New insights on the first generation of galaxies from the *James Webb* Space Telescope

Nicolas Laporte

23 May 2024 – SEGI seminar

Outline

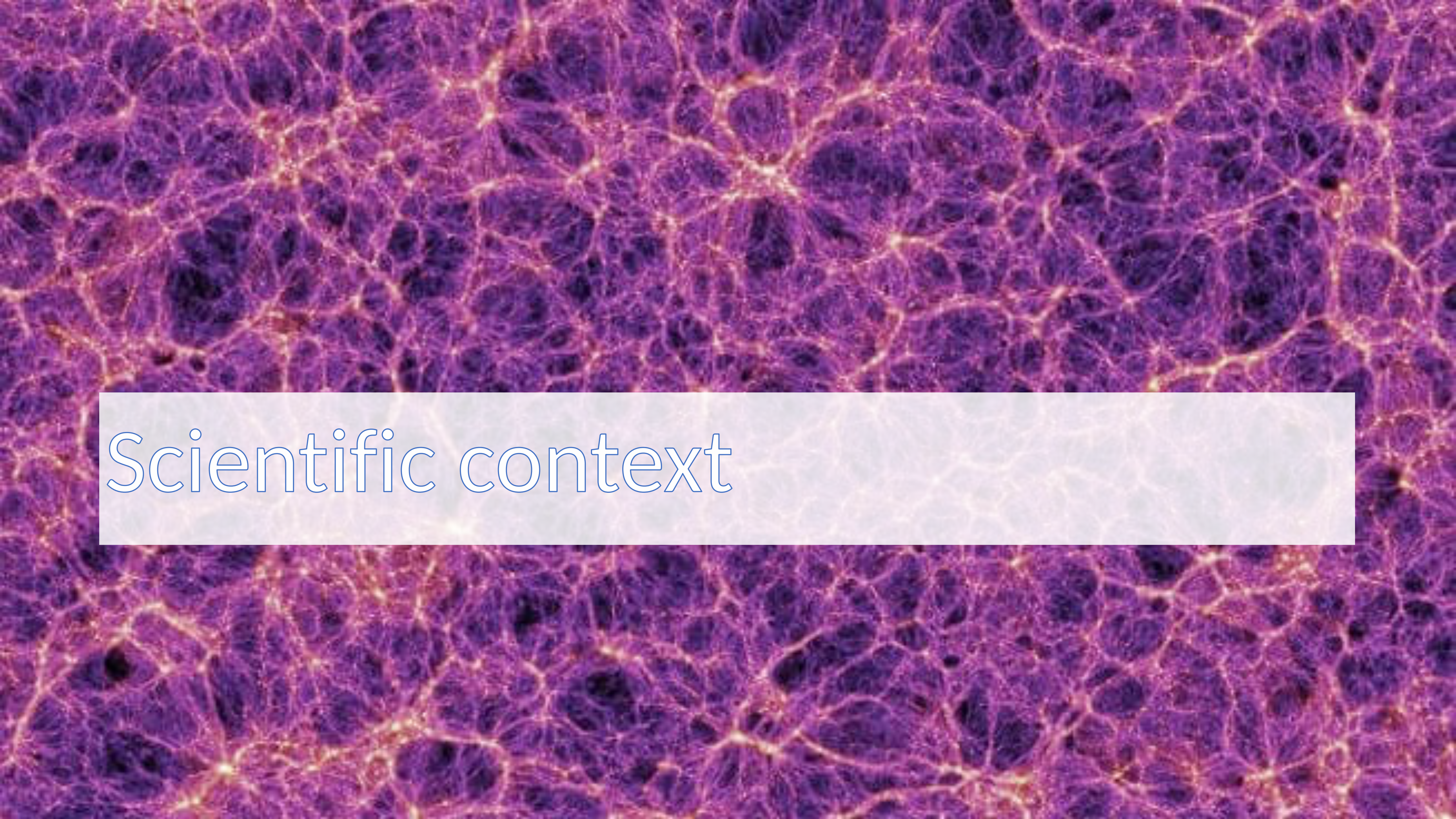
- Scientific context
  - The first Gyr of the Universe
  - The properties of the first galaxies

- The quest for **Cosmic Dawn**
  - Results from *Hubble* and ALMA
  - The James Webb Space Telescope
  - Latest results from JWST

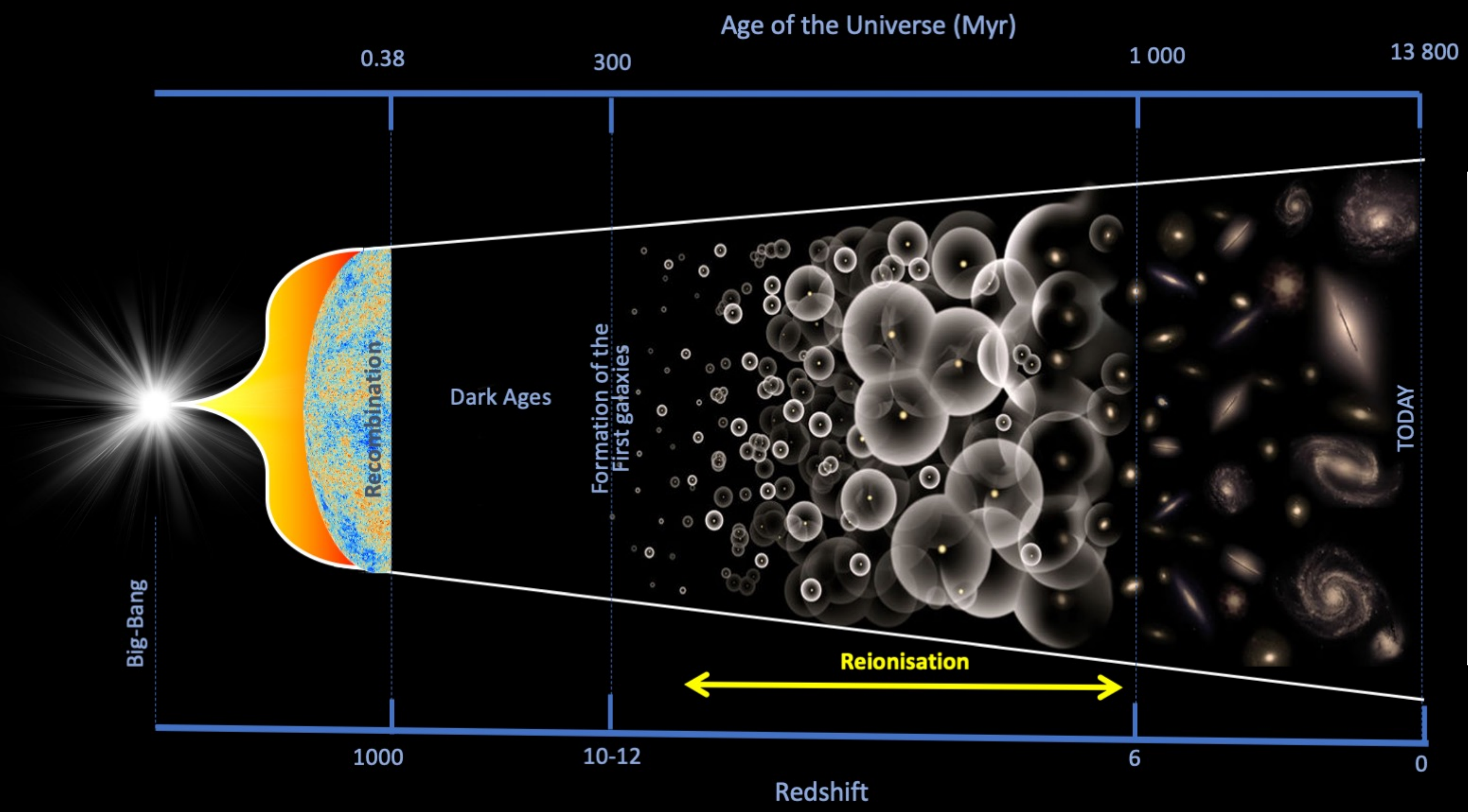
- The first AGN and stars
  - The most distant AGNs
  - First detection of pop.III stars ?

Hubble Ultra Deep Field
Ellis et al. (2012)

Scientific context



The history of our Universe



REDSHIFT vs AGE OF THE UNIVERSE

- z=1100 : t=380,000 yrs
- z=15 : t=300 Myrs
- z=10 : t=500 Myrs
- z=7 : t=800 Myrs
- z=6 : t=1 Gyr
- z=2 : t=3.3 Gyr
- z=1 : t=6 Gyr
- z=0 : t=13.8 Gyr

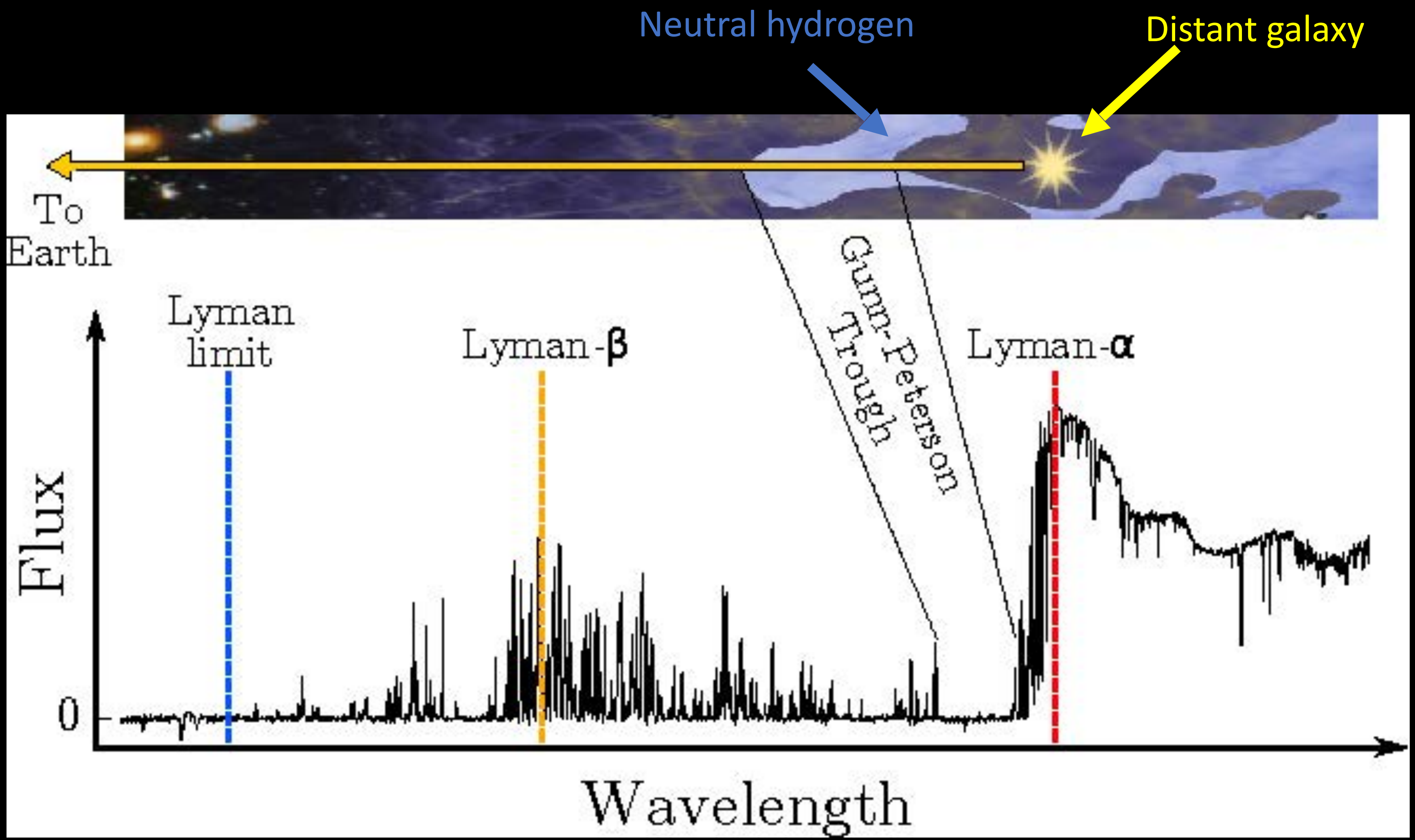
The Epoch of Reionisation

- The **reionisation** is the process during which the neutral hydrogen formed at the recombination epoch is ionised
- The first stars are massive (up to 1000 $M_{\odot}$) with a short lifetime (a few million years) but they emit a large number of UV photons
- Each star/galaxy produces ionised bubbles that eventually merge increasing the transparency of the Universe

Credit: the SPHINX collaboration

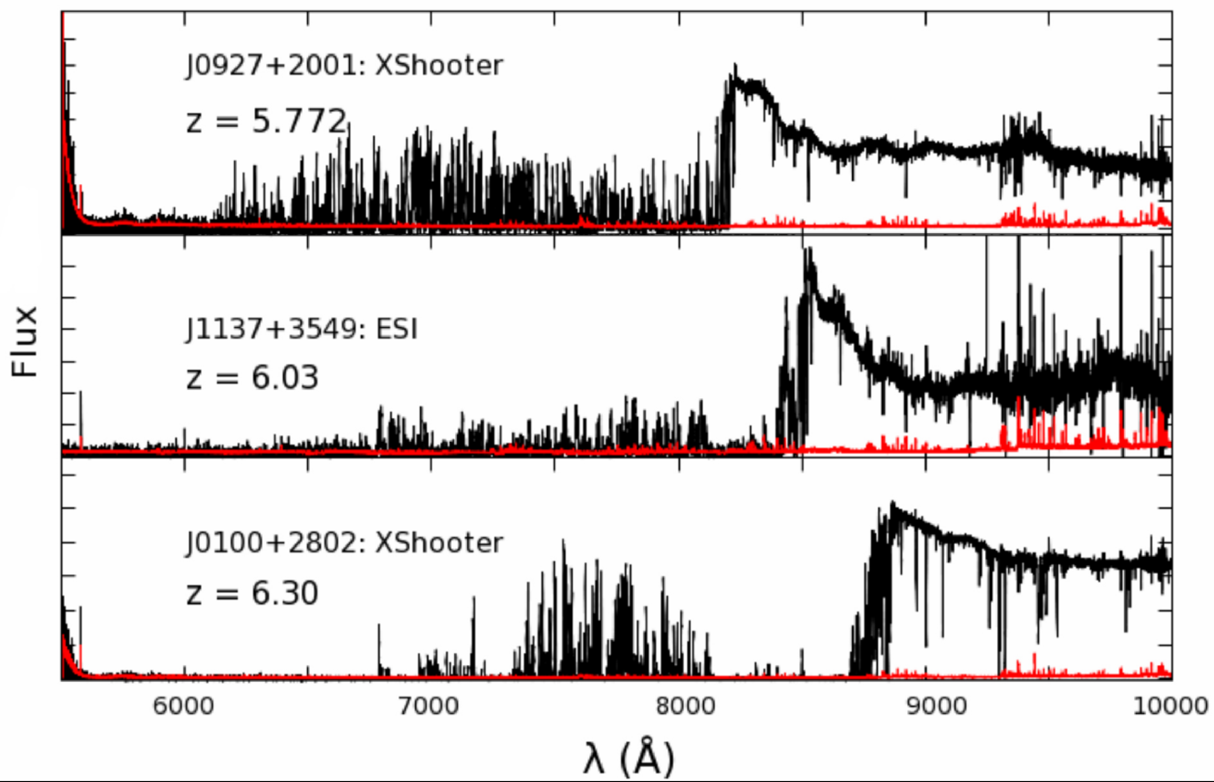
Rosdahl et al. (2022), Katz et al. (2022), Maji et al. (2022)

The Gunn Peterson Trough



- Distant galaxies emit UV lights
- The UV photons ionise the neutral hydrogen in the environment of the galaxy
- If neutral hydrogen remains along the line of sight (*ie. the emission takes place during the EoR*) then an absorption will appear in the spectra of the galaxy

The Epoch of Reionisation : observational probes

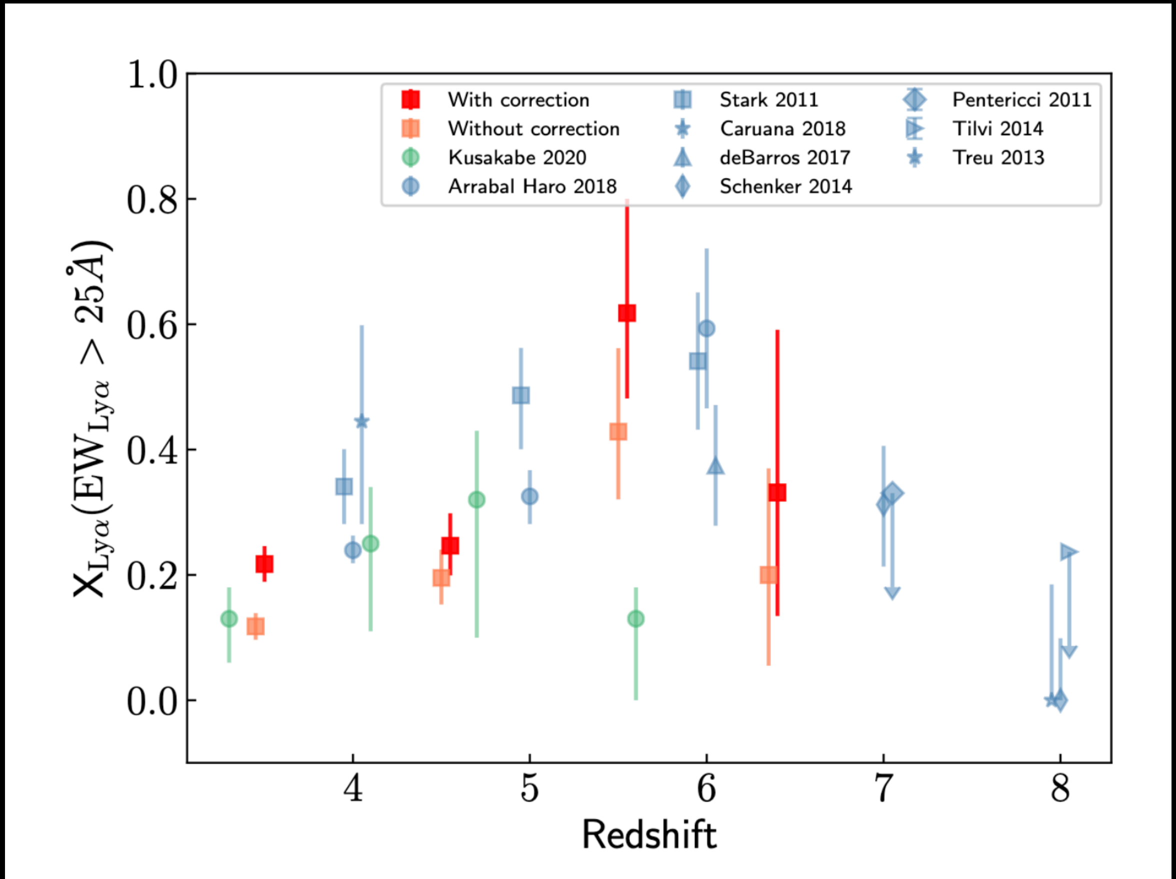


Bosman et al. (2018)

See also Fan et al. (2006)

- Neutral Hydrogen clouds along the line of sight absorb radiation below the Lyman-alpha limit : this is **the Gunn Peterson effect.**
- To be detected, it requires very high signal-to-noise ratio.
- Therefore, this technique can only be applied to quasars spectra
- From distant quasars observations, the end of the reionisation epoch is estimated near $z \sim 6$

The Epoch of Reionisation : observational probes

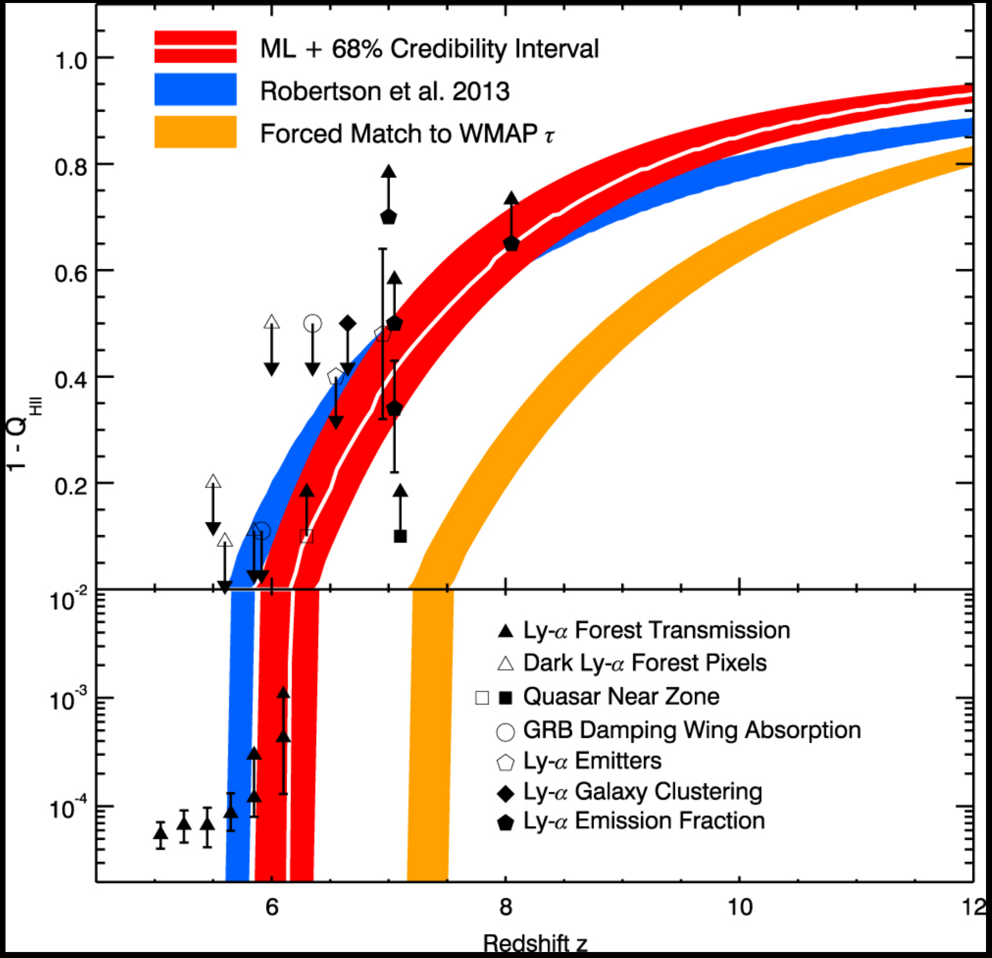


De la Vieuville et al. (2020)

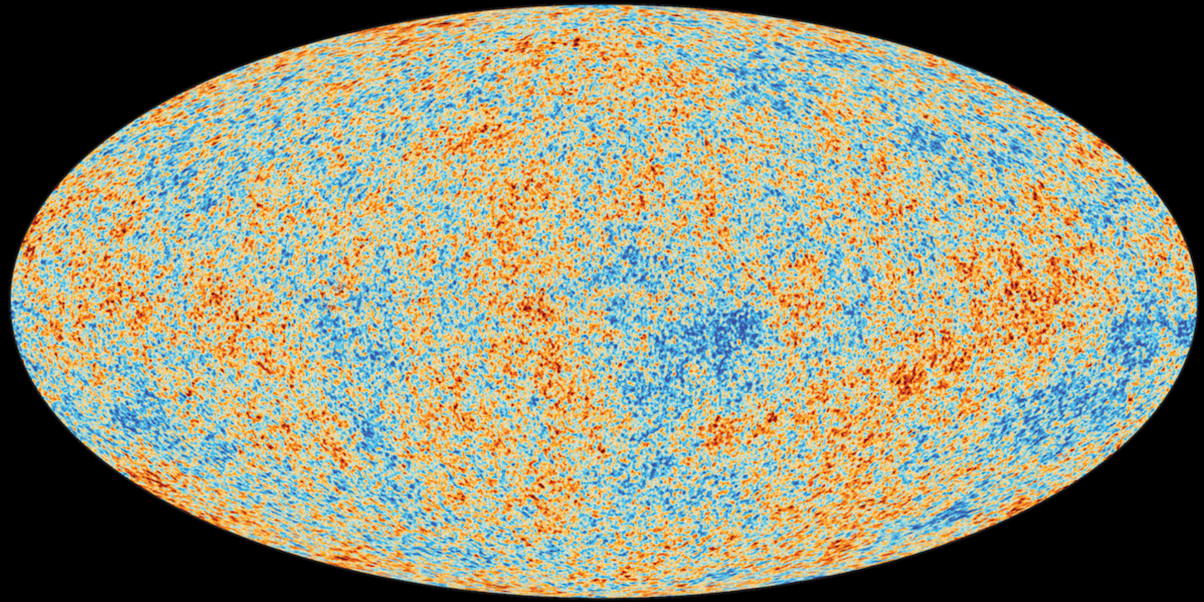
See also Stark et al. (2017), de Barros et al. (2019)

- The brightest UV rest-frame emission line expected in star-forming galaxies is Ly-α
- However, if Ly-α is emitted by a galaxy surrounded by neutral hydrogen, it will be absorbed
- Deep spectroscopic surveys show a strong decrease in the detectability of Ly-α at z>6

The Epoch of Reionisation : observational probes

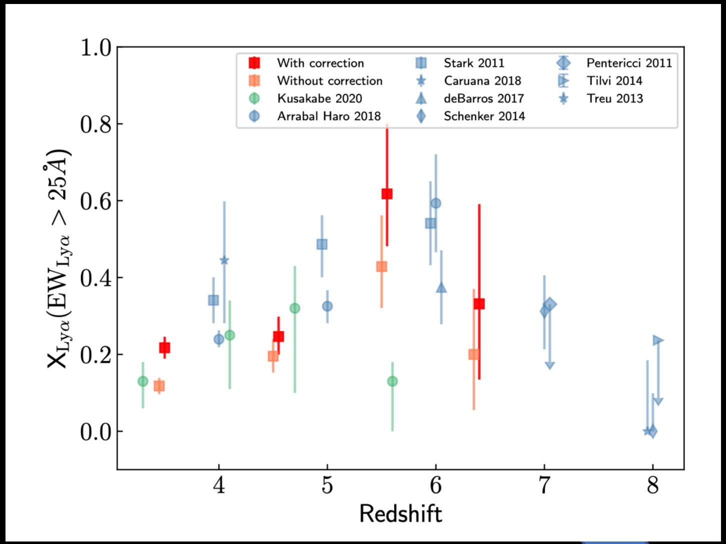


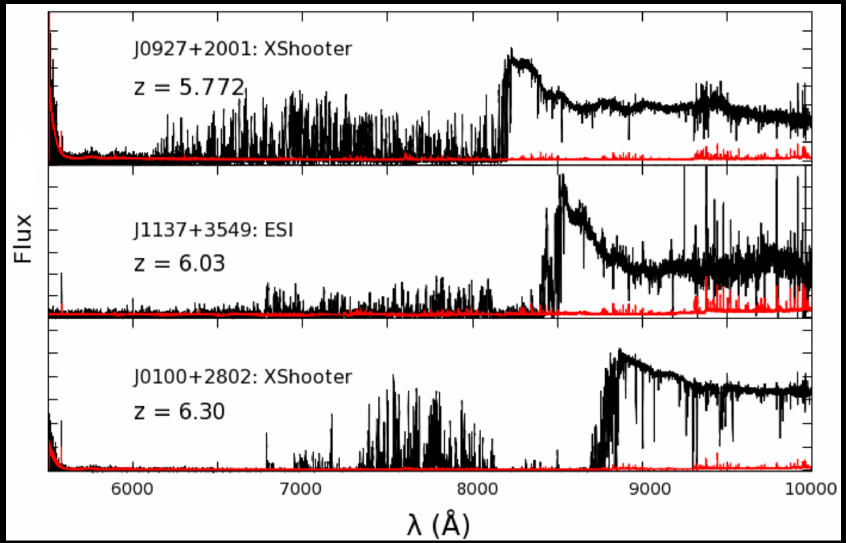
Robertson et al. (2015)

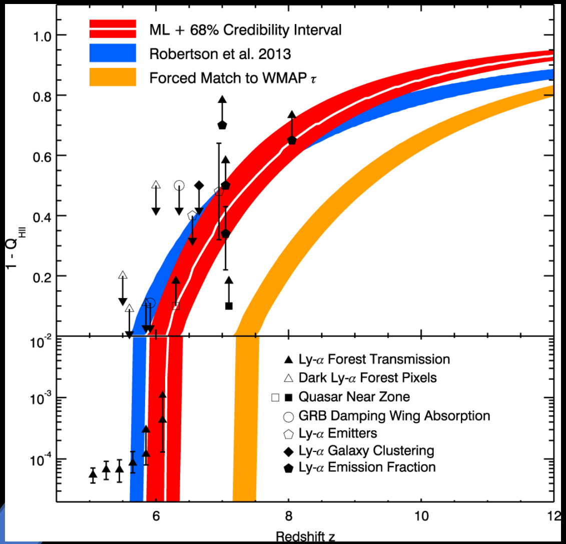


- The reionisation of the neutral hydrogen produces free electrons that interact with Cosmic Microwave Background (CMB) photons and induce polarization
- Measuring the Thomson optical depth from the CMB gives an estimate of the evolution of the neutral fraction over cosmic time
- *Planck* observations show that the neutral fraction of the hydrogen is negligible at z<6

The Epoch of Reionisation : observational evidences

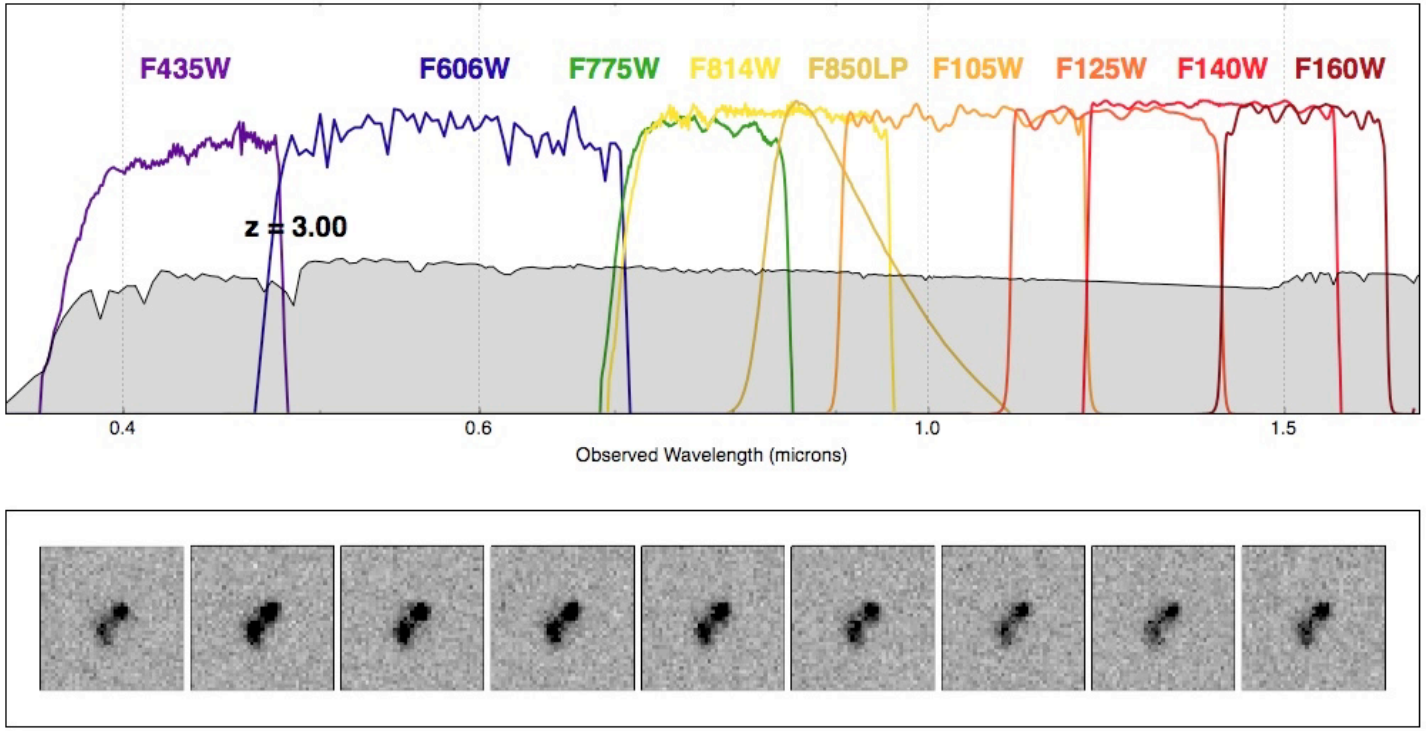




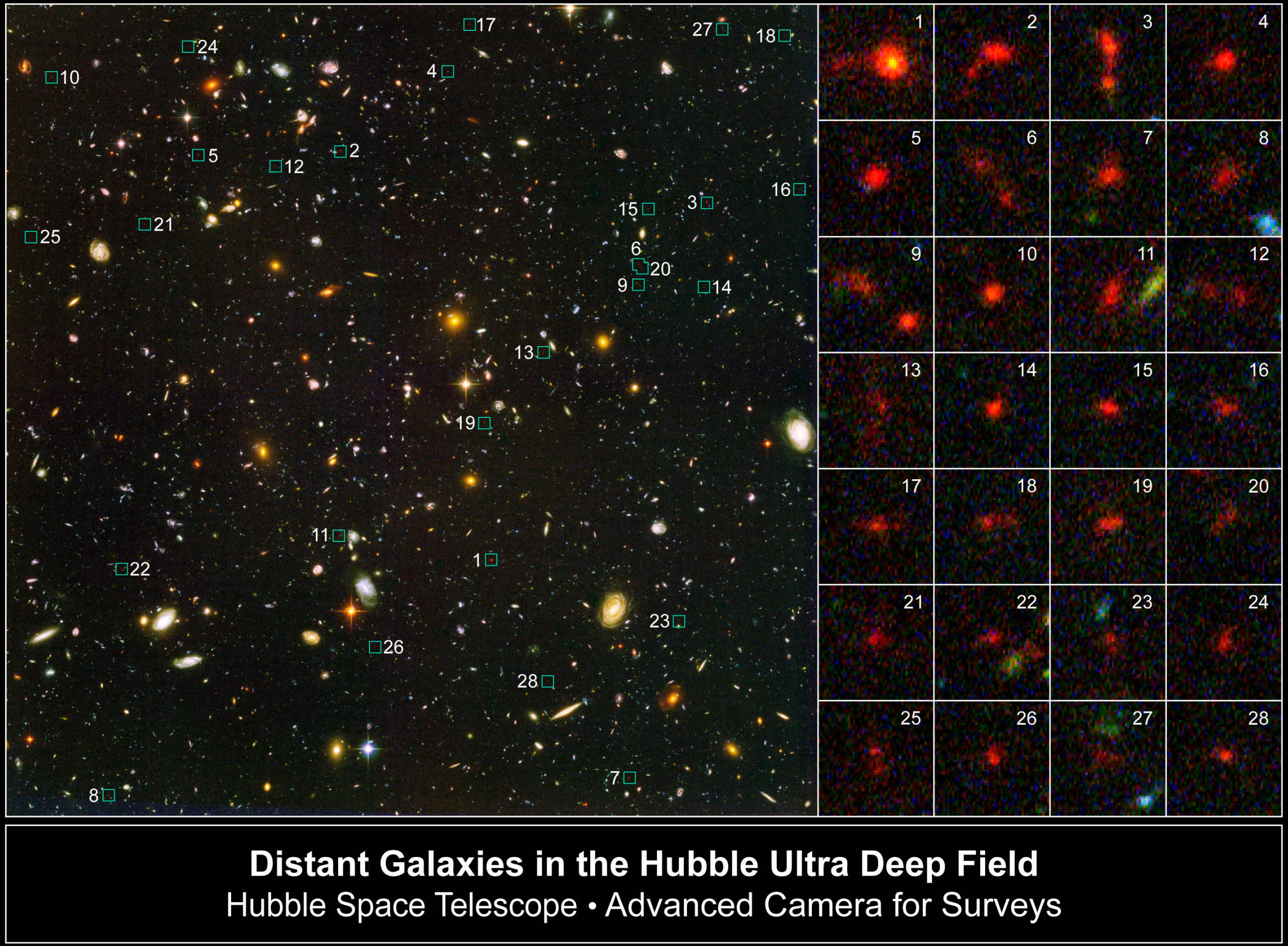


By z=6, the first population of galaxies has produced enough UV photons to ionise the neutral hydrogen formed at the recombination epoch.

