Early Universe Discoveries with JWST

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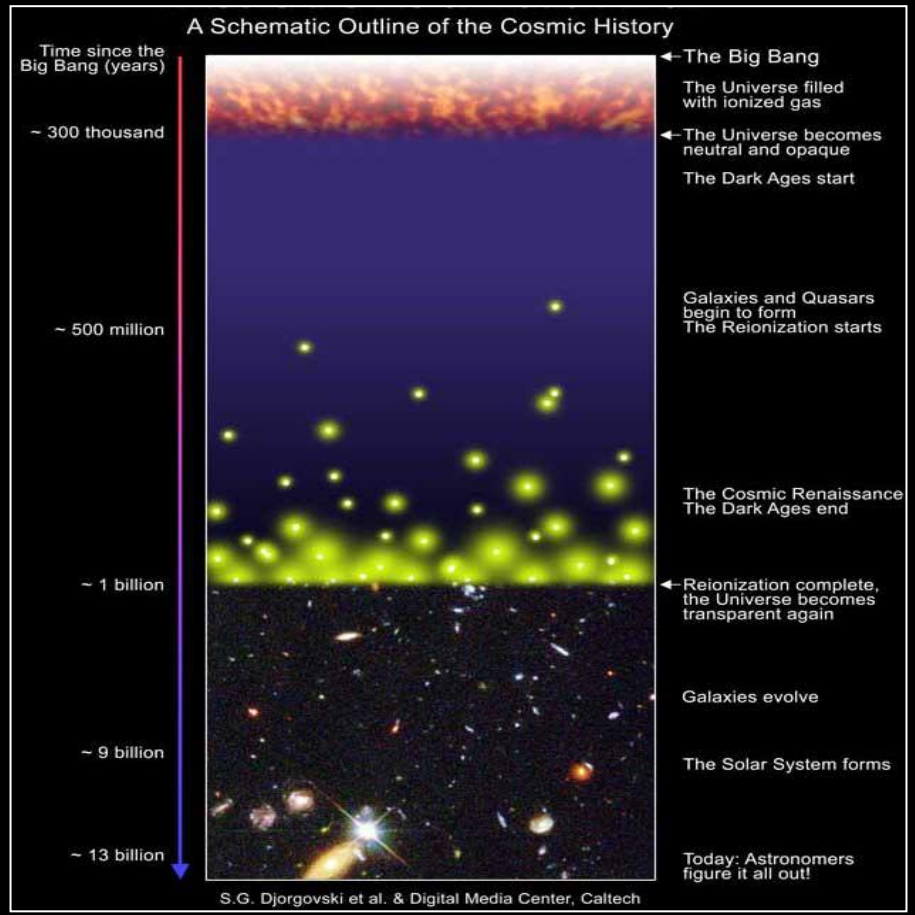
MIRI European Consortium

CENTRO DE ASTROBIOLOGÍA

CSIC Consejo Superior de Investigaciones Científicas

INTA Instituto Nacional de Técnica Aeroespacial

JWST & Primordial Universe: History of the Universe



Begin Dark Ages (z~1000, 0.3Myr)

Begin Reionization (z~15-10, 300Myr)

⇦ First stars, galaxies & QSO

Begin Galaxy Assembly (z~6, 1Gyr)

⇦ Formation & evolution of Galaxies & AGNs

Today (z=0)

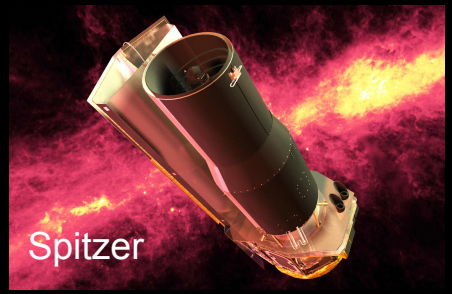
JWST & Primordial Universe: Detection of galaxies in the EoR pre-JWST

Hubble space telescope

Telescope covering the UV, optical, and near-infrared range

λ ~ 200-1600 nm

Characterization of the UV spectrum of bright galaxies in the EoR



Spitzer

Telescope covering the near and mid infrared range

λ ~ 3.6-4.5 μm

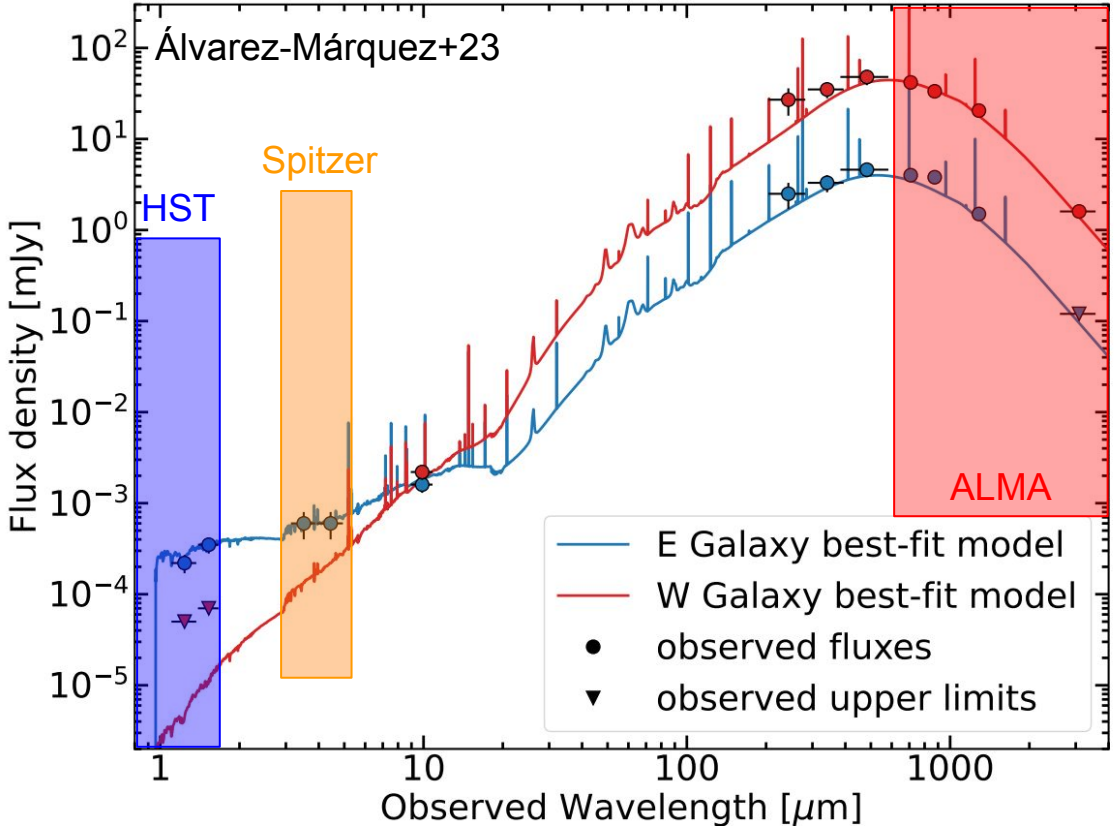
Characterization of the optical spectrum of bright galaxies in the EoR

