Hunting for the first galaxies with JWST

Zihao Li

Chengzhe Li

History of the first galaxy record

Galaxy	redshift	method	Year of discovery
Andromeda	0	Cepheid variable star	1923
NGC 4853	0.0026	Spectrum	1930
LEDA 25177	0.13	Spectrum	1936
3C 368	1.131	Spectrum	1982
PHS 1614+051	3.215	Spectrum + photometry	1985
SSA 22-HCM1	5.77	Spectrum + photometry	1999
HCM-6A	6.56	Spectrum + photometry + lensing	2002
GN-z11	10.6	Spectrum + photometry	2016
HD1	13.21	photometry	2022

History of the first galaxy record

- Hubble used the period-luminosity relation of Cepheid to determine the distance of Andromeda.
- Andromeda is the first galaxy confirmed outside our Milky Way.

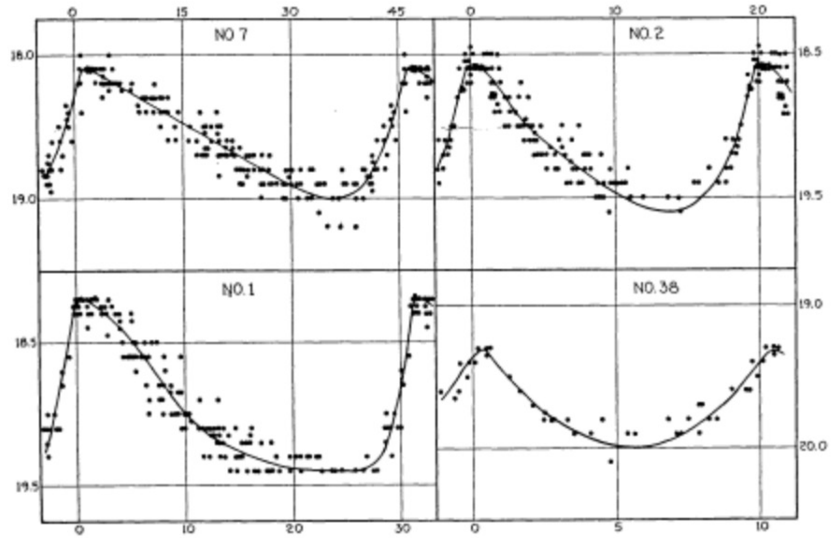
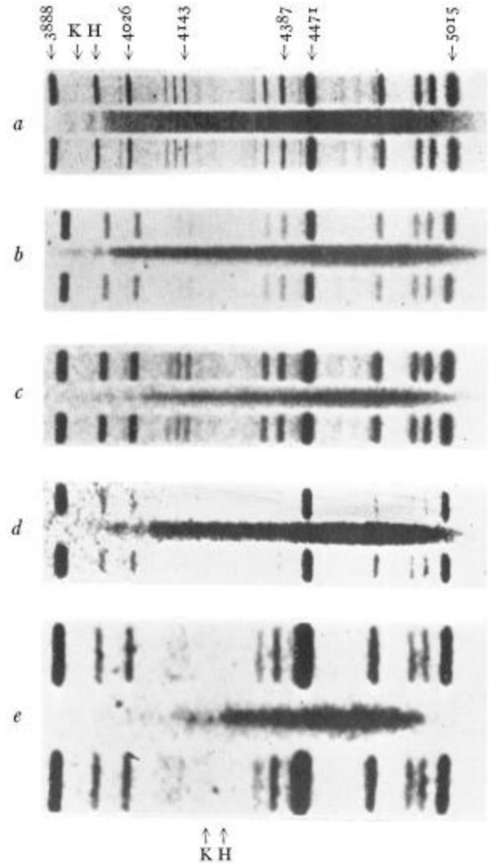


FIG. 1.—Light-curves of four Cepheids in M 31; ordinates, photographic magnitudes; abscissae, days.

