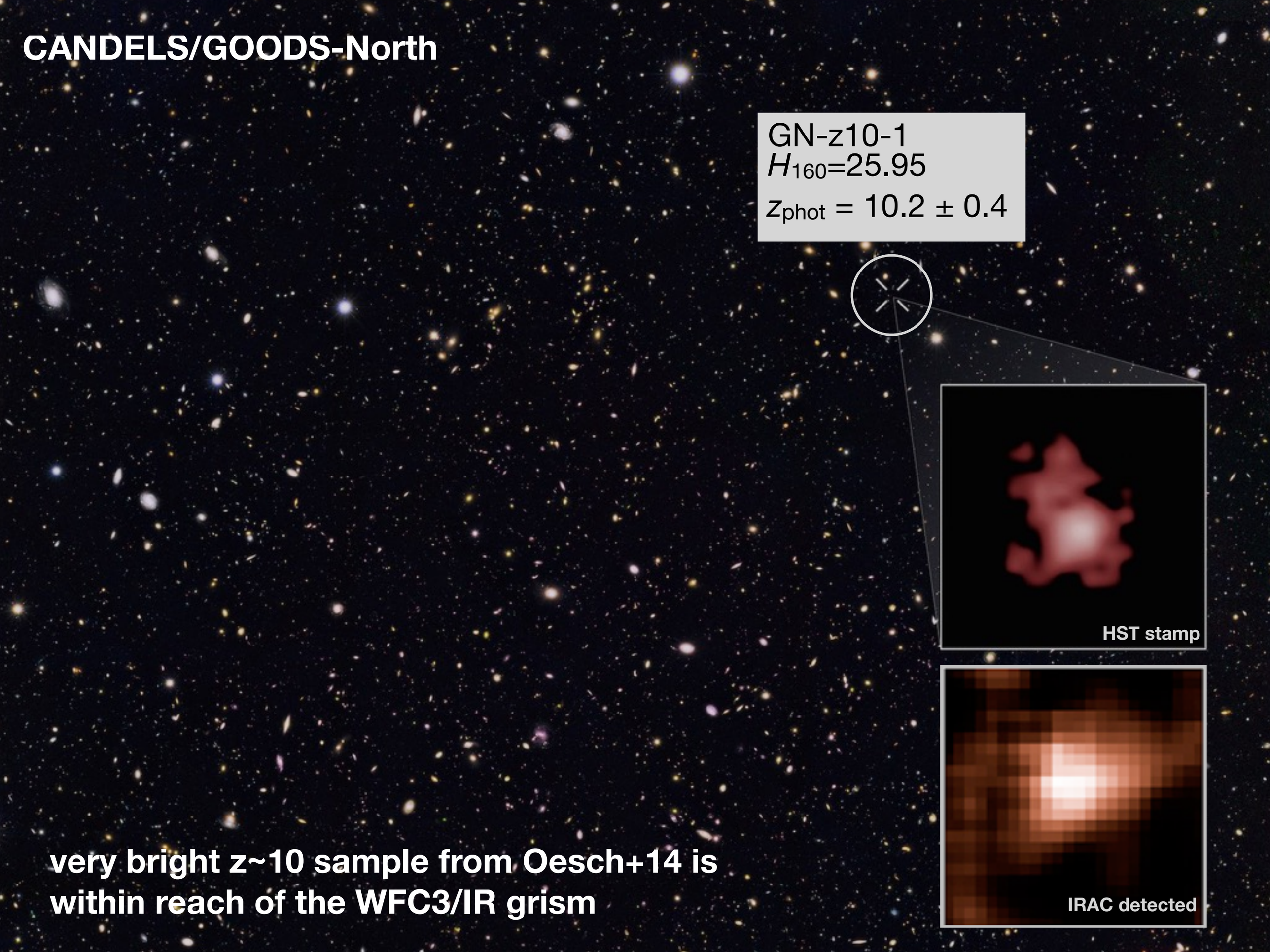
If Lyα disappears, need different technique to measure redshifts:
***continuum breaks (as done for QSOs)***