Atacama Large Millimeter Array

Interferómetro cubriendo el rango submilimétrico y milimetrico

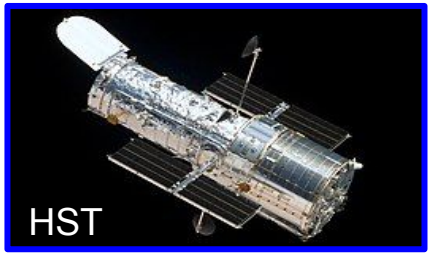
λ ~ 0.4-8.6 mm

Characterization of the neutral, ionized, and cold molecular gas, as well as dust emission in bright galaxies of the EoR

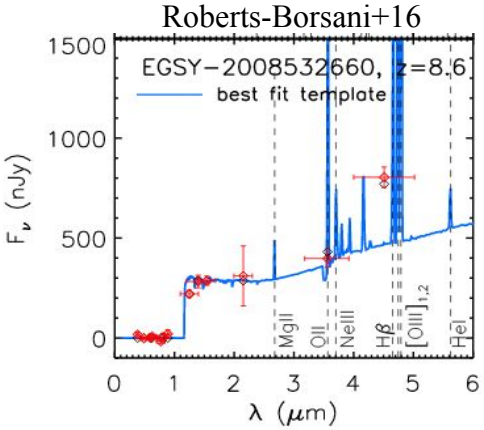

Álvarez-Márquez+23
HST
Spitzer
ALMA
E Galaxy best-fit model
W Galaxy best-fit model
observed fluxes
observed upper limits
Flux density [mJy]
Observed Wavelength [μm]
10^{2}
10^{1}
10^{0}
10^{-1}
10^{-2}
10^{-3}
10^{-4}
10^{-5}
1
10
100
1000

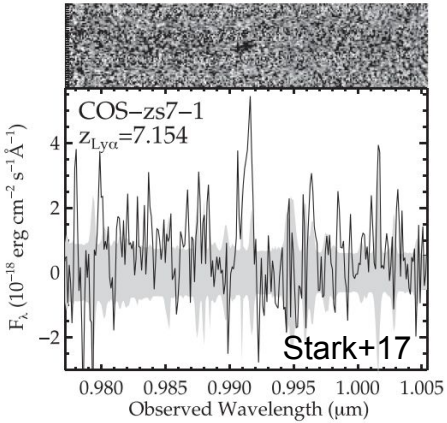

ALMA

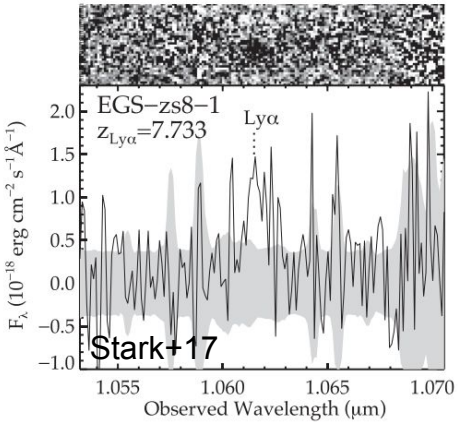

Spitzer

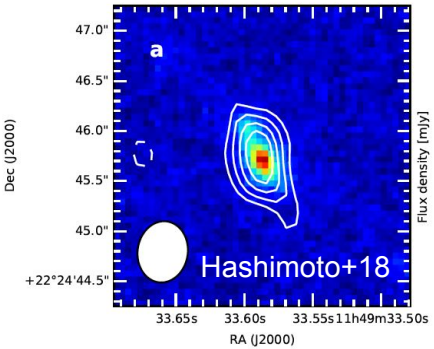

HST

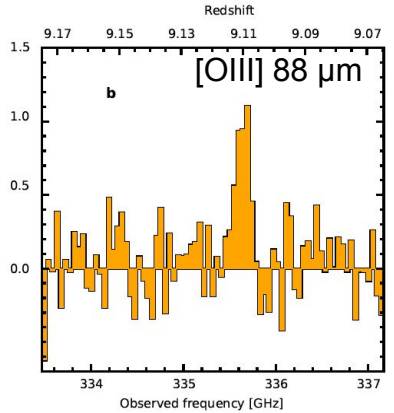
- **Deep surveys from HST & Spitzer have detected hundreds of galaxies at z > 7**
  - Identified as line emitters (e.g., Stark et al. 2013)
- **Spectroscopic confirmation was challenging prior to JWST**
  - Detection of the Lyα line from ground-based telescopes/HST (Stark et al. 2017)
  - Detection of far-infrared lines ([CII] 158 μm or [OIII] 88 μm) in the submillimeter with ALMA/NOEMA (Hashimoto et al. 2018)
- **Only a few dozen galaxies were spectroscopically confirmed in the EoR before JWST**



