JWST:
eyes to the distant, infrared Universe

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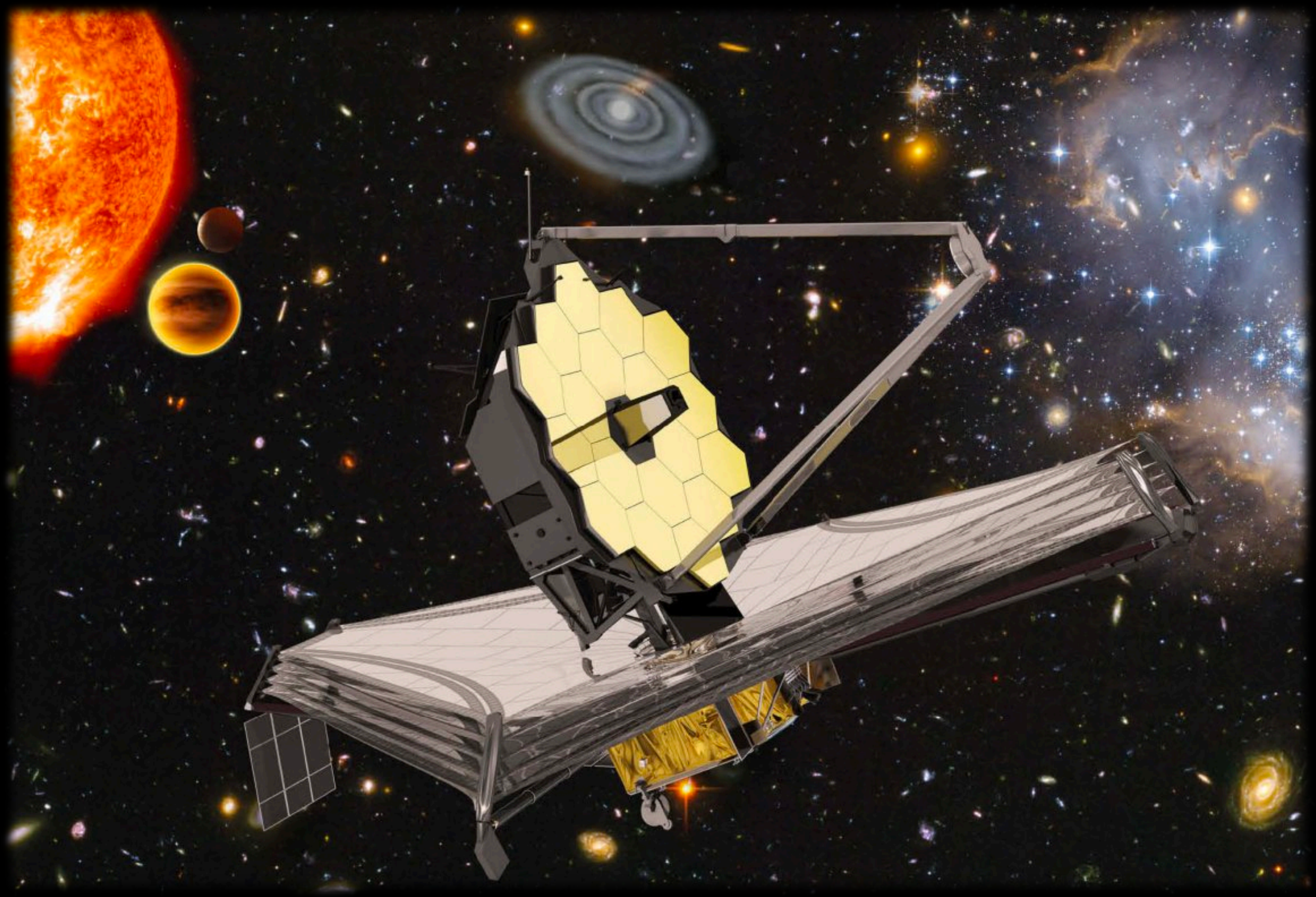
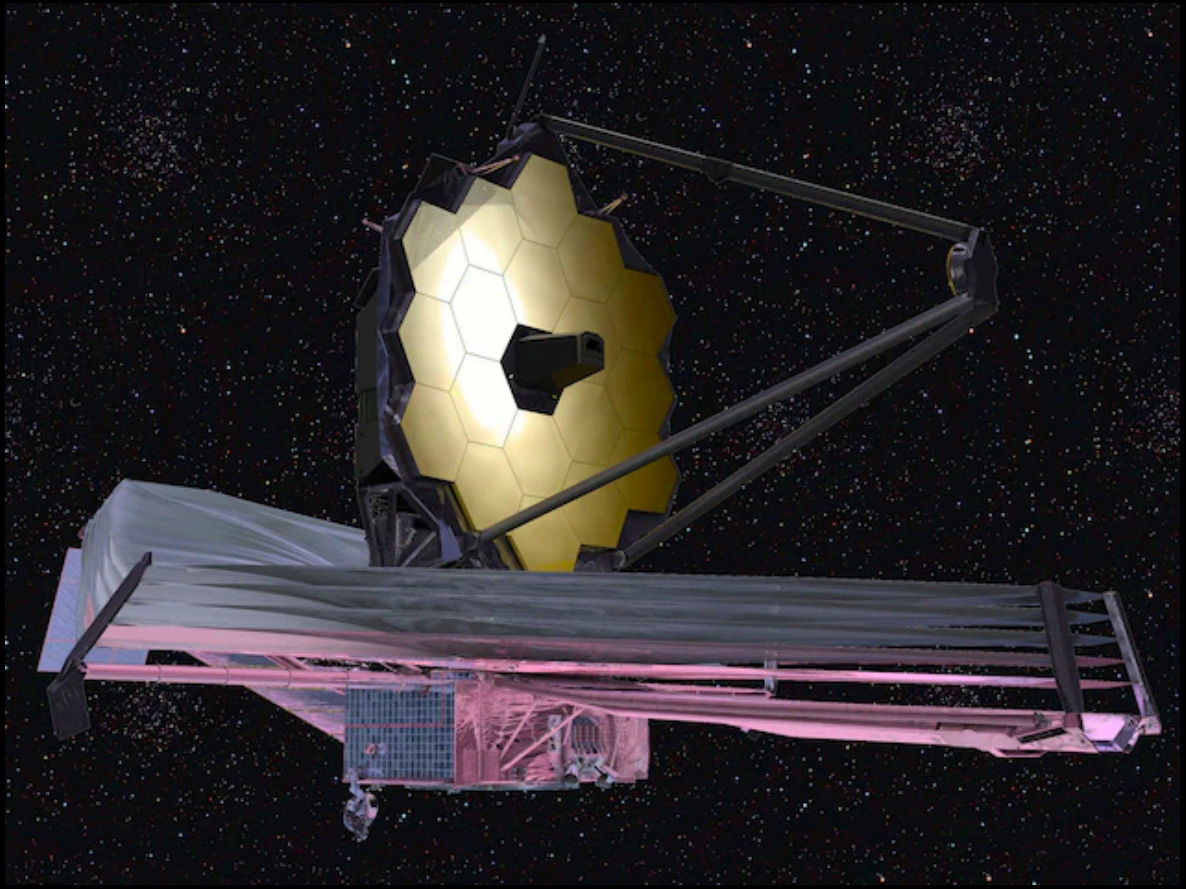
2. Astrophysics Group, SISSA, Trieste



HEP colloquia, Uni. of Warsaw, 25/11/2022

Content

1. Advent of astronomical extragalactic research in 21. century
2. Why we need JWST to understand evolution of galaxies?
3. "Unfold the Universe" - how JWST works?
4. Science and first results with JWST



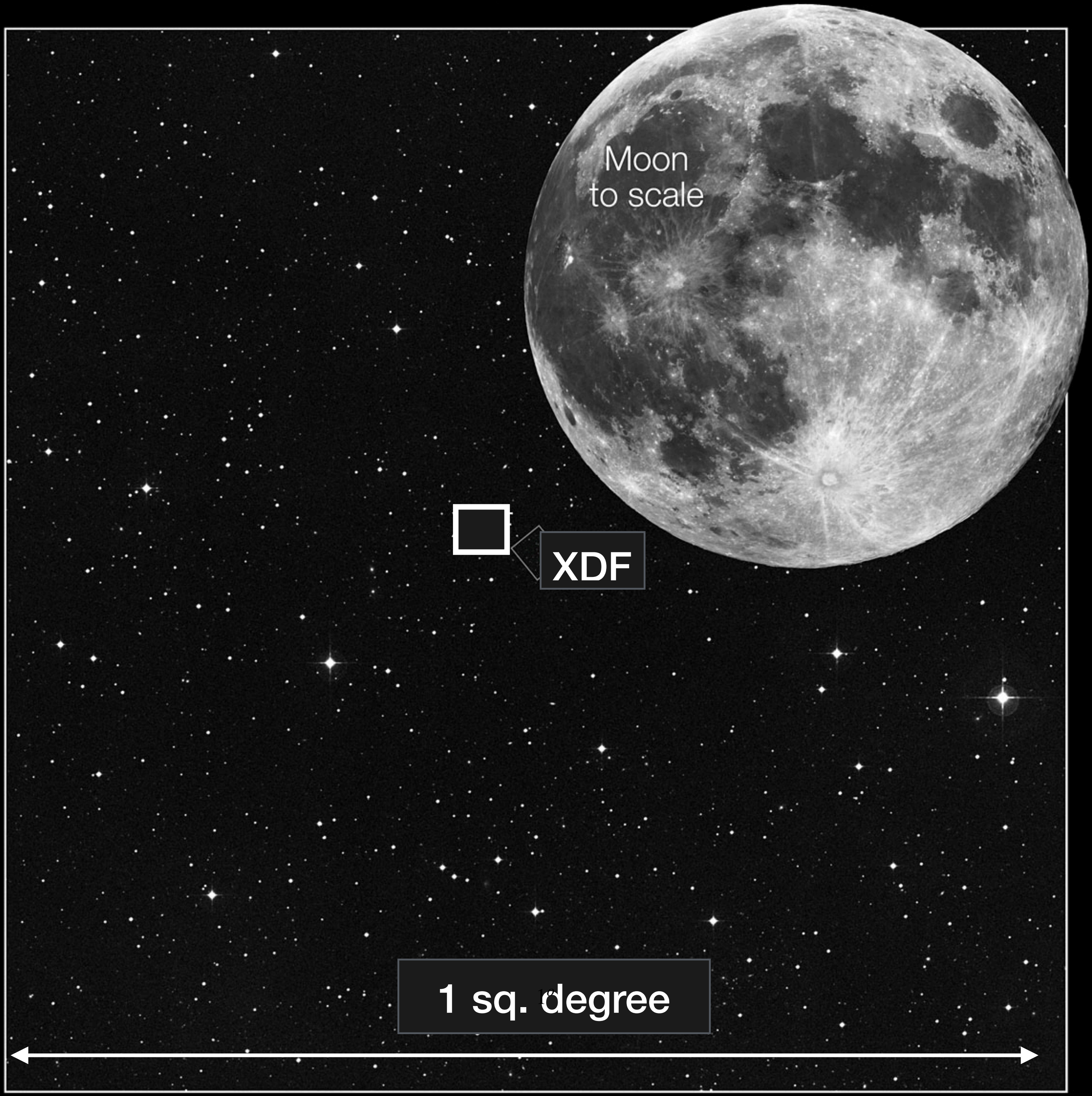
1. Legacy of astronomical discoveries in the last decades

paving the road for JWST

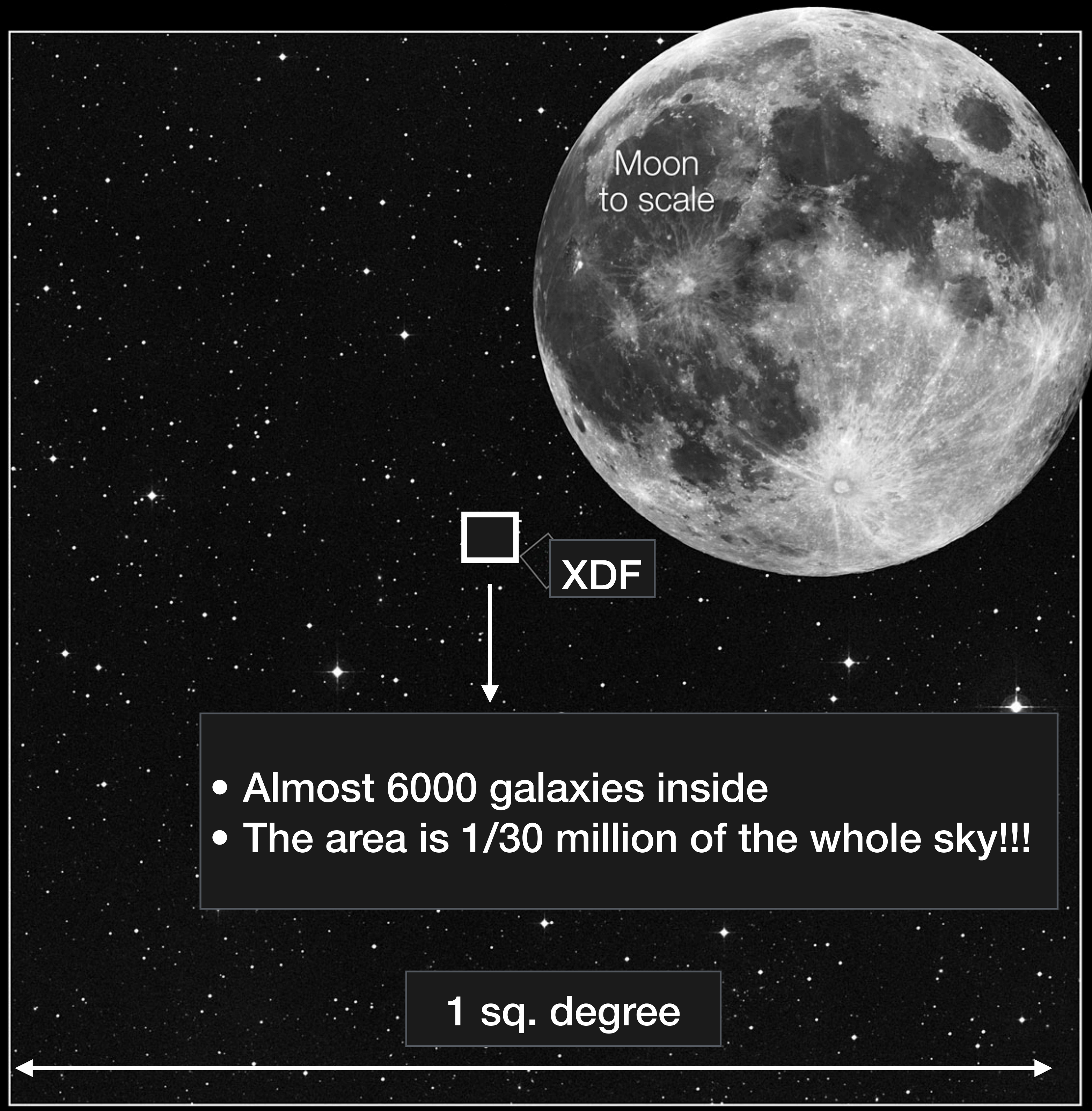
1. Hubble space telescope: *an infinite legacy*

Hubble space telescope (launched 1990)

1.2 Distant Universe: Hubble (eXtreme) Deep Field (XDF)

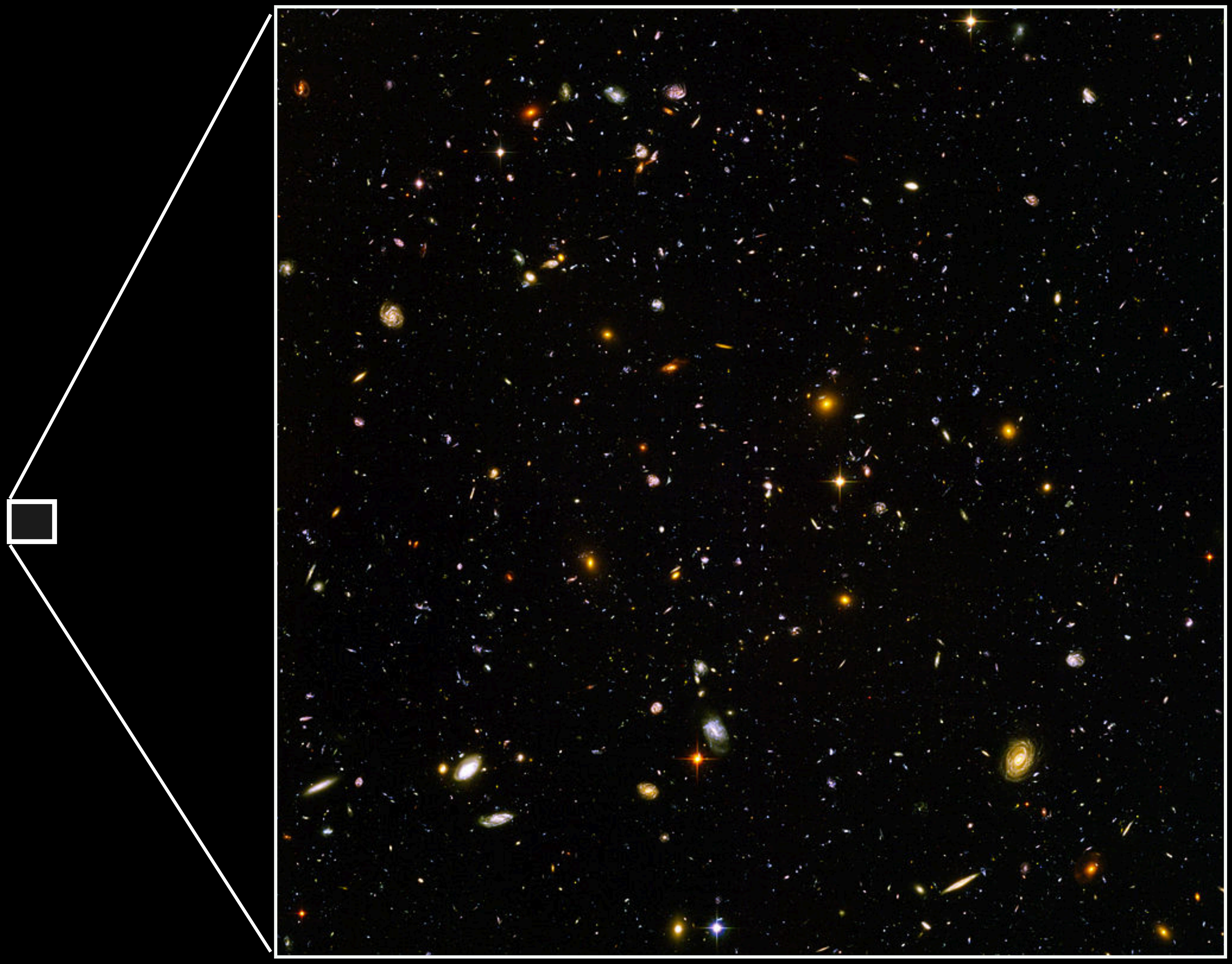


1.2 Distant Universe: Hubble (eXtreme) Deep Field (XDF)

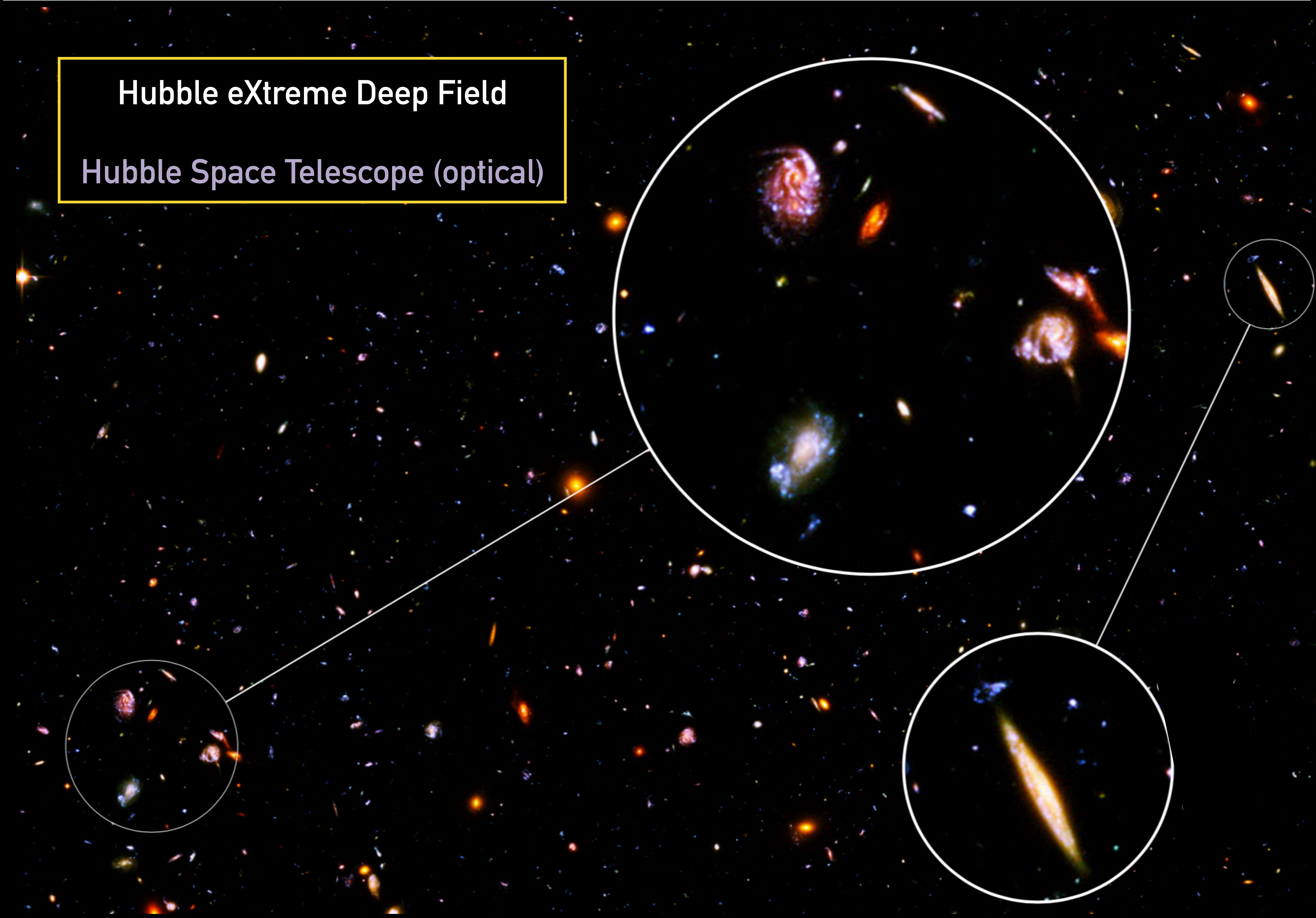


- Almost 6000 galaxies inside
- The area is 1/30 million of the whole sky!!!

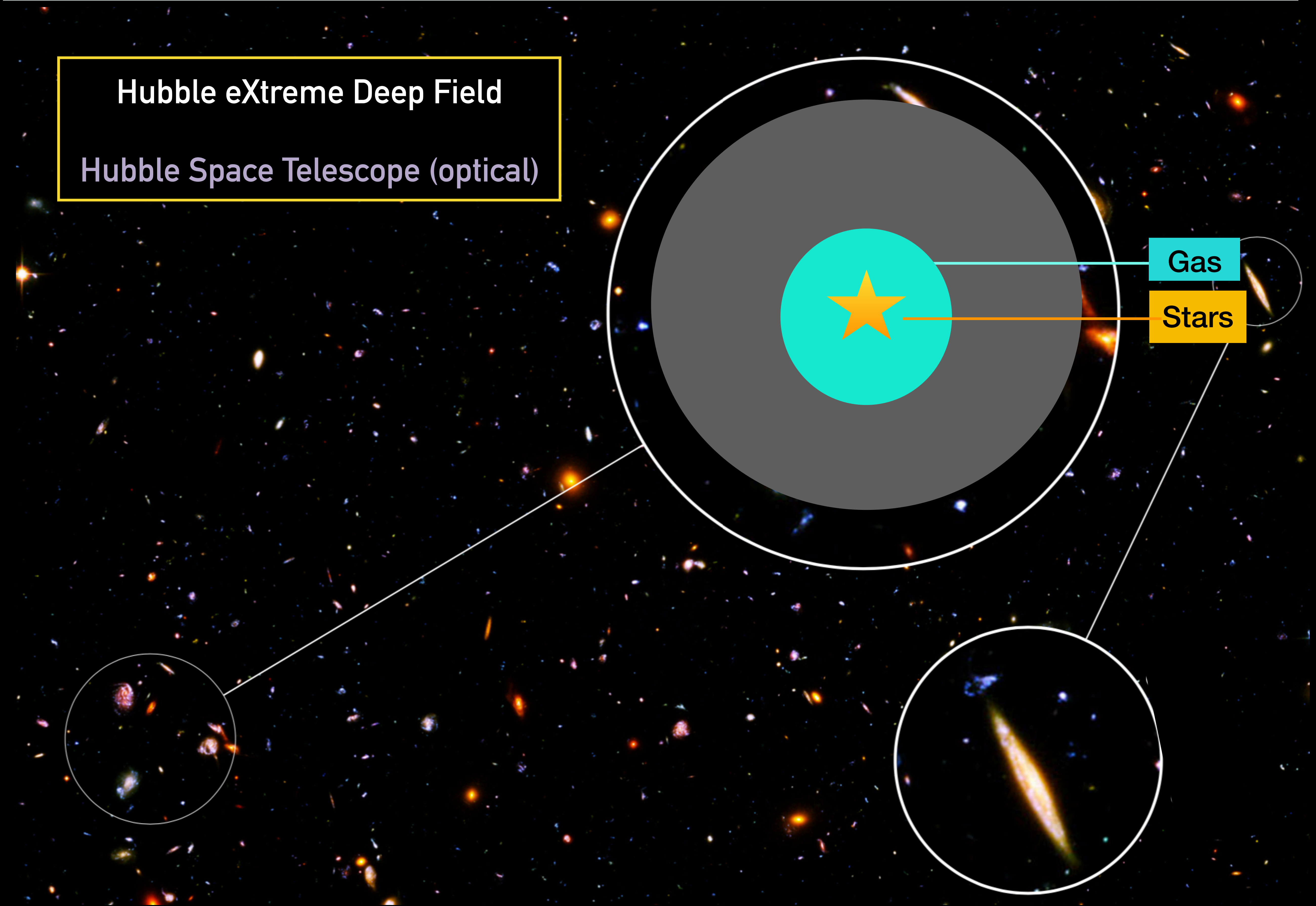
1.2 Distant Universe: Hubble (eXtreme) Deep Field (XDF)



1.3 Galaxy evolution: optical perspective

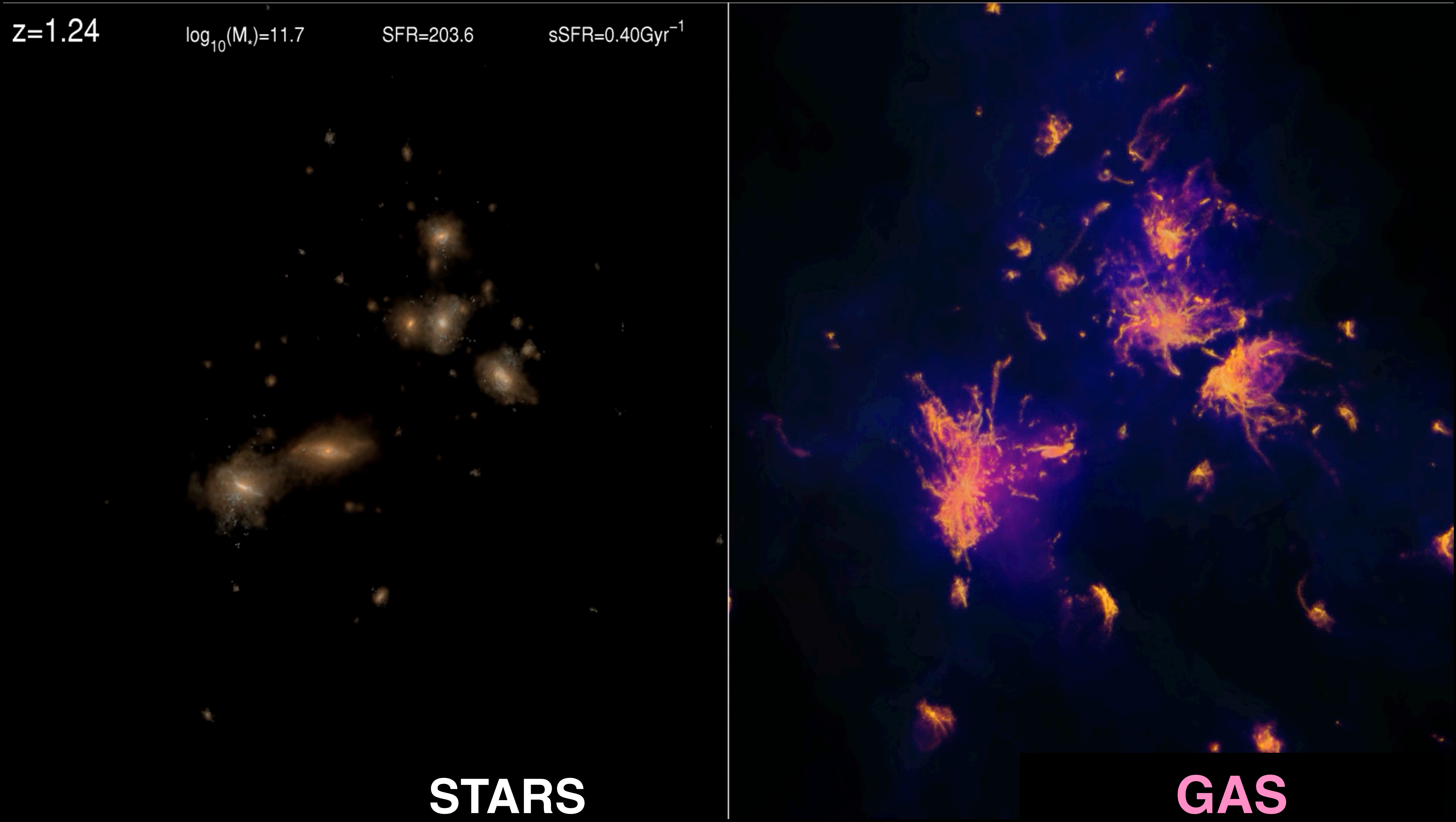


1.3 Galaxy evolution: optical perspective



1.3 Galaxy evolution

ILLUSTRIS SIMULATION



1.4 Searching for the most distant galaxies

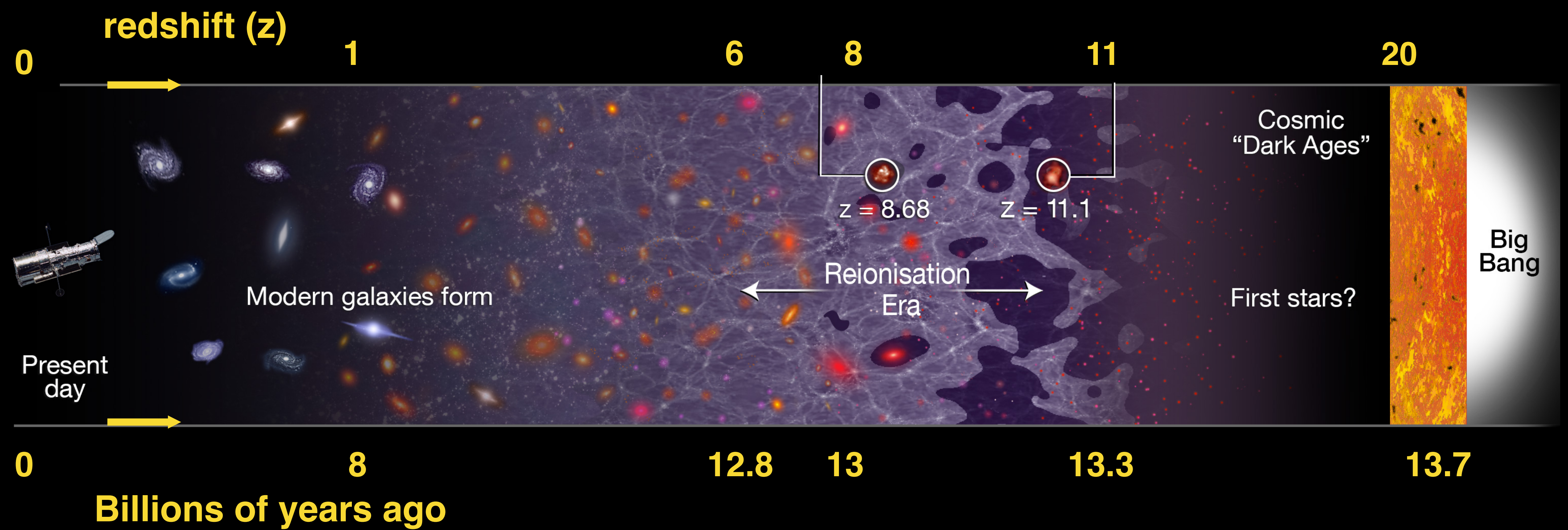
1.4 Searching for the most distant galaxies