Hubble. 1929

History of the first galaxy record

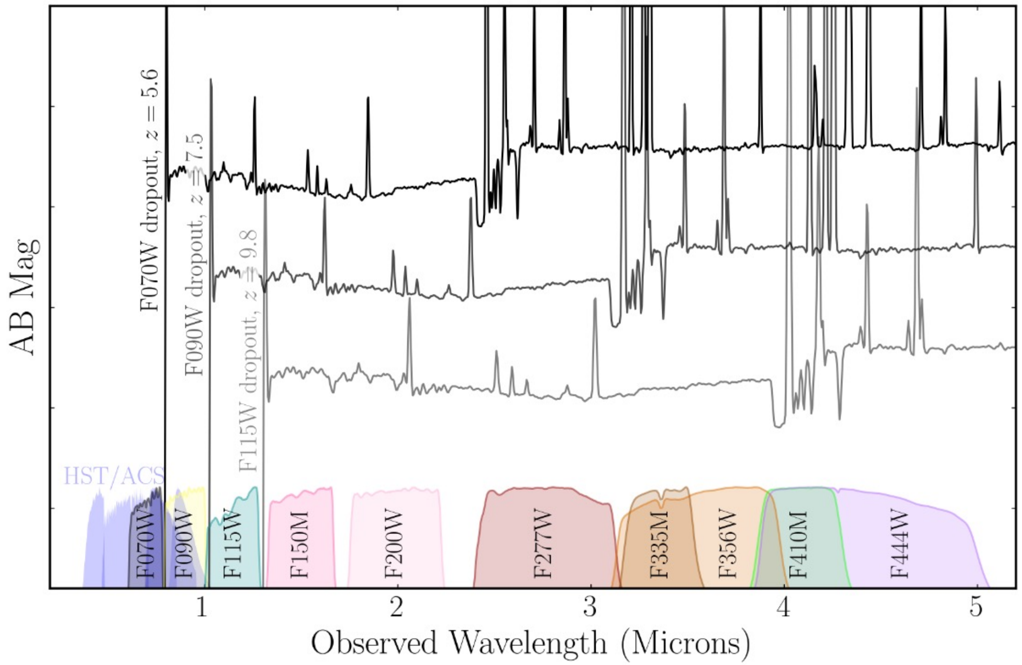
- Measure spectra redshift later became a standard way to measure distance of more distant galaxies.
- Humason used the shifts of emission lines to determine the redshift and found the most distant galaxy LEDA 25177 in 1936.



Humason. 1931

Select the first galaxies

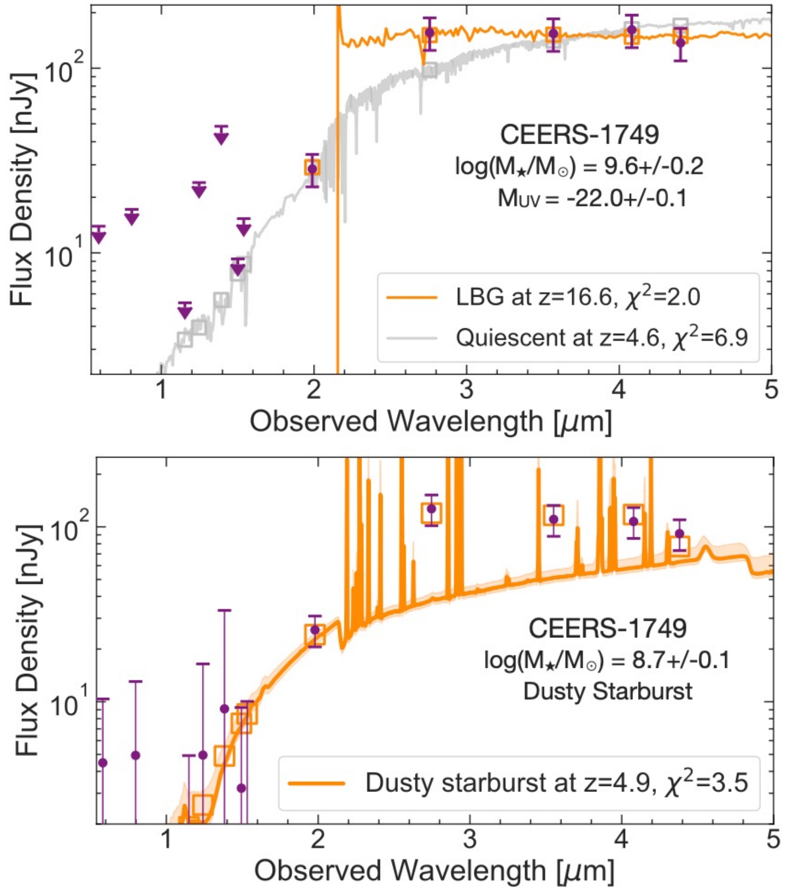
- A photon emitted with wavelength blueward of lyman alpha will be absorbed by neutron hydrogen in IGM.
- We can select high-z candidates using such drop out.