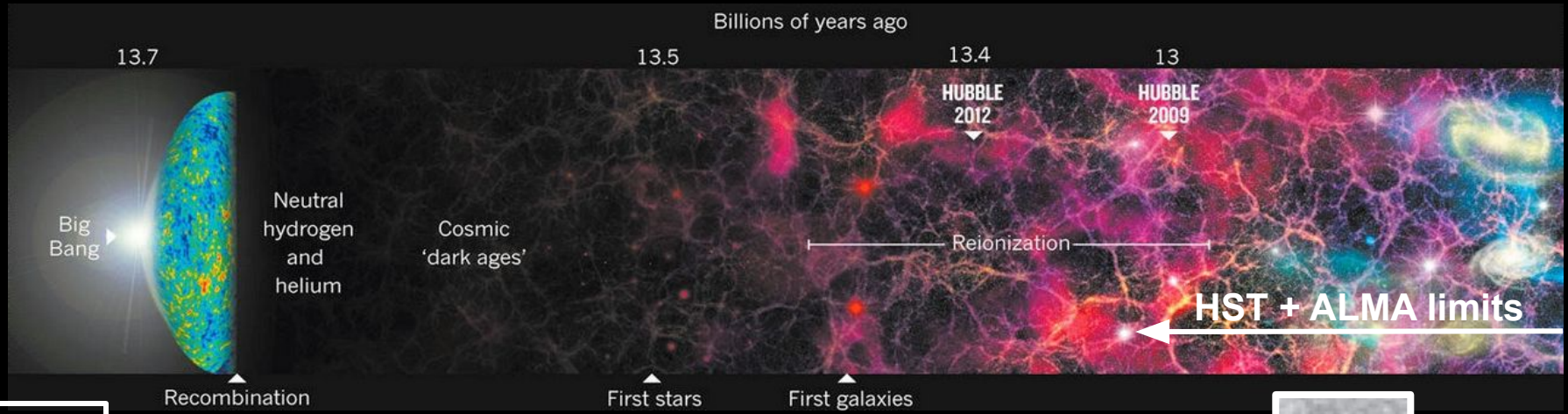




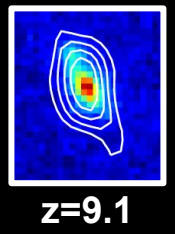


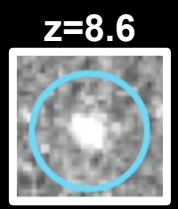


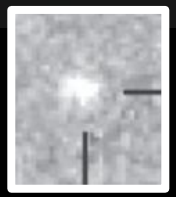
JWST & Primordial Universe: Redshift frontier (pre-JWST)

