UNIVERSITÉ DE GENÈVE
FACULTÉ DES SCIENCES
Département d'astronomie

Spectroscopic Confirmation of a Luminous Galaxy at the Beginning of Cosmic Reionization

IAP Colloquium

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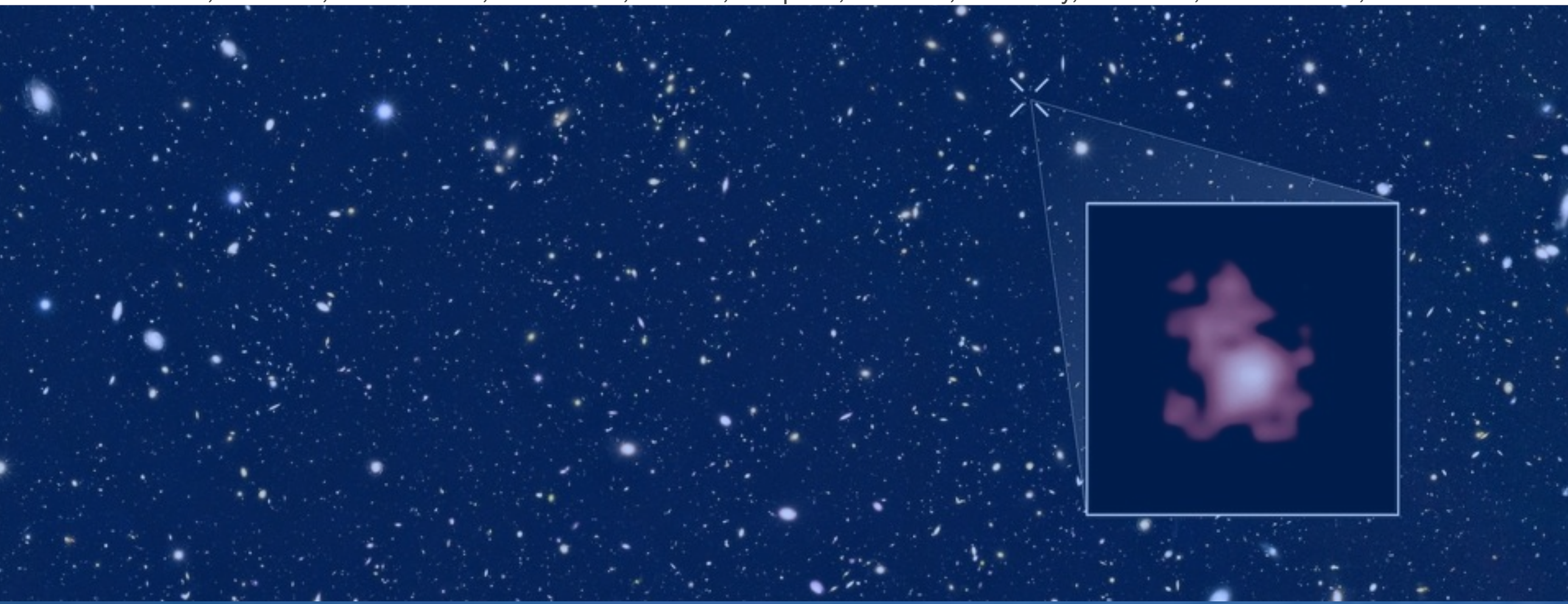
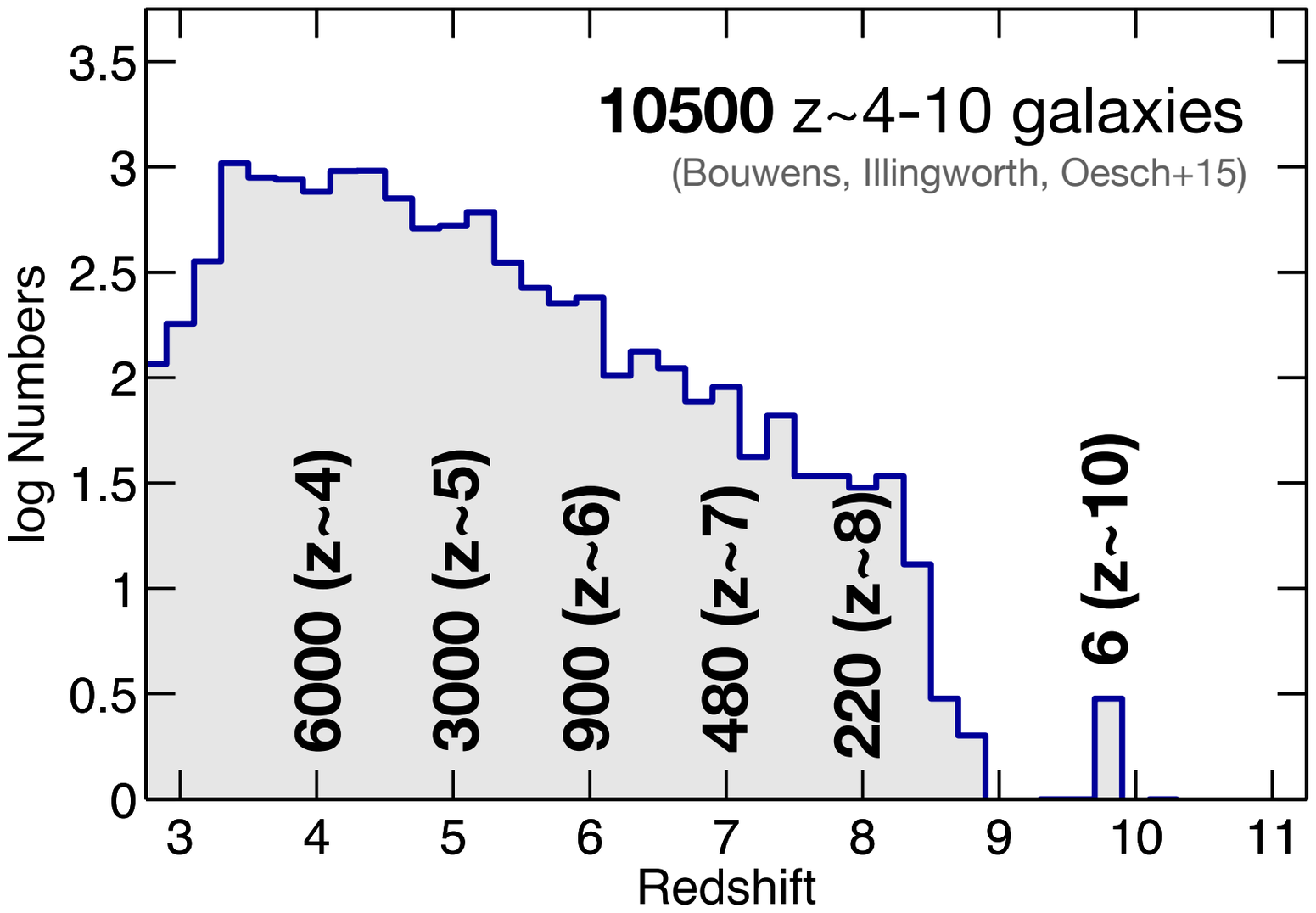
in collaboration with **XDF Team+**: ***G. Brammer,*** R. Bouwens, I. Labbé, G. Illingworth, M. Franx, P. van Dokkum, D. Magee, V. Gonzalez, M. Trenti, C.M. Carollo, M. Stiavelli, R. Smit, L. Spitler, G. Fazio, M. Ashby, S. Willner, I. Momcheva, R. Skelton



Unprecedented Galaxy Samples at z>=4

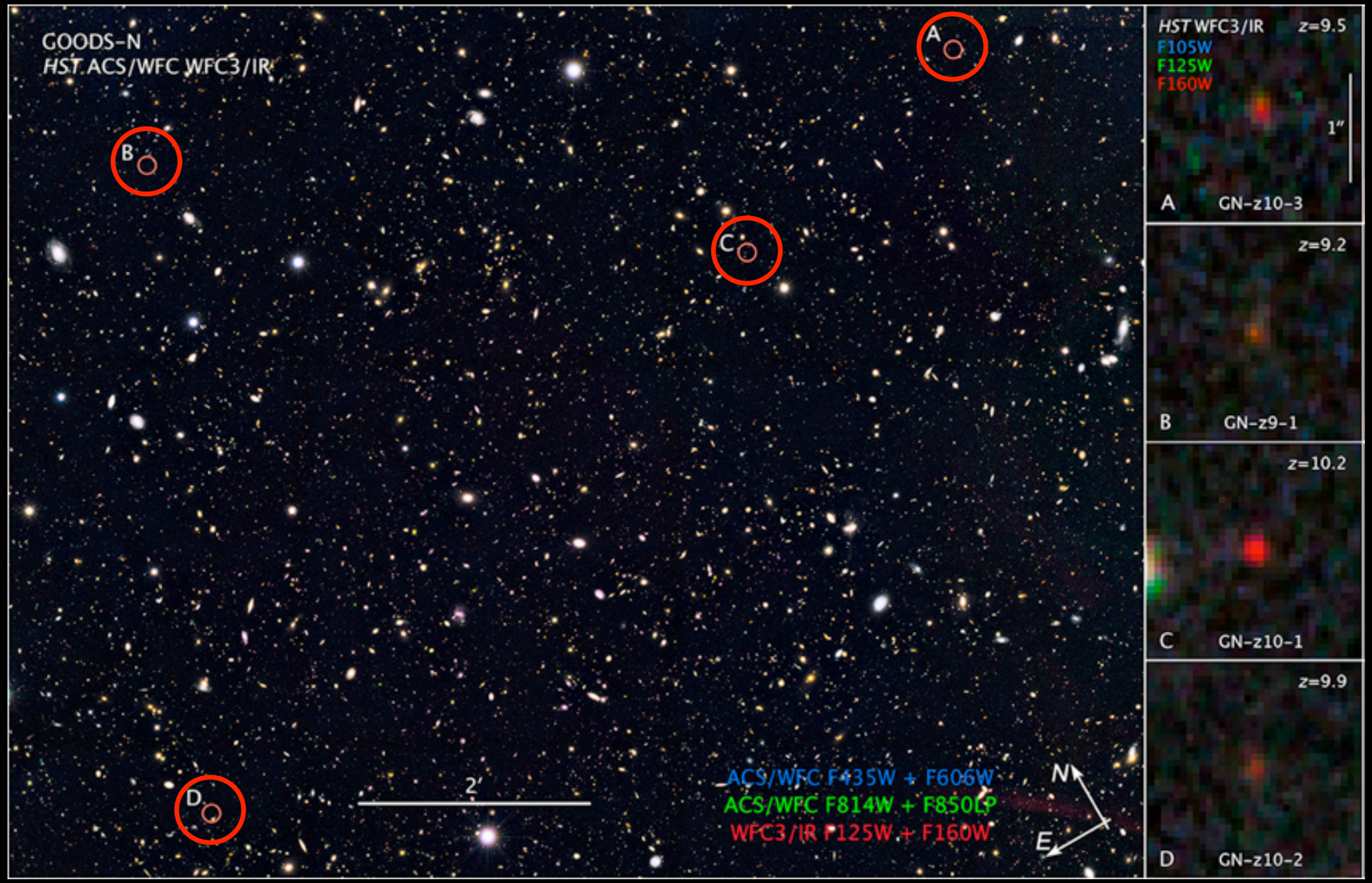
(from HST's blank fields only)