The most distant galaxy confirmed before 2022

GN-z11 (z=11.1)

(Oesch et al. 2016)

1.5 Galaxy evolution in pre-JWST era

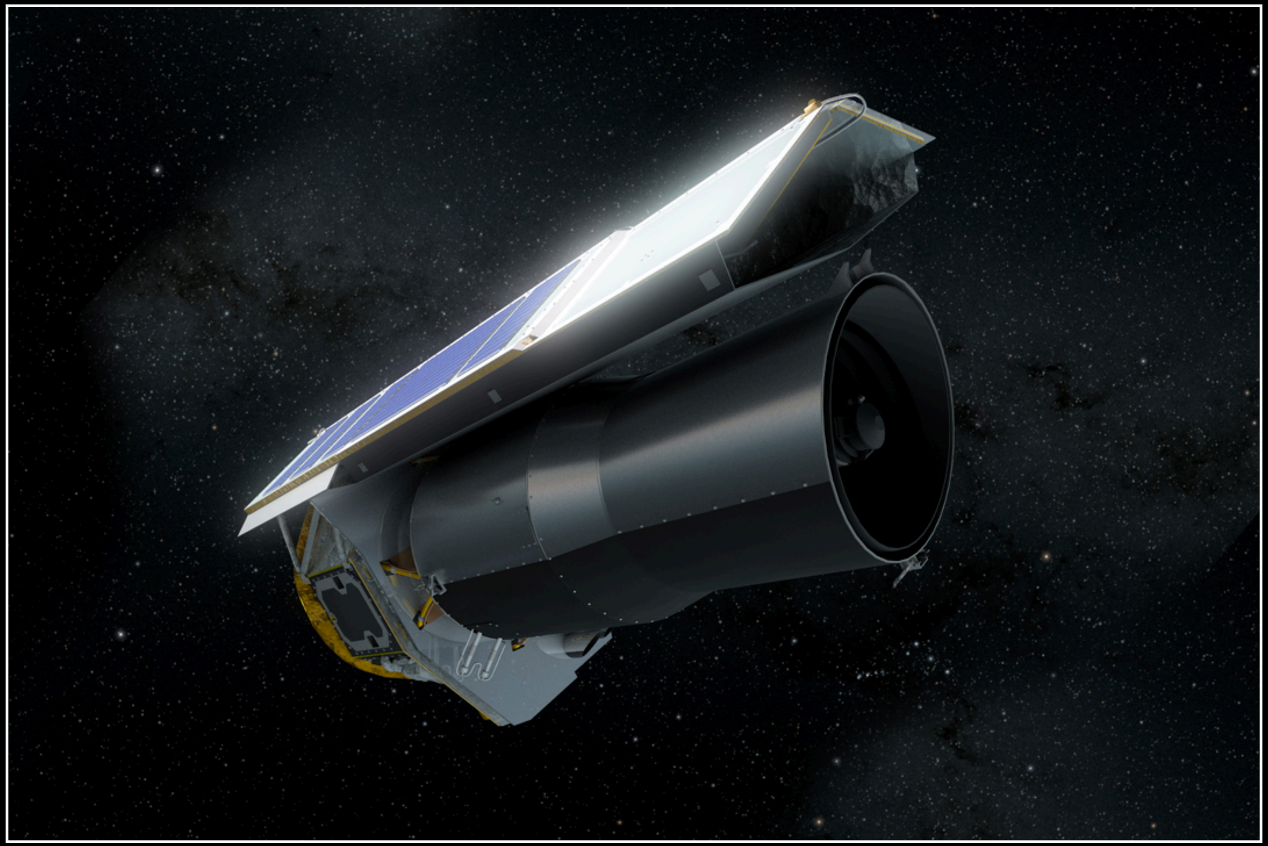


Credit: NASA, ESA, A.Field

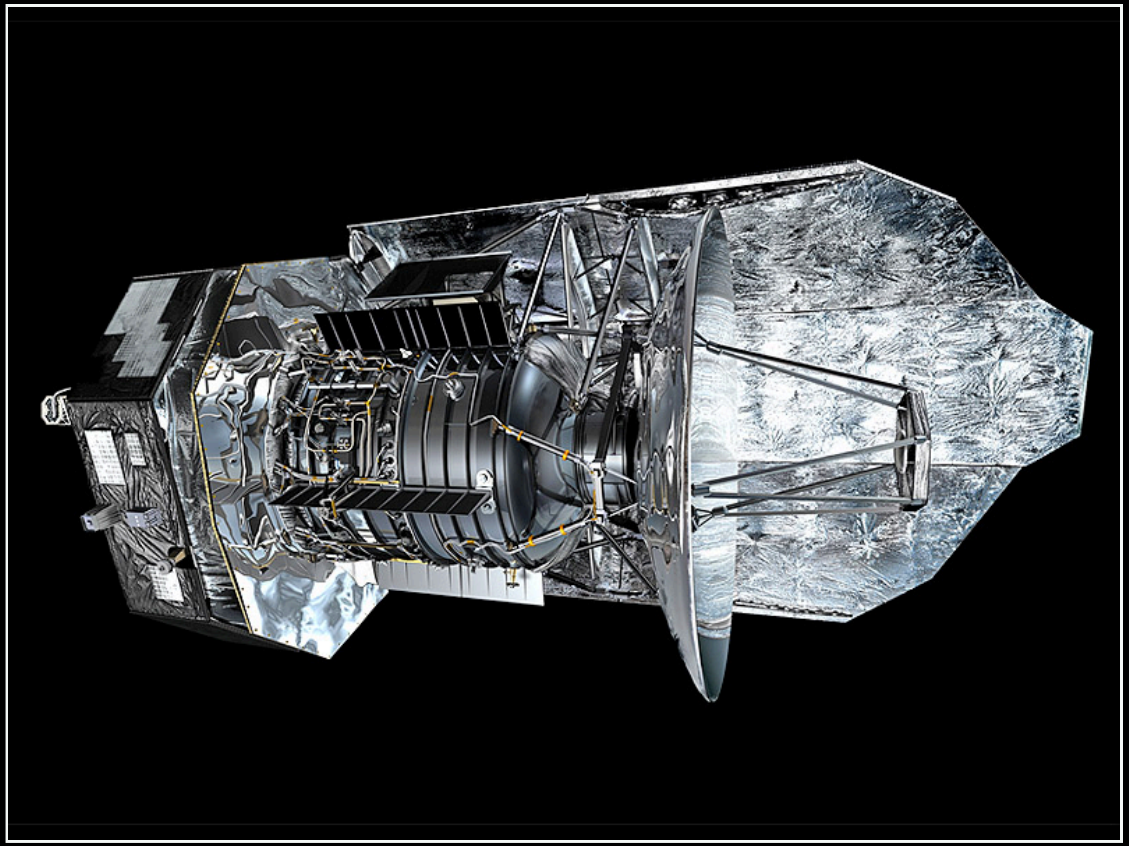
- Current estimate 200 billion galaxies in the Universe identified…
- … but predictions say that we yet have to find 10 times more!!!

2. Why do we need JWST?

2. Galaxy evolution: an infrared window

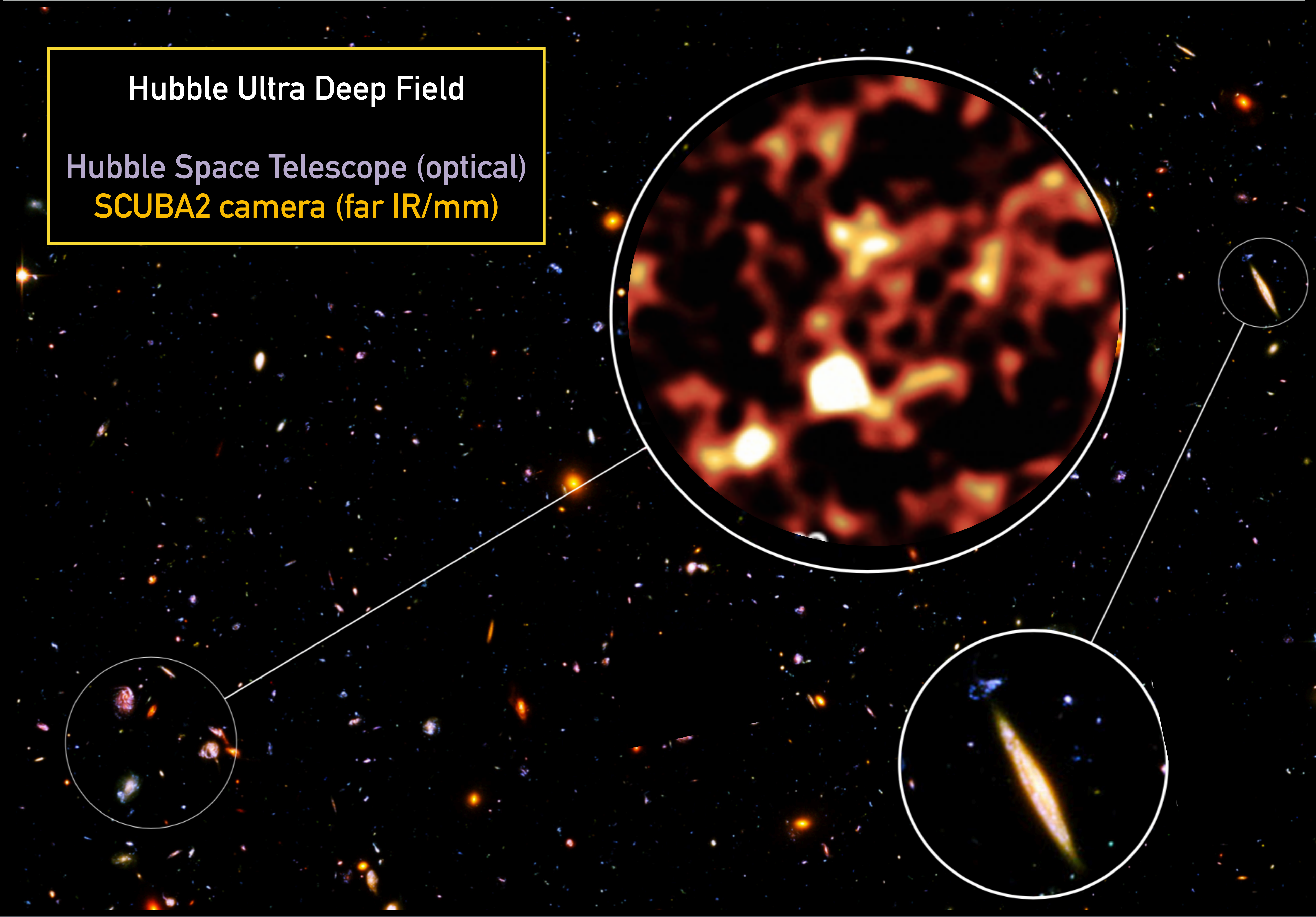


Spitzer space telescope
(mid-IR)

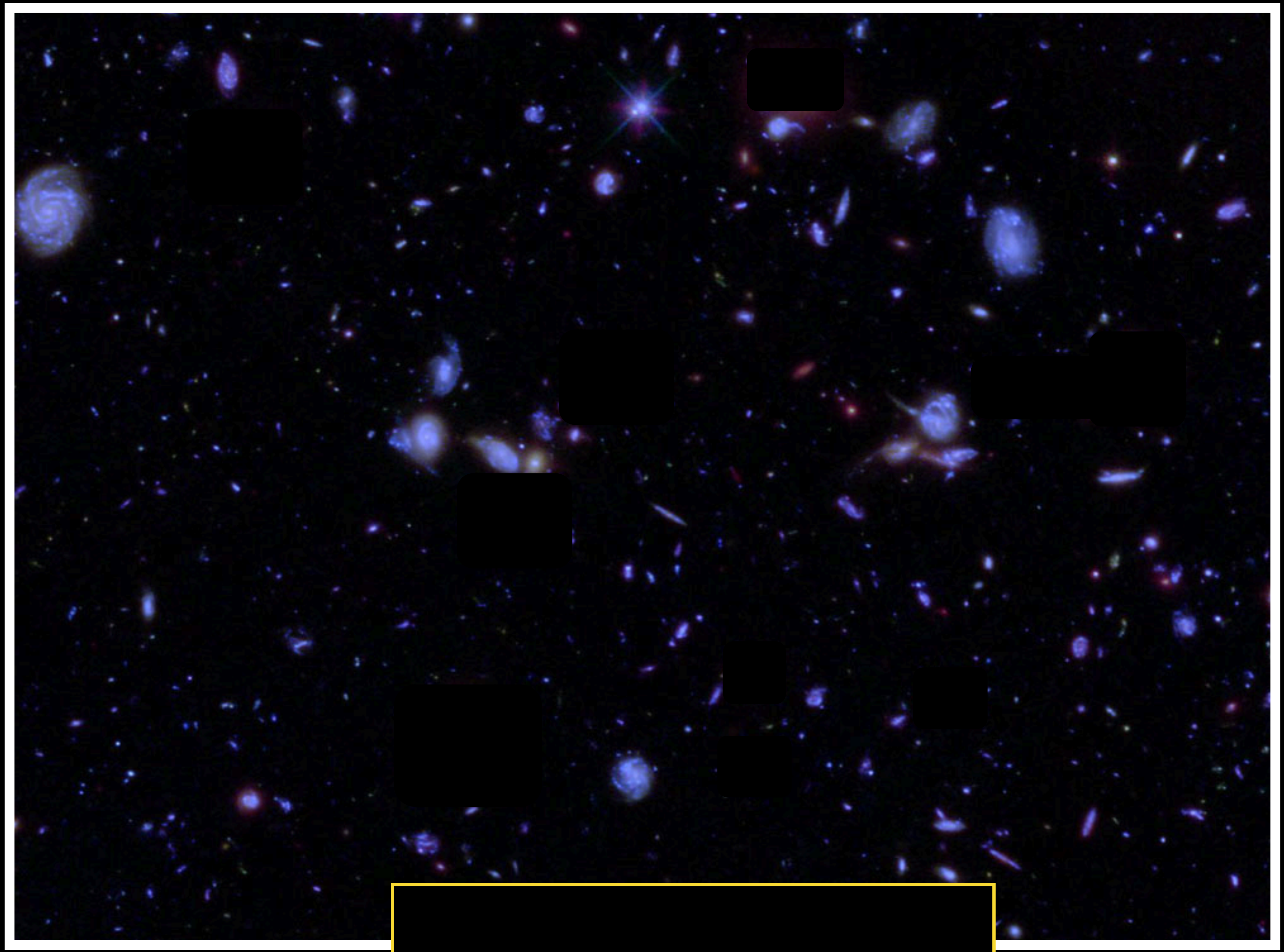


Herschel space telescope
(far-IR)

2. Galaxy evolution: an infrared window

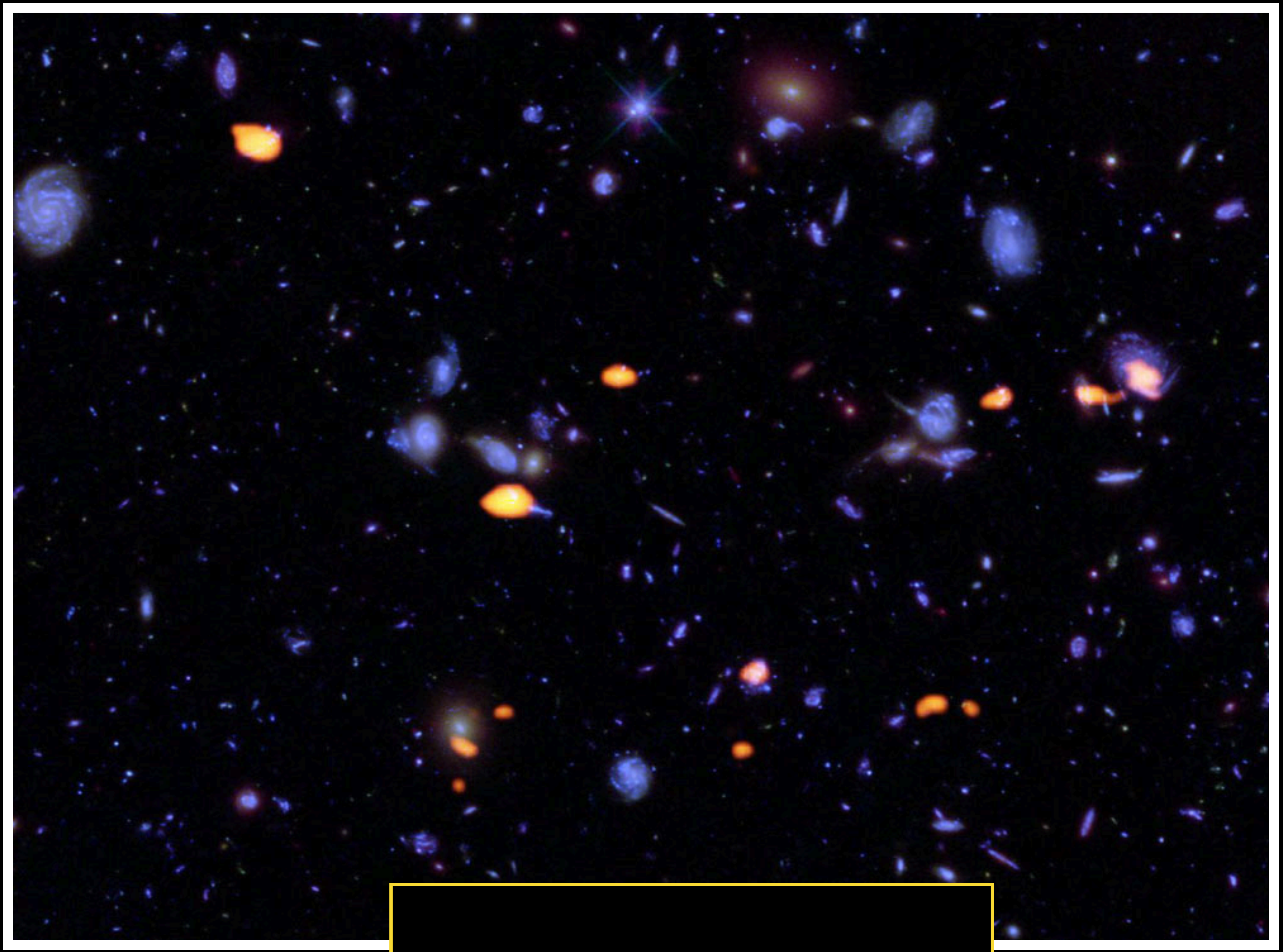


Hubble XDF field without dust emission



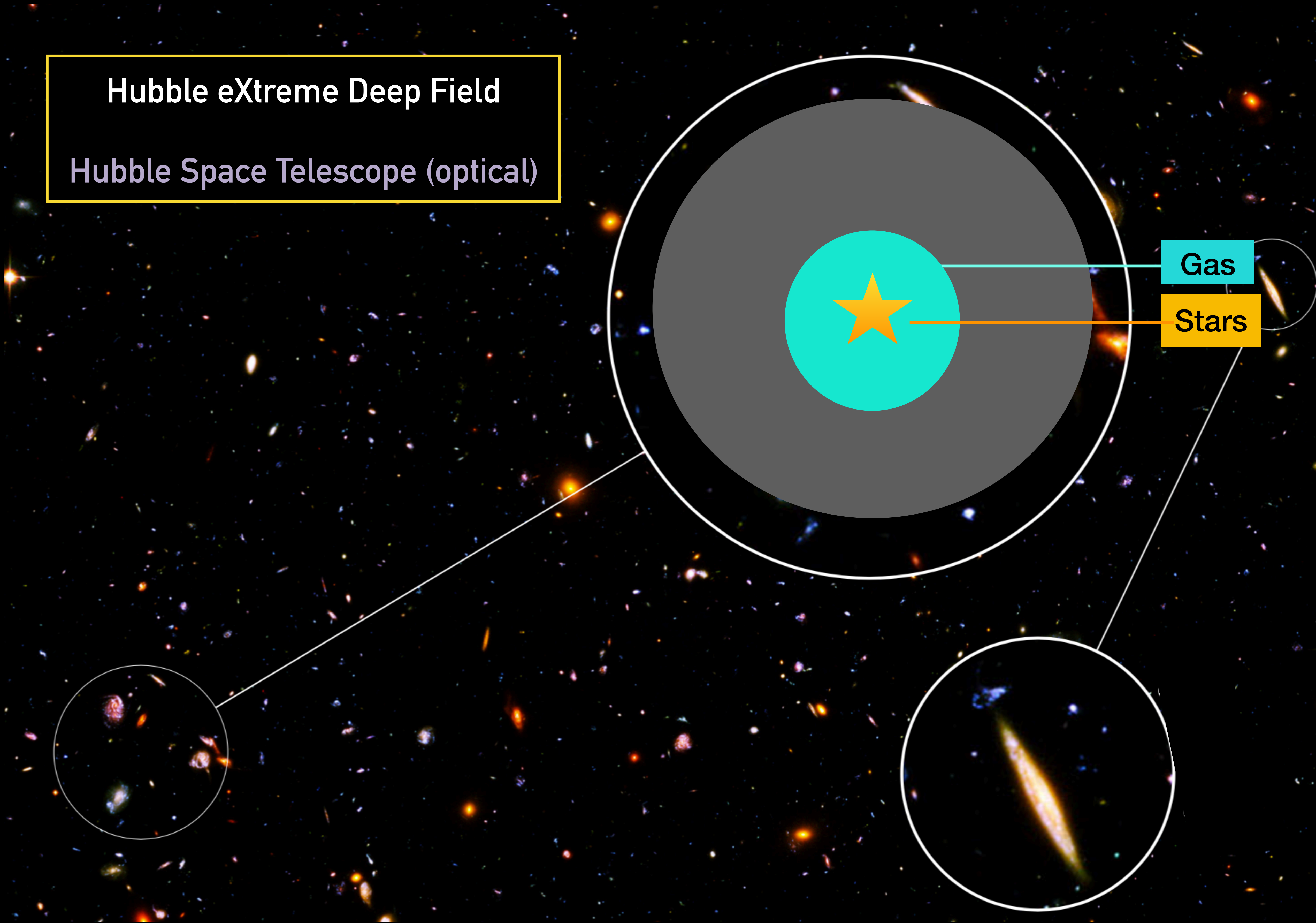
Hubble Space Telescope

Hubble XDF field with dust emission

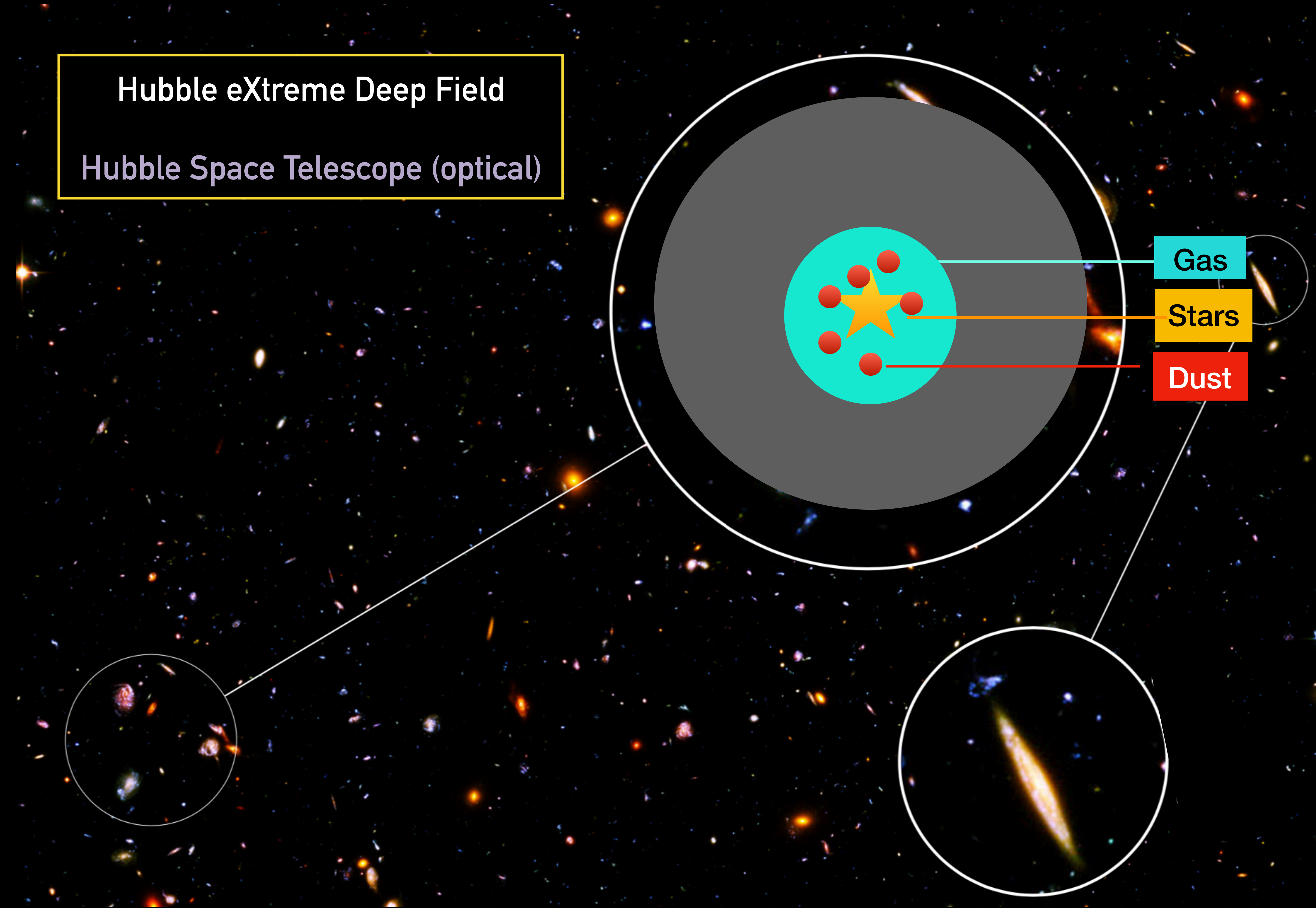


Hubble Space Telescope
ALMA (sub-mm)