Hainline et al. 2023

Select the first galaxies

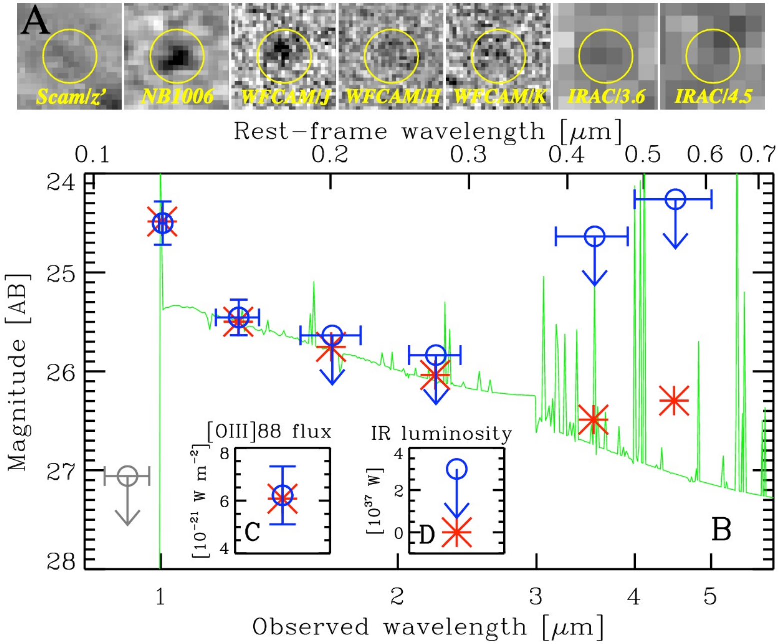
- However, We may confuse low redshift interlopers (dusty star-forming, quiescent with Balmer break) with high redshift Lyman break galaxies.



Naidu et al. 2022

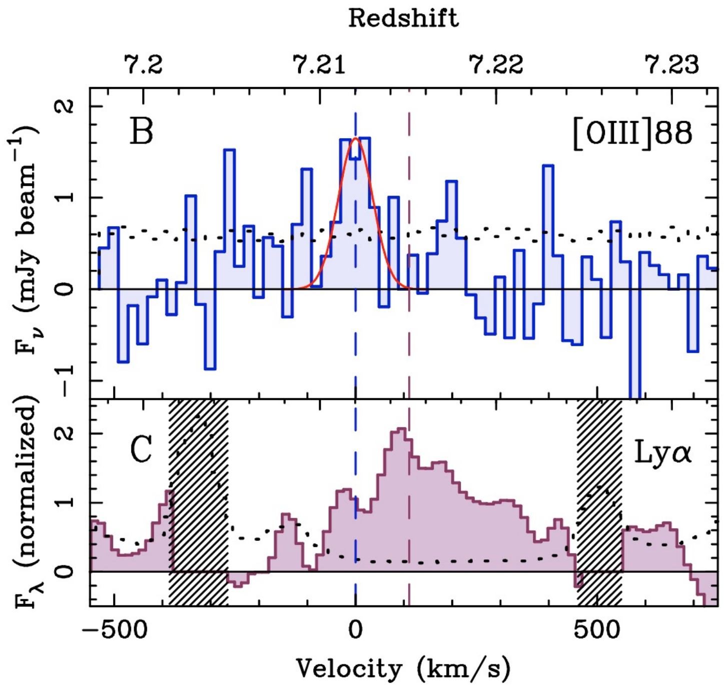
Confirm the first galaxies in pre-JWST era

- People found SXDF-NB1006-2 at z=7.2, using HST, Spitzer and ground based telescopes.



