The James Webb Space Telescope: Revealing the Secrets of an Invisible Universe

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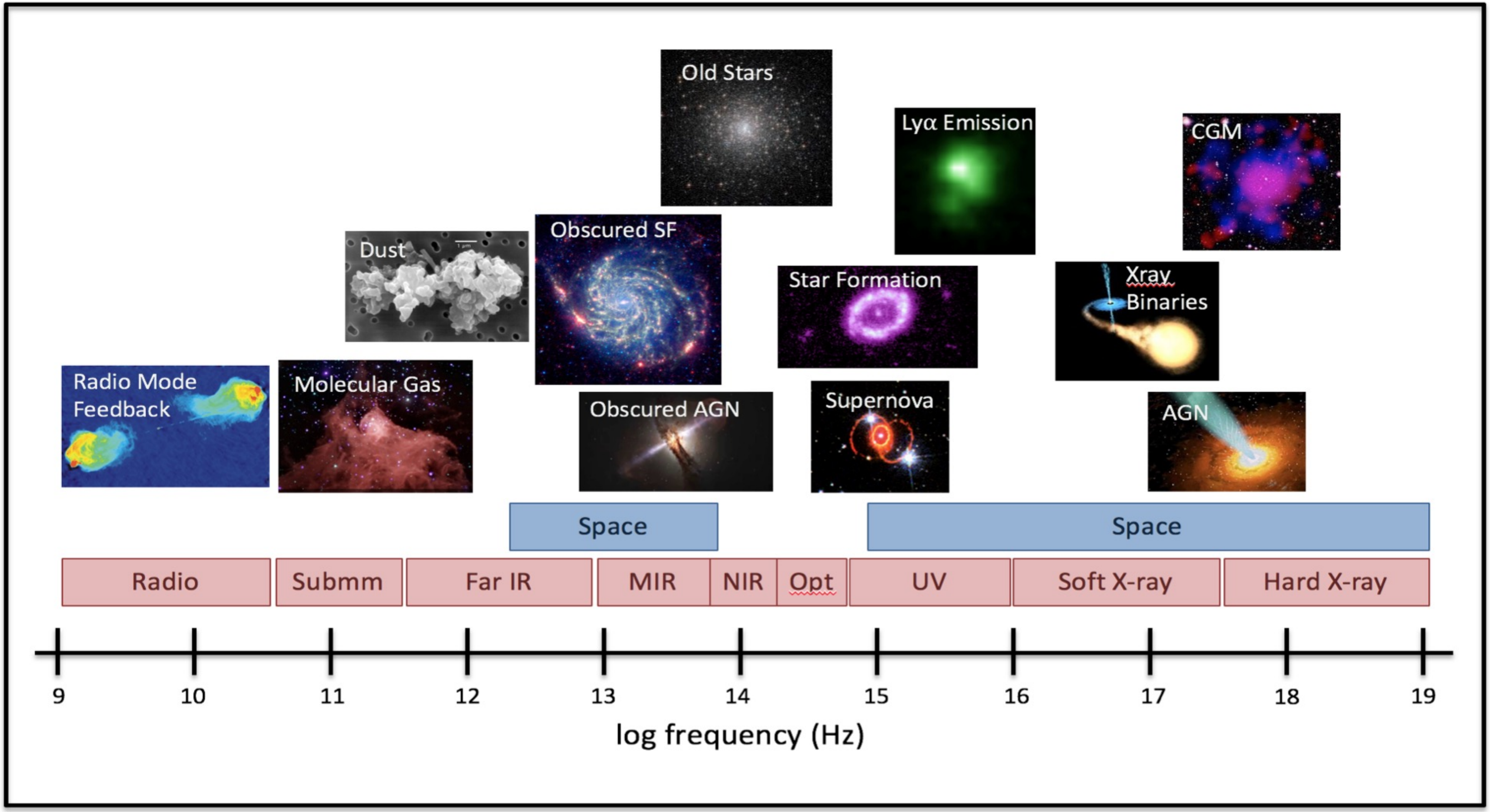
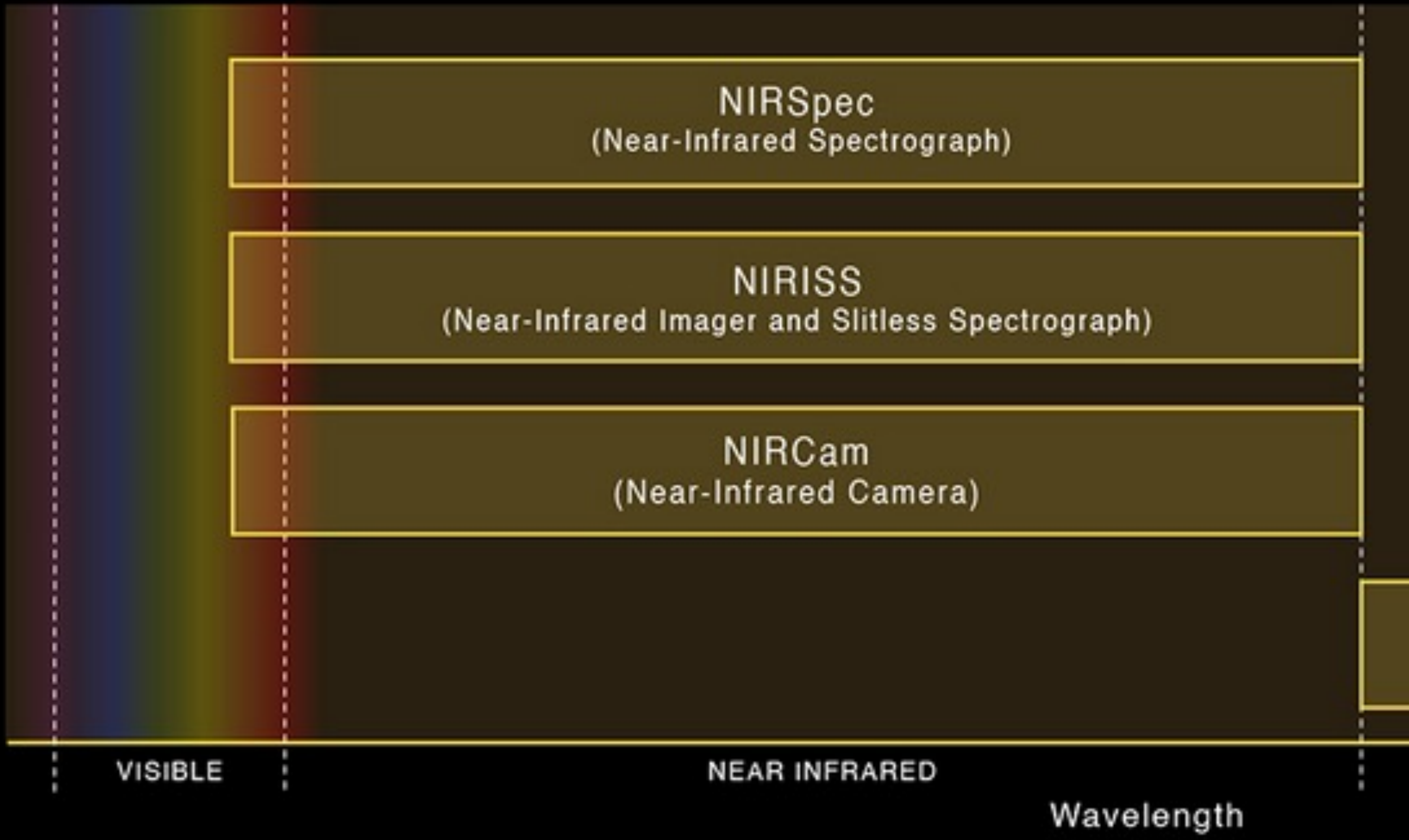
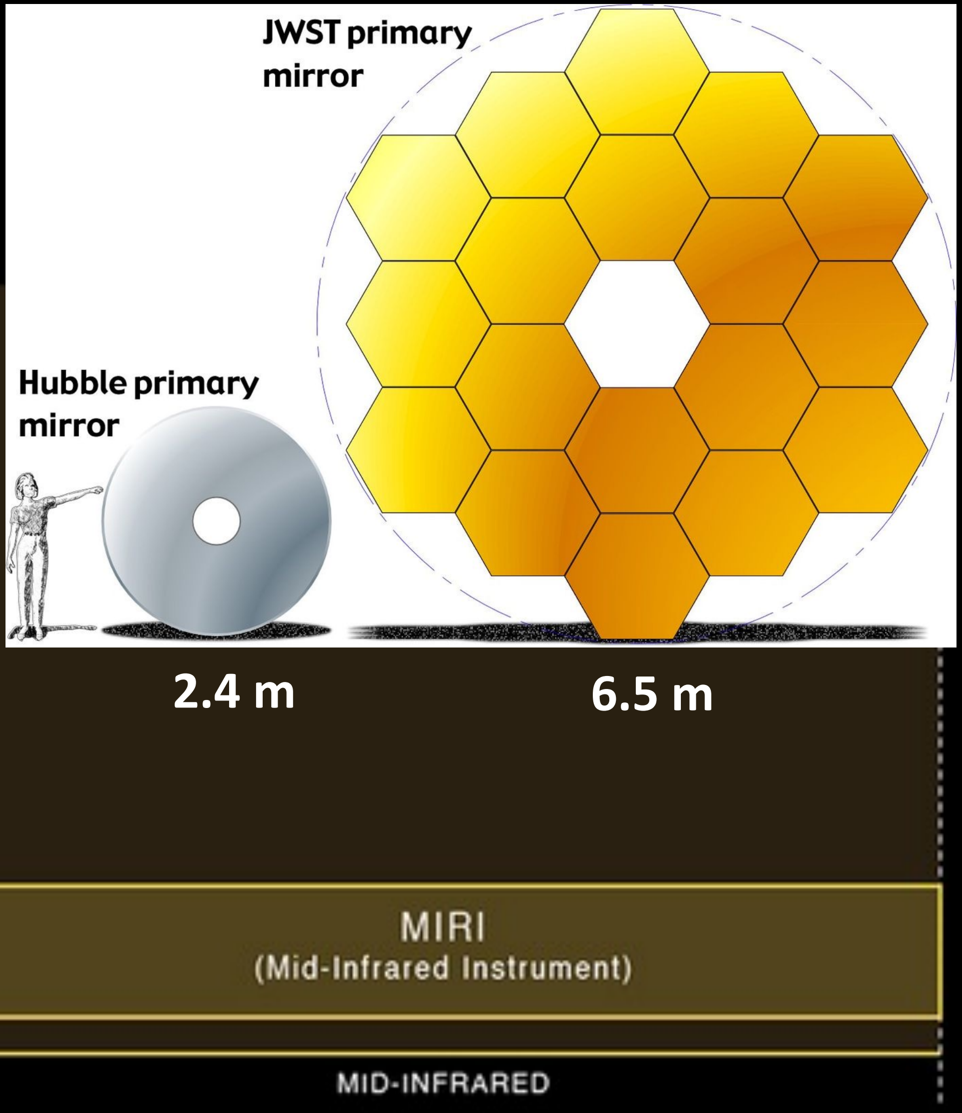
and the Cosmic Evolution Early Release Science Team



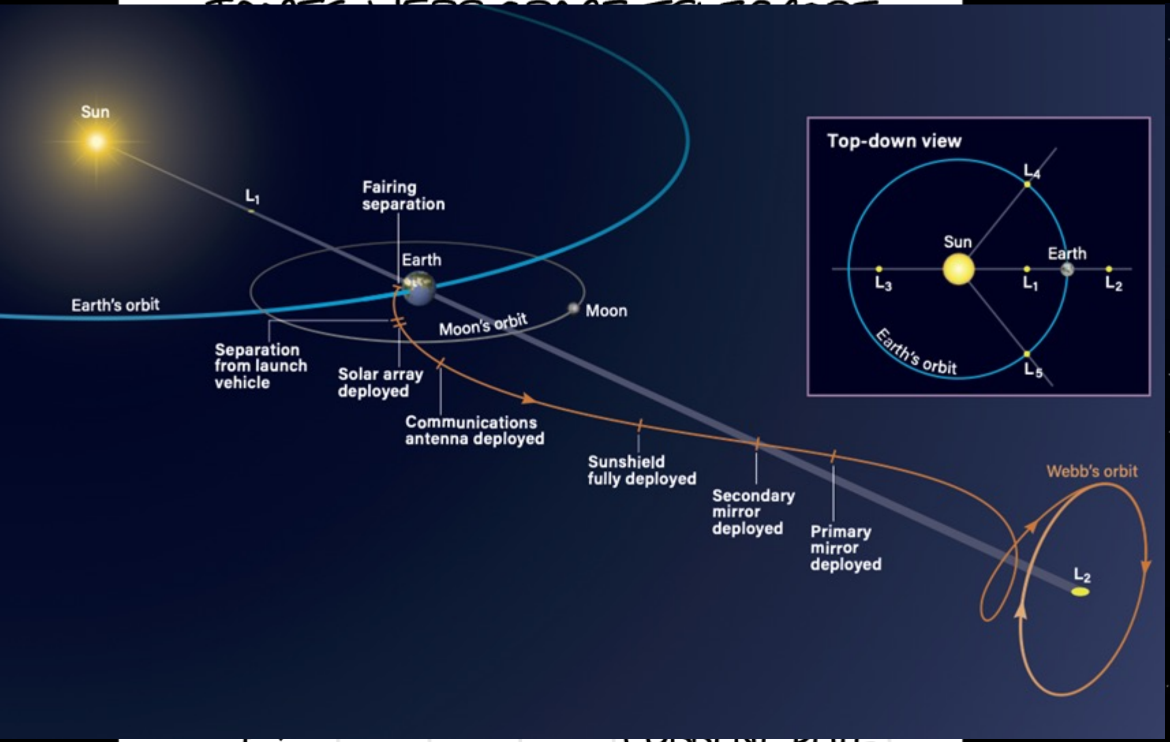
The Great Observatories SAG Report, 2019