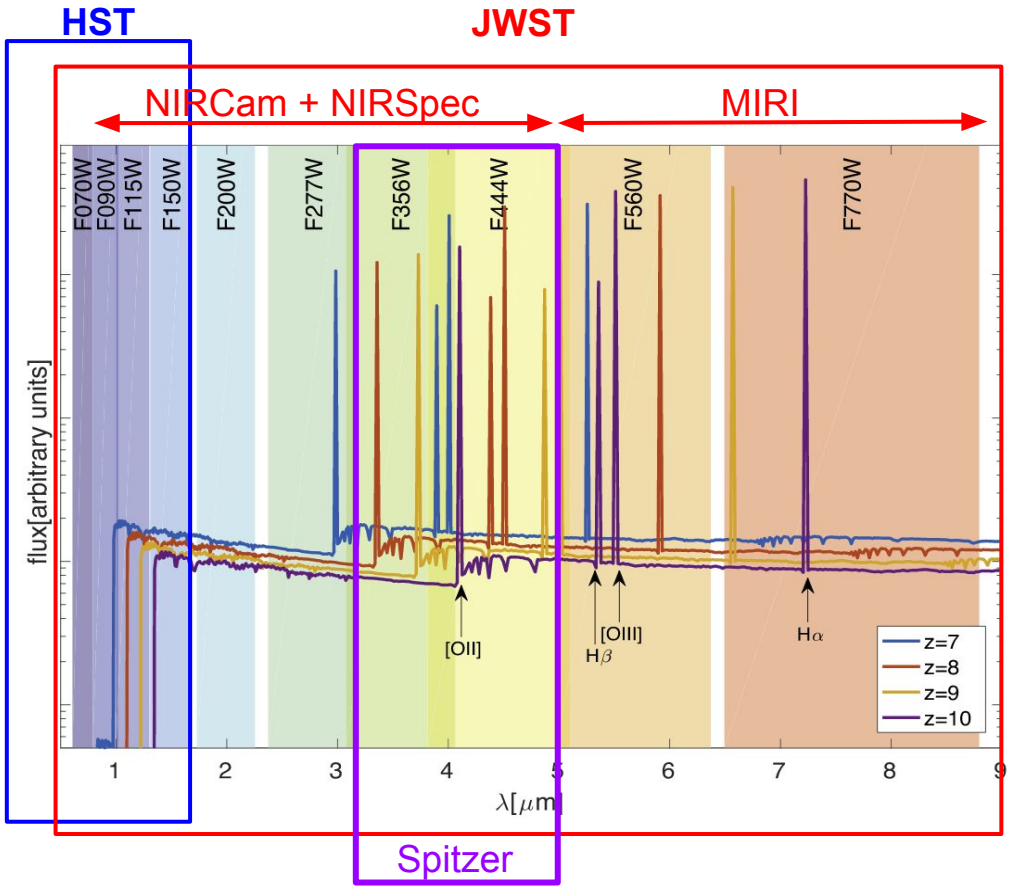


HST & ALMA



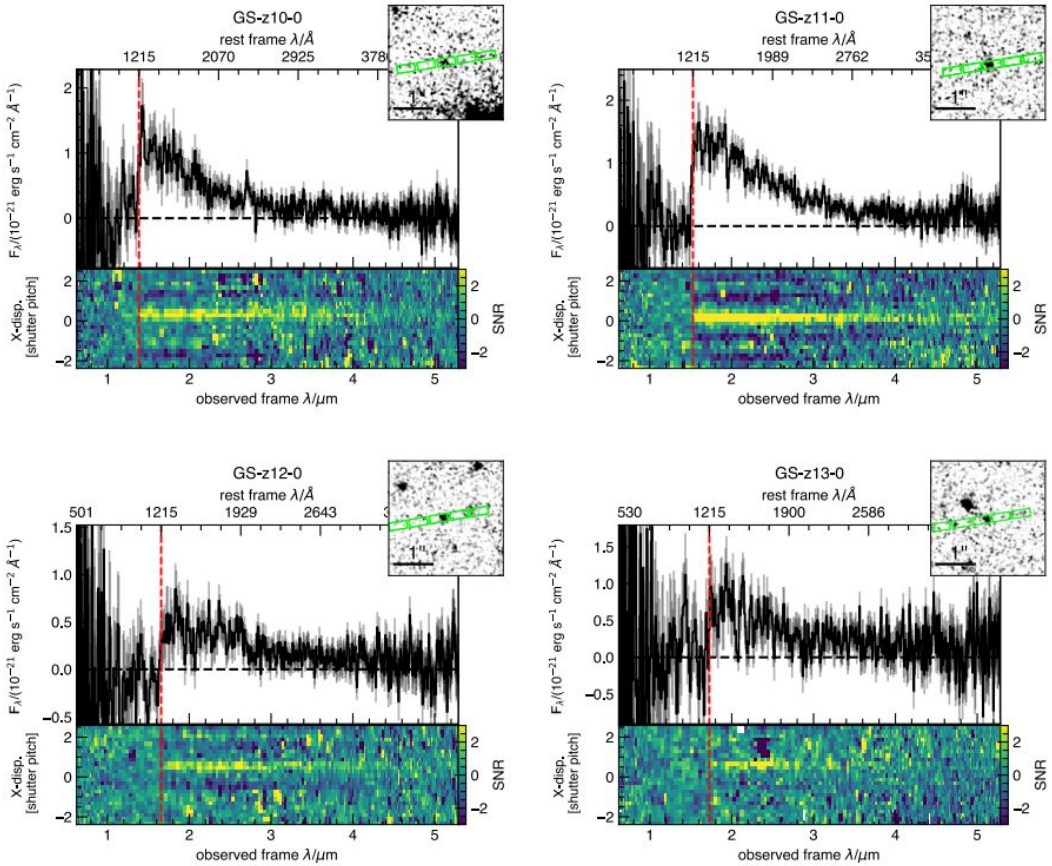






JWST allows us to observe the rest-frame UV, optical, and near-infrared spectrum of galaxies in the EoR:

- **NIRCam**: Imaging in the UV and optical
- **MIRI imager**: Imaging in the optical and near-infrared
- **NIRSpec IFS & SMA**: Spectroscopy in the UV and optical
- **MIRI MRS & LRS**: Spectroscopy in the optical and near-infrared



Curtis-Lake+23; Arabal Haro+23; …

NIRSpec is powerful to confirm galaxies at z>9-10 from the detection of the Ly-α break

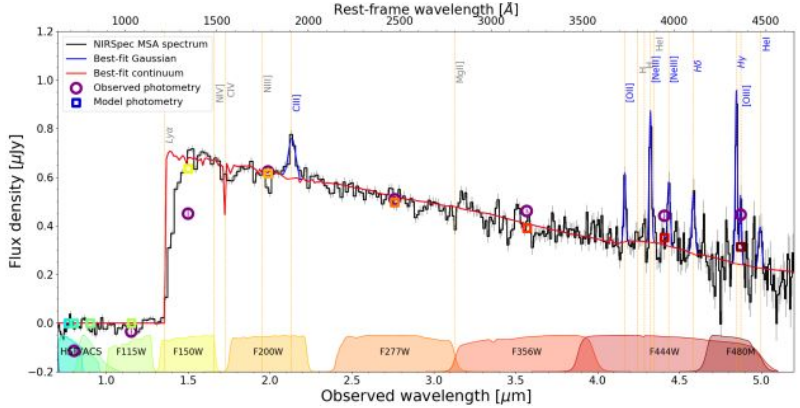
Bright optical lines (Hβ, [OIII]4960, 5008, Hα) are not covered by NIRSpec

Most of the cases the depths are not sufficient to detect faint UV/optical lines

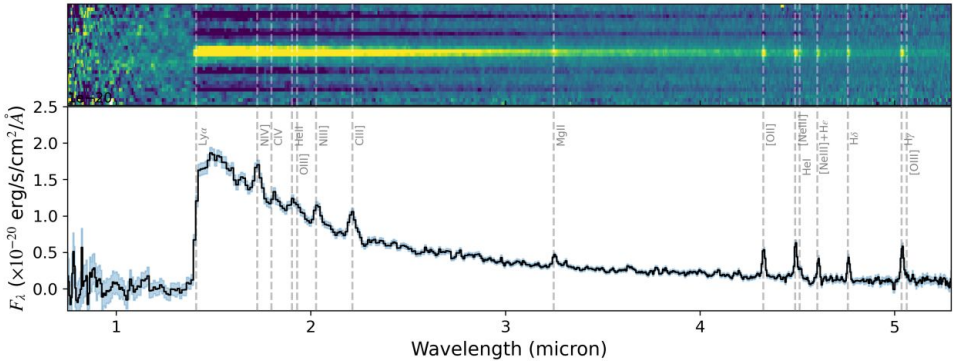
Expensive in telescope time for faint sources

Analysis of bright or lensed galaxies help to reduce exposure times and detect emission lines

MACS0647-JD (z~10.2; 460Myr)



GNz11 (z~10.6; 440Myr)



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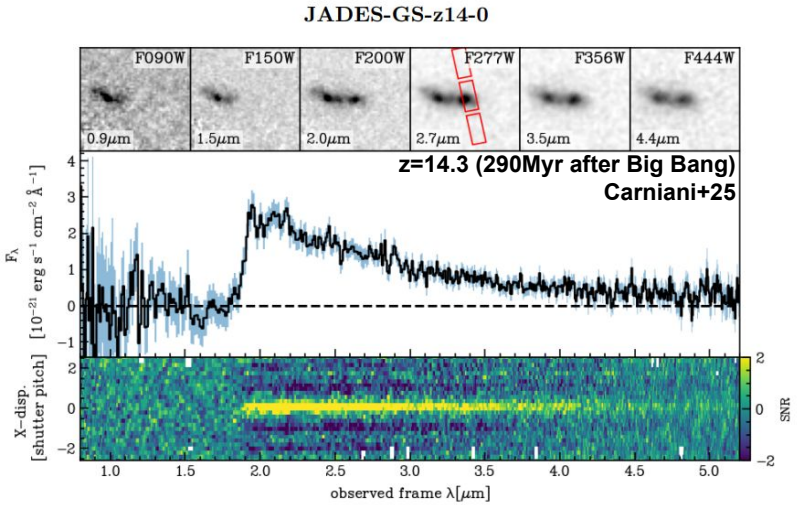
Bunker+23; Hsiao+24