***Note:*** at z>6 these are the Lyα continuum breaks



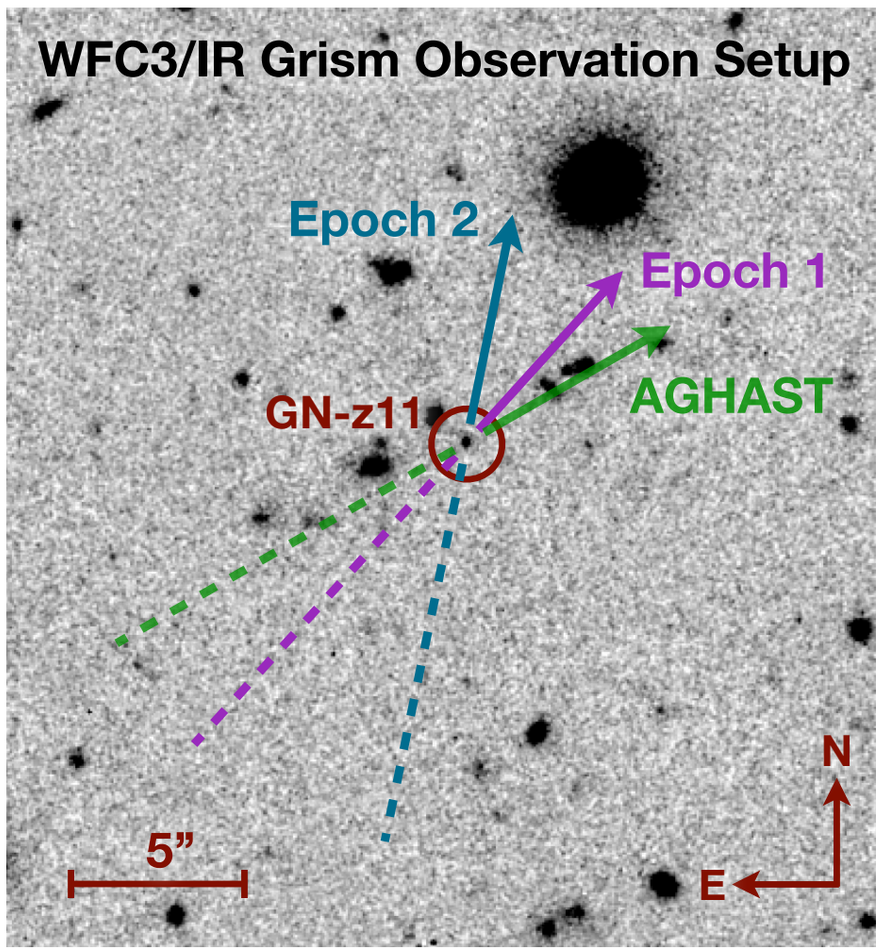

**Problem**: the background in the NIR is very high from the ground and faintness of galaxies compared to QSOs



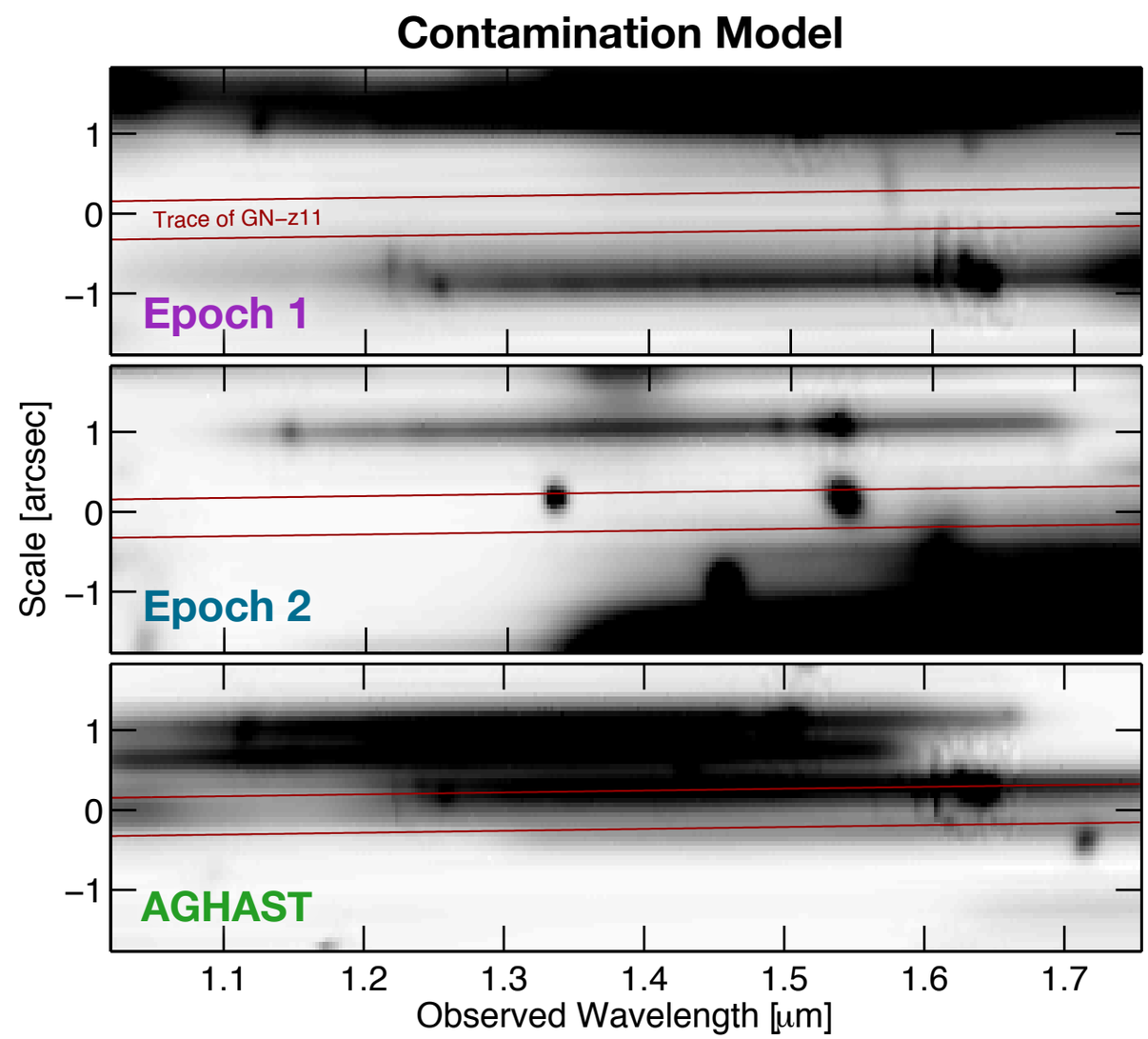

very bright z~10 sample from Oesch+14 is within reach of the WFC3/IR grism

# Neighbor Contamination in Grism Spectra

Even in a blank field, it's difficult to identify orientations with minimal contamination.
Previous AGHAST spectra heavily contaminated.

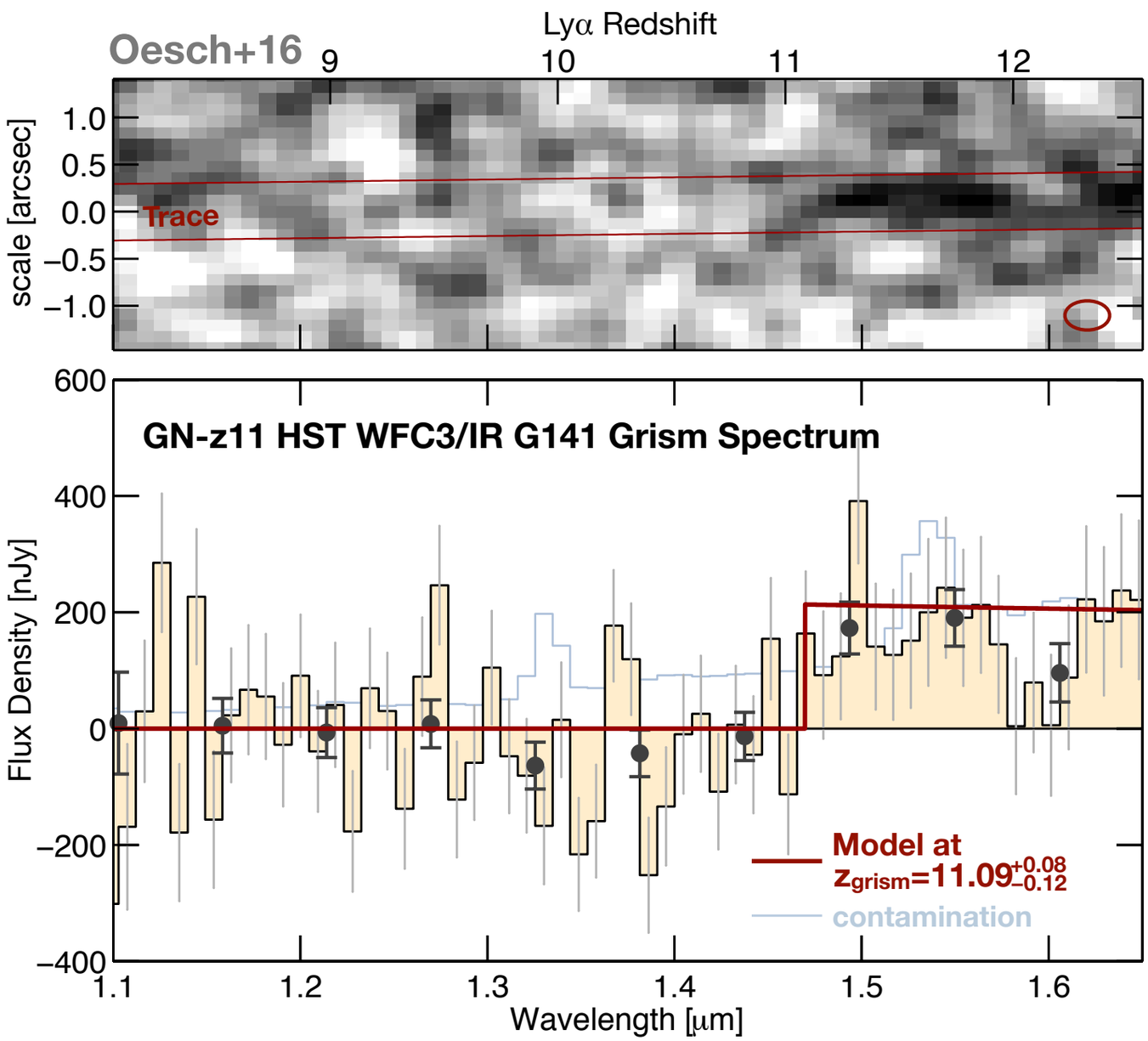



Oesch+16




Perform full 2D contamination modelling and neighbor subtraction
(based on 3D-HST grism pipeline; Brammer+12, Momcheva+15)