The Lyman Break technique
to identify the most distant galaxies

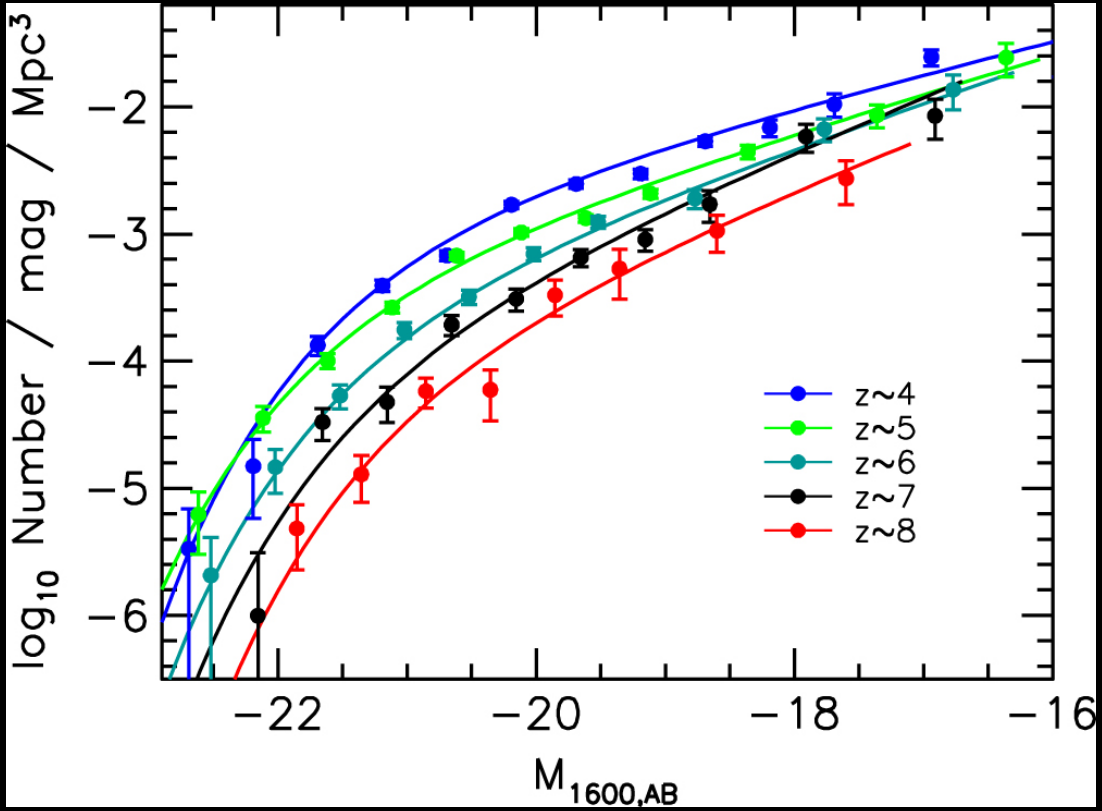


The deepest survey *of the Hubble Space Telescope*



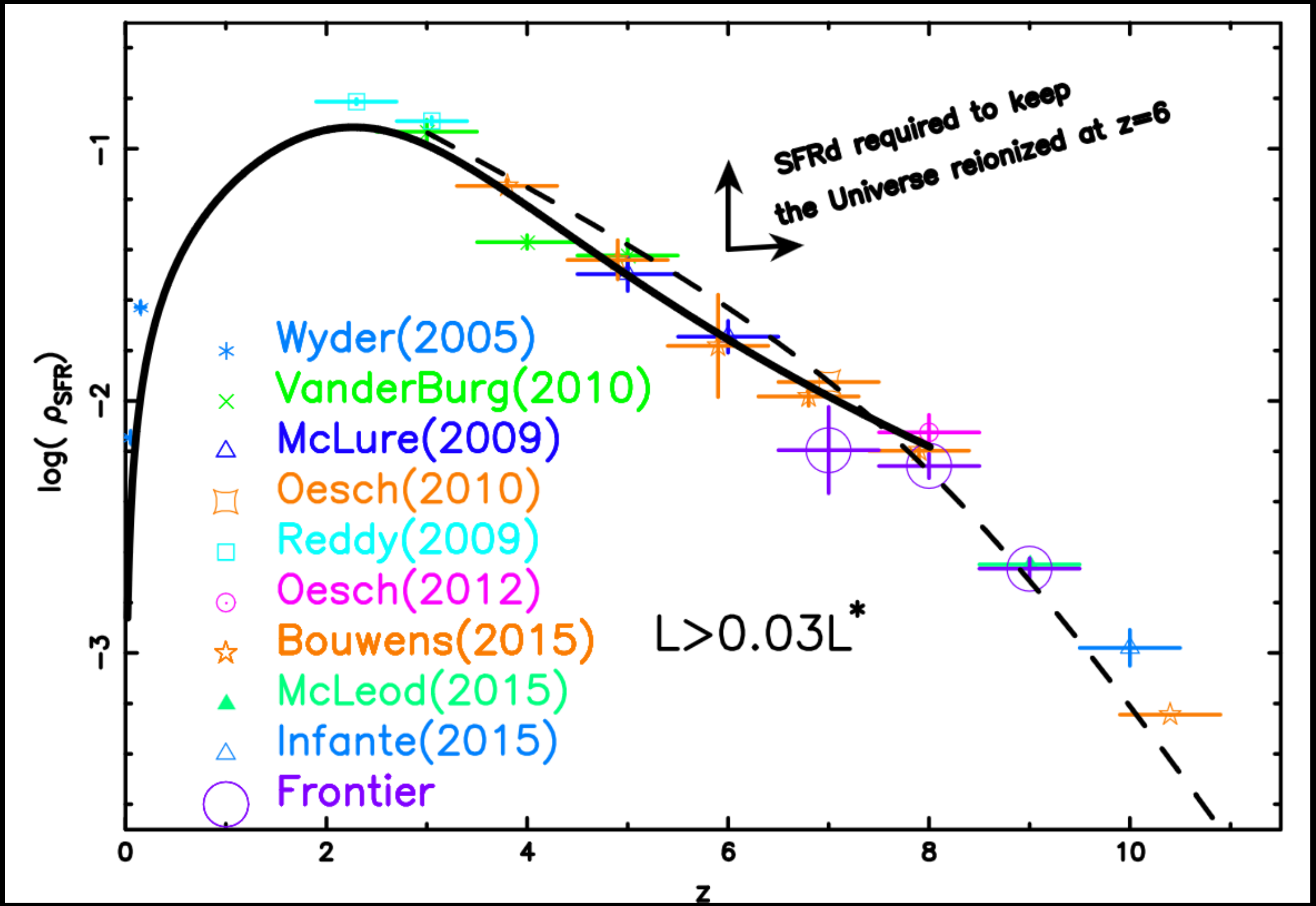
NASA, ESA, R. Bouwens and G. Illingworth (University of California, Santa Cruz)

STScI-PRC06-12



Bouwens et al. (2015)

The UV photons production *by the most distant galaxies*



Laporte et al. (2016)

- Within the last decade, deep surveys (eg, CANDELS, Frontier Fields, WUDS, UltraVISTA) have discovered 1000s of galaxies at z>6 (Bouwens et al. 2015)
- Assuming that z>6 galaxies have similar properties as low-redshift galaxies, we cannot explain the end of the epoch of reionisation at z=6.

The Epoch of Reionisation : open questions

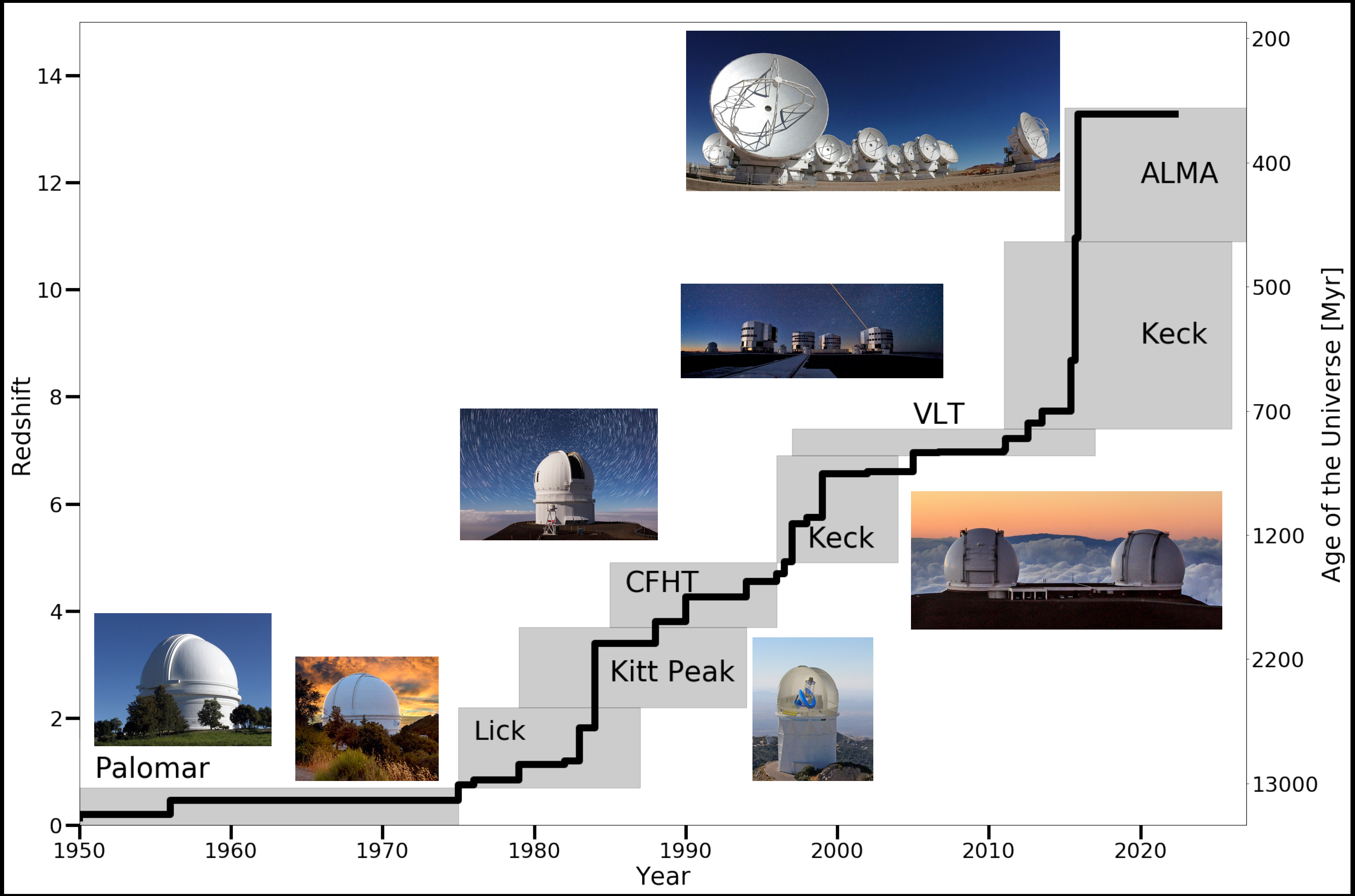
- **When did the first galaxies form ?**
- **How did they form ?**
- **What are the physical properties of the first galaxies ?**
- **When did the first black holes form ?**
- **How did the first galaxies and black holes evolve over the first billion years ?**

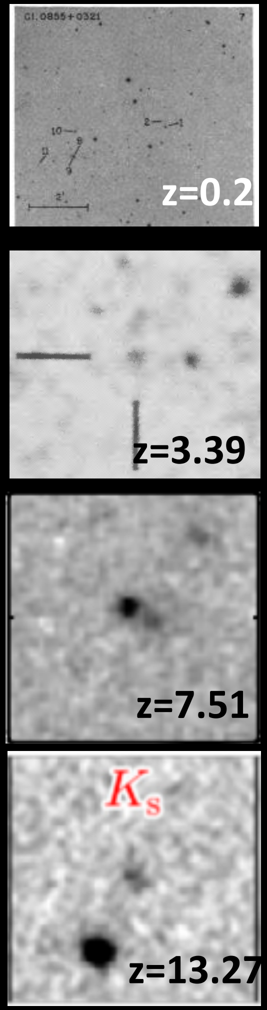
CANDELS/UDS – Grogin et al. (2011)

See also McCracken et al. (2012) Lotz et al. (2017), Pelló et al. (2018)

The quest for Cosmic Dawn

The "hunt" for the most distant galaxies
between 1950s and 2022





Humason et al. 1956
Minkowski 1960
Spinrad et al. 1975
Spinrad & Smith 1976
Smith et al. 1979
Spinrad 1982
Spinrad & Djorgovsky 1984
Lilly 1988
Chambers et al. 1990
Lacy et al. 1994
Petitjean et al. 1996
Franz et al. 1997
Day et al. 1998
Hu et al. 1999, 2002
Pelló et al. 2004
Iye et al. 2006
Fontana et al. 2010
Vanzella et al. 2011
Ono et al. 2012
Shibuya et al. 2012
Finkelstein et al. 2013
Oesch et al 2014
Zitrin et al. 2015
Oesch et al. 2016

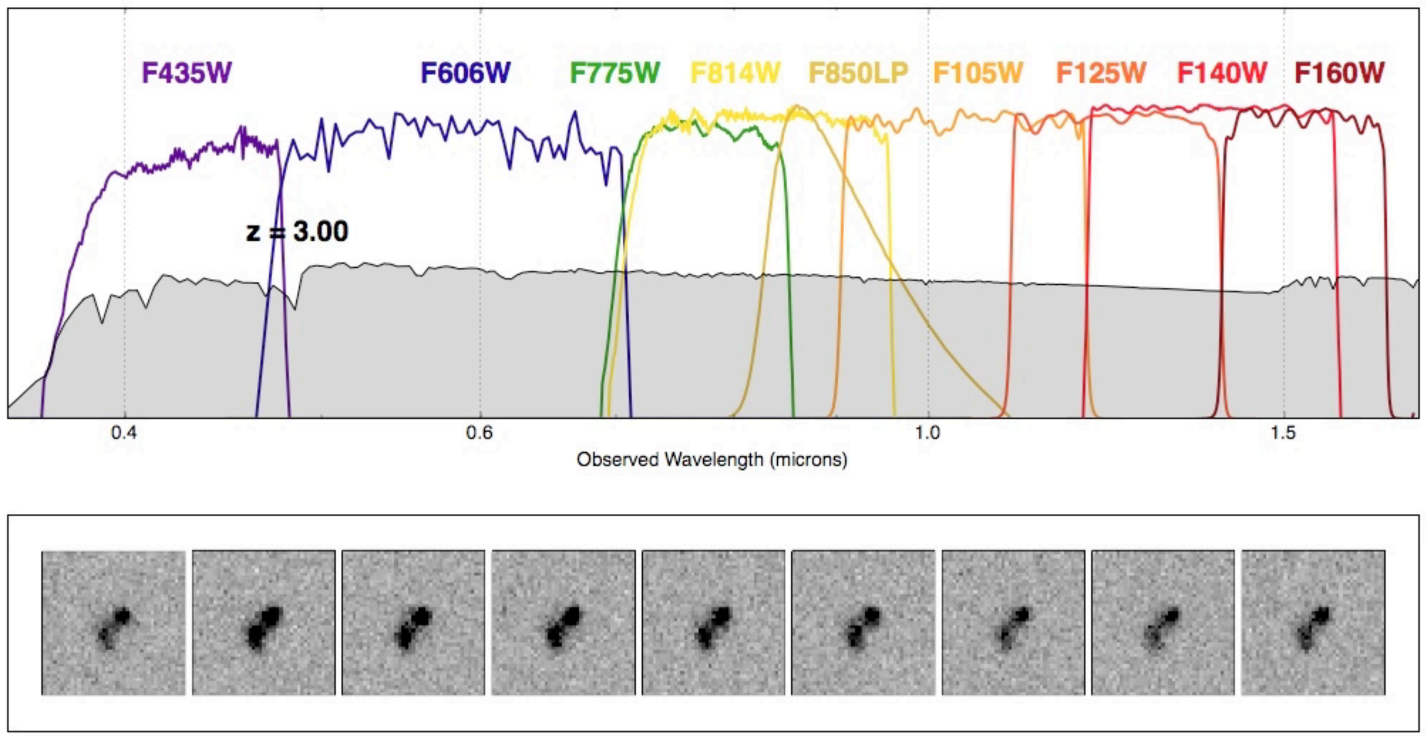
When did the first galaxies form in the early Universe ?

1. **Direct probe** : *Search for galaxies at z>12*
   - How far can we go in redshift and still observe galaxies ?

2. **Indirect probe** : *Determine the age of the most distant galaxies*
   - What parameters can we used to determine their age ?
   - Can we measure the age of all galaxies at very high-z ?
   - Are there any examples of ”old” z>8 galaxies ?

Direct probe of "Cosmic Dawn"

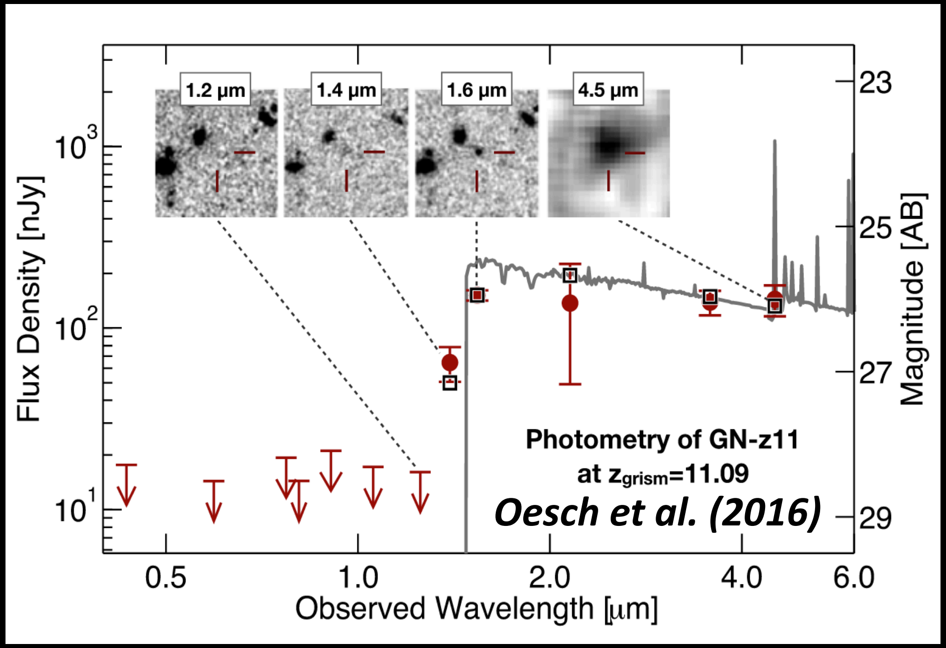
the highest redshift galaxy



Direct probe of "Cosmic Dawn" the highest redshift galaxy

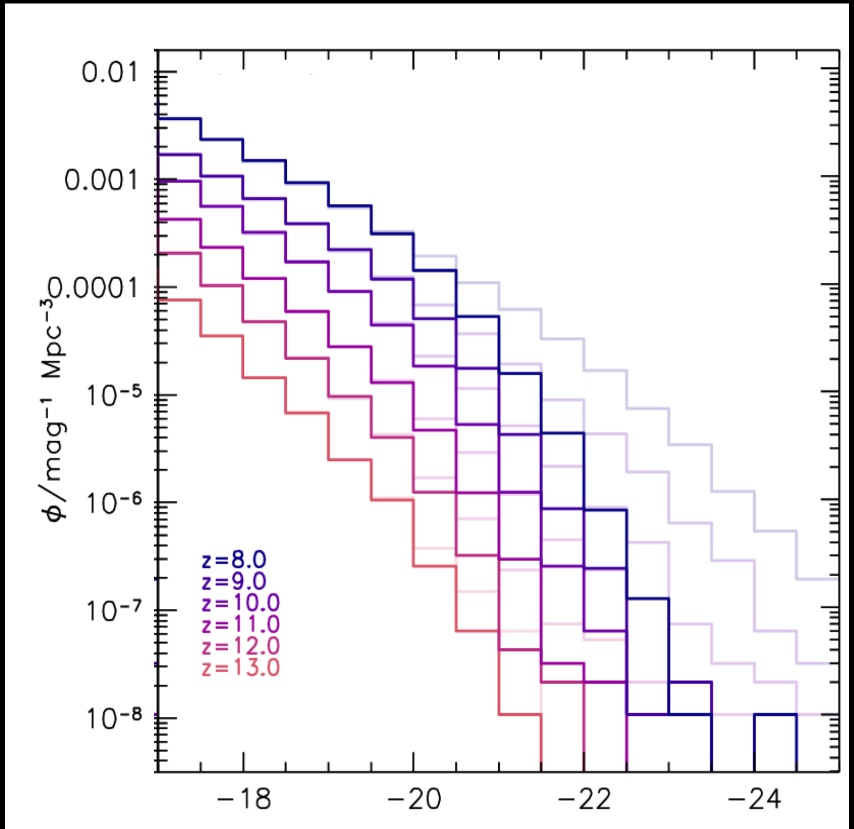
Effective Surface	N(z>11)
HUDF [4.7 arcmin^2 – H=30 AB]	**0.5**
CANDELS [668 arcmin^2 – H=27.5 AB]	**0.5**
UltraVISTA [1.5 degres^2 – H=24.0 AB]	**0.0**

Only ≈1 z≈11 galaxy is expected in the current deepest surveys



We found 1 z≈11 galaxy candidate in the CANDELS survey.

JWST and ELTs are clearly needed to increase the number of z>11 objects



Wilkins et al. (2017)

See also Coe et al. (2013), Salmon et al. (2019), Bowler et al. (2020), Jiang et al. (2020), Harikane et al. (2022)

See also Mason et al. (2015)

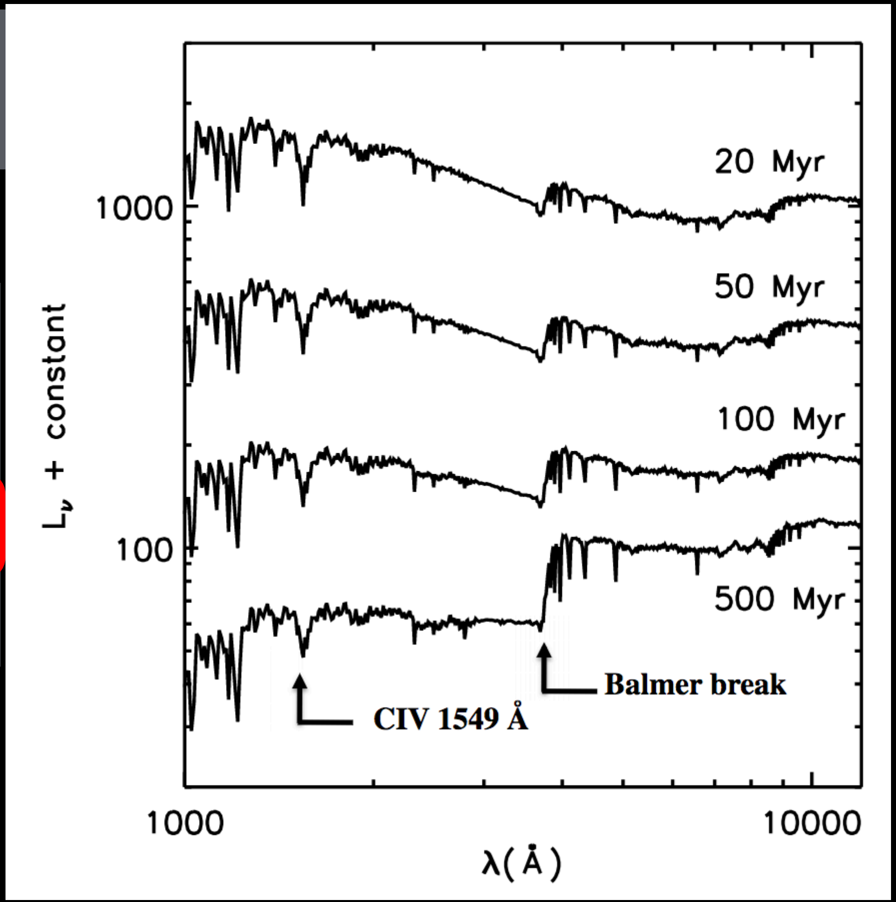

As far as Hubble can observe,
galaxies are seen !