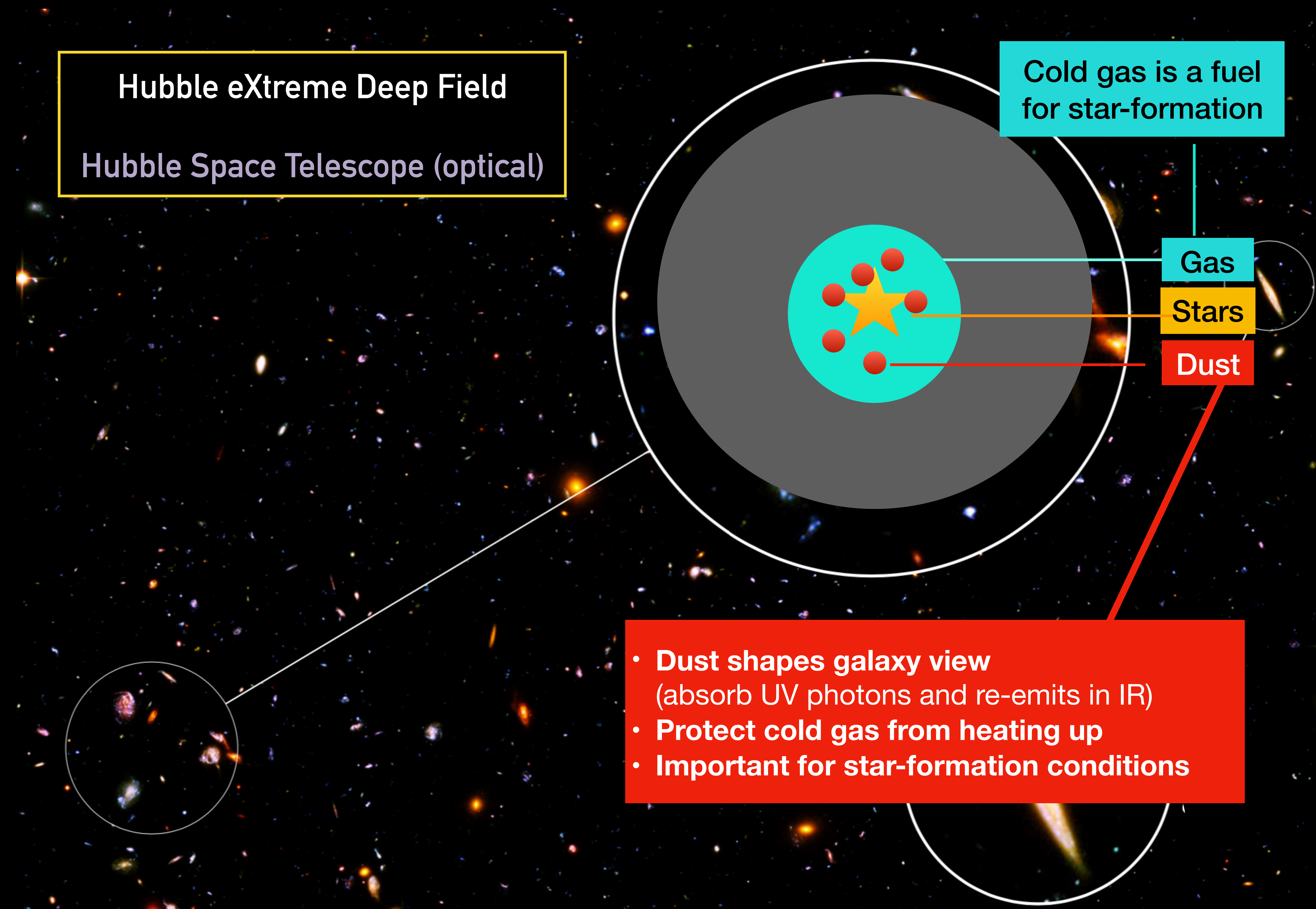
2. Galaxy evolution: an infrared window



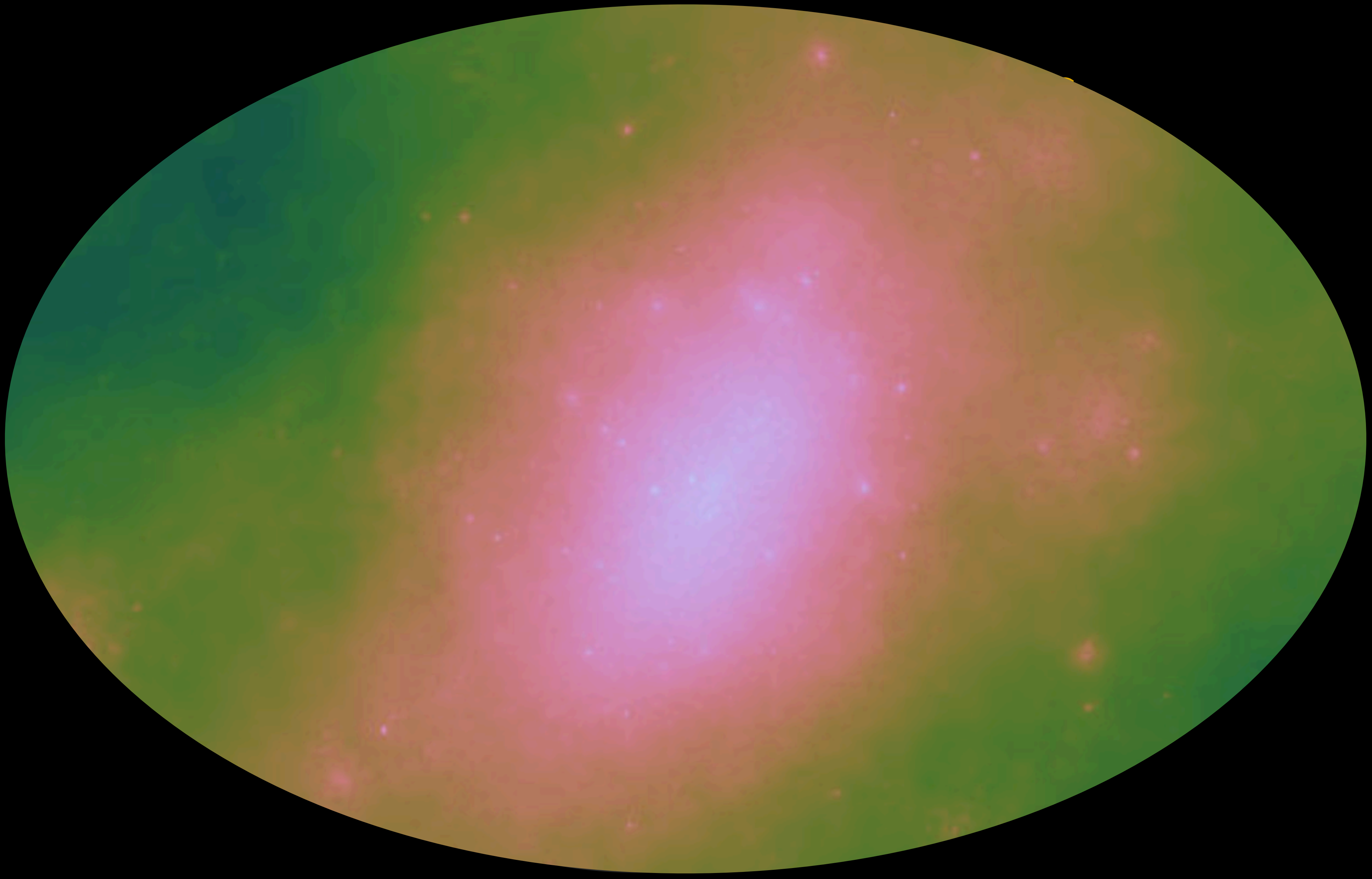
2. Galaxy evolution: an infrared window



2. Galaxy evolution: an infrared window



2.1 Why worrying about dust in galaxies?



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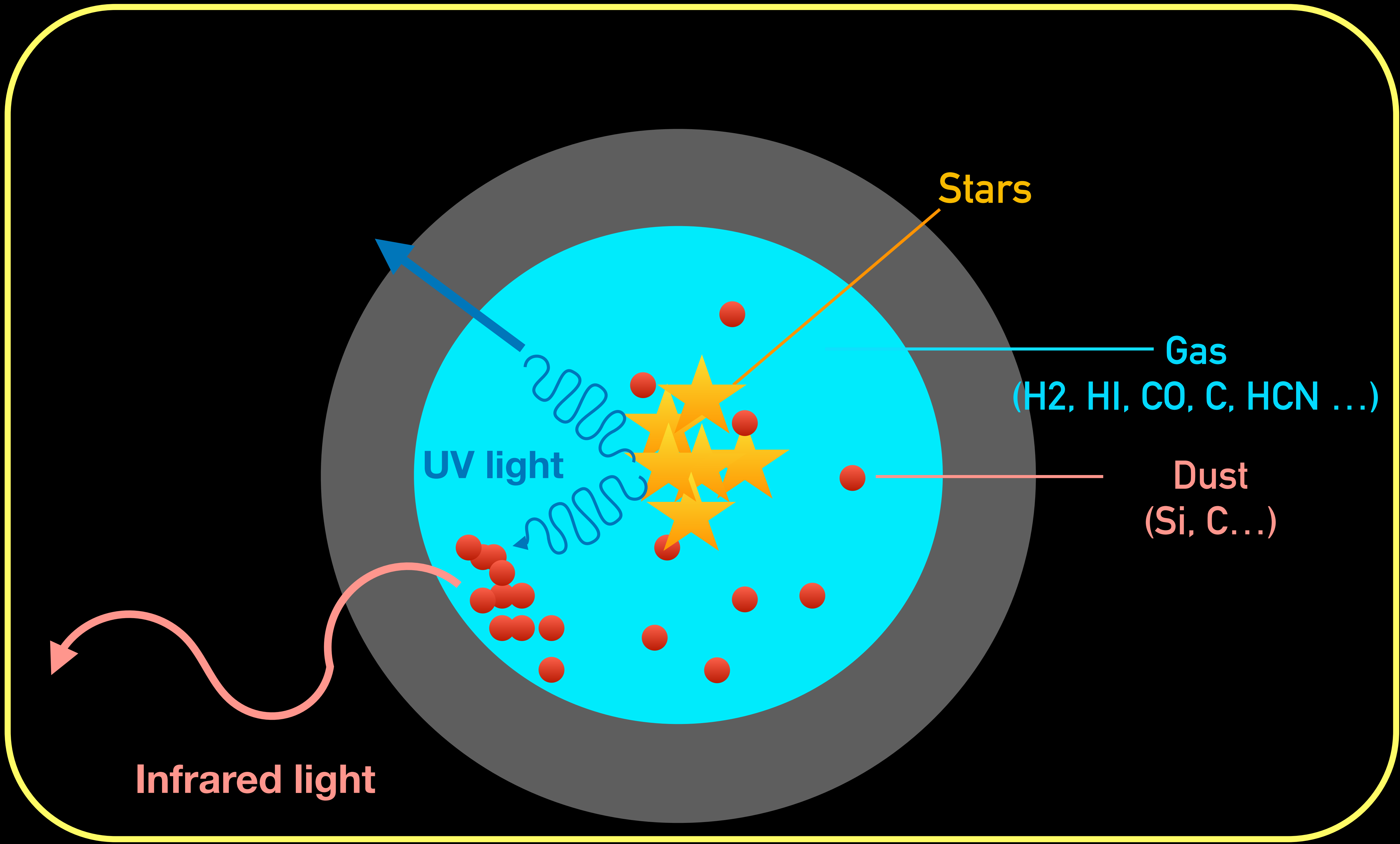
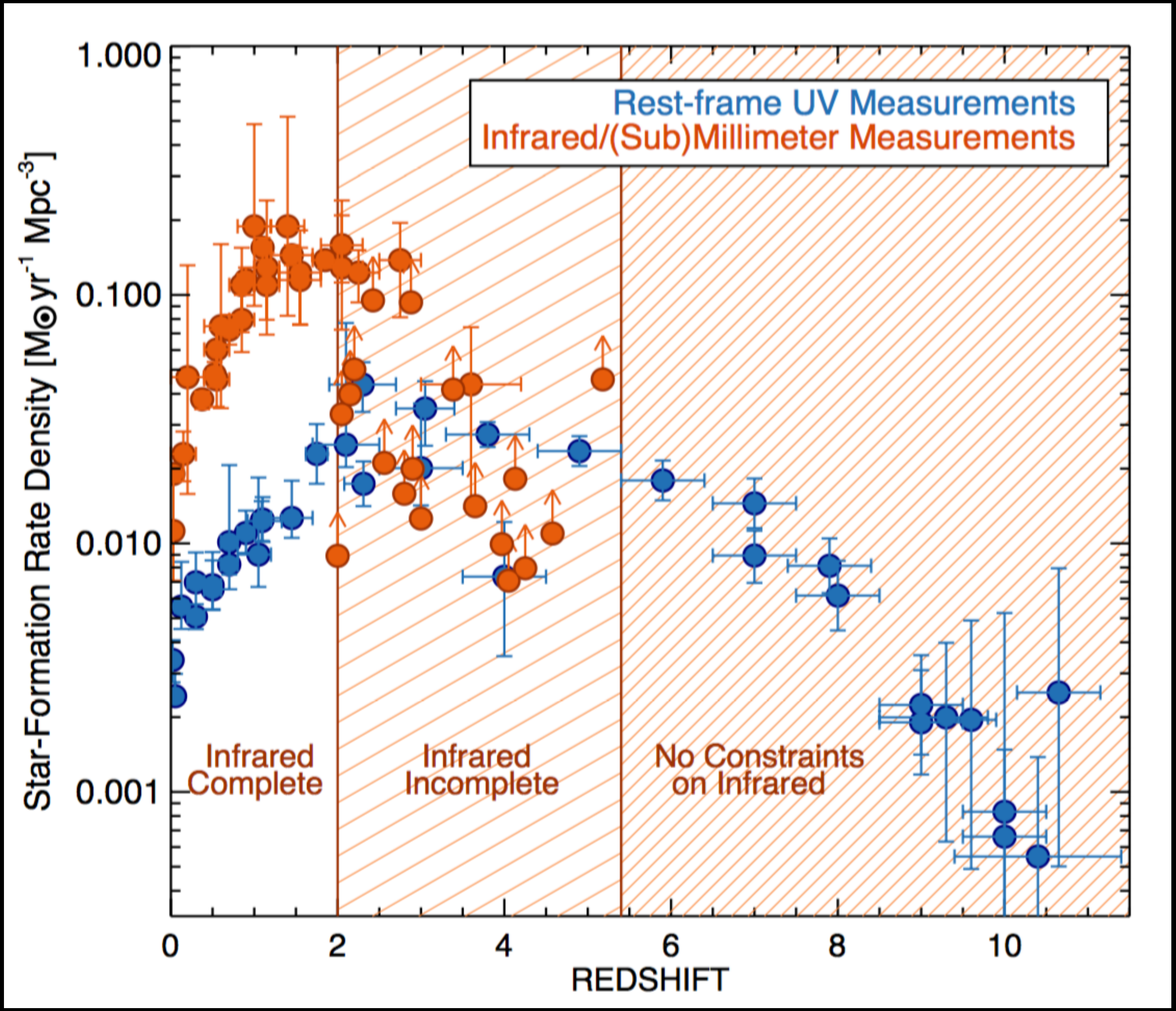


Dust accounts only 1% of the interstellar medium mass, but it's crucial in galaxies!

2.2. History of galaxy star-formation



Credit: Casey et al. 2019

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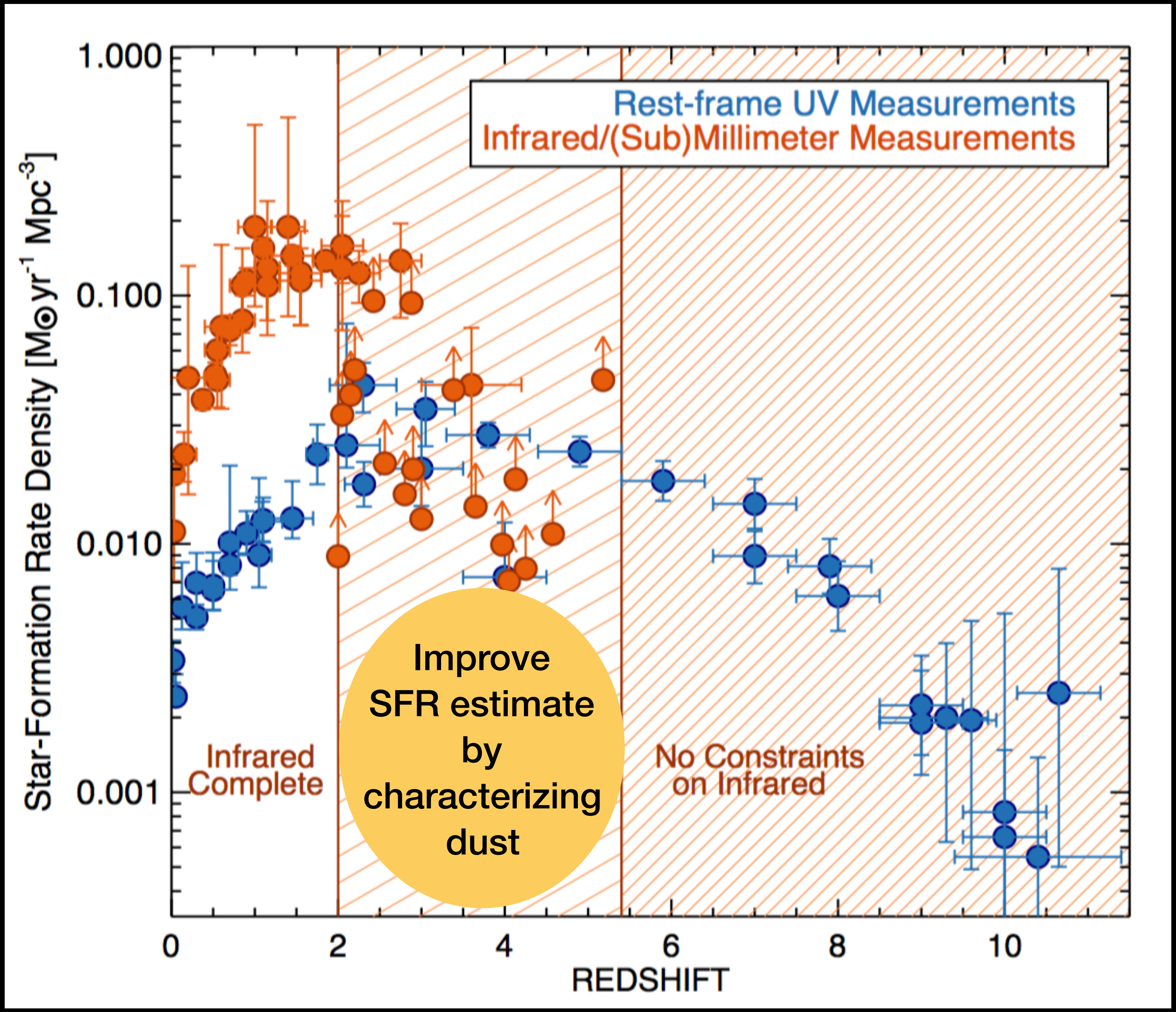
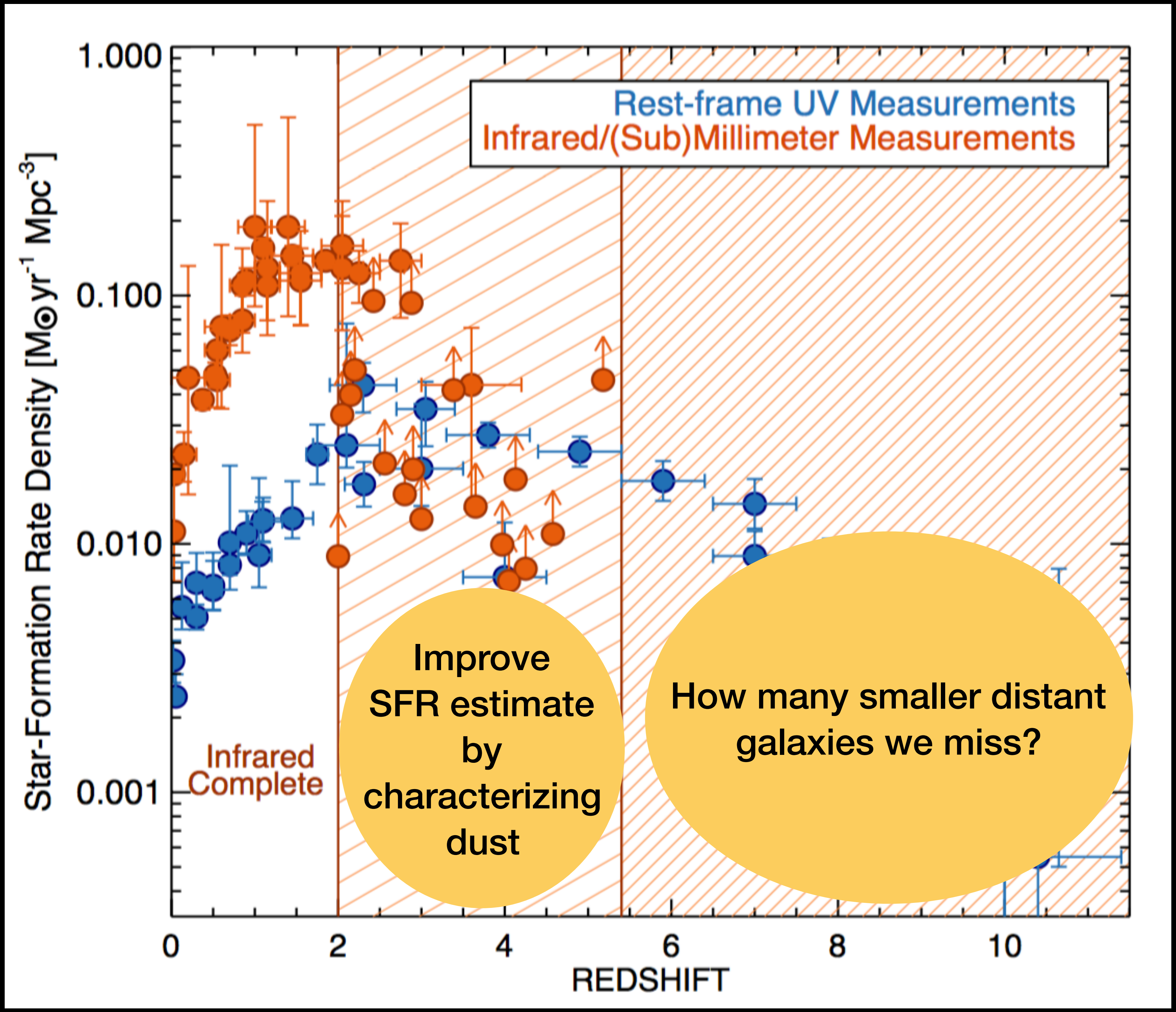


Credit: Casey et al. 2019

2.2. History of galaxy star-formation



Credit: Casey et al. 2019

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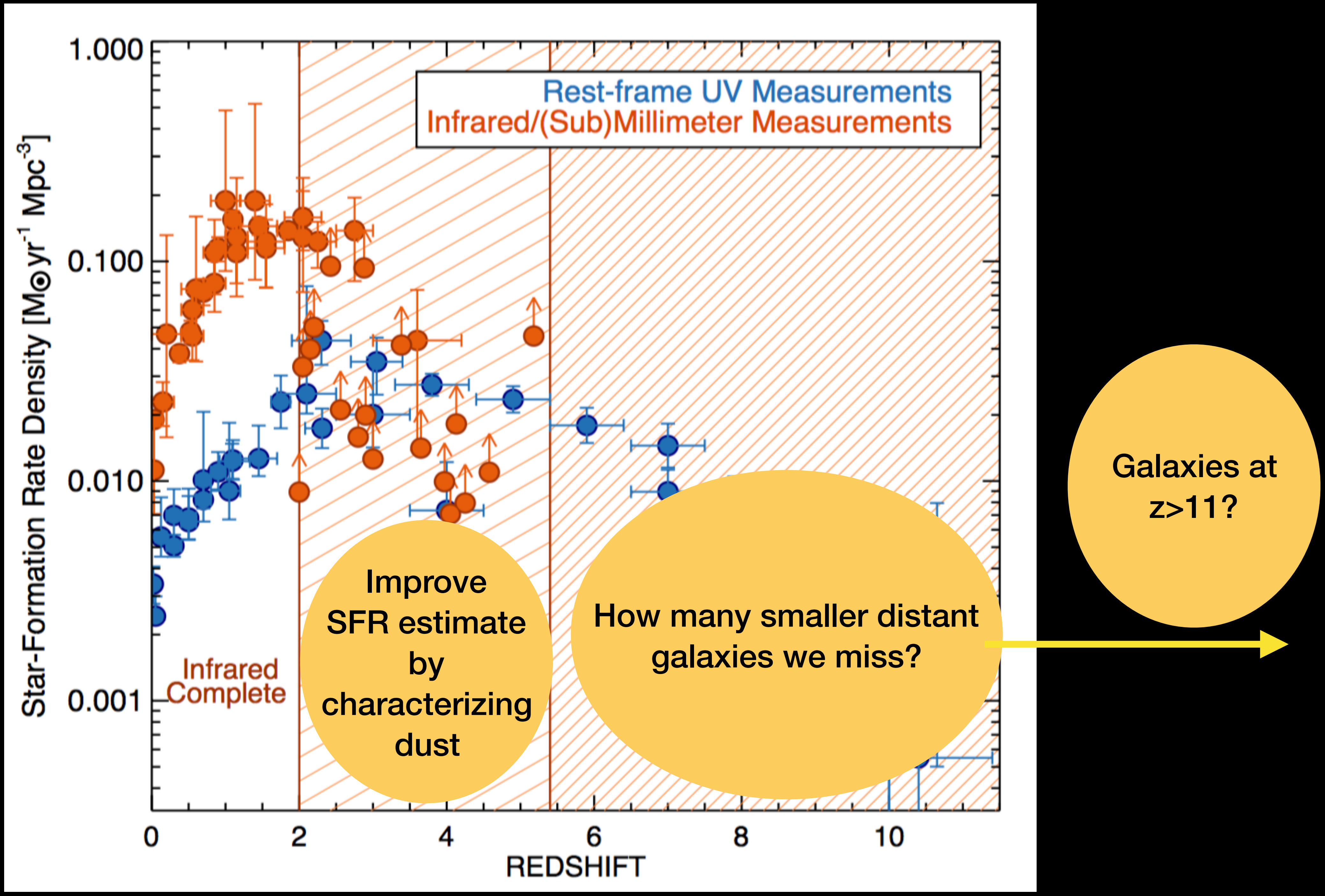
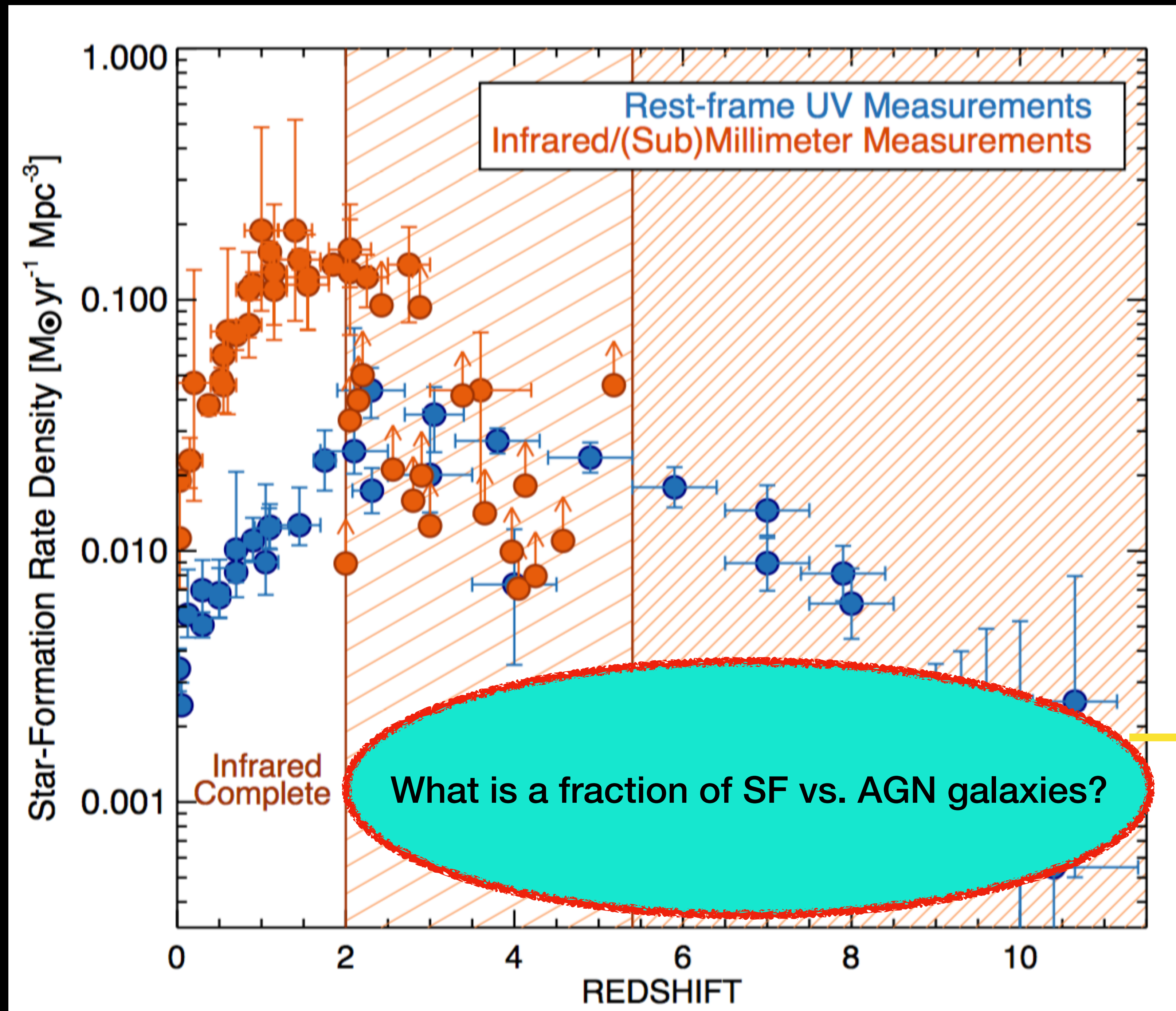


Credit: Casey et al. 2019

2.2. History of galaxy star-formation

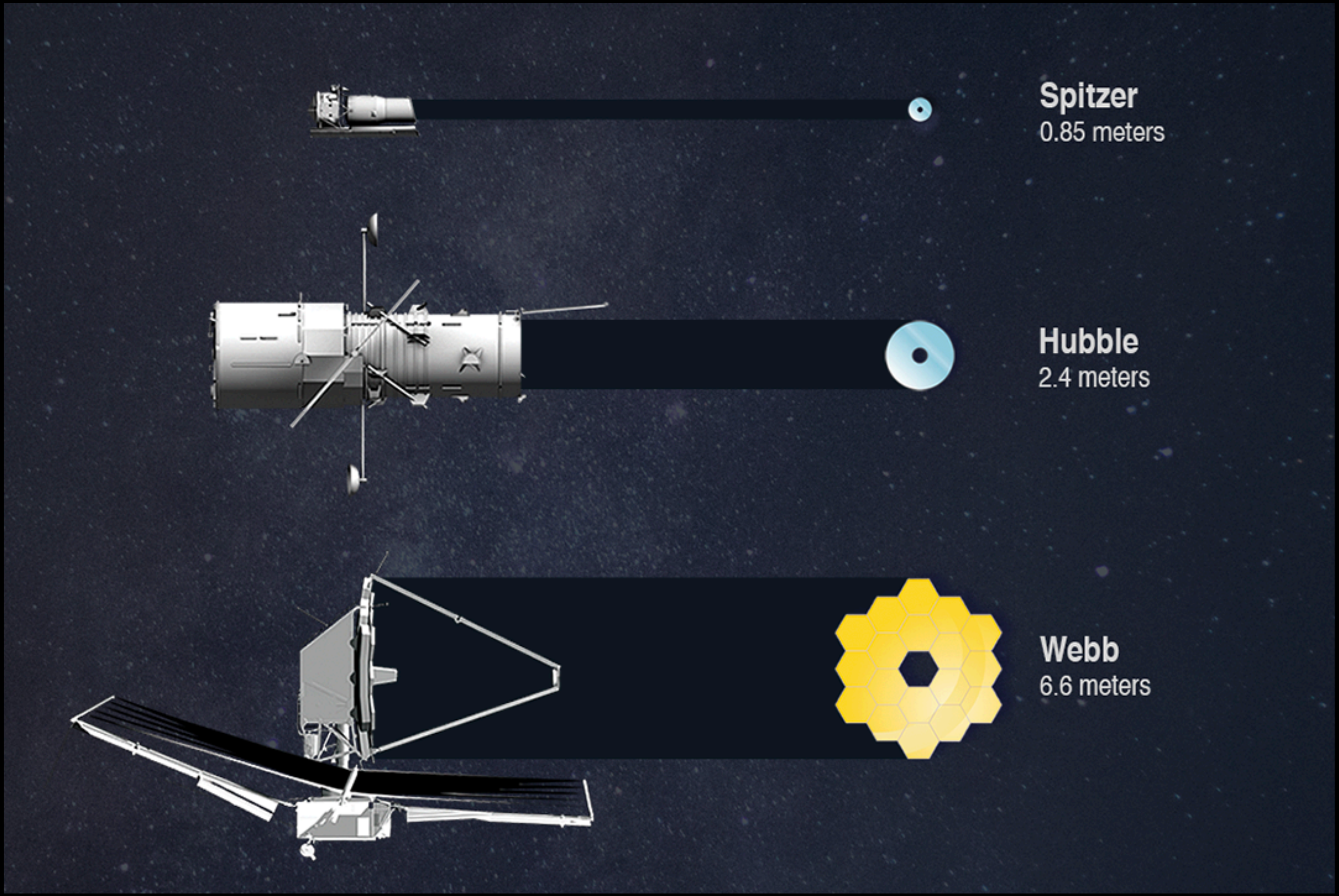


Galaxies at z>11?