# Lyman Break Detection at z=11

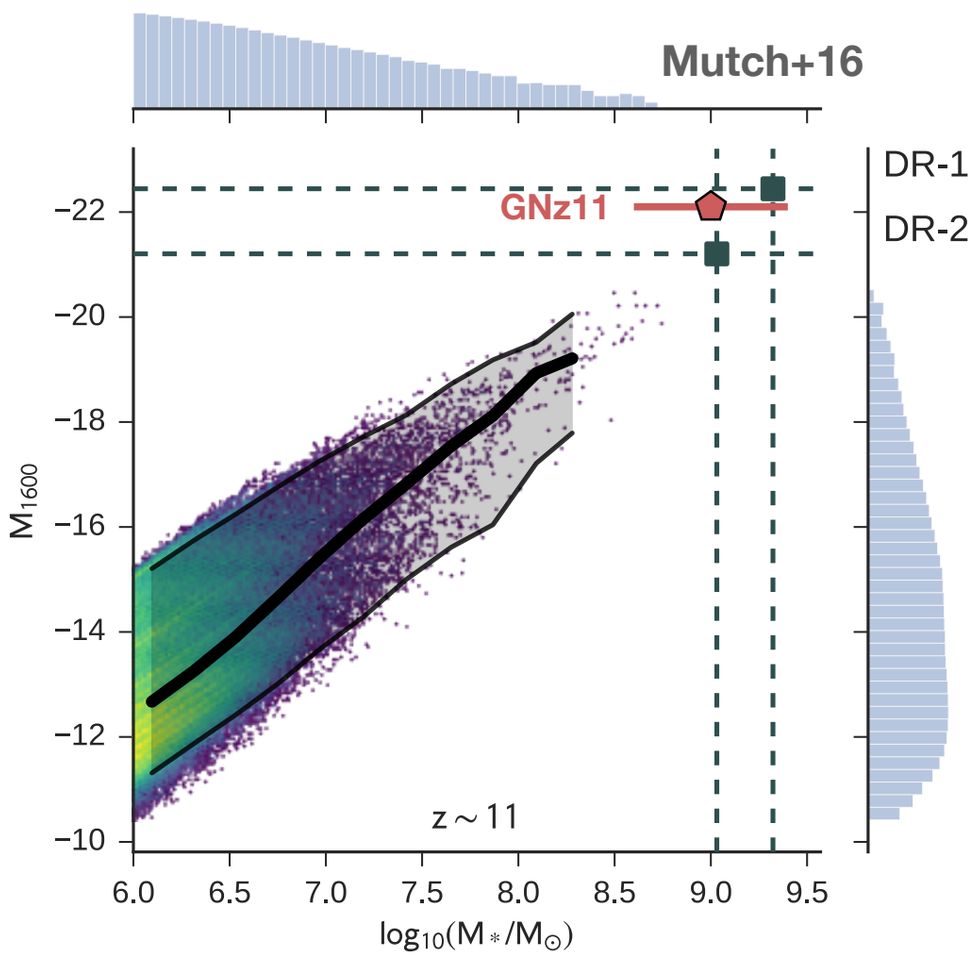


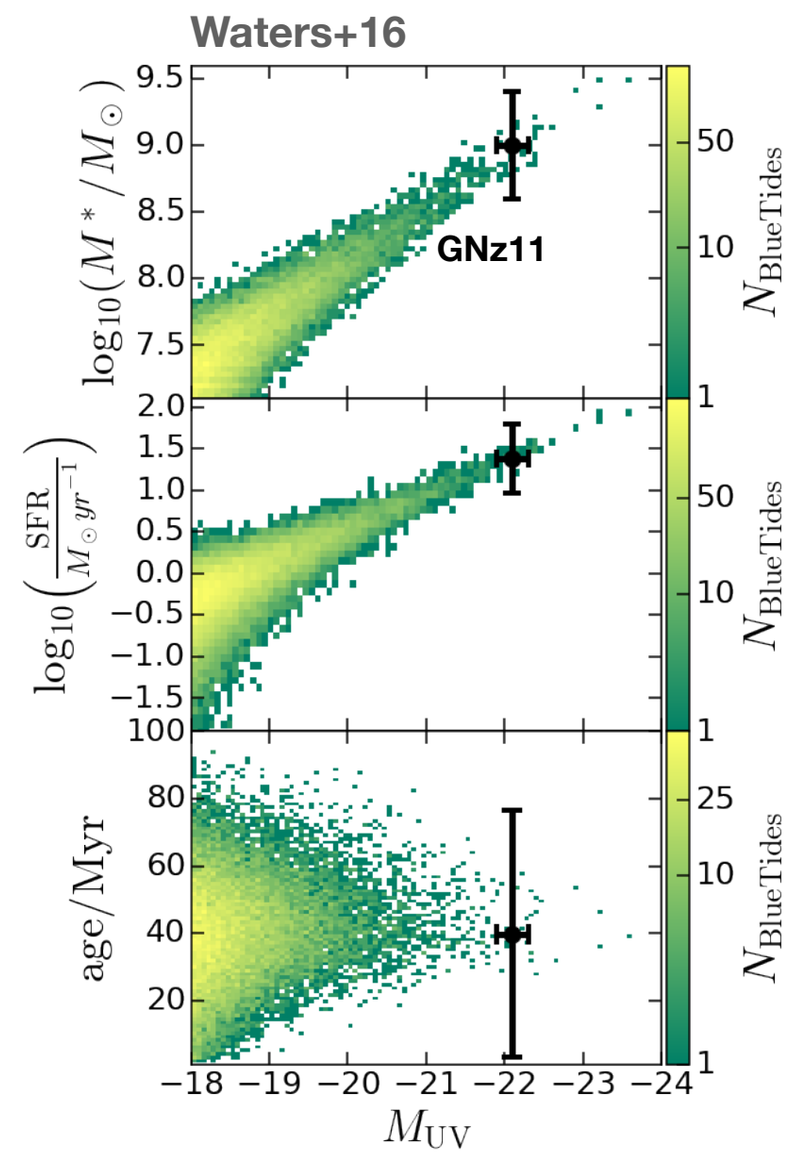

- 12 orbits of HST grism spectra with WFC3/IR
- Detect UV continuum (at 5.5σ) and a break at λ > 1.47 μm
- Rule out potential lower redshift solutions (quiescent galaxy at z~2 or strong emission line source)
- Best-fit redshift: z=11.09+-0.10

**GN-z10-1 → GN-z11**

Most distant source ever seen
Build-up of massive galaxies well underway at 400 Myr after Big Bang