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

Current frontier: z~9-10

Sample of 4 Bright z~9-10 Galaxy Candidates



H=26.8

H=26.6

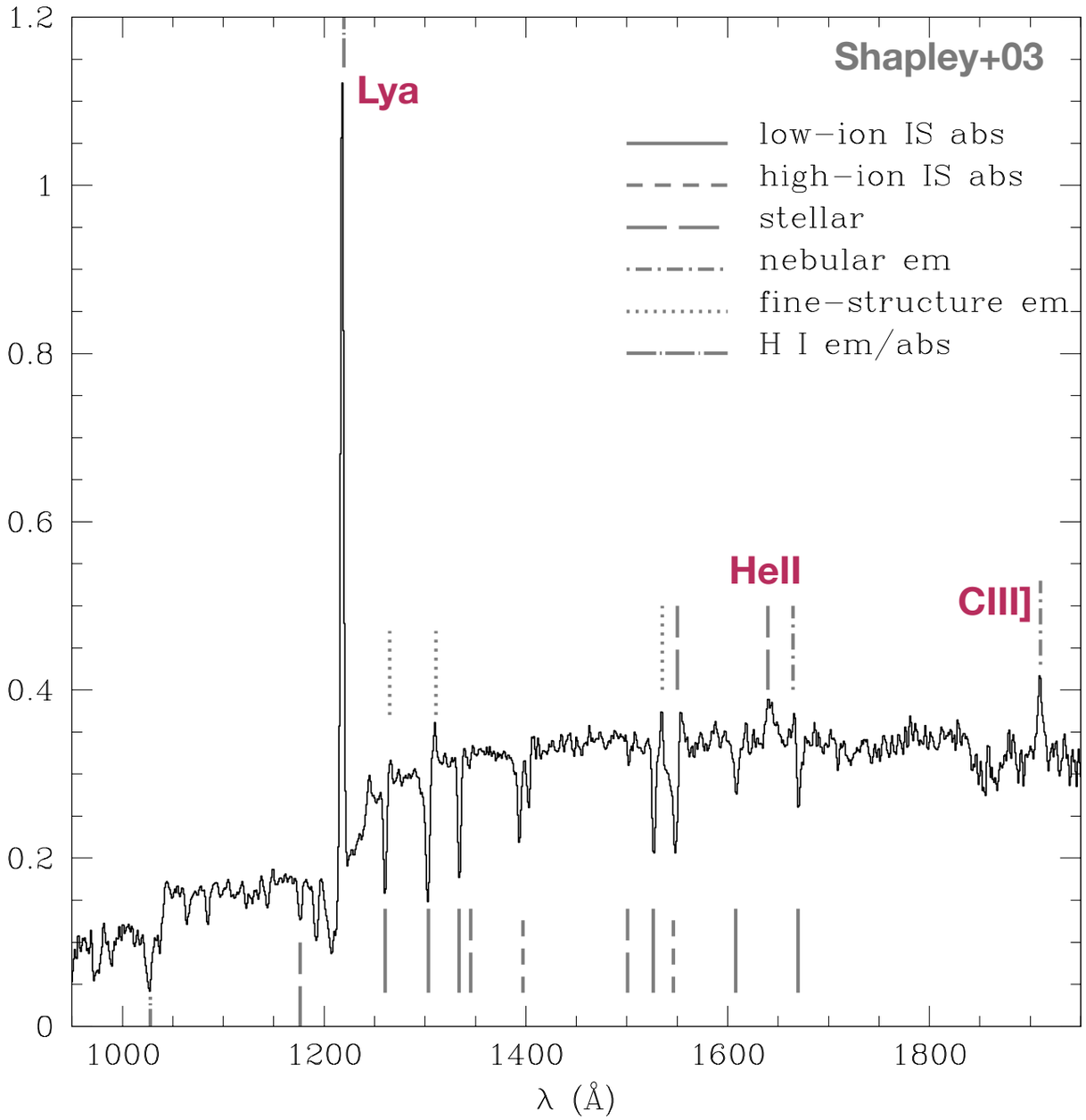
H=26.0

H=26.8

NASA and ESA

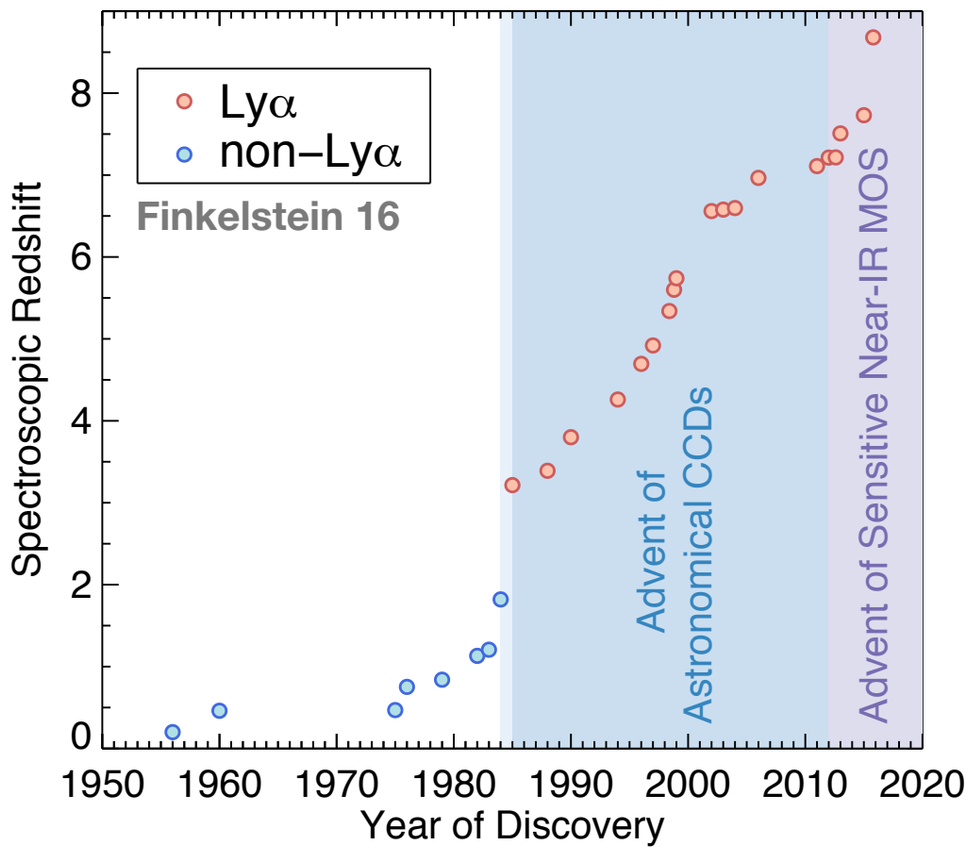
STScI-PRC14-05a

Spectroscopic Features of High-z Galaxies

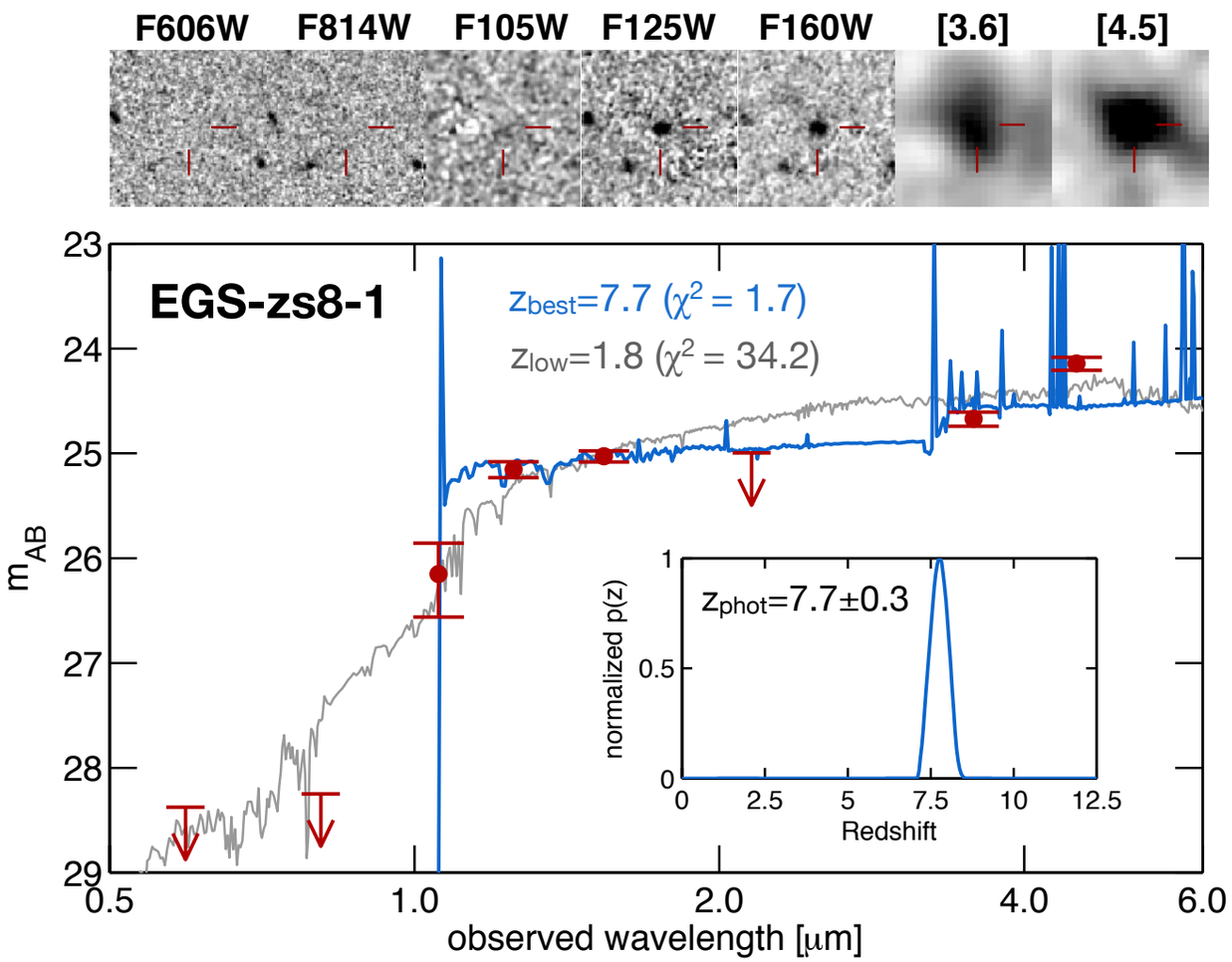


Lya is the most promising feature of high-redshift spectra

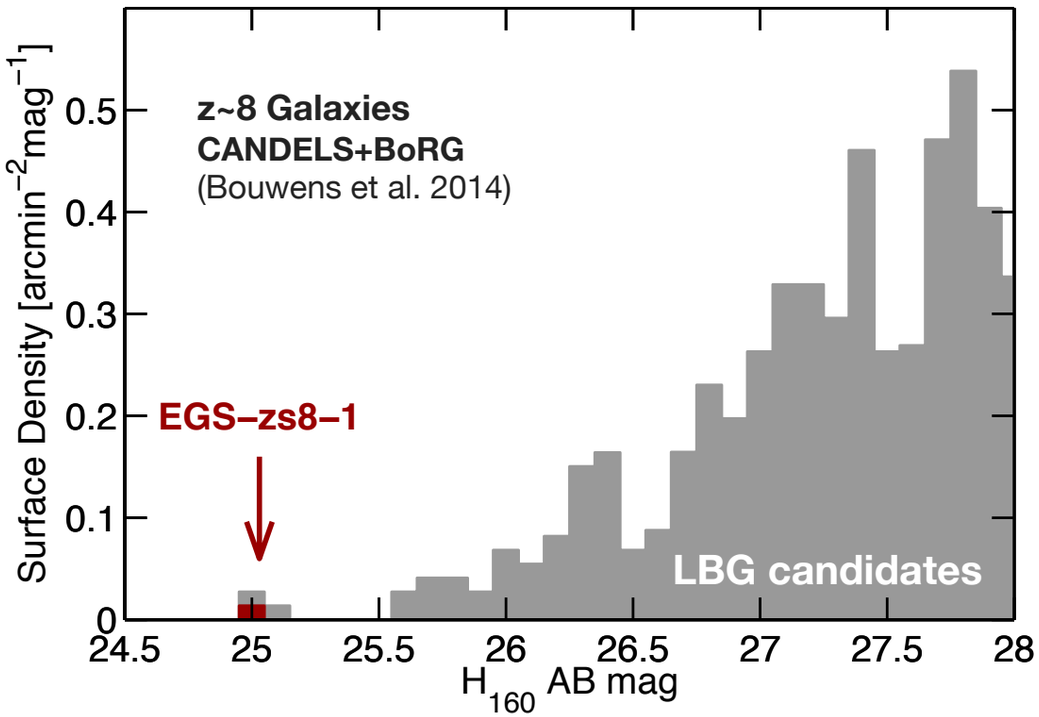
Other emission lines very weak, but possible to detect (e.g. Stark+15,16)