Narrow band imaging reveals Lya emission at z=7.2

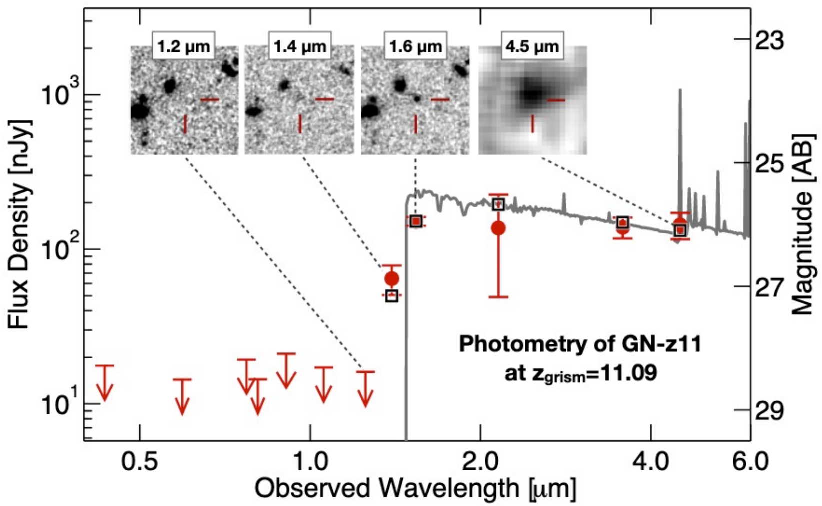
Inoue et al. 2016

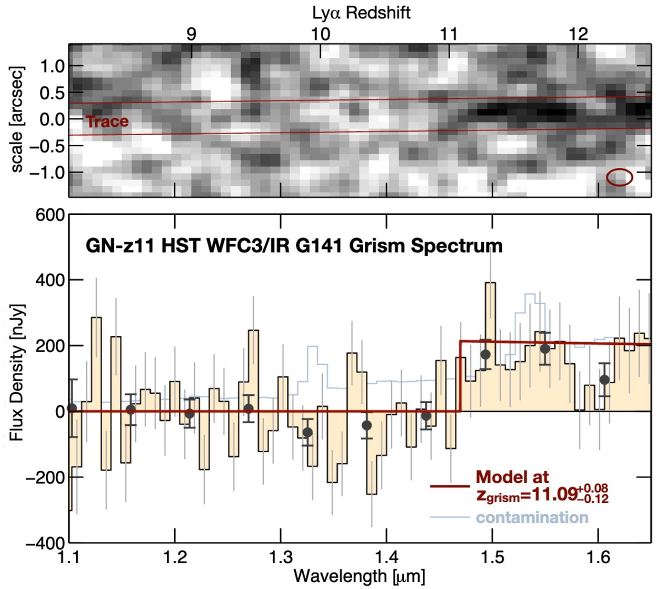


[OIII] emission in ALMA spectrum and Lya emission in Keck spectrum

Confirm the first galaxies in pre-JWST era

- Using HST imaging and grism, people found the most distant galaxy GN z-11 at z=11





Broad band Photometry detected Lyman break

The Lyman break is confirmed by grism spectroscopy

Oesch et al. 2016

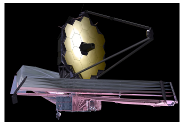
Why JWST?

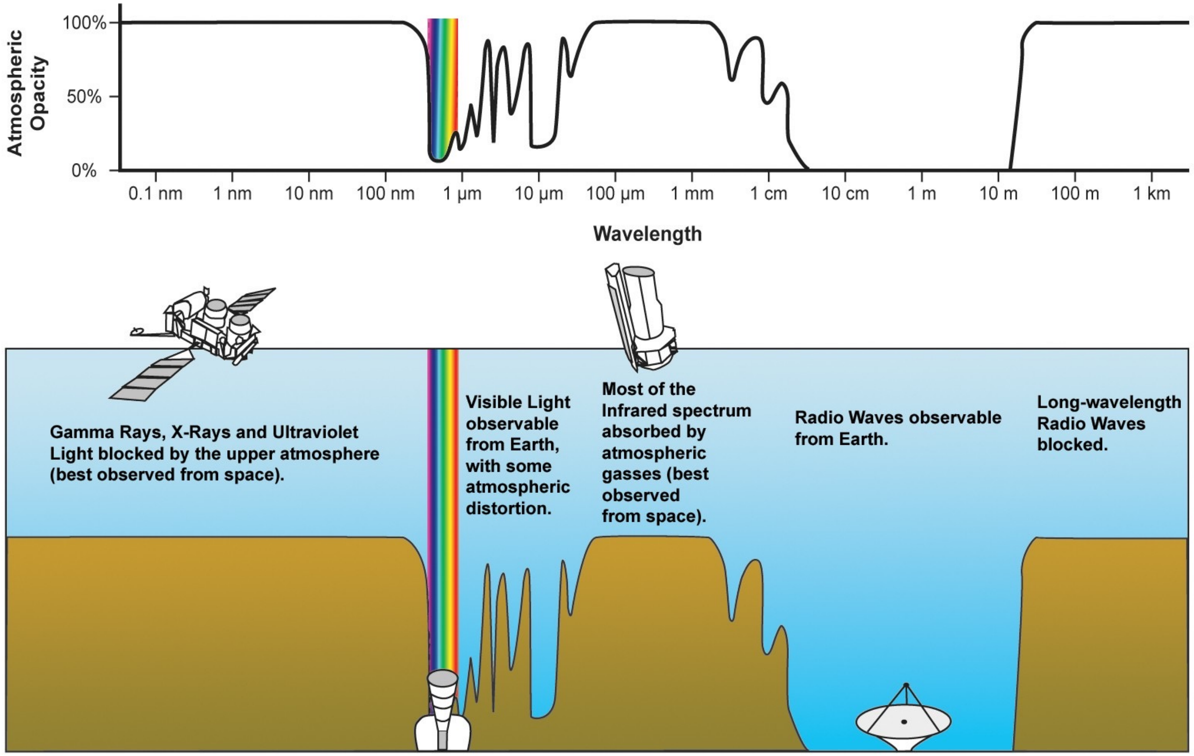
Weakness of ground based telescopes:

- Low atmosphere opacity and contaminating skylines in near-infrared range.
- Hard to resolve compact high-z galaxies limited by seeing.