# Physical Properties of GN-z11 in Line with Models

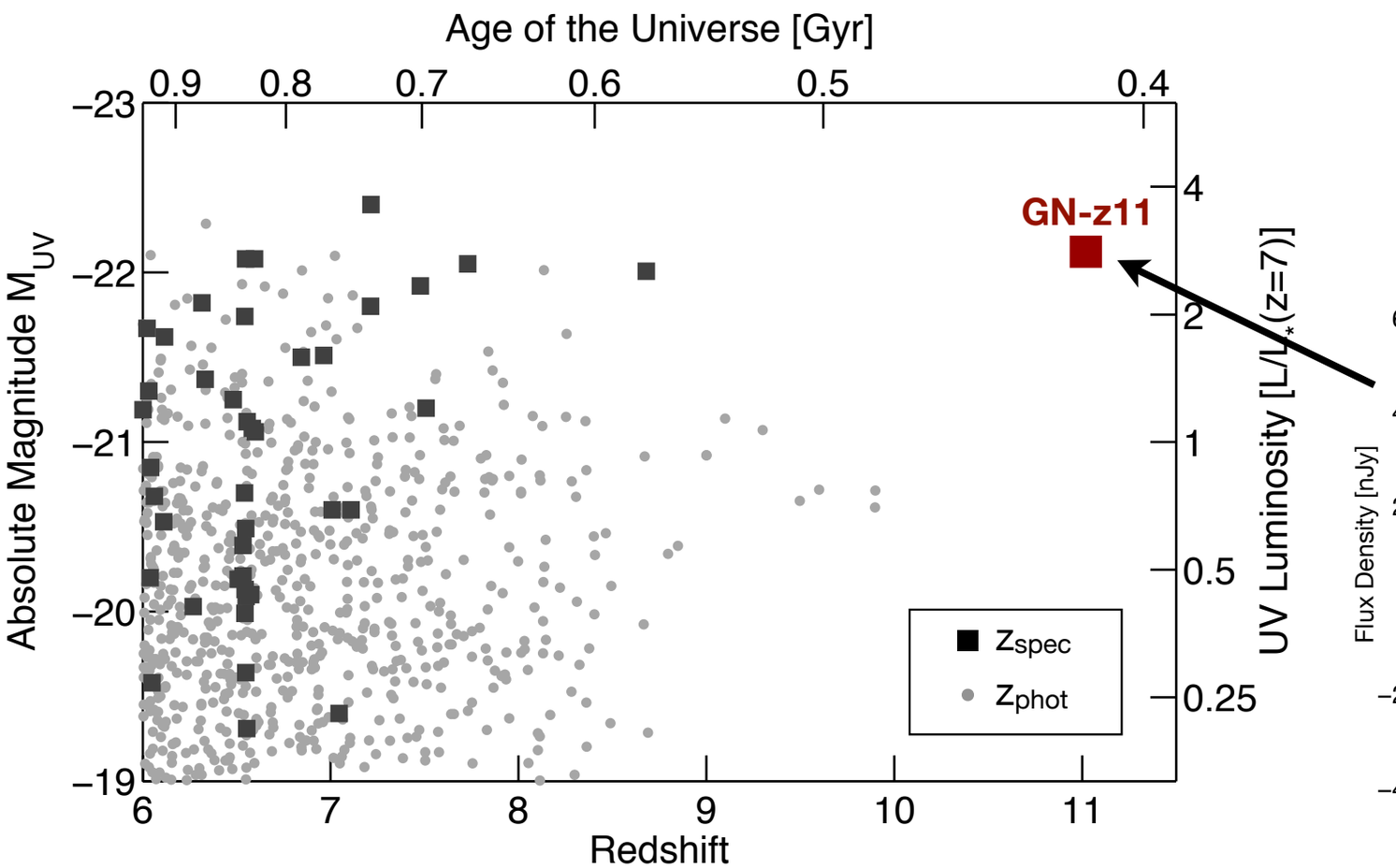


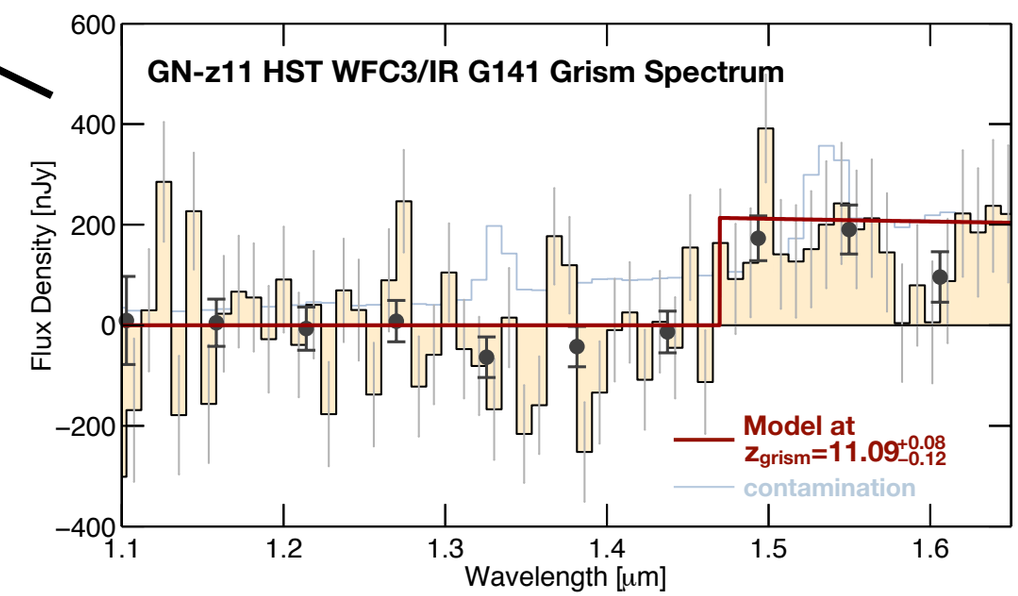

The derived physical properties (SFR, mass, and age) of GN-z11 are in very good agreement with expectations from large-volume simulations

**However:** did not expect to find such a source in the current HST fields

# The Current Spectroscopic Frontier

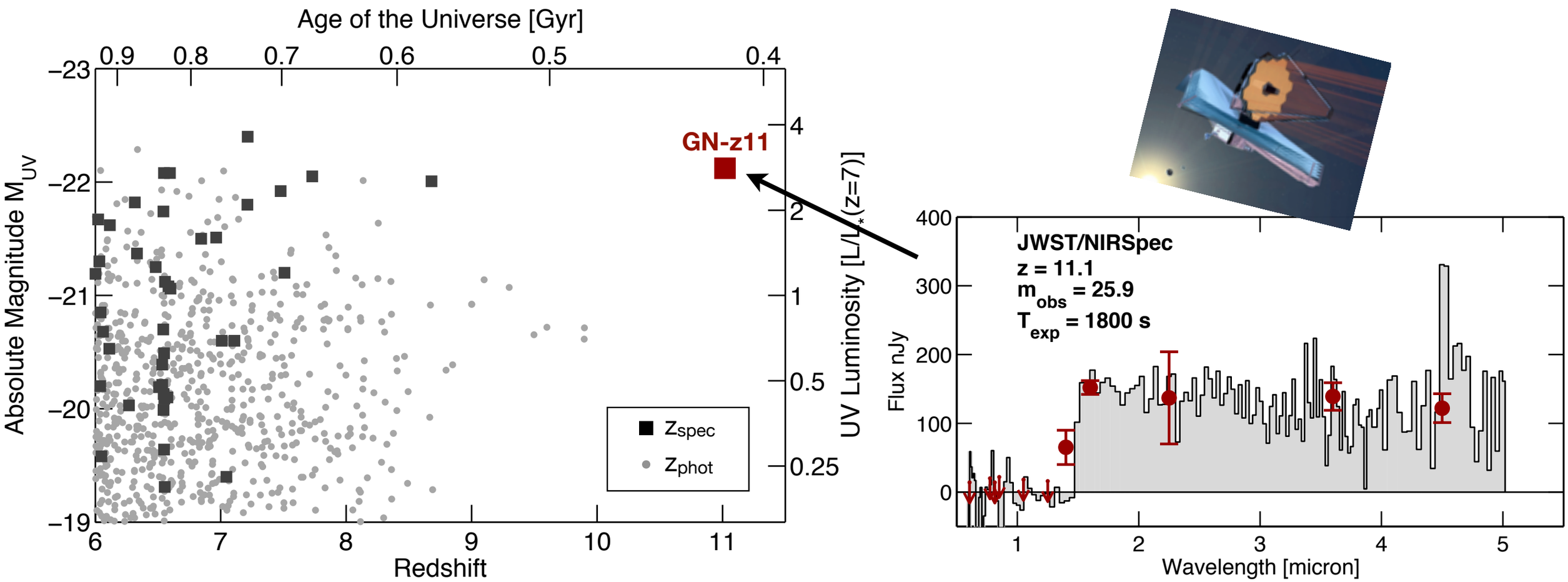



GN-z11 is by far the most distant known source




With surprising discovery of GN-z11,
HST+Spitzer have already **reached into JWST territory**