Bright z~8 Galaxies with Spectroscopic Redshifts



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

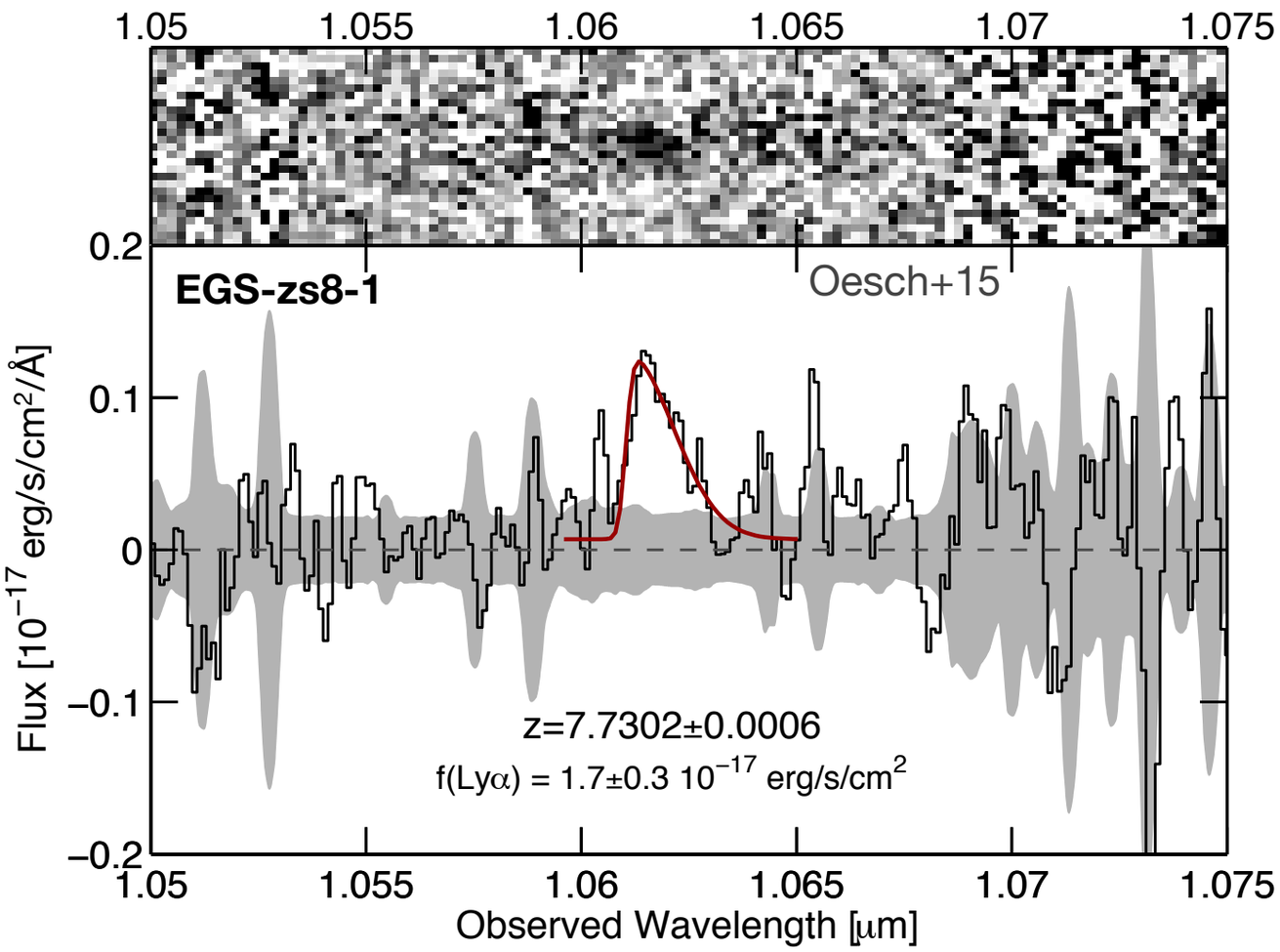


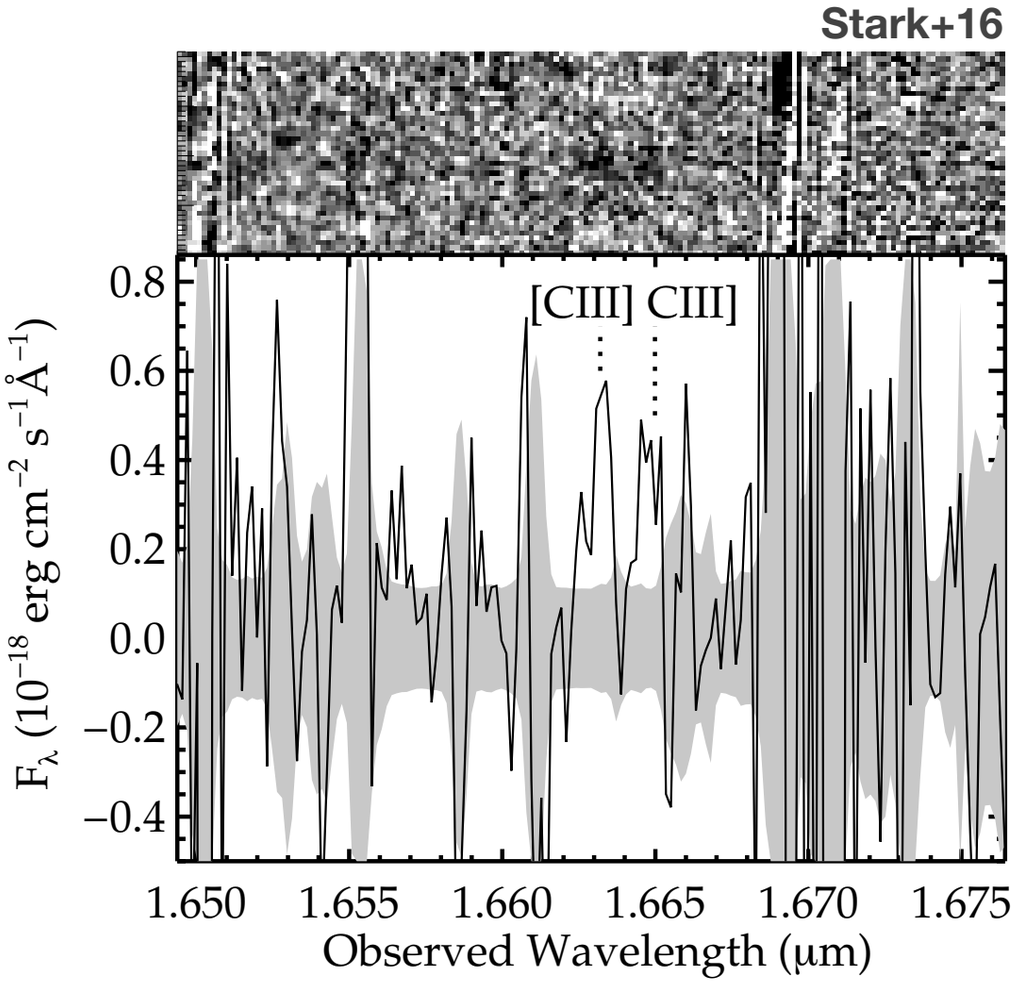
Spitzer/IRAC colors allow us to exploit very wide area imaging data to search for rare, ultra-luminous z~8 galaxy candidates with robust photometric redshifts

Bright z~8 Galaxies with Spectroscopic Redshifts

100% spectroscopic success rate via Lyα detection in such galaxies!

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





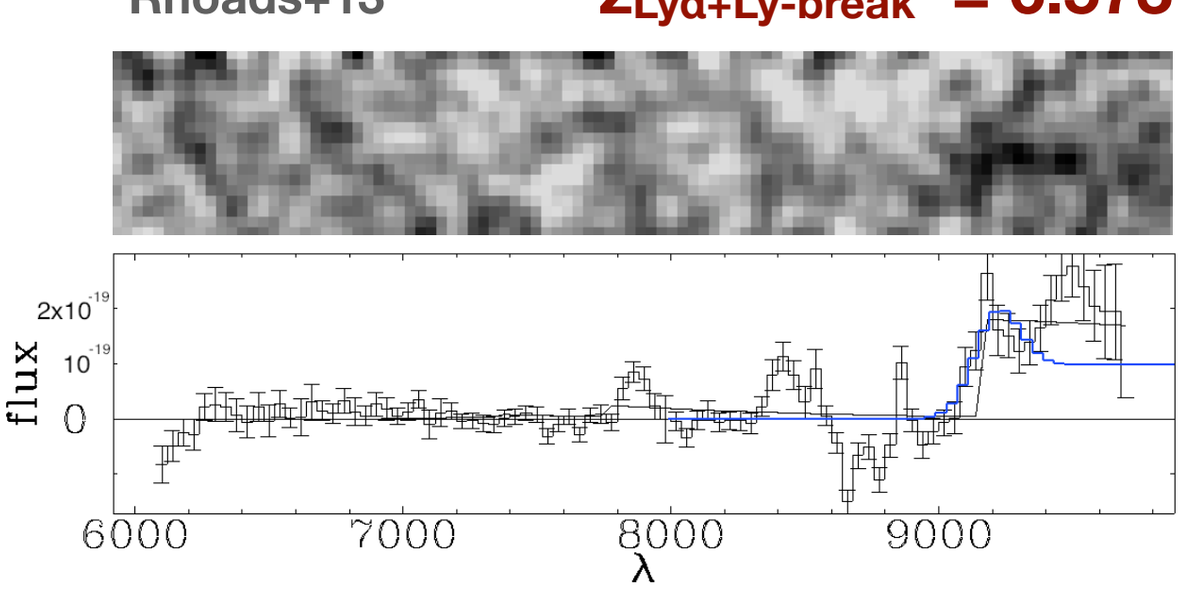
EGS-zs8-1 now has a three line redshift z=7.73.
Very large EW CIII] emission. (see Dan's Talk)

Different Way Forward: Continuum Break Redshifts

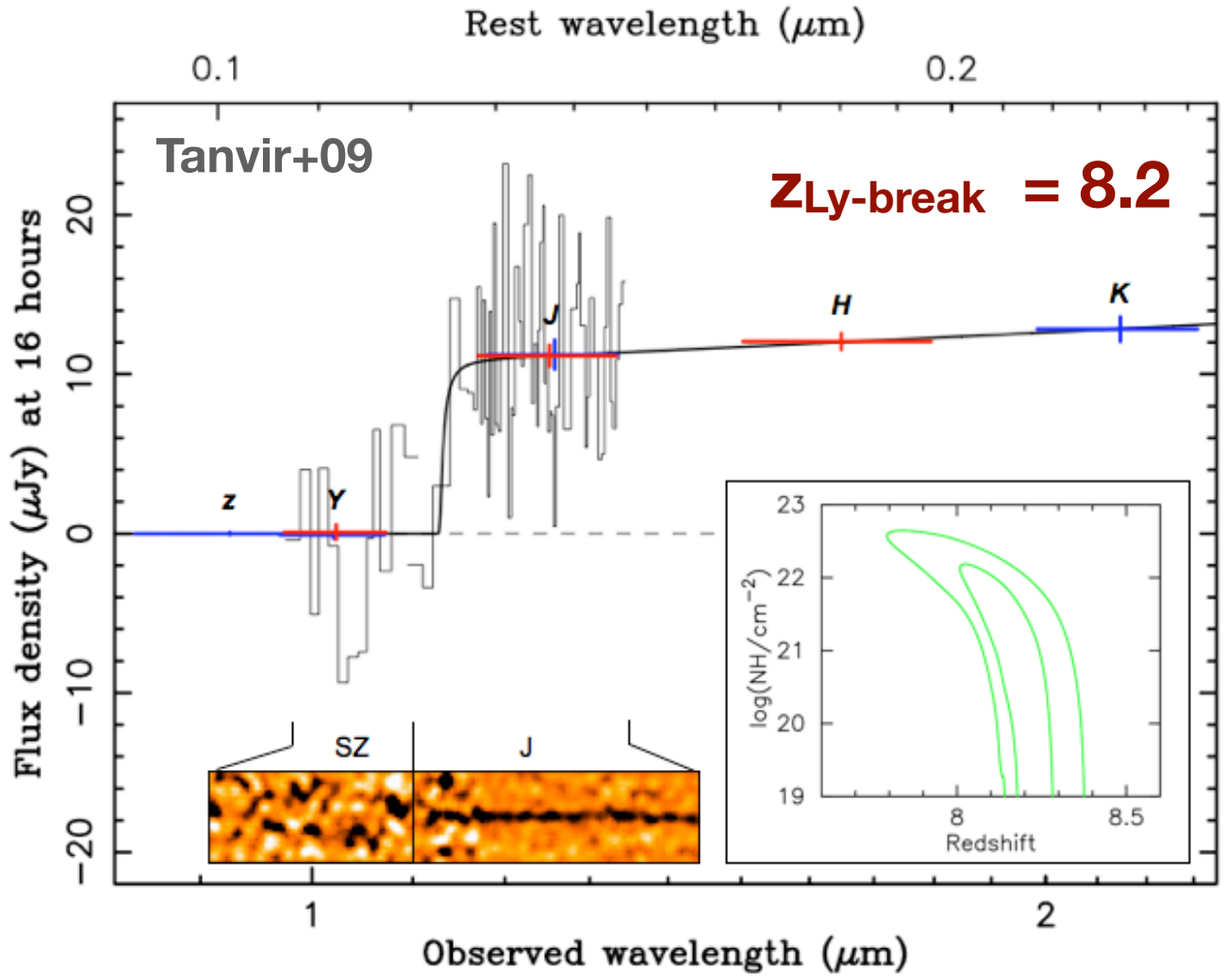
If Lyα disappears, need different technique to measure redshifts:
continuum breaks

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

Rhoads+13 $z_{Ly\alpha+Ly\text{-}break} = 6.573$



Tanvir+09 $z_{Ly\text{-}break} = 8.2$

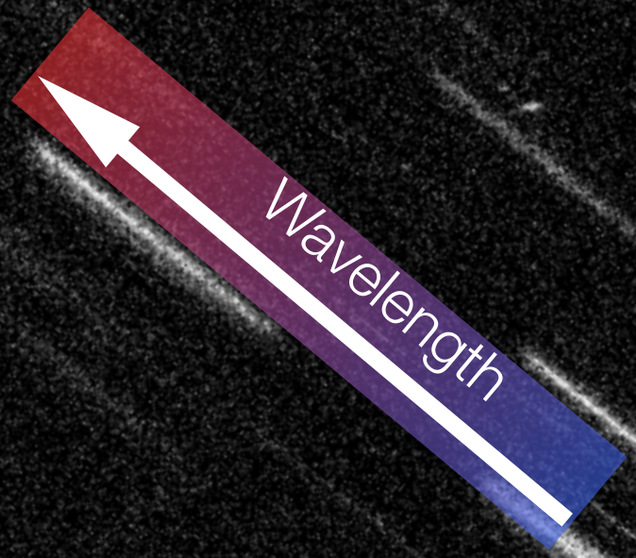


Problem: the background in the NIR is very high from the ground

HST Grism

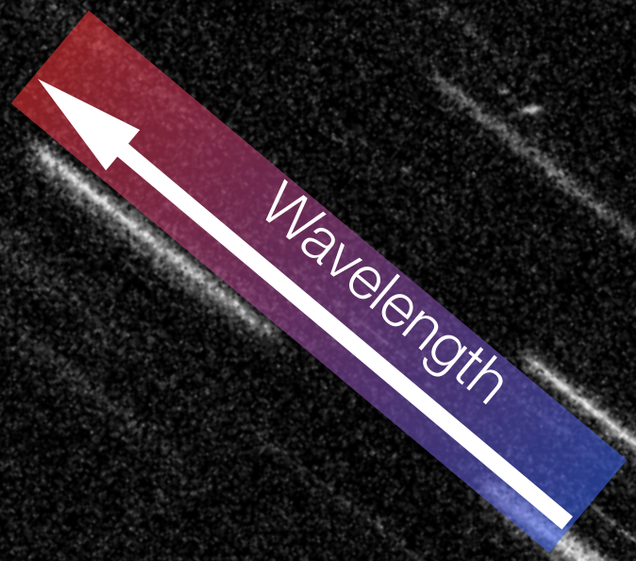
Slide Credit: I. Momcheva

HST Grism



Slide Credit: I. Momcheva

HST Grism



3D-HST

WISPS
WFC3 Infrared Spectroscpic Parallel Survey

GLASS
The Grism Lens-Amplified Survey from Space

FIGS and others...