JWST's advantage:

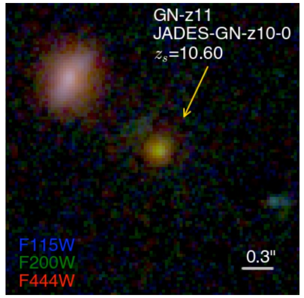
- NIRSpec, NIRCam, MIRI, NIRISS can take near-infrared spectra, covering many redshifted emission lines that are inaccessible to pervious telescopes.
- High spatial resolution to study high-z galaxies morphology (e.g., star-forming regions, mergers).

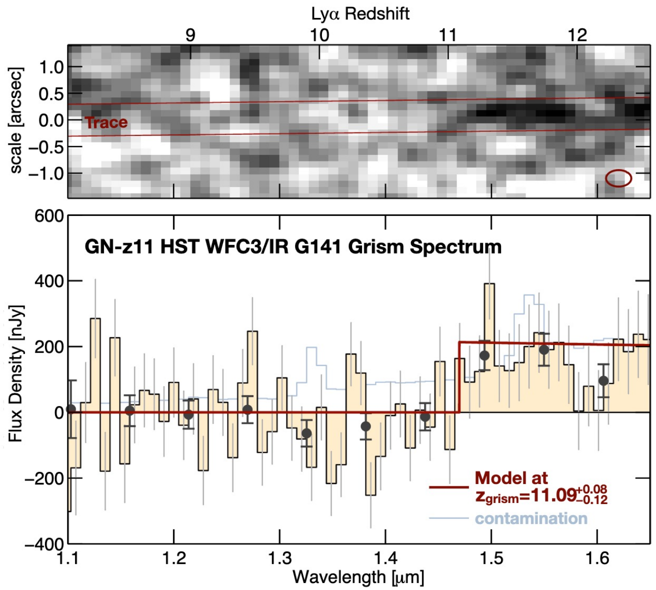




Confirm the first galaxies with JWST

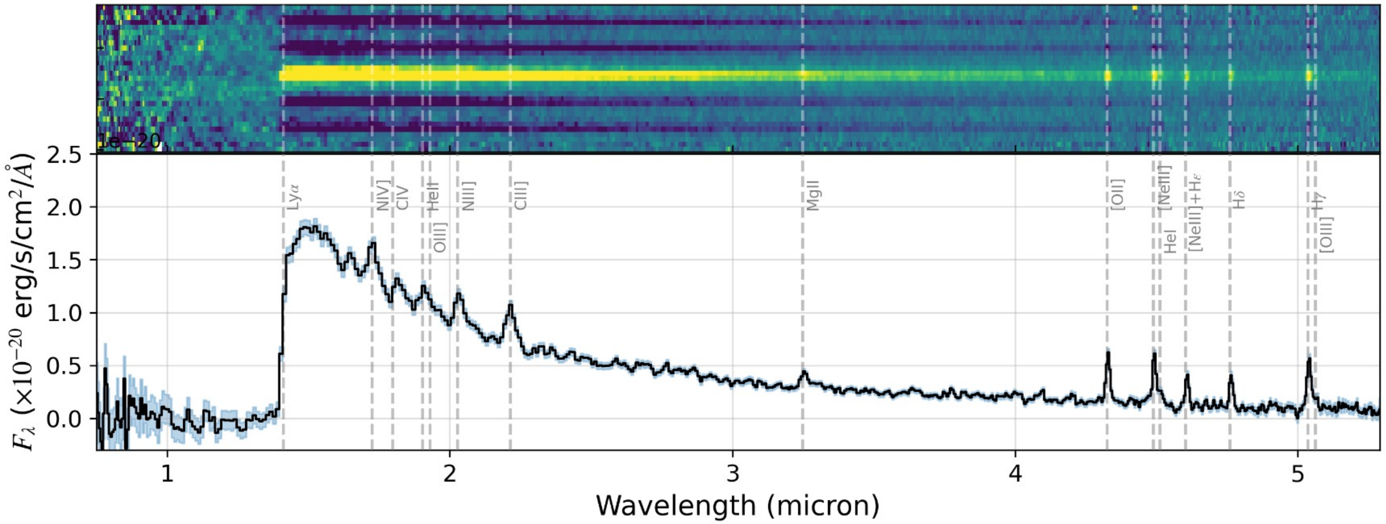
- HST only tentatively detected lyman break of GN z-11
- JWST clearly resolves Lyman break feature as well as many emission lines with which redshift can be secured.