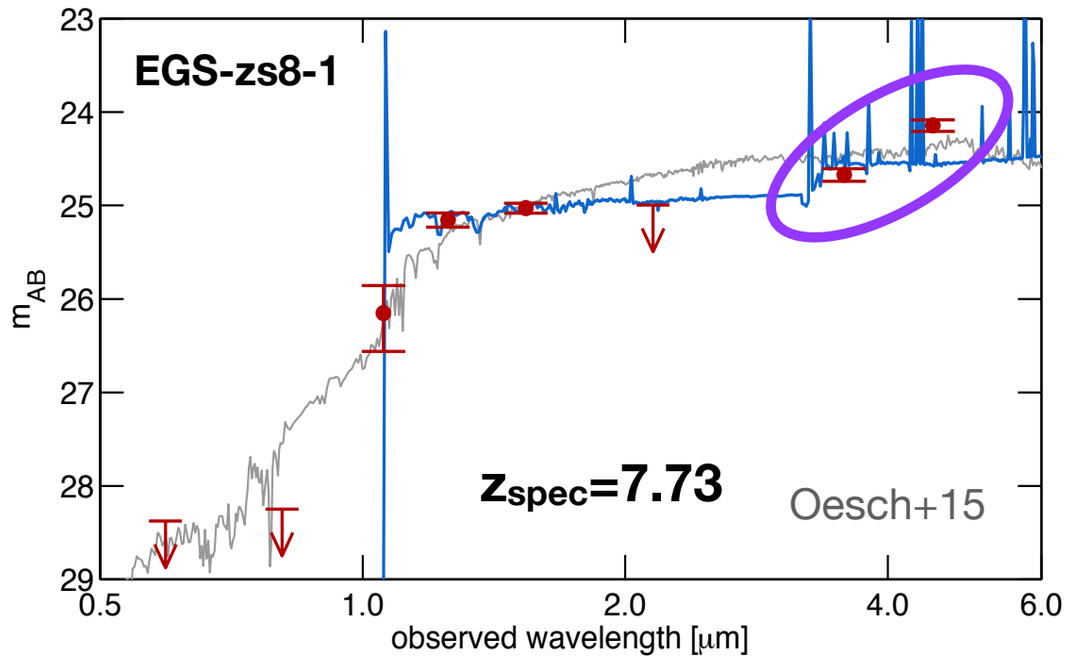
# Moving Forward with JWST NIRSPEC

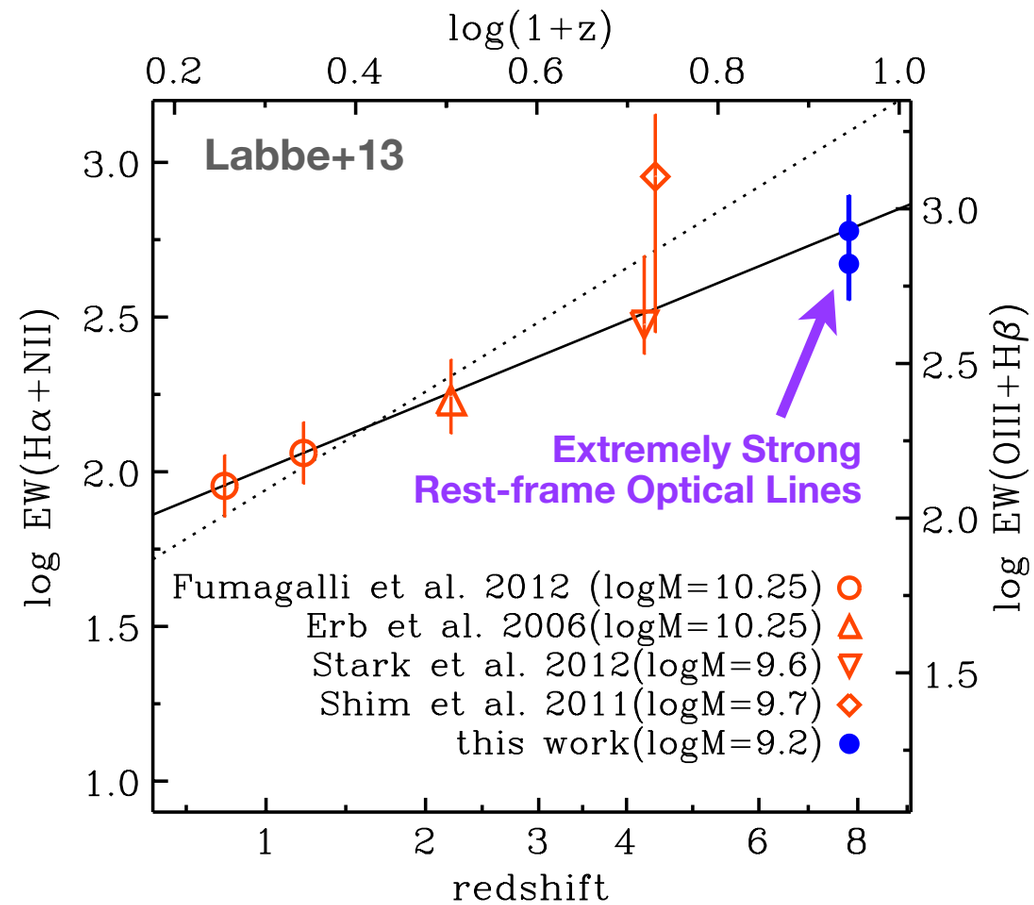


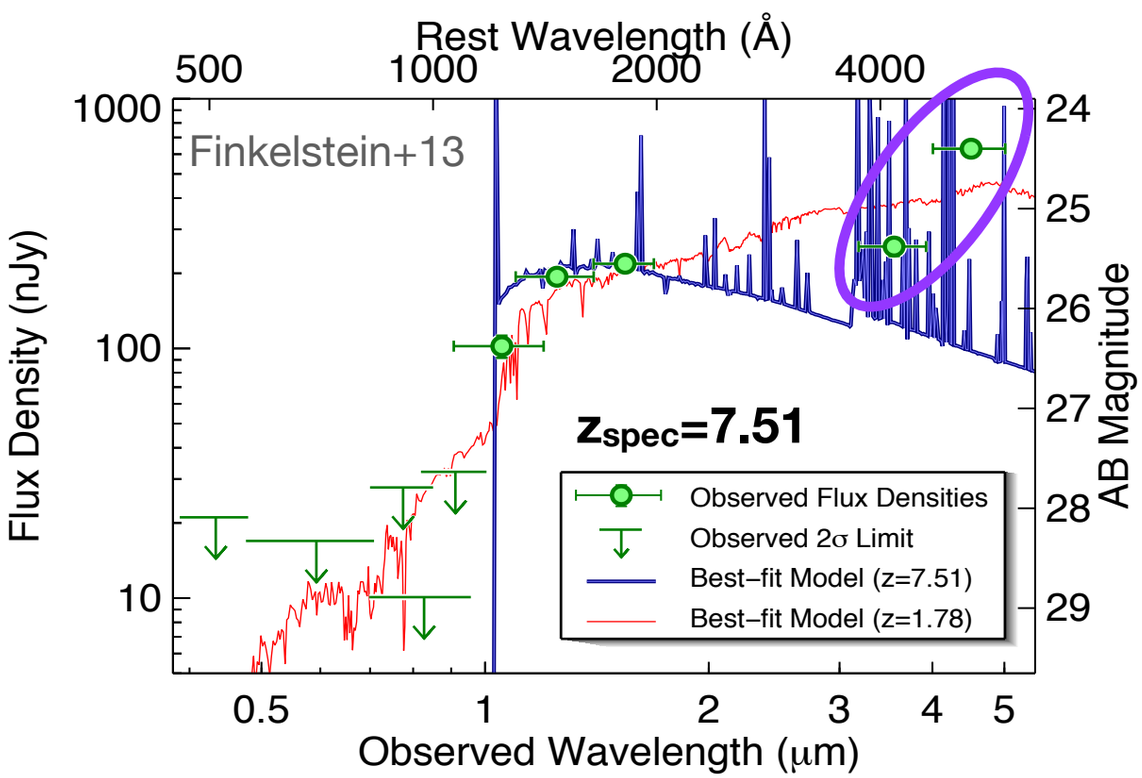

However, JWST spectroscopy will completely **revolutionize** this field!

JWST can in principle get spectroscopic redshifts for every single source currently known with HST