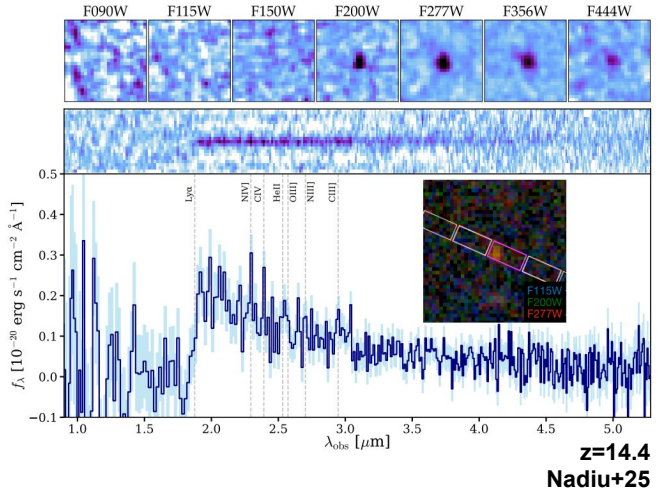
The highest spectroscopically confirmed galaxies are located ~300 Myr after the Big Bang

- Confirmed by the detection of the Ly-α break with NIRSpec R100
- No detection of emission lines in the UV rest-frame spectra
- Bright UV galaxy with Muv ~ 20.8



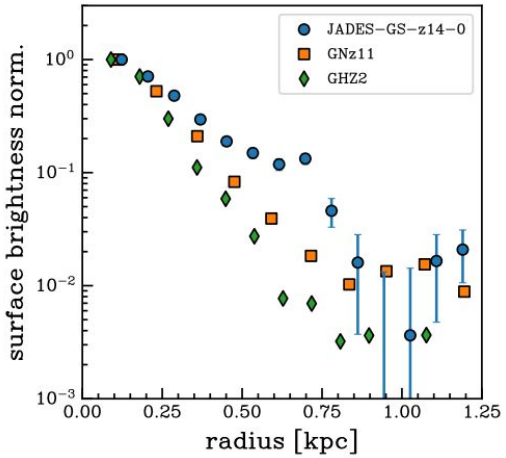
JWST is detecting a large number of bright galaxies in the primordial Universe in contradiction of cosmological simulations

Rapid evolution of galaxies in the early Universe

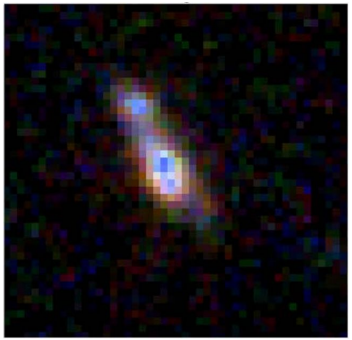


Diversity of morphologies and structure in primordial galaxies:

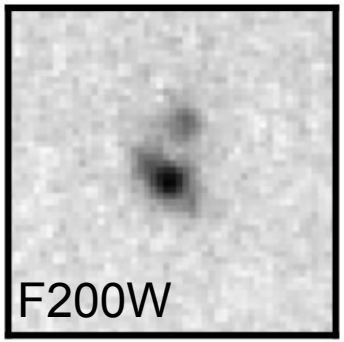
- Clumpy systems as MACS1149-JD1
- Really compact galaxies as GNz11 and GHZ2
- Merging systems as MACS0647-JD
- Extended systems as JADES-GS-z14-0



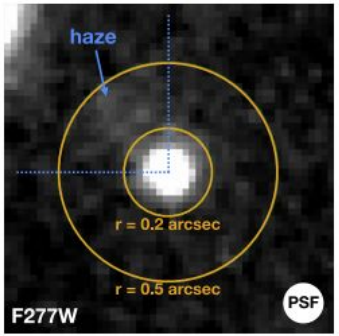
MACS1149-JD (z~9.1)



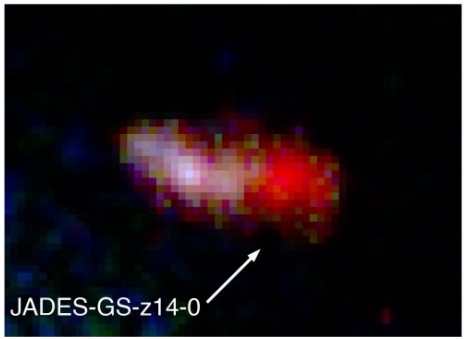
MACS0647-JD (z~10.2)



GNz11 (z~10.6)



JADES-GS-z14-0 (z~14.3)



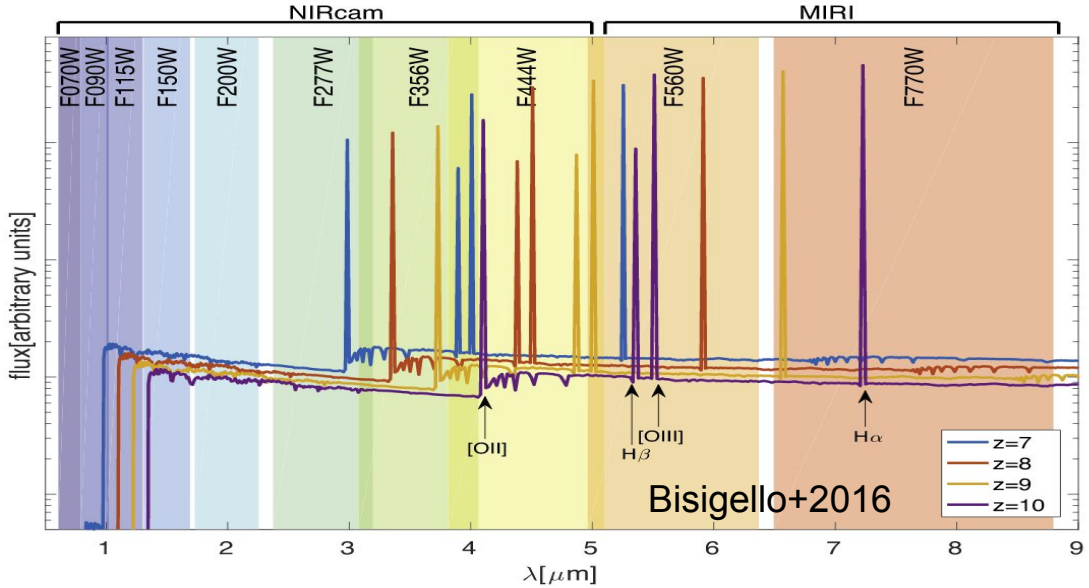
UV and optical lines are key ingredients to investigate the physical properties galaxies:

- Tracers of star-formation, metallicity, dust attenuation, radiation sources, electron temperature and density, …