HST WFC grism

Oesch et al. 2016



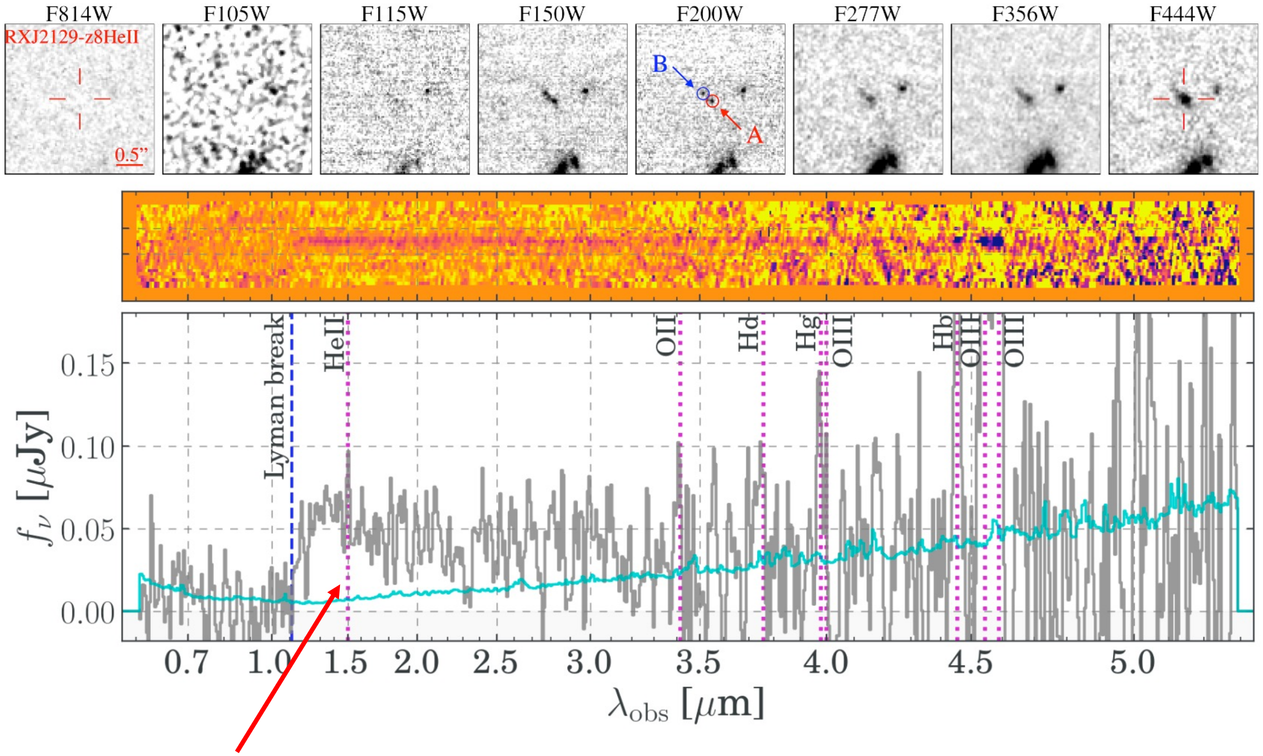
JWST NIRSpec prism

Bunker et al. 2023

Science cases with first galaxies

Searching for Pop III star

- The HeII emission may be produced by massive, metal free Pop III stars, which have strong ionizing flux.
- Although Wolf-Rayet stars, X-ray binaries, AGN may also produce it.