# High Redshift Galaxies Show Extreme Lines




All sources with spectroscopic redshift at z>7.2 show extremely red IRAC colors

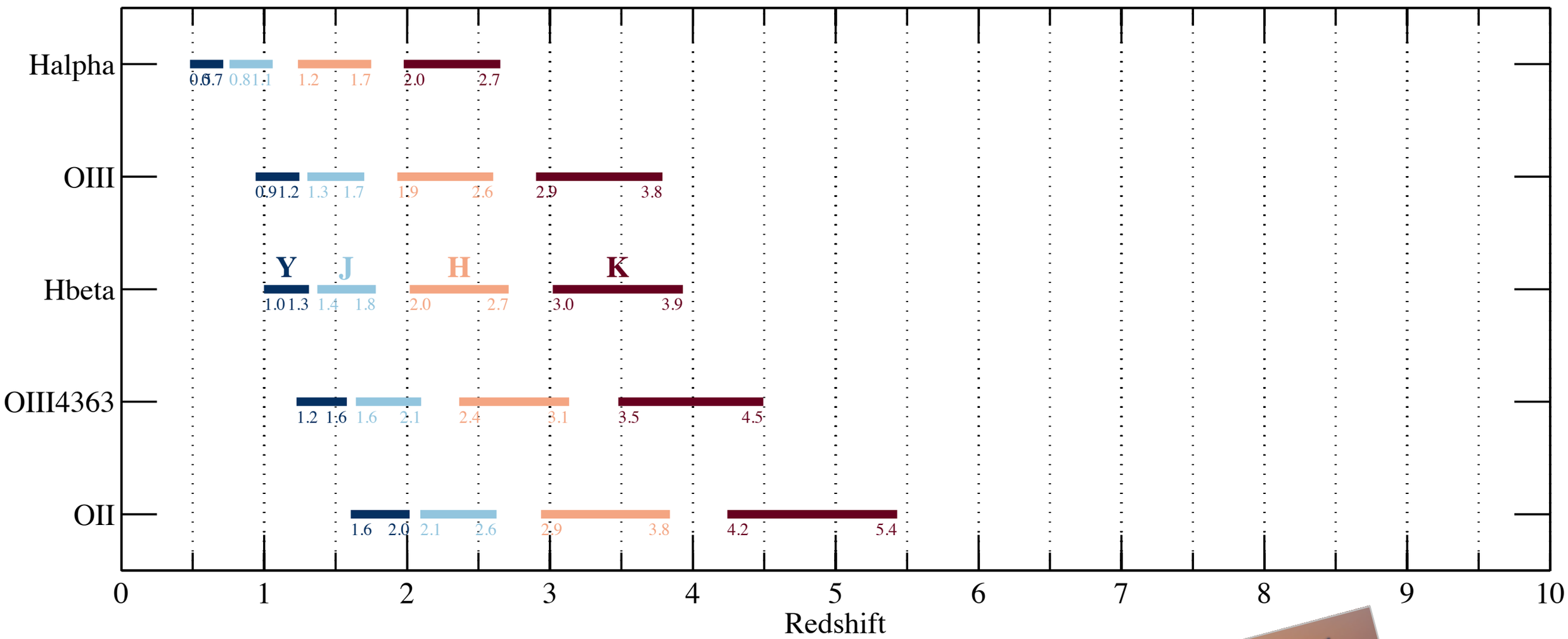
Rest-frame equivalent widths on **average** are 700 Å!

**What is driving this strong evolution?**

see also: Schaerer&deBarros09, deBarros+14, Shim+11, Smit+14

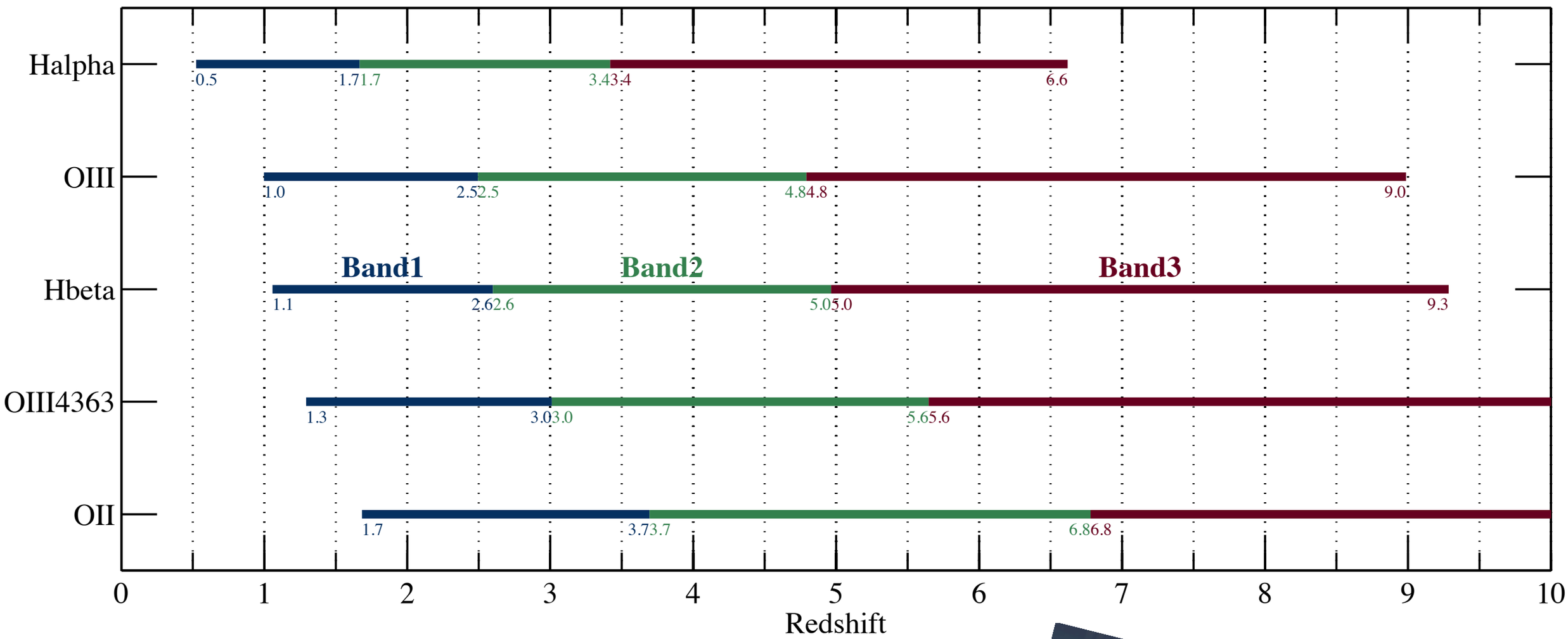
# Rest-Frame Optical Emission Line Coverage