Credit: Casey et al. 2019

3. JWST - “unfold the Universe”

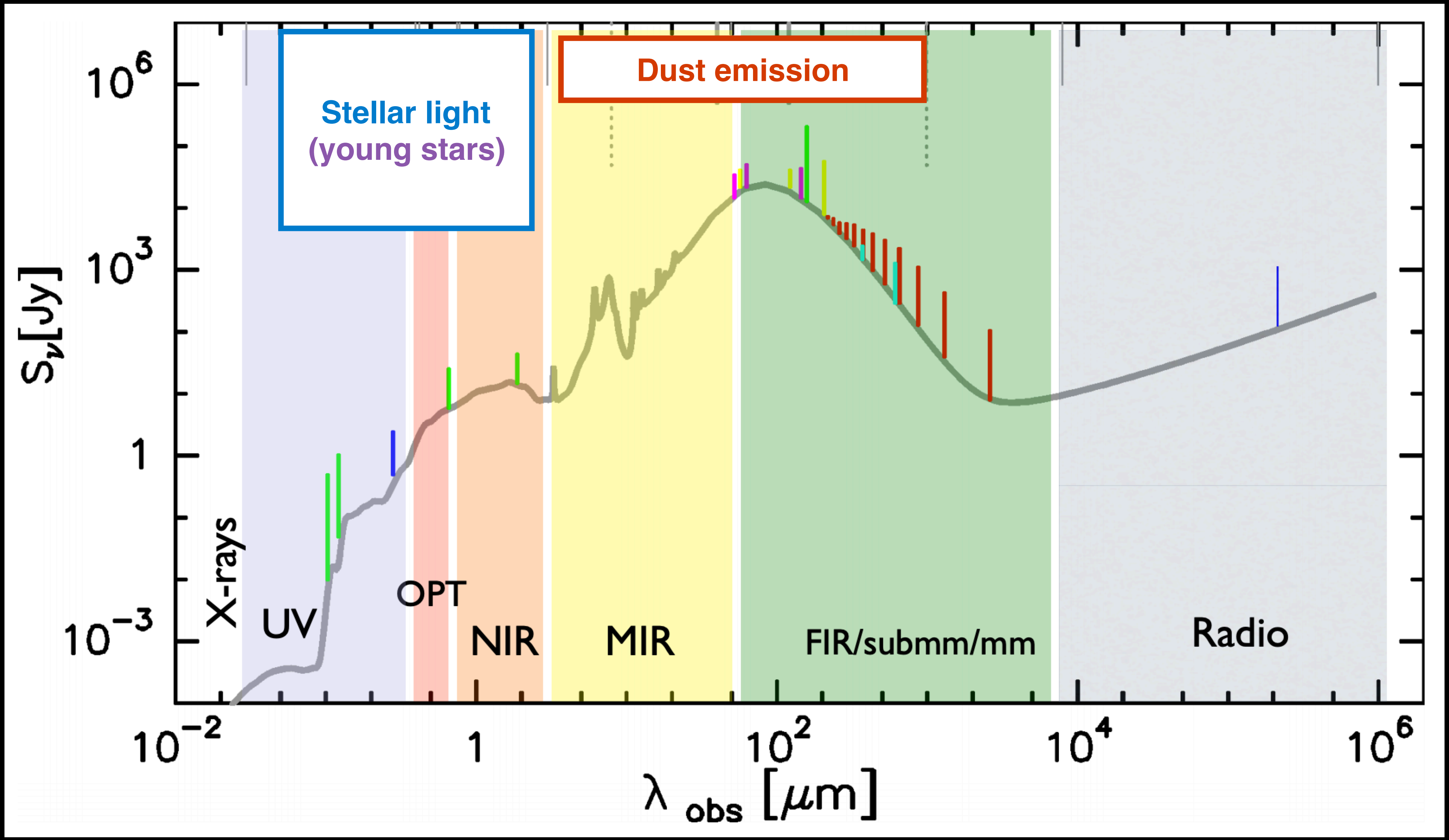
3. Unfold the Universe



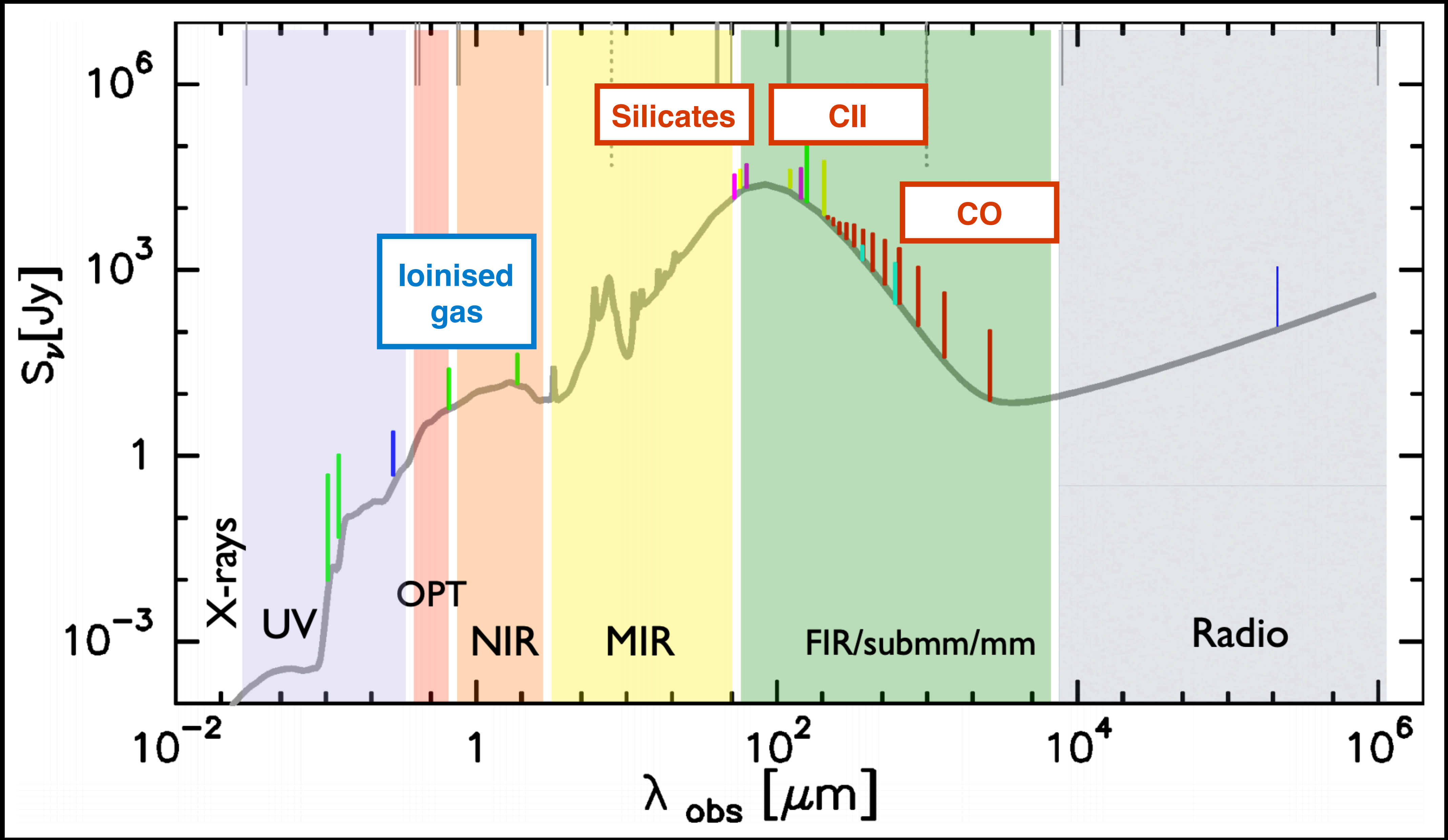
JWST primary mirror is the largest ever sent into space

3. Unfold the Universe

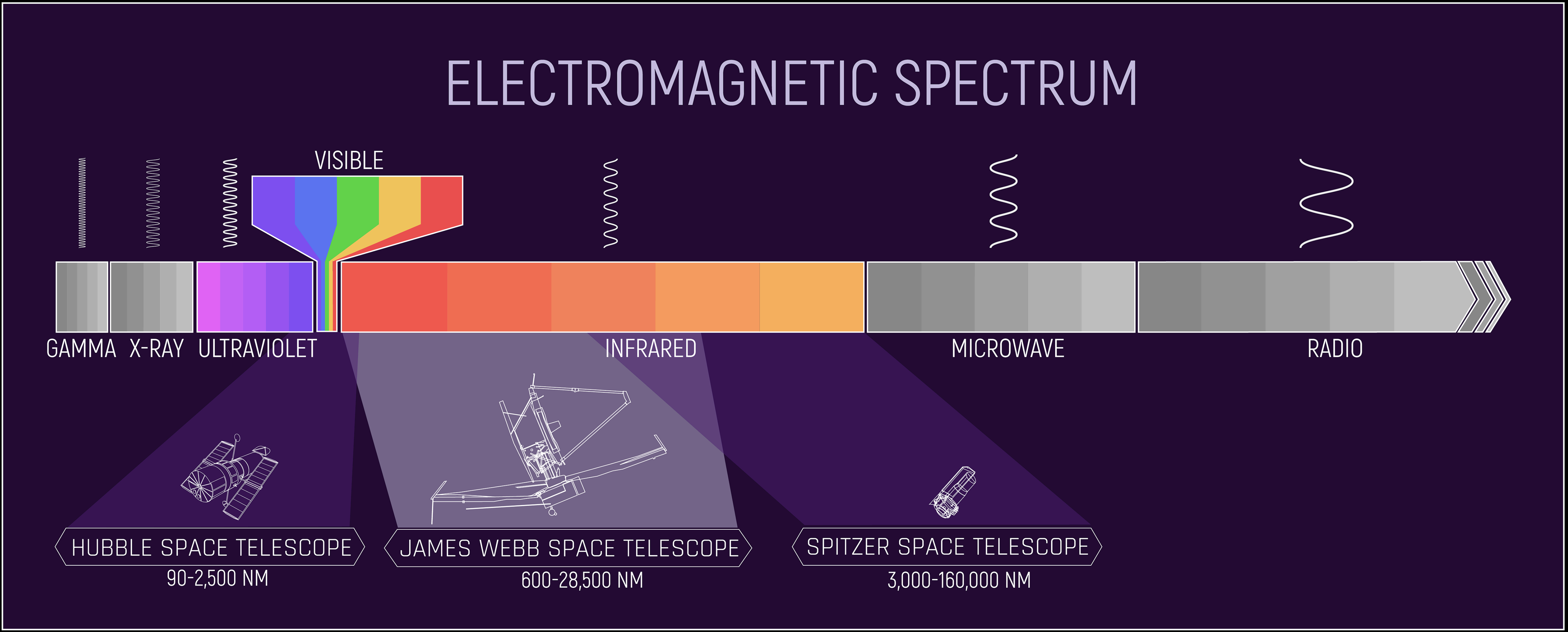
Full Spectral Energy Distribution (SED) of galaxies



Full Spectral Energy Distribution (SED) of galaxies



2. JWST - new window into (mid)infrared Universe

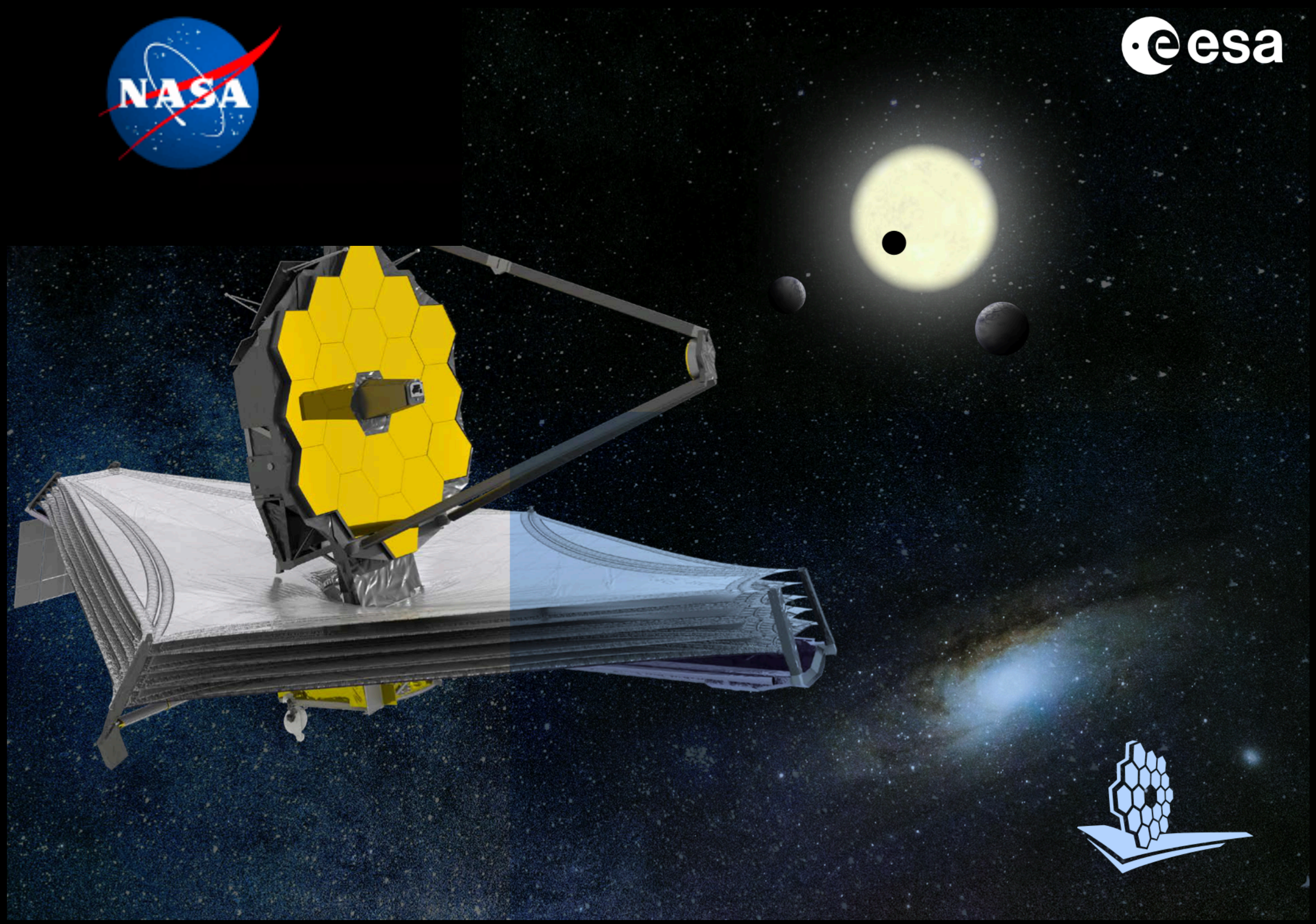


JWST will cover the wide range of near-IR-to-mid-IR

James Webb Space Telescope (JWST)

- Collaboration: NASA/ ESA/ Canadian Space Agency
- Primary mirror: D=6.5m
- NIR-instruments and MIR-instruments

JWST in a nuttshell



- In L2 point (1.5 billion km from Earth)
- PRIMARY MIRROR (D= 6.5m)
  (gold-plated beryllium)
- 18 mirror segments / 5 sunshield layers
- 4 SCIENCE INSTRUMENTS
  (near-IR and mid-IR)

JWST in a nuttshell

- PRIMARY MIRROR (gold-plated beryllium)
  Diameter = 6.5m

- 18 hexagonal segments
- Collecting area: 25 m2

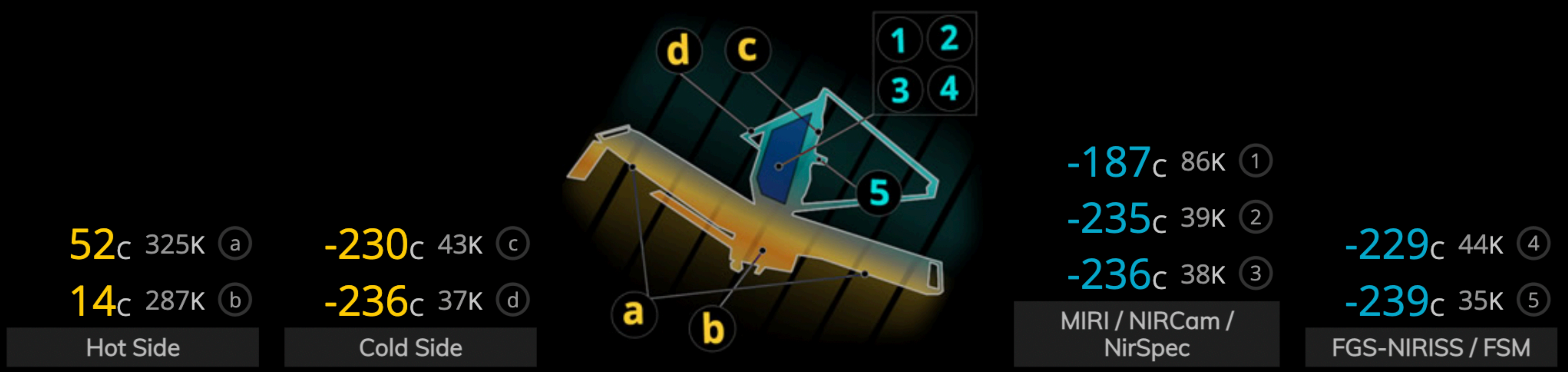
- SECONDARY MIRROR:
  Diameter = 0.75m

- 132 micro-motors for mirror adjustments

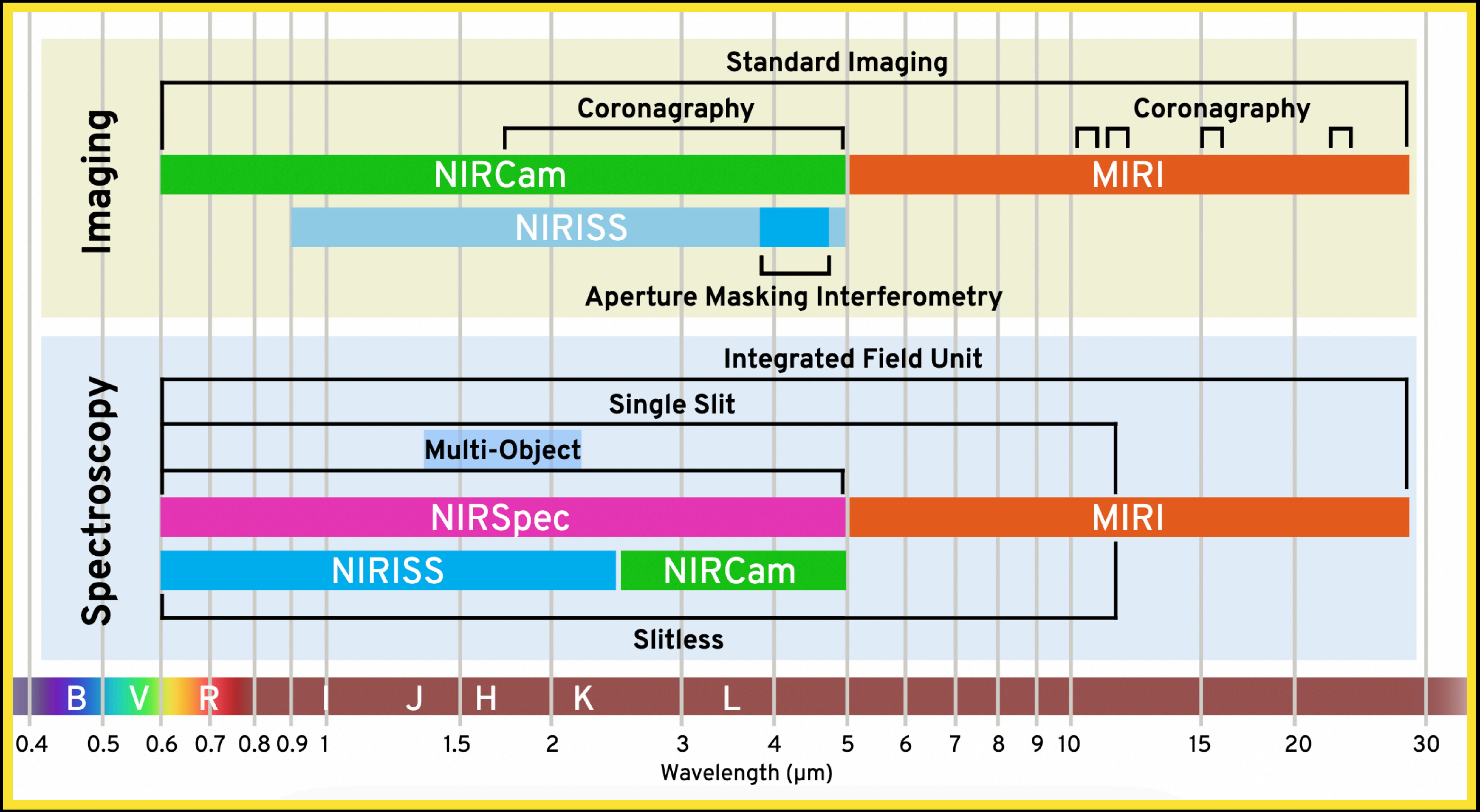
JWST in a nuttshell

Temperatures must be kept <50K

- Sunshield (Aluminium + dopped silicon)
- Cryocooler (Helium)



3. JWST: instruments

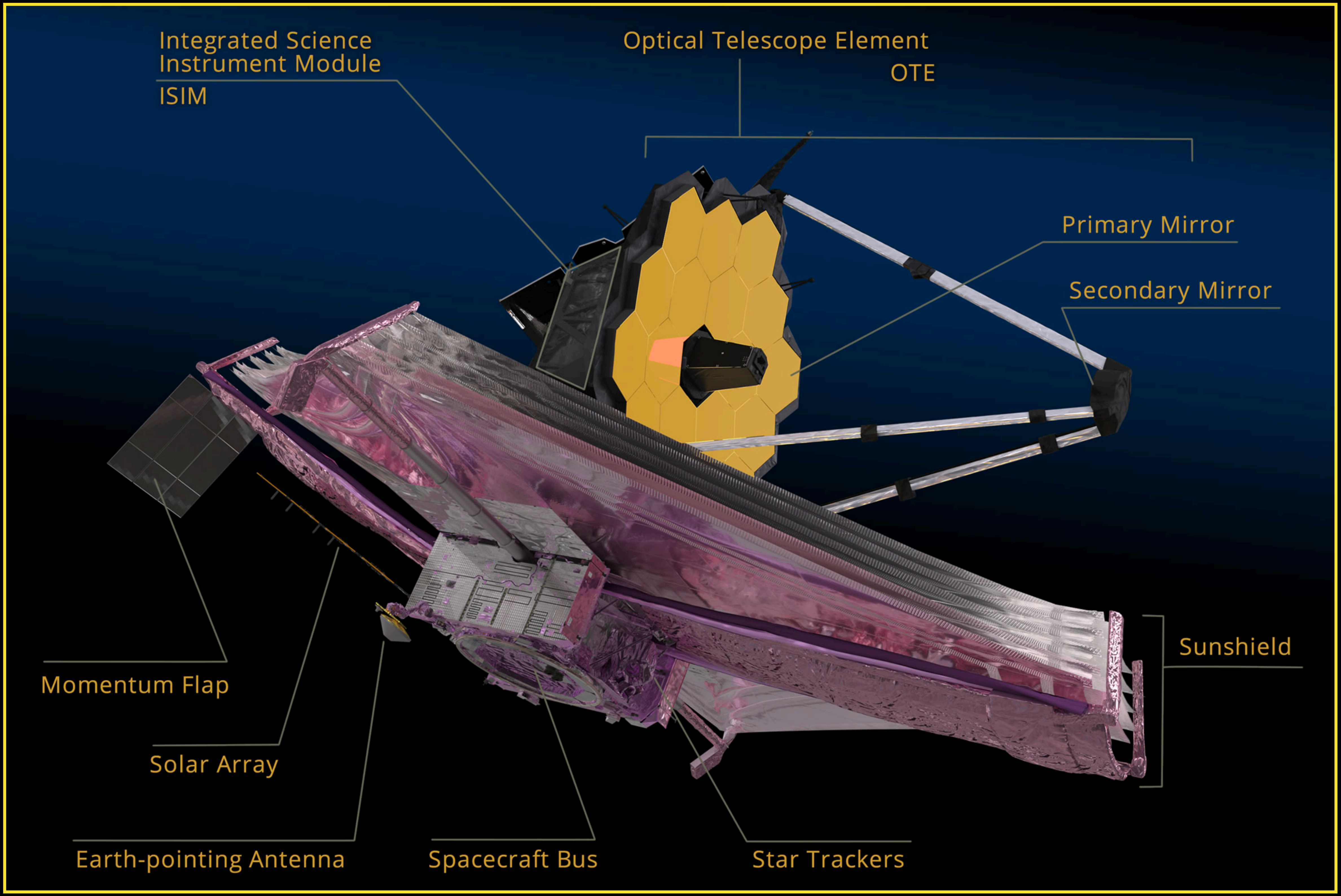


Credit: JWST/NASA

Proposing science to JWST
Extremely competitive… and it will be!