Slide Credit: I. Momcheva

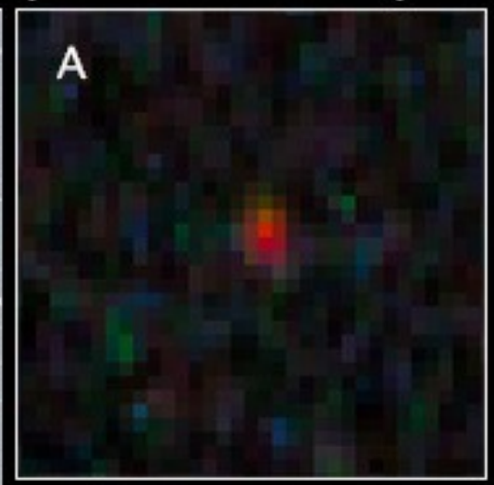
A

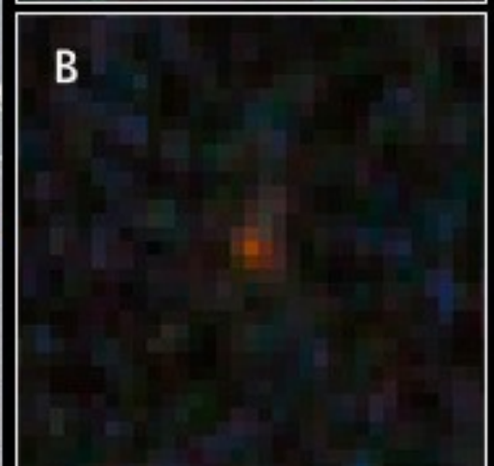
C

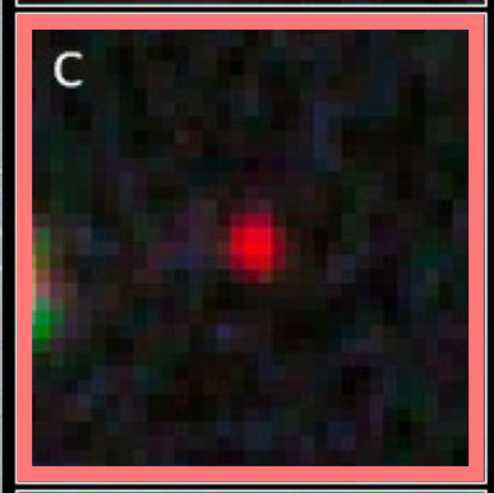
GN-z10-1
H_{160}=25.95
z_{phot} = 10.2 ± 0.4