Ground-based multi-object spectrographs now trace galaxy build-up to z~2-4

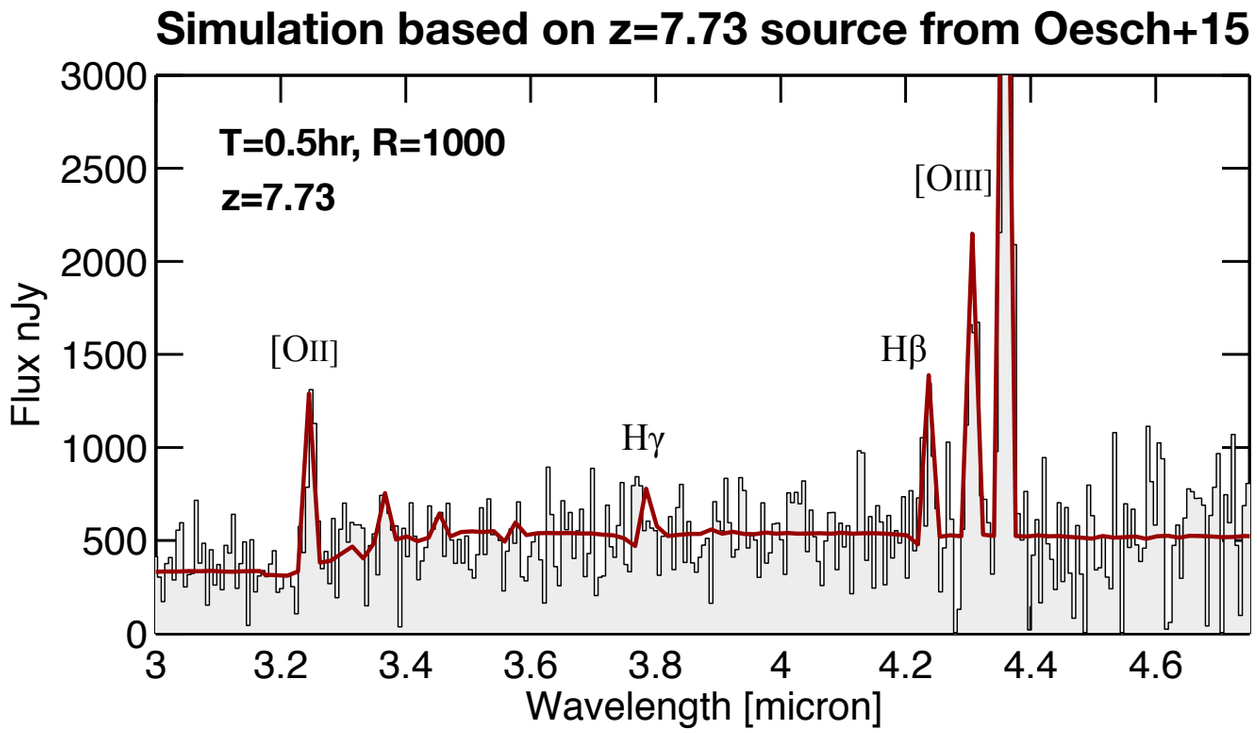


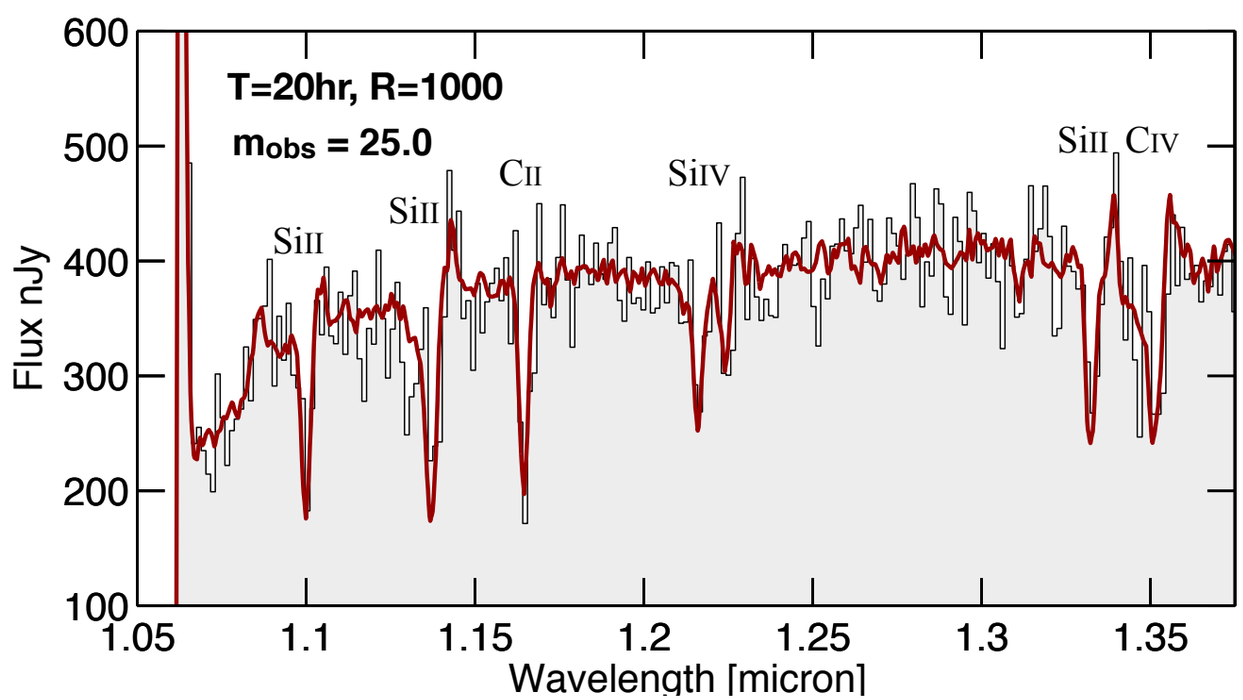

# Rest-Frame Optical Emission Line Coverage

JWST will seamlessly extend these surveys to z~7-9




# JWST/NIRSpec: Unprecedented Spectra




- JWST will be extremely efficient in spectroscopic characterization of z>7 galaxies; rest-frame optical lines will be extremely easy to detect
- For brightest targets, like the recently confirmed target EGS-zs8-1 at z=7.73, we will even be able to measure absorption lines individually
- Are working on collecting largest possible samples of very bright galaxies at z>=8