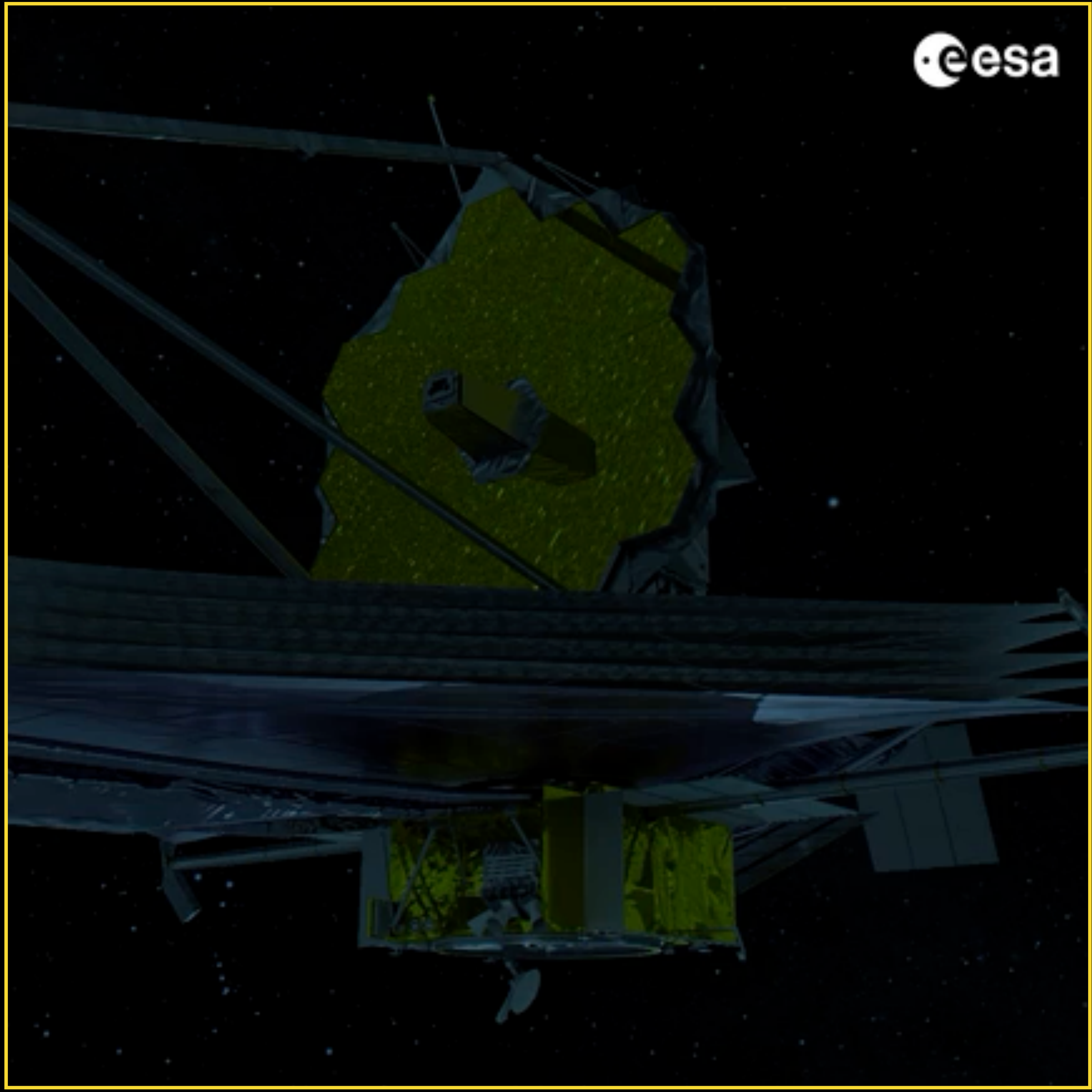
General Observer Program (GO)

- Cycle 1 (1200 proposals / 24 500h requested)
- Available (1600h)

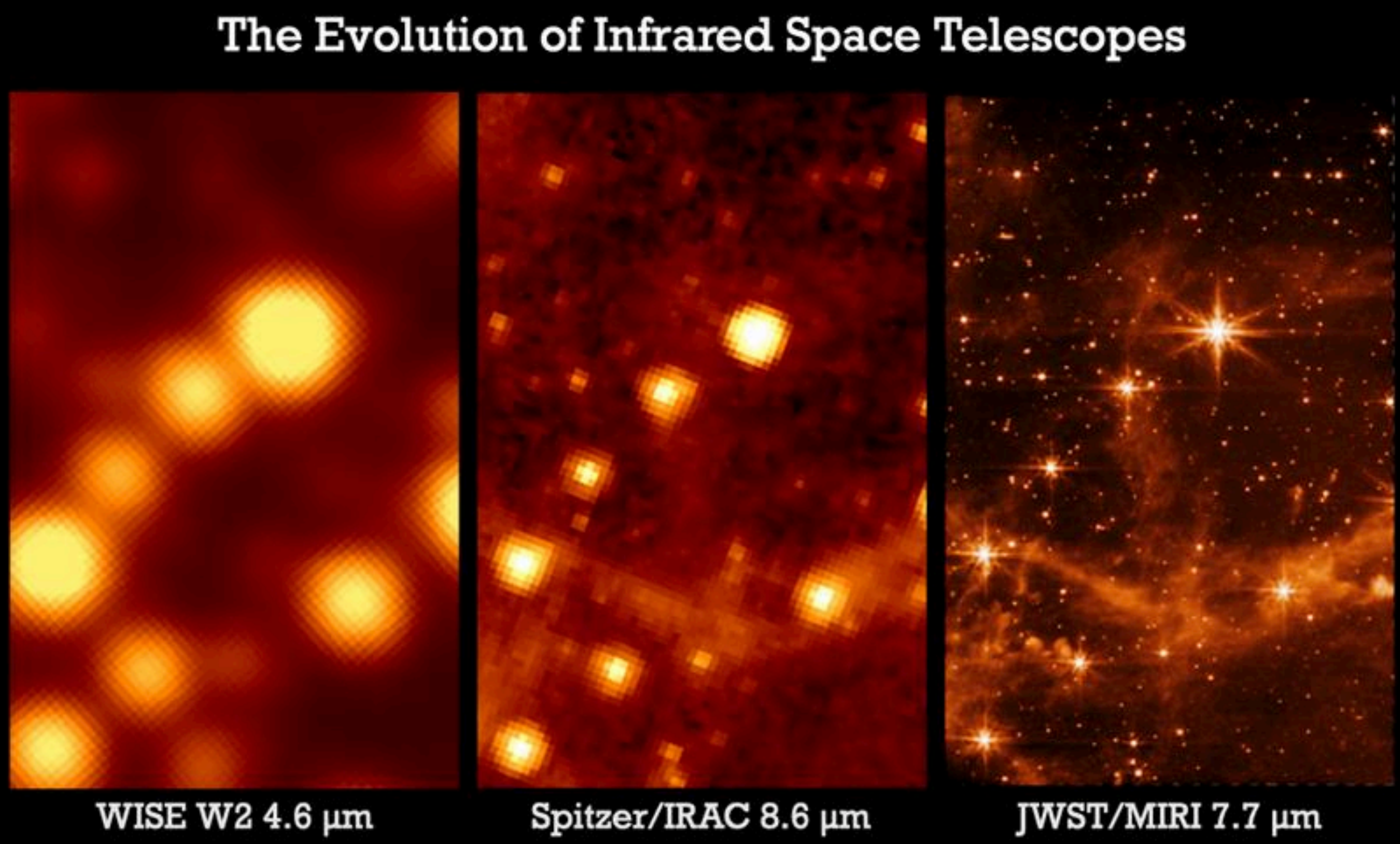

Integrated Science
Instrument Module
ISIM
Optical Telescope Element
OTE
Primary Mirror
Secondary Mirror
Sunshield
Momentum Flap
Solar Array
Earth-pointing Antenna
Spacecraft Bus
Star Trackers

4. First results

JWST as time machine

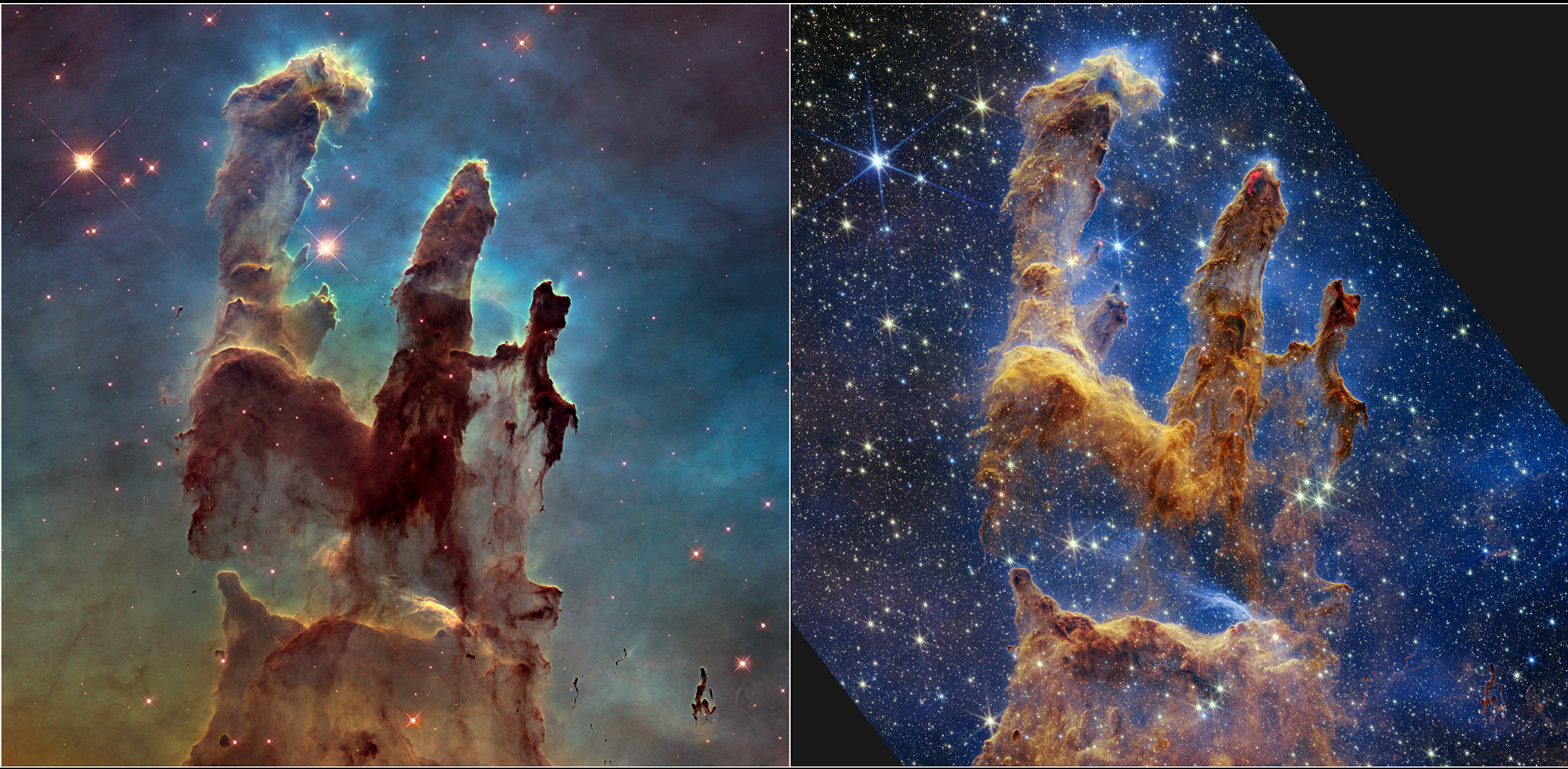


4.1 Comparing the infrared view with other space telescopes



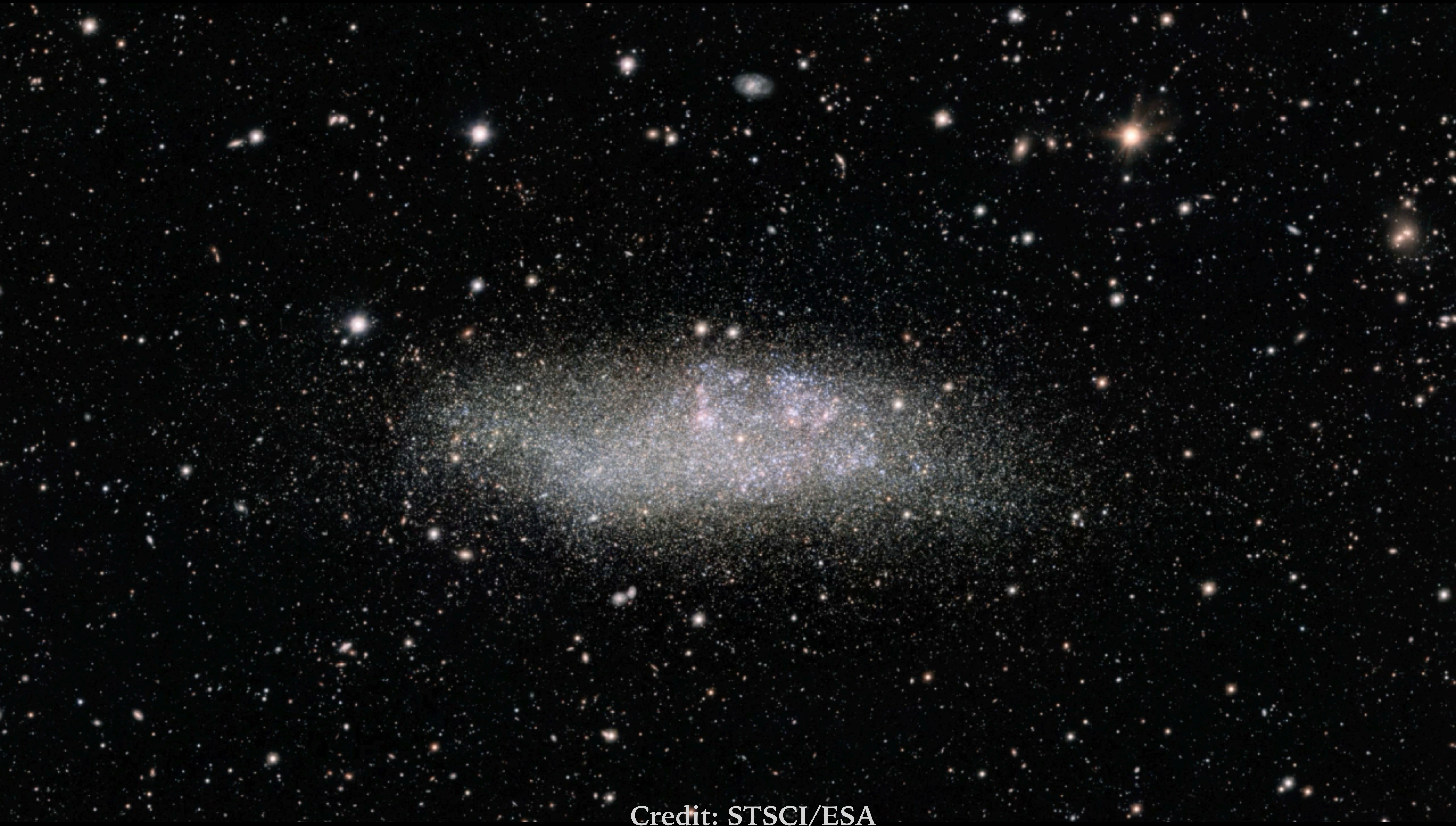
4.1 Mapping the dust in star-forming regions

"Pillars of creation" (Eagle nebula, 6500 ly away from us)

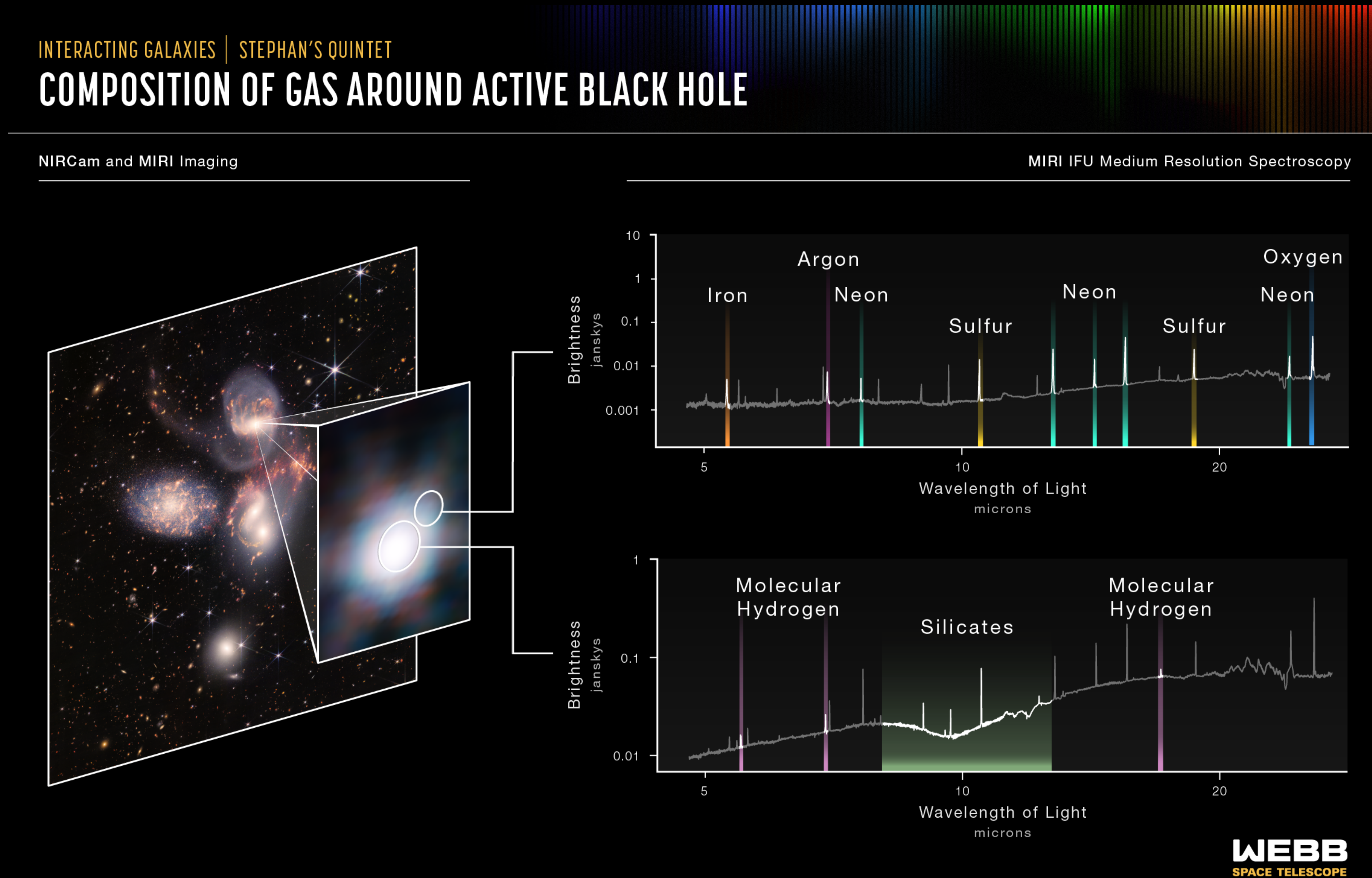


Credit: STSCI/ESA

4.1 View into star clusters: Earth telescopes vs. JWST

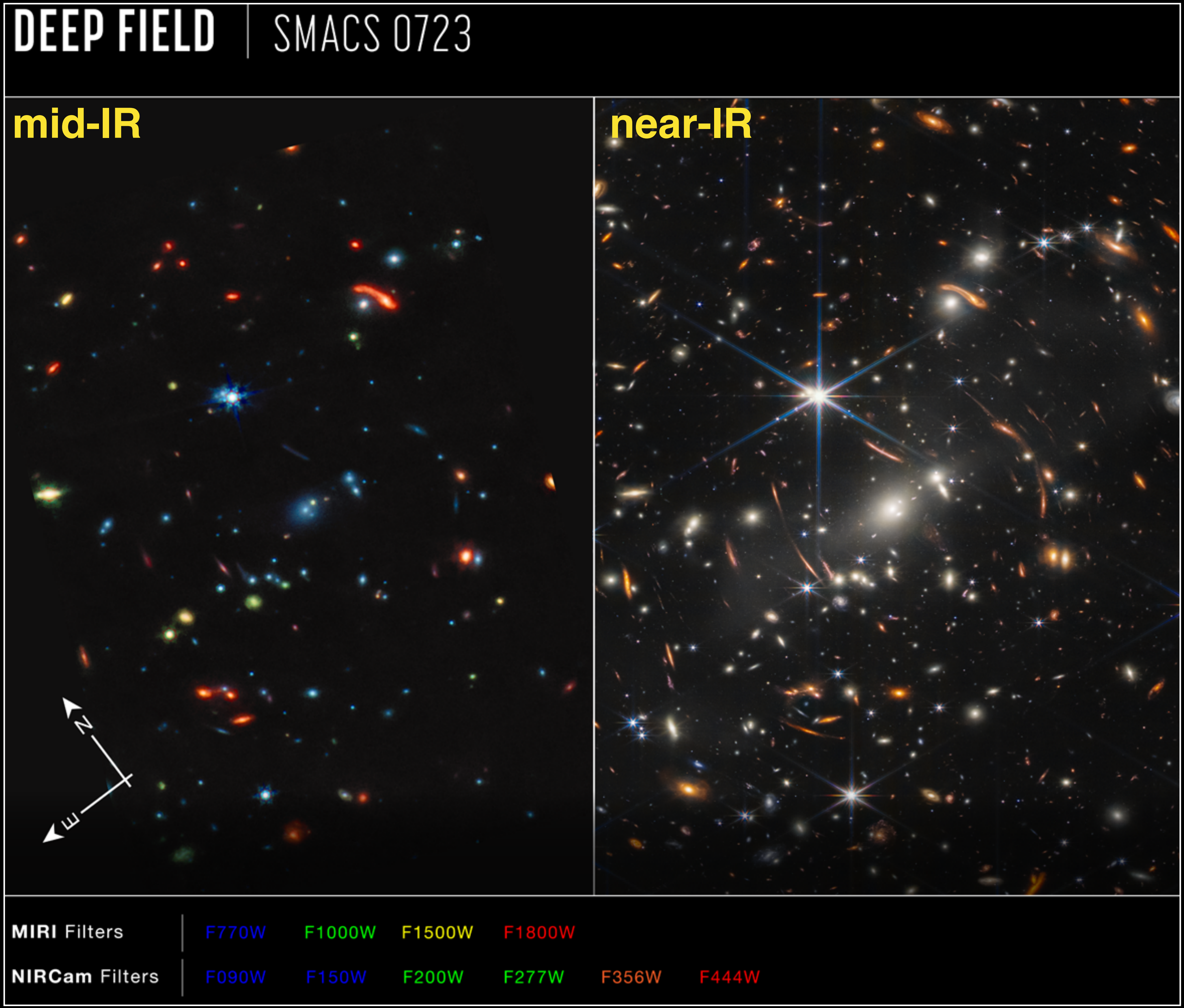


4.1 Interplay of gas & dust around black holes

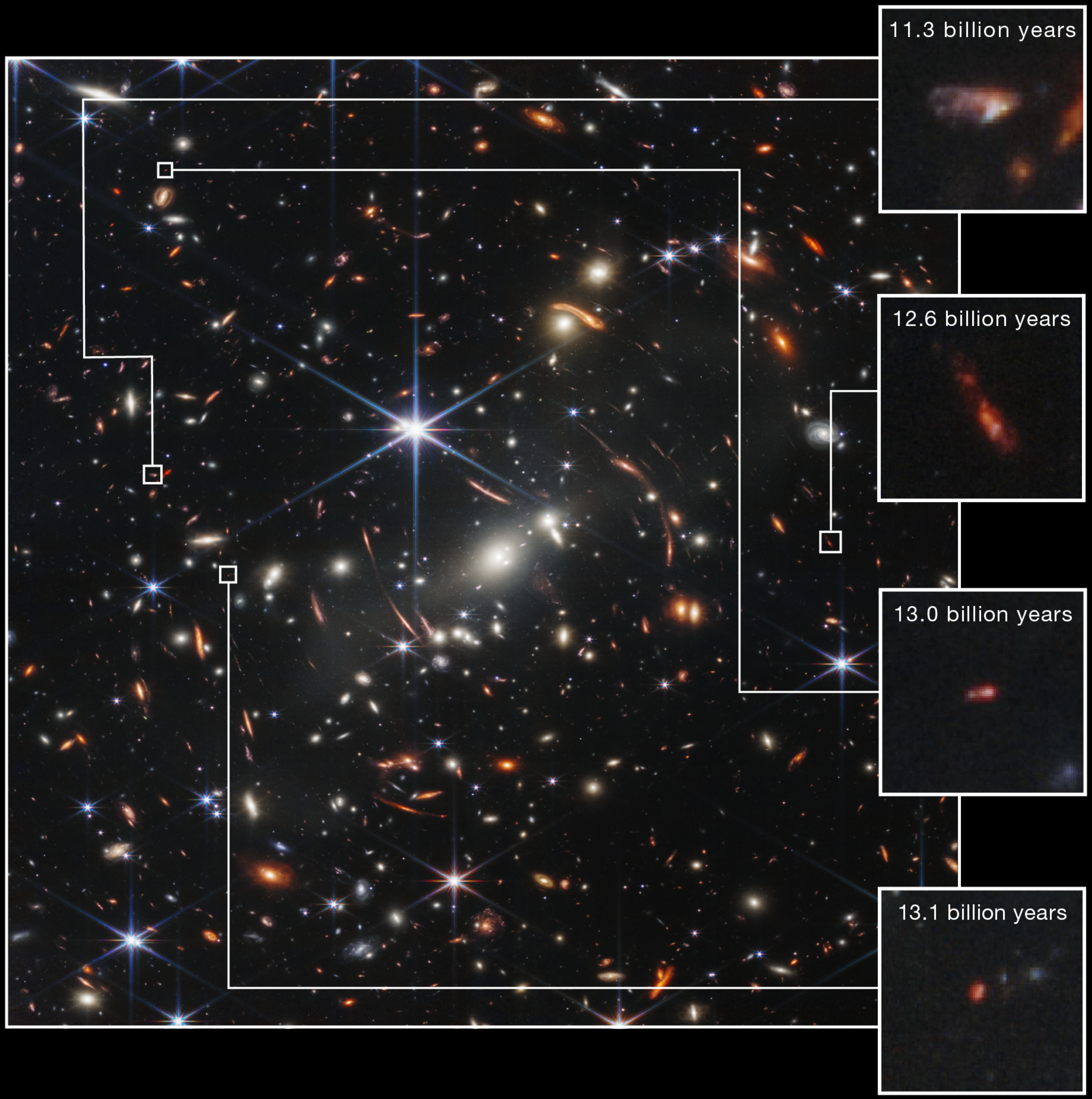


Credit: STSCI/ESA

4.2 The deepest view of galaxies …. EVER MADE

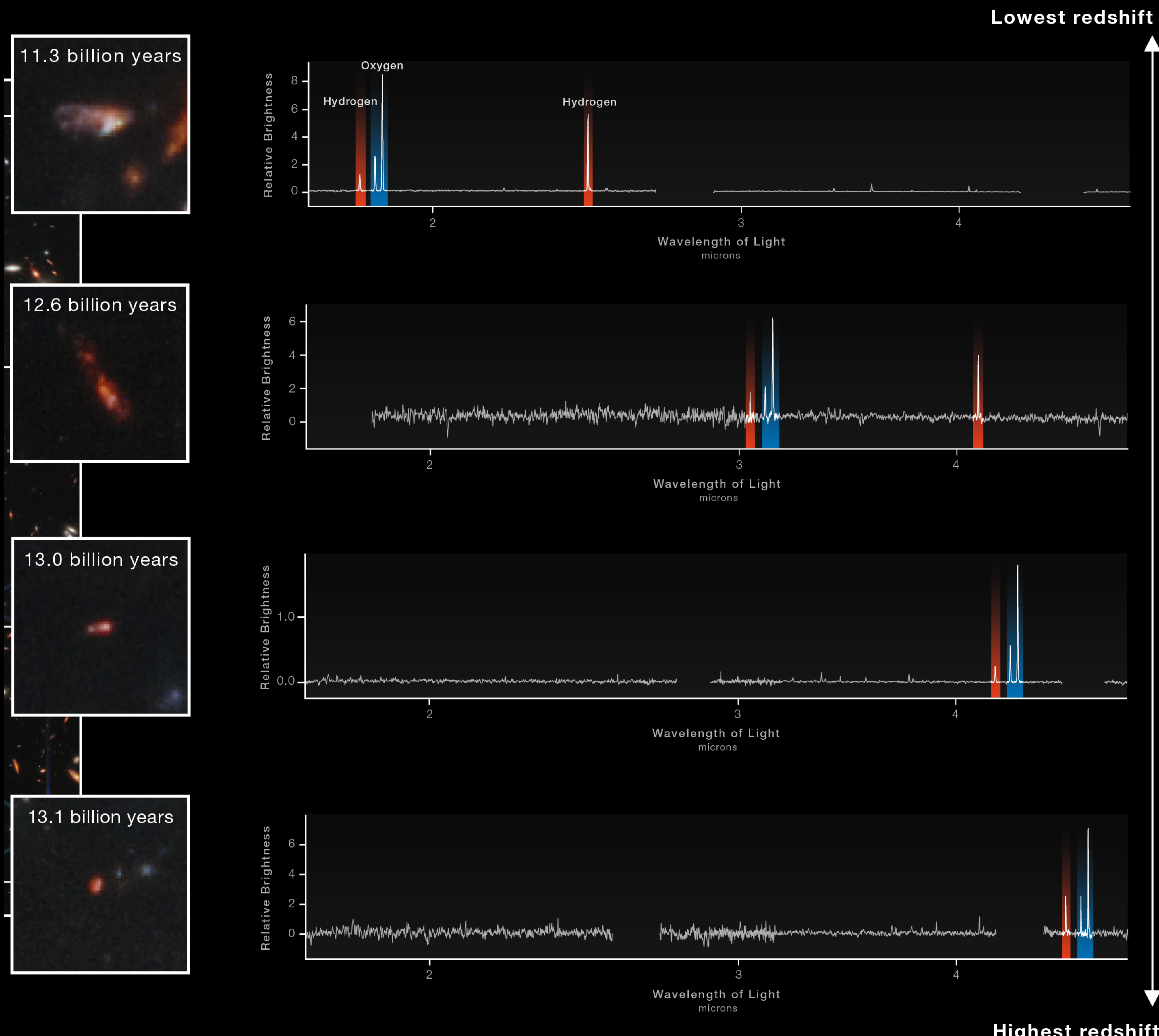


4.2 Images of very distant galaxies with JWST…



WEBB
SPACE TELESCOPE

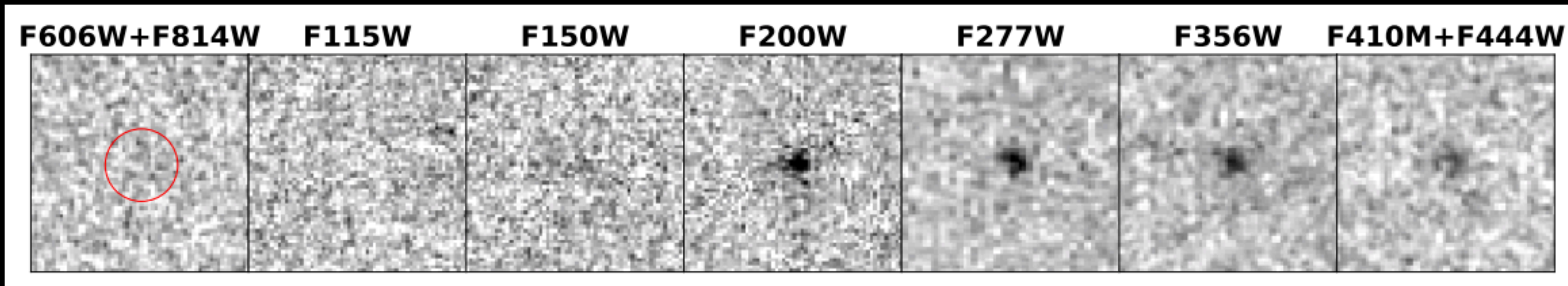
4.2 …and galaxy near-IR spectra with JWST

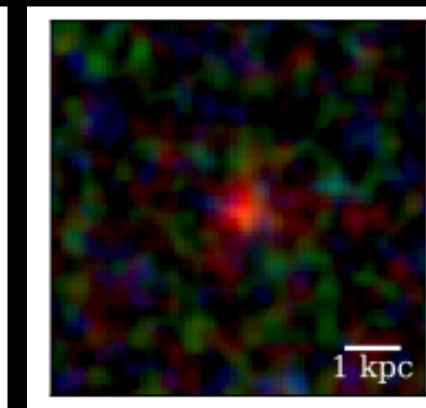


4.2 The deepest view of galaxies …. EVER MADE

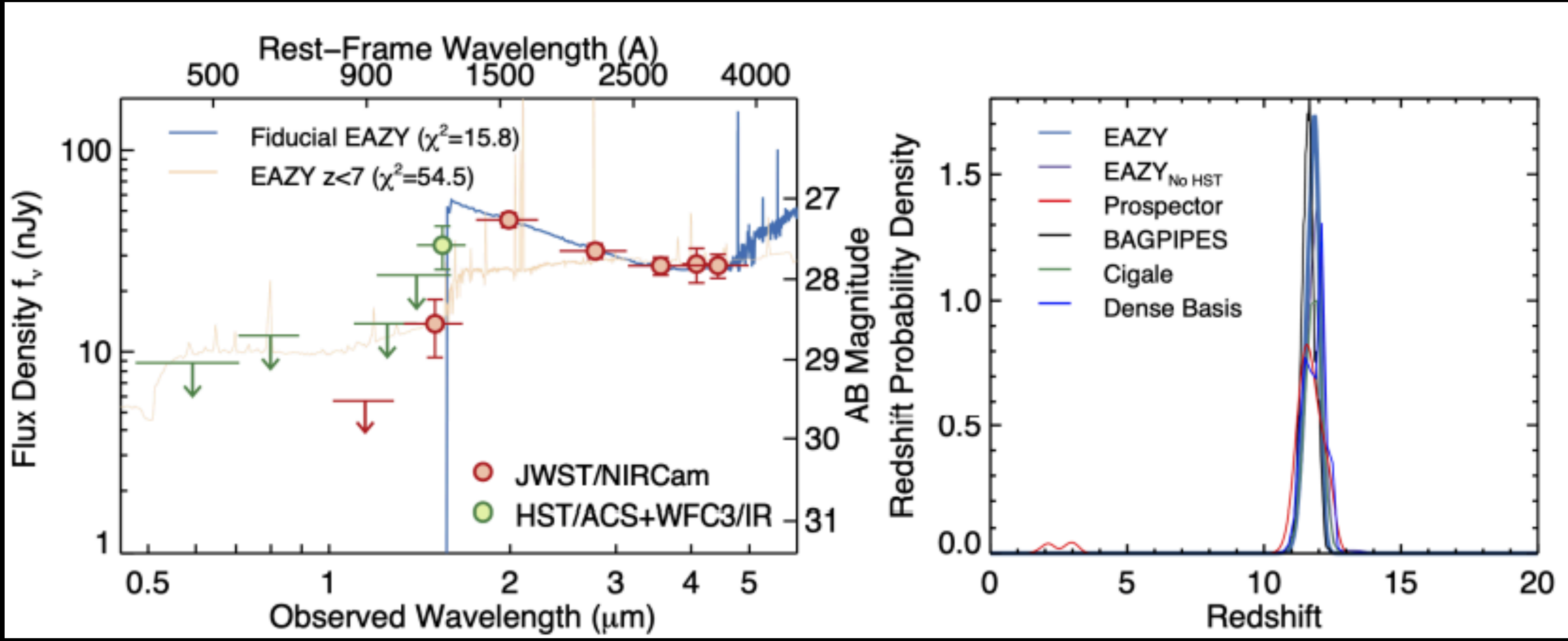
Image of a galaxy @ z=12

(Finkelstein et al. 2022)