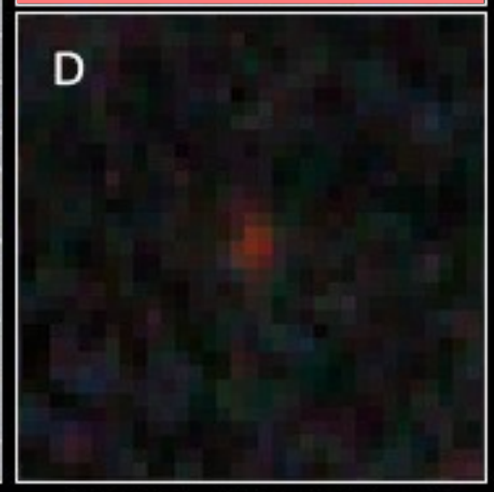
target of 12 orbit WFC3 grism program

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



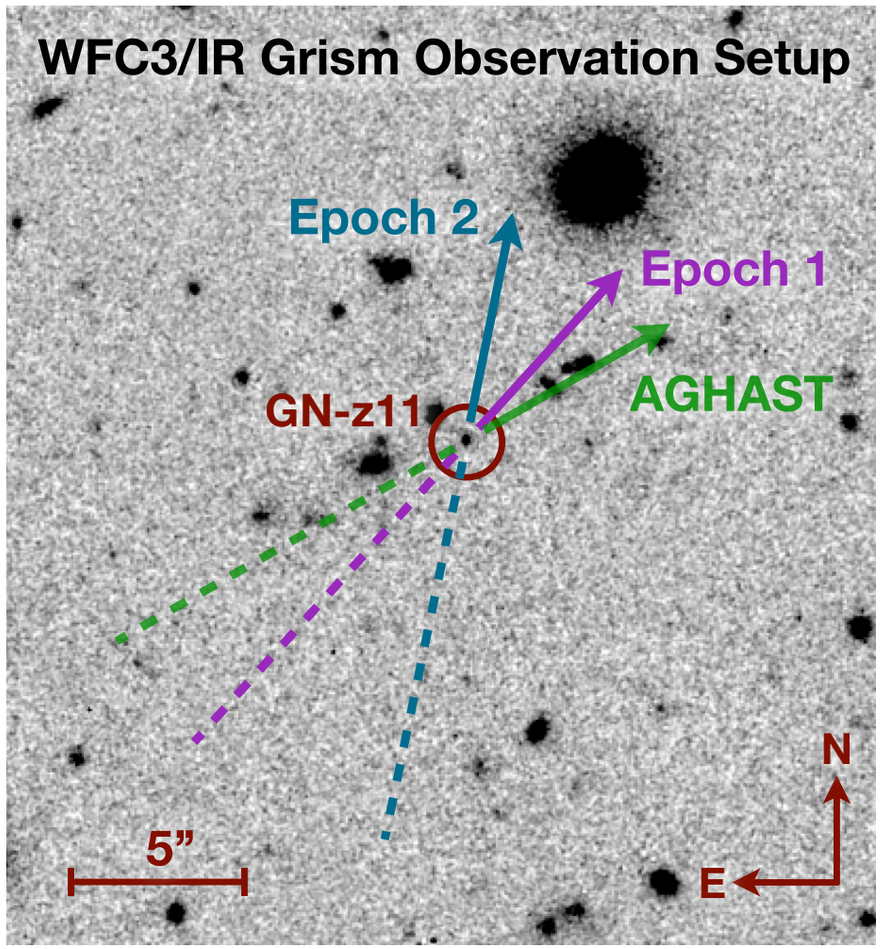




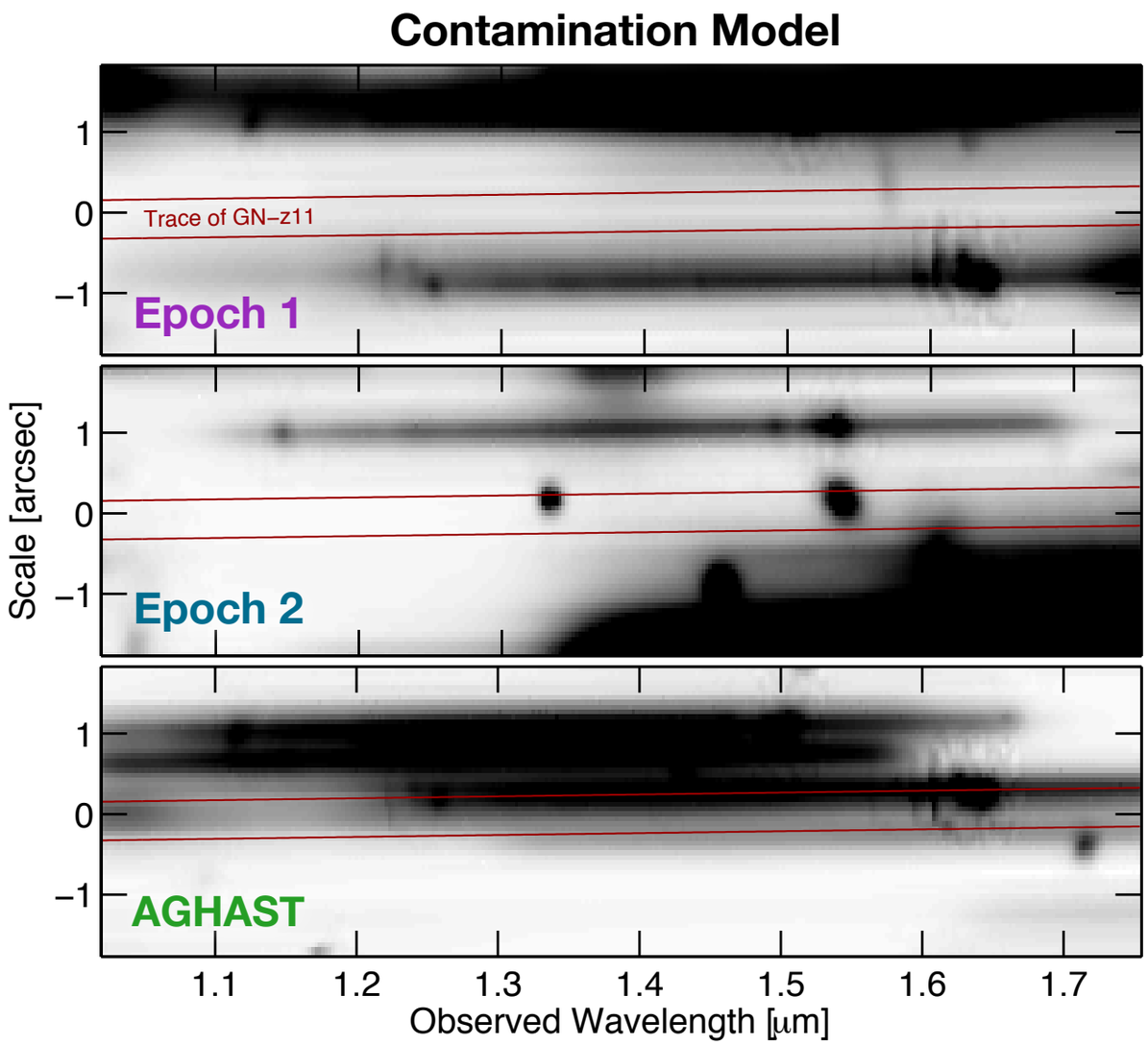


Neighbor Contamination in Grism Spectra

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



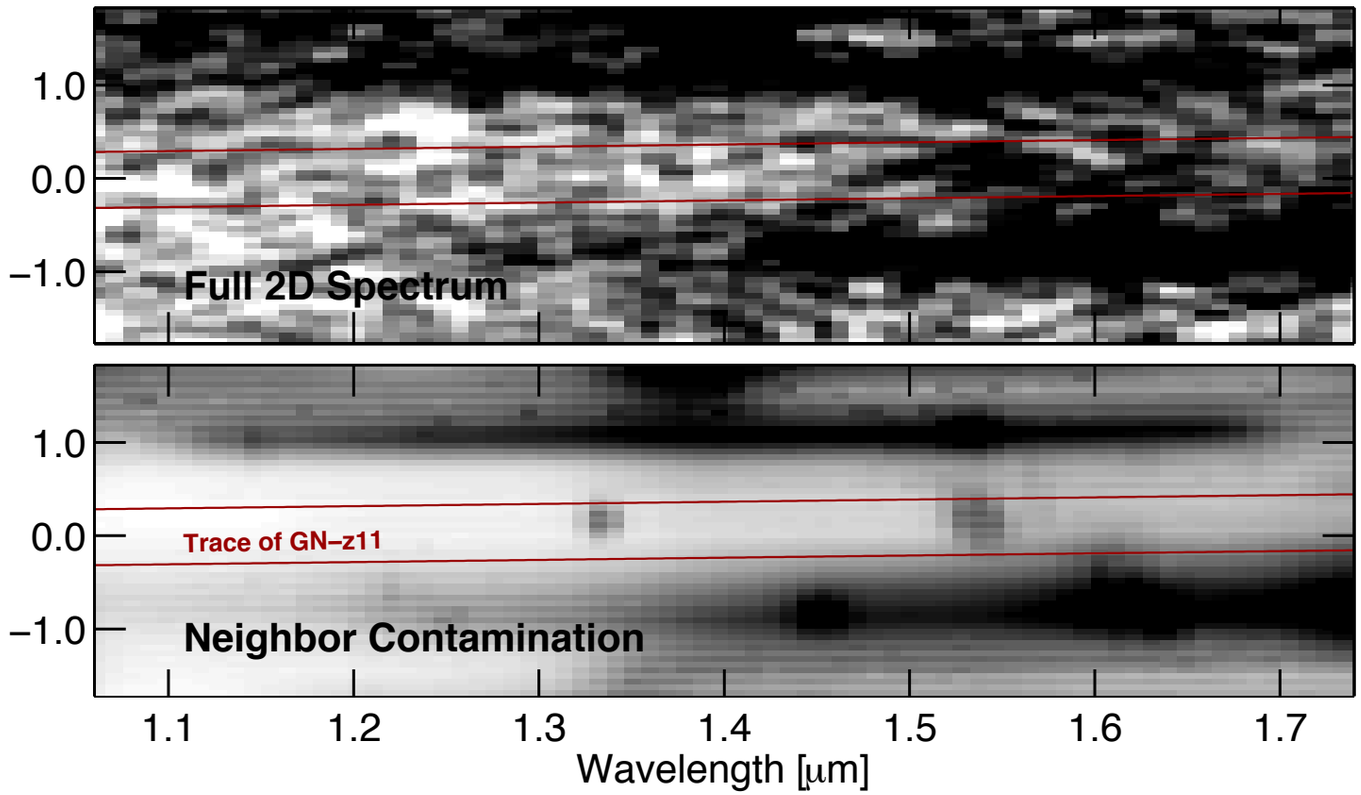
Oesch+16



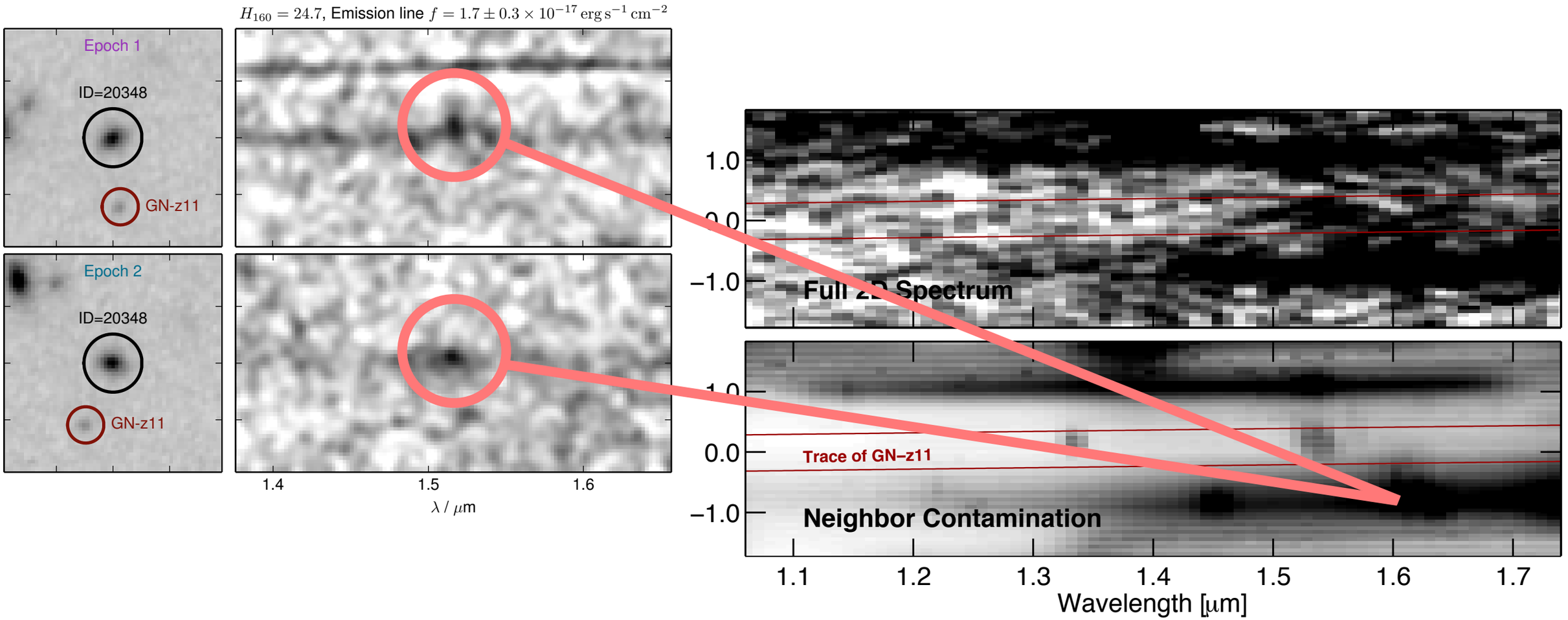
Perform full 2D contamination modelling and neighbor subtraction
(based on 3D-HST grism pipeline; Brammer+12, Momcheva+15)

Grism Extraction and Contamination Modeling

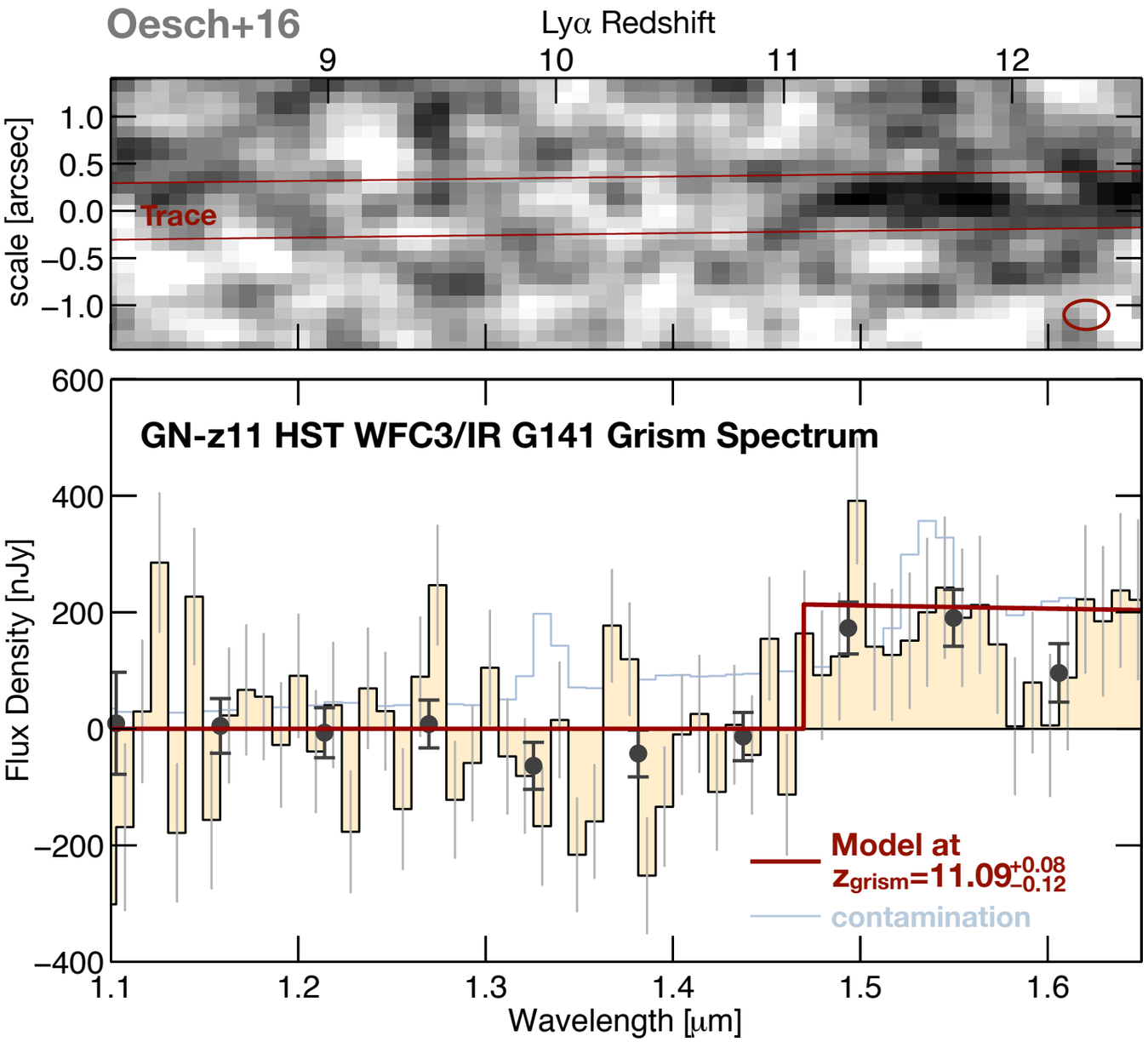
- Analysis based on 3D-HST Pipeline (Brammer+12, Momcheva+15)
- *Interlaced* combination of individual exposures
- Yields well-understood noise properties of the final spectra
- Full 2D modeling of contaminants



Grism Extraction and Contamination Modeling

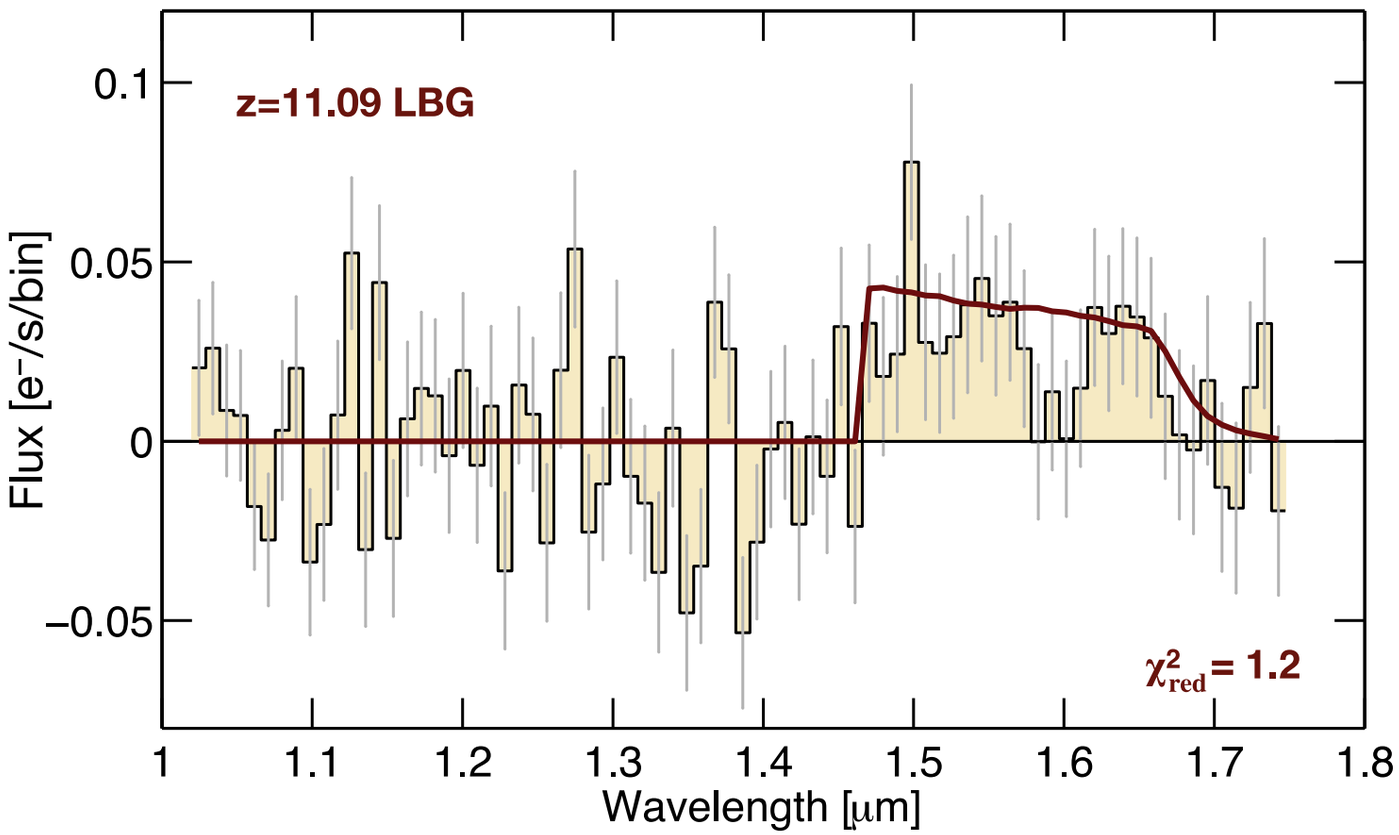


Lyman Break Detection at z=11



- Overall continuum detection ~5.5σ at λ > 1.47 μm
- Detected at 1-1.5σ per resolution element (91 Å)
- Detection in both epochs individually (but at low S/N)
- Break factor (f_{red}/f_{blue}) of >3.1 (2σ, 500 Å) rules out z~2-3 interloper
  (Maximally old BC03 model at z=2.7 a factor of <2.7 defined the same way)
- Rule out emission line contaminant
- Best-fit redshift: z=11.09+-0.10