JWST Quick Facts

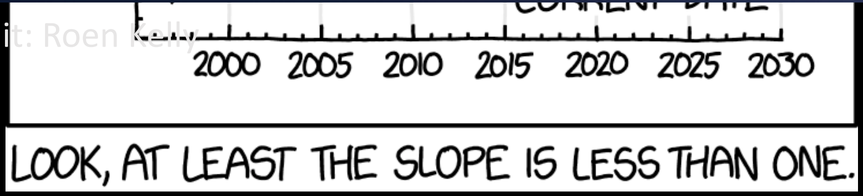




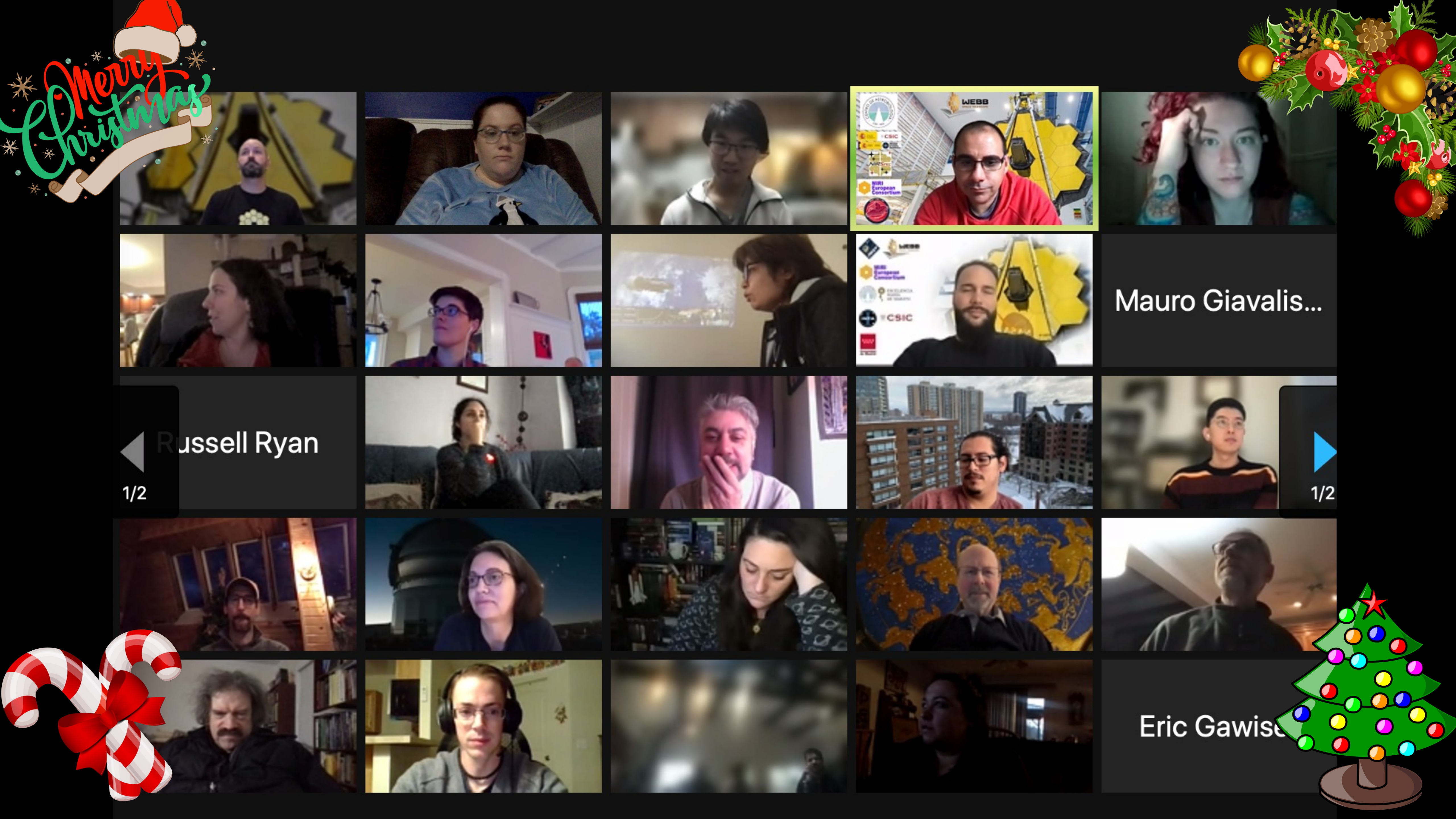
JWST: Just Wait and See Telescope



Credit: Roen Kelly



Credit: XKCD

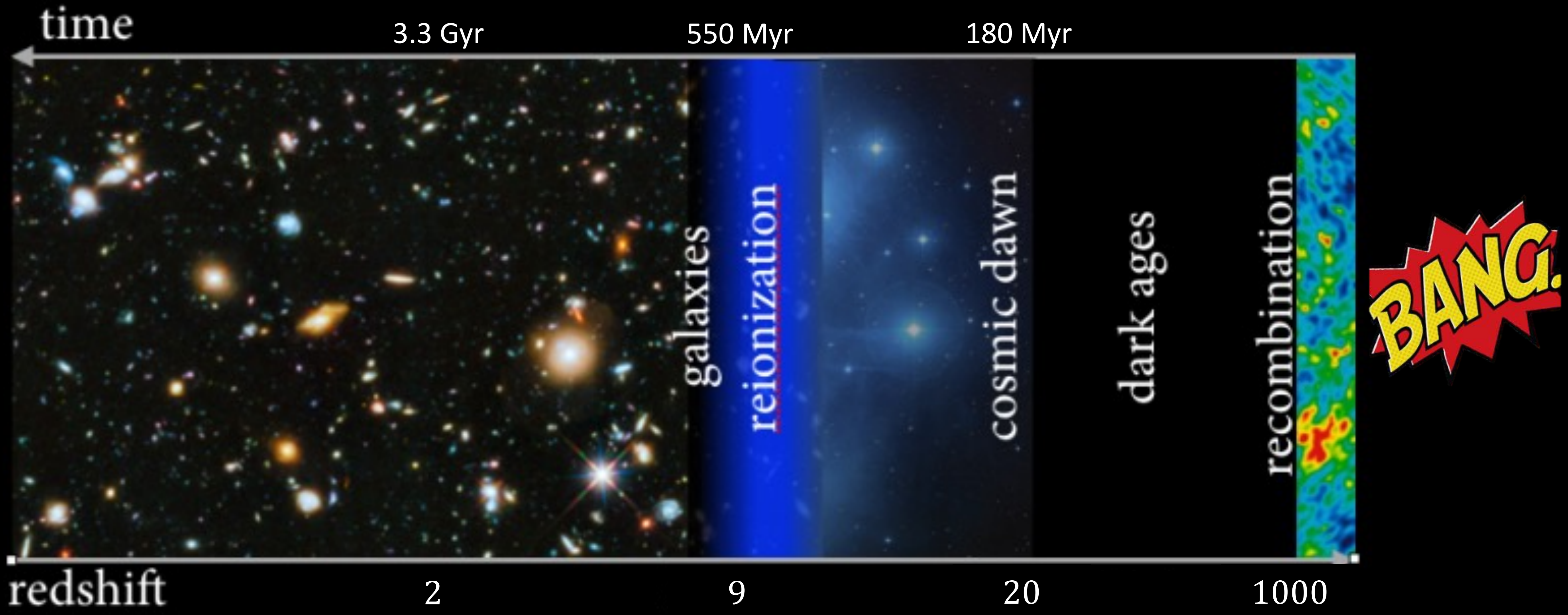

Merry Christmas
WEBB
CSIC
Mauro Giavalis...
Russell Ryan
1/2
1/2
Eric Gawise

How do black holes and star co-evolve?

When did galaxies obtain their structure?

What galaxies are responsible for reionizing the Universe?

When did the first galaxies appear? What are their properties?



Credit: Stacy McGaugh

Cosmic Dawn: $z > 9$

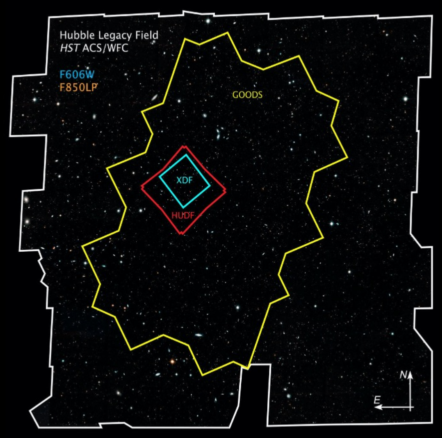
The universe prior to 550 million years

The Hubble Deep Field:

The beginning of the beginning

- Taken in 1995
- Total: 100 hours
- 11.5 $arcmin^2$
- most distant galaxy @ z = 11.1 (414 Myr)

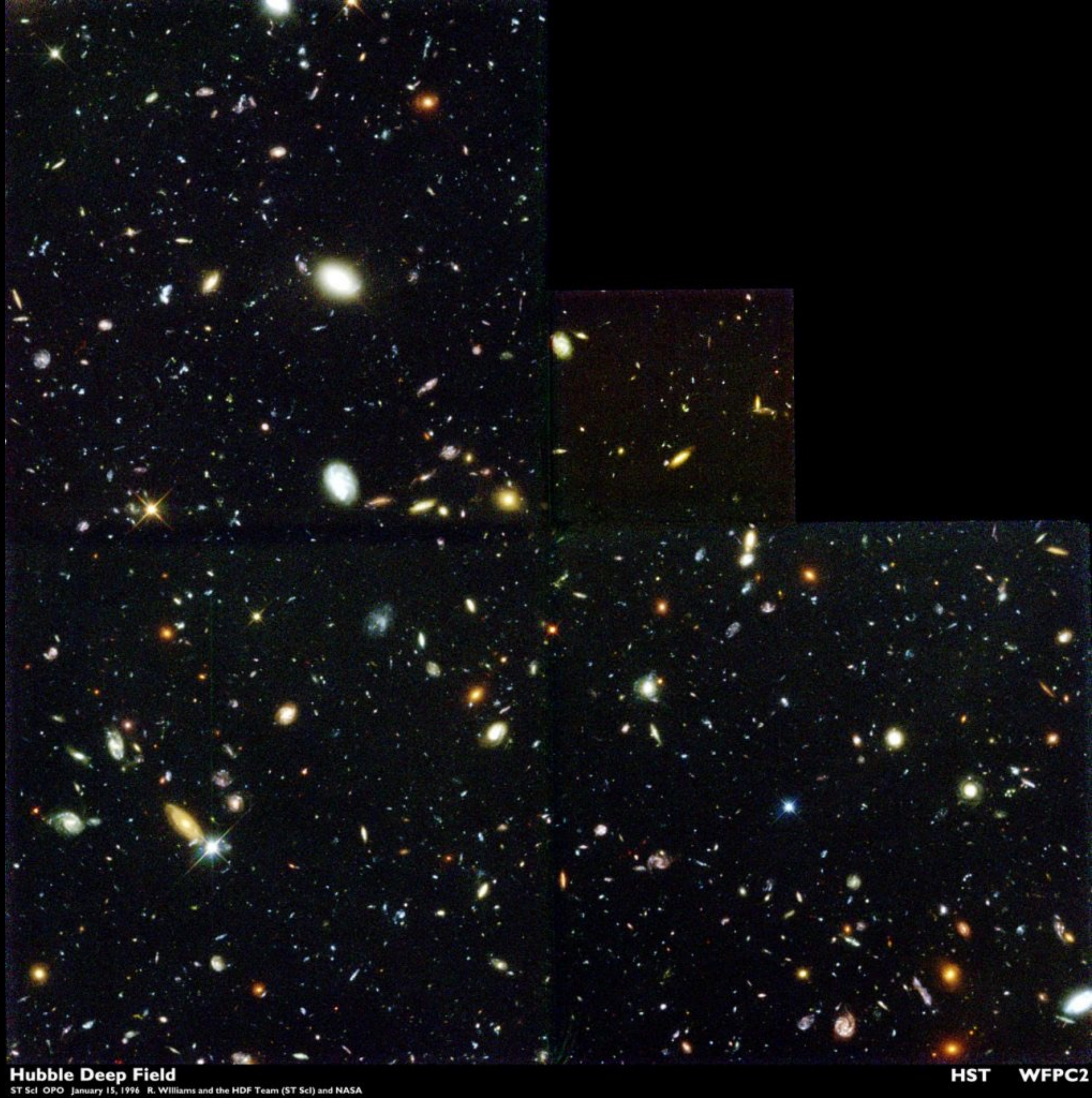
Hubble Legacy Field



30'

The Moon

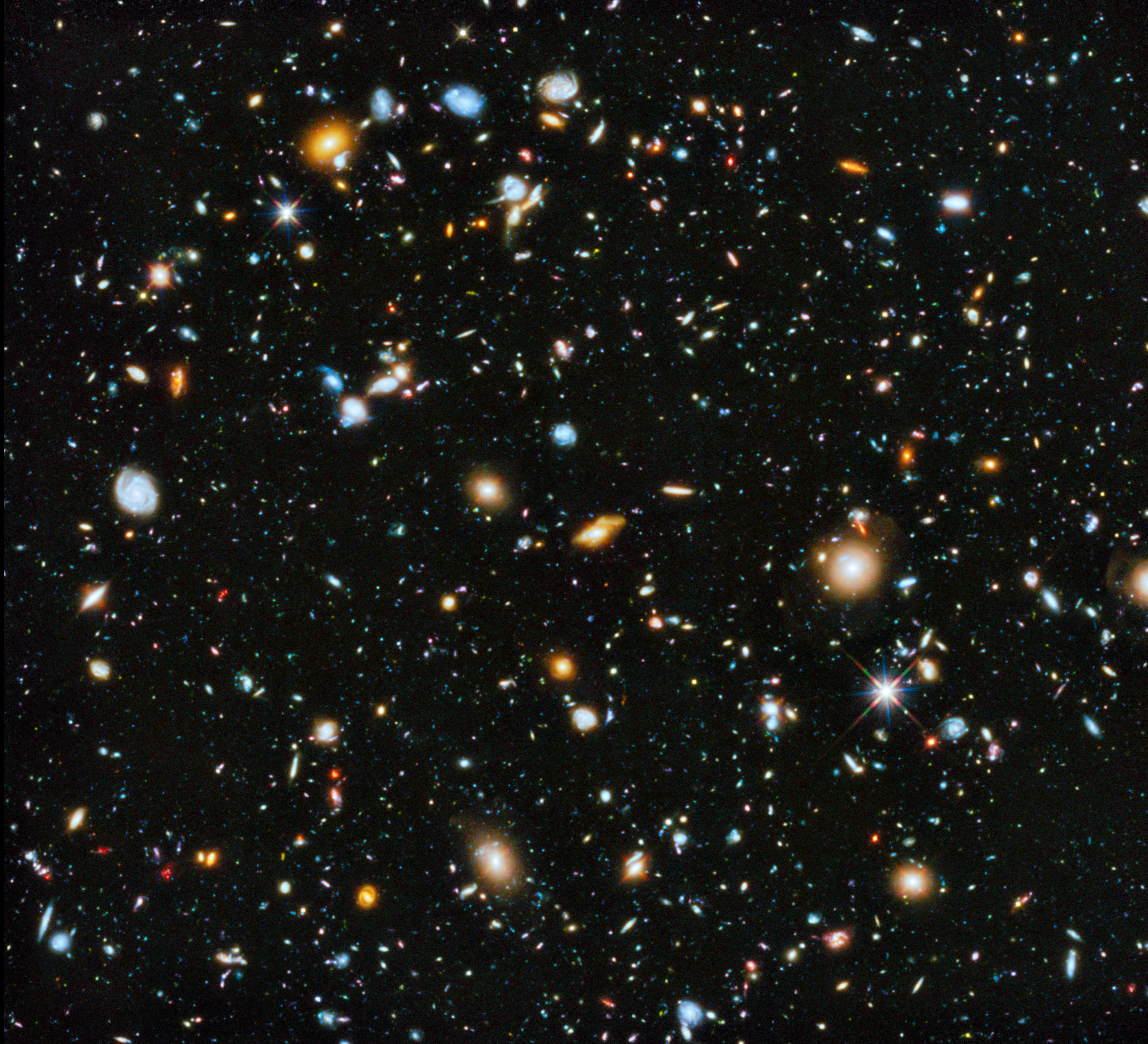
30'