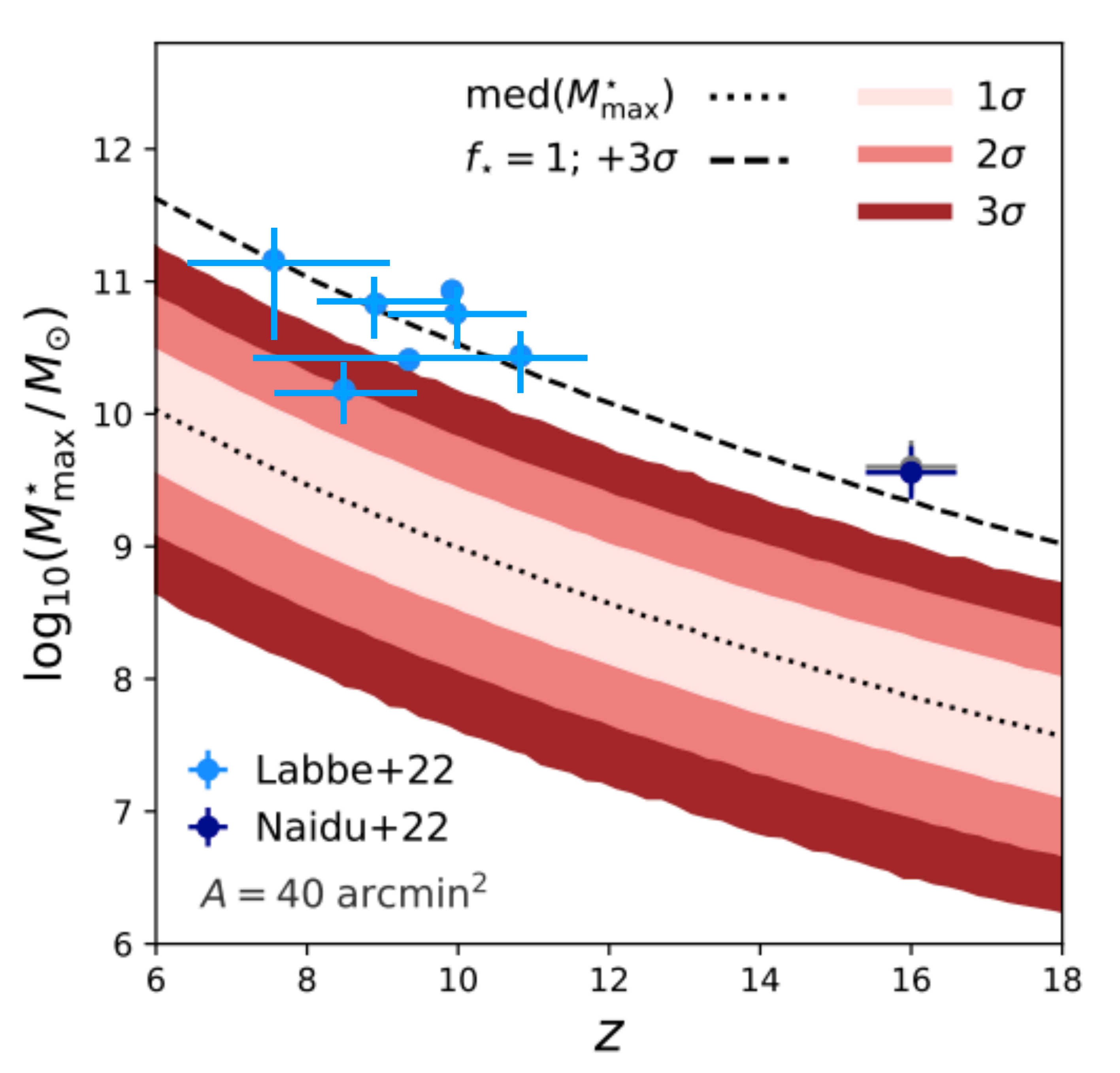


SED of a galaxy @ z=12



4.3 Observations vs. theory: tension with LCDM model?

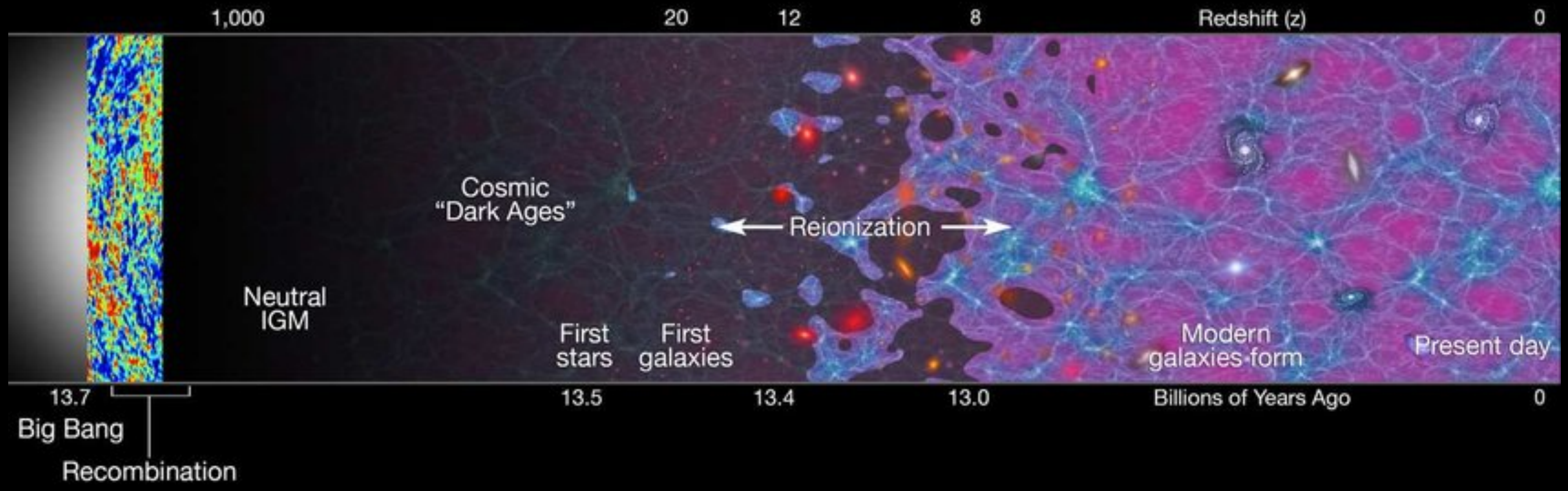
maybe NOT, if we account for all biases…



Credit: Lovell et al. 2022

Future with JWST

How Universe become ionised plasma?



Future with JWST

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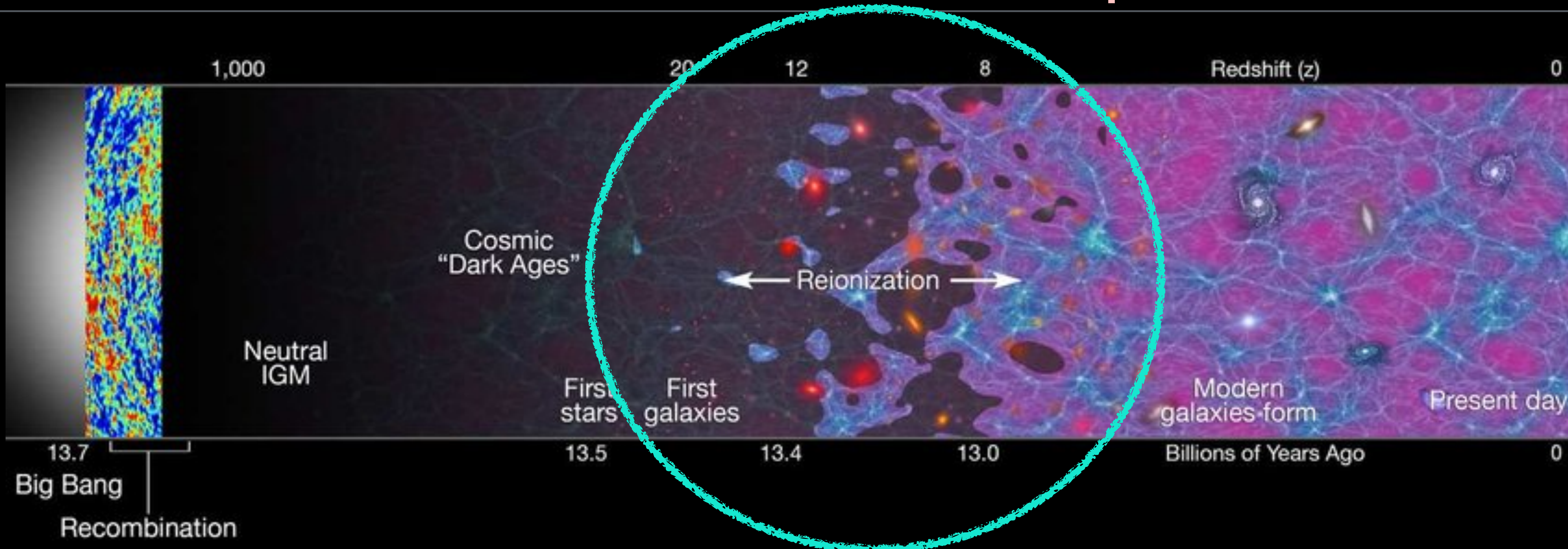
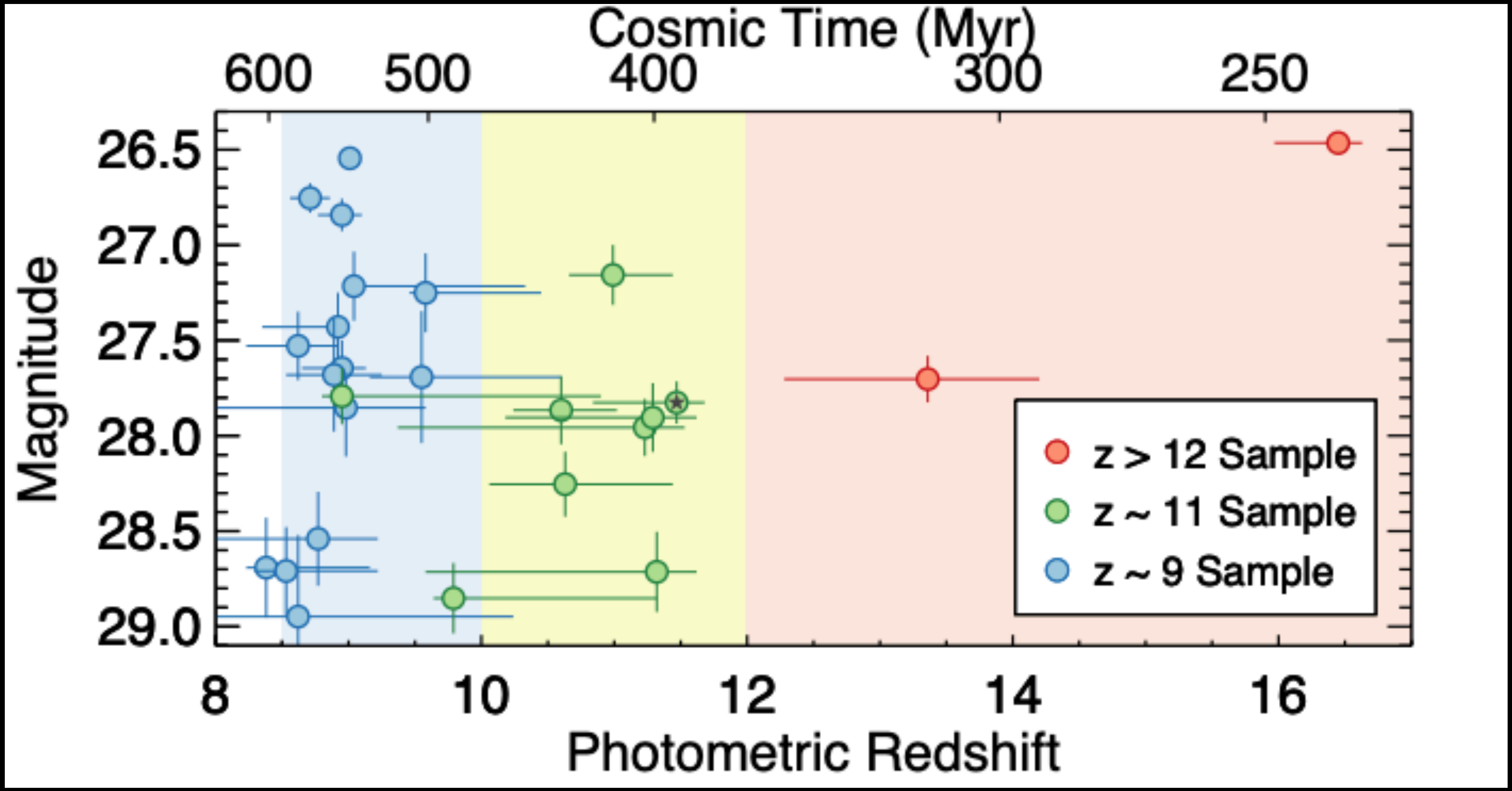


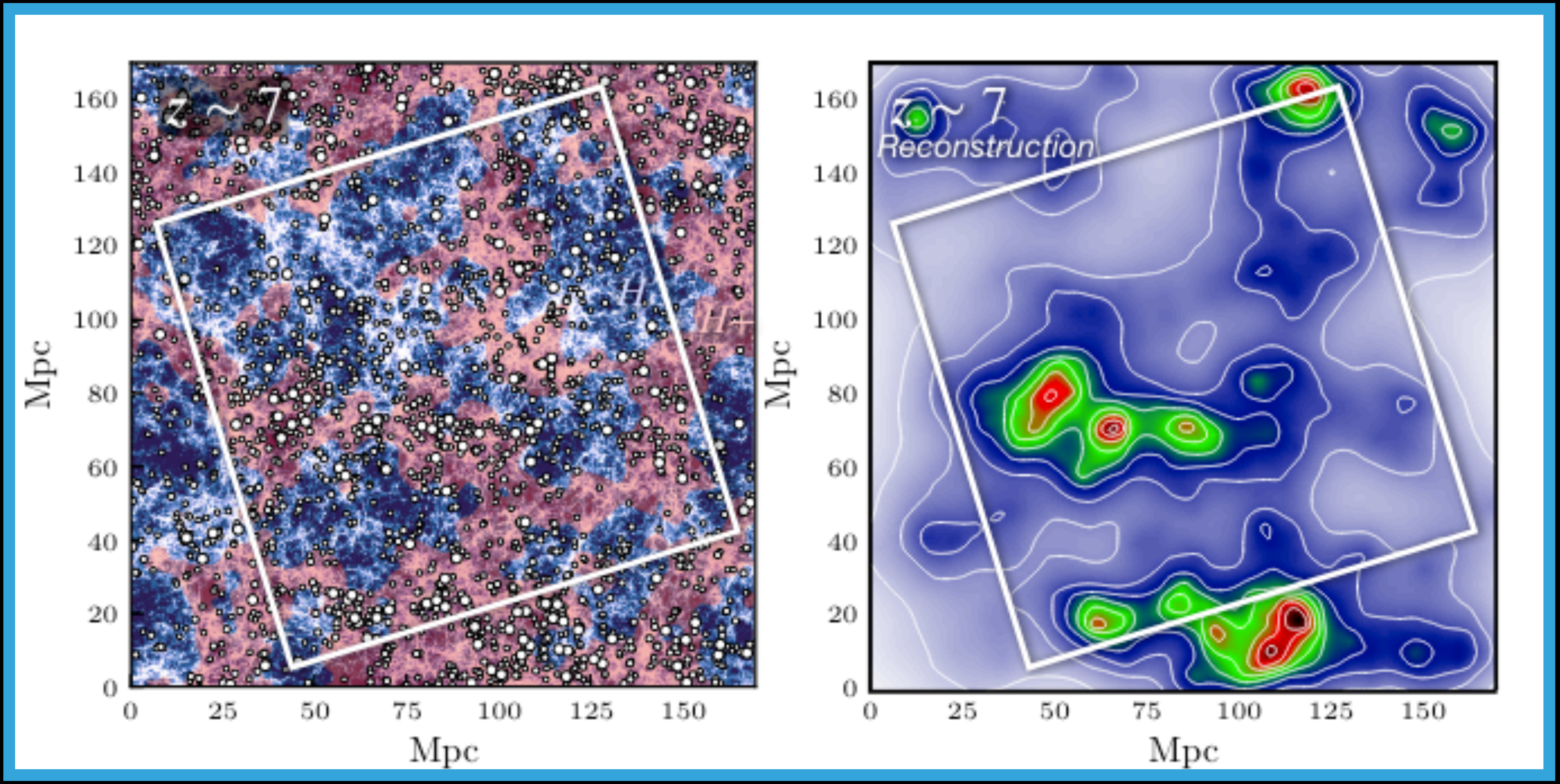
4.2 The deepest view of galaxies …. EVER MADE

We find many very distant galaxies so far… can we explain them?



(Finkelstein et al. 2022)

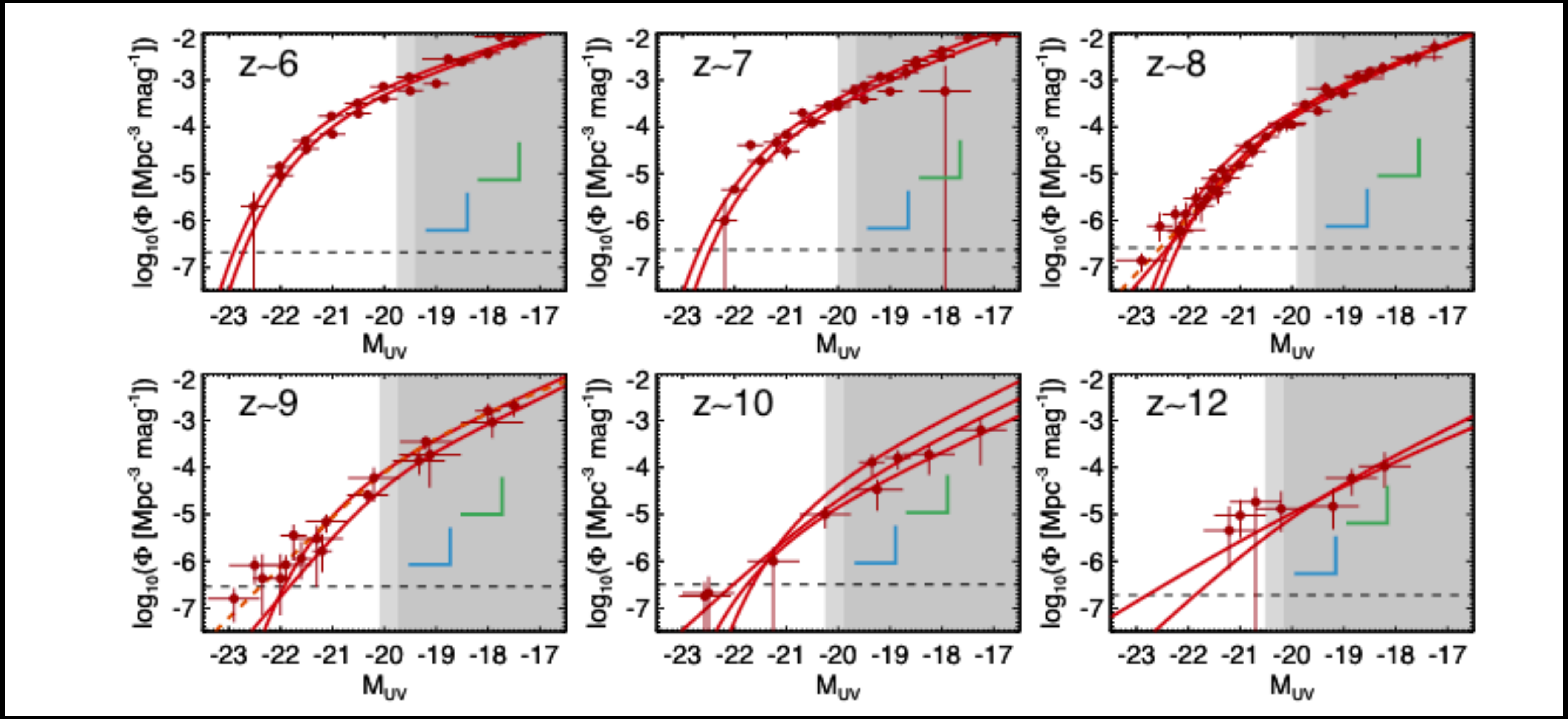
Are high-z galaxies strongly clustered?



insight from simulations

Future with JWST

Are high-z galaxies strongly clustered?



(Casey et al. 2022)

- **Future deepest survey with JWST will quantify number density of most distant galaxies**

Take-away messages

- JWST provides completely new view on infrared & distant Universe.
- So far, number of galaxies found within the first 1 Gyr after Big Bang is higher than expected from LCDM models.
- Main goals of future surveys are:

1) detailed characterisation of warm dust in distant galaxies
2) unveiling the census of SF vs AGN galaxies @z>7-15
3) answering the question how many of these extremely distant galaxies are clustered or isolated
4) how fast after their formation, galaxies enriched with dust and metals

Comments/Questions

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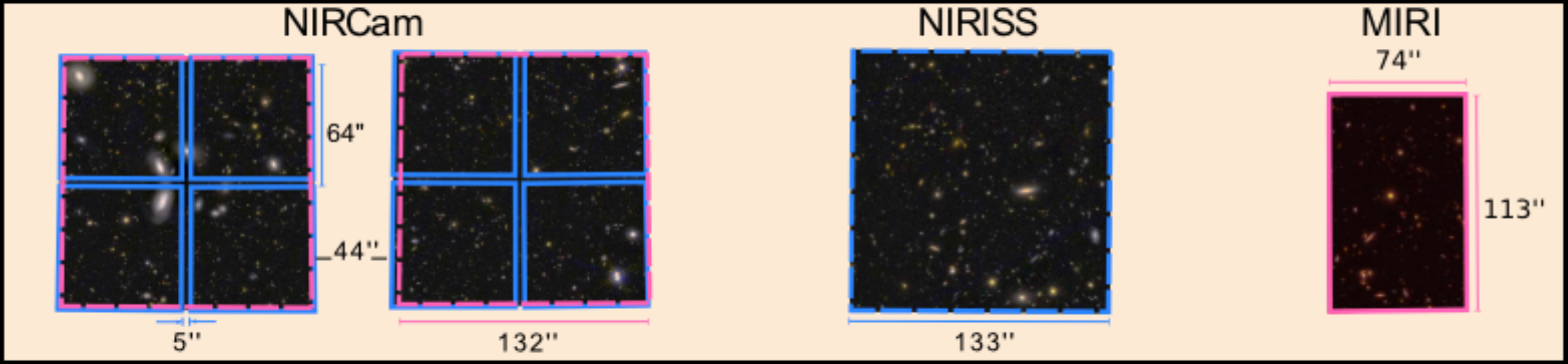
@darkOenergy

3. JWST: instruments



imaging + spectra

Additional slides

Email:

Evolution of dusty galaxies
interplay of SF and SMBH

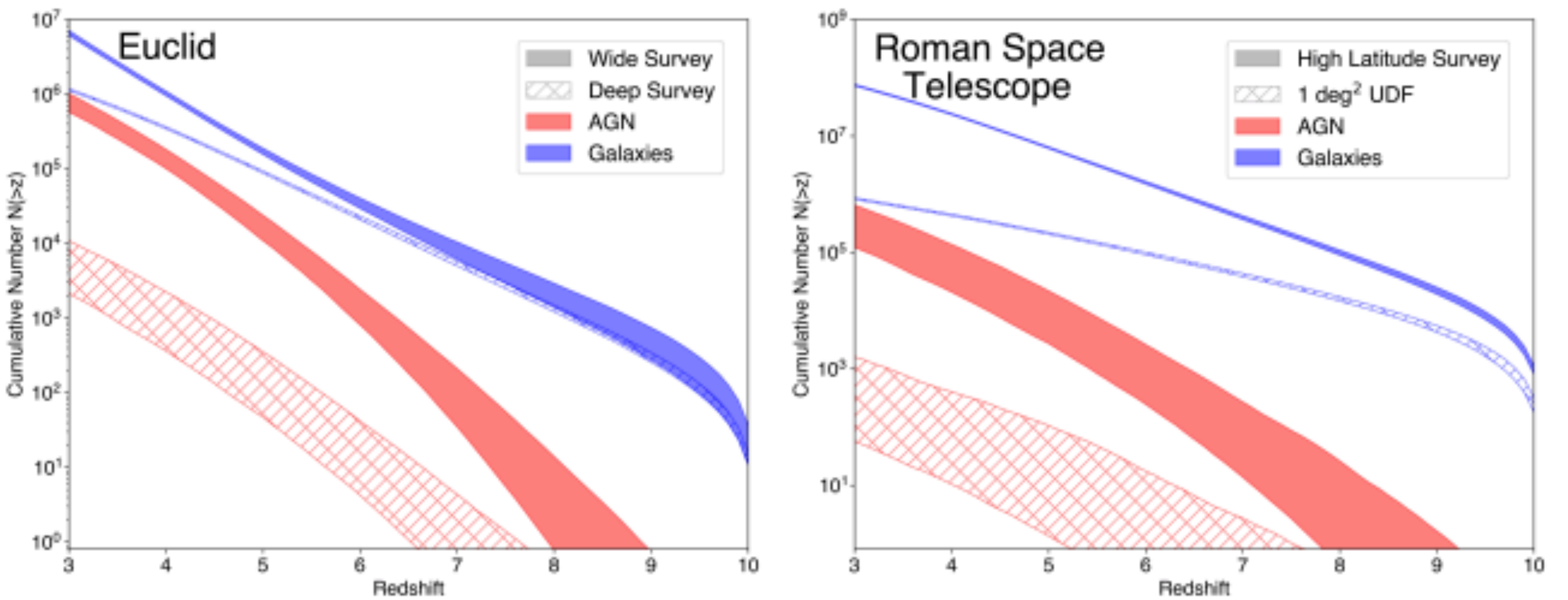
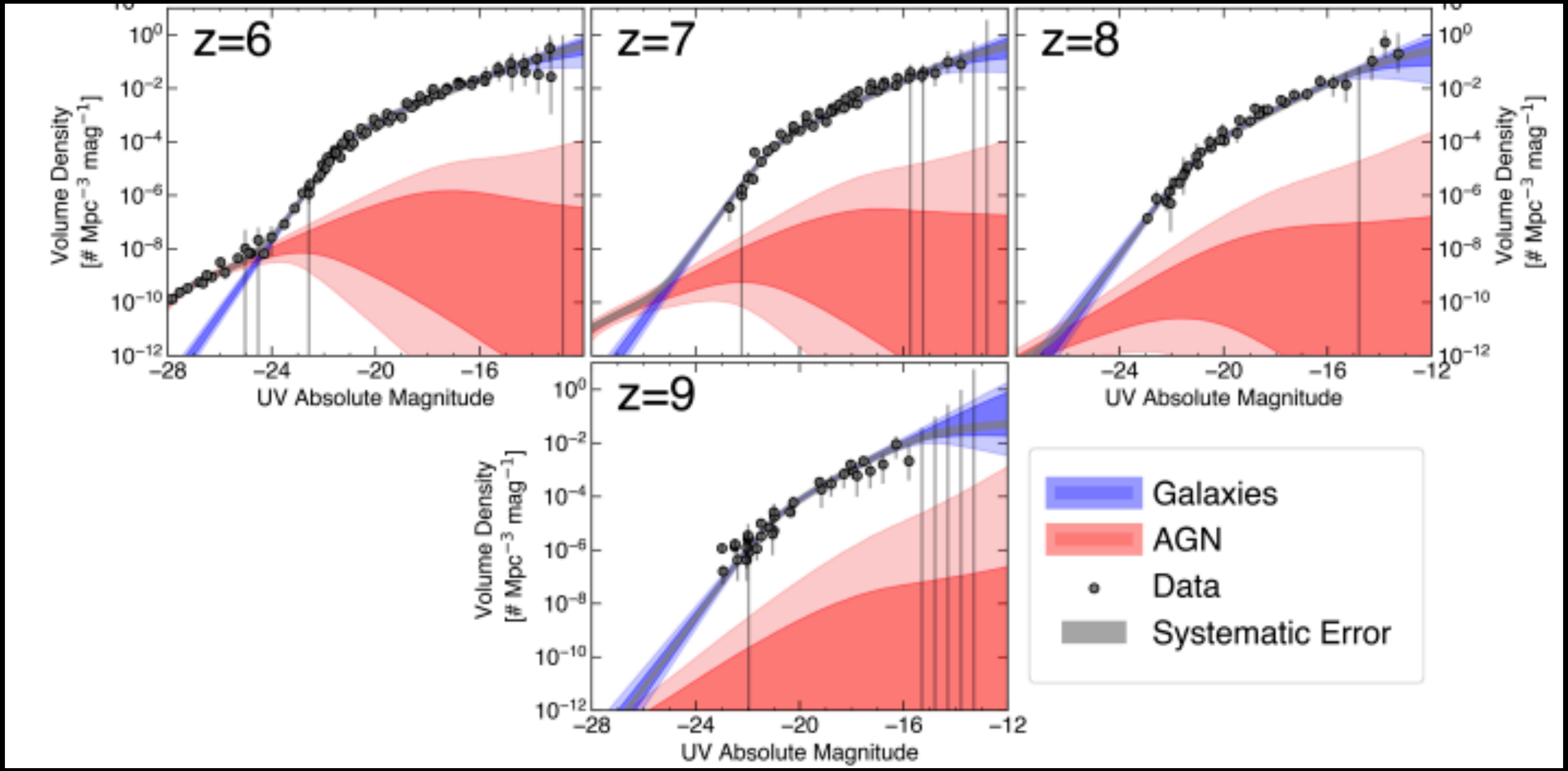