For primordial Galaxies (z>9-10);

- Bright optical emission lines (Hβ, [OIII], Hα) enter in the MIRI wavelength domain
- NIRSPec only covers the UV to Balmer Break spectral range with faint emission lines

MIRI has a relevant role to characterize that primordial galaxies



Spatially-resolved Hα emission

- Two clumps (S & N)
- High (~15) SNR

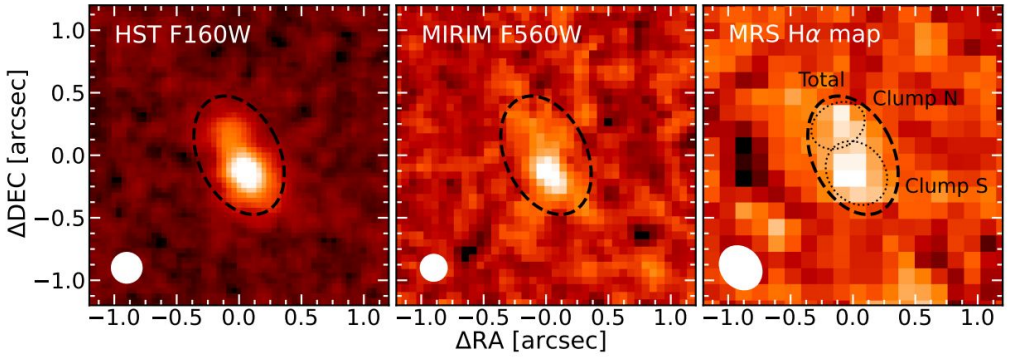
Spectrally-resolved Hα emission

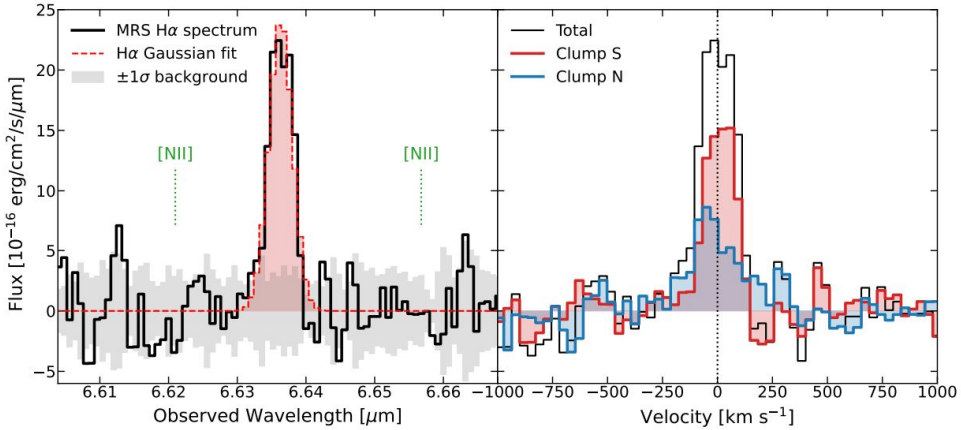
- Dynamical mass of 2.4x10^9 M$_\odot$
- Different kinematics in each clump

Larger ionizing photon production efficiency

Large variations of the EW of Hα between N and S clumps indicating differences in SFHs:

- Clump N, EW$_0$(Hα) > 2000 Å, dominated by a young SF burst (<5Myrs)
- Clump S, EW$_0$(Hα) ~ 500 Å, SF over a larger period of time (~50 Myr)





Álvarez-Márquez+24

MRS observed optical [OIII]5008 and Hα lines with SNR~10

- Spectrally-resolved (FWHM~160km/s)

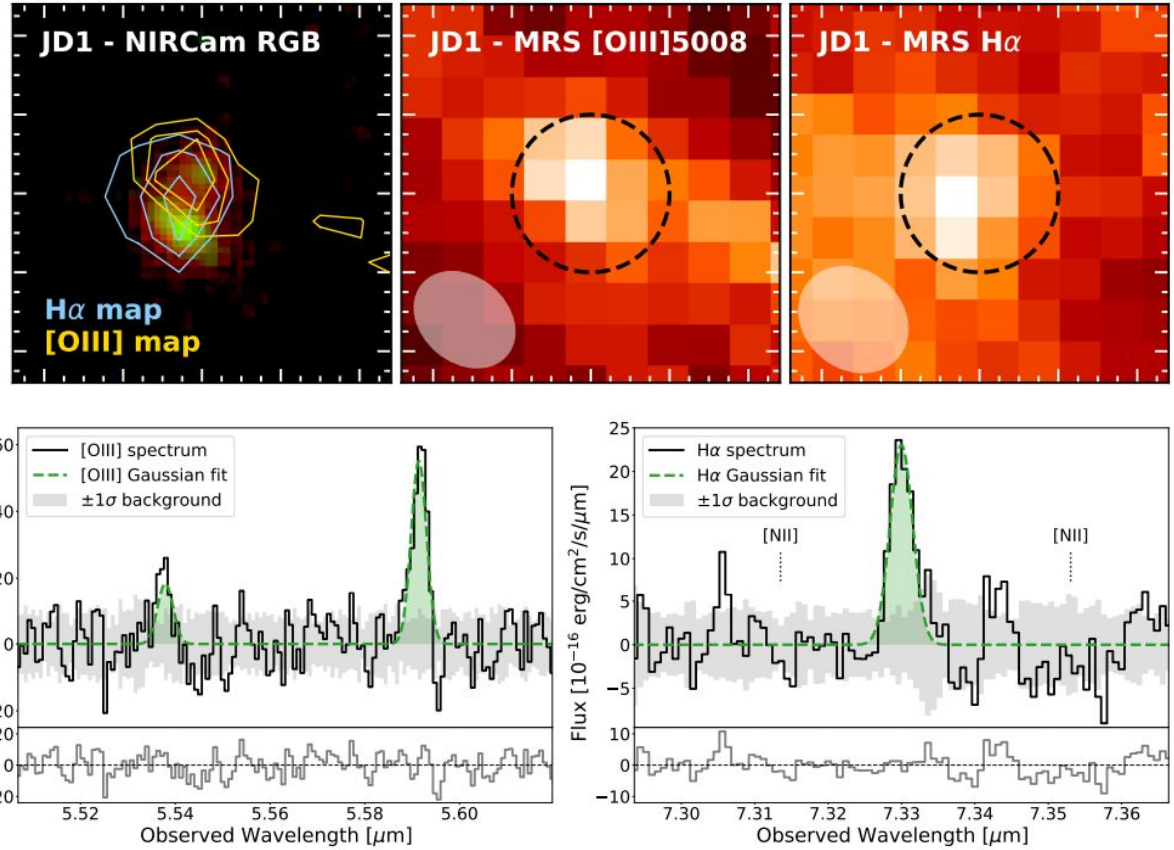
NIRSpec have detected faint UV/optical emission lines