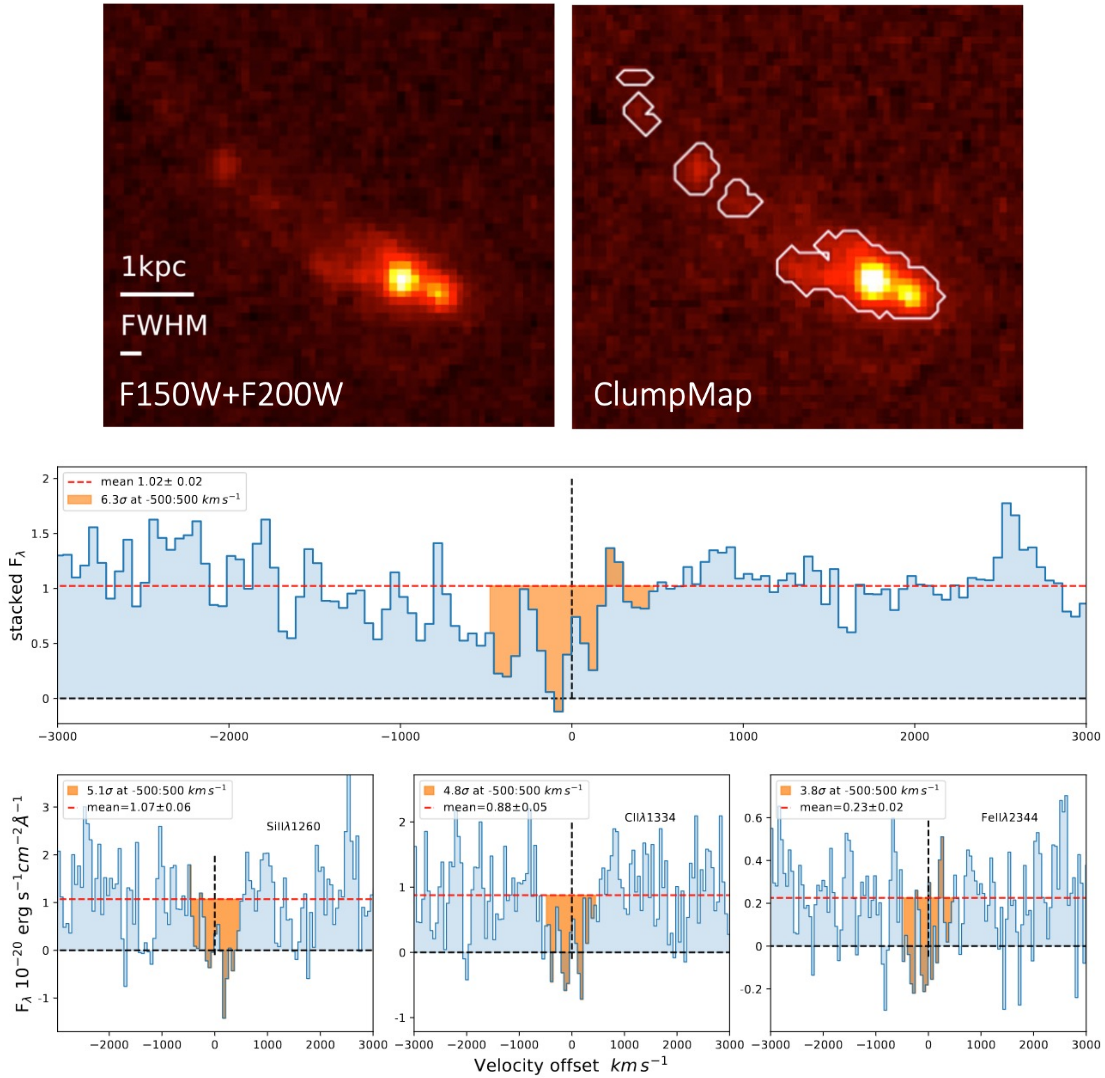
Tentative detection of HeII emission?

Wang et al. 2022

Constrain cosmology

An interacting galaxy at z=9.3

- Mass of this galaxy is estimated by SED to be $2.5\times10^{9}M_{\odot}$
- All galaxies at this early time recorded before are below $5\times10^{8}M_{\odot}$
- Evidence of rapid and efficient built up of mass and metals in the immediate aftermath of the Big Bang through mergers.
- Massive galaxies are present at earlier times than expected.