Indirect probe of "Cosmic Dawn"
the age of the most distant galaxies

<u>Definition of the age of a galaxy</u> : period during which a galaxy is forming stars

Two methods can be used to determine the age of a very high-redshift galaxy :

- constraining the size of the Balmer Break
- measuring the dust content

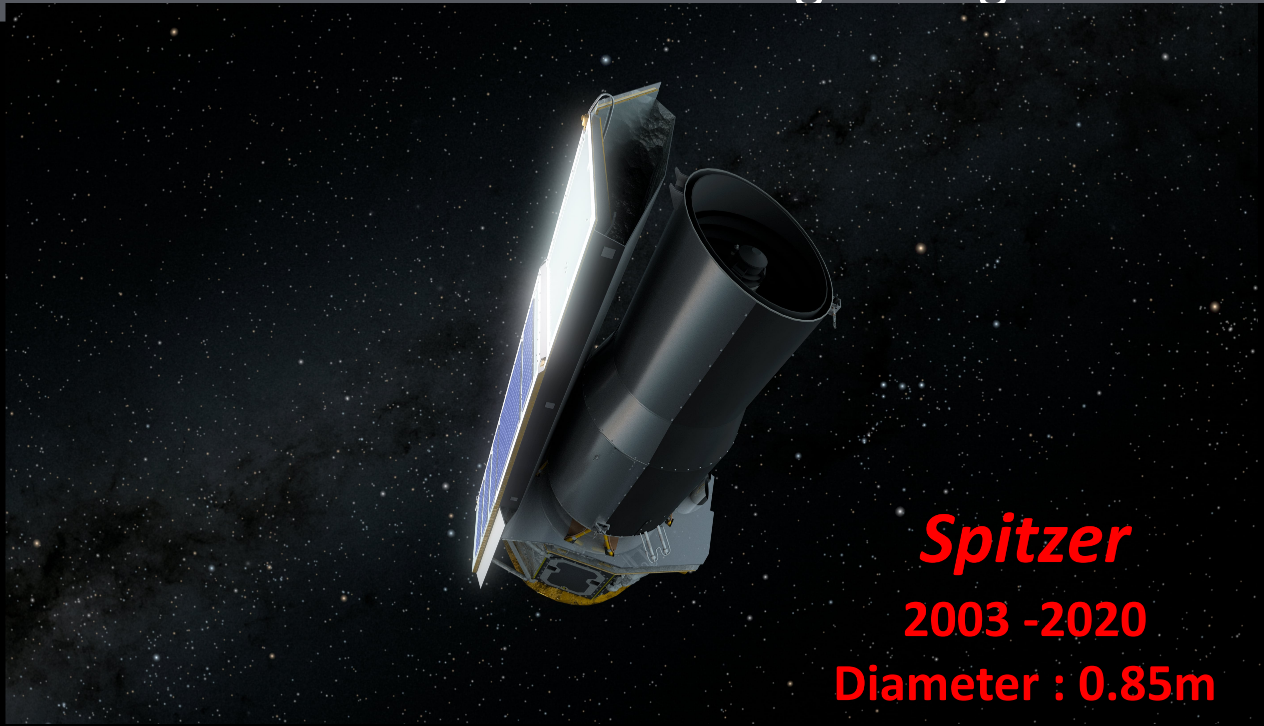


Scoville et al. (2015)

Indirect probe of "Cosmic Dawn"
detecting the Balmer break

- The Balmer break is at $\sim 4000\text{Å}$
- At z>8, it is seen at $(1+z) \times 4000 = 3.6\mu m$

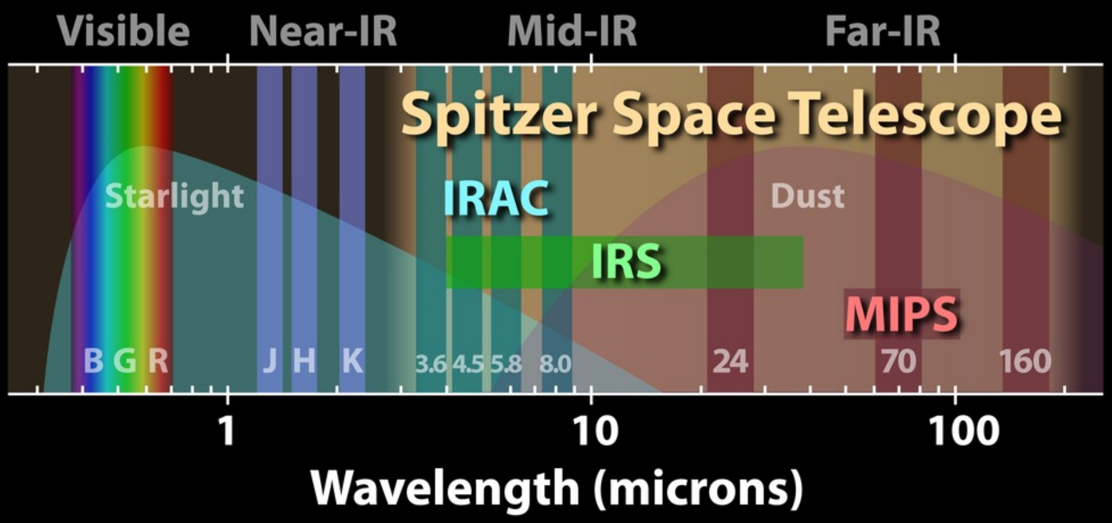
  → well above the wavelength range of *Hubble*



Spitzer

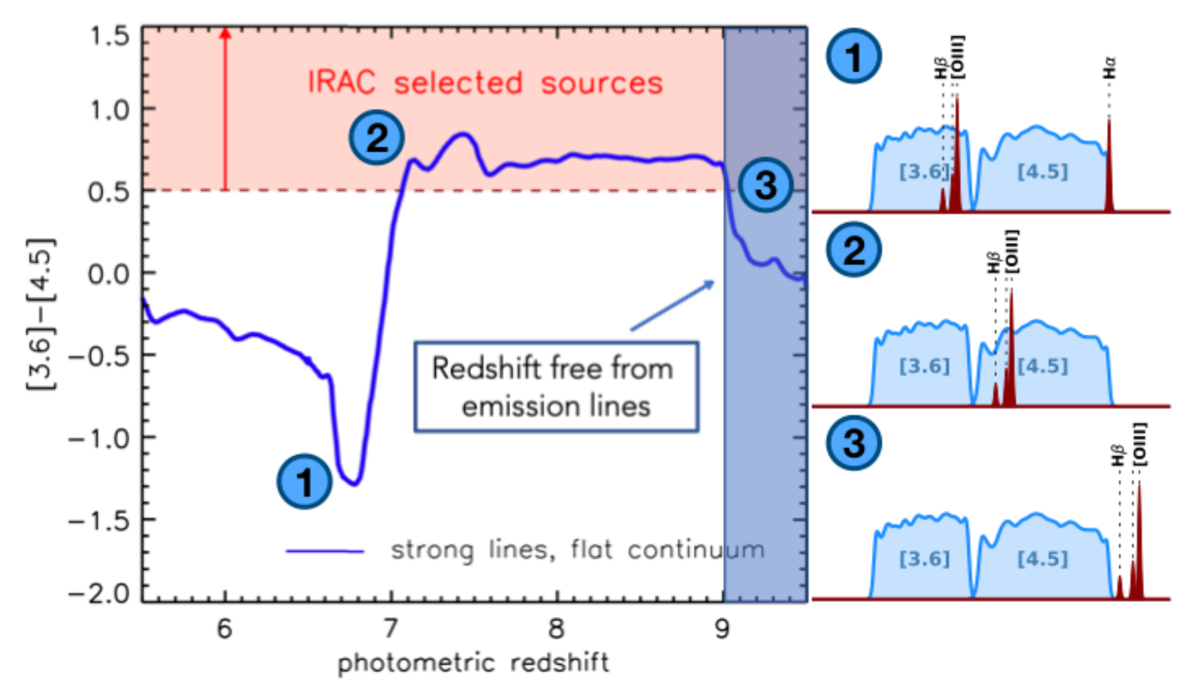
2003 -2020

Diameter : 0.85m

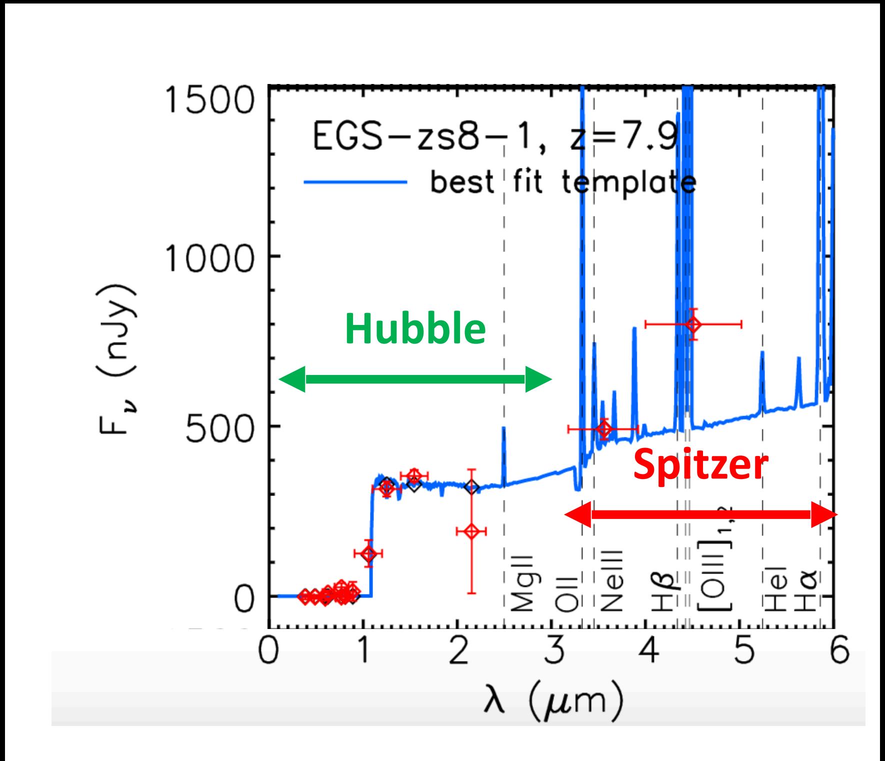


Indirect probe of "Cosmic Dawn" determining the age of the most distant galaxies

However, strong emission lines at z>8 can mimic the Balmer break and lead to a wrong estimate of the age

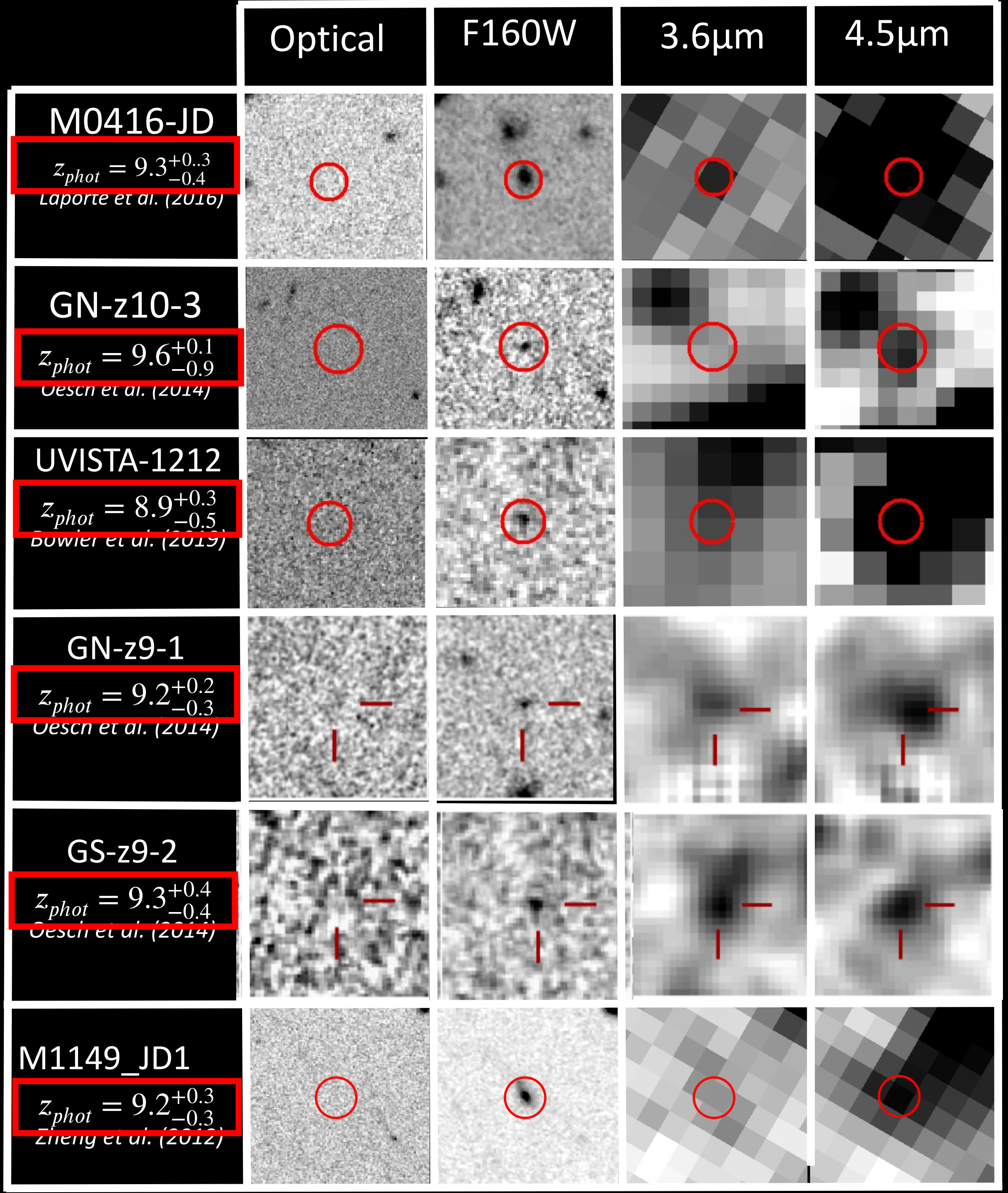


See also : Labbe et al.(2013), Smit et al. (2014)

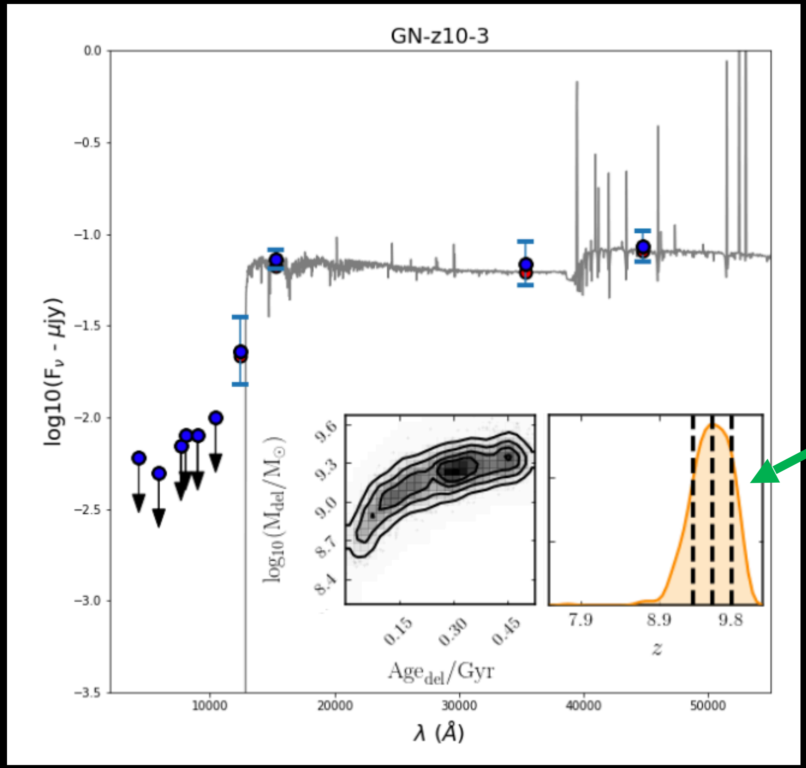


Roberts-Borsani et al. (2016)

The Spitzer bands are free from contamination at z>9



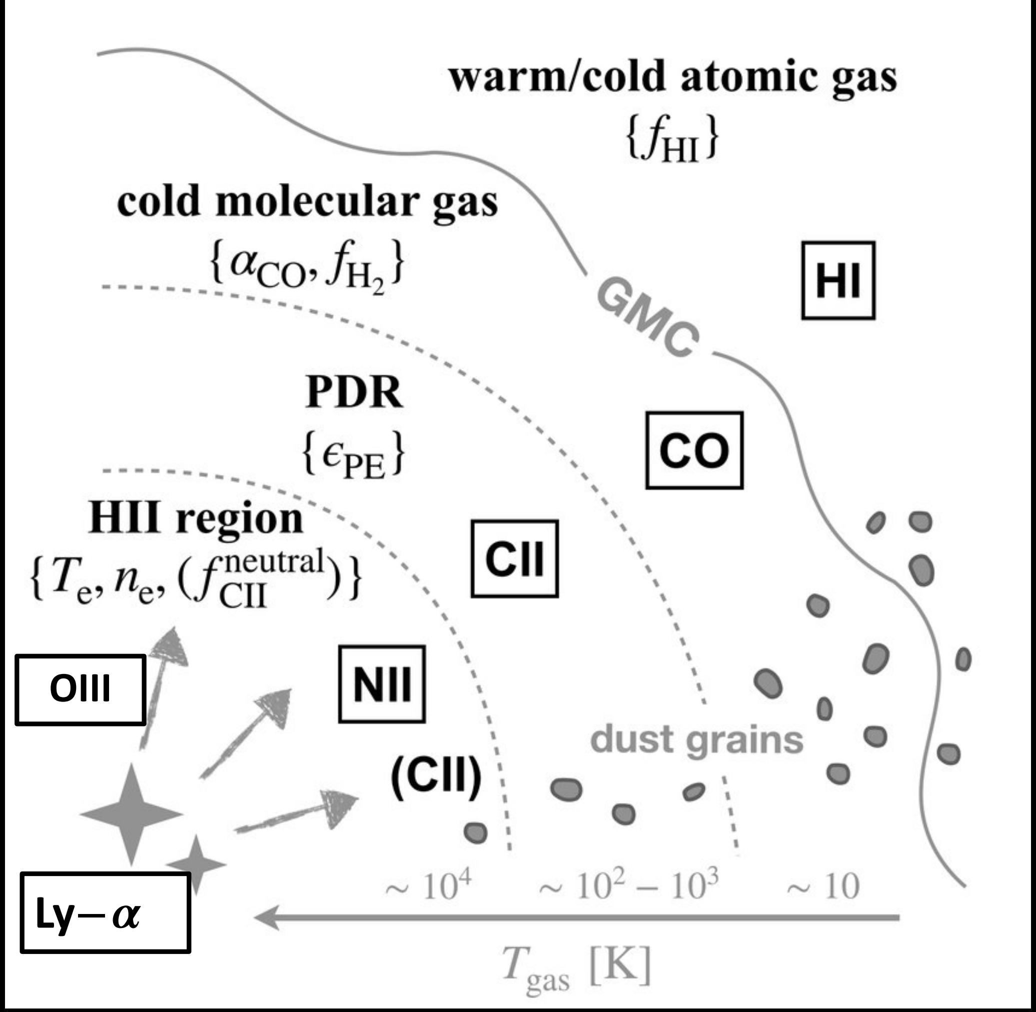
The ***photometric redshift*** is estimated from a fit of the observed photometry with galaxies templates



Error bars on the photometric redshift are usually large

Spectroscopic redshift is needed to confirm that the Balmer Break is clearly detected

The need for optical-IR (rest-frame) spectroscopy



Sun et al. (2019)

The only way to get reliable constraints on the redshift of distant galaxies is by detecting emission lines

The Inter-Stellar Medium (ISM) of galaxies is multi-phases :

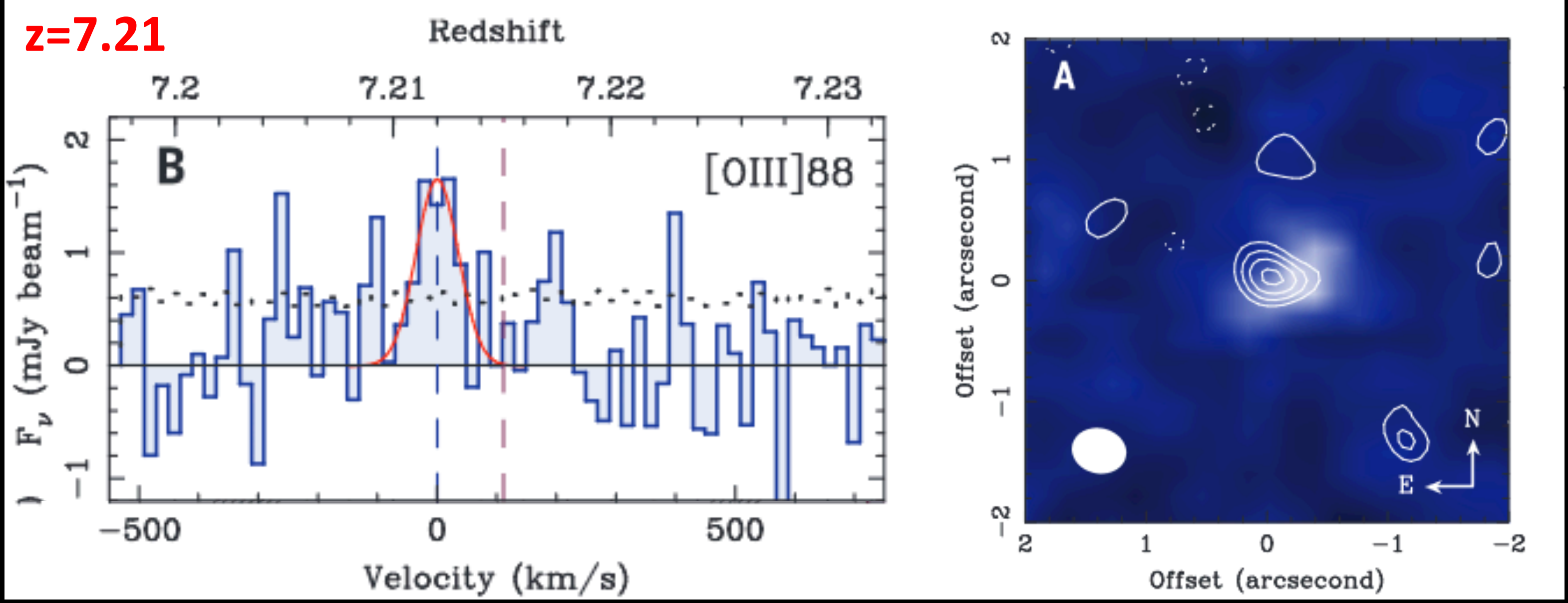
- Ionised (near the stars)
- Neutral
- Molecular

However, Ly-α is a resonant line and is therefore absorbed by the neutral hydrogen surrounding galaxies in the early Universe

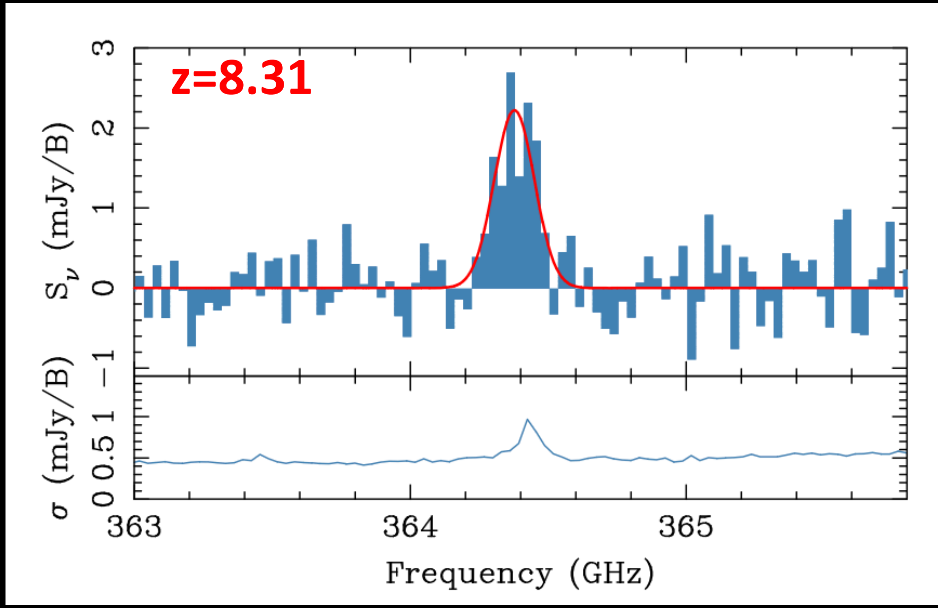
One needs to target optical emission lines to confirm the redshift of distant galaxies

ALMA as a *redshift machine* (before James Webb)

ALMA as a *redshift machine (before James Webb)*



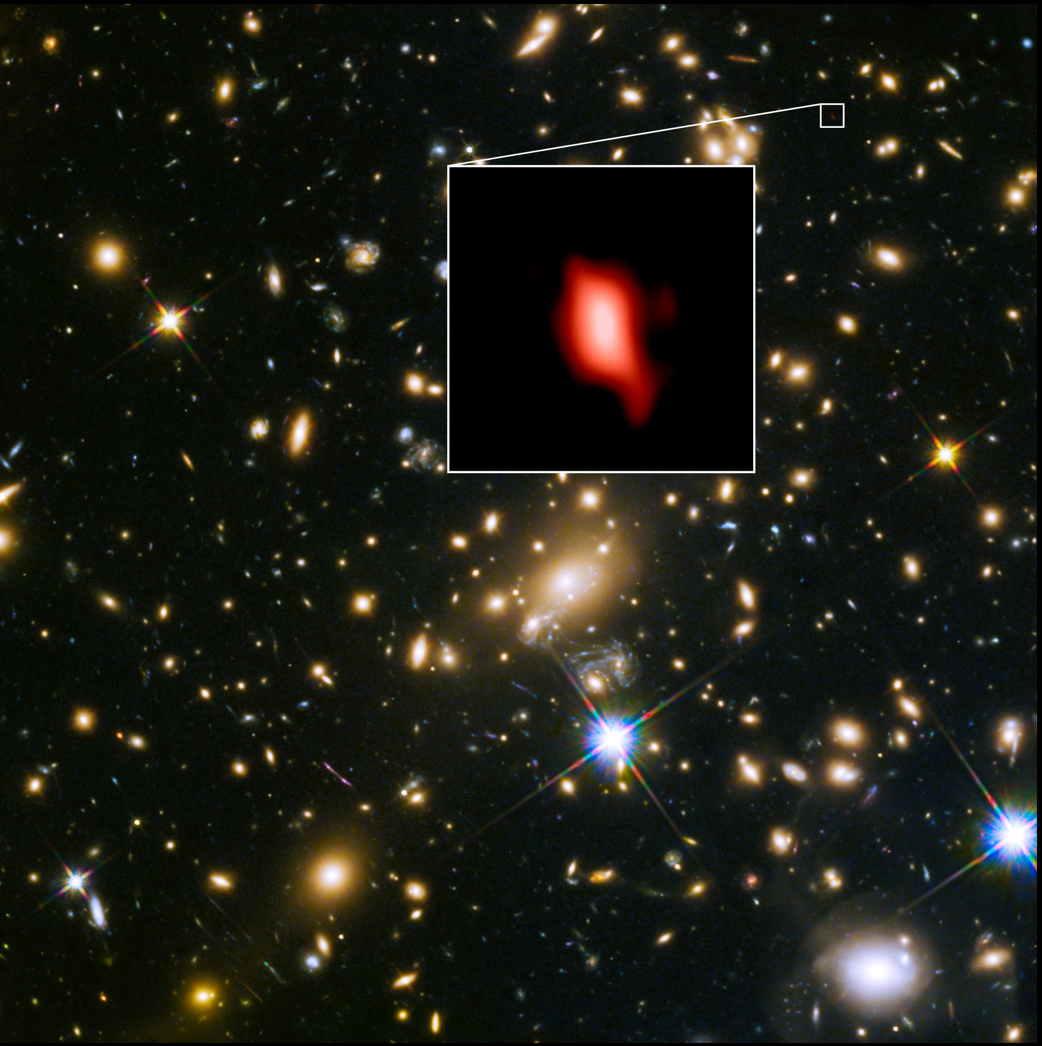
Inoue et al. (2016)



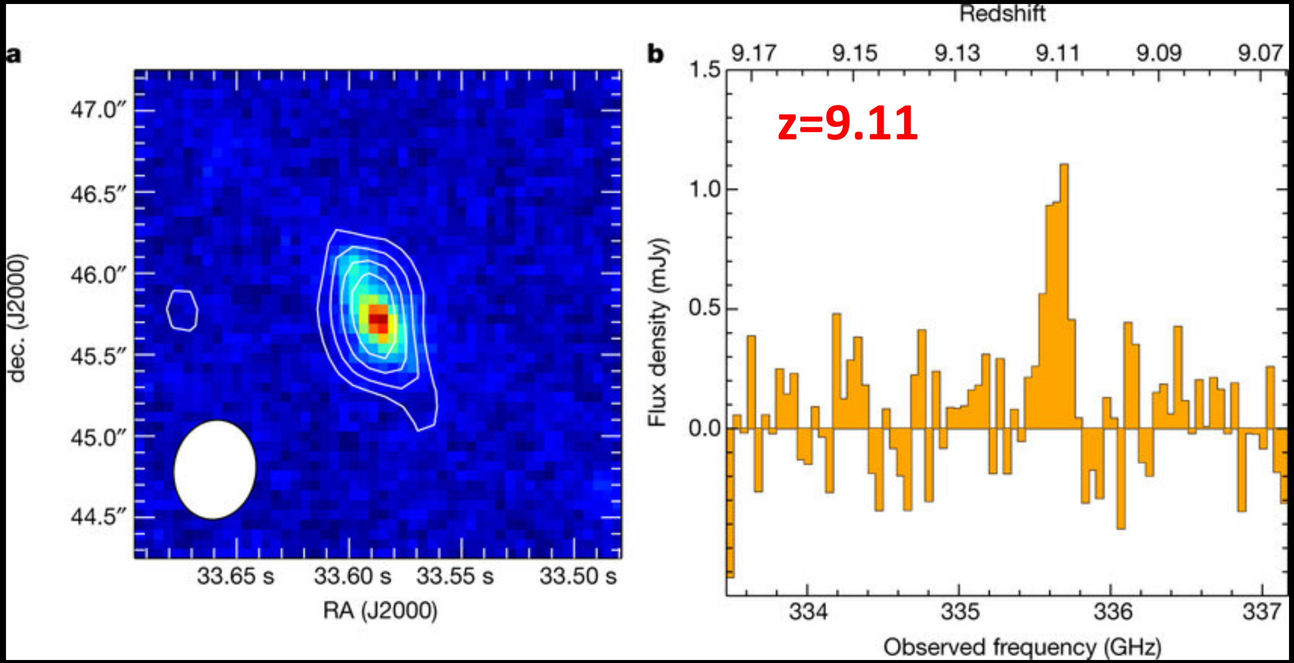
Tamura et al. (2019)

The first spectroscopic confirmation of a galaxy at z>7 with ALMA has been done in 2016 with the detection of [OIII]88μm

The most distant spectroscopic confirmation with ALMA

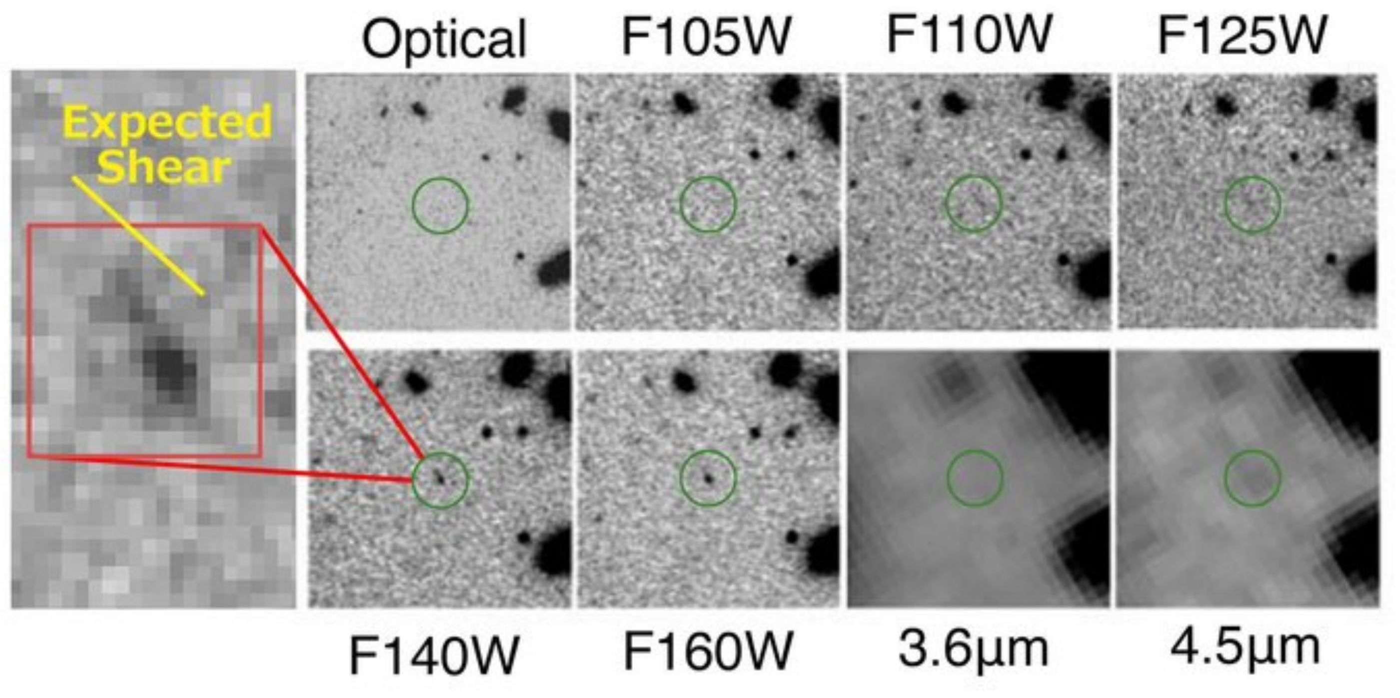


Hashimoto et al. (2018)

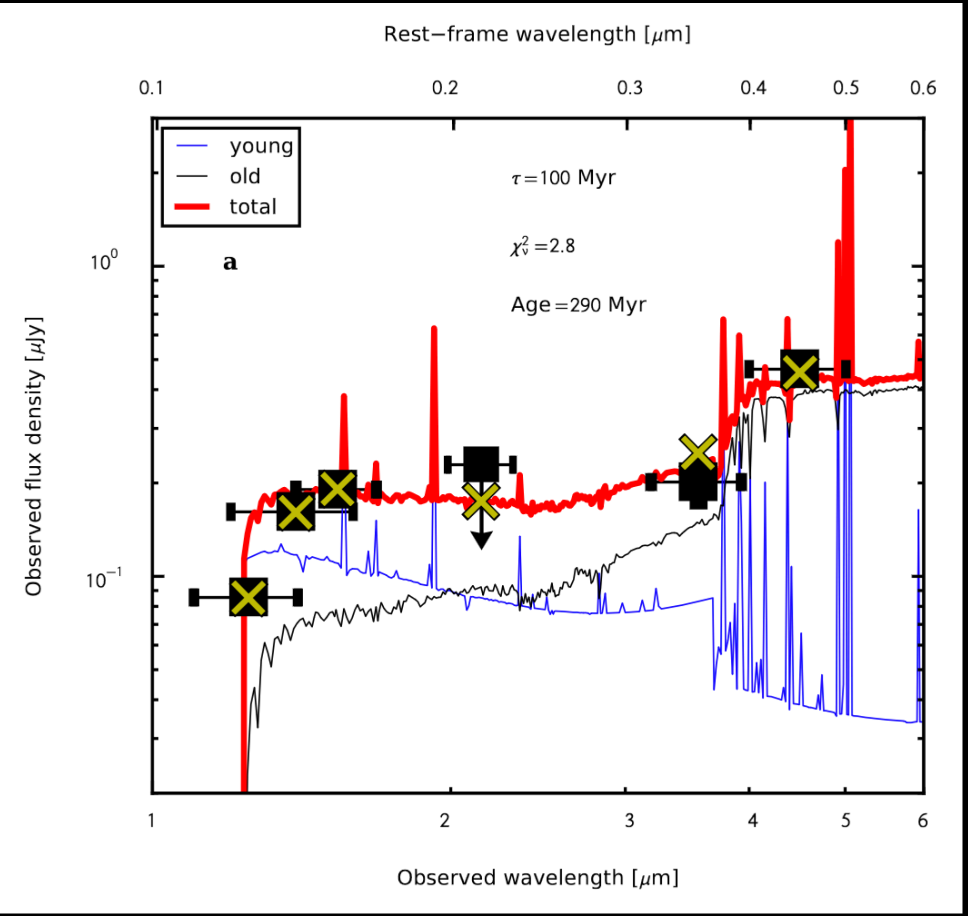


The most distant detection with ALMA is a lensed galaxy (MACS1149-JD1) with a spectroscopic redshift of z=9.11 .