Most distant galaxy with a direct metallicity calculation

- NIRSpec + MRS
- Metallicity of 0.1$Z_{\odot}$
- Mass-metallicity relation

High resolution NIRSpec separate [OII] doublet

- High densities (~1000cm^{-3})



Hsiao, Álvarez-Márquez+24; Abdurro'f+24

MIRI view of primordial galaxies: MACS0647-JD (z~10.2)

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- Spectrally-resolved (FWHM~160km/s)

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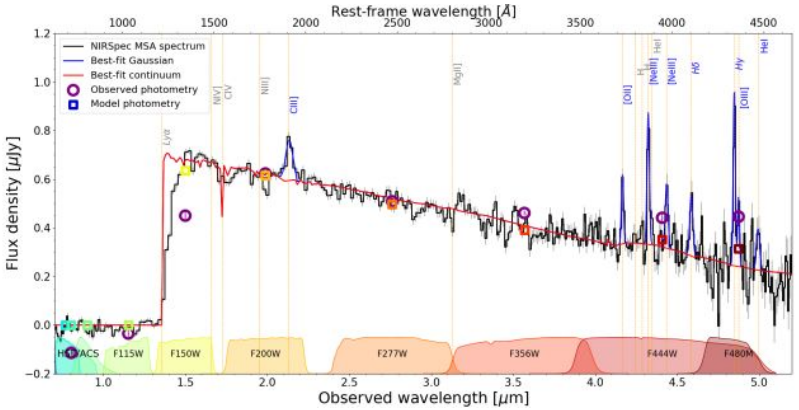
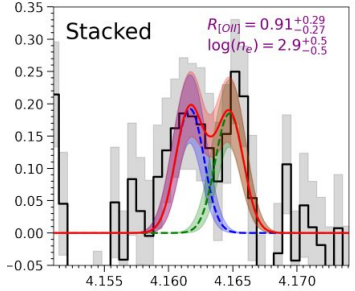
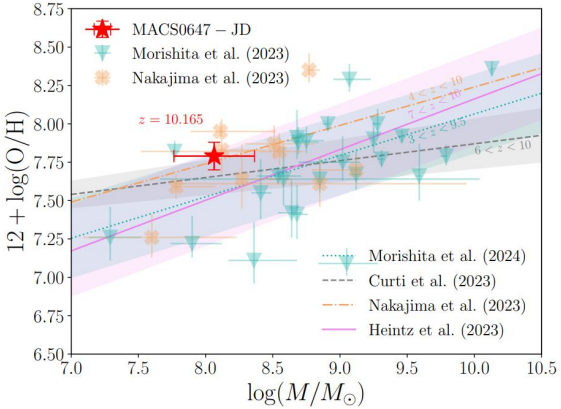
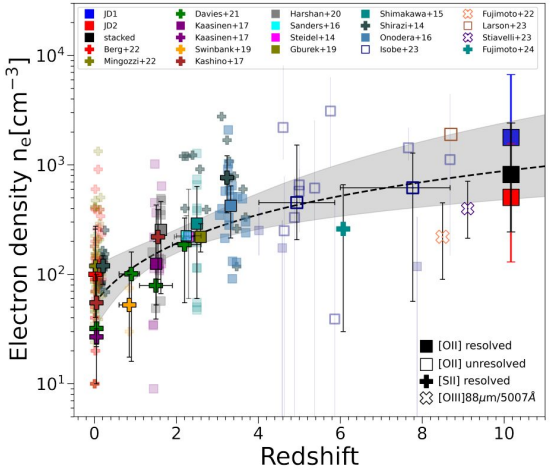








Hsiao, Álvarez-Márquez+24; Abdurro'f+24

MIRI/LRS observations of GHZ2 at z=12.3

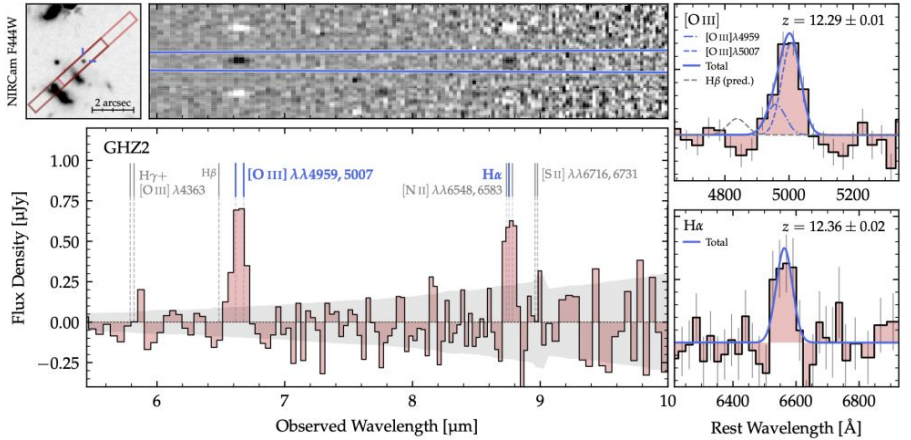
Most distant galaxy with direct detection of [OIII] and Hα

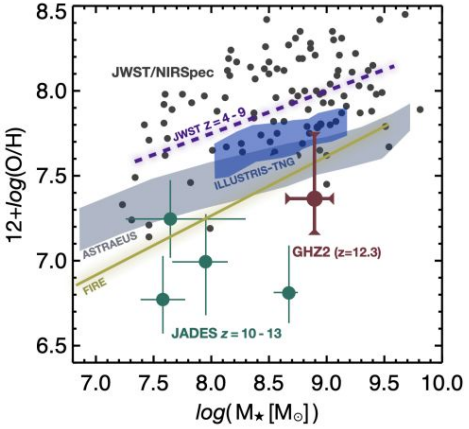
Metallicity estimation from a non-direct method