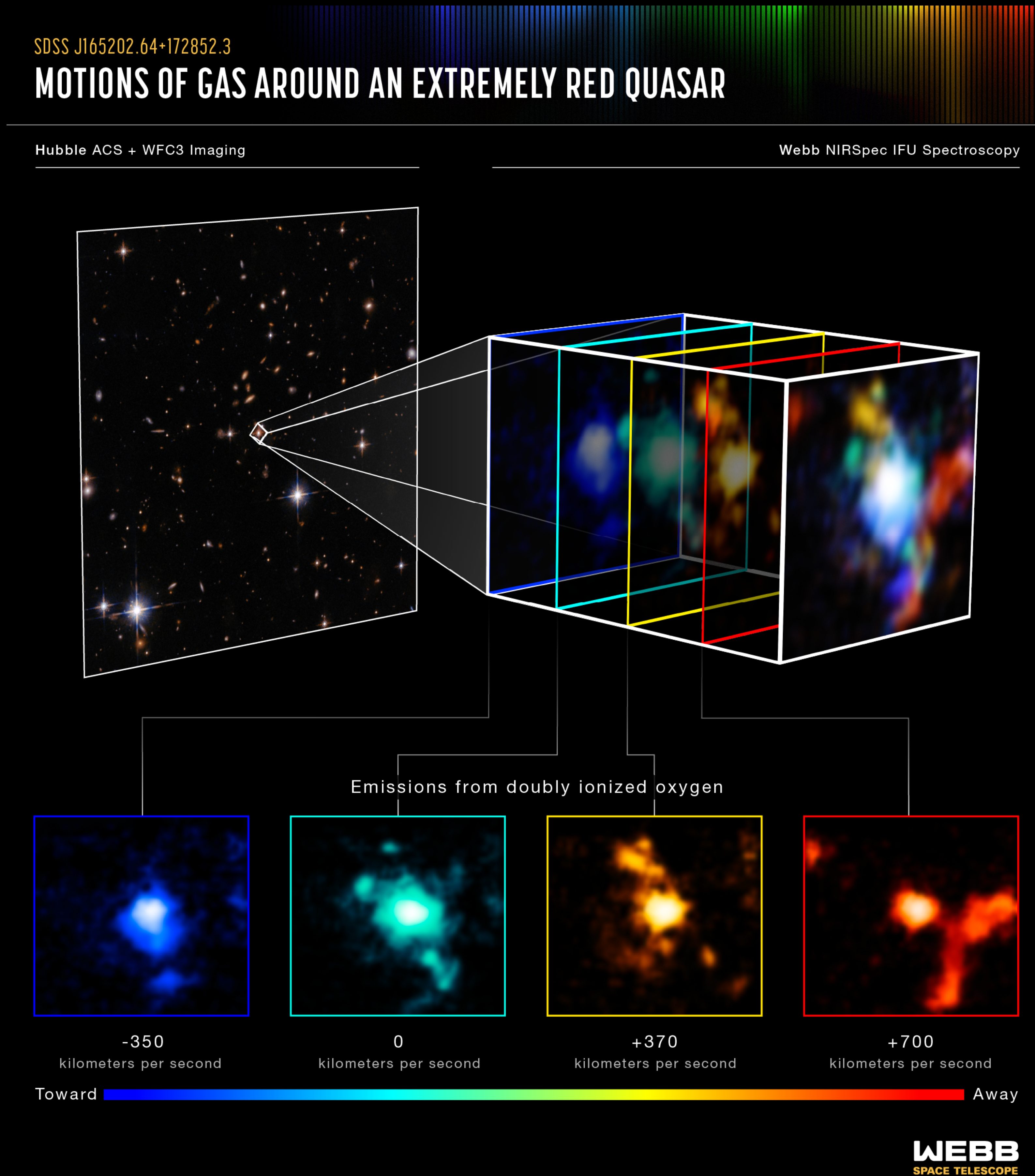
Figure 10. Predicted cumulative number (number at redshift $> z$, integrated up to $z = 10$) of AGN and star-forming galaxies. The left panel shows the *Euclid* Observatory, with the filled and hatched curves denoting the Wide and Deep surveys, respectively. The right panel shows the predictions for the *NGRST*, with the filled and hatched curves denoting the High Latitude Survey and a hypothetical 1 deg^2 ultra-deep survey, respectively. All four surveys will be capable of studying star-forming galaxies out to $z \gtrsim 10$. Additionally, we predict that the *Euclid* Wide survey and *NGRST* High Latitude Survey will be able to discover large numbers of AGNs at $z > 7$, constraining our high-redshift AGN luminosity functions predicted here.

Future with JWST

SF galaxies vs. AGN galaxies



- **Is number density of AGN galaxies significant in early Universe???**



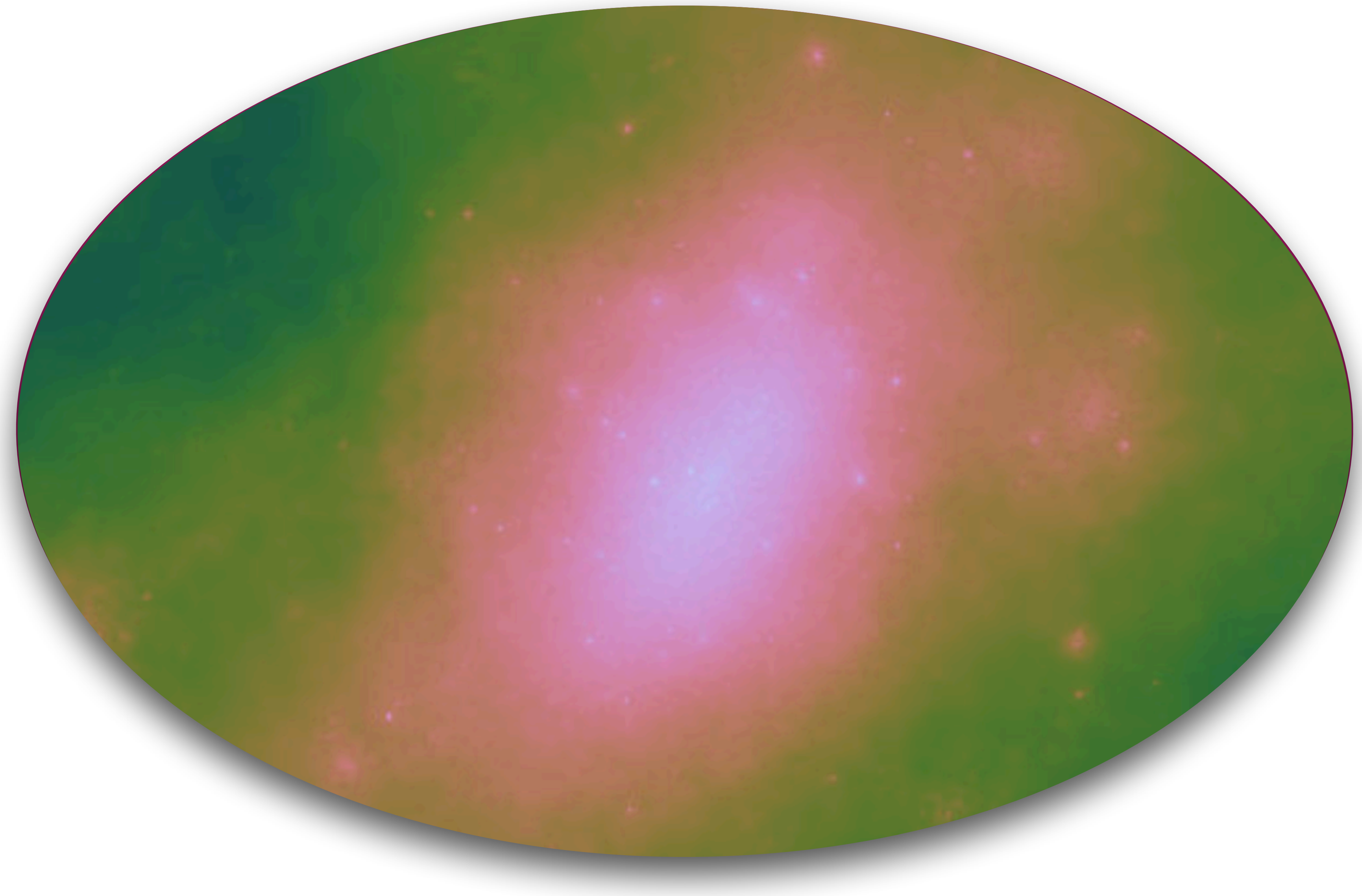
SDSS J165202.64+172852.3
MOTIONS OF GAS AROUND AN EXTREMELY RED QUASAR
Hubble ACS + WFC3 Imaging
Webb NIRSpec IFU Spectroscopy
Emissions from doubly ionized oxygen
-350
kilometers per second
0
kilometers per second
+370
kilometers per second
+700
kilometers per second
Toward
Away
WEBB
SPACE TELESCOPE

JAMES WEBB SPACE TELESCOPE

DEEP FIELD | SMACS 0723

MIRI Filters	F770W	F1000W	F1500W	F1800W		
NIRCam Filters	F090W	F150W	F200W	F277W	F356W	F444W

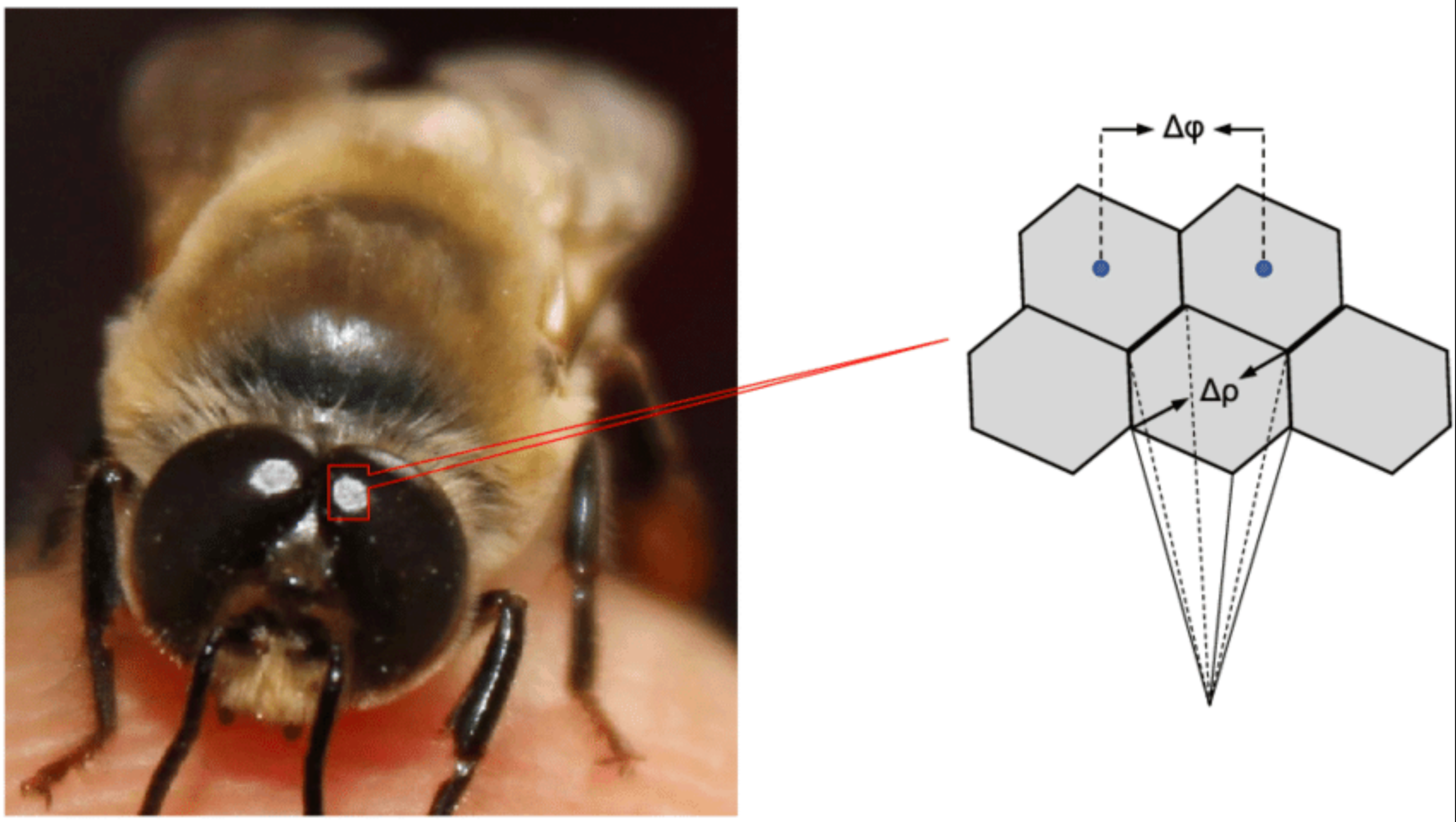
Interplay of metals, gas, stars and dust in galaxy evolution



➡ Importance of dust modelling within the galaxy evolution framework

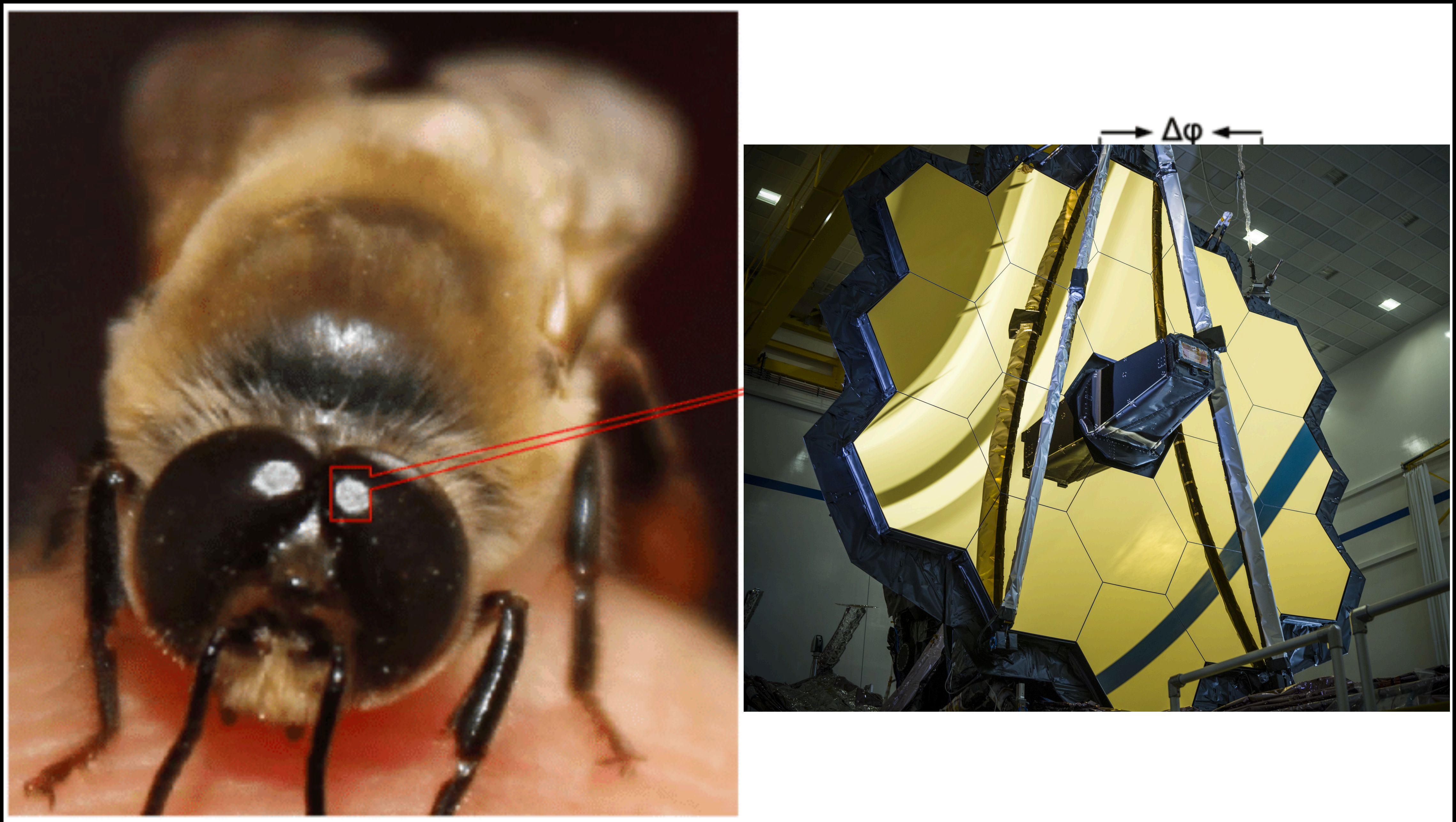
ADDITIONAL SLIDES

Honeybee view



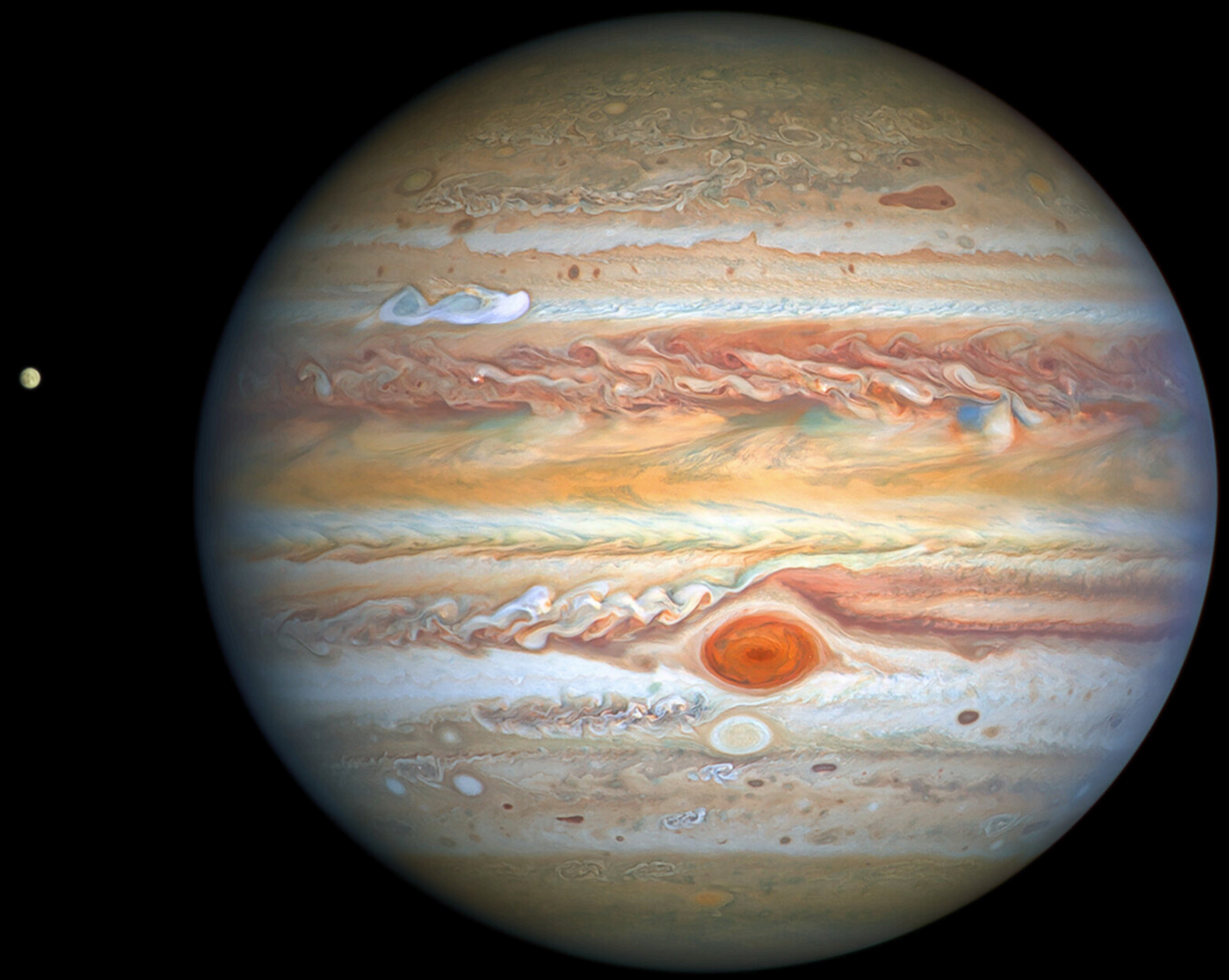
Honeybee's compound eye structures. The cllustered receptors (ommatidiae) are arranged hexagonally with angular separation & each has its own small receptive field Δρ.
(credit: Wang et al. 2019)

Honeybee view



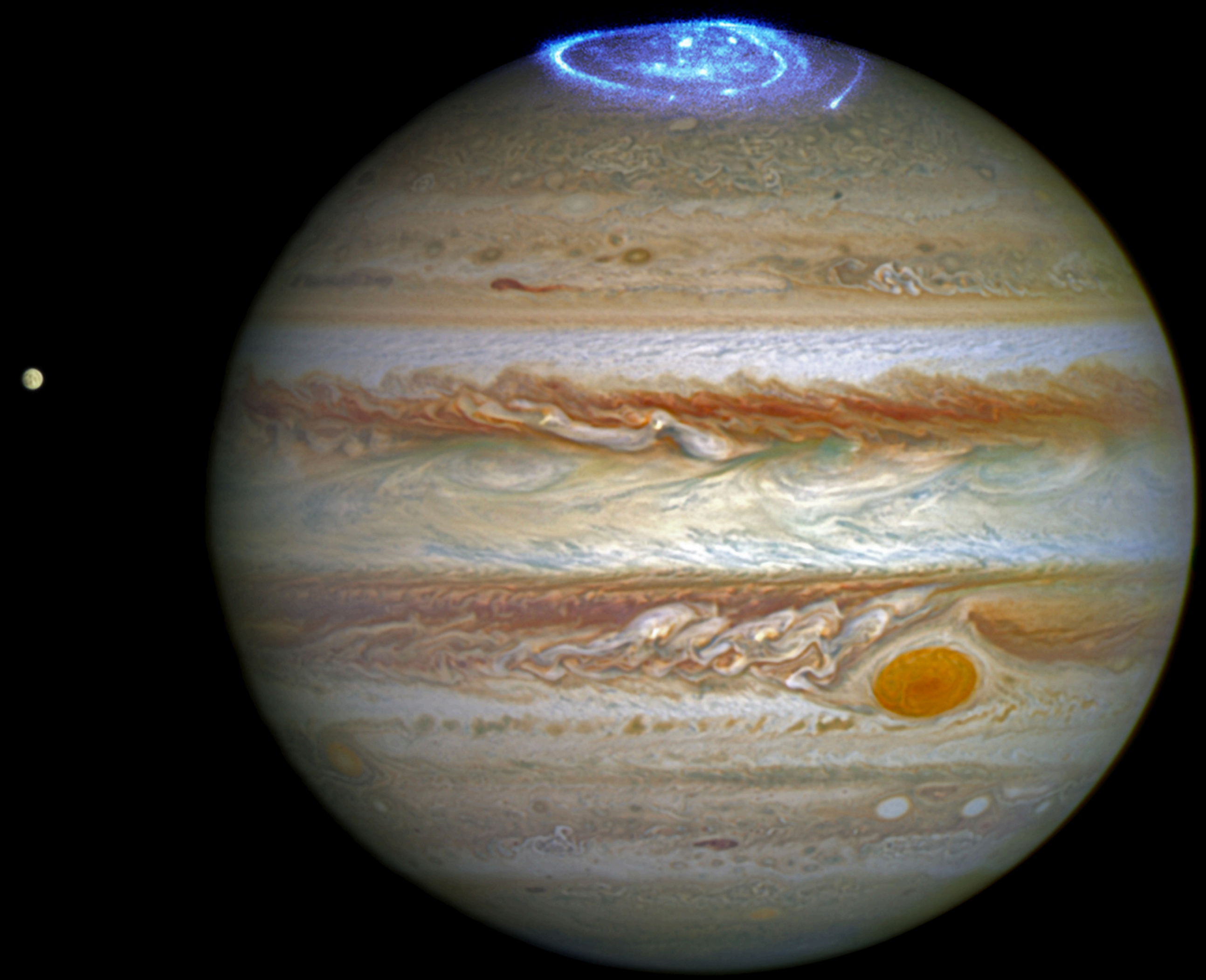
Honeybee's compound eye structures. The cllustered receptors (ommatidiae) are arranged hexagonally with angular separation & each has its own small receptive field Δρ. (credit: Wang et al. 2019)

1.1 Nearby Universe



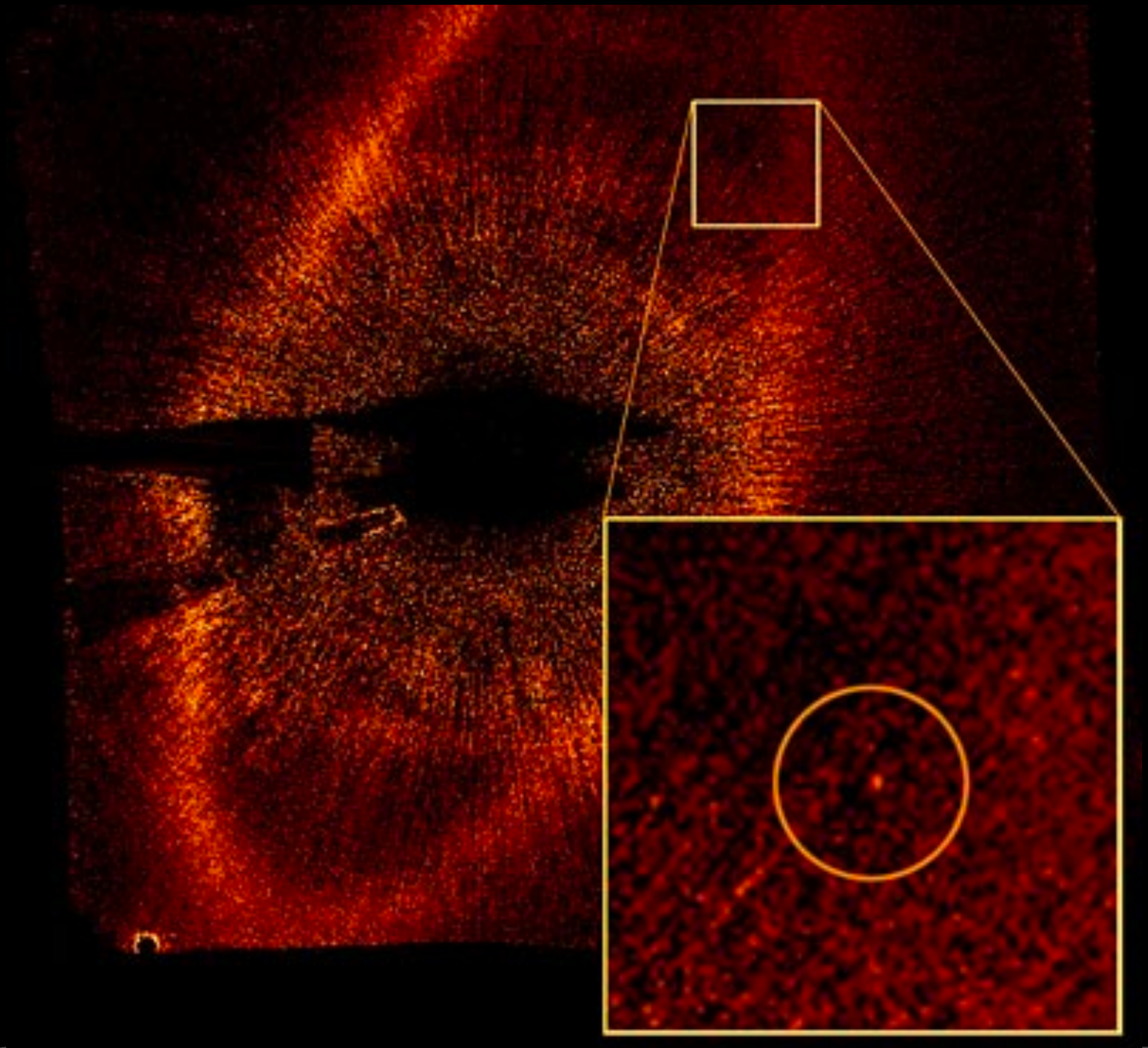
HST image of Jupiter
(credit: NASA)

1.1 Nearby Universe



HST image of Jupiter's aurrora
(credit: NASA)