Lyman Break Detection



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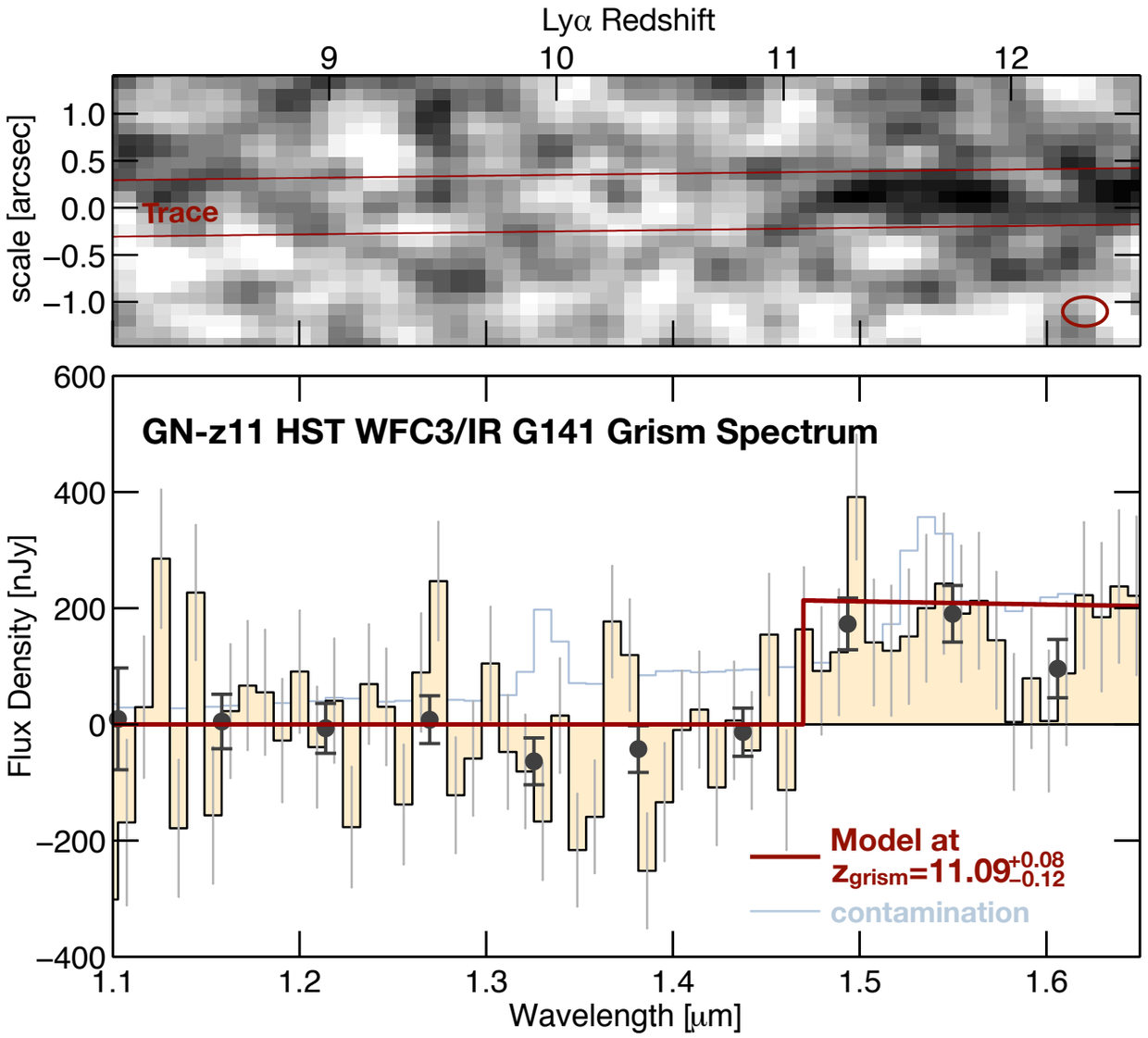
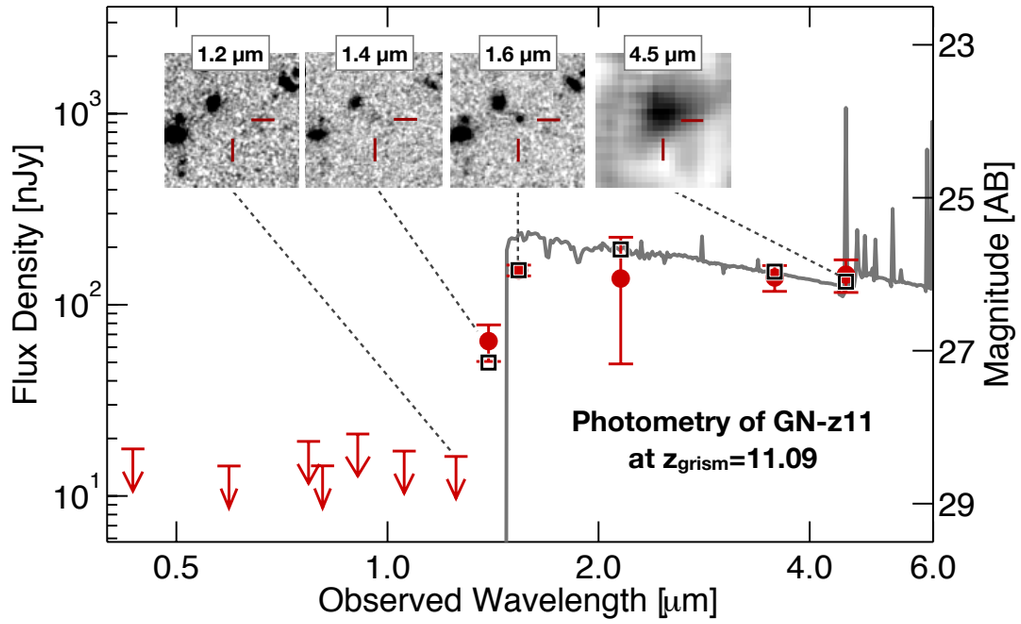
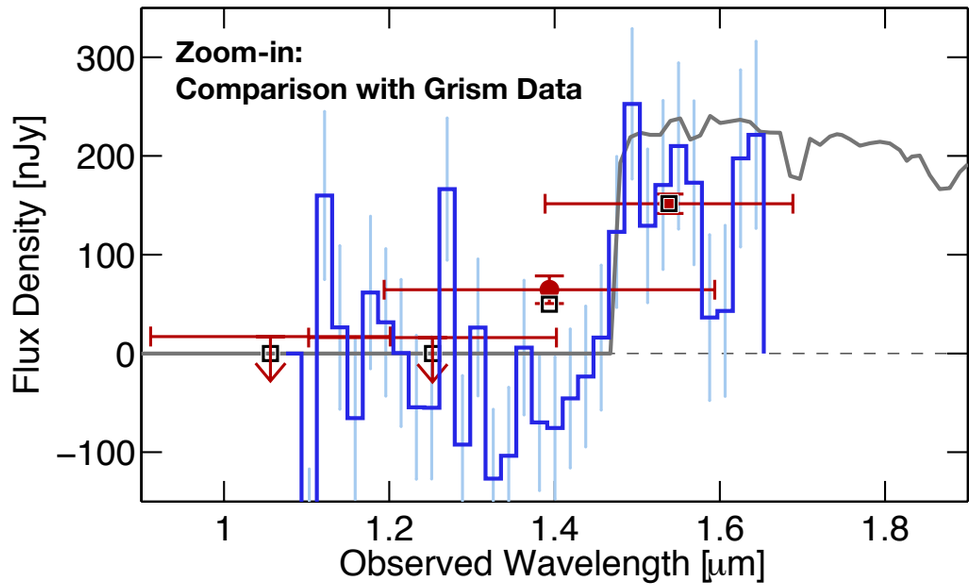
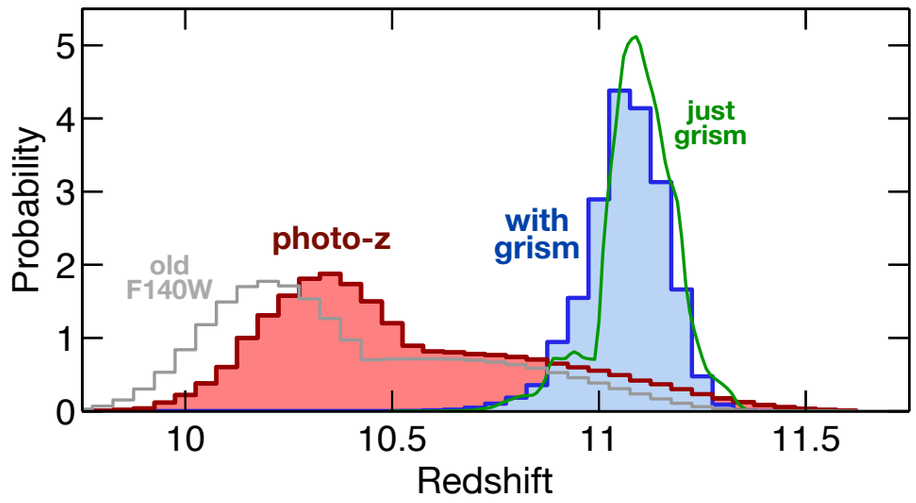
Best-fit redshift of *combined* spectra + photometry: **z=11.1 ±0.1**

(GN-z10-1 ➜ GN-z11!)

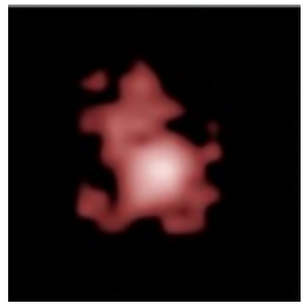


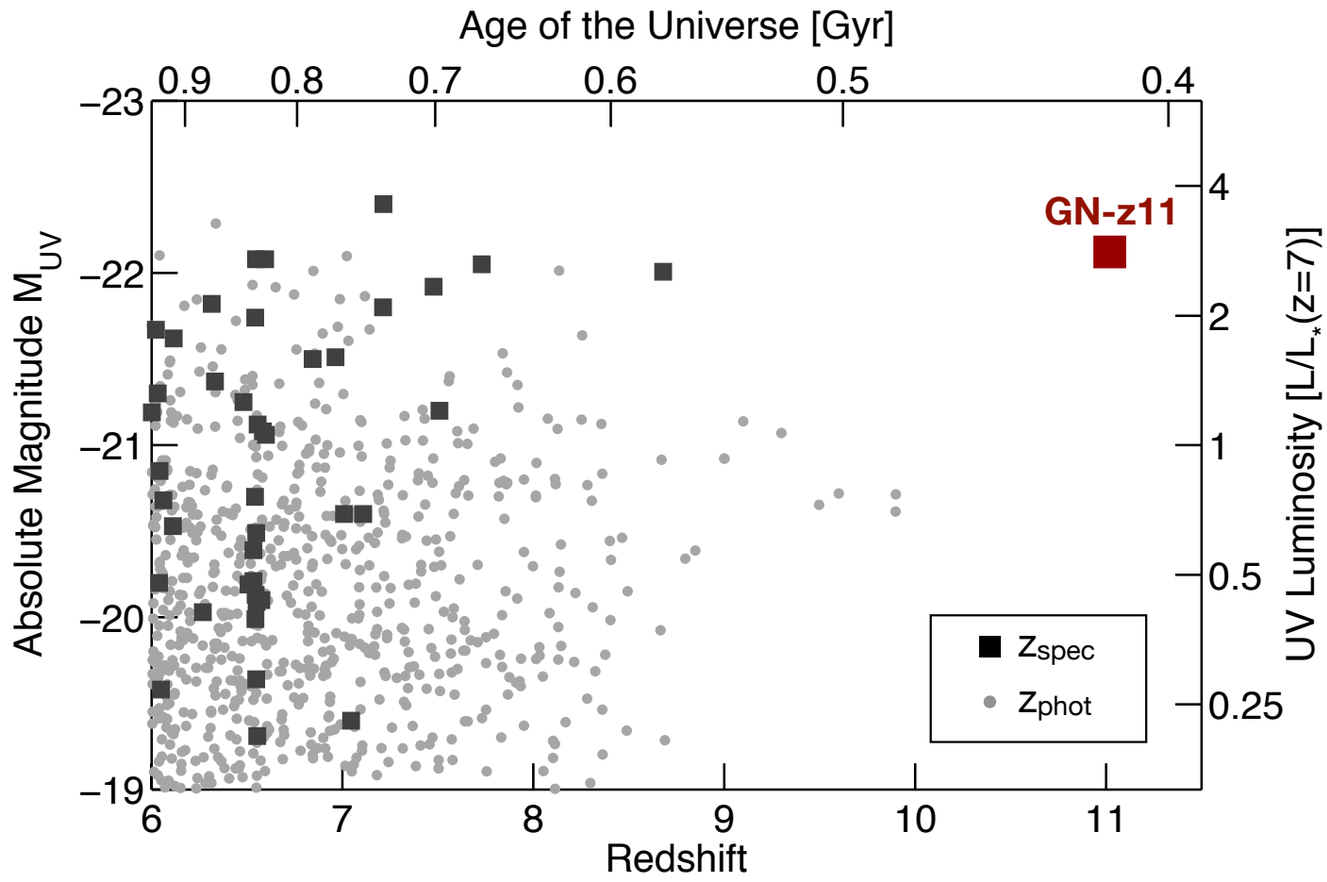


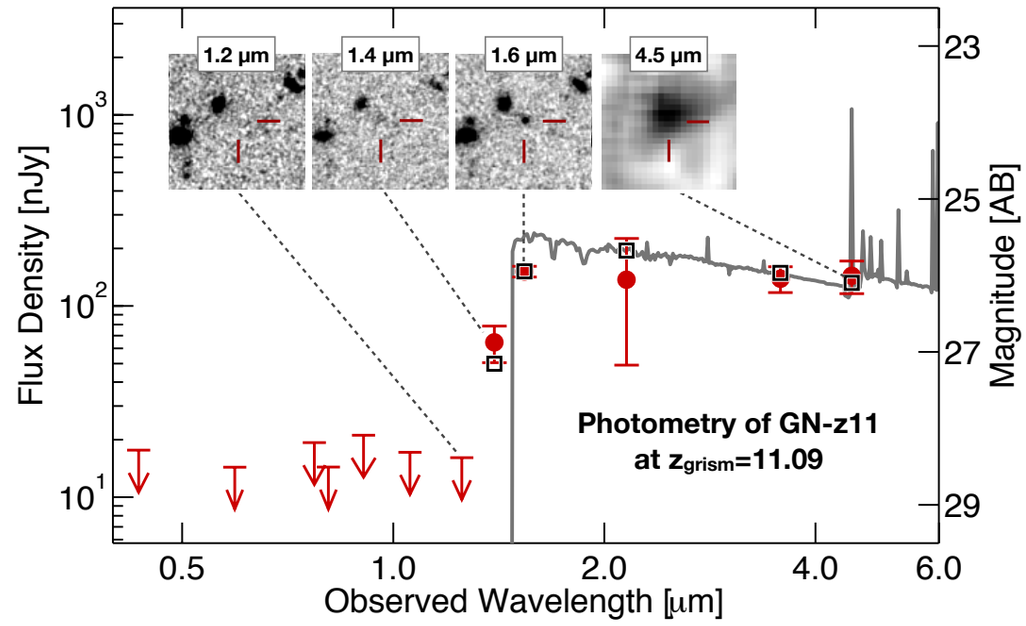




Physical Properties of GN-z11





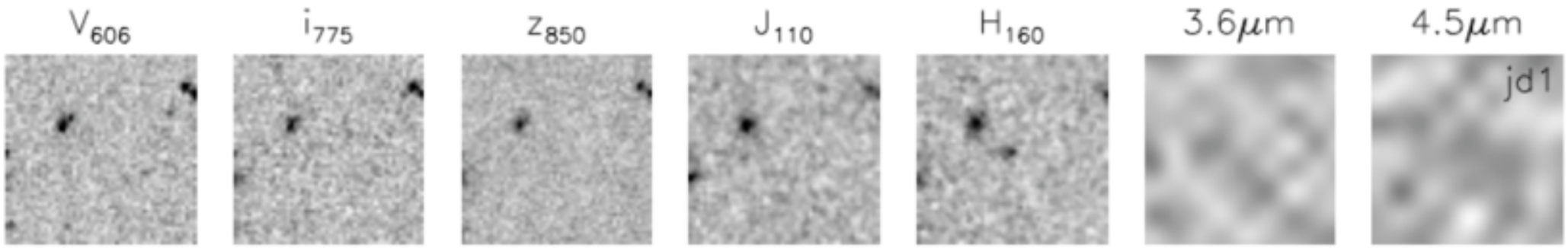


- UV luminosity ~ 3×*L**(*z*=7)
- Stellar mass ~ 10^9 $M_\odot$
- SFR~24 $M_\odot$/yr, age~40 Myr