The first detection of a Balmer Break at z>9

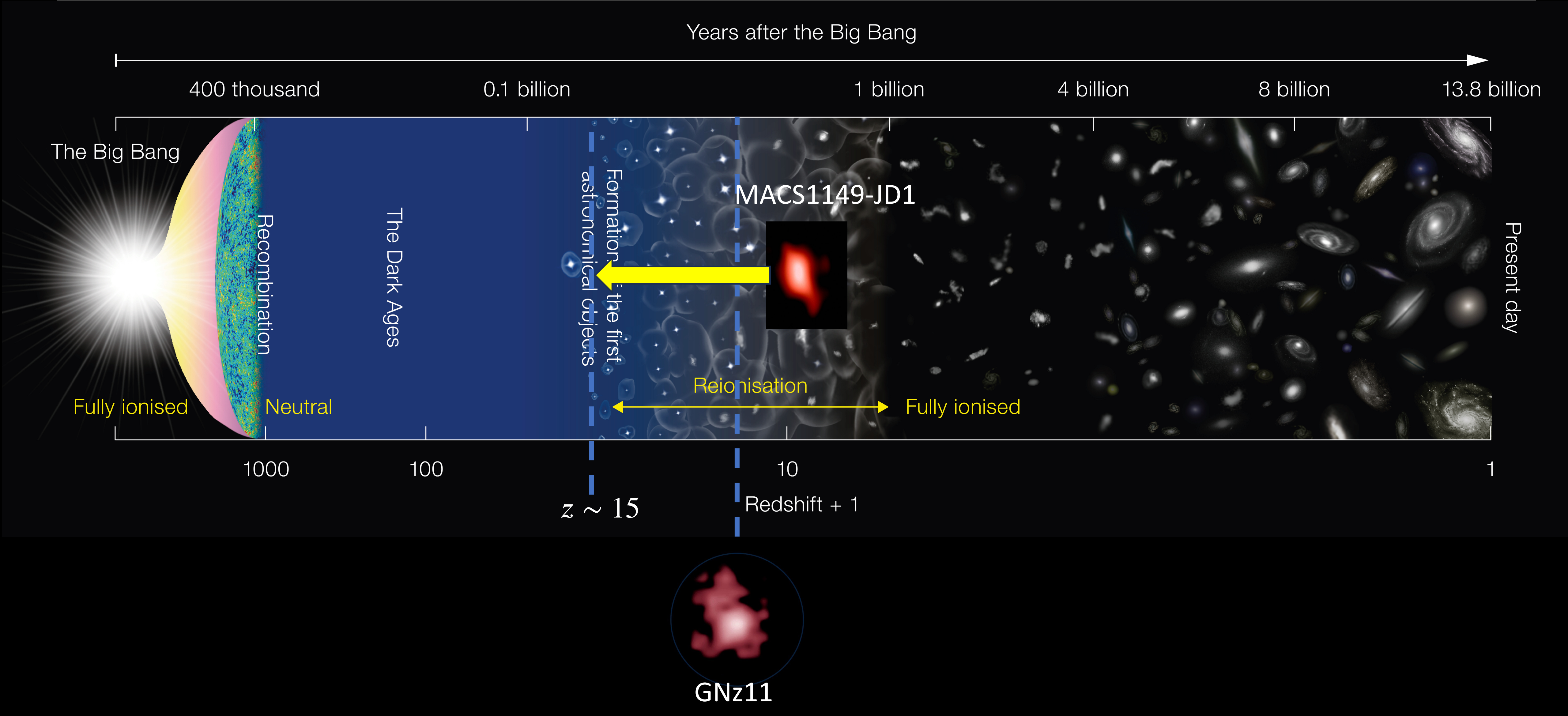


Zheng et al. (2014)

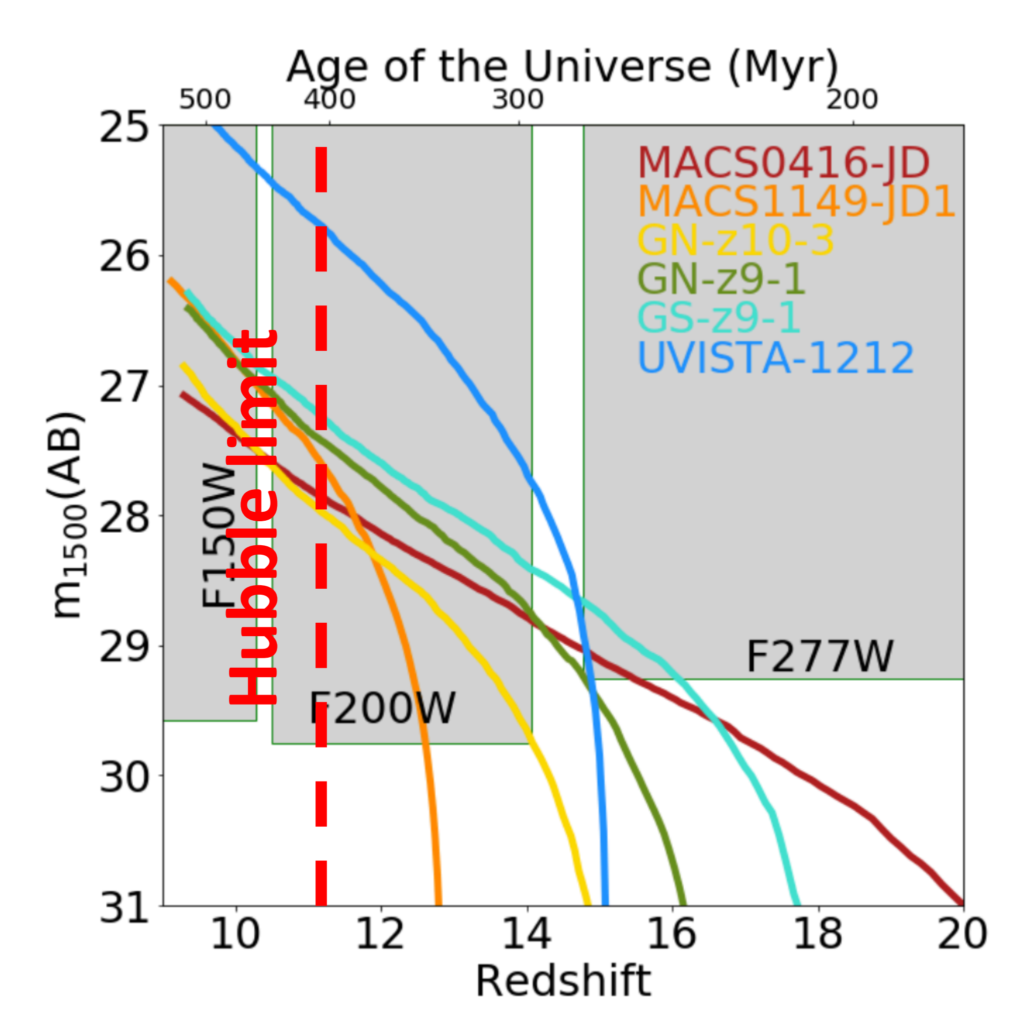


By modelling the stellar population of this galaxy, we show that : (i) it is composed of 2 stellar populations ; (ii) the old stellar population has an age of 290Myr

Pushing back in time the *Cosmic Dawn*

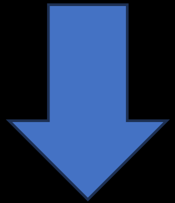


Pushing back in time the Cosmic Dawn



Doing the same exercise for all galaxies showing a Balmer Break at z>9, we can place Cosmic Dawn at a redshift $z \sim 15 - 20$

Caveats : this conclusion is obtained from only 6 galaxies (the only galaxies detected by both Hubble and Spitzer)

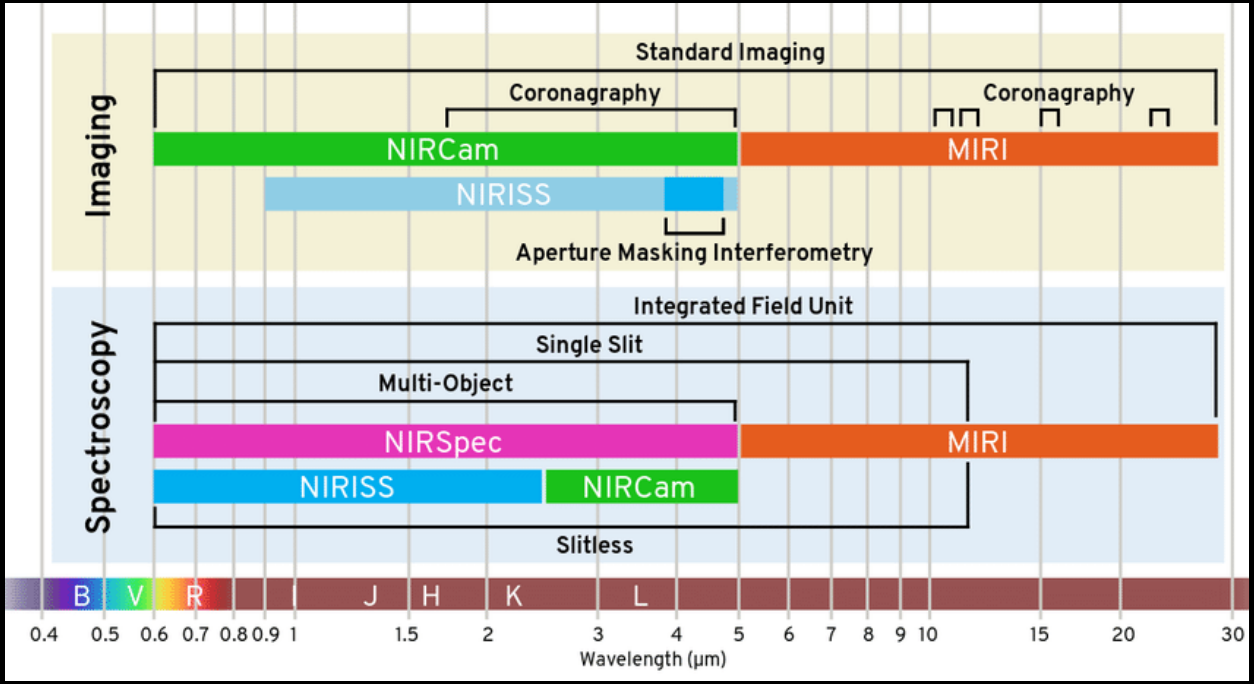


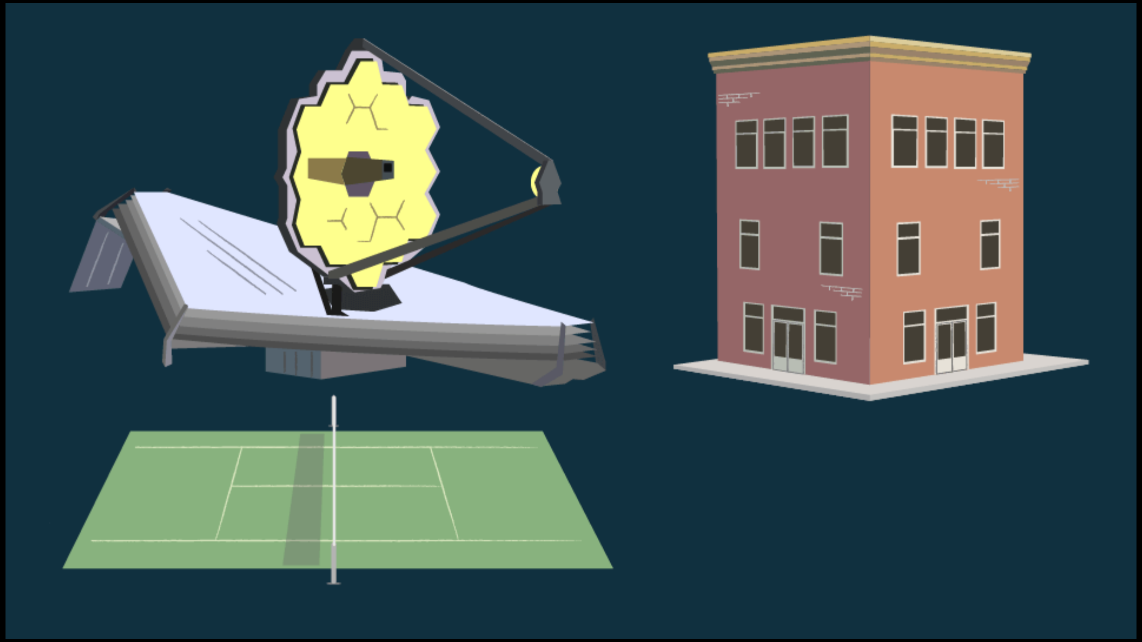
More Balmer breaks candidates or observation of z>11 galaxies are needed


REDUCED AIRFLOW
LOW RH
Marklift

A new telescope to explore the early Universe

- 6.5m diameter mirror
- 4 instruments
- 3 modes : imaging, spectroscopy, coronagraph

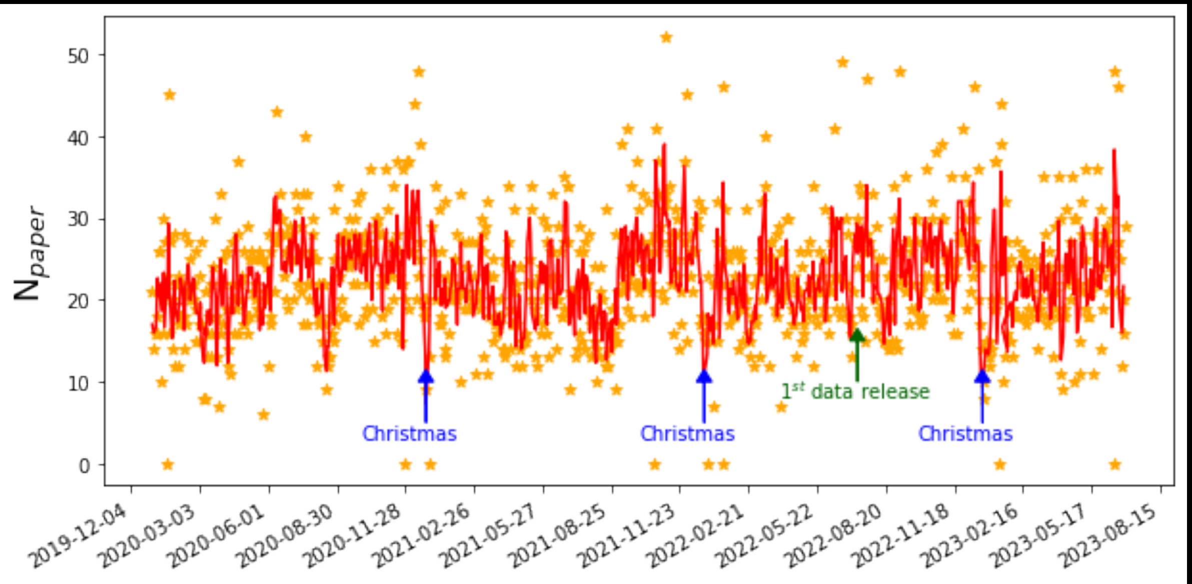




- Key questions:
  - The formation of the galaxies
  - The study of exoplanets atmospheres
  - The study of dark energy

The starting point : december 25th 2021

Within the first month after the release of the first images



Number of publication submitted each day on Astro-pH/galaxies

TIMELINE OF THE FIRST PAPERS

- **15th July 22 :** Pascale et al. (2022) ; Mahler et al. (2022)
- **18th July 22** : Caminha et al. (2022)
- **19th July 22** : Carnall et al. (2022) ; Cheng et al. (2022)
- **20th July 22** : Castellano et al. (2022) ; Naidu et al. (2022) ; Ferreira et al. (2022)
- **21st July 22** : Schaerer et al. (2022)
- **22nd July 22** : Suess et al. (2022)
- **25th July 22** : Adams et al. (2022) ; Leethochawalit et al. (2022)
- **26th July 22** : Atek et al. (2022) ; Roberts-Borsani et al. (2022) ; Trump et al. (2022) ; Curti et al. (2022) ; Sun et al. (2022) ; Donnan et al. (2022) ; Chen et al. (2022) ; Yan et al. (2022) ; Morishita et al. (2022) ; Santini et al. (2022), Merlin et al. (2022)

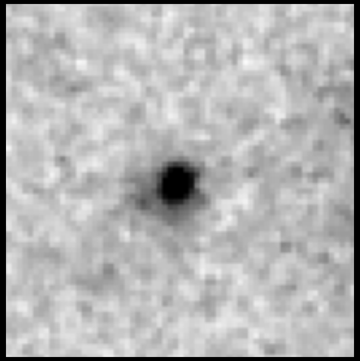
ERO SMACS0723	ERS CEERS	Comissionning data
ERS GLASS	*Lensing*	

Hubble's record broken in less than a week !

z=13

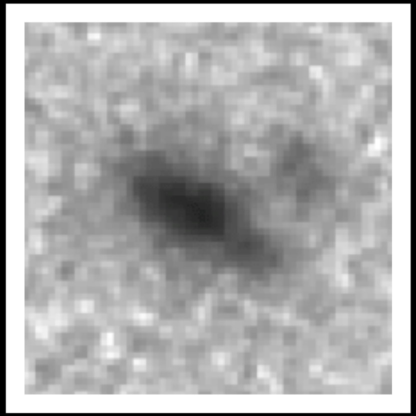
GLASS-z13 (Naidu et al. 2022)

z=16.39±0.27



CEERS- 93316 - Donnan et al. (2022)

z=17



CEERS-1749 (Naidu et al. 2022)

See also Atek et al. (2022), Castellano et al. (2022), Fujimoto et al. (2022), Tacchella et al. (2022)

An *intriguing* result : too distant, too massive !

Article

nature

A population of red candidate massive galaxies ~600 Myr after the Big Bang

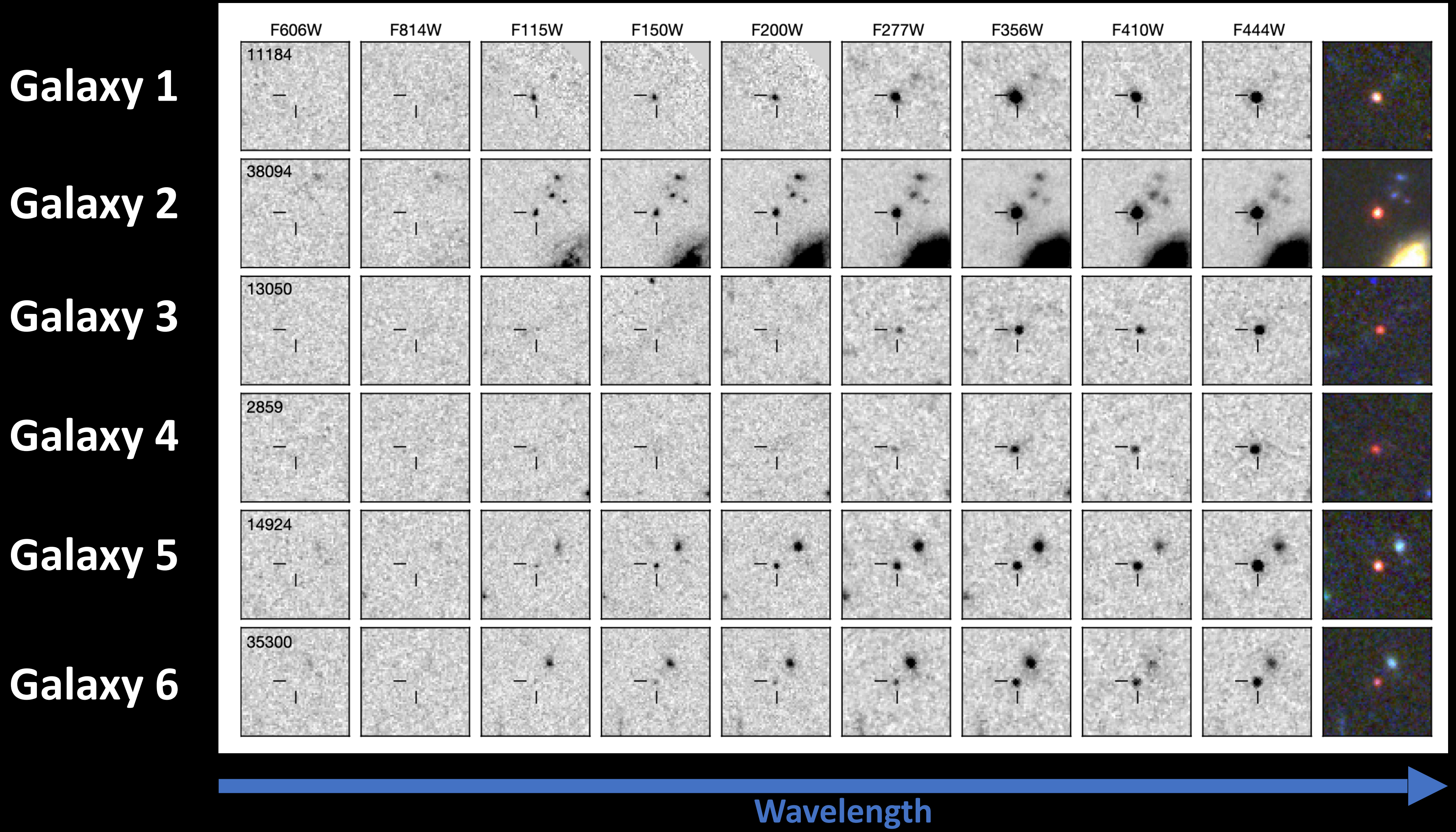
https://doi.org/10.1038/s41586-023-05786-2

Received: 25 July 2022

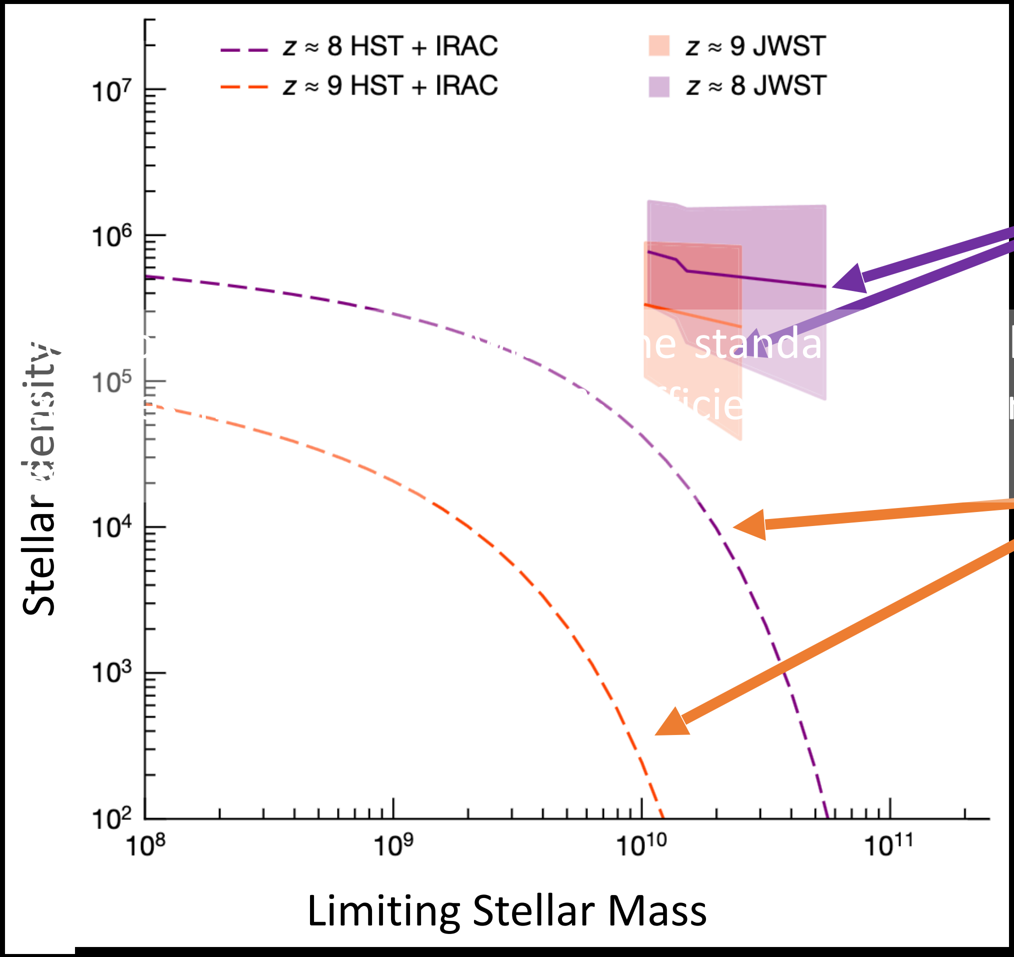
Accepted: 2 February 2023

Ivo Labbé[1]✉, Pieter van Dokkum[2], Erica Nelson[3], Rachel Bezanson[4], Katherine A. Suess[5,6], Joel Leja[7,8,9], Gabriel Brammer[10], Katherine Whitaker[10,11], Elijah Mathews[7,8,9], Mauro Stefanon[12,13] & Bingjie Wang[7,8,9]

An *intriguing* result : too distant, too massive !

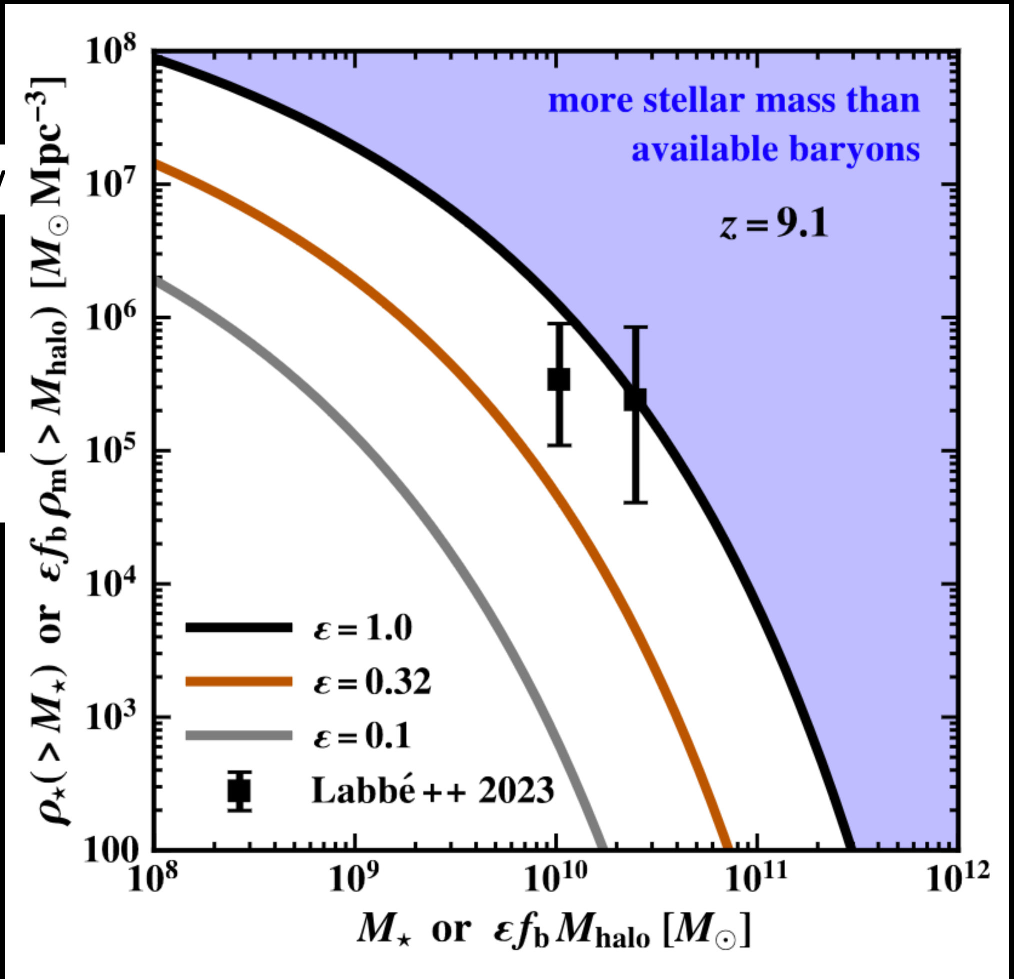


An *intriguing* result : too distant, too massive !



observ

expected



Labbe et al. (2023)

An *intriguing* result : too distant, too massive !

z=13

z=17

GL

al. 2022)

An *intriguing* result : too distant, too massive !

id	ra	dec	redshift	stellar mass $\log(M_*/M_\odot)$
2859	214.840534	52.817942	8.11(+0.49, −1.49)(+0.75, −2.30)	10.03(+0.24, −0.27)(+0.46, −0.75)
7274	214.806671	52.837802	7.77(+0.05, −0.06)(+0.27, −2.15)	9.87(+0.09, −0.06)(+0.30, −1.36)
11184	214.892475	52.856892	7.32(+0.28, −0.35)(+0.38, −0.46)	10.18(+0.10, −0.10)(+0.42, −0.43)
13050	214.809155	52.868481	8.14(+0.45, −1.71)(+2.45, −2.33)	10.14(+0.29, −0.30)(+0.45, −0.54)
14924	214.876150	52.880833	8.83(+0.17, −0.09)(+0.67, −3.22)	10.02(+0.16, −0.14)(+0.90, −1.63)
16624	214.844772	52.892108	8.52(+0.19, −0.22)(+0.46, −0.80)	9.30(+0.27, −0.24)(+0.72, −0.87)
21834	214.902227	52.939370	8.54(+0.32, −0.51)(+1.52, −2.92)	9.61(+0.26, −0.32)(+0.49, −1.50)
25666	214.956837	52.973153	7.93(+0.09, −0.16)(+0.23, −2.32)	9.52(+0.23, −0.10)(+0.52, −1.17)
28984	215.002843	53.007594	7.54(+0.08, −0.14)(+1.25, −1.98)	9.57(+0.13, −0.15)(+0.47, −1.42)
35300	214.830662	52.887777	9.08(+0.31, −0.38)(+0.40, −3.50)	10.40(+0.19, −0.23)(+0.60, −2.11)
37888	214.912510	52.949435	6.51(+1.42, −0.28)(+1.58, −0.90)	9.23(+0.25, −0.10)(+0.92, −1.17)
38094	214.983019	52.955999	7.48(+0.04, −0.04)(+0.74, −0.56)	10.89(+0.09, −0.08)(+0.22, −1.99)
39575	215.005400	52.996706	8.62(+0.34, −0.57)(+0.45, −2.51)	9.33(+0.43, −0.39)(+0.69, −1.11)

Labbe et al. (2023)

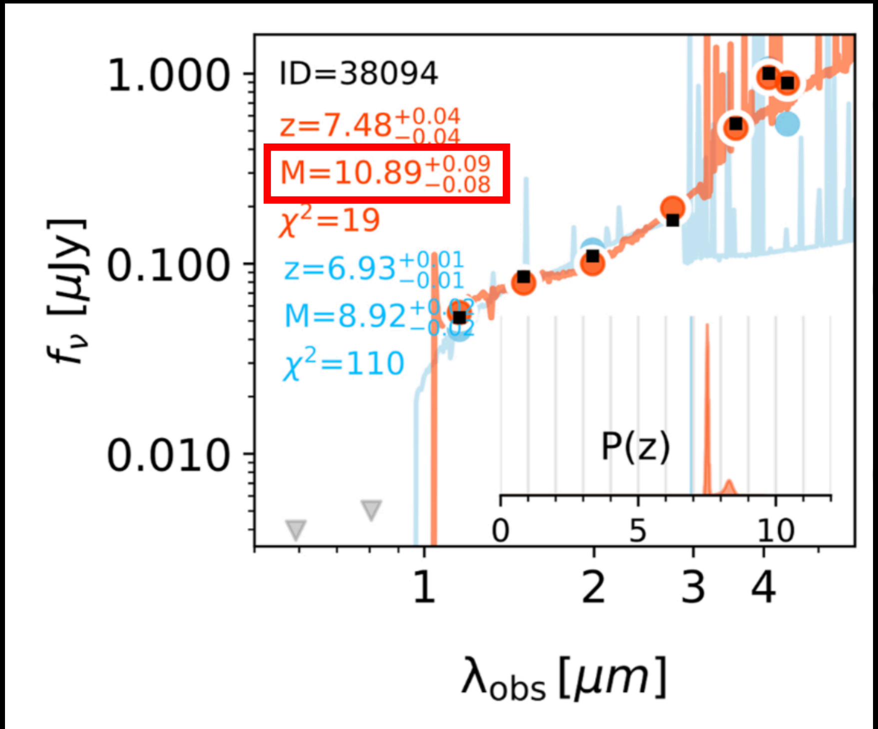
Before questioning the standard model, it is important to look at whether the estimates of distances (redshift) or stellar masses are correct.