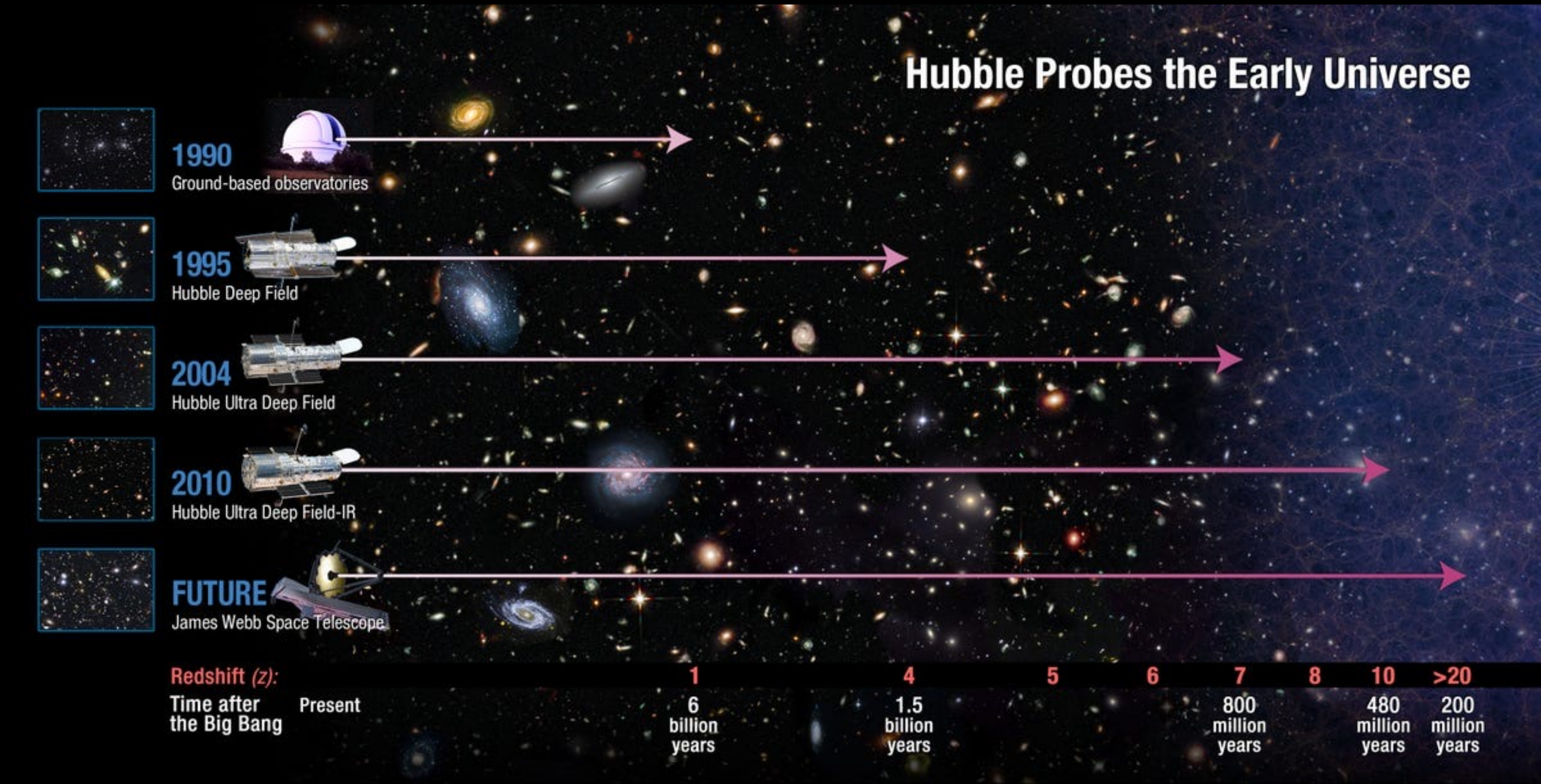


Hubble Ultra Deep Field:

The final frontier

- Taken in 2004
- Total: 11.5 days
- 96 hrs / filter
- 10,000 galaxies
- Optical and UV
- The furthest humanity *had* seen





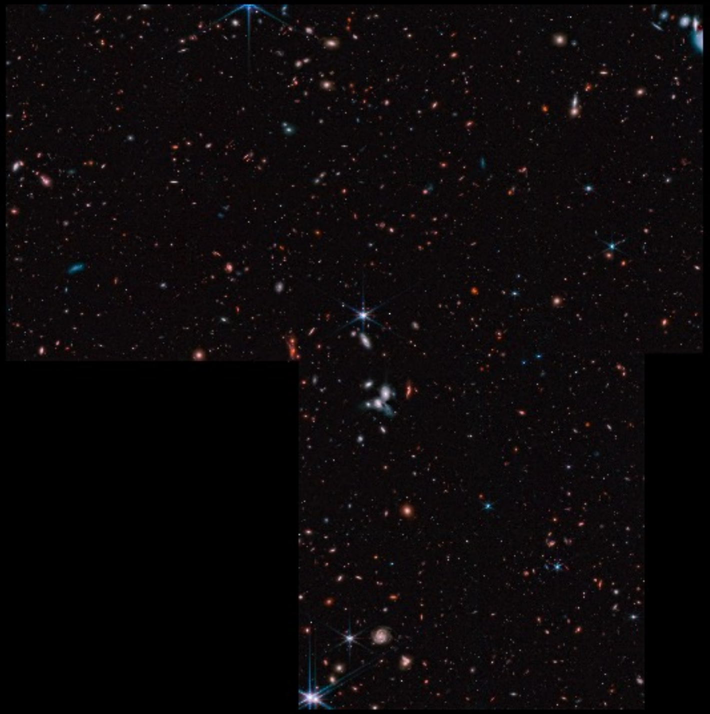
Hubble Probes the Early Universe
1990
Ground-based observatories
1995
Hubble Deep Field
2004
Hubble Ultra Deep Field
2010
Hubble Ultra Deep Field-IR
FUTURE
James Webb Space Telescope
Redshift (z):
1
4
5
6
7
8
10
>20
Time after the Big Bang
Present
6 billion years
1.5 billion years
800 million years
480 million years
200 million years

CEERS EGS Field:
Closer to the edge

- Total: 7 hours
- < 1 hr per filter
- 10x bigger than HUDF

CEERS JWST/NIRCam F115W F150W F200W F277W F356W F410M F444W
NASA/STScI/CEERS/TACC/S. Finkelstein/M. Bagley/Z. Levay






CEERS JWST/NIRCam F115W F150W F200W F277W F356W F410M F444W

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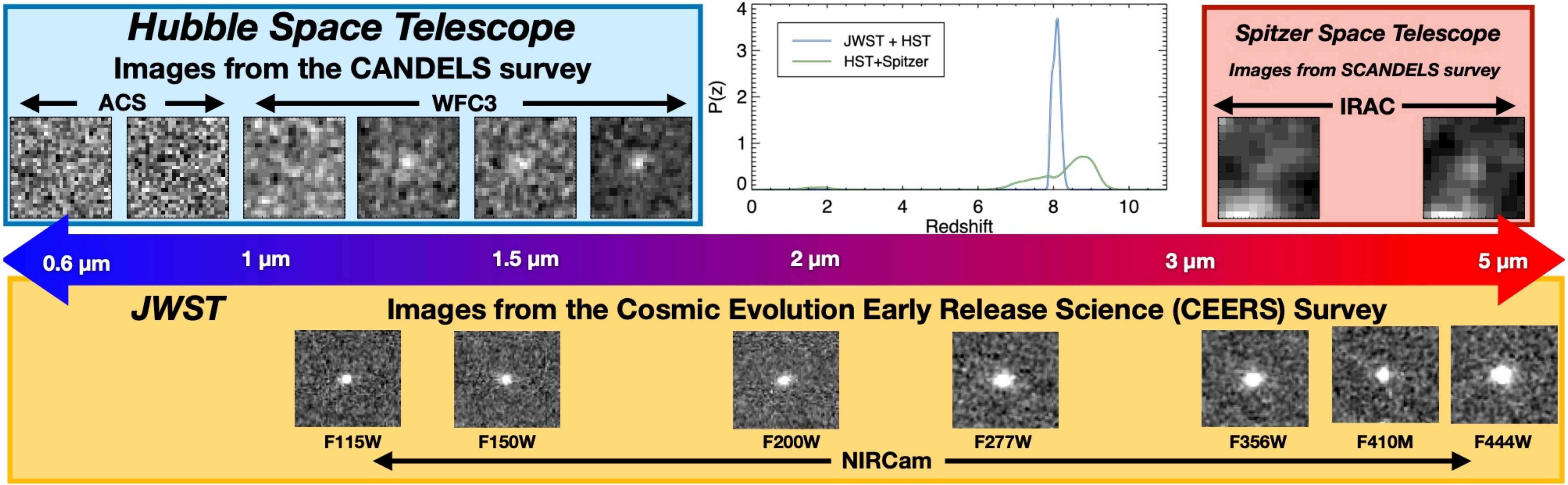
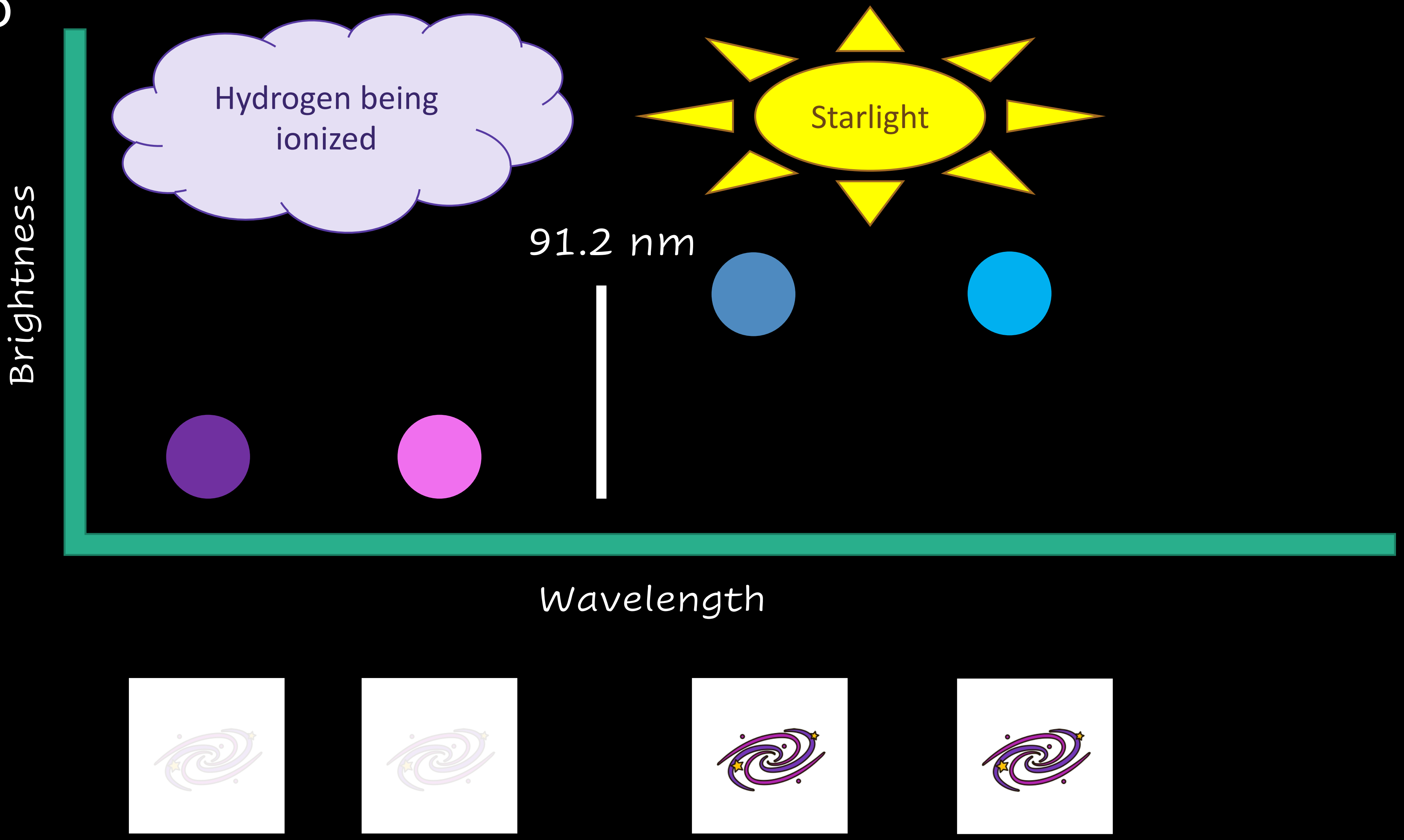


Hubble Space Telescope
Images from the CANDELS survey
ACS
WFC3
JWST + HST
HST+Spitzer
P(z)
Redshift
0
1
2
3
4
0
2
4
6
8
10
Spitzer Space Telescope
Images from SCANDELS survey
IRAC
0.6 μm
1 μm
1.5 μm
2 μm
3 μm
5 μm
JWST
Images from the Cosmic Evolution Early Release Science (CEERS) Survey
F115W
F150W
F200W
F277W
F356W
F410M
F444W
NIRCam

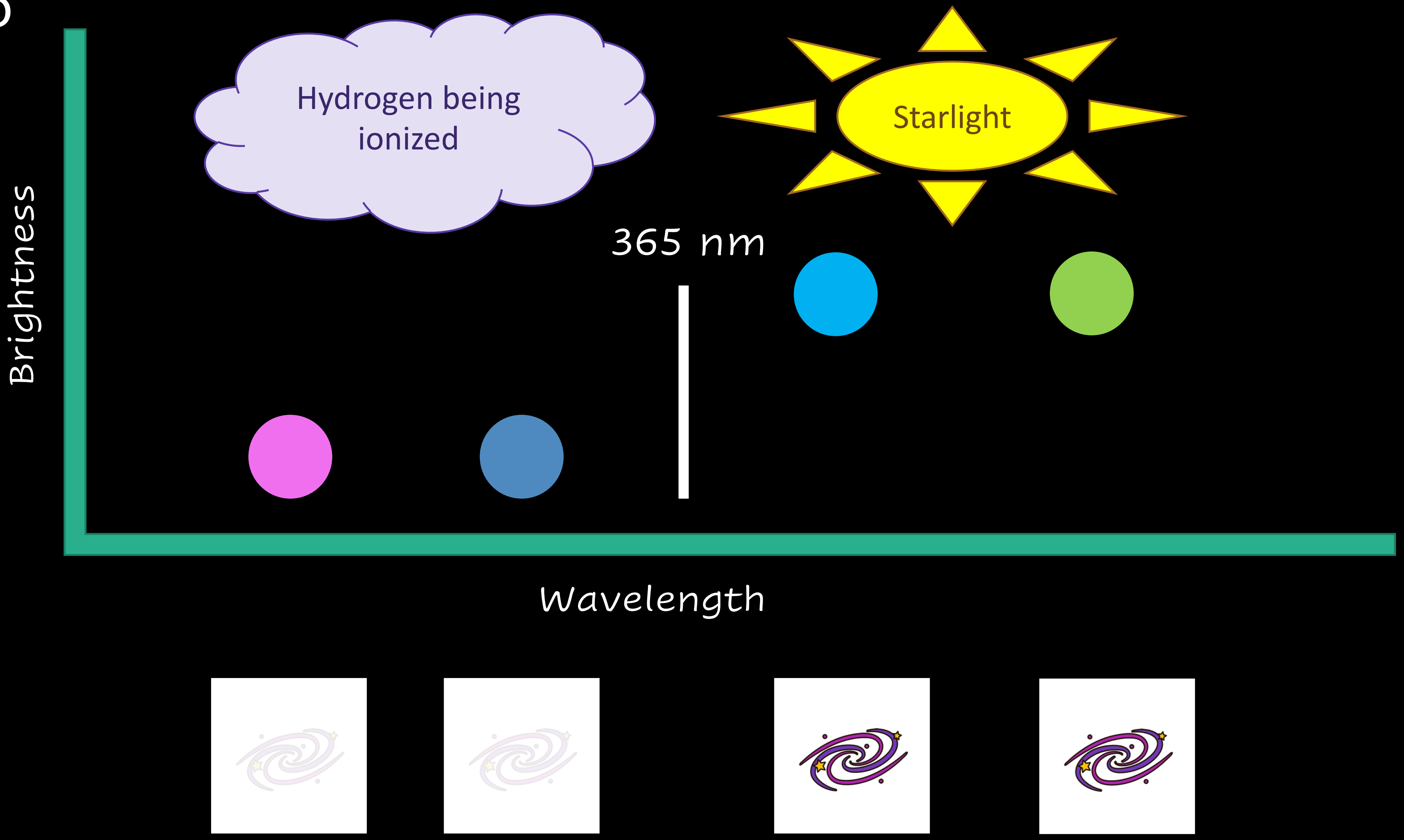
Why IR?

$z = 0$


Hydrogen being ionized
Starlight
91.2 nm
Brightness
Wavelength

Why IR?