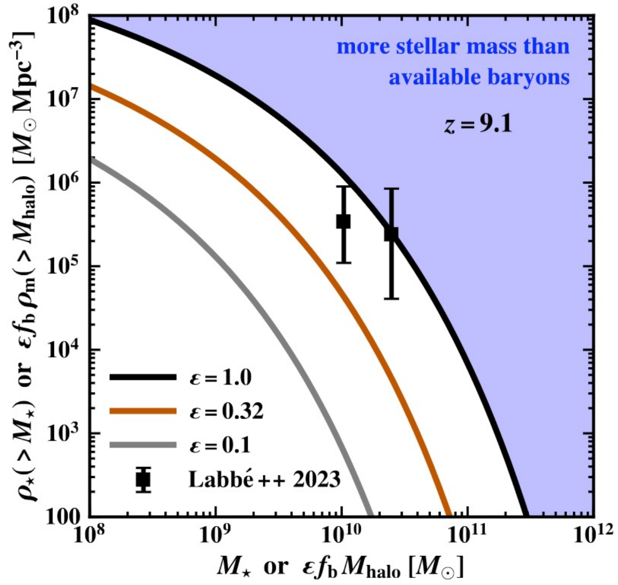


Detection of absorption lines

Boyett et al. 2023

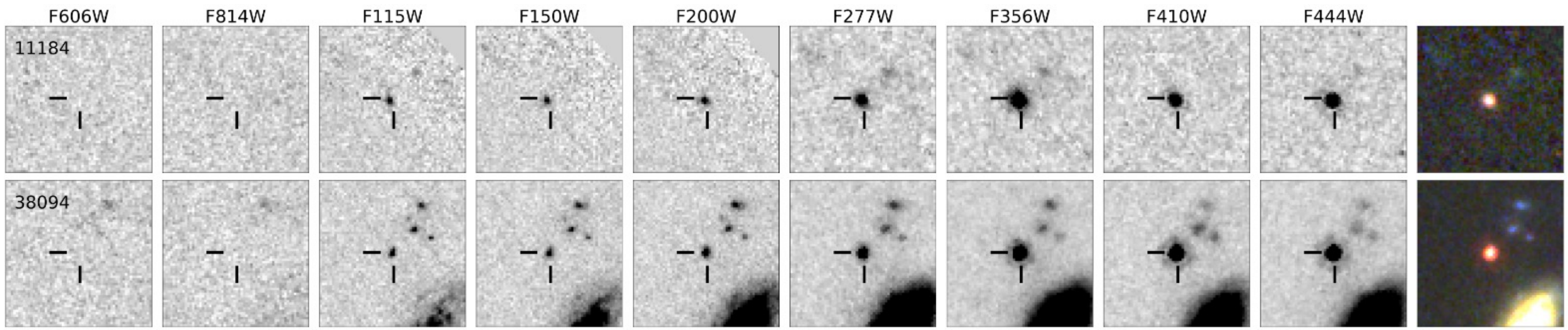
Constrain cosmology

ϵ: efficiency of turning baryon to stellar mass



Boylan-Kolchin. 2023

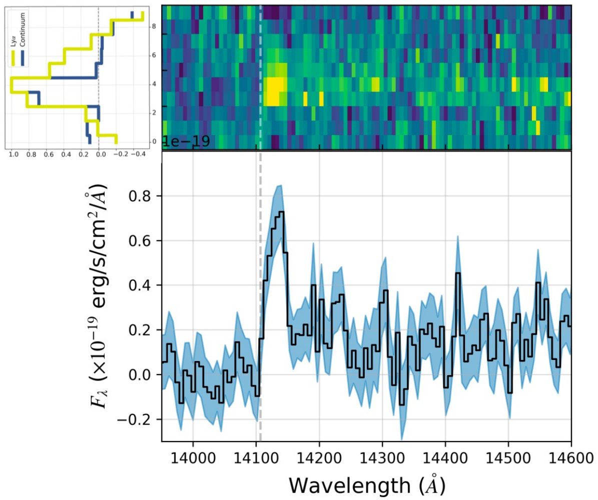
JWST found several galaxies at z>8 that are so massive than standard LCDM model could realize.



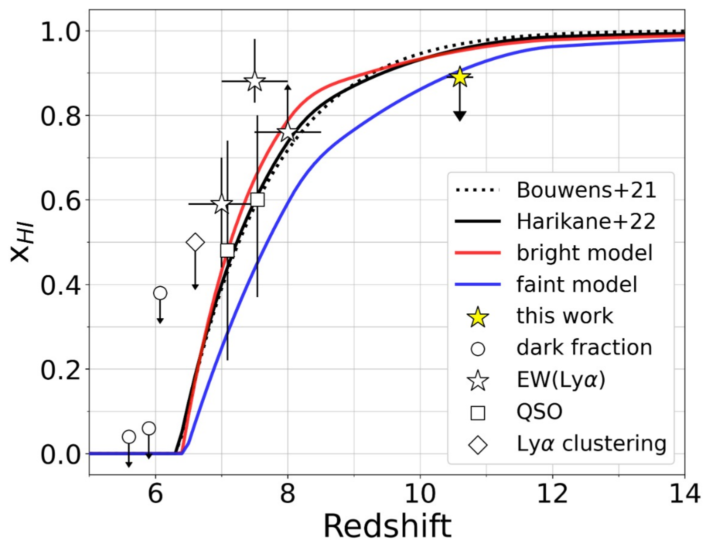
Labbé et al. 2023

Constraining the Reionization Process

- The equivalent width of Lyman alpha emission constrains the IGM neutron fraction.
- The discovery of GN z-11 supports the model that the faint galaxy play the major role in reionization.



Lya emission line of GN z-11
Bunker et al. 2023



The reionization History
Bruton et al. 2023

Take home message

- With the ability of detecting near-infrared to mid-infrared light and high diffraction limit, JWST are able to resolve emission lines of very high redshift galaxies (first galaxies).
- We may find evidence of Pop III stars in the first galaxies.
- The finding of massive galaxies at z>8 may constrain the galaxies formation under LCDM model.
- The finding of lyman alpha emission in first galaxies could constrain reionization history.