REDSHIFT → **Spectroscopy**

STELLAR MASSES → **Models**

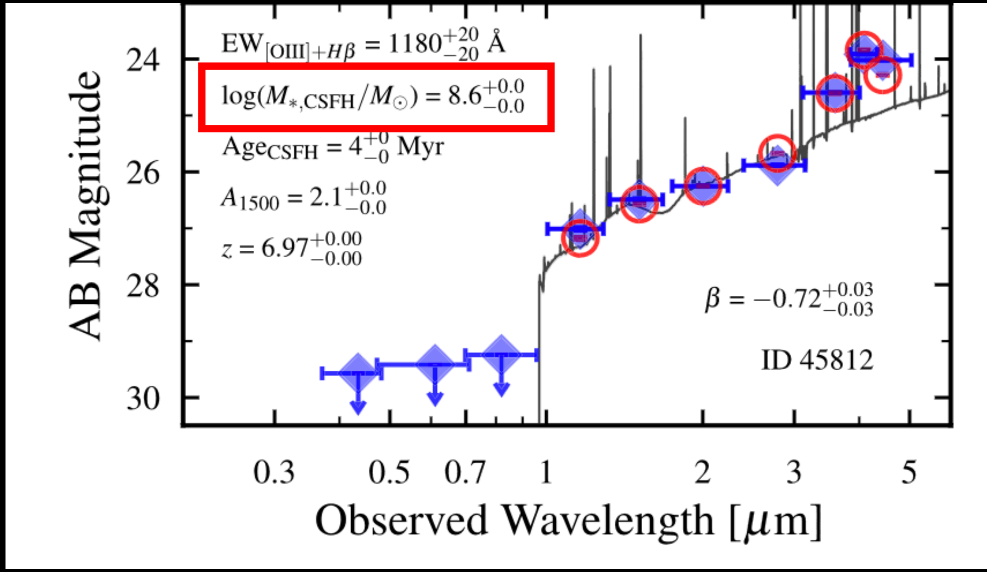
An *intriguing* result : too distant, too massive !

STELLAR MASSES



Labbe et al. (2023)

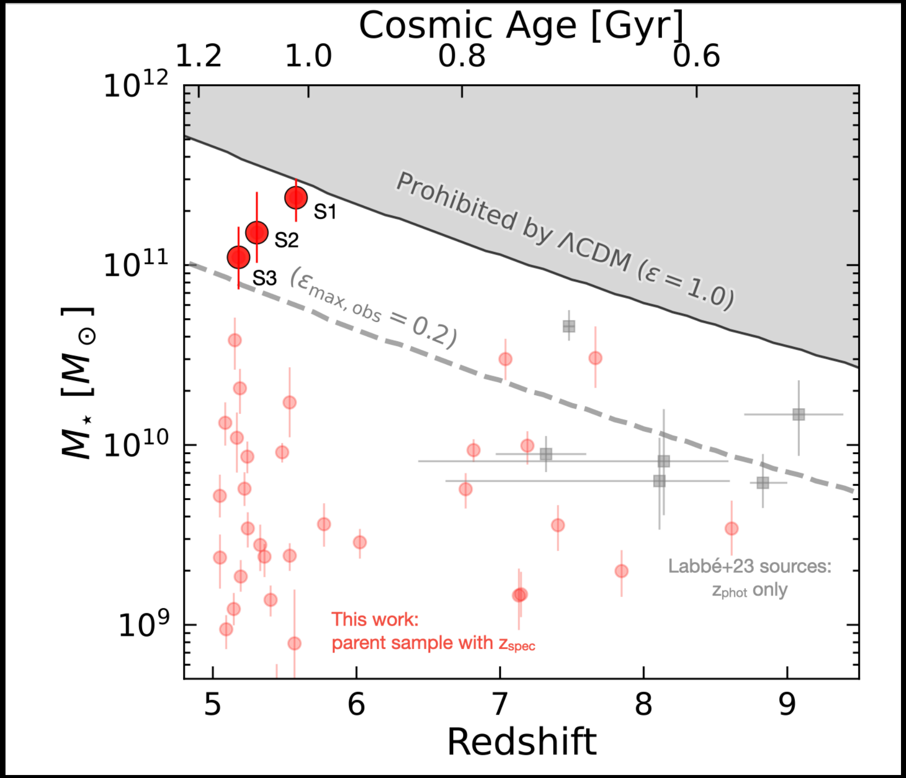
The first galaxies are forming a lot of stars, and could therefore be more ionising than local galaxies.



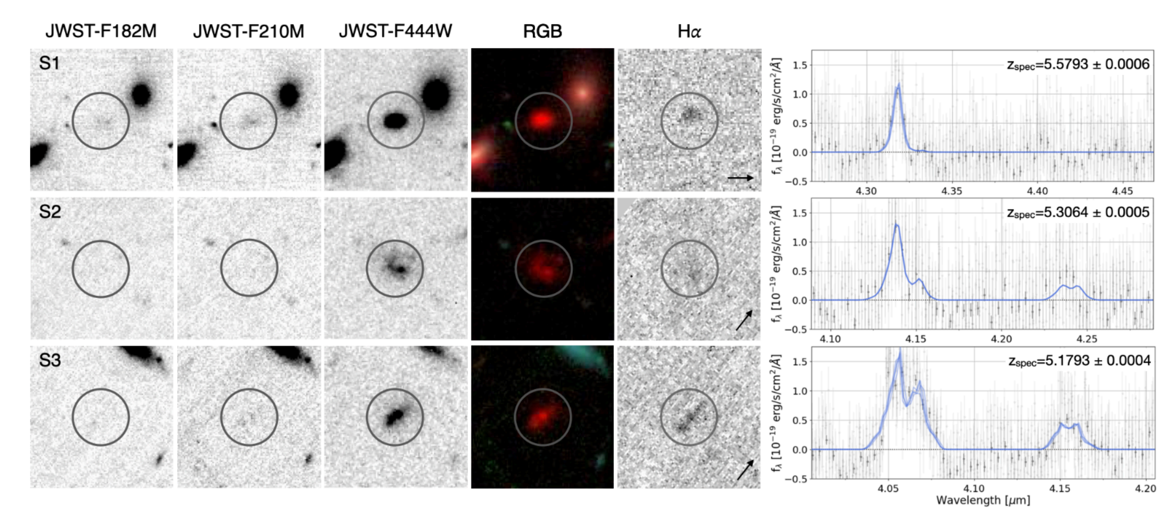
Endsley et al. (2023)

At lower redshift (z~5 – 6) a higher SFE

STAR FORMATION EFFICIENCY



Xiao et al. (2023)

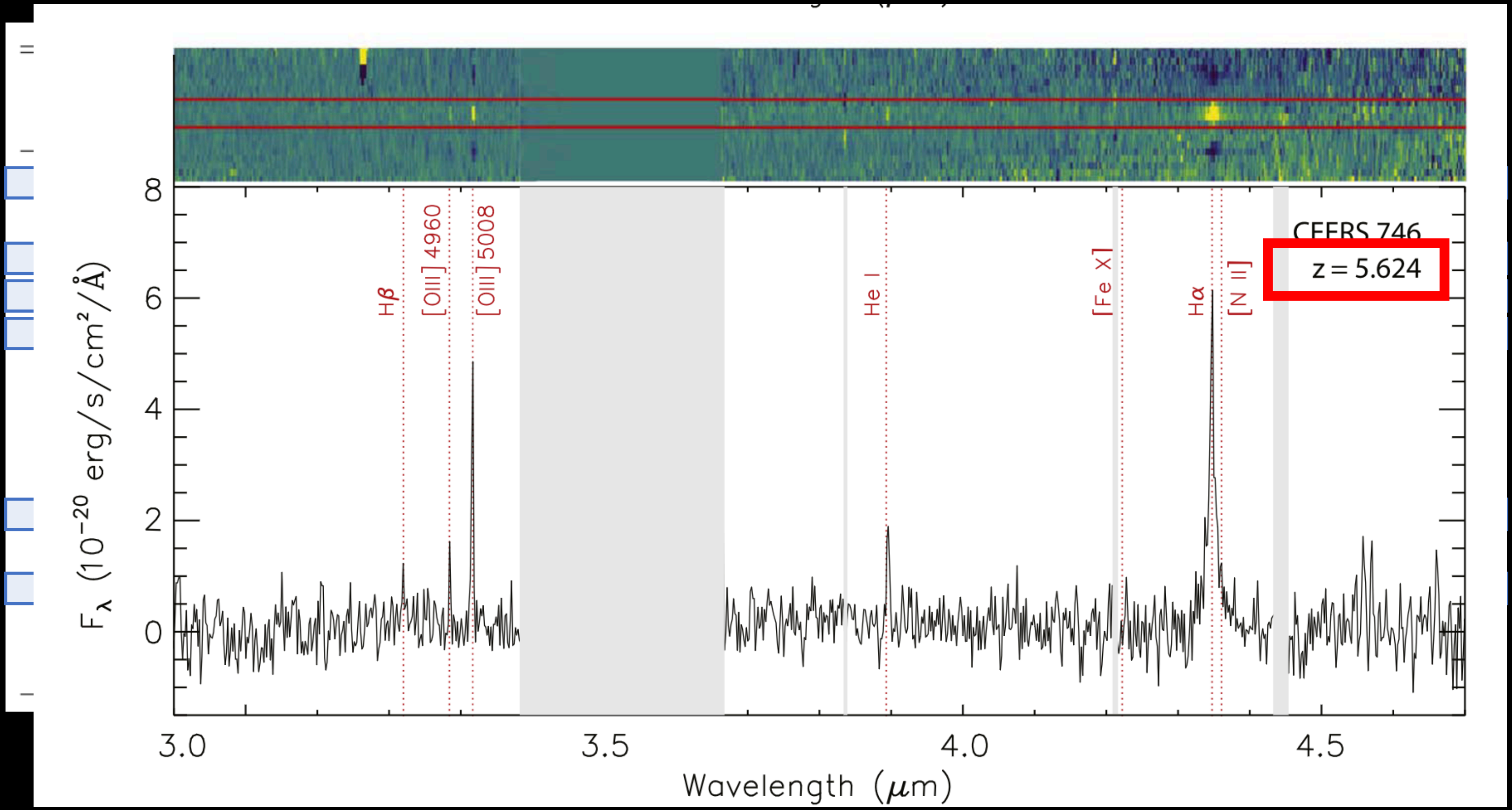


A team from the Geneva Observatory has recently measured precisely the stellar masses of a sample of spectroscopically confirmed galaxies at z~5 – 6

Conclusion : *their star formation efficiency is ~50%*

An *intriguing* result : too distant, too massive !

REDSHIFT



Kocevski et al. (2023)

Spectroscopic observations of one of the most massive galaxies from Labbe's sample is at lower redshift, and therefore its stellar masse has been overestimated

More interestingly, this source seems to be an AGN at z=5.7 !

Why the z_{phot} of this galaxy is wrong ?

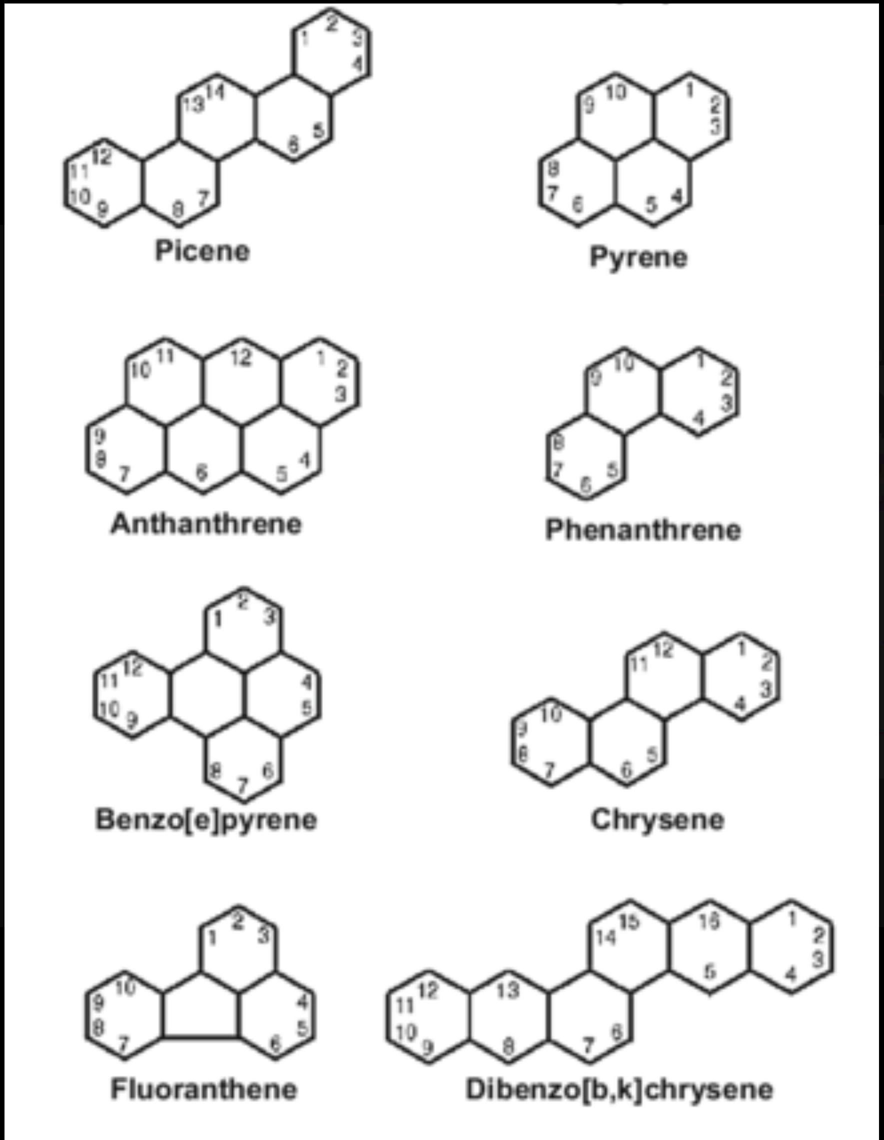
Why the z_{phot} of this galaxy is wrong ?

Dust is an important component of the ISM. It accounts for

- 50% of the heavy elements
- 1% of the baryonic mass of a galaxy
- 40% of the luminosity of a galaxy

Dust grains are produced by stars at the end of their life (e.g., after SNe). Their size is ranging from 1nm to $1\mu m$ with a mean size of about 0.1 μm. This explains why dust grain absorb mainly at optical wavelength.

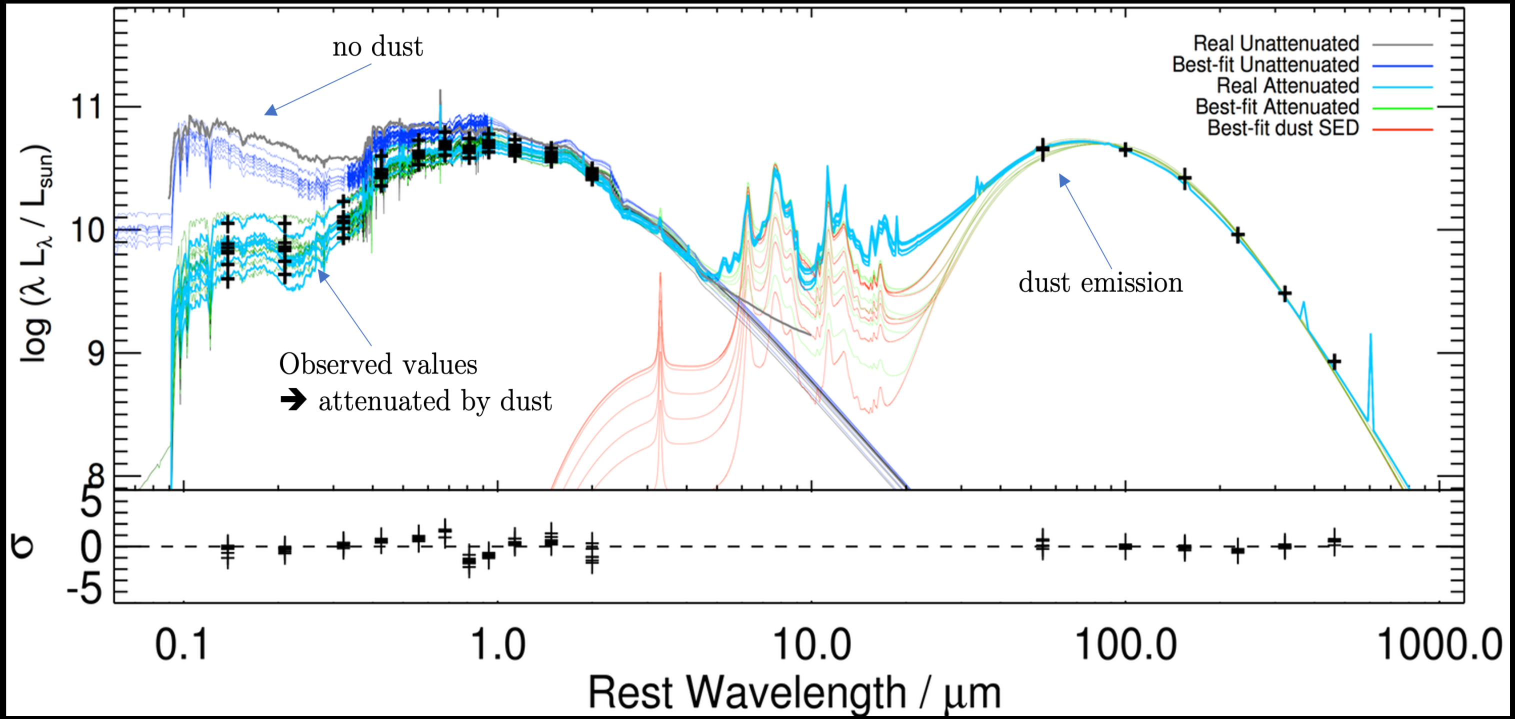
The smallest dust grains are just large molecules such as PAHs, the larger are amorphous grain of silicates and carbon, but with an icy surface layer



Why the z_{phot} of this galaxy is wrong ?

Typically, dust heated by UV emission reaches temperature of 100K in star-forming regions.

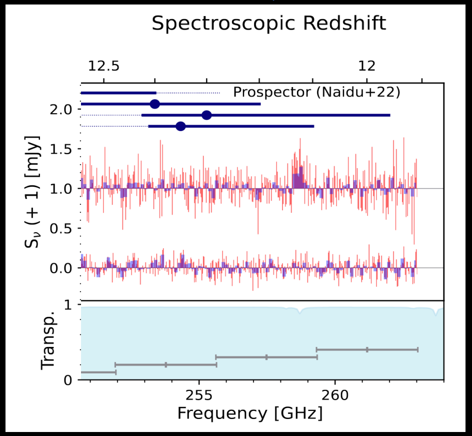
If there is a significant amount of dust, then the ISM is optically thick and leads in efficient cooling.



When did the first galaxies form in the early Universe ?

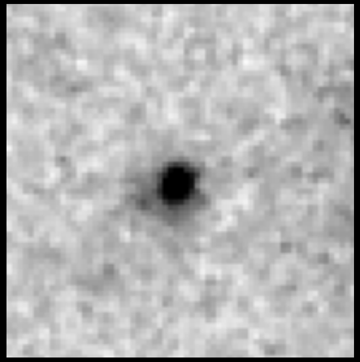
z=13

GLASS-z13 (Naidu et al. 2022)

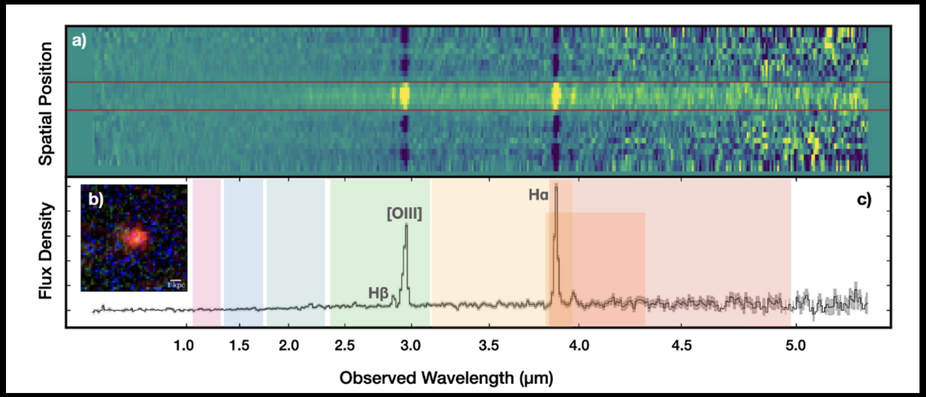


Bakx et al. (2022)

z=16.39±0.27

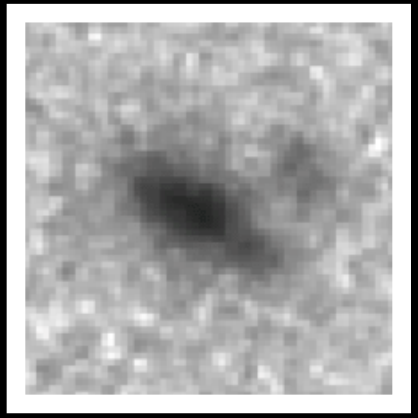


Donnan et al. (2022)

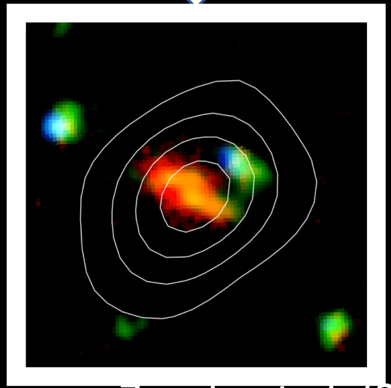


Arrabal Haro et al. (2023)

z=17



CEERS-DSFG-1 (Finkelstein et al. 2022)



Zavala et al. (2022)

See also Castellano et al. (2022), Donnan et al. (2022), Fujimoto et al. (2022), Tacchella et al. (2022)

Spectroscopic redshifts are key to study the early Universe

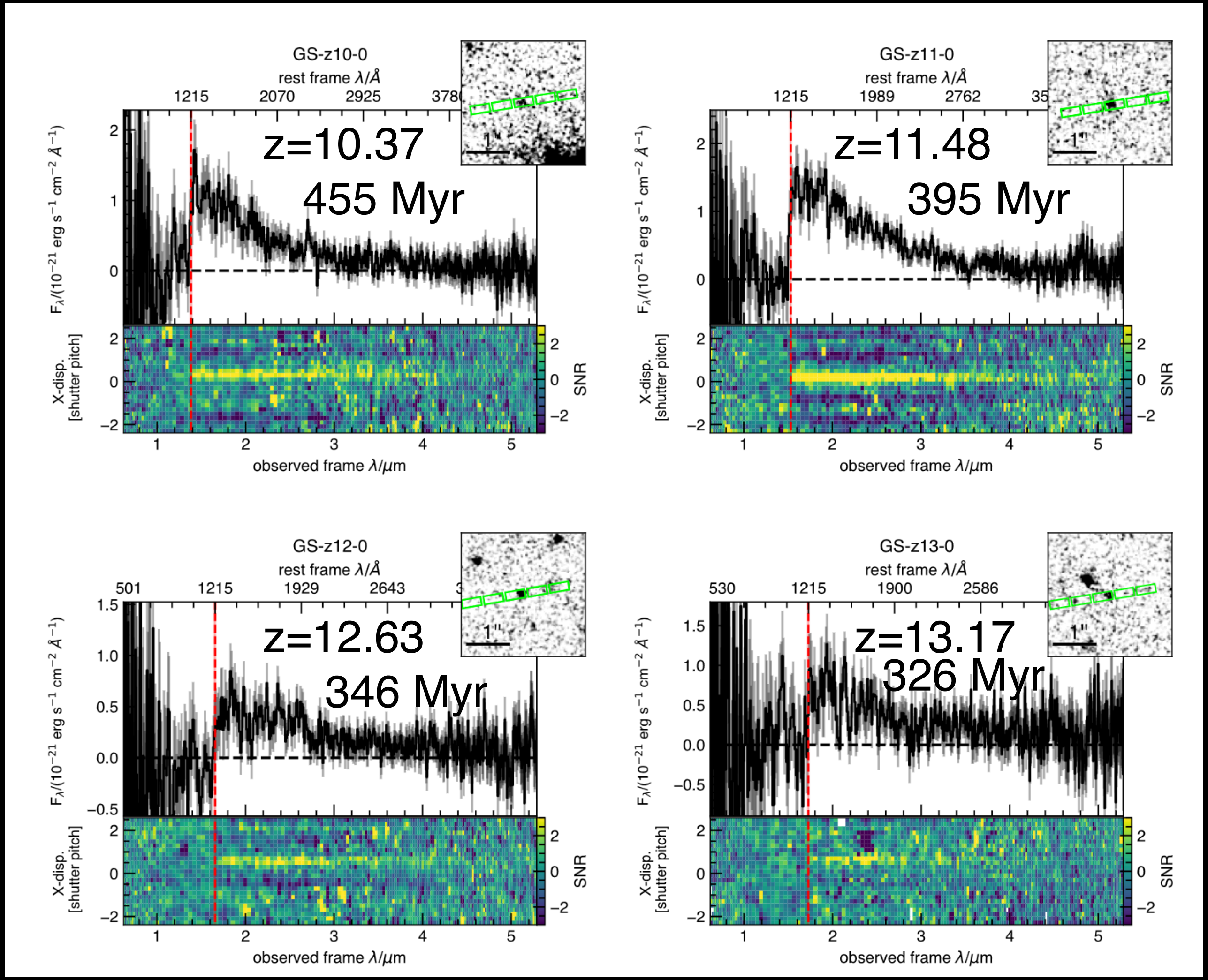
However, getting a spectroscopic redshift is time consumming.
Ideally, we want to get the spectra of 100s of galaxies per pointing.
Spectrographs on board space observatories usually have a small field of view and a limited number of targets can be observed simultaneously.

Ground-based spectrographs are ideal !