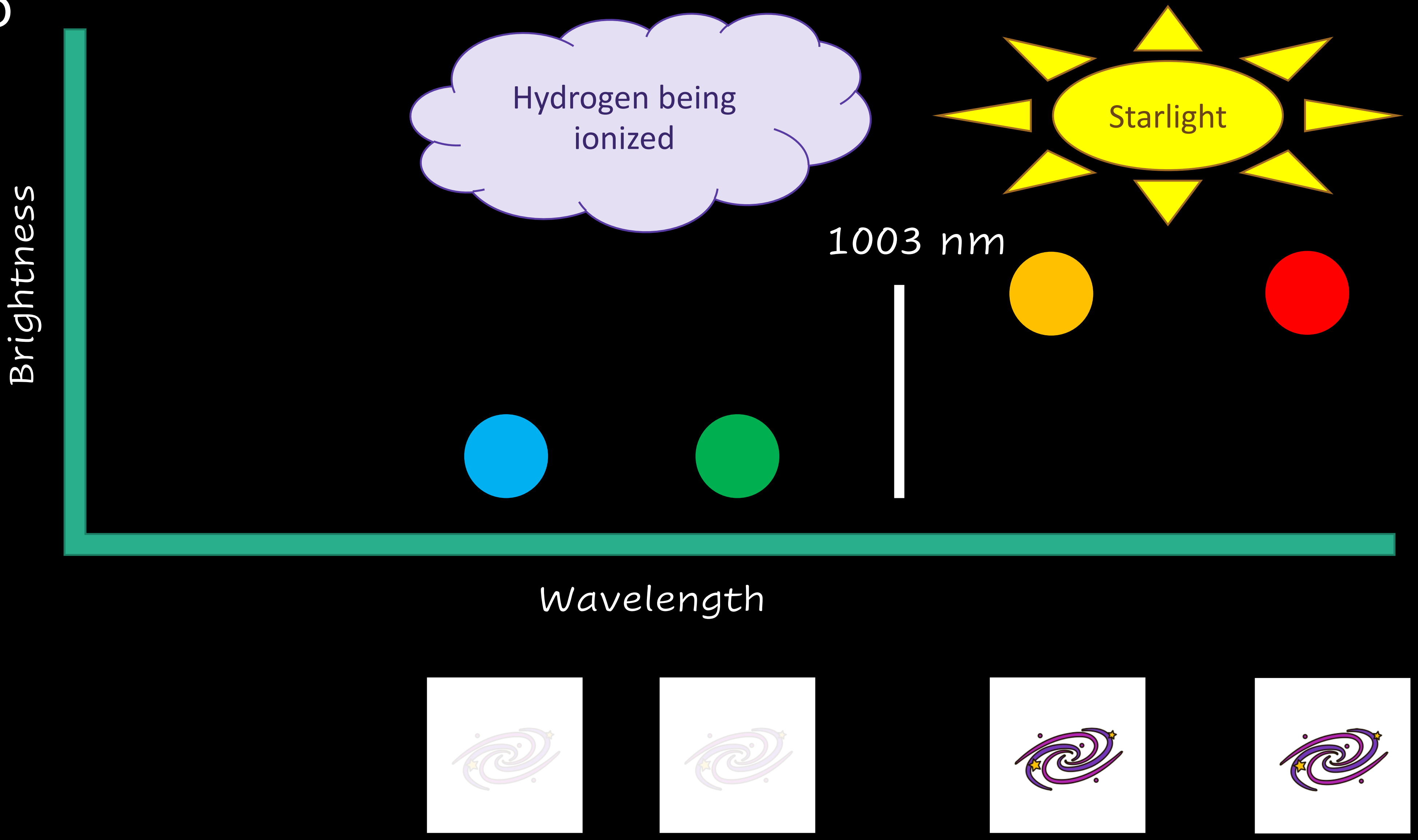
$z = 3$



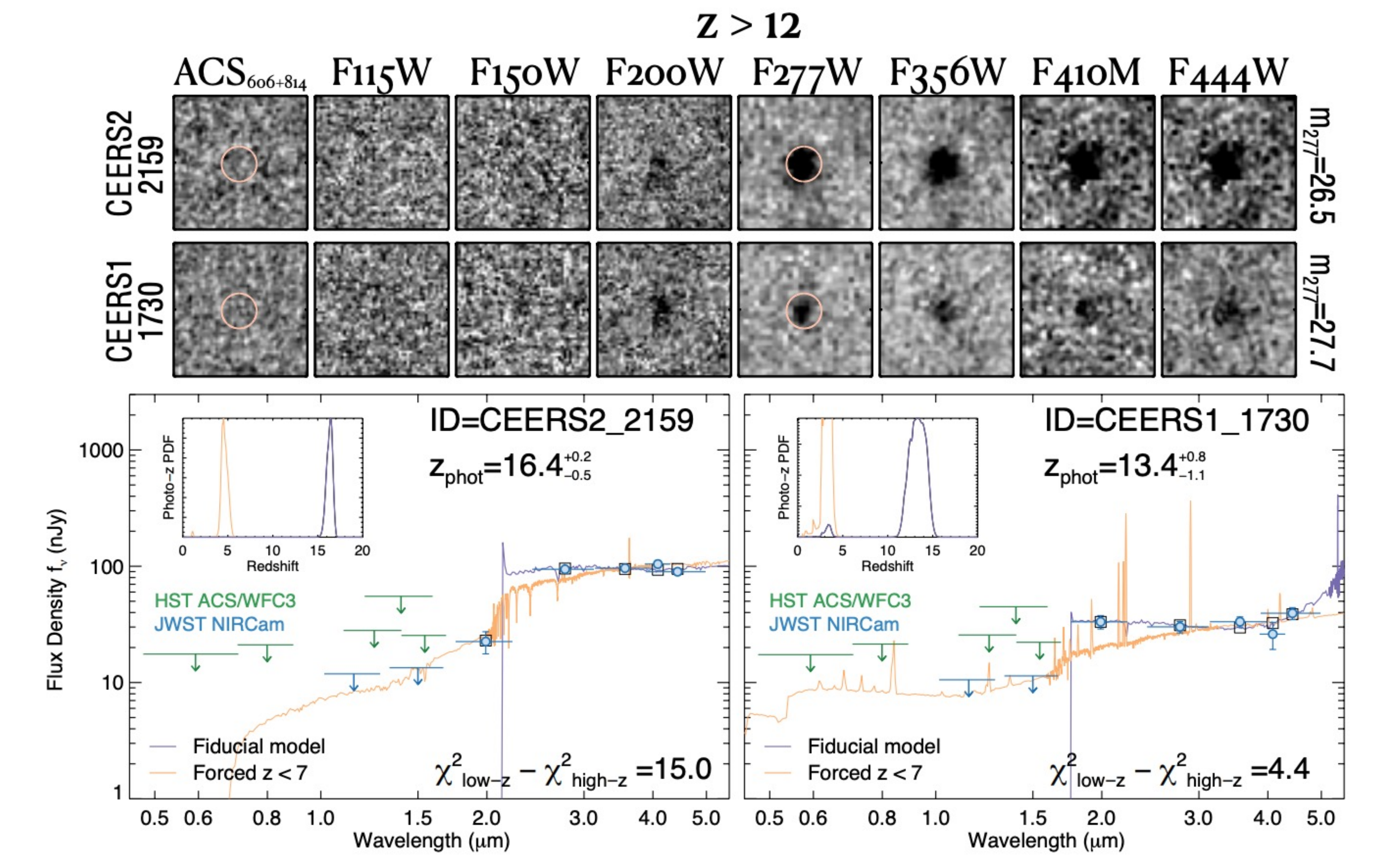
Brightness
Hydrogen being ionized
Starlight
365 nm
Wavelength

Why IR?

$z = 10$

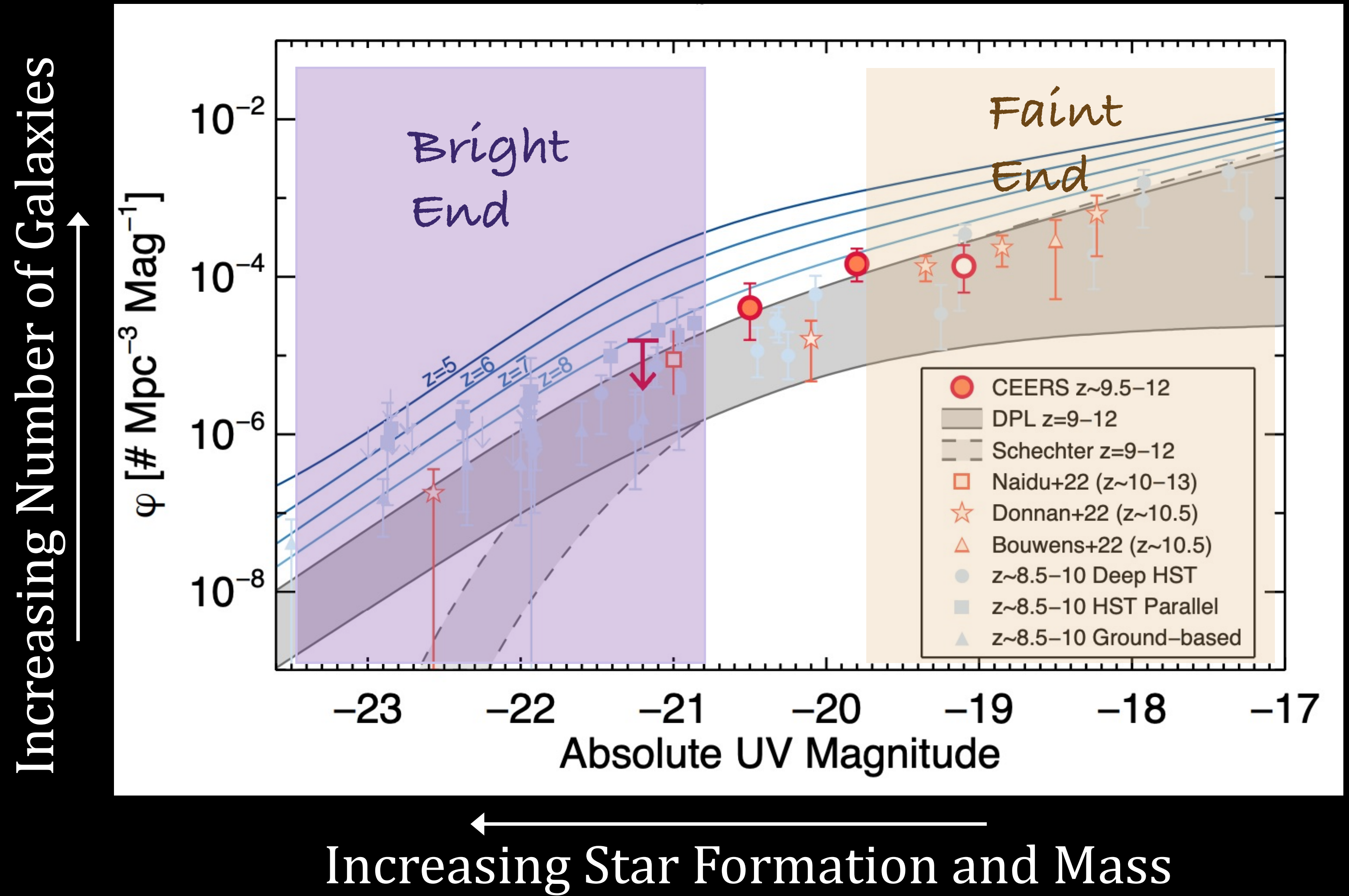


Brightness
Hydrogen being ionized
Starlight
1003 nm
Wavelength



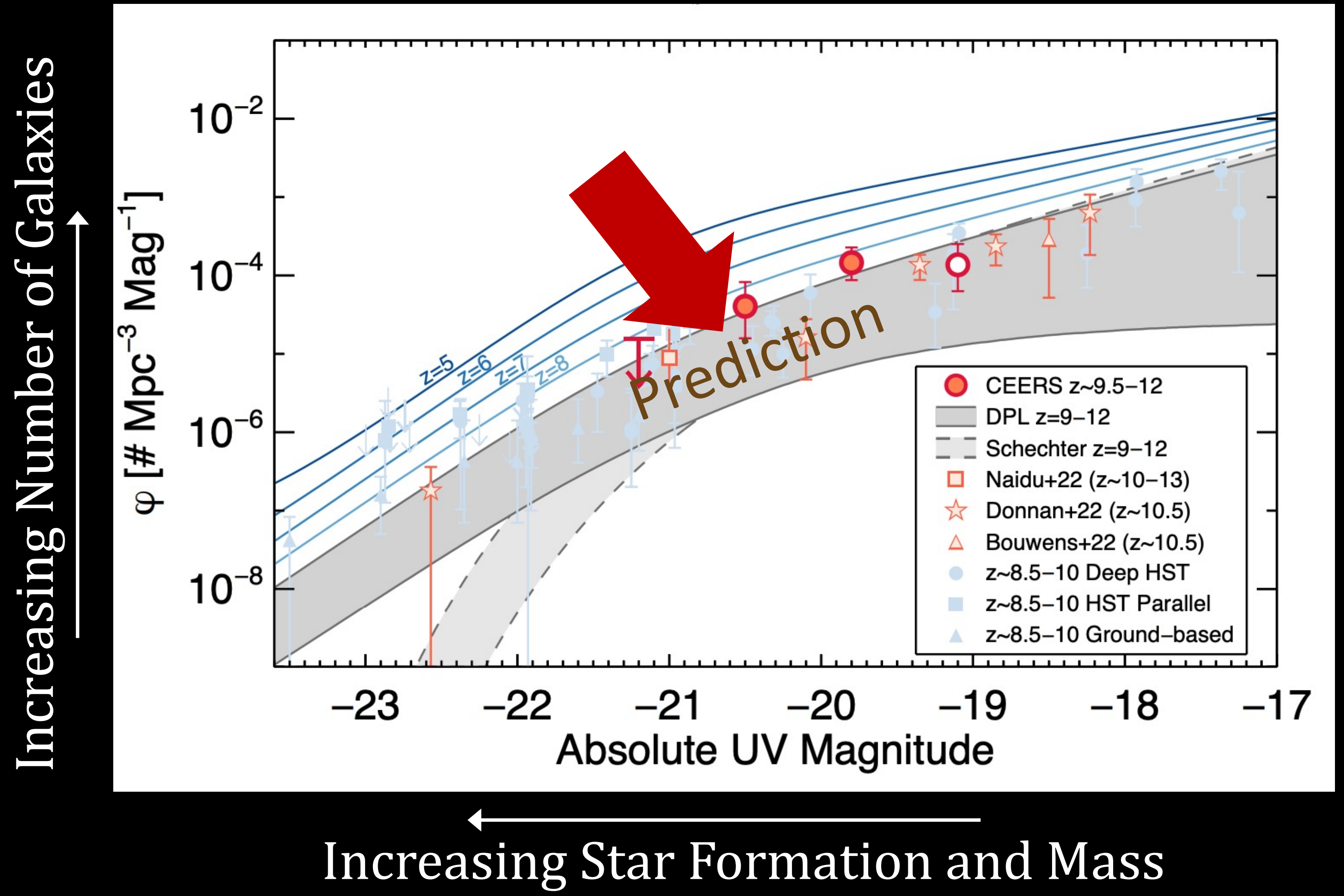
Finkelstein et al., incl. Kirkpatrick, (2022, submitted)