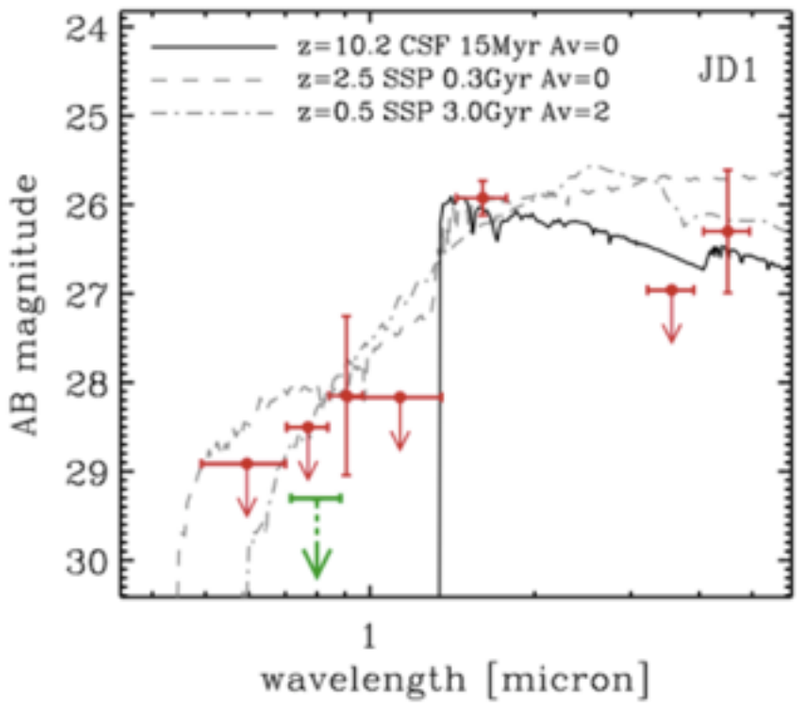
Massive galaxy formation well under-way at z~11

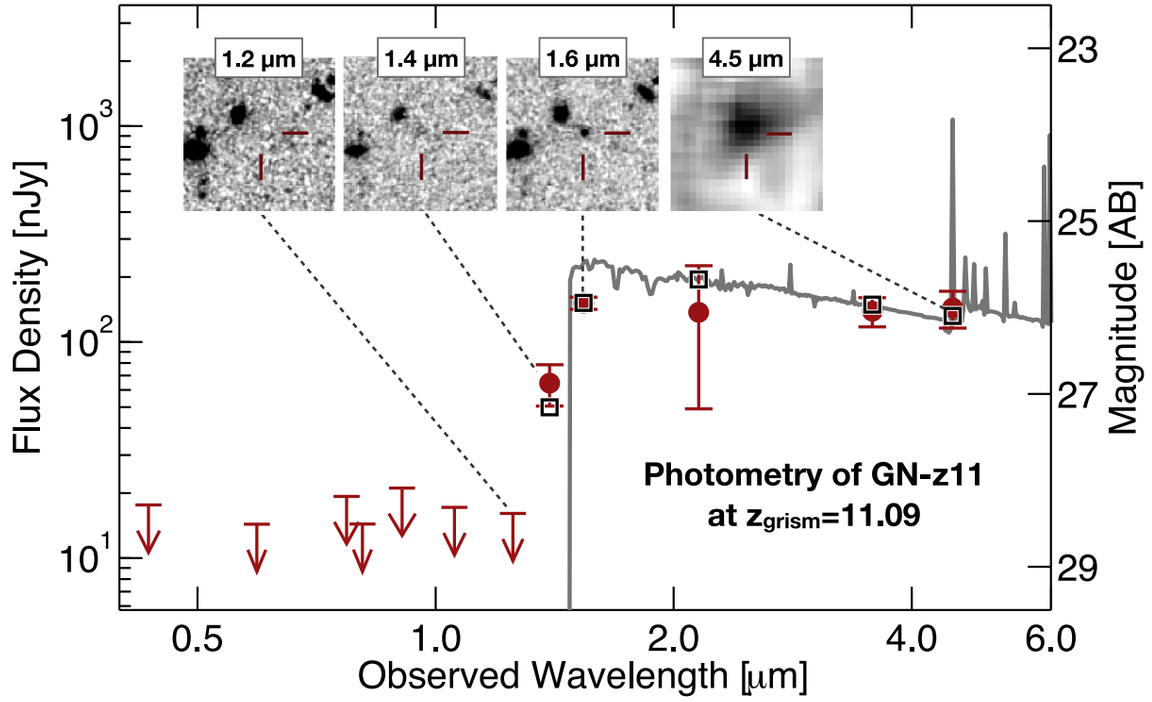
R.A.	12 : 36 : 25.46
Dec.	+62 : 14 : 31.4
Redshift $z_{\rm grism}$	$11.09^{+0.08\,a}_{-0.12}$
UV Luminosity M_{UV}	-22.1 ± 0.2
Half − Light Radius^b	0.6 ± 0.3 kpc
$\log M_{gal}/M_\odot$ ^{c}	9.0 ± 0.4
$\log$ age/yr ^{c}	7.6 ± 0.4
SFR	$24 \pm 10\ M_\odot\ {\rm yr}^{-1}$
$A_{\rm UV}$	< 0.2 mag
UV slope β $(f_\lambda \propto \lambda^\beta)$	-2.5 ± 0.2^d

GN-z11 was “known” since 2008



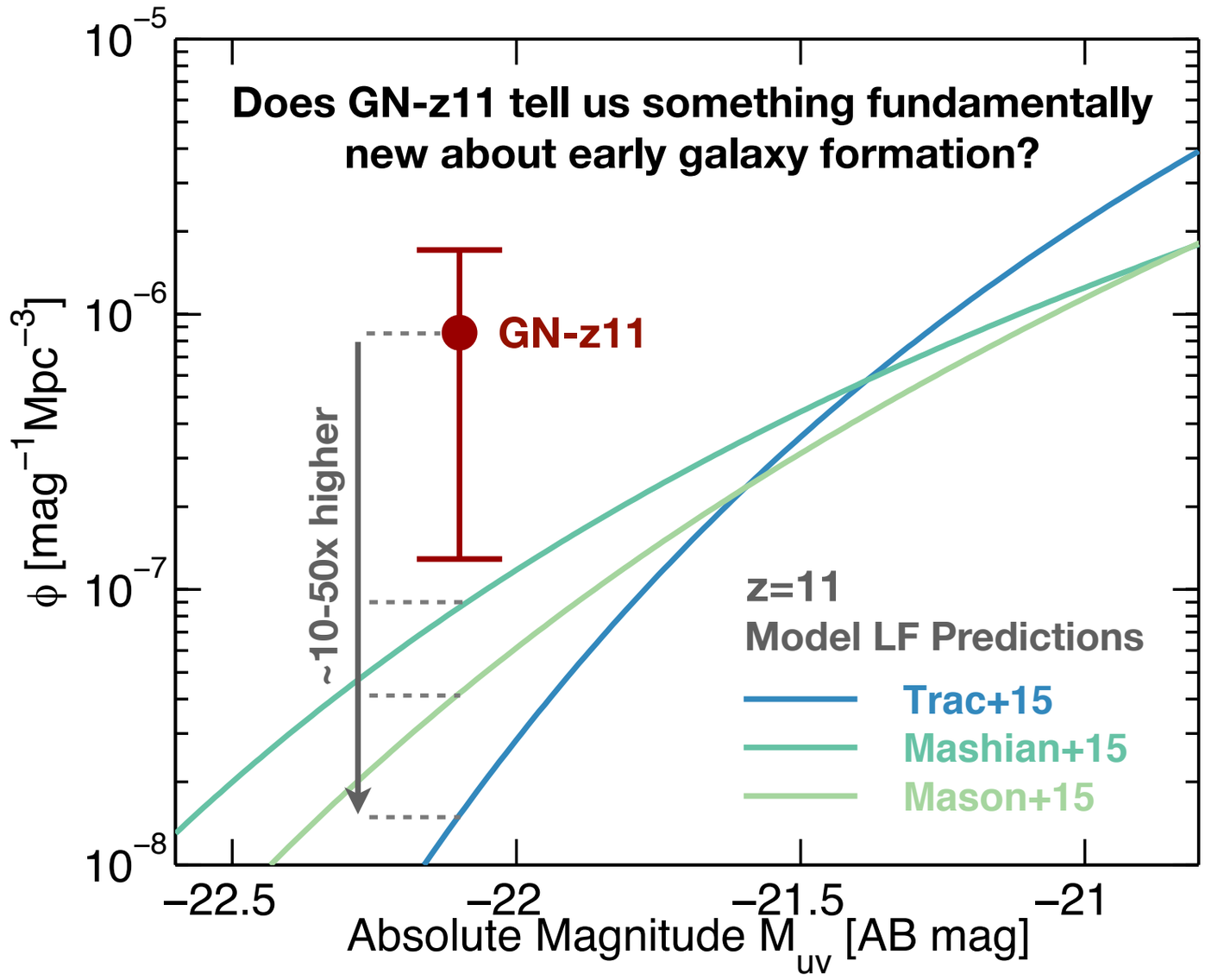
From presentation slides of Ivo Labbe in 2008





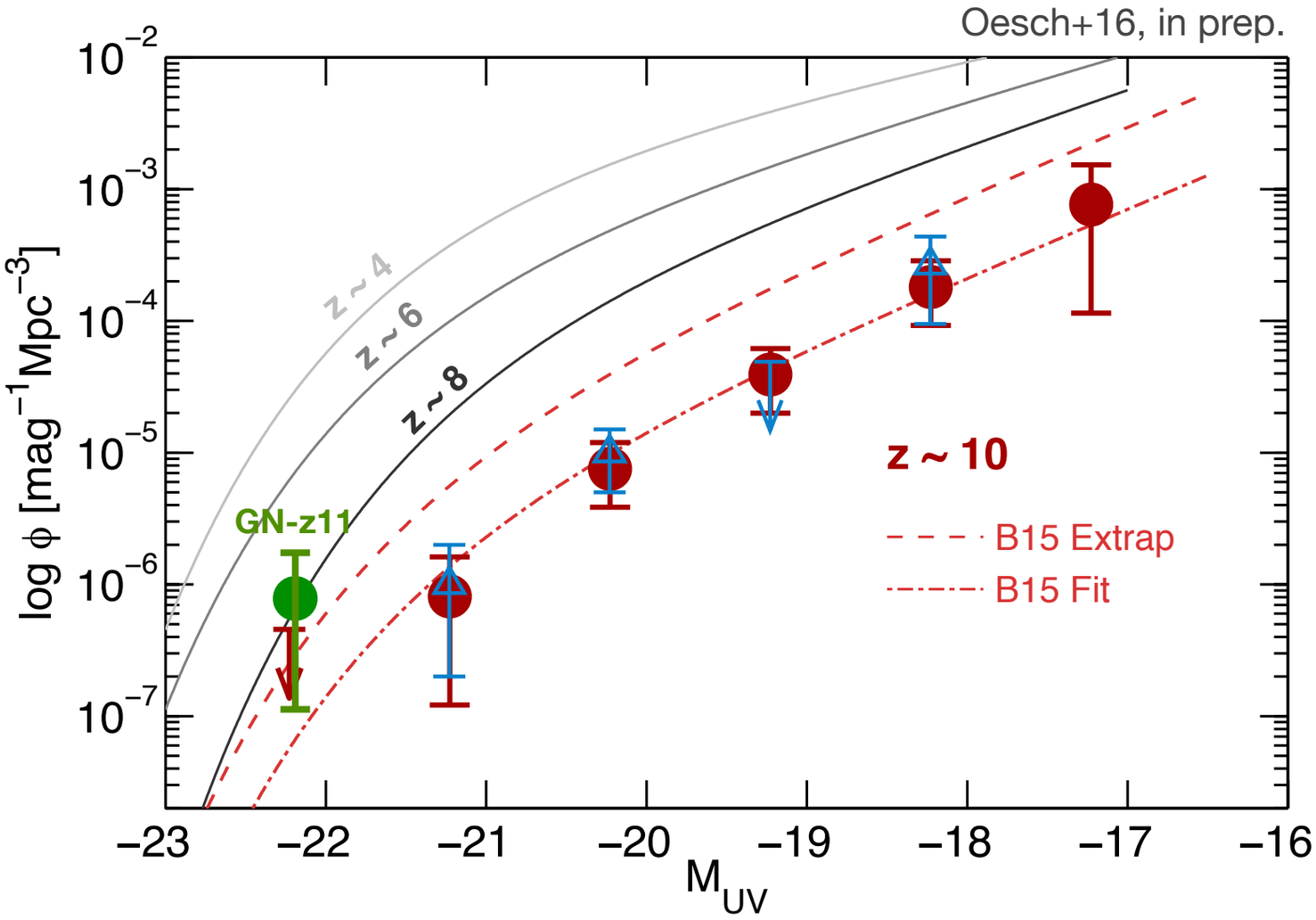
same photo-z as with new data, but was ruled out as not likely to lie at z>9 due to single band detection and its luminosity (Bouwens+10)