MOSAIC

First light : **2032**

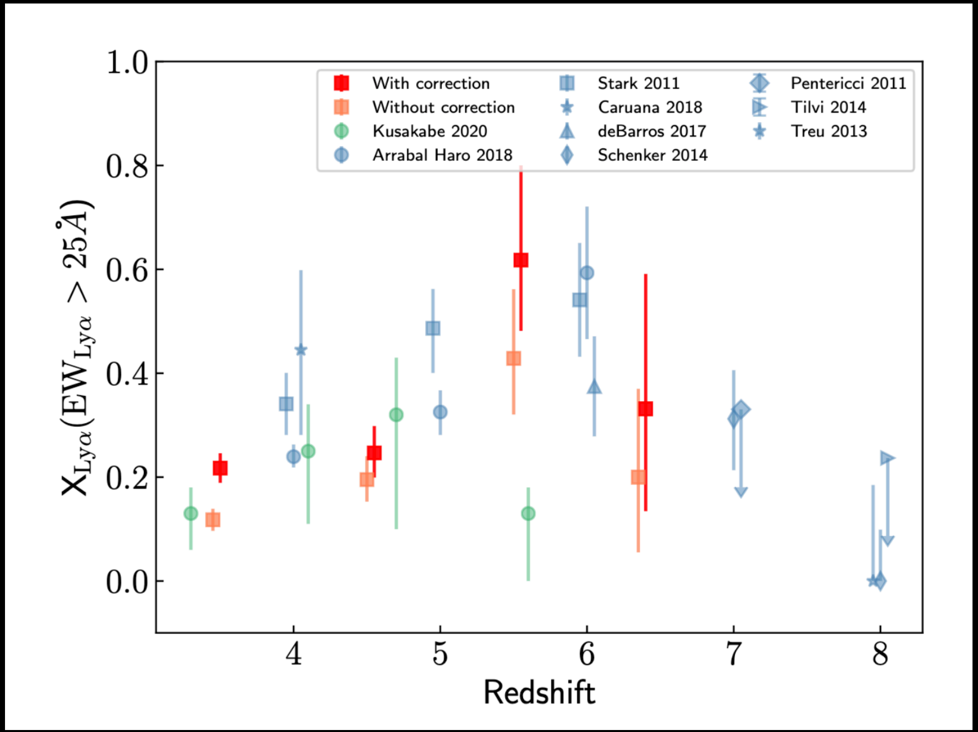
The first JWST "redshift record"



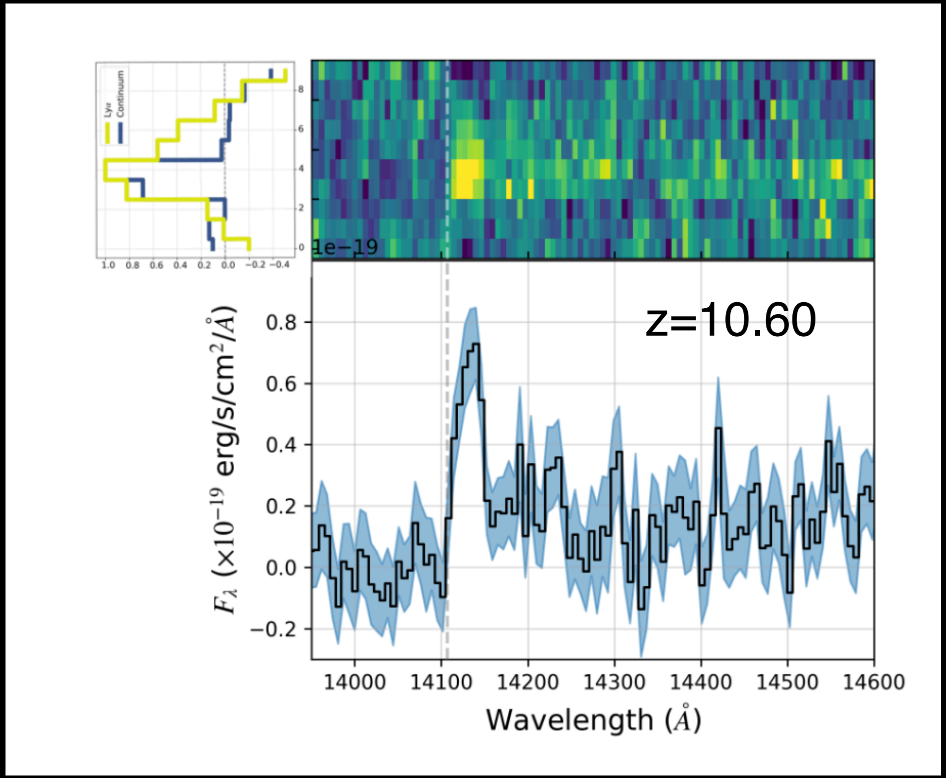
Curtis Lake et al. (2023)

A puzzling detection of Ly-α deep into the Reionisation

Ly-α is a resonant line and is therefore strongly absorbed by the neutral hydrogen surrounding galaxies in the early Universe



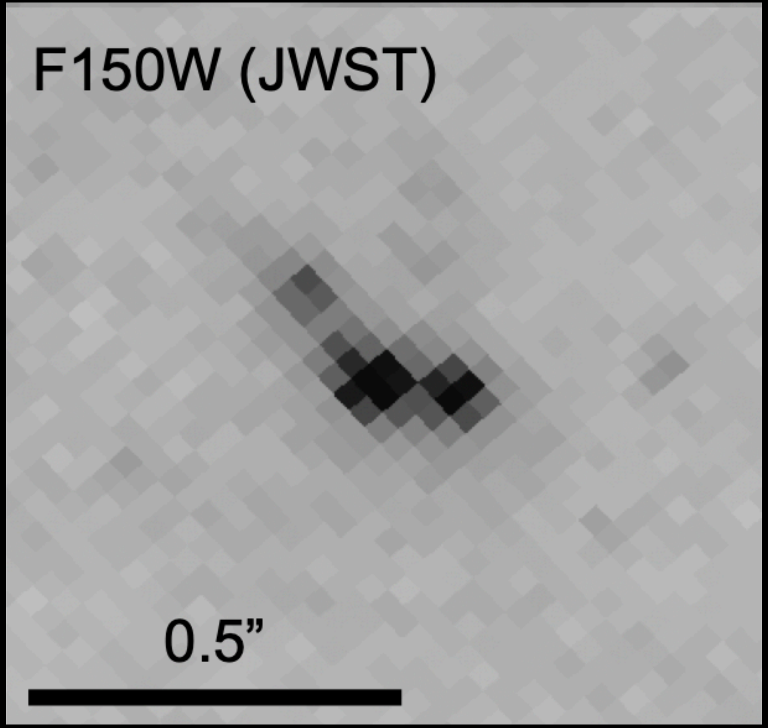
De la Vieuville et al. (2020)



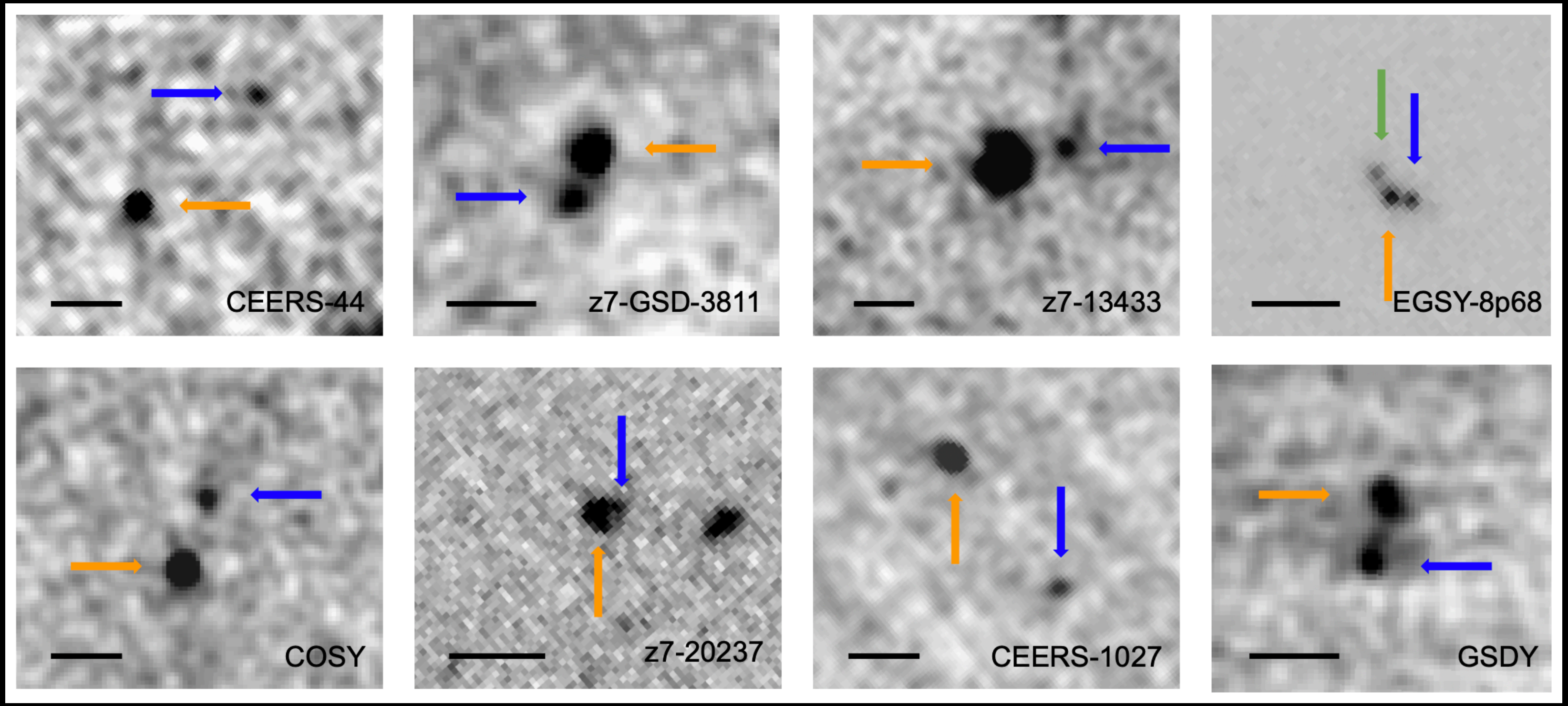
Bunker et al. (2023)

Interacting galaxies are numerous in the early Universe

Callum Witten (IoA/Cambridge)

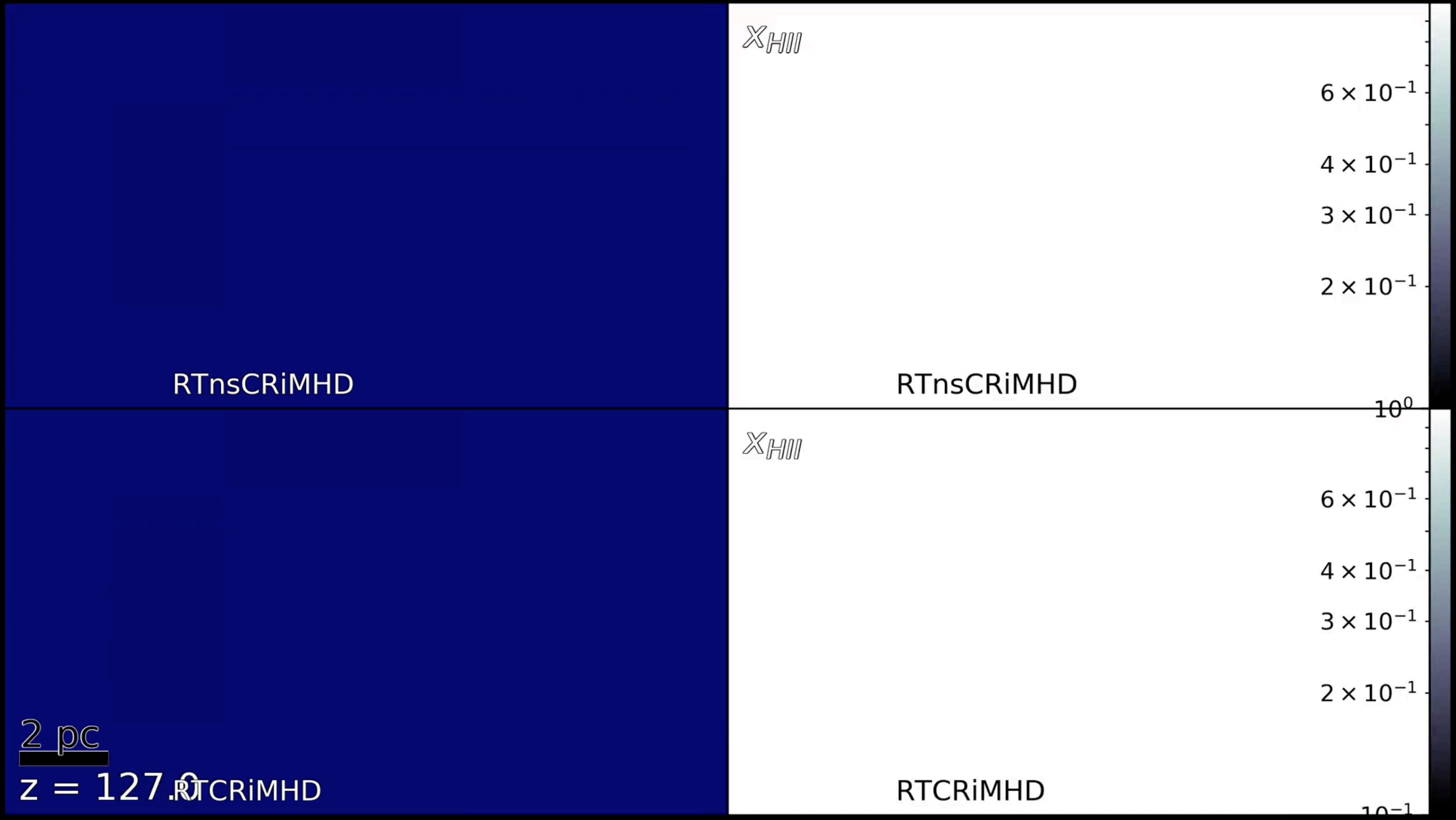


Witten et al. (2023)



Using NIRCam/JWST data, we demonstrate that all galaxies at $z>7$ with Ly-α emission are interacting galaxies.

Interactions between galaxies blow away the neutral gas

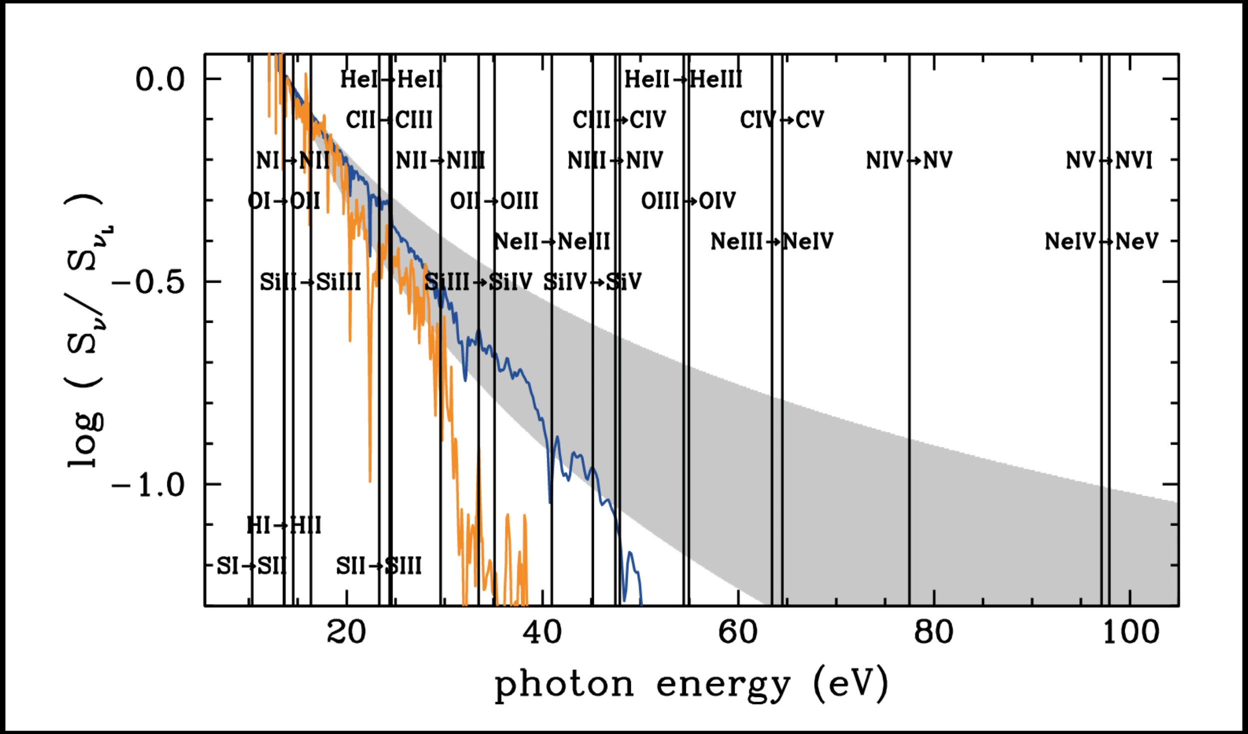


Witten et al. (2023)

The first AGN and stars

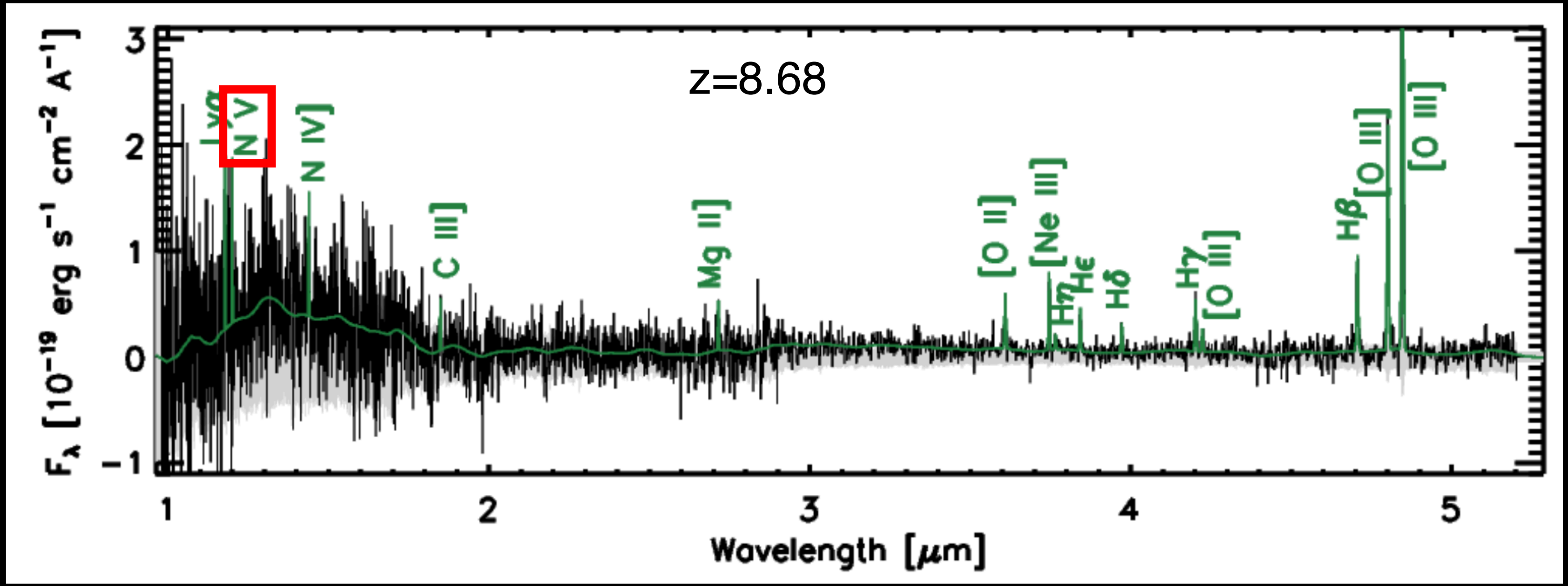
Evidence for massive black holes in the early Universe

The high radiation field of massive black hole (Active Galactic Nuclei – AGN) leads to the detection of peculiar emission lines (NV, NeIV)



Feltre et al. (2016)

Evidence for massive black holes in the early Universe



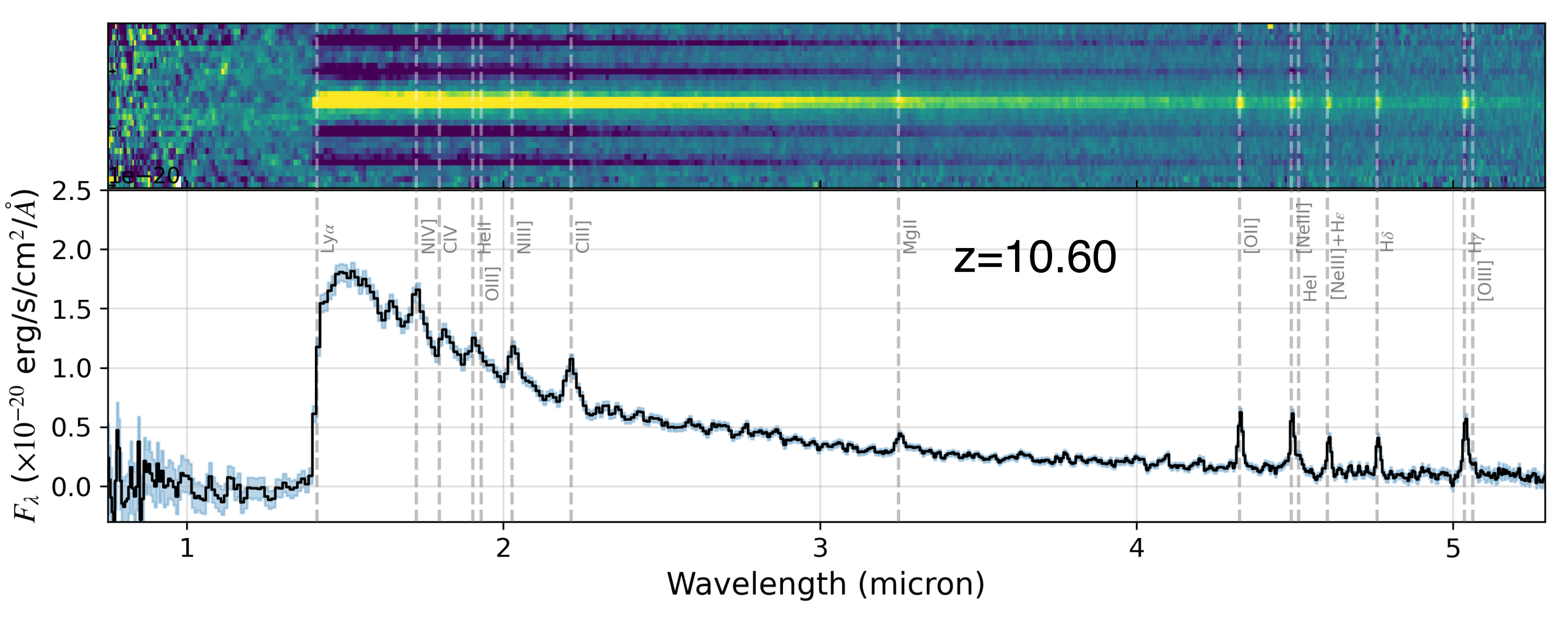
Larson et al. (2023)

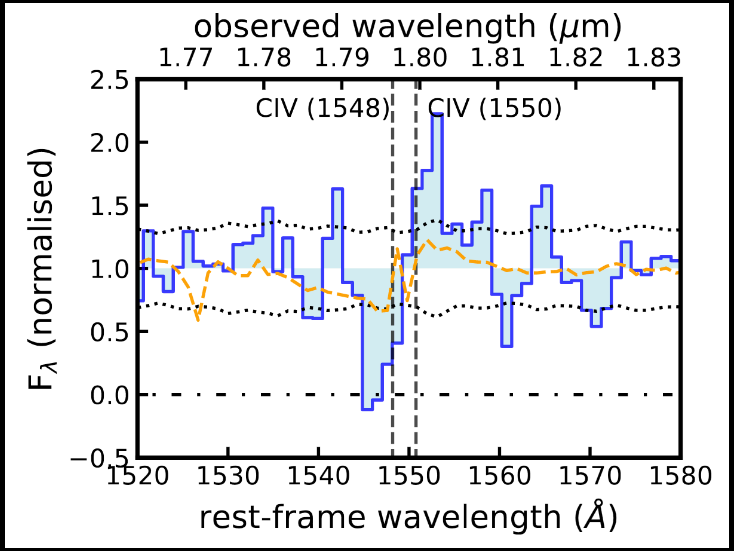
- $M_{star} \sim 3 \times 10^9 M_\odot$
- SFR = 30 $M_\odot$/yr
- $M_{BH} \sim 1 \times 10^7 M_\odot$

The large number of AGN detection at z>7 was unexpected by current models of galaxy formation. Within the first 6 months of JWST observation, many AGN have been identified at z>7.

See also Laporte et al. (2017), Maignali et al (2018)

Evidence for massive black holes in the early Universe





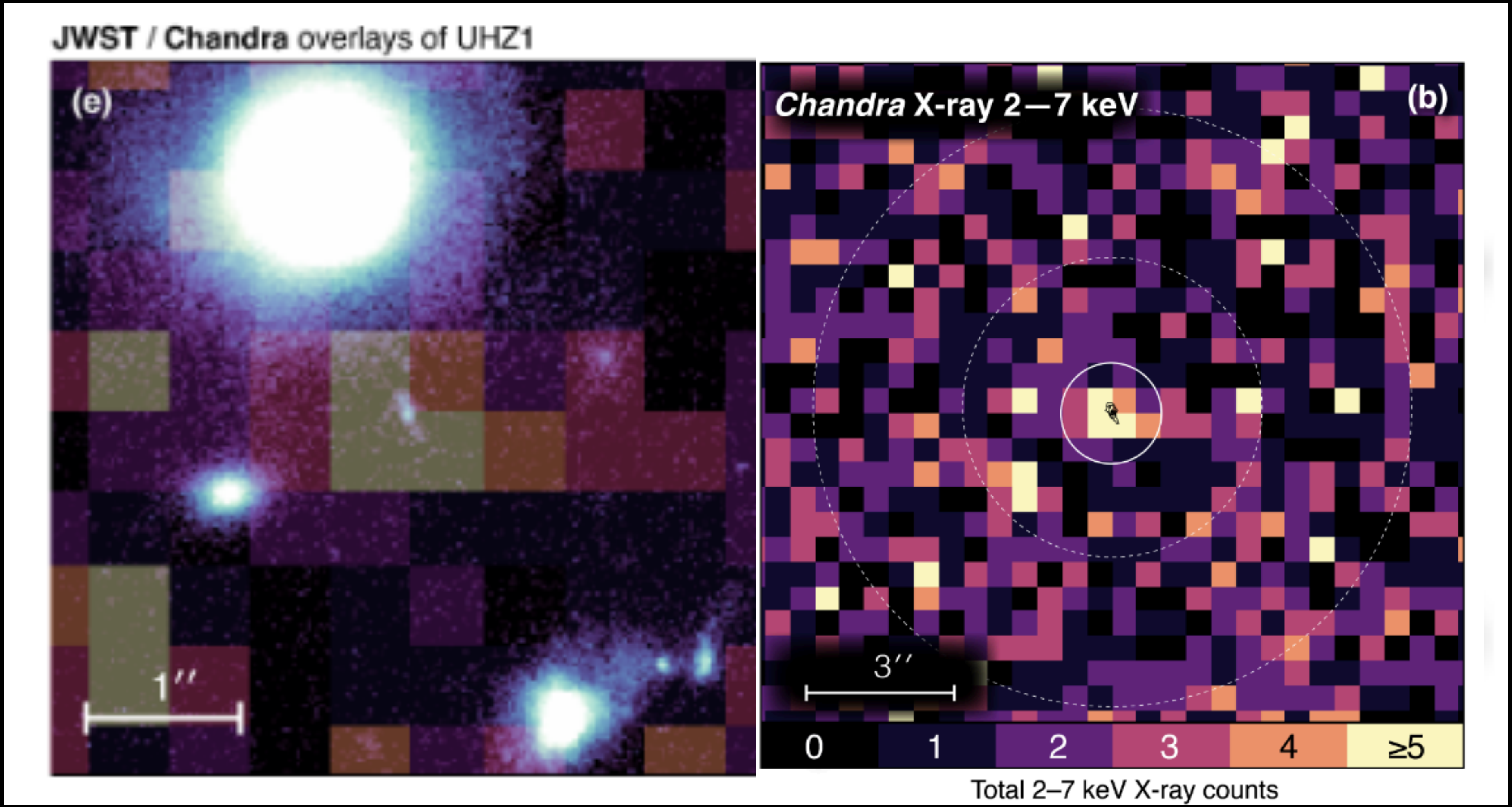
Bunker et al. (2023), Maiolino et al. (2023)

Detection of NeIV tracing high gas density (>10^10 cm^-3)

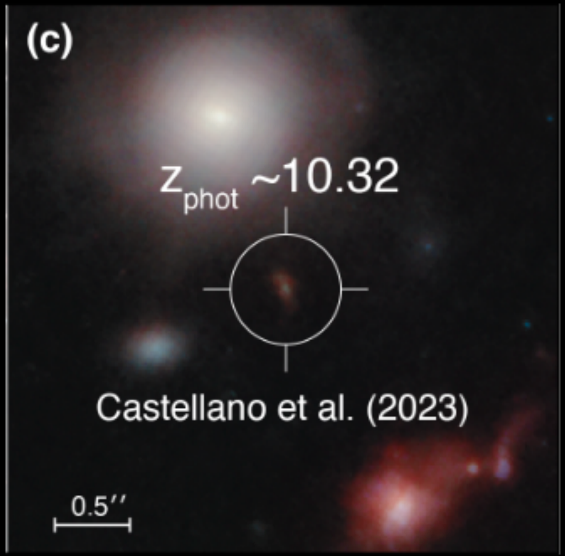
The most distant galaxy identified by the *Hubble* Space Telescope host a massive black hole (although there is still an active debate) just ~400 Myr after the Big-Bang

This super-massive black hole ($\sim 3 \times 10^6 M_\odot$) may have been accreting at super-Eddington over the last 100 Myr and could have originated from a stellar mass seeds at $z \sim 15$

An X-ray detected AGN at $z = 10.1$?



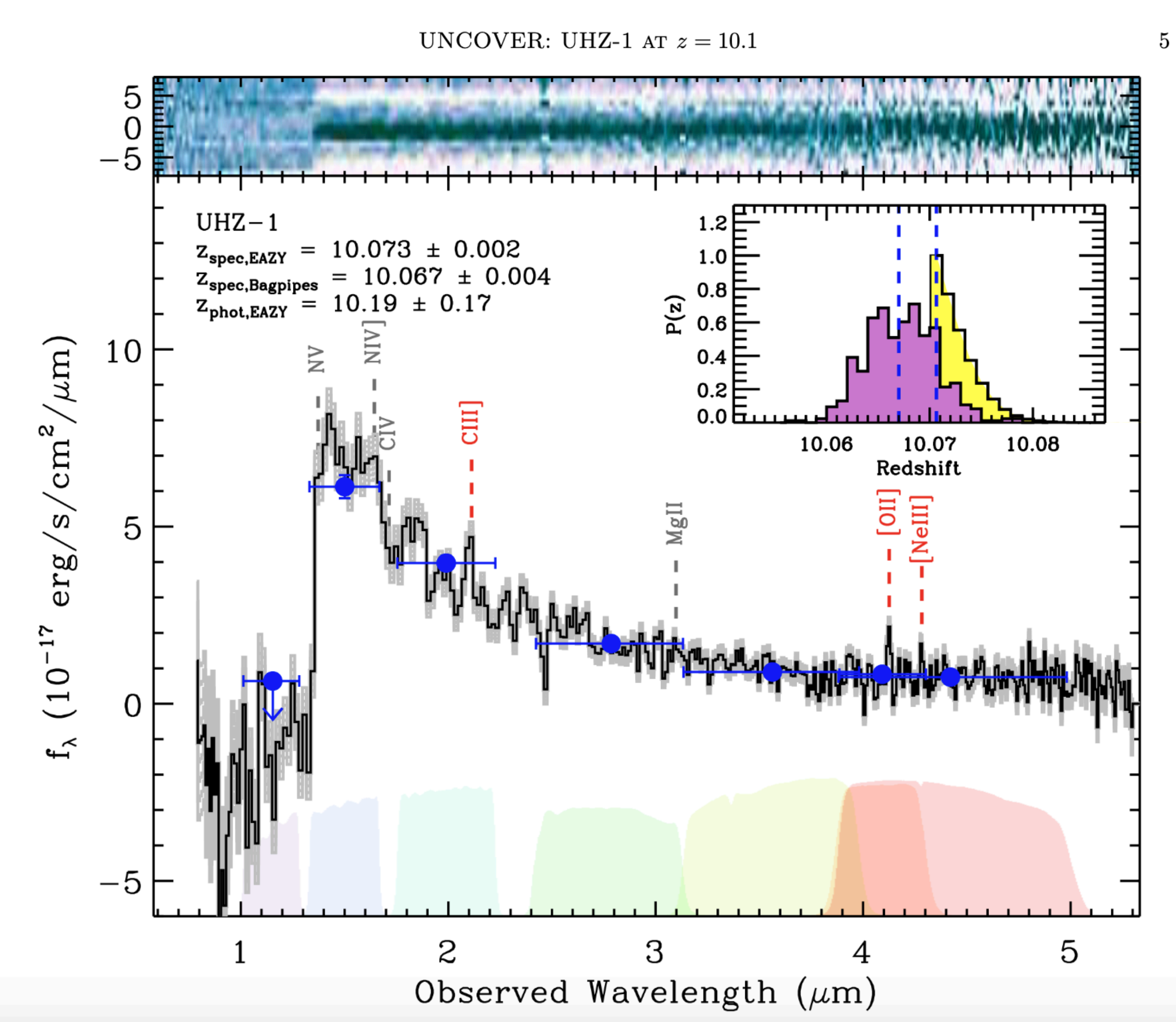
Bogdán et al. (2023)



$z_{phot} \sim 10.3$
$L_{bol} \sim 5 \times 10^{45} erg/s$
$M_{BH} \sim 4 \times 10^{7} M_{\odot}$

$$\frac{M_{BH}}{M_{\star}} \sim 0.1\%$$

An X-ray detected AGN at $z = 10.1$?