The UV Luminosity Function at High z



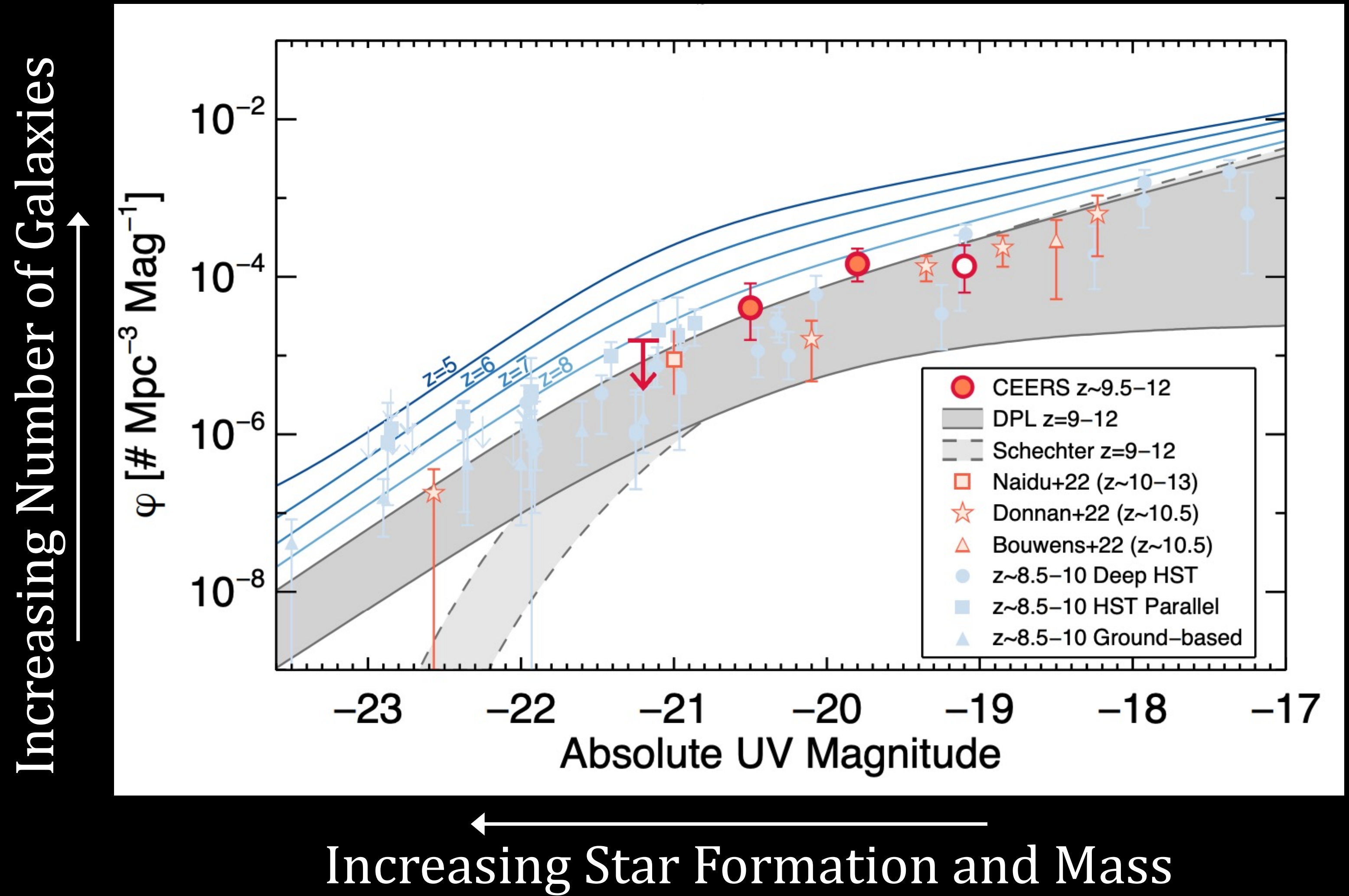
- CEERS: 26 galaxies at z>9
- Luminosity function: How bright and faint galaxies are there?

The UV Luminosity Function at High z



- CEERS: 26 galaxies at z>9
- Luminosity function: How bright and faint galaxies are there?
- Evolution with redshift: How do numbers of galaxies change as universe ages?

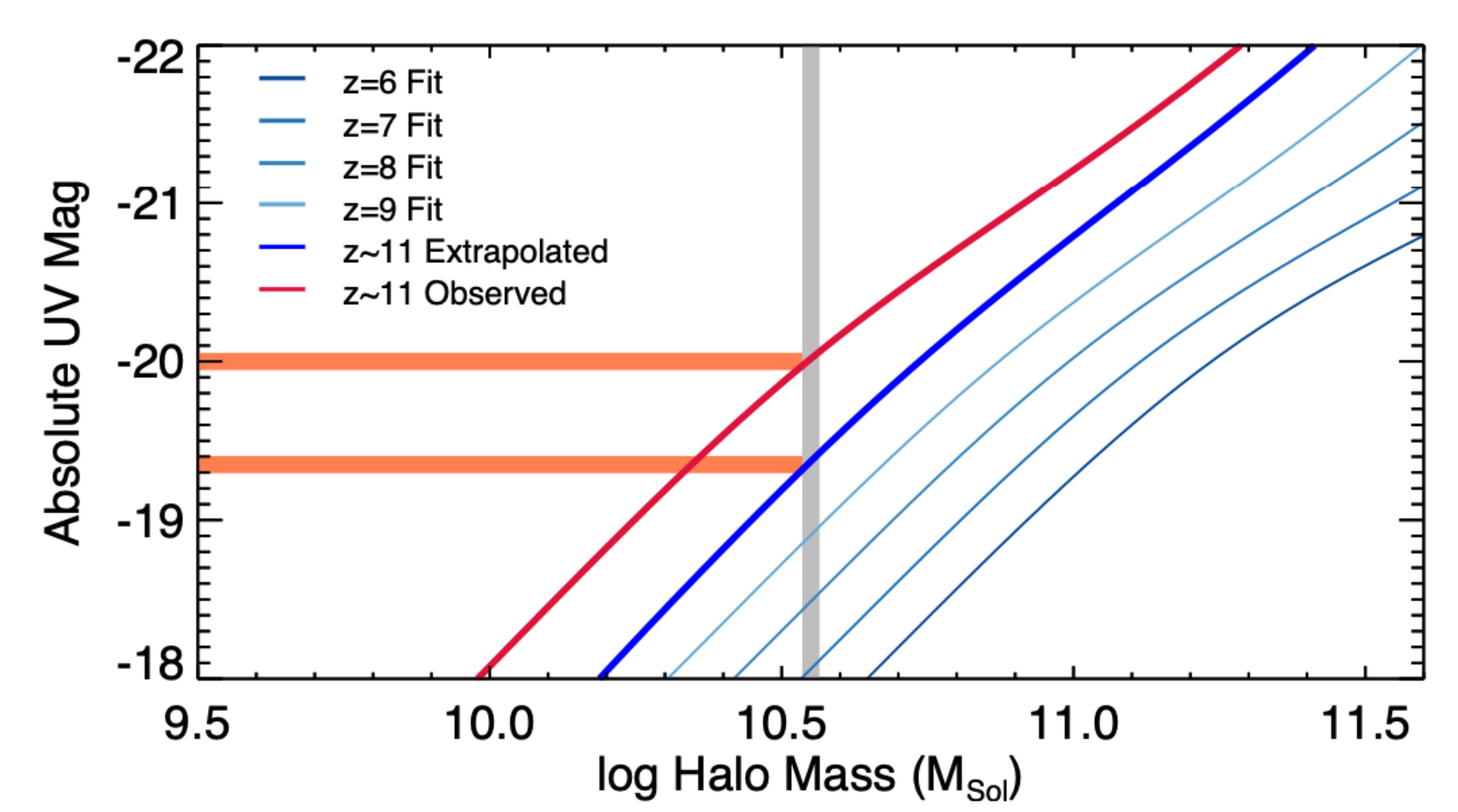
The UV Luminosity Function at High z



- CEERS: 26 galaxies at z>9
- Luminosity function: How bright and faint galaxies are there?
- Evolution with redshift: How do numbers of galaxies change as universe ages?
- Luminosity evolution is slowing

There are more, bigger galaxies sooner than predicted!

Dark Matter Halo Masses



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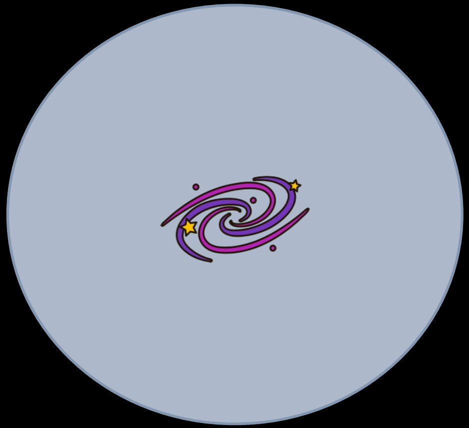


- Based on abundance matching with cosmological simulations, galaxies with M_{UV} = -20 reside in halos with masses 3.5×10^{10} $M_{\odot}$
- This does not match the prediction!
- Galaxies are nearly 2$\times$ brighter than expected

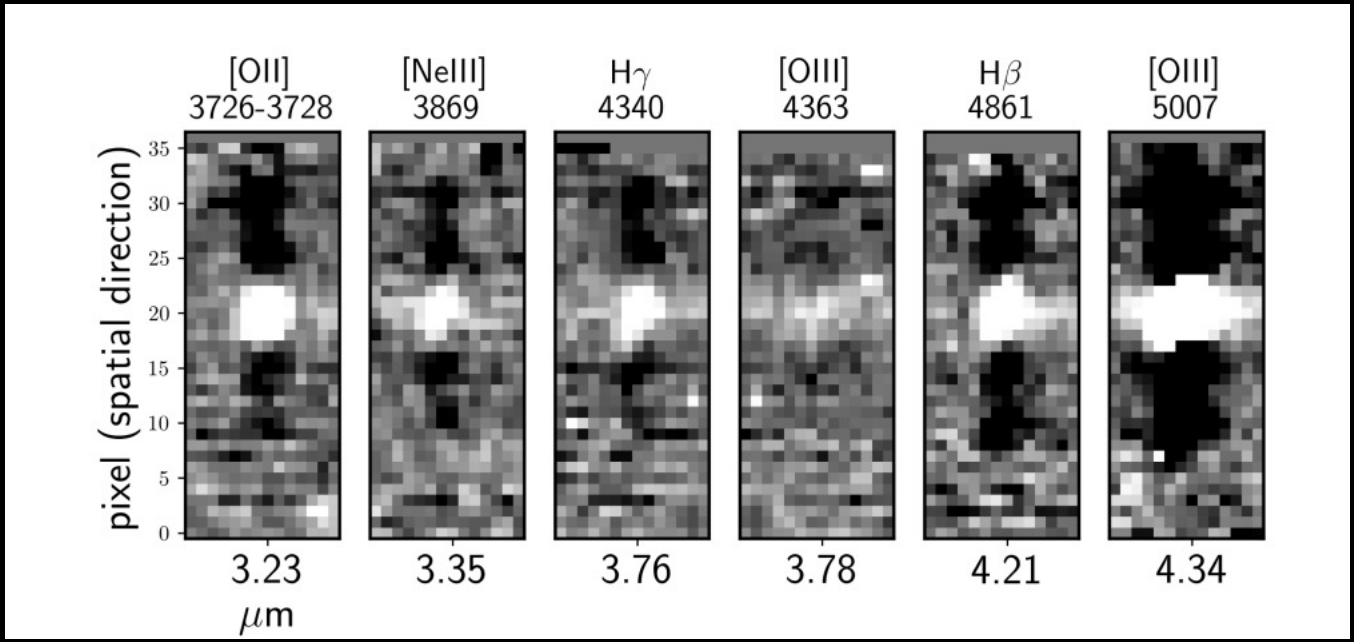
Epoch of Reionization: z = 5 - 9

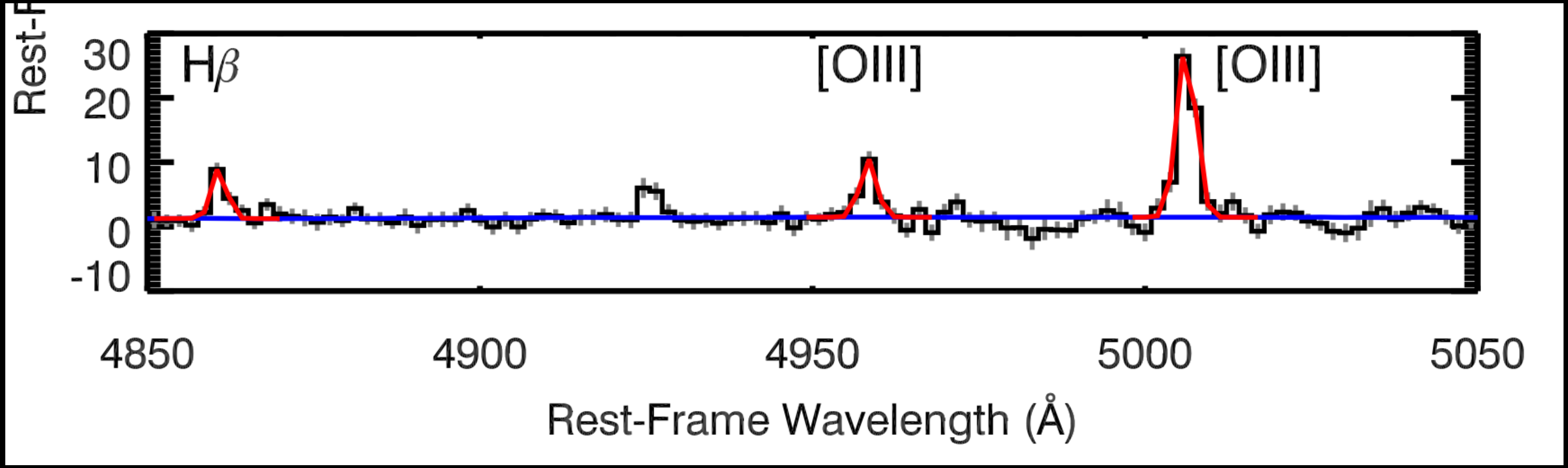
The universe from 550 million to 1.2 billion years