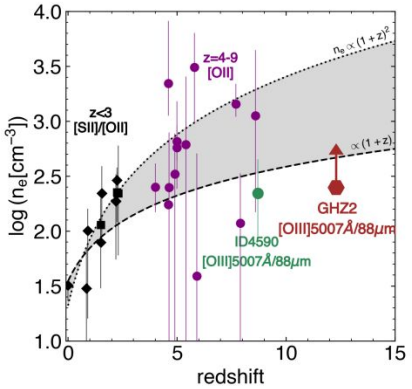
High electron densities

Non-spectrally resolved due to the low resolution of the LRS

- Needs MRS observations for higher SNR and access to kinematics







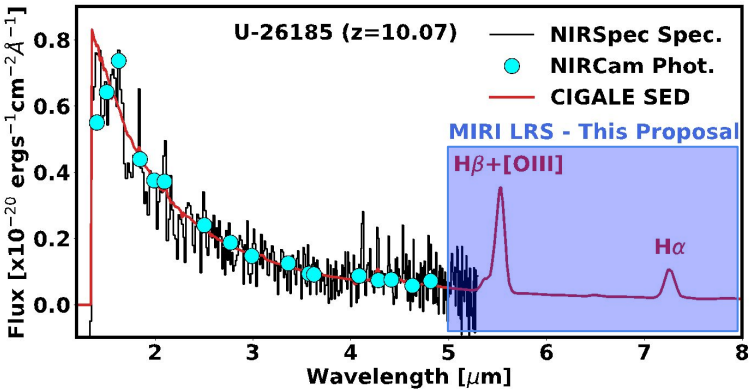
Zavalla+24

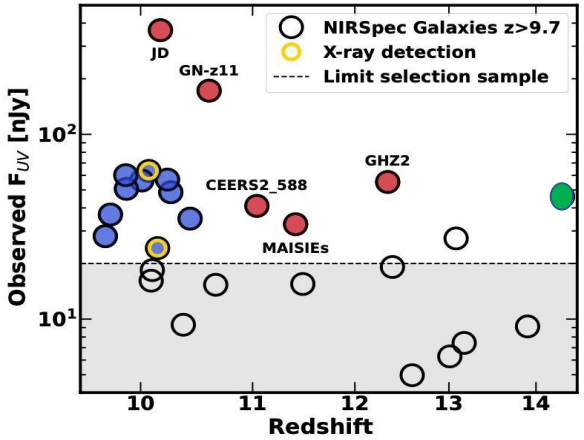
PRISMS. PRImordial galaxy Survey with MIRI-LRS Spectroscopy at z~10

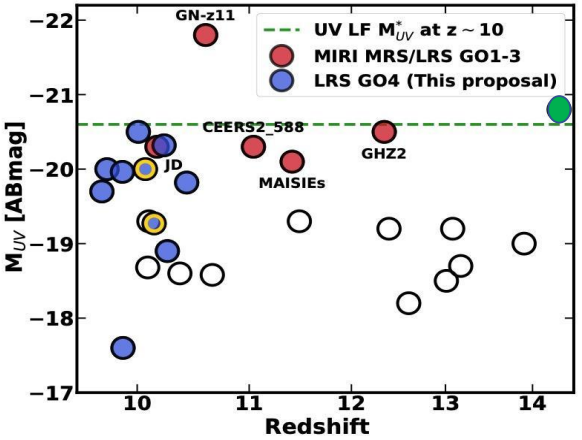
JWST Cycle 4 program:

- PIs: J. Álvarez-Márquez & L. Colina
- Total of 129 hours
- Observed between 2025 to 2026
- MIRI low resolution spectroscopy
- Survey of 10 galaxies at z~10
- Detection of Hβ+[OIII] & Hα

First statistical study of the ISM properties (SFR, dust, metallicity, ionization, …) of galaxies 500 Myr after the Big Bang.

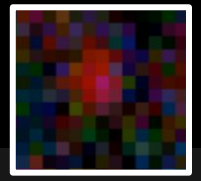


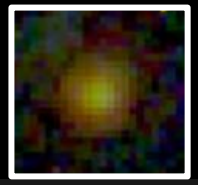


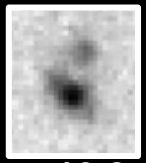


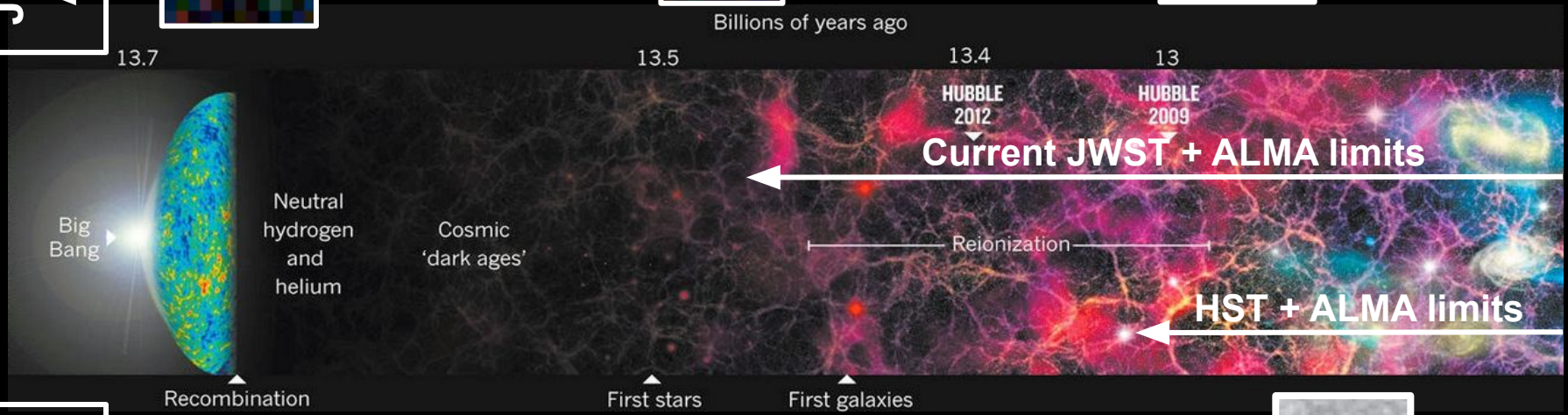
JWST & Early Universe: Redshift frontier

JWST & ALMA









HST & ALMA