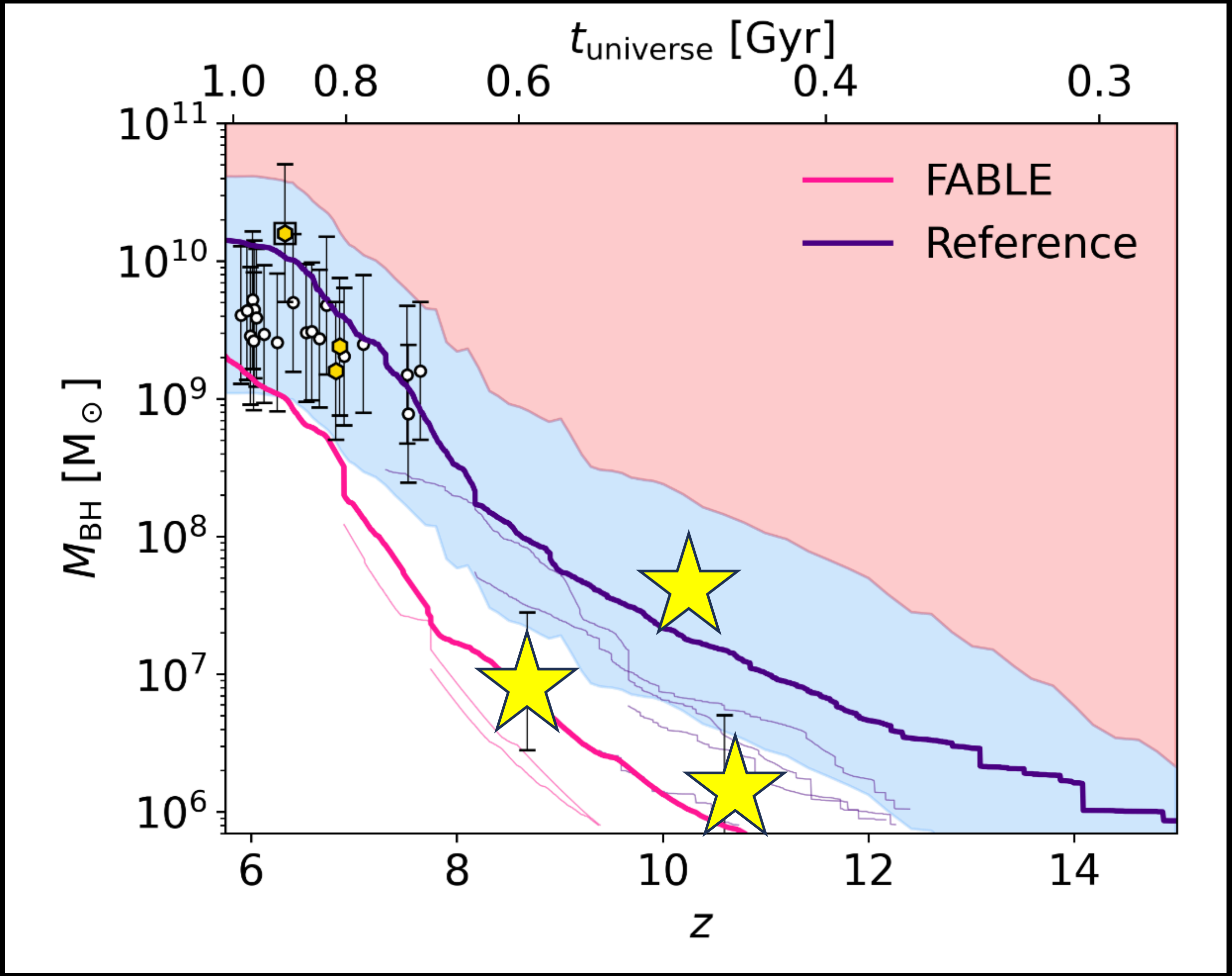
Goulding et al. (2023)

JWST/NIRspec spectrum confirm the redshift of this AGN candidate (z=10.1).

However, the resolution of NIRSpec-prism (R~100) is not sufficient to detect any high-ionisation potential emission line and therefore confirm the AGN nature of this source.

High-resolution ground-based spectroscopy is needed !

Are these Super Massive Black Holes expected ?



Bennett al. (2023)

Using zoom-in simulations, we can demonstrate that super-Eddington accretion is needed to explain such SMBH at z>8

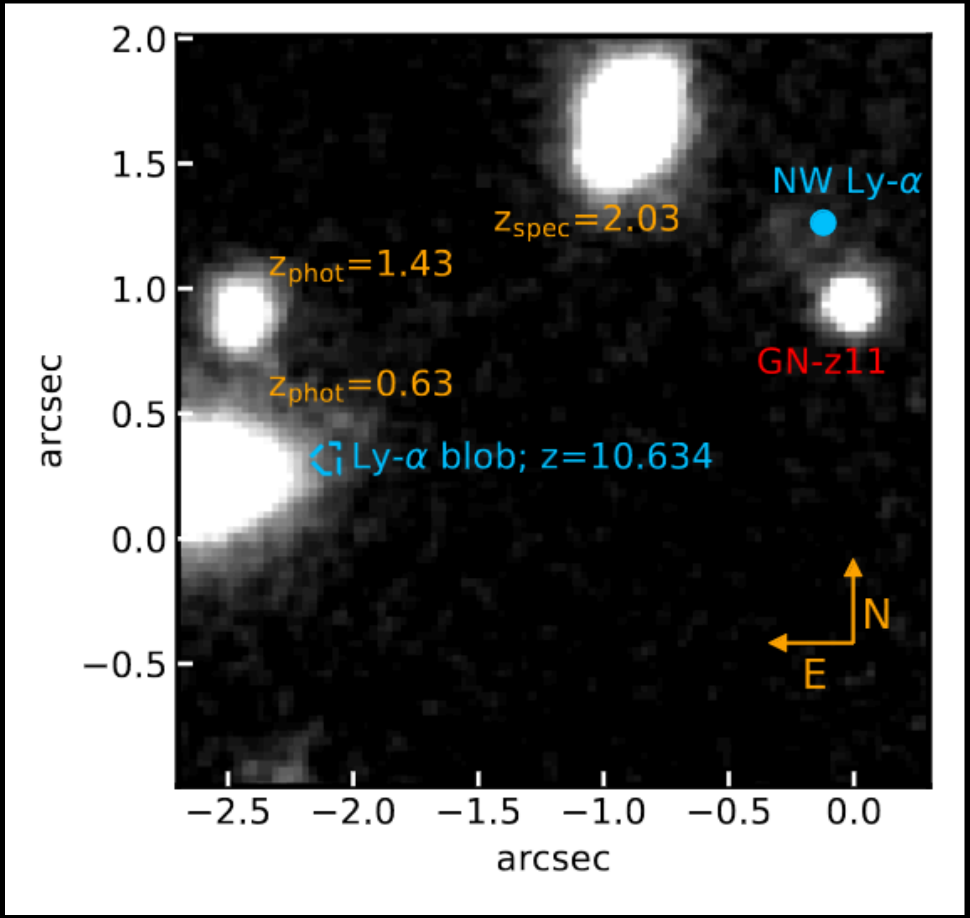
So far only 3 black holes at z>8 have been spectroscopically confirmed within the first year of JWST suggesting they are not rare.

The future of AGN in the early universe studies

Planned launch : **2035**

Two instruments :
- **X-IFU (spectrograph)**
- **WFI (imager)**

An AGN at the core of a protocluster at z=10.6 ?



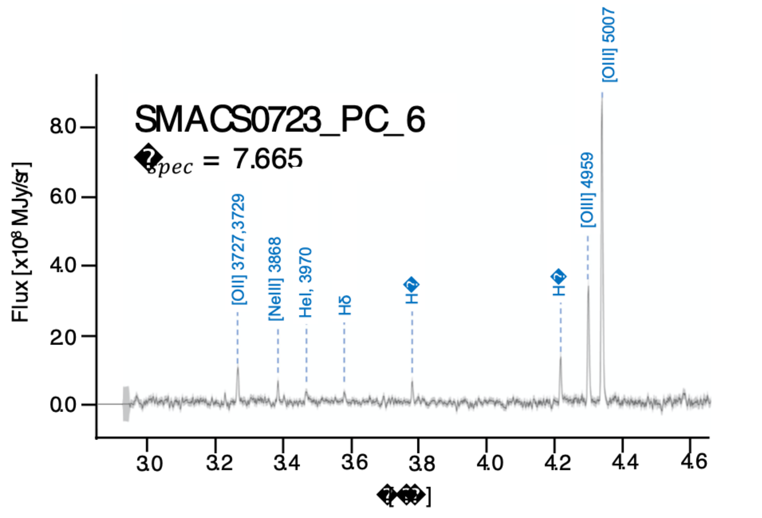
Scholtz et al. (2023)

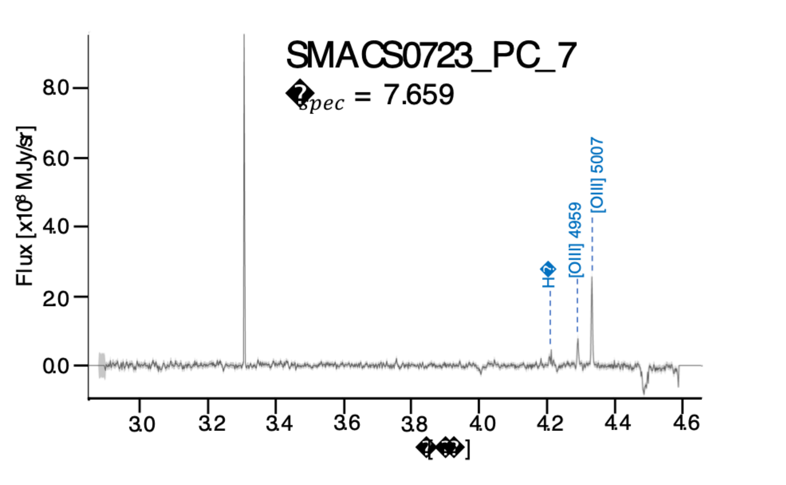
Recent DDT observations with NIRSpec-IFU/JWST shows that several Ly-α emitters are detected in the vicinity of GNz11 (the most distant object with detected Ly-α)

A preliminary analysis of this field shows that the overdensity parameter is at least 27, the densest field at such high-redshift

More JWST observation to follow in February 2024 !

Another example of AGN at the core of a protocluster ?





Two gala
at the sa

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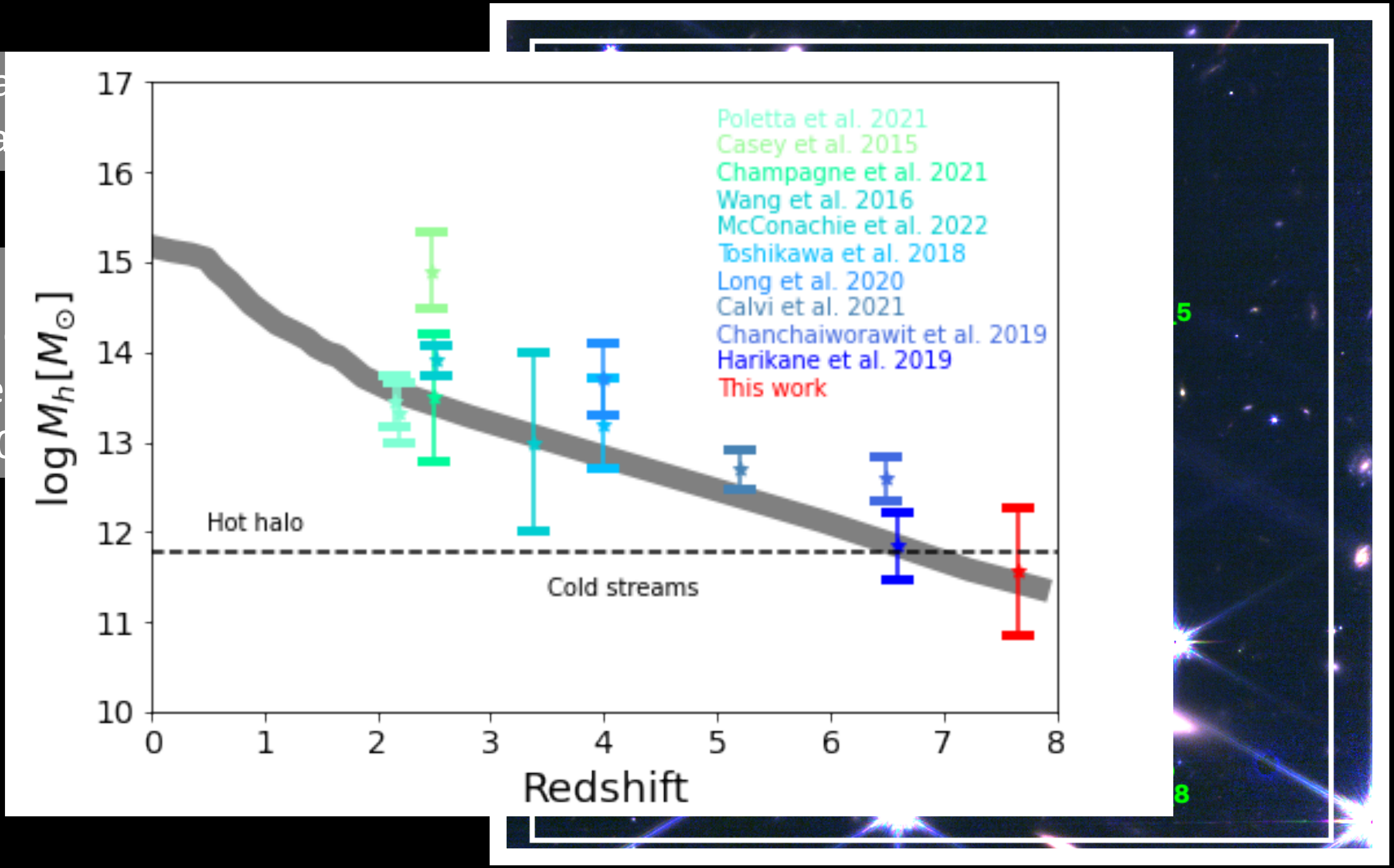
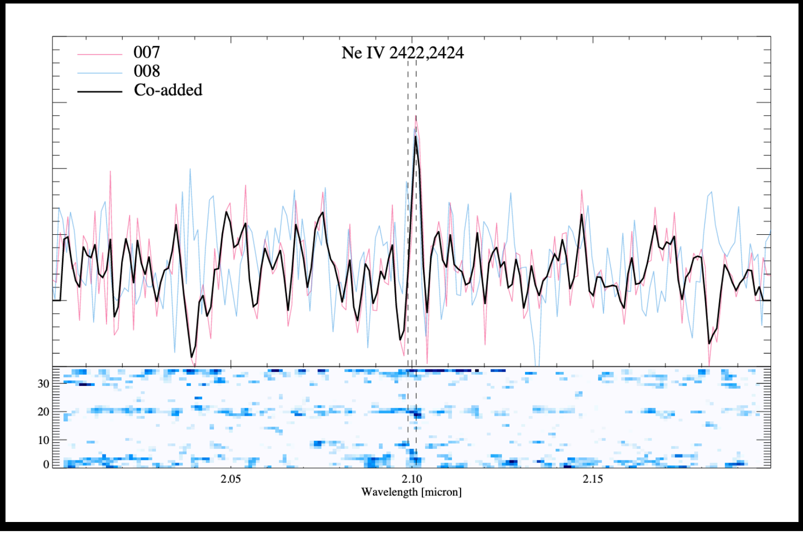
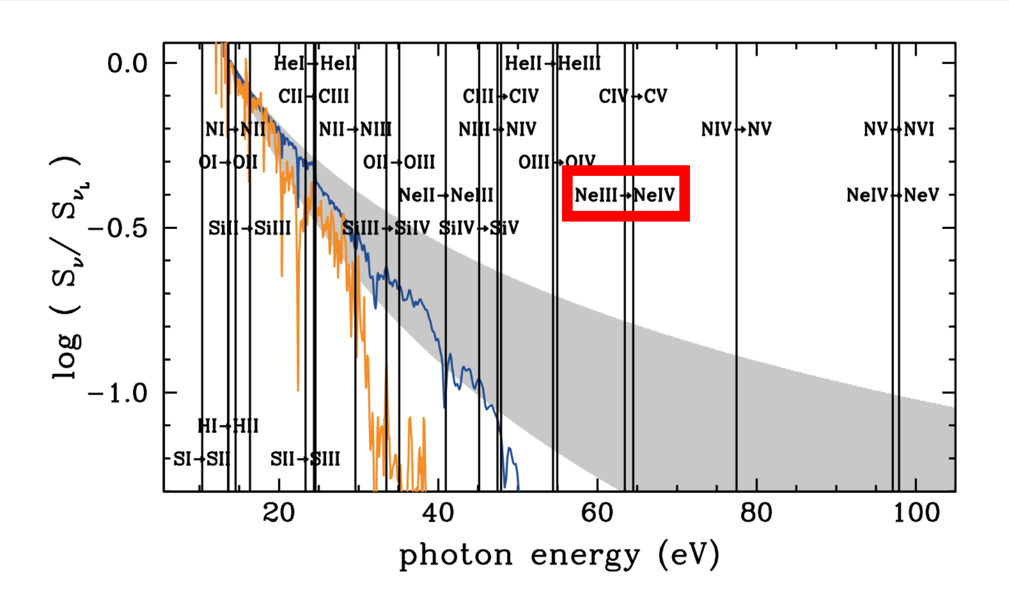


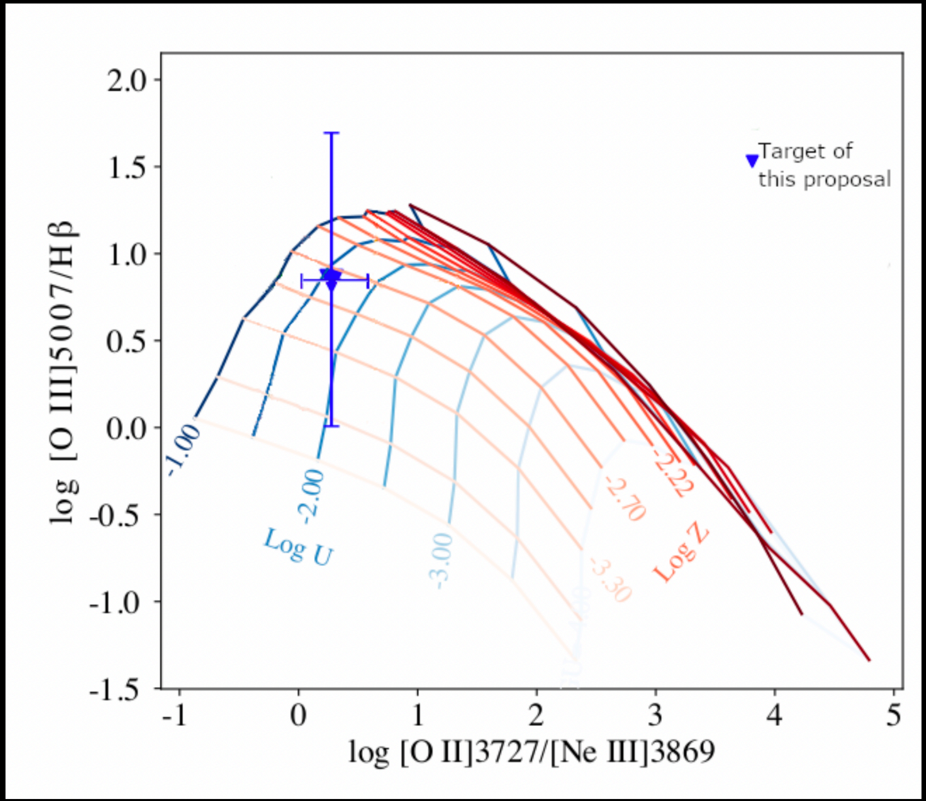
The total dark matter haloe mass of this protocluster agrees well with the expectation from the evolution of a Coma-like cluster.

Laporte et al. (2022)

Another example of AGN at the core of a protocluster ?



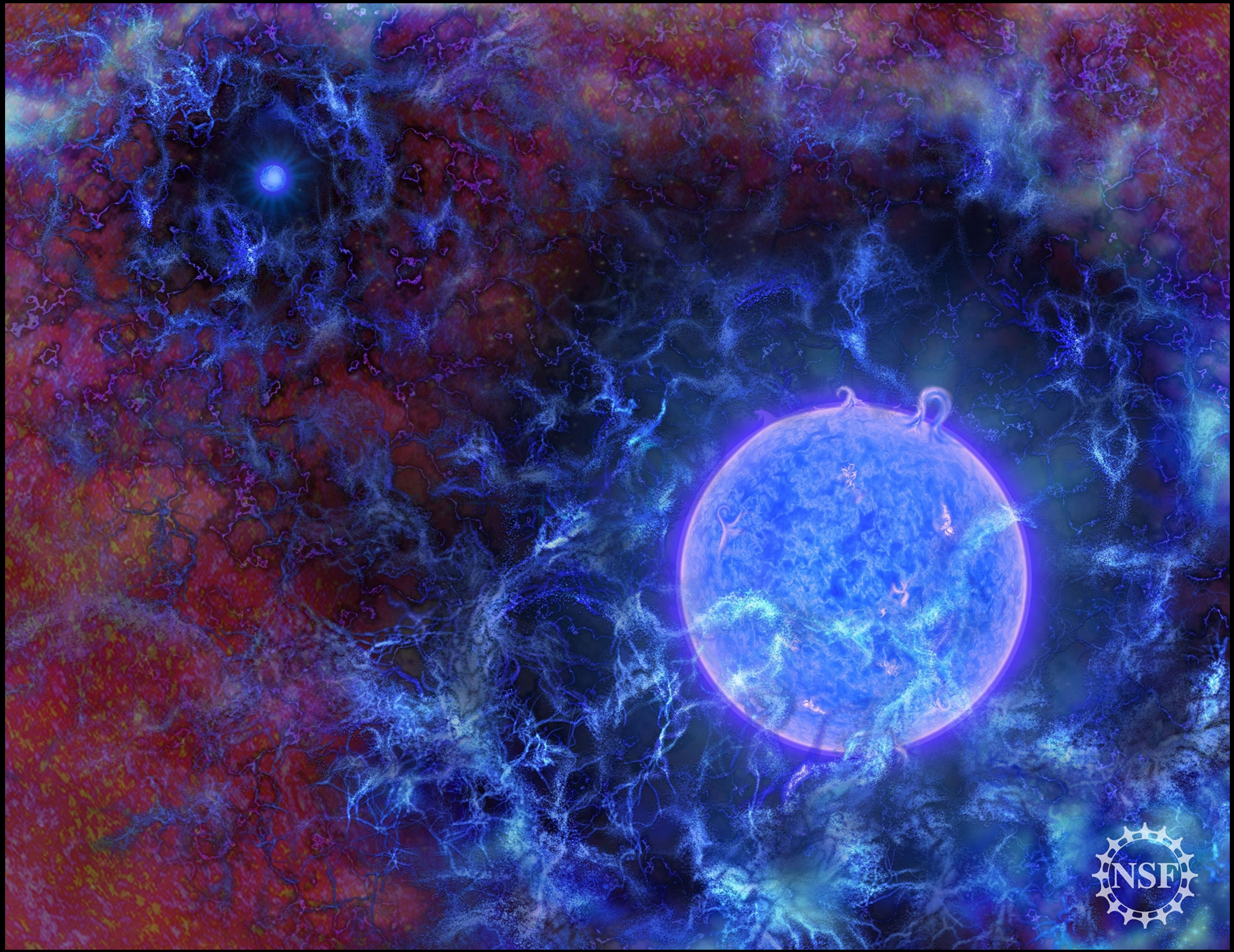




Brinchmann (2022)

One member of this protocluster may host an AGN at z=7.66

The next frontier : the first stars (population III)



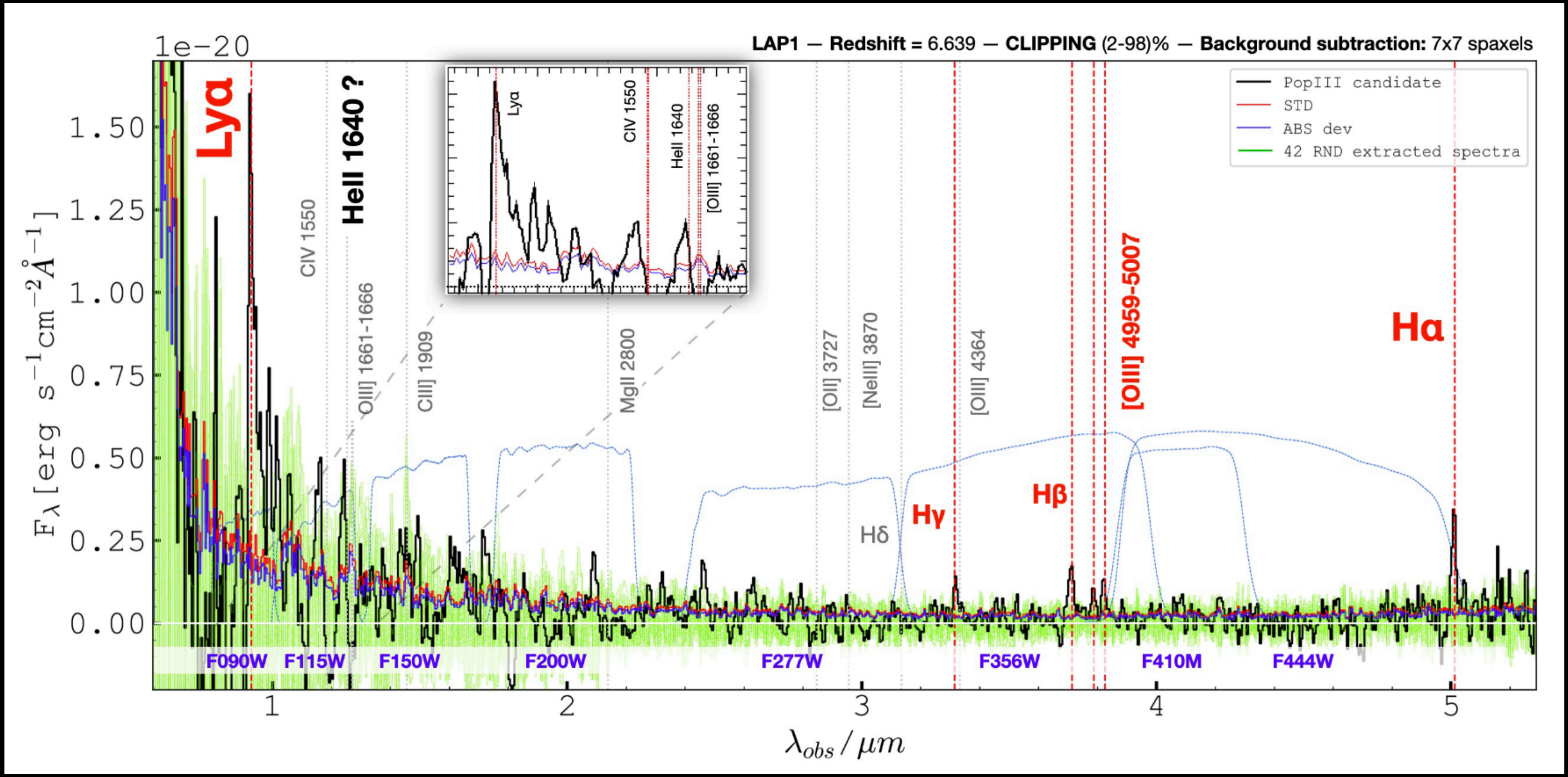
The first stars form from pristine gas mostly composed of neutral hydrogen and helium

The metallicity of these stars should be very low ($<0.02 Z_\odot$)

They are extremely massive (up to 3000 $M_\odot$) but with a very short lifetime (<10 Myr)

To detect them, we need to observe them at the right epoch….

A first robust detection of pop III stars ?

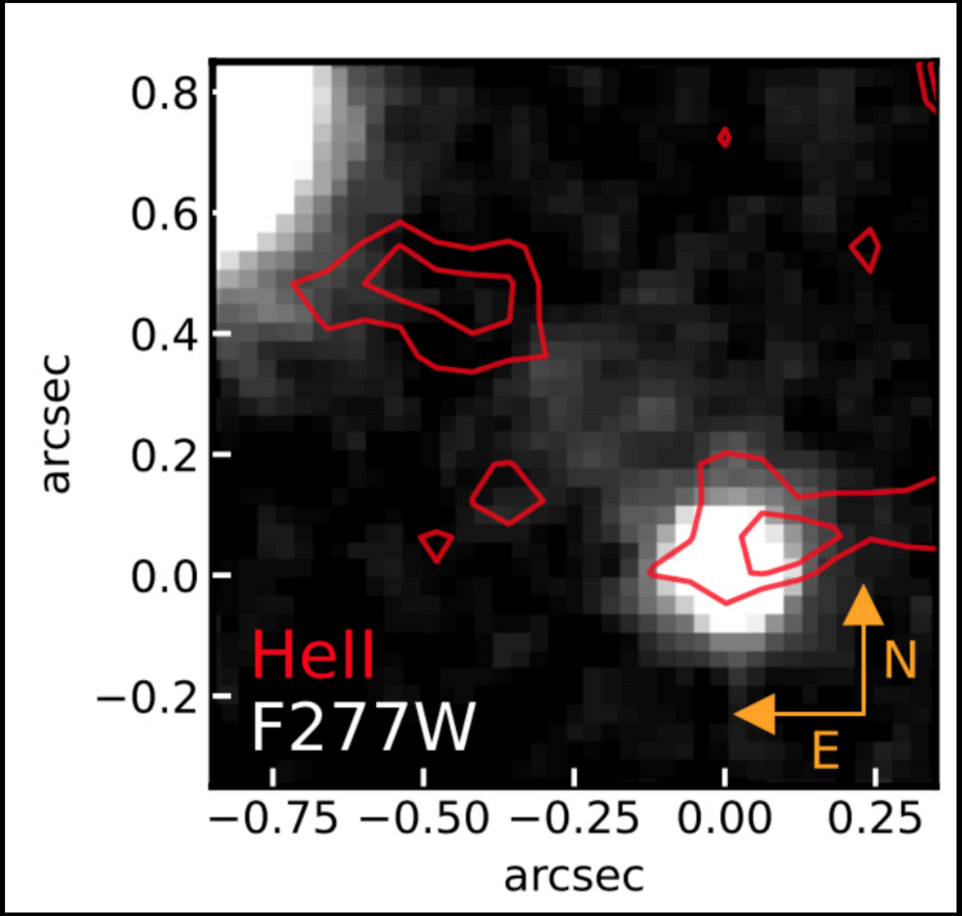


Vanzella et al. (2023)

The strong detection of hydrogen lines (H α, Lyα, etc..) and the absence of Carbon or Oxygen lines suggest that this object is a very metal poor galaxy.

The redshift is puzzling. Can we have bubble of pristine gas at z=6.64 ?