GN-z11 is off the Charts



- Detection of GN-z11 in existing data is quite unexpected, given current models
- Expected to require 10-100x larger areas to find one such bright z~11 galaxy as GN-z11
- Difficult to draw conclusions based on one source. **Need larger survey!**

The UV Luminosity Function at the Cosmic Frontier



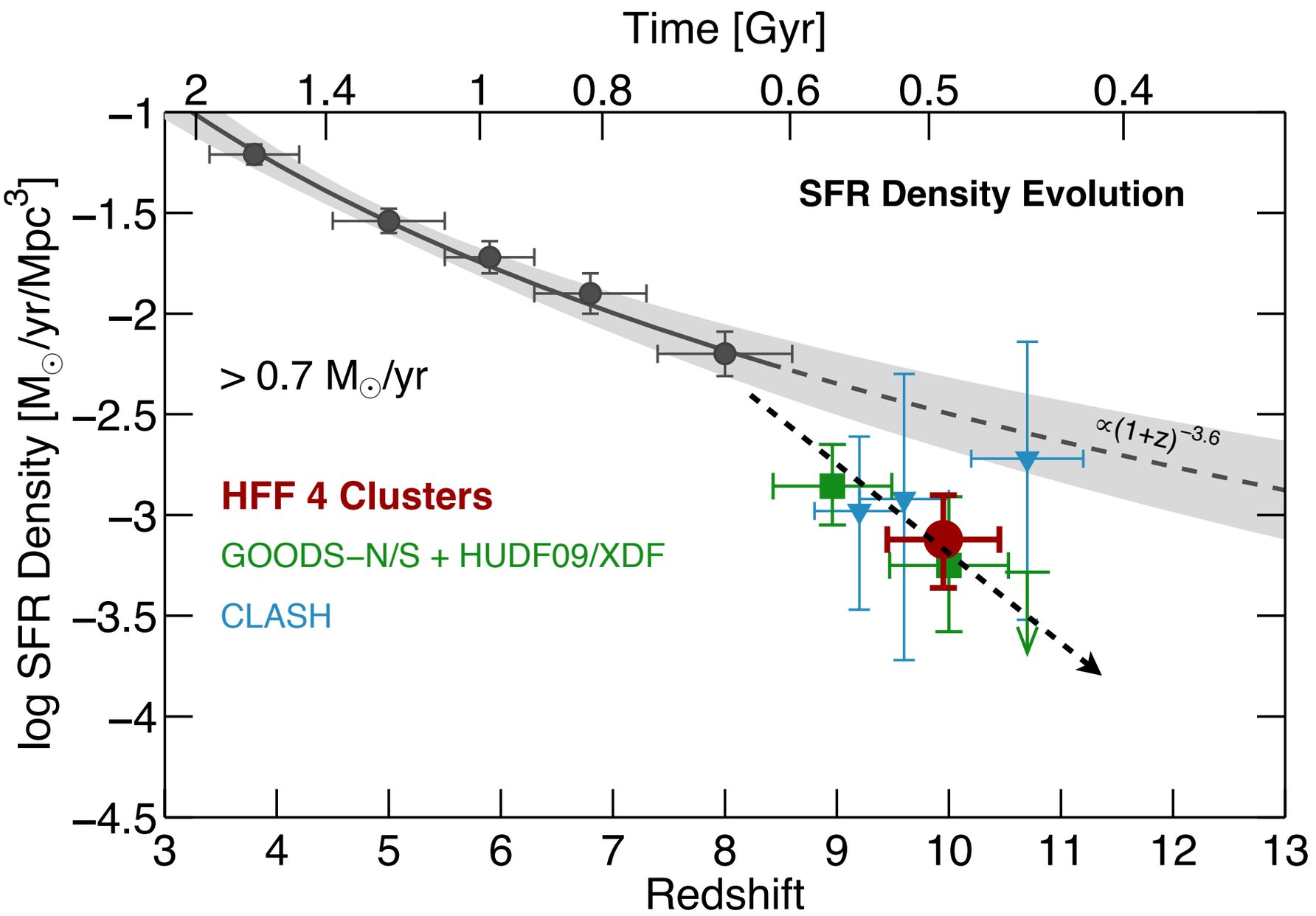
Including HFF galaxy candidates, now have a quite good estimate of the UV LF at z~10.

It lies a factor ~4-5x below the extrapolation from lower redshift trends.

There just aren't a lot of z~10 galaxies out there!

Slower evolution at bright end?

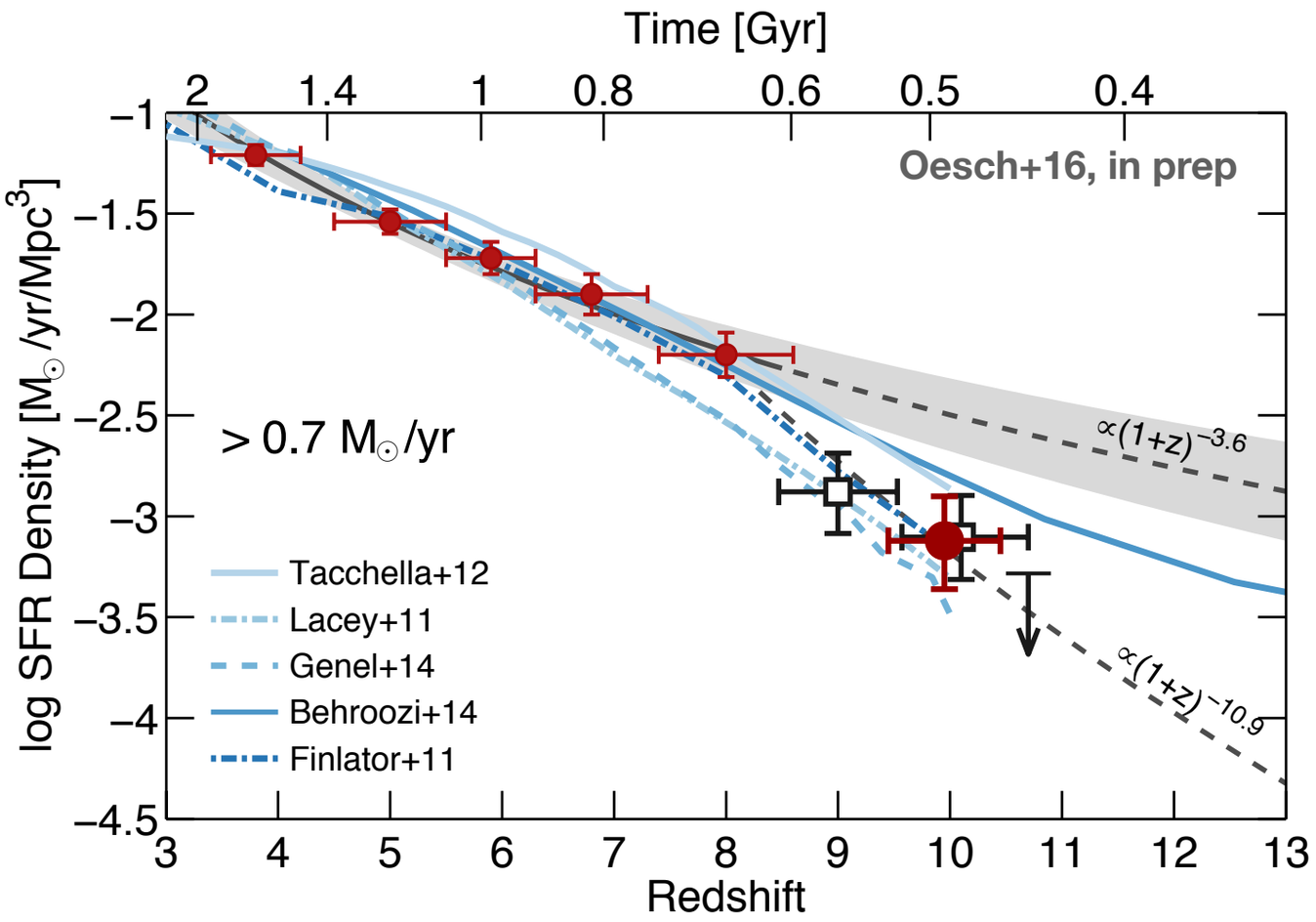
SFRD Evolution at z>8

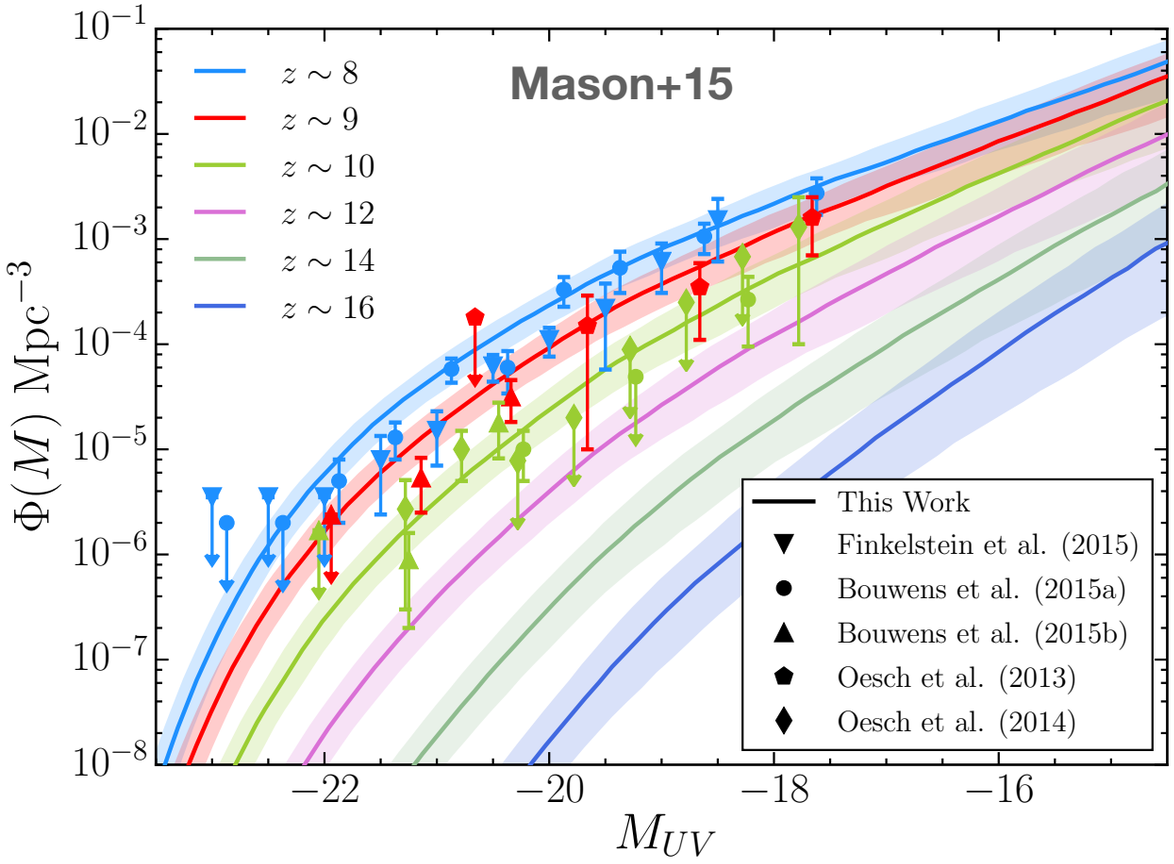


Full analysis of first 4 HFFs confirms:
SFRD evolves very rapidly beyond z~8, faster than across z=4-8

see also: Zheng+12, Coe+13, Bouwens+13/15, Ellis+13, McLure+13, Ishigaki+14

Rapid Decline Consistent with Models





Rapid decline in the cosmic SFRD is consistent with most models,
but there is a considerable range in predicted evolutions at z>8.

Need to understand this before launch of JWST to plan most efficient surveys!

Summary

- **Deep imaging with HST** enabled the detection of a **large sample** of galaxies at z>3 (11'000), and extended our frontier into the heart of the cosmic reionization epoch (>800 galaxies at z~7-10). **Spectroscopy lagging behind.**

- **Cosmic Frontier:** Have obtained a grism **continuum break redshift** for a surprisingly luminous galaxy in the GOODS-N field: **GN-z11 with z_{grism}=11.1**

- GN-z11 is reliably detected in IRAC, enabling first insight into physical properties of galaxies at z>10: We have now explored **97% of cosmic history** in build-up of star-formation and mass

- Discovery of **GN-z11 in current search area is surprising** according to models: **Need larger area surveys** to confirm the number densities of bright galaxies at z>10. Needs to be done **now with HST**, likely won't be done with JWST!

- Despite the discovery of GN-z11, the **cosmic SFRD** (dominated by faint galaxies) evolves declines **rapidly at z>8** by a factor 10x in only 170 Myr