Hubble

Spectroscopy

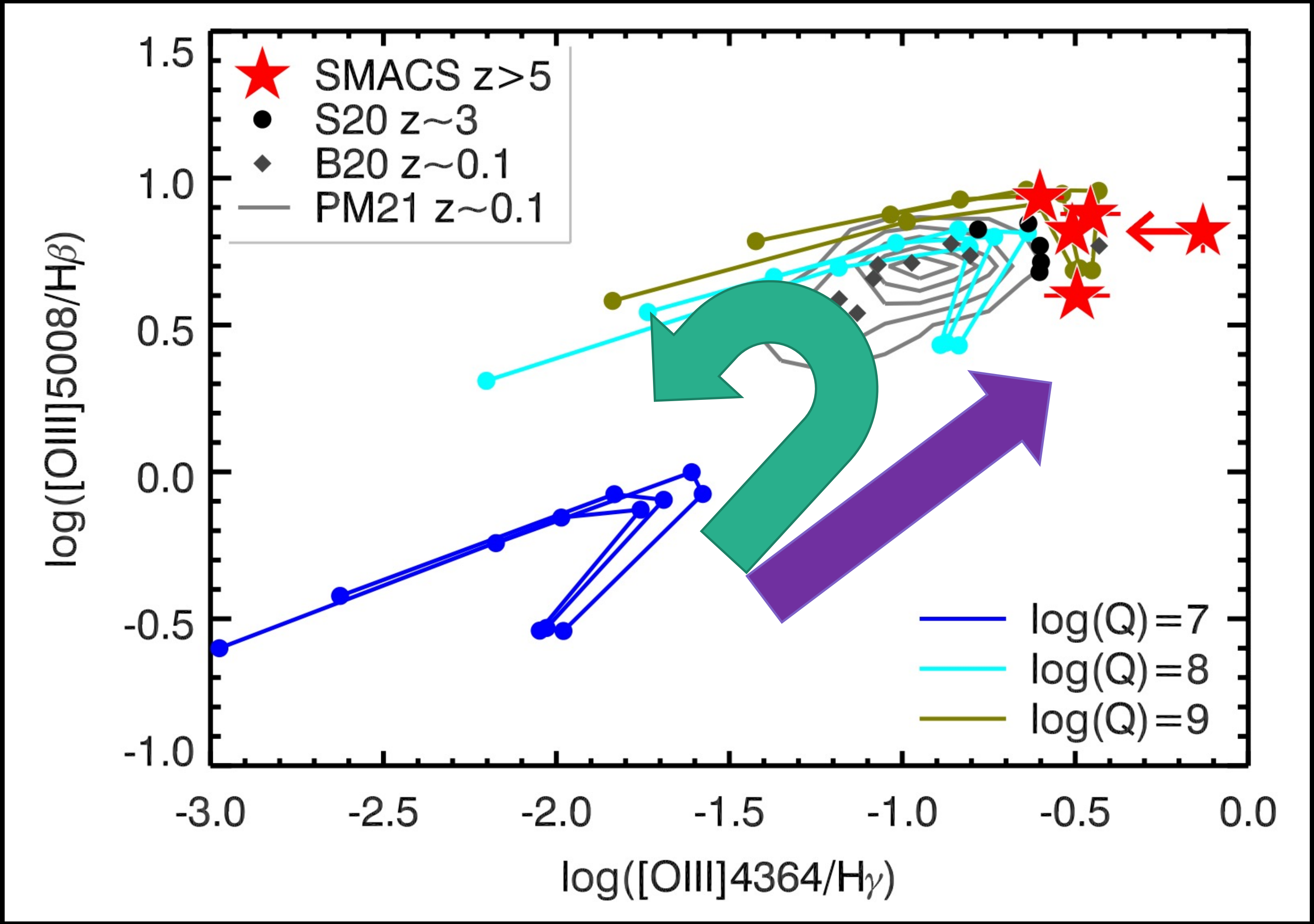
- NIRSpec grating
- Can detect many key lines
- Not possible with Hubble
- Measured emission in 5 galaxies



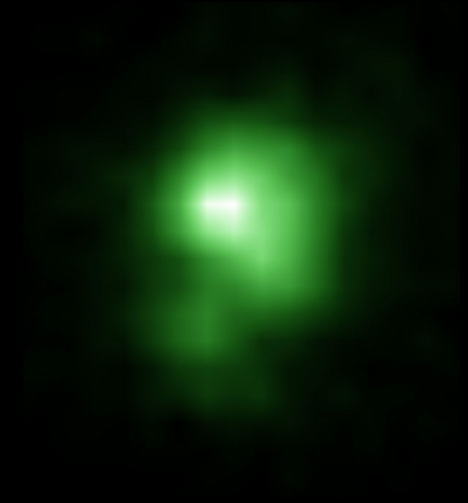


Trump et al., incl. Kirkpatrick, (2022)

The Physics of the Interstellar Medium

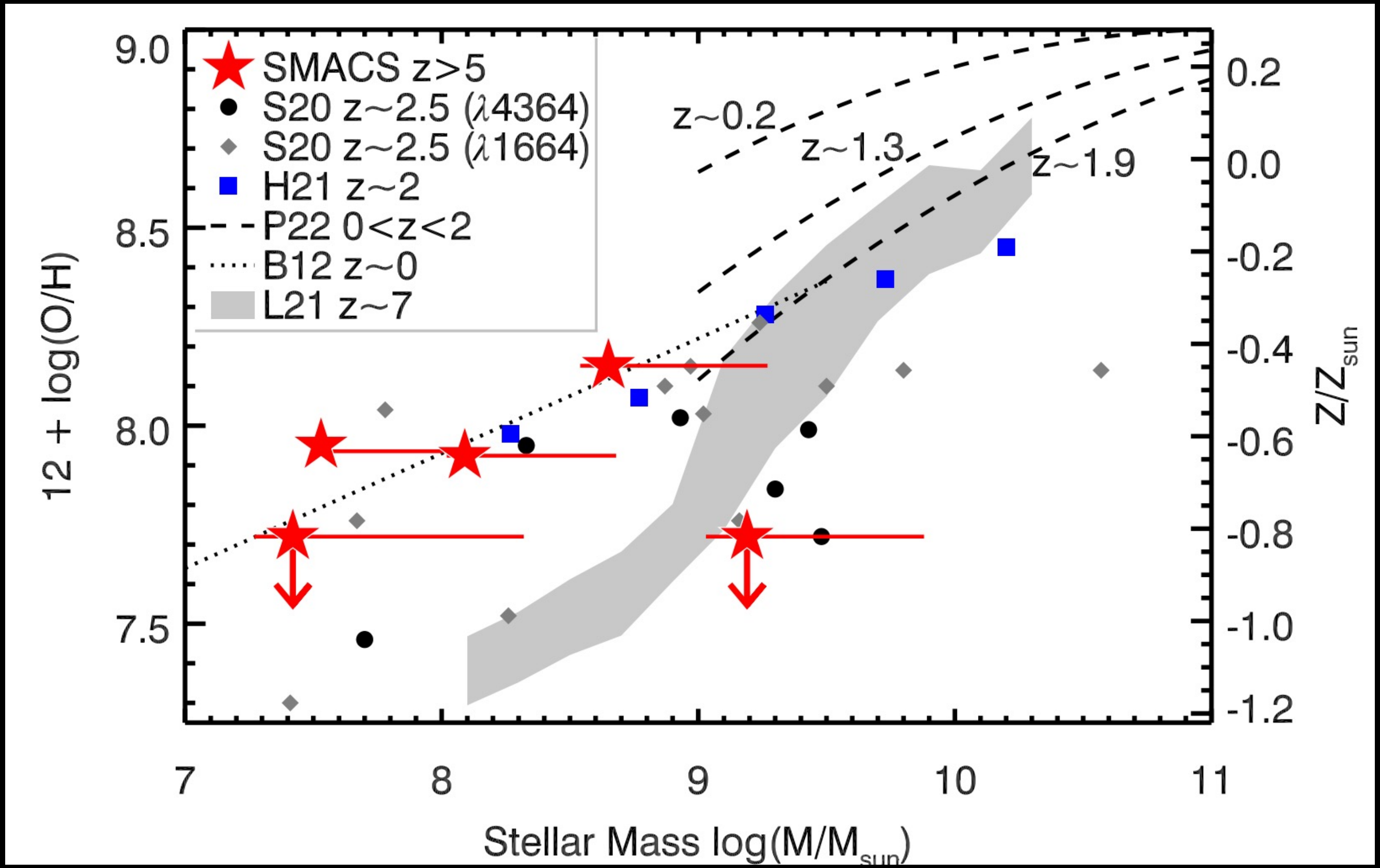


- Ionization: how many massive stars are being formed?
- Metallicity: how many generations of stars have there been?



Credit: NASA/HST

Evolution of the Mass-Metallicity Relationship

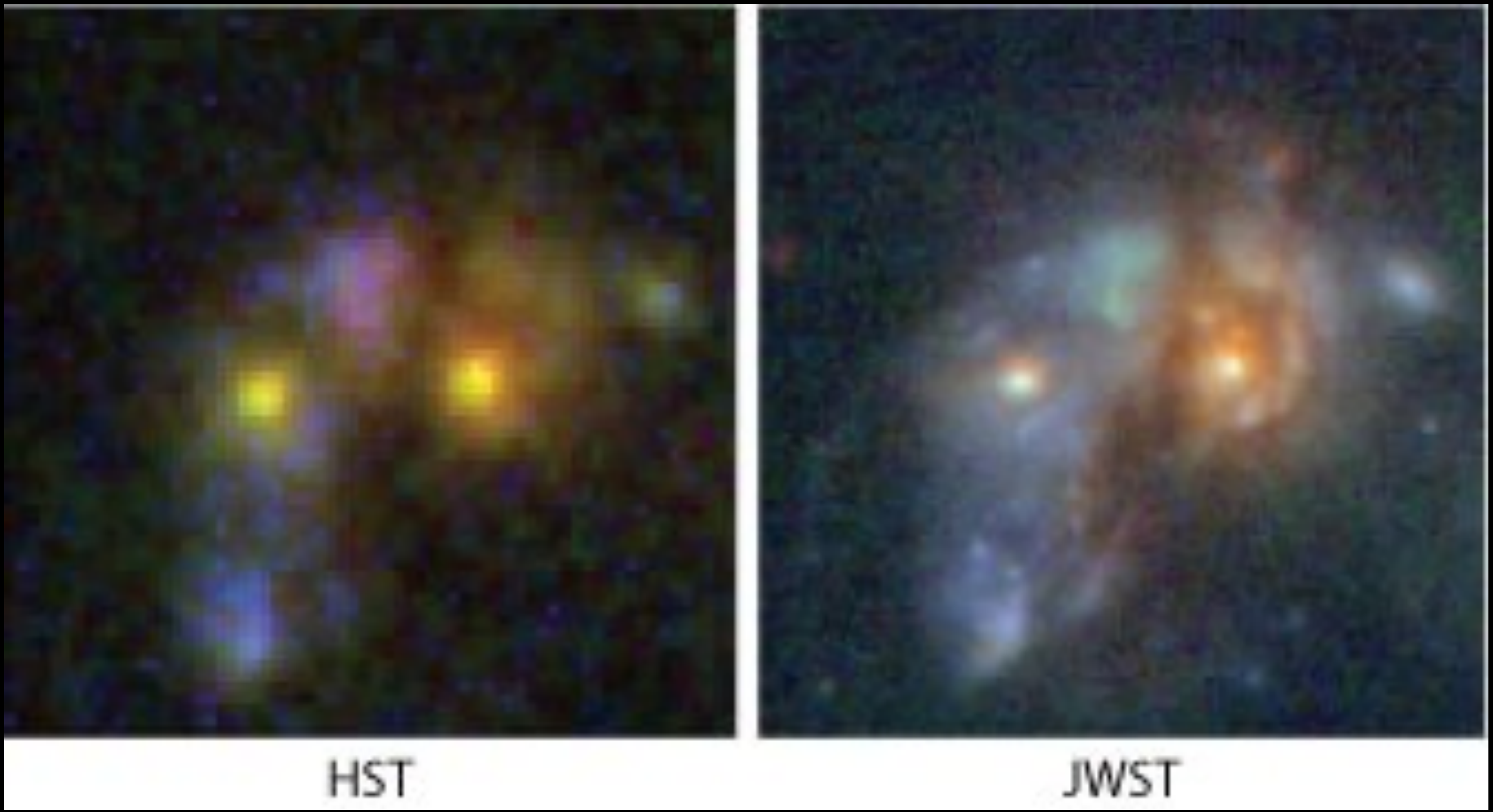


Trump et al., incl. Kirkpatrick, (2022)

- Diversity of metallicities
- Enrichment may happen faster than previously thought
- Evidence for obscured star formation?

Galaxies have more metals than expected!

Morphologies



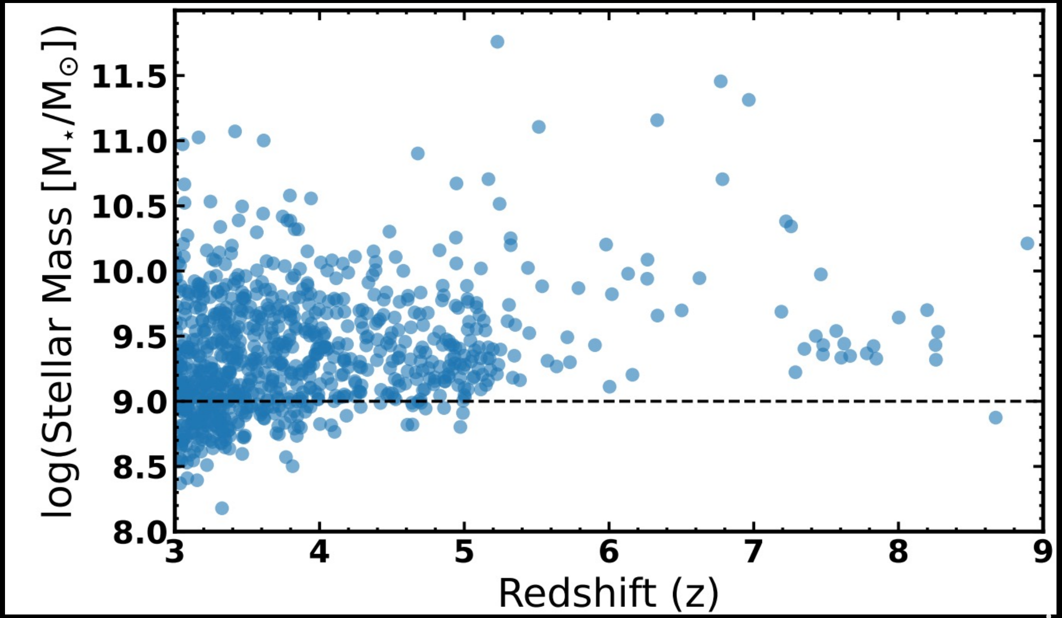
JWST has improved resolution and sensitivity to Hubble.

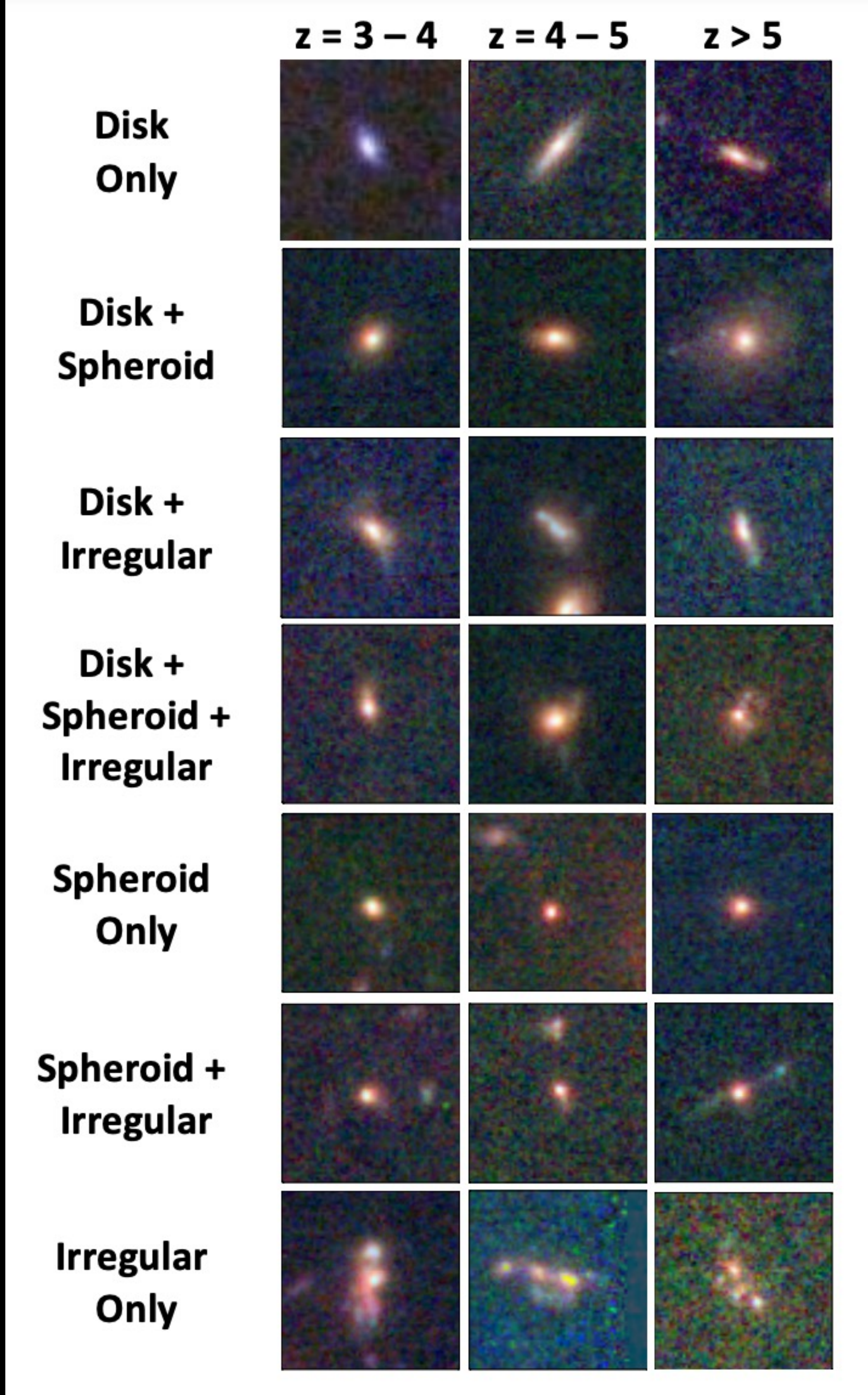
This allows us to see more detail and fainter features.