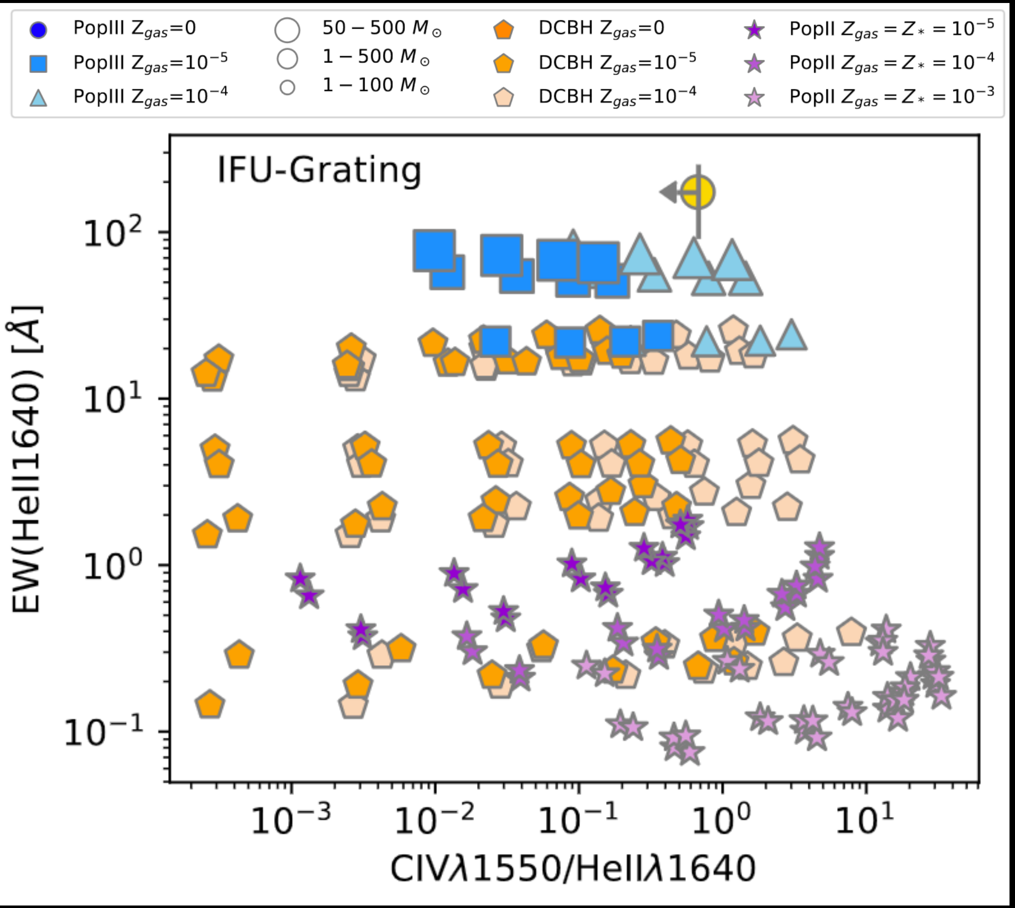
Another tentative detection at higher redshift (z=10.6)



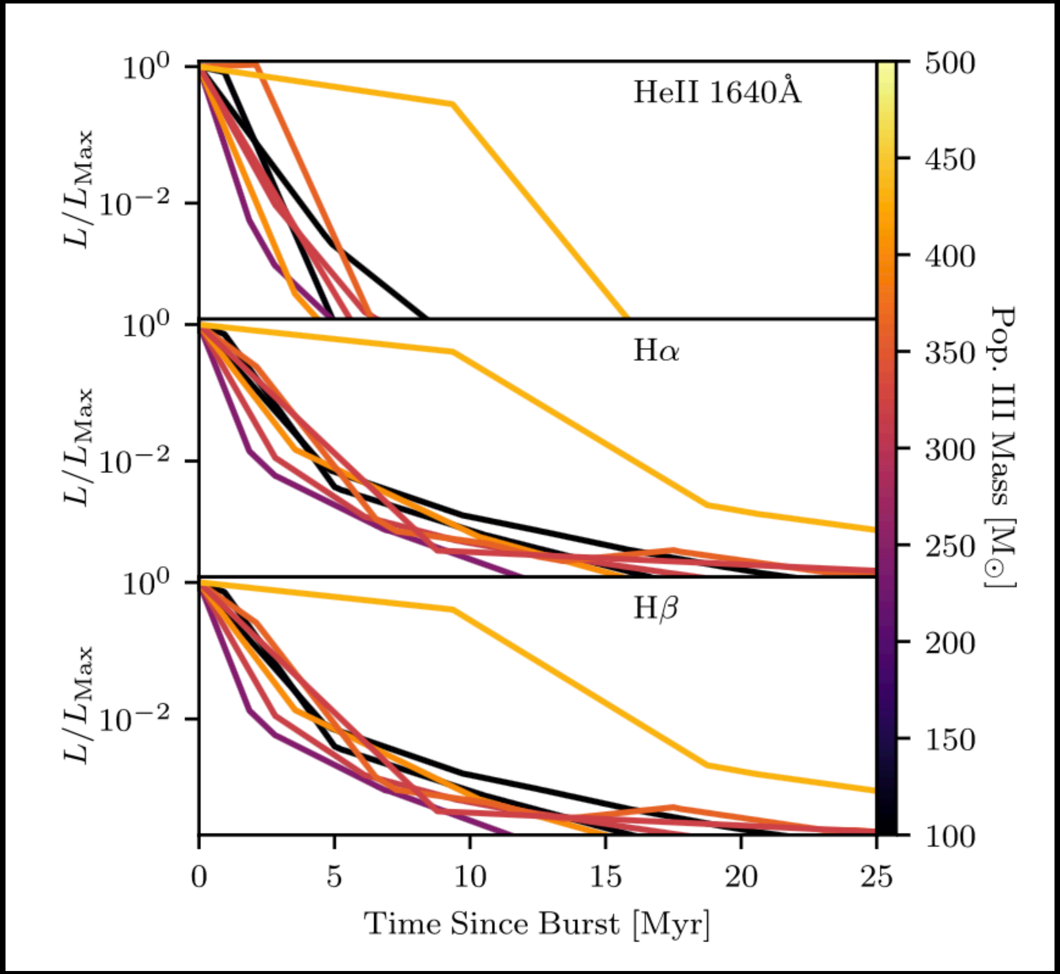
Maiolino et al. (2023)

The line ratio in this galaxy seems consistent with what is expected for popIII stars.

The absence of constrain from other hydrogen lines makes this detection still strongly debated.

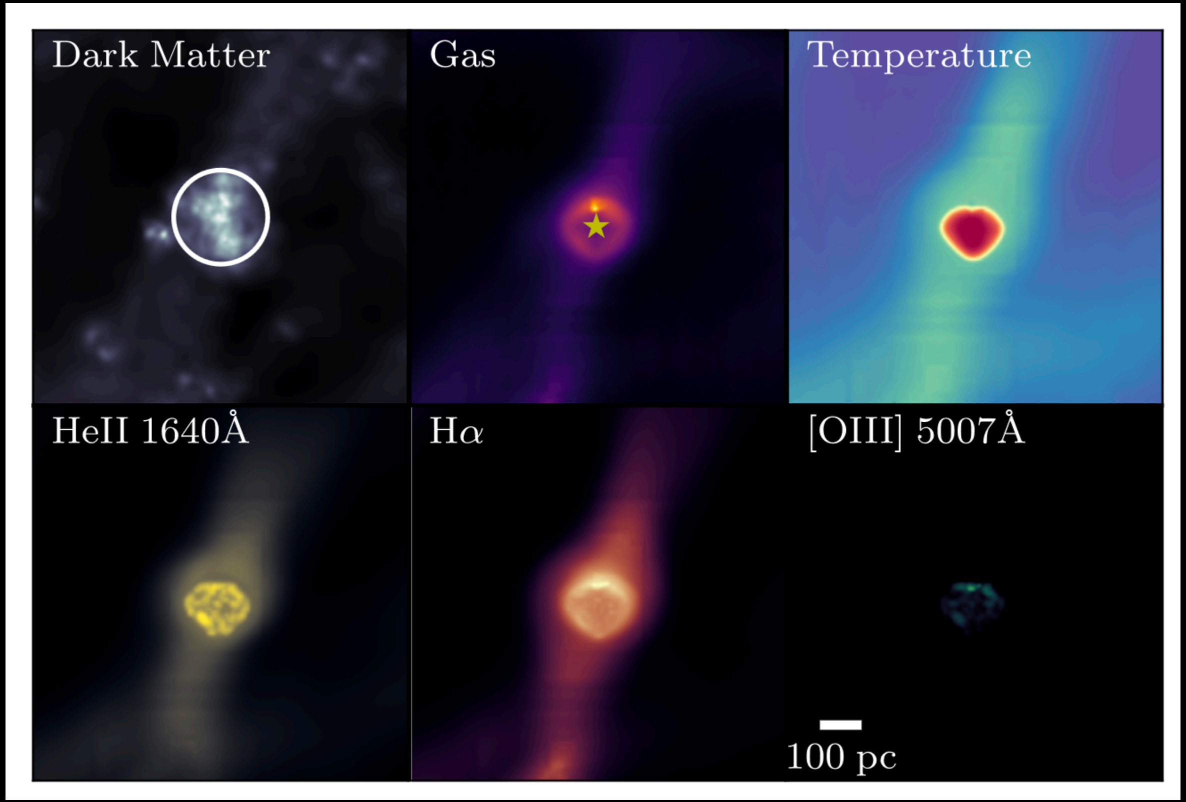


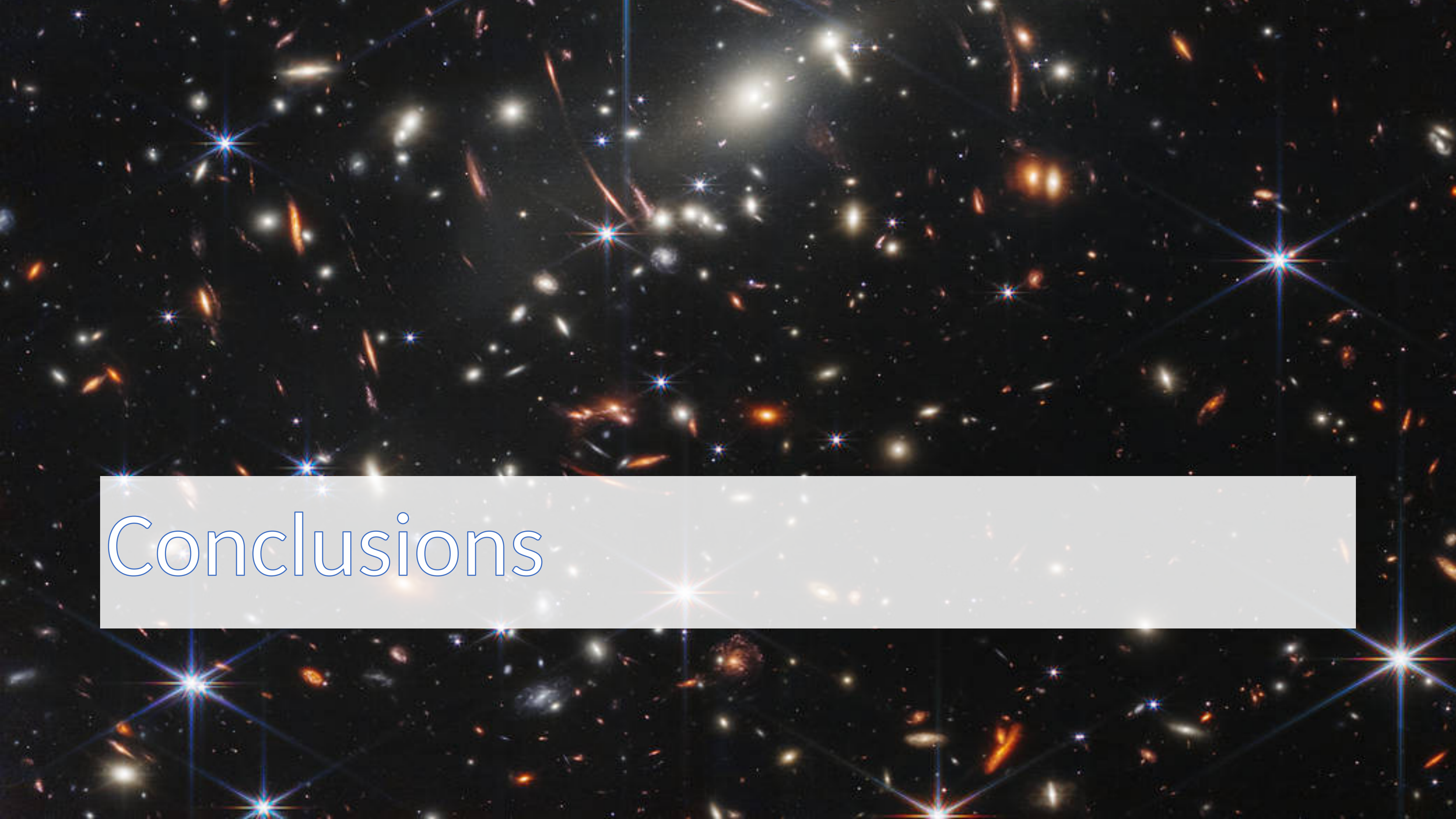
The challenge of identifying popIII stars in the early Universe



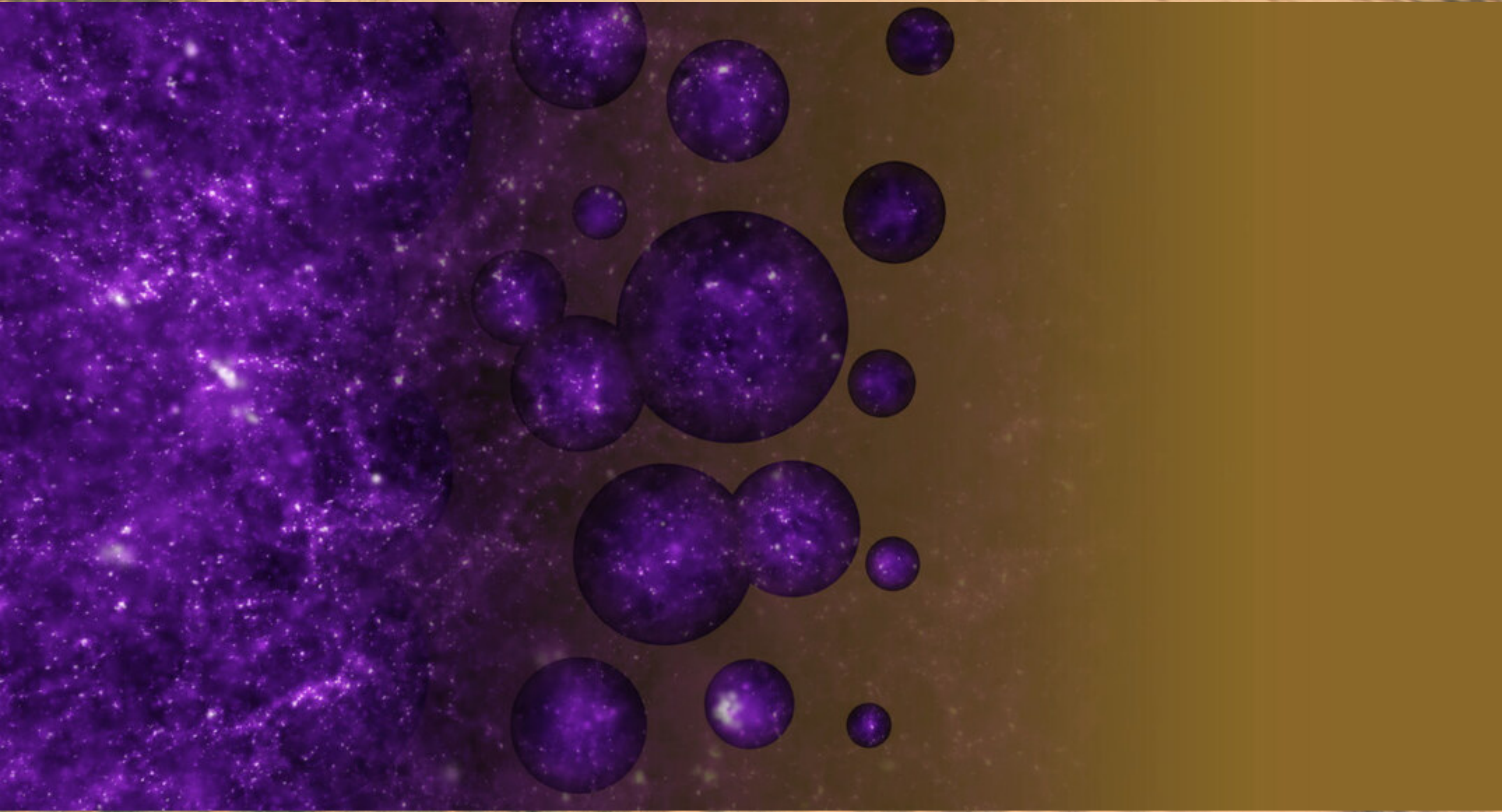
Katz et al. (2023)

According to hydrodynamic simulations, the luminosity of hydrogen and helium lines is maximum for only 2 Myr, and decreases very rapidly after.





Conclusions



The JWST will not address all the questions on the early Universe : other instruments will be needed !

- When did the first galaxies form in the early Universe, and start to ionise the neutral hydrogen ?
  - ✓ Recent observations show evidence of star-formation at z>15, confirmed with the first JWST observations !
  - ✓ High-resolution of these “old” objects at z>9 indicates they may have a disk, although the merger hypothesis could not be totally excluded

- How common are AGN at z>8 and what are their properties ?
  - Frequency of AGN detection at high- z
    - ✓ After ~2 years of JWST observations, most of the brightest galaxies identified with HST host a black hole
    - ✓ But the sensitivity of JWST may not be sufficient to identify fainter AGN
  - How can we explain SMBH at z>8
    - ✓ Super Eddington accretion is needed from stellar mass seeds at z>15

The shape of Ly-α at z=6-7 with high-resolution spectrograph

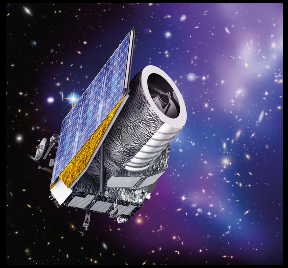
MEGARA

The continuum of z=6-7 galaxies by stacking 1000s spectra

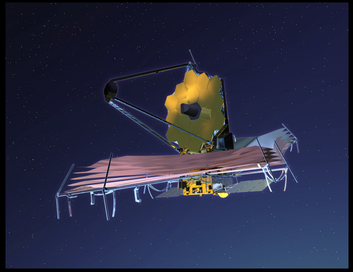
SKA
SQUARE KILOMETRE ARRAY

The spatial distribution of ionising sources by identifying ionised bubbles at z>6

Identifying AGN candidates at z>6 in its large surveys



Direct detection of AGN at high-redshift

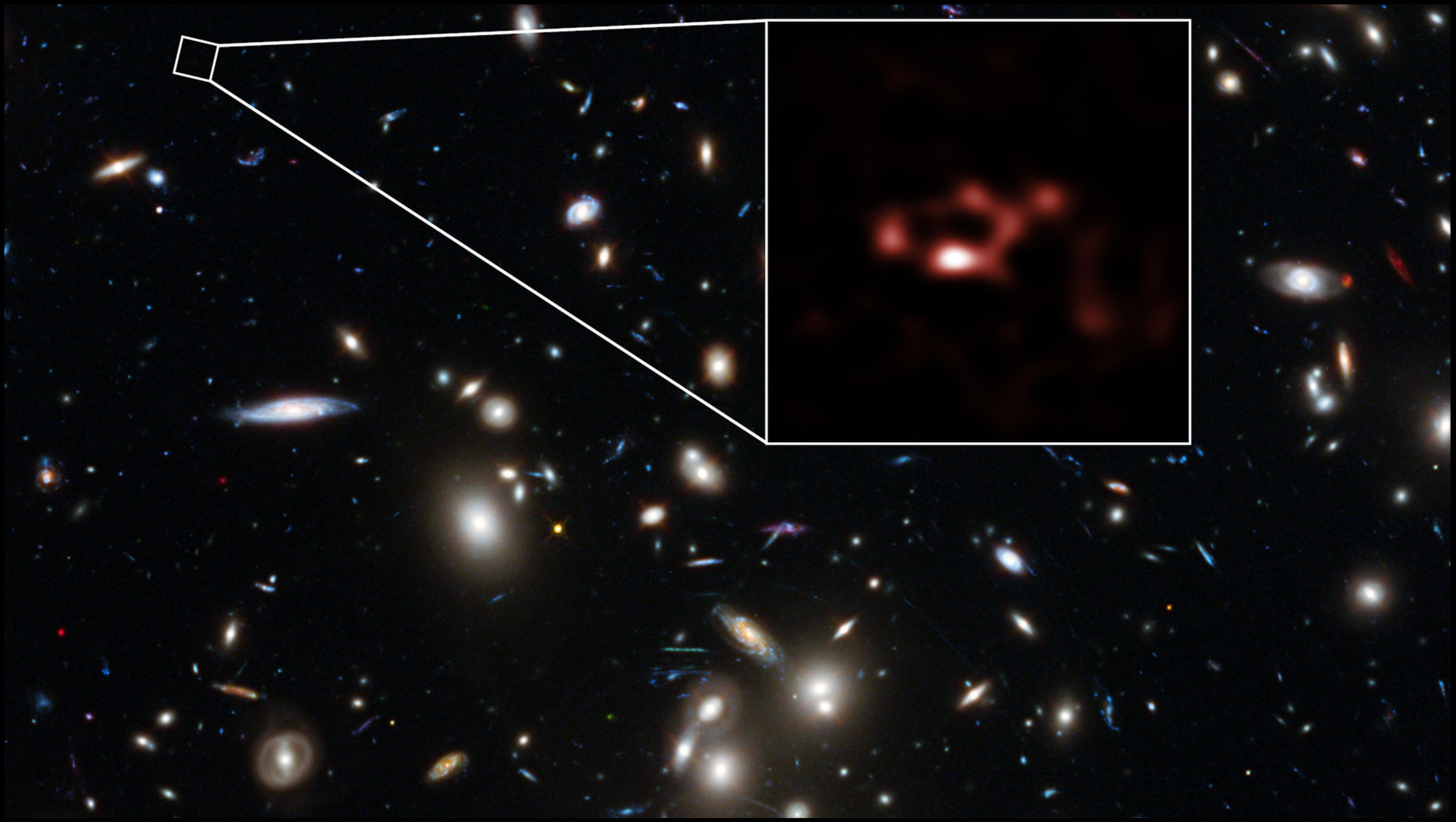


Direct observations of Cosmic Dawn

Number densities of the faintest galaxies at z>8

The metallicity of 1000s of z>6 galaxies with extremely Large Telescope

Dust content of galaxies in the early Universe



Laporte et al. (2017)

A2744_YD4

- **Redshift :** $z \sim 8$
- **Age of the Universe : 650 Myr**

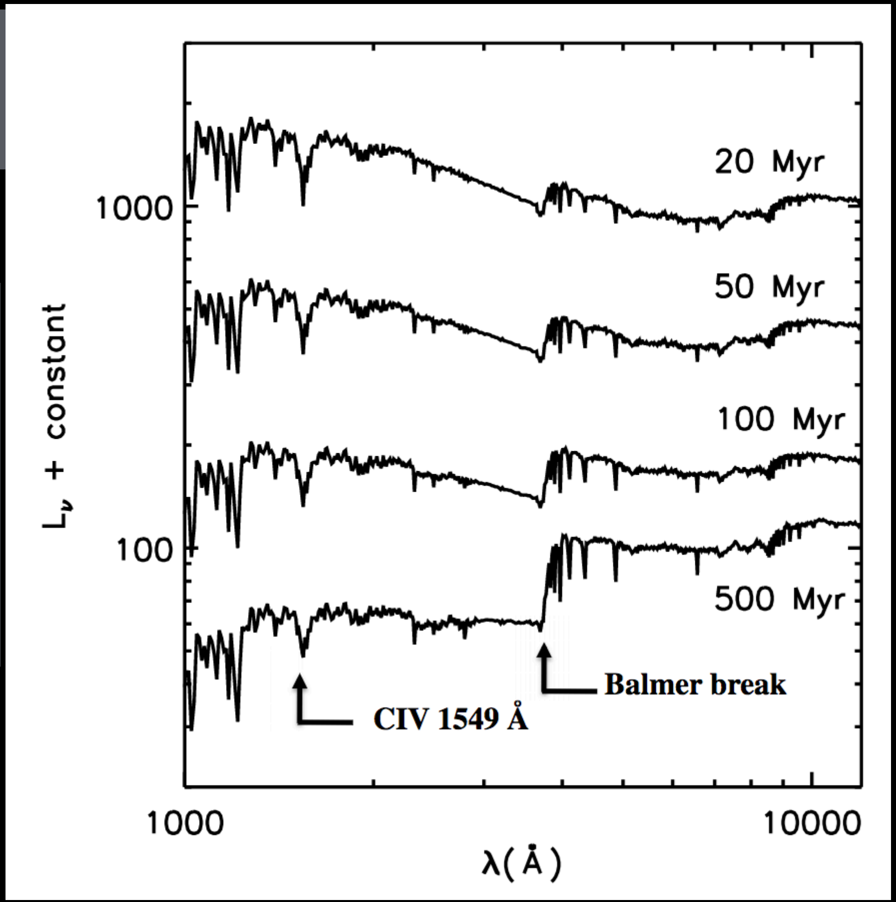
- **Mass :** $2 \times 10^9 \, M_\odot$
- **Dust mass :** $6 \times 10^6 M_\odot$

Indirect probe of "Cosmic Dawn"
the age of the most distant galaxies

Definition of the age of a galaxy : period during which a galaxy is forming stars

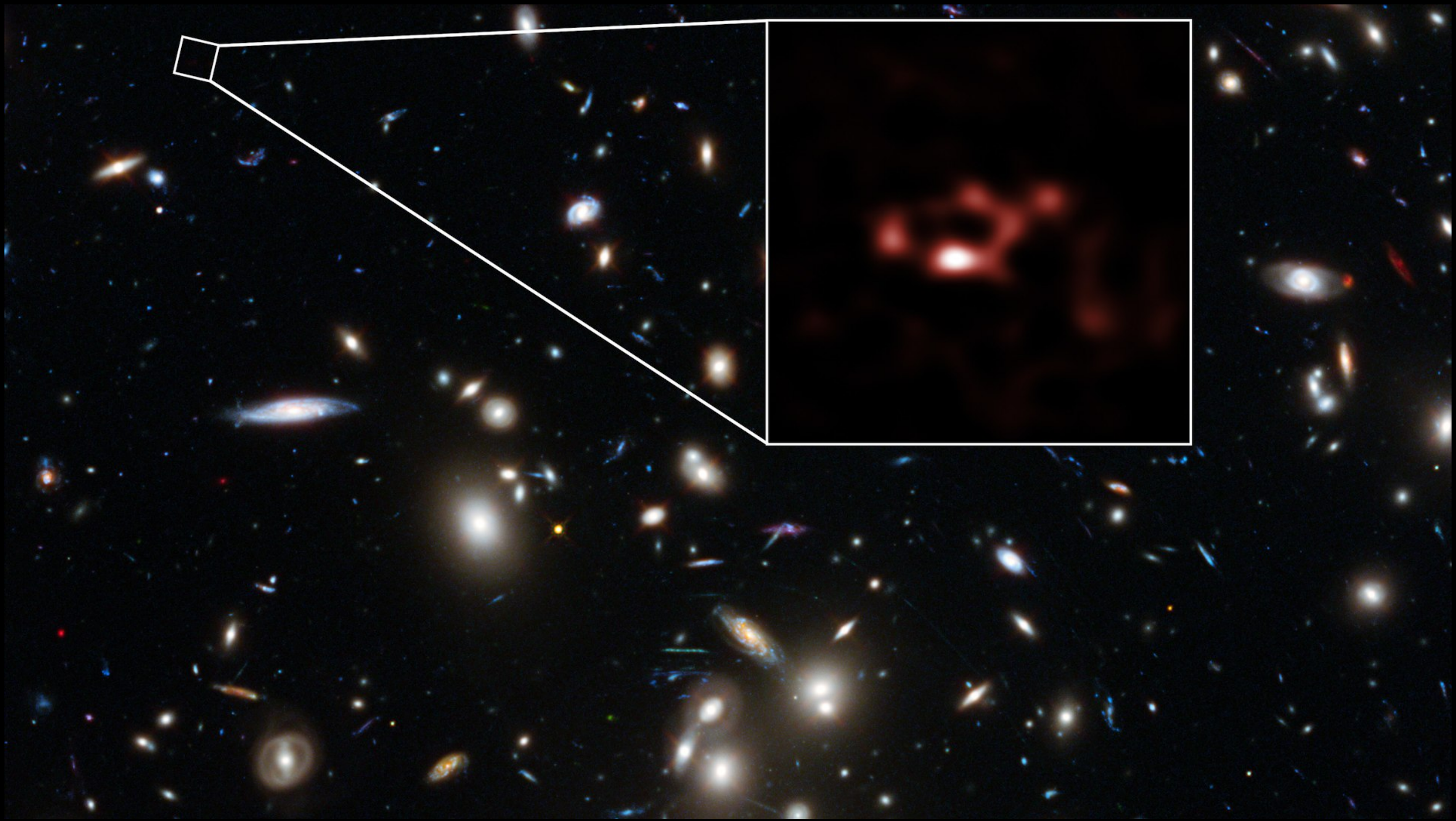
Two methods can be used to determine the age of a very high-redshift galaxy :

- constraining the size of the Balmer Break
- measuring the dust content



Scoville et al. (2015)

Dust content of galaxies in the early Universe



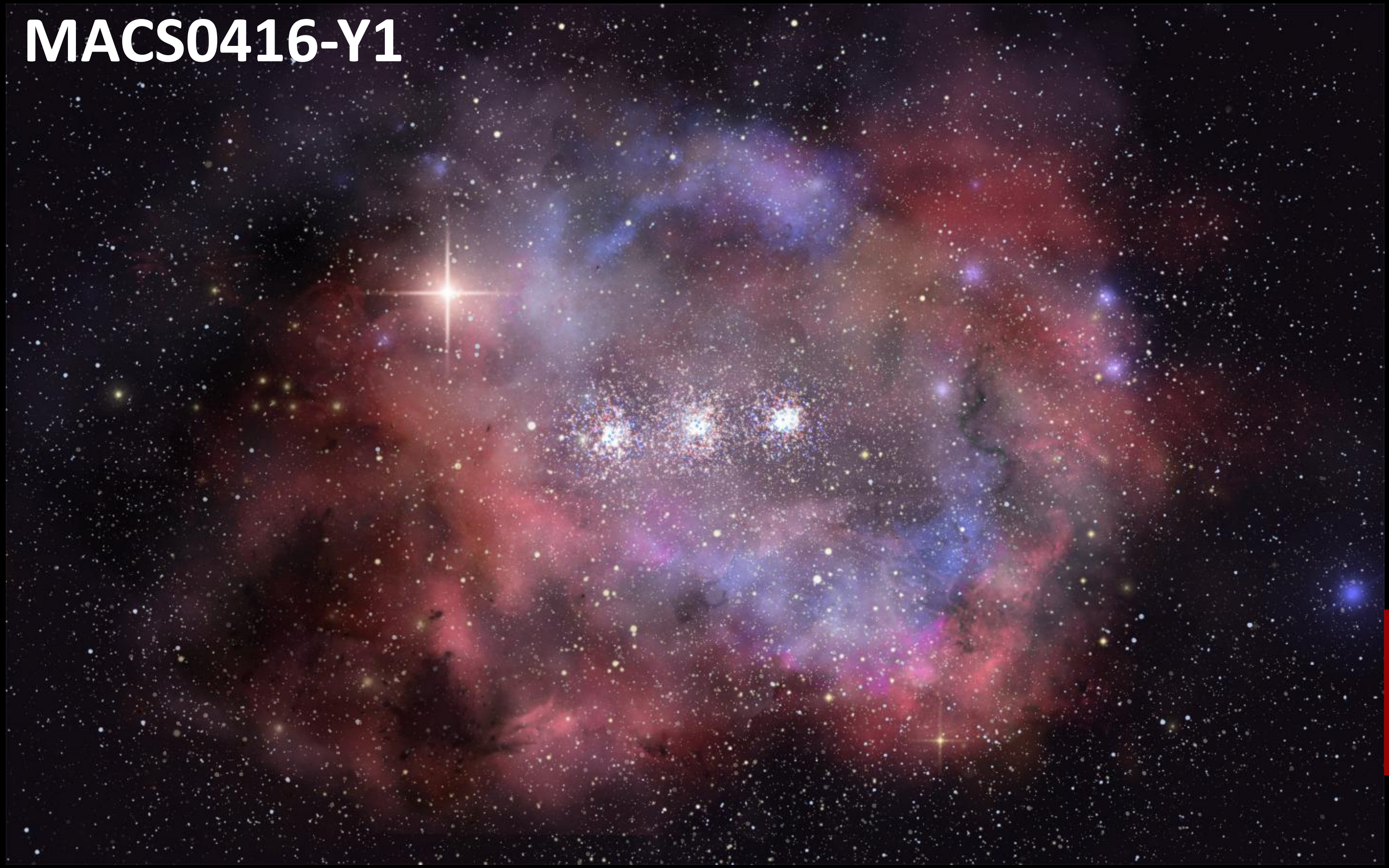
Laporte et al. (2017)

A2744_YD4

- **Redshift :** $z \sim 8$
- **Age of the Universe : 650 Myr**
- **Mass :** $2 \times 10^9 \, M_\odot$

Age : 300 Myr

Indirect probe of "Cosmic Dawn" the age of the most distant galaxies



Tamura et al. (2018)

The amount of dust produced per supernova is still uncertain

It varies between :

$0.5\,M_{\odot} \;->\; 2\,M_{\odot}$

This method is not accurate !