***What is the ionization state of gas in early galaxies?***

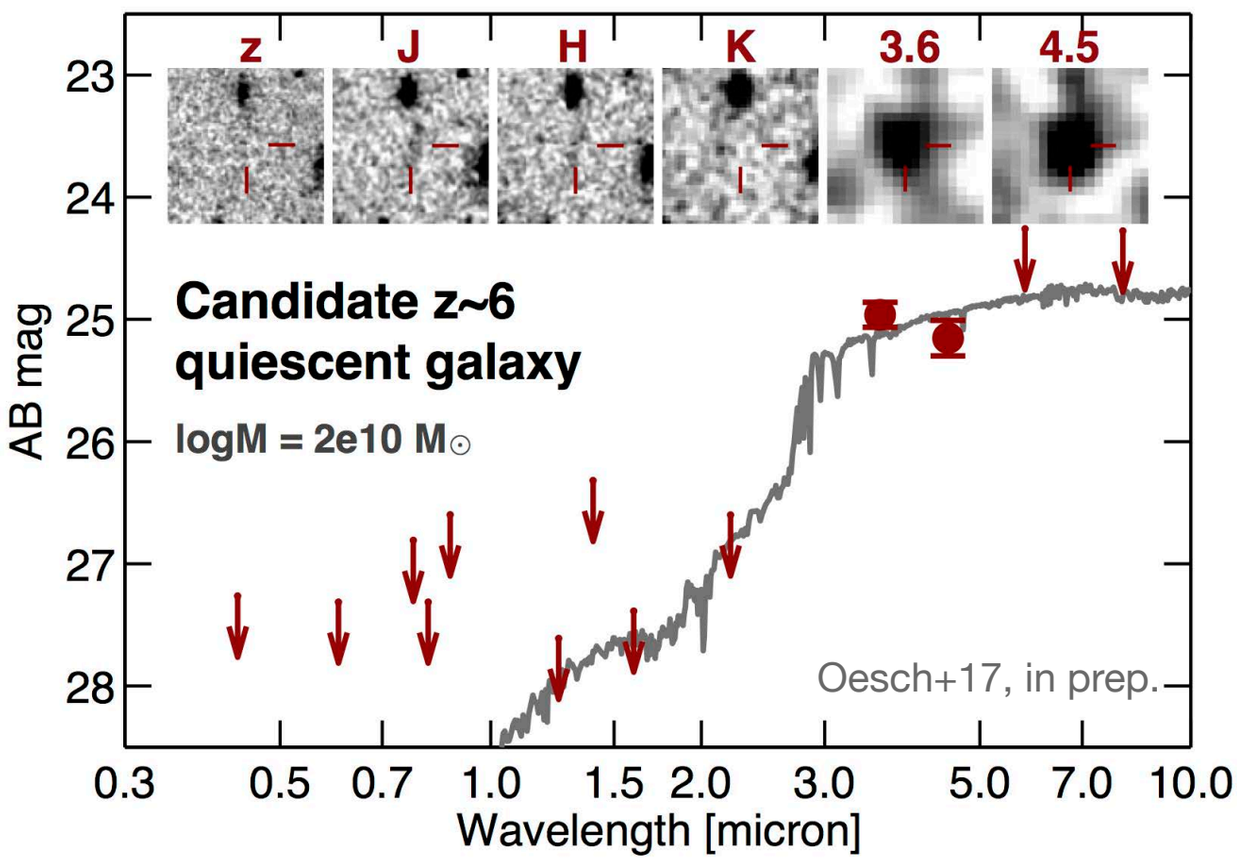
***What is their dynamical state?***

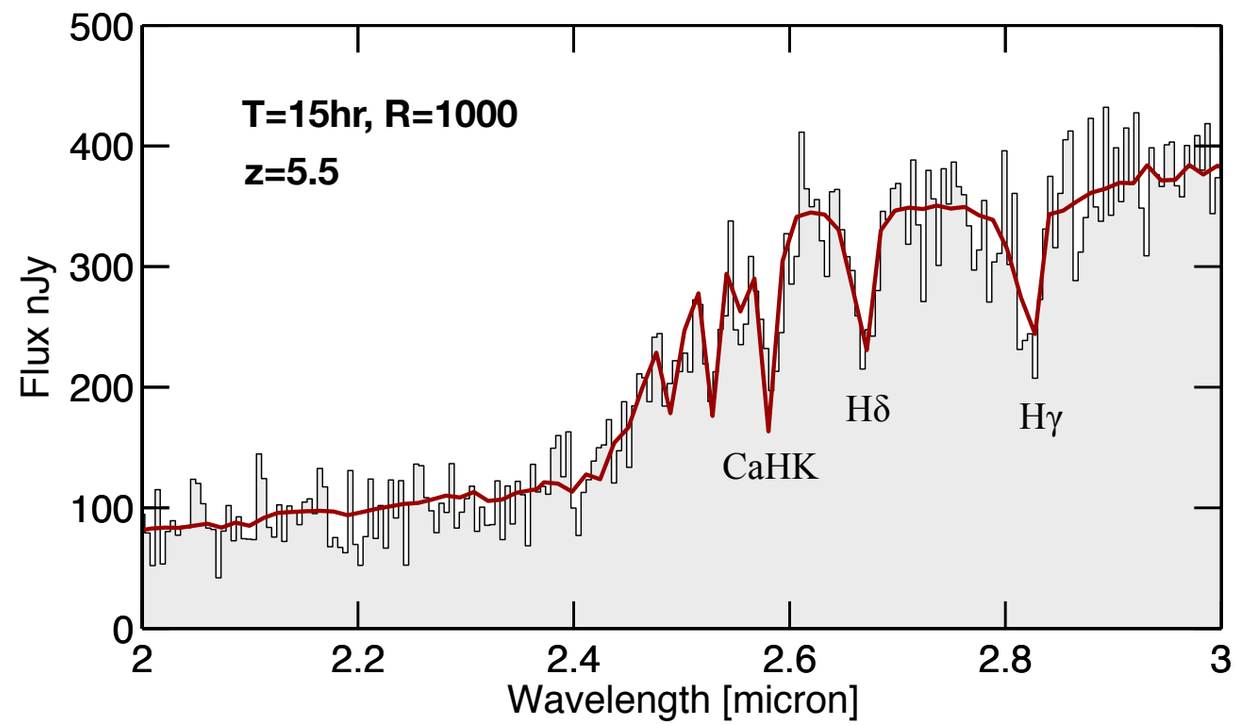
***How fast did they build up their metals?***

# When did the First Quiescent Galaxies Form?

The emergence of the quiescent galaxy population is a crucial test for galaxy formation models.

quiescent = no star-formation




Few candidate, passive galaxies exist at z>3. JWST will get redshifts for these and probe their star-formation histories with continuum spectroscopy.

➔ Indirect constraints on epoch of first galaxy formation.

# Summary

- Combination of HST and Spitzer/IRAC allows us to probe the build up of both the **star-formation rate** and **stellar mass** density over **97% of cosmic history**, revealing large samples of galaxies at z>6

- Current **spectroscopic samples at z>6** are still **extremely small** due to a lack of strong Lyα emission lines in the EoR. But HST has recently extended spectroscopic frontier to z=11.1, only ~400 Myr after the Big Bang

- **JWST** will completely **revolutionize this field**. Strong lines will be detected out to the most distant and faintest sources found with HST. Will finally get a handle on the **physics** of early galaxy build up.

- **Unique information** will come from absorption line spectroscopy from **luminous sources**. Important to build up such samples before JWST launch.

Best-fit redshift of *combined* spectra + photometry: ***z*=11.1 ±0.1**

**(GN-z10-1 ➜ GN-z11!)**