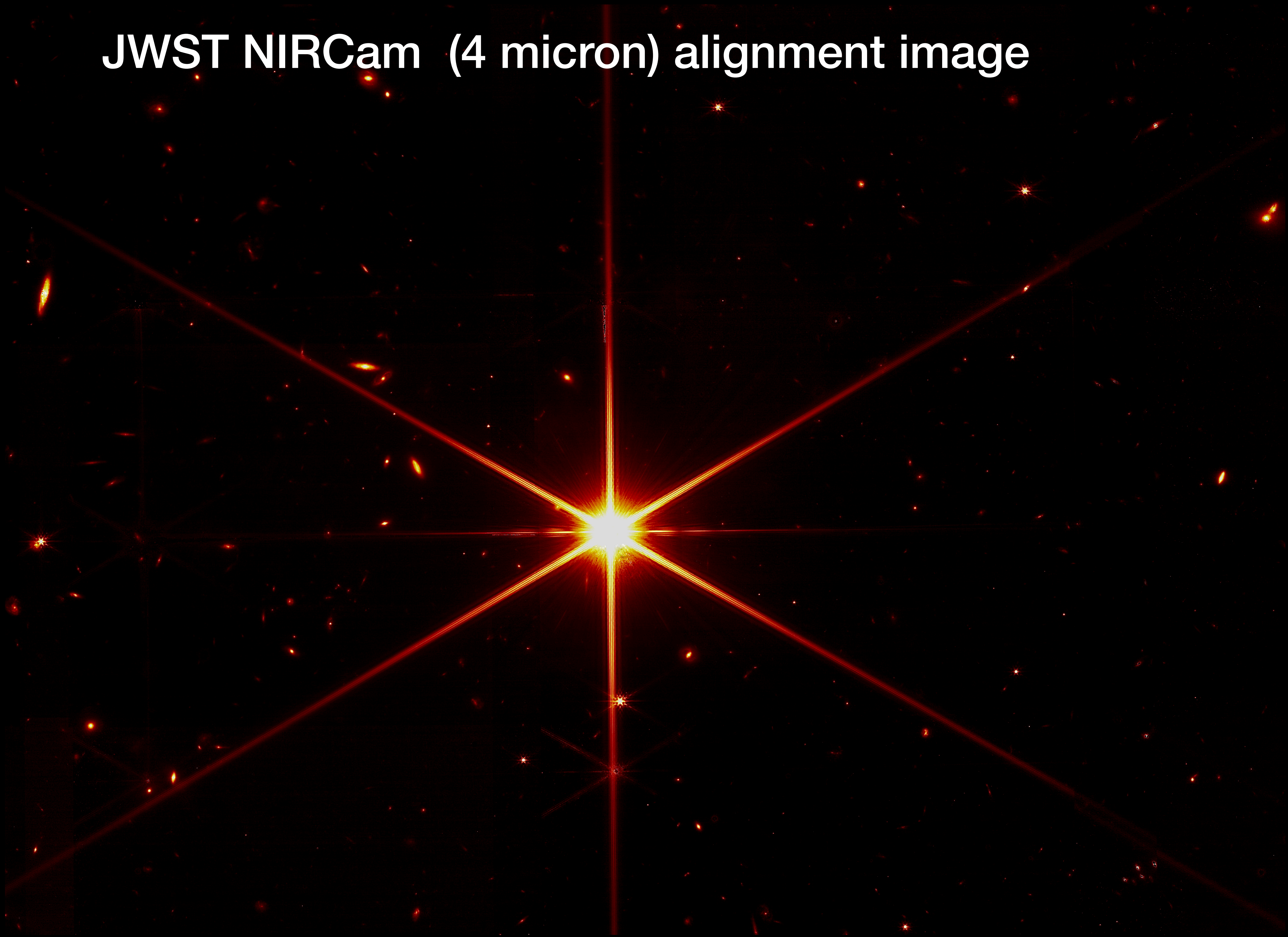
1.1 Nearby Universe



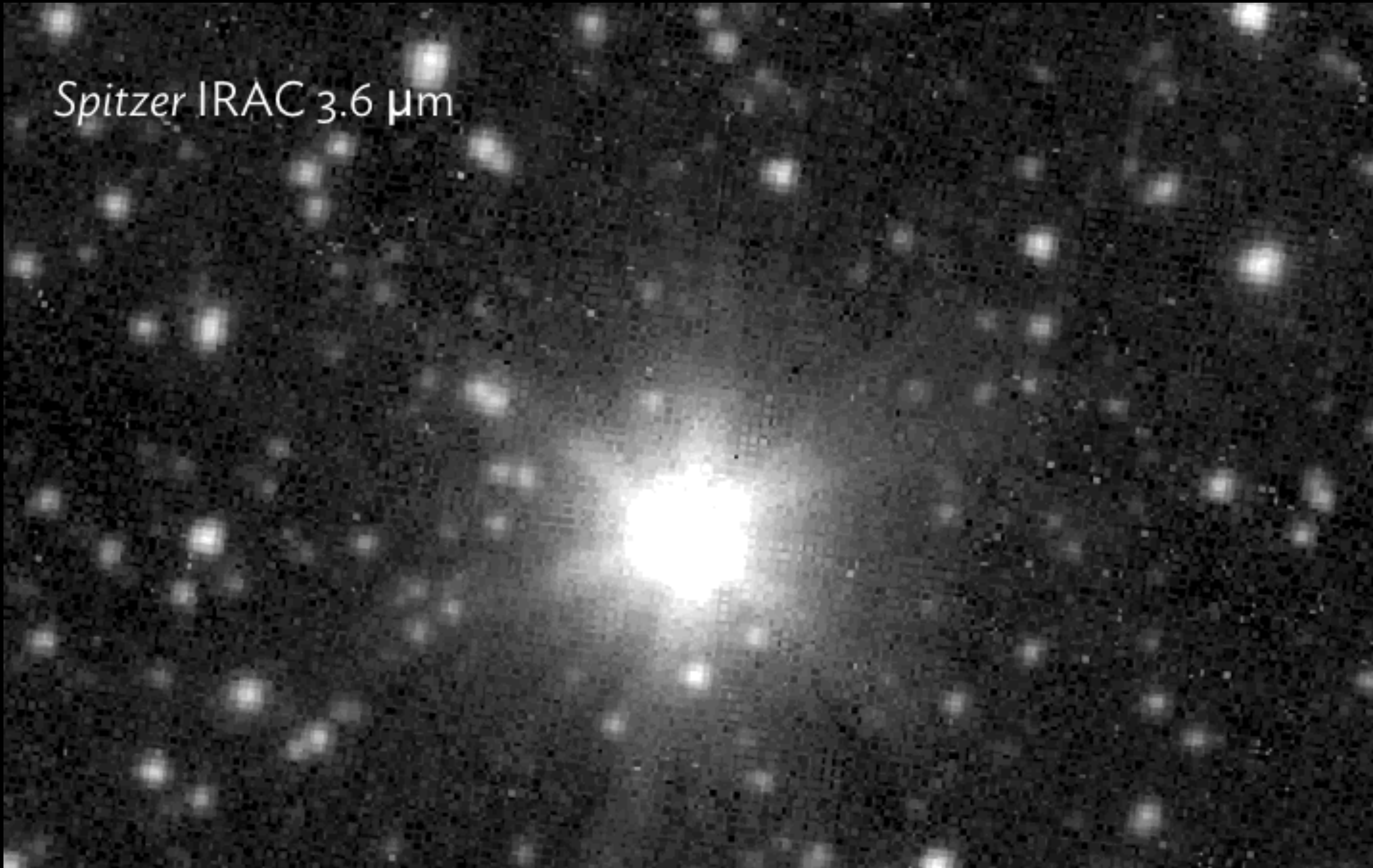
First ever image of an exoplanet 25 light years away
(~ Jupiter mass size, distant to the star at 11 billion km)

(credit:Kalas/UC Berkley)

JWST NIRCam (4 micron) alignment image



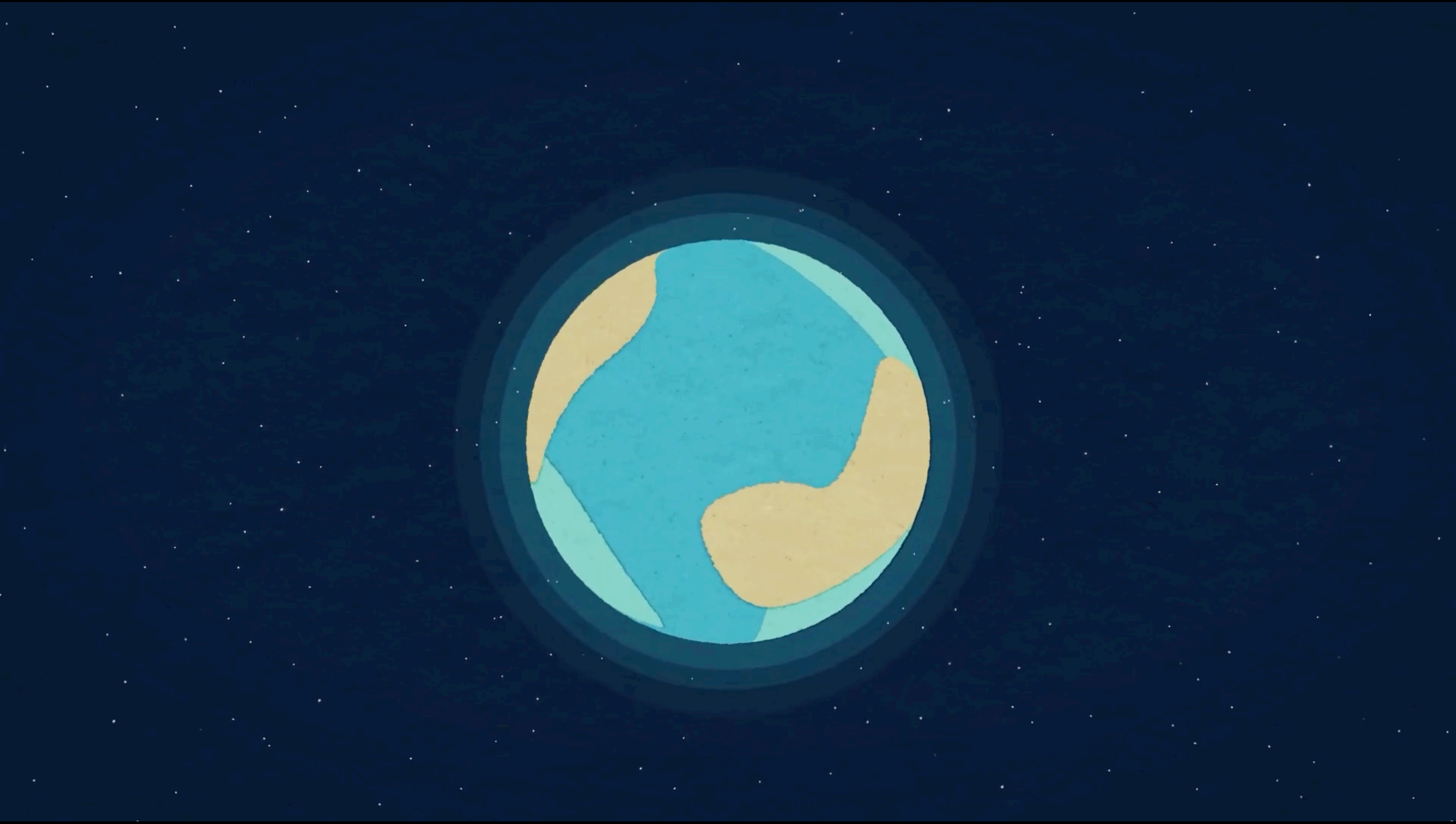
JWST



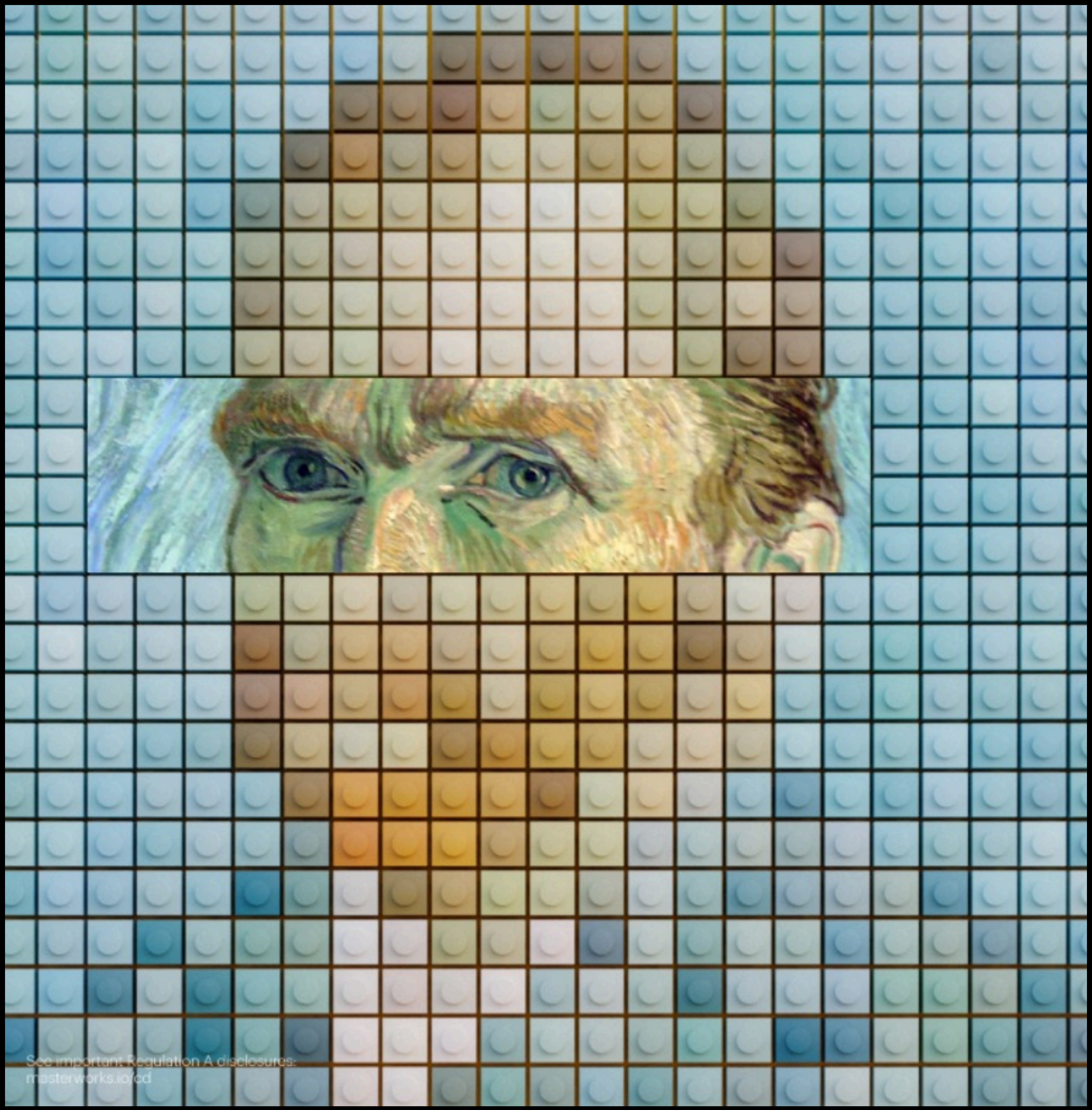
Worlds outsides our Solar system: EXOPLANETS

This video shows a fly-through of the bright double star Alpha Centauri A and B. In the final sequence we close in on Alpha Centauri B and a newly discovered planet swims into view. This Earth-mass planet is the closest exoplanet known and the lightest ever found around a star like the Sun.

Worlds outsides our Solar system: EXOPLANETS



JWST



Worlds outsides our Solar system: EXOPLANETS

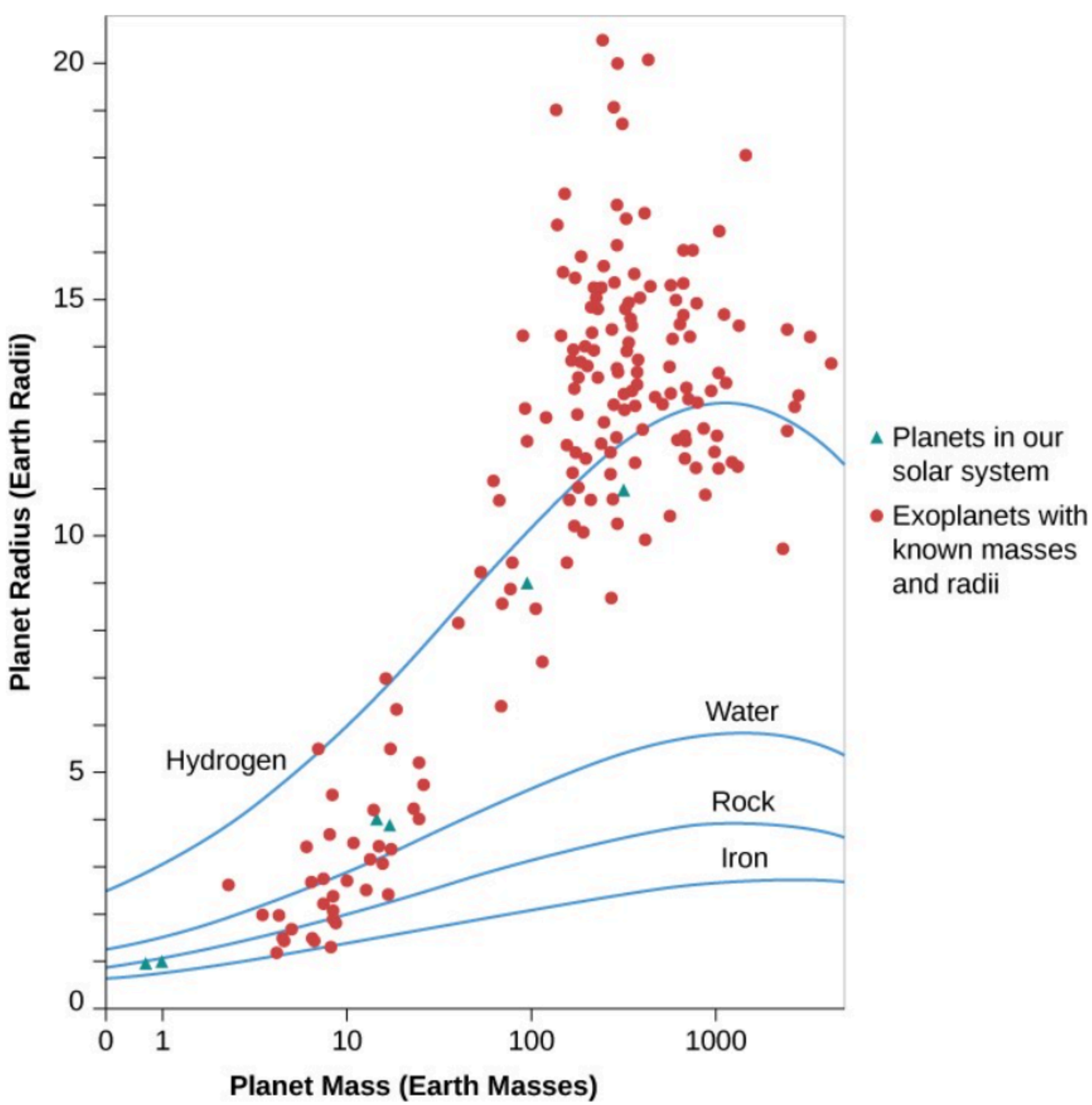


Figure 4: Exoplanets with Known Densities. Exoplanets with known masses and radii (red circles) are plotted along with solid lines that show the theoretical size of pure iron, rock, water, and hydrogen planets with increasing mass. Masses are given in multiples of Earth's mass. (For comparison, Jupiter contains enough mass to make 320 Earths.) The green triangles indicate planets in our solar system.

Worlds outsides our Solar system: EXOPLANETS

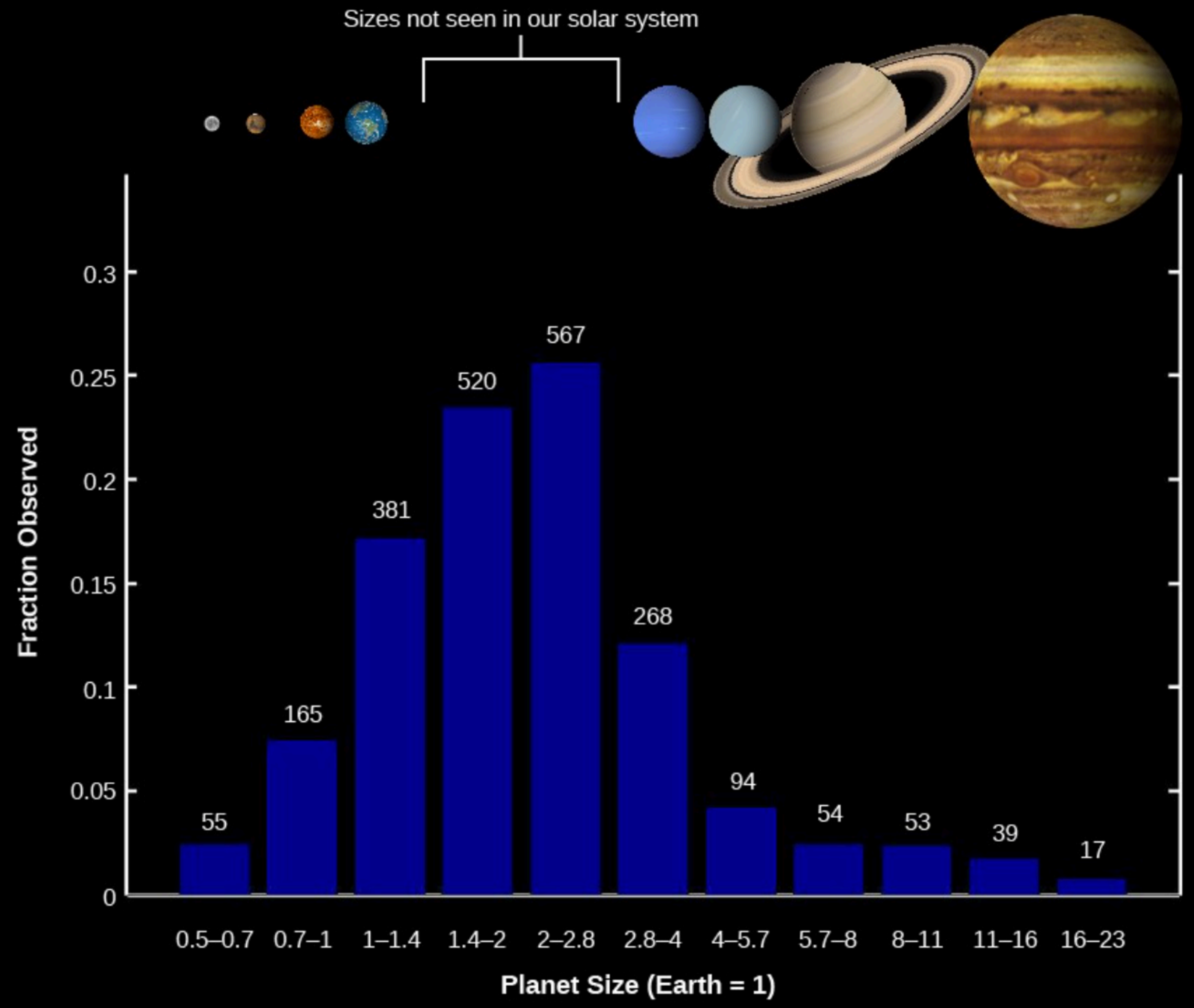
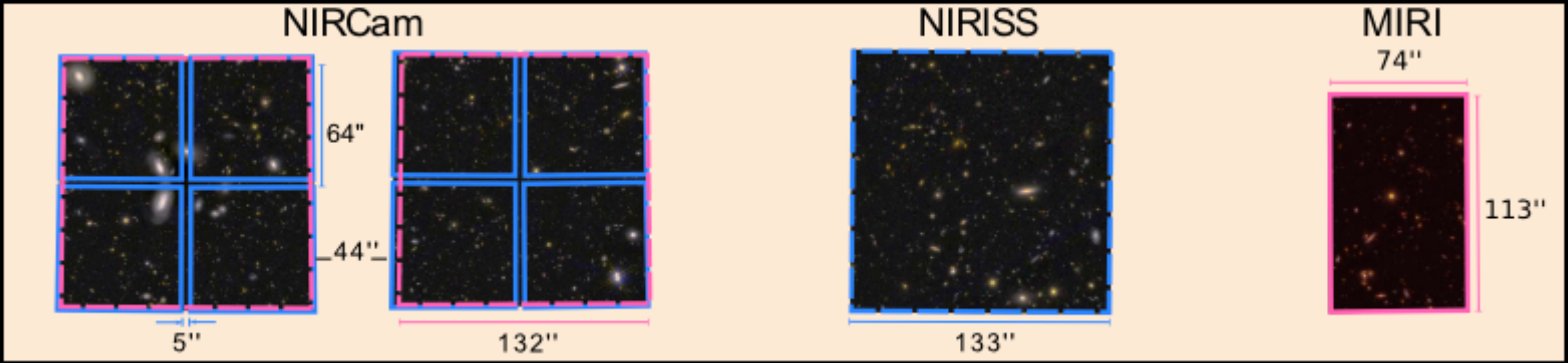


Figure 2: Kepler Discoveries. This bar graph shows the number of planets of each size range found among the first 2213 Kepler planet discoveries. Sizes range from half the size of Earth to 20 times that of Earth. On the vertical axis, you can see the fraction that each size range makes up of the total. Note that planets that are between 1.4 and 4 times the size of Earth make up the largest fractions, yet this size range is not represented among the planets in our solar system. (credit: modification of work by

3. JWST: instruments



Credit: JWST/NASA

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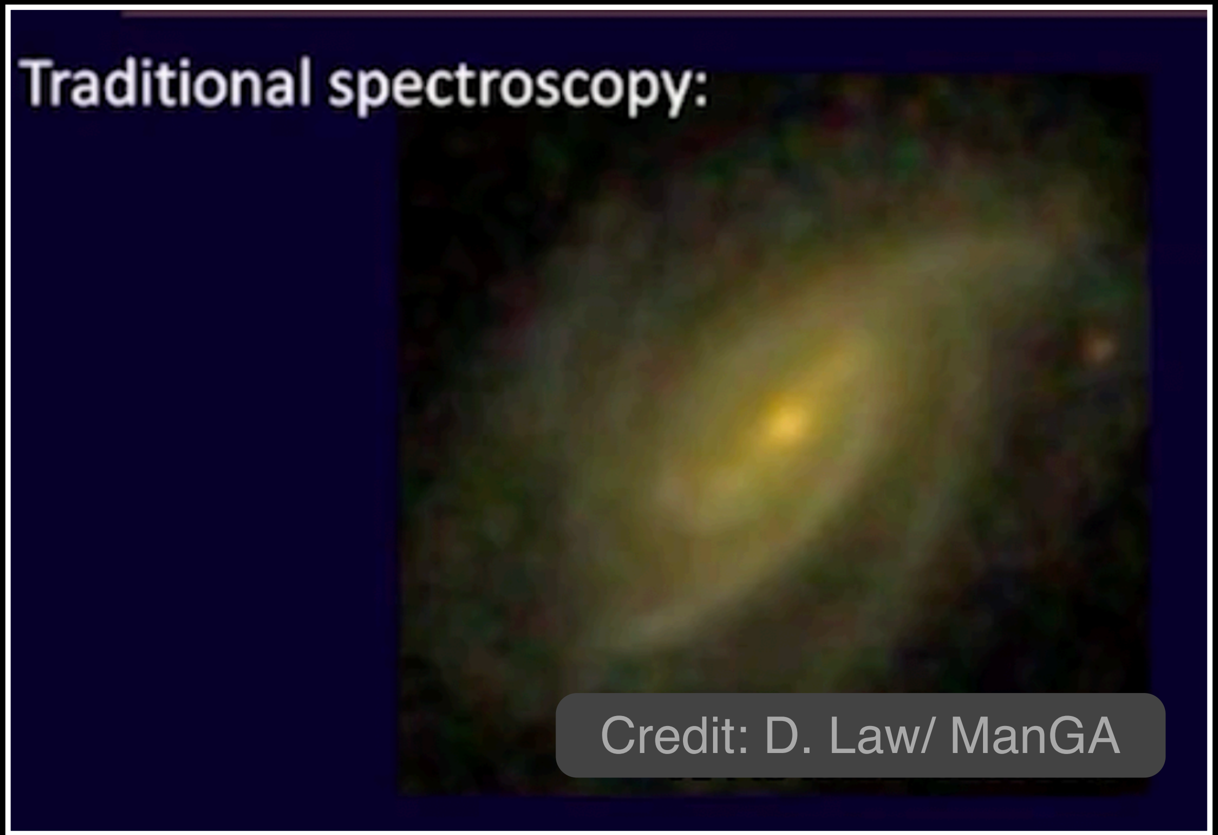

Credit: JWST/NASA

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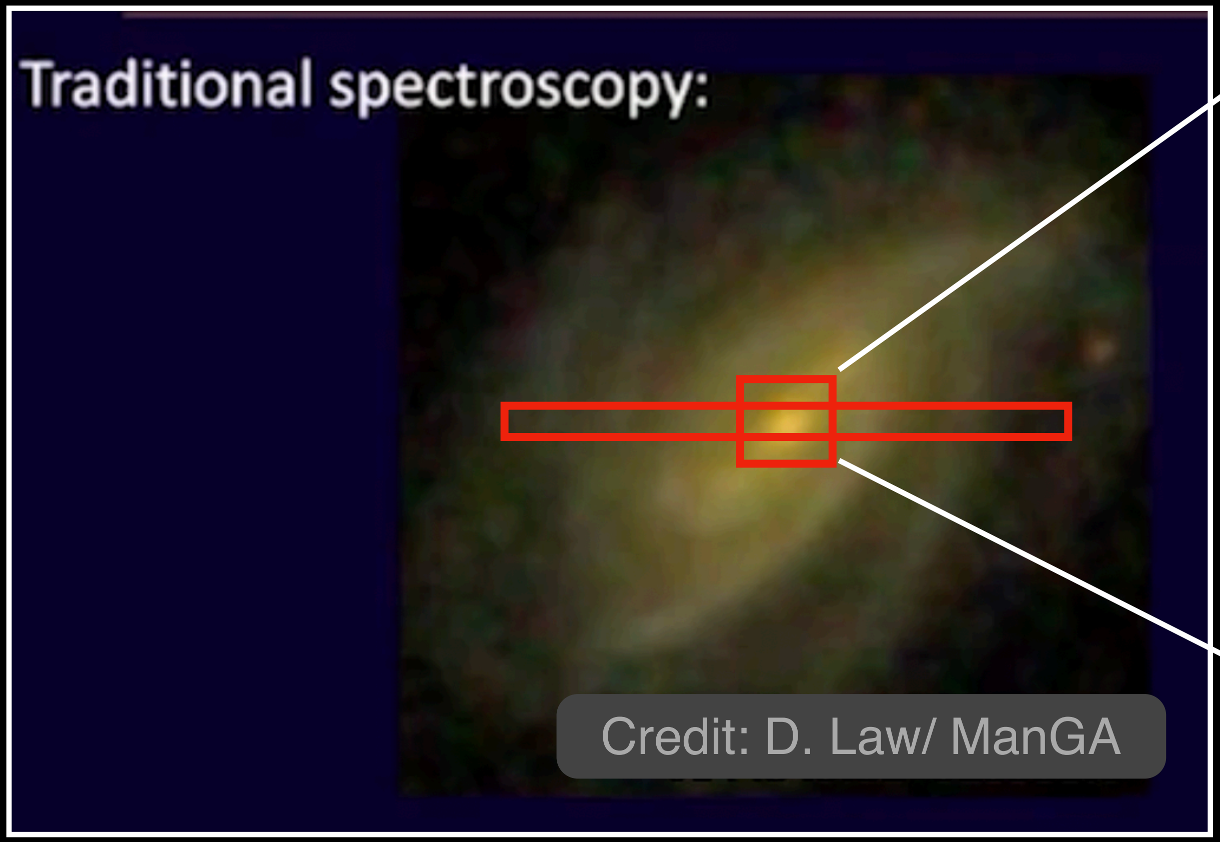

- Metalllicity
- Star-formation rate
- History of star-formation
- Kinematics
- AGN presence…

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