Credit: CEERS

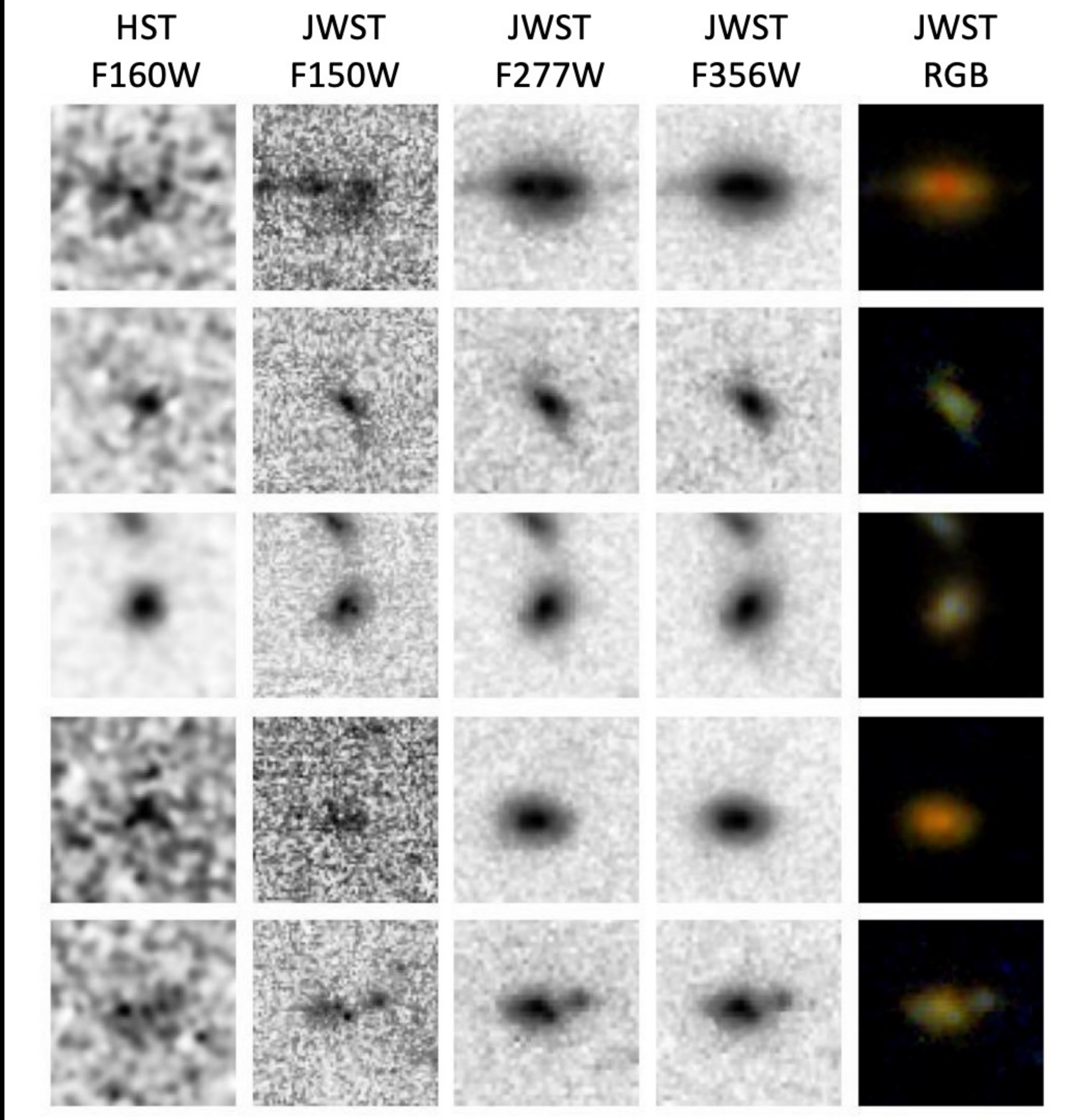
Classifying Galaxy Morphology

- 850 galaxies at $z = 3 - 9$
- visually classified NIRcam images (2-4μm)





Kartaltepe et al., incl. Kirkpatrick, (2022)

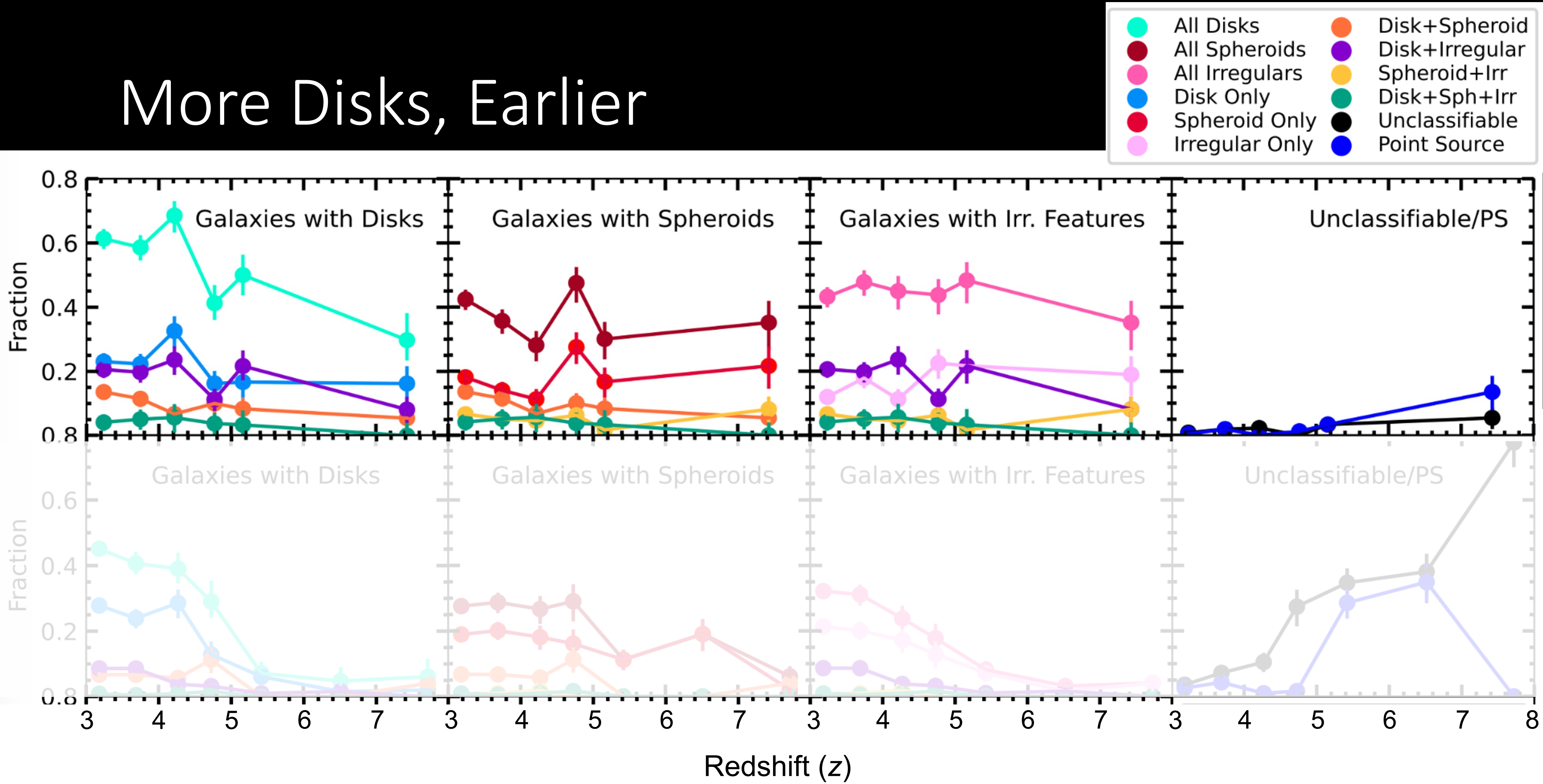


Comparison with Hubble

Because of the longer wavelength coverage, JWST can pick up features that Hubble misses

Longer wavelengths allow us to see more of the stellar population

More Disks, Earlier



Kartaltepe et al., incl. Kirkpatrick, (2022)

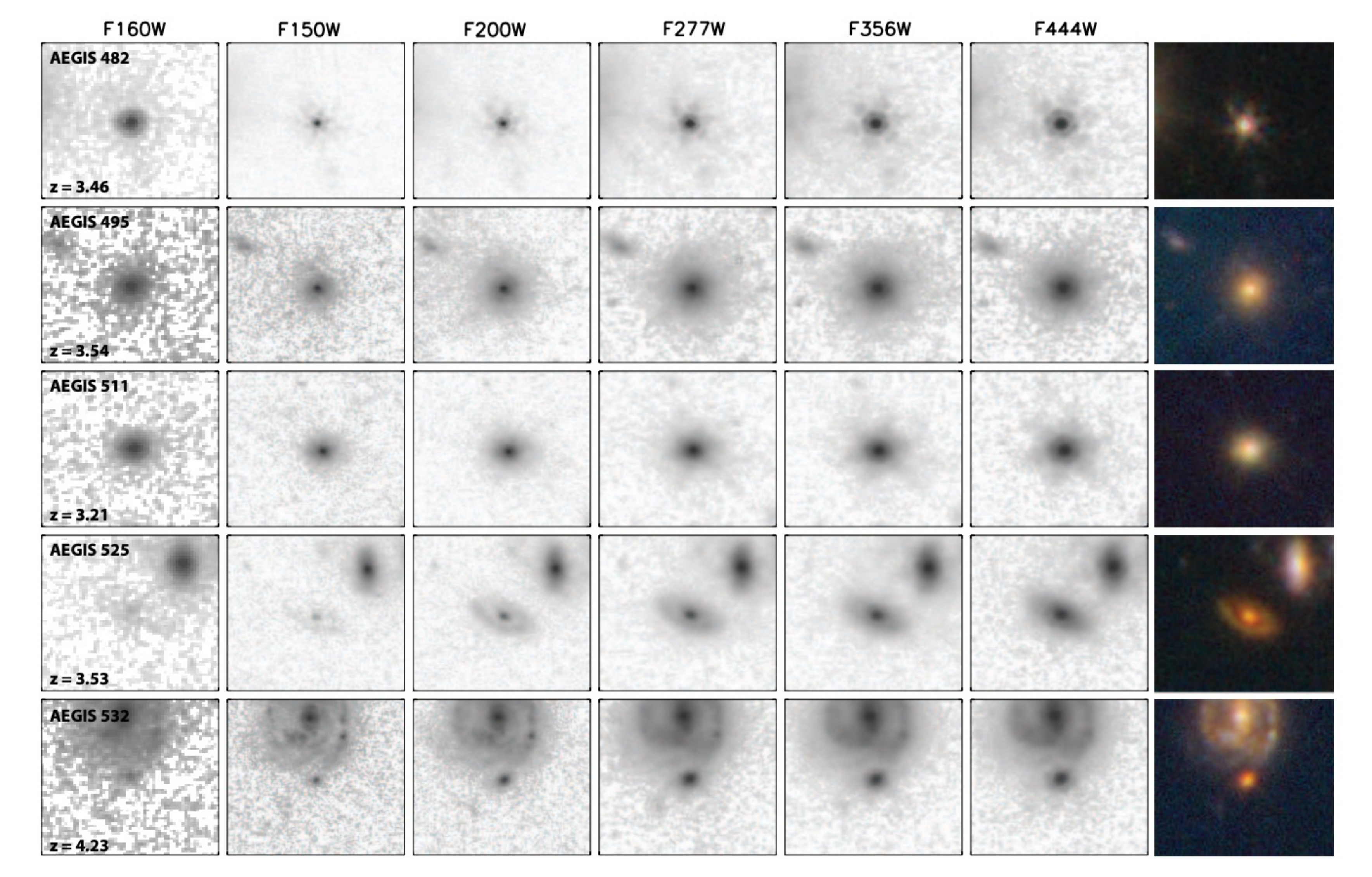
Cosmic Noon: z = 1 - 5

The universe from 1.2 – 5.5 billion years

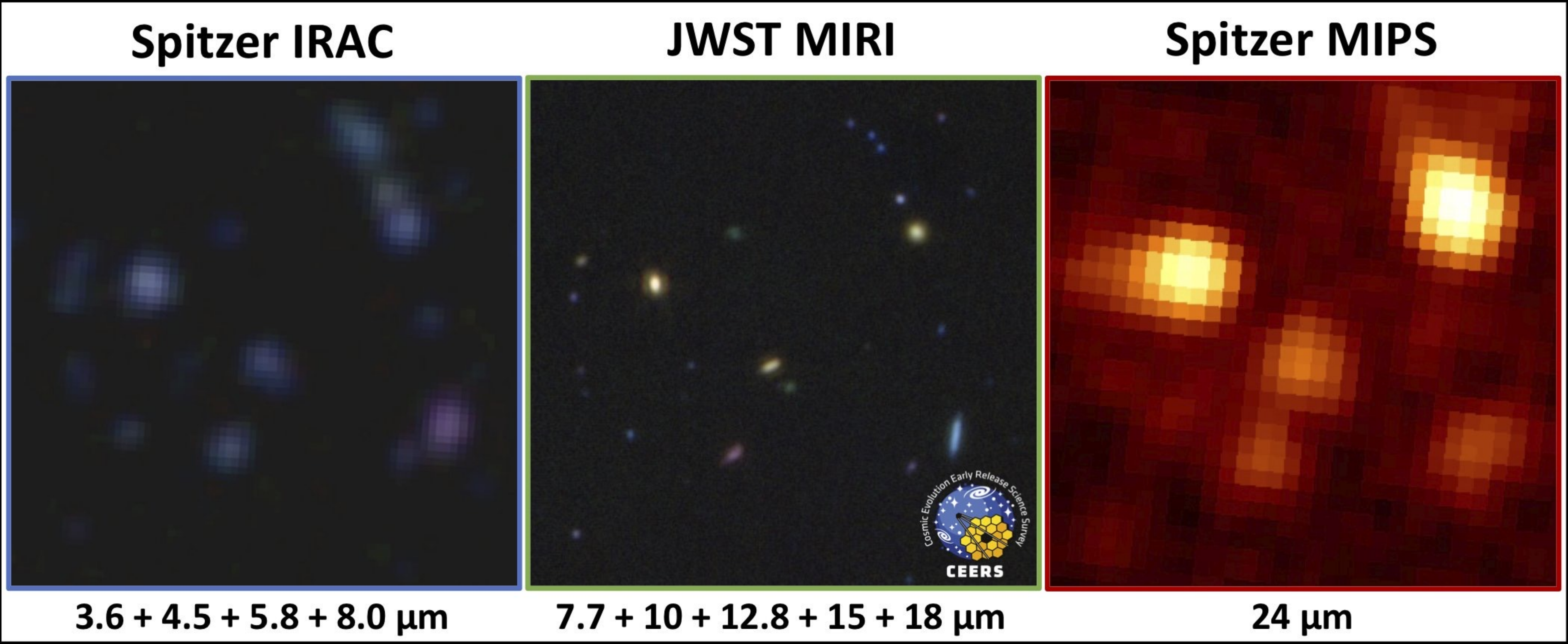
Supermassive Black Hole Growth at $z > 3$

- X-ray AGN
- AGN at z > 3 are in isolated galaxies
- Galaxies are quiescent
- Galaxies are all massive: $M_\star > 10^{11} M_\odot$

Some AGN hosts evolve very quickly!

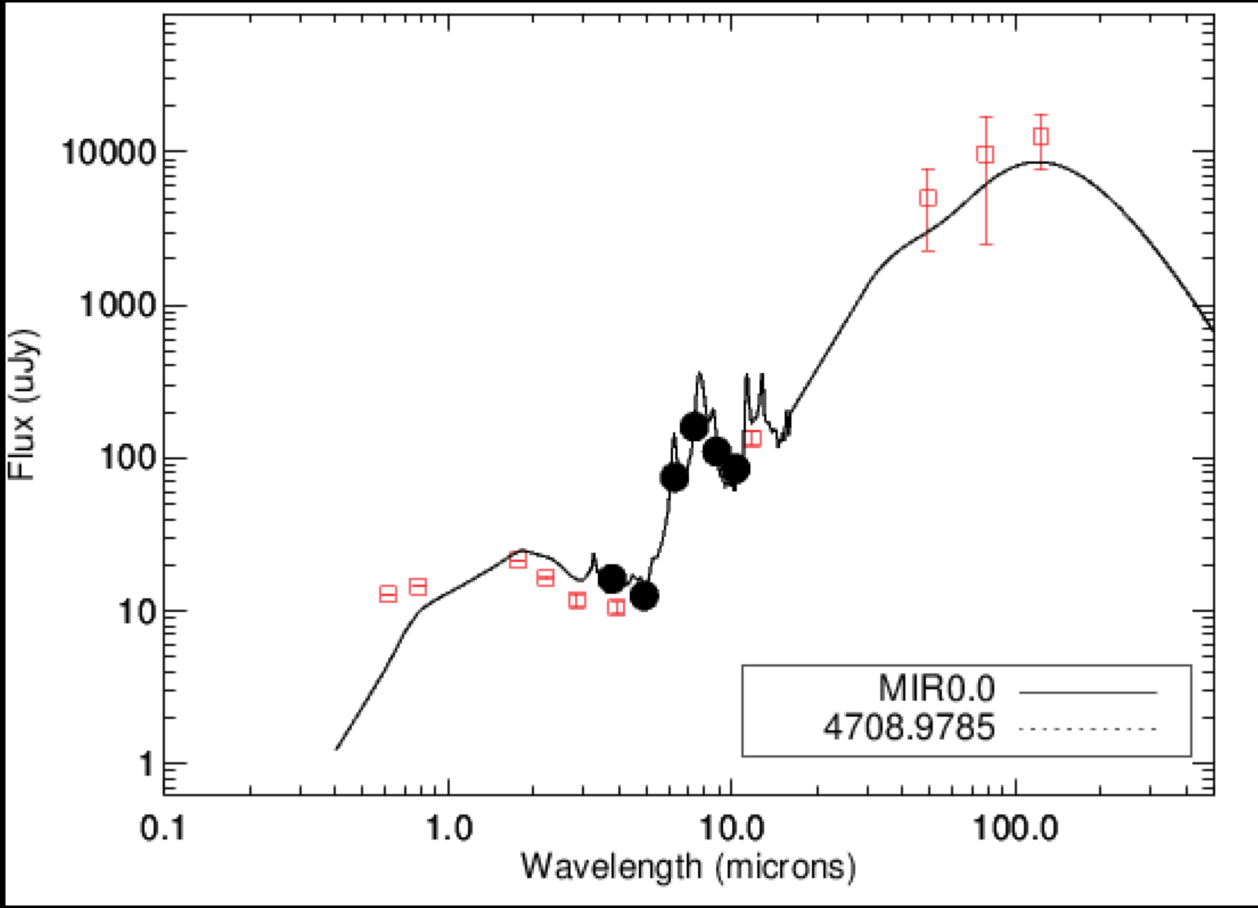


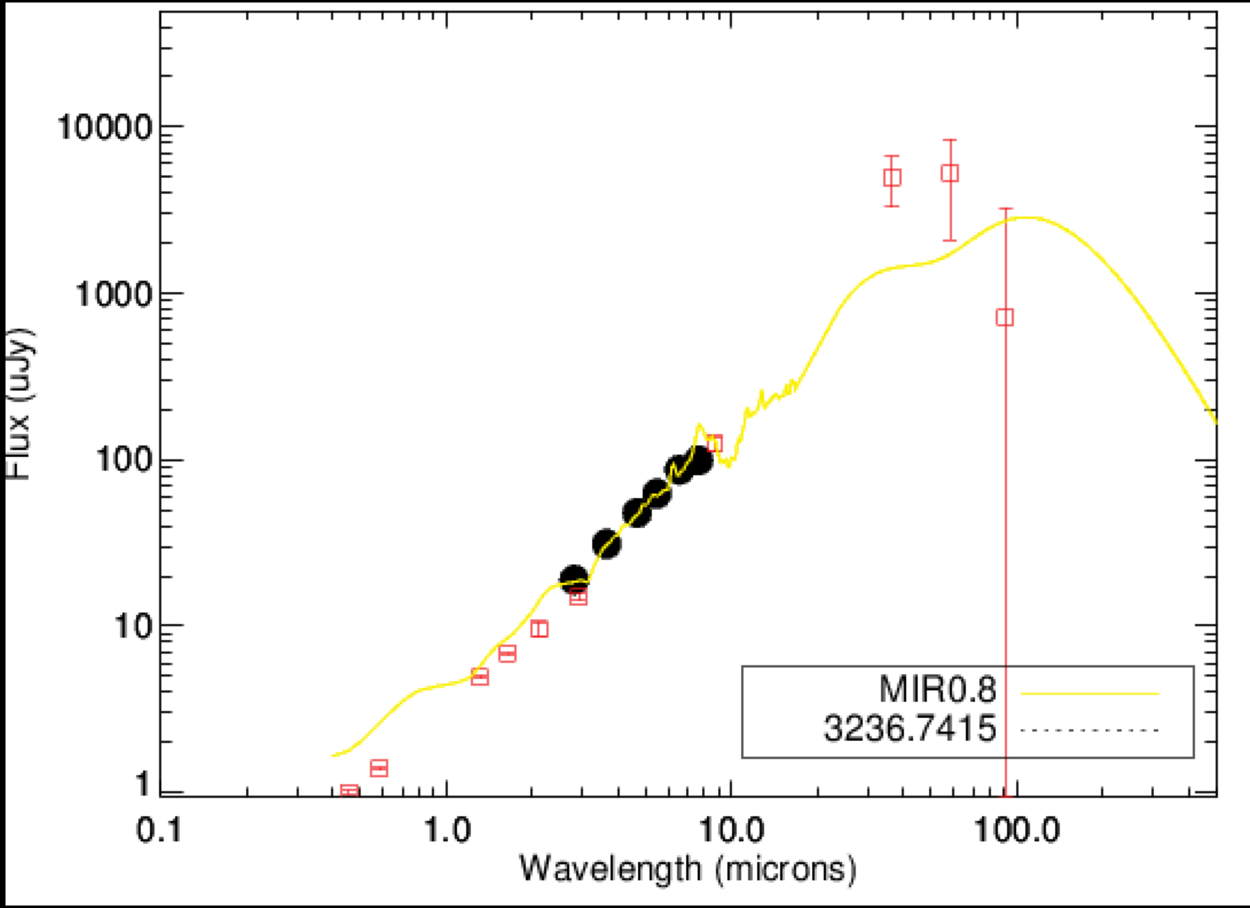
Kocevski et al., incl. Kirkpatrick, (2022)



~ 280 galaxies detected in 2 MIRI pointings

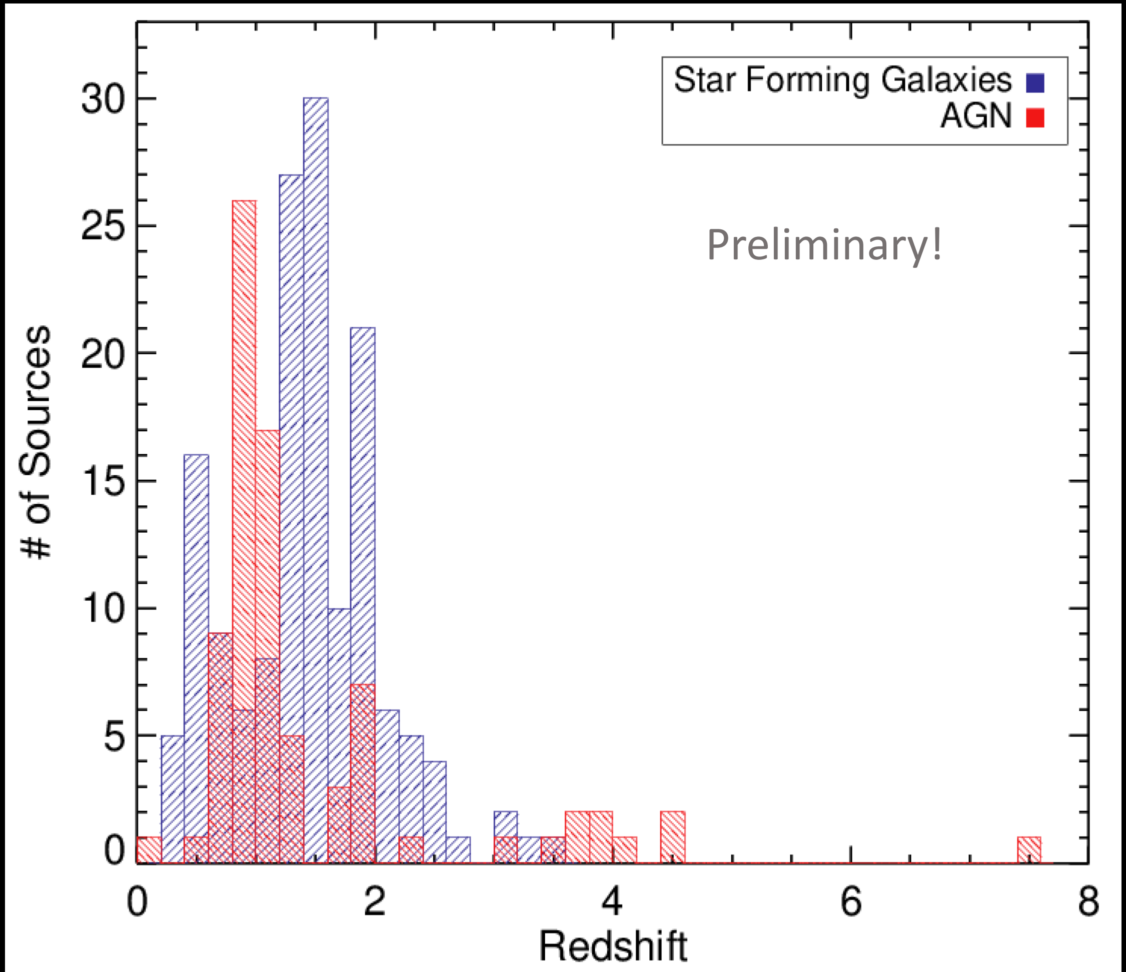
Black Hole Emission or Star Formation

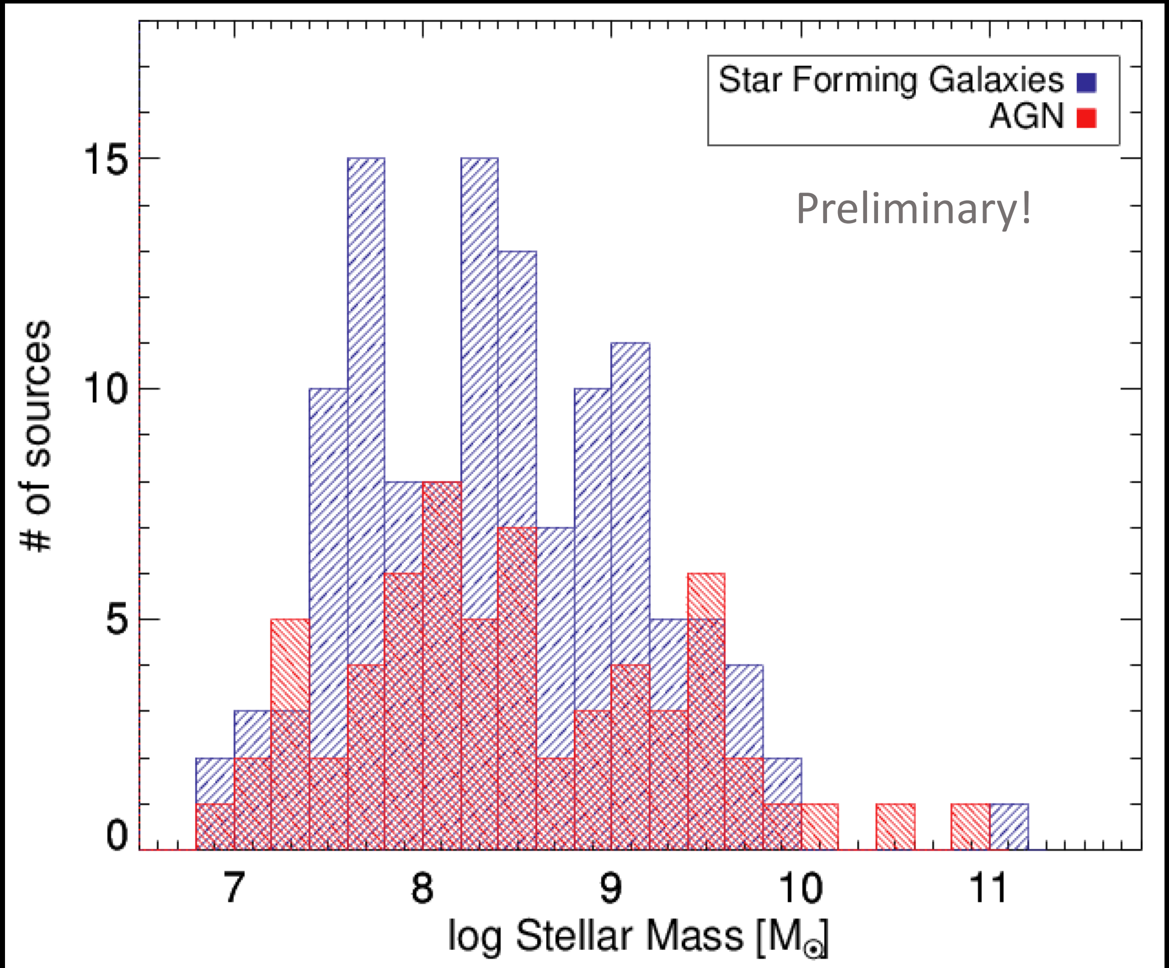




Kirkpatrick et al, in prep

Potentially Many Low Mass AGN!





Take-Aways

- JWST was a great investment!
- The galaxies at the highest redshifts are brighter than predicted
  - Evidence for massive star formation?
- Some galaxies at $z > 5$ display significant chemical enrichment
  - Is there more dust in early galaxies than previously thought?
- There are more disk galaxies earlier in the universe’s history than previously thought
  - How did they form?
- Energetic AGN in massive galaxies are isolated
  - What were the triggering mechanisms for the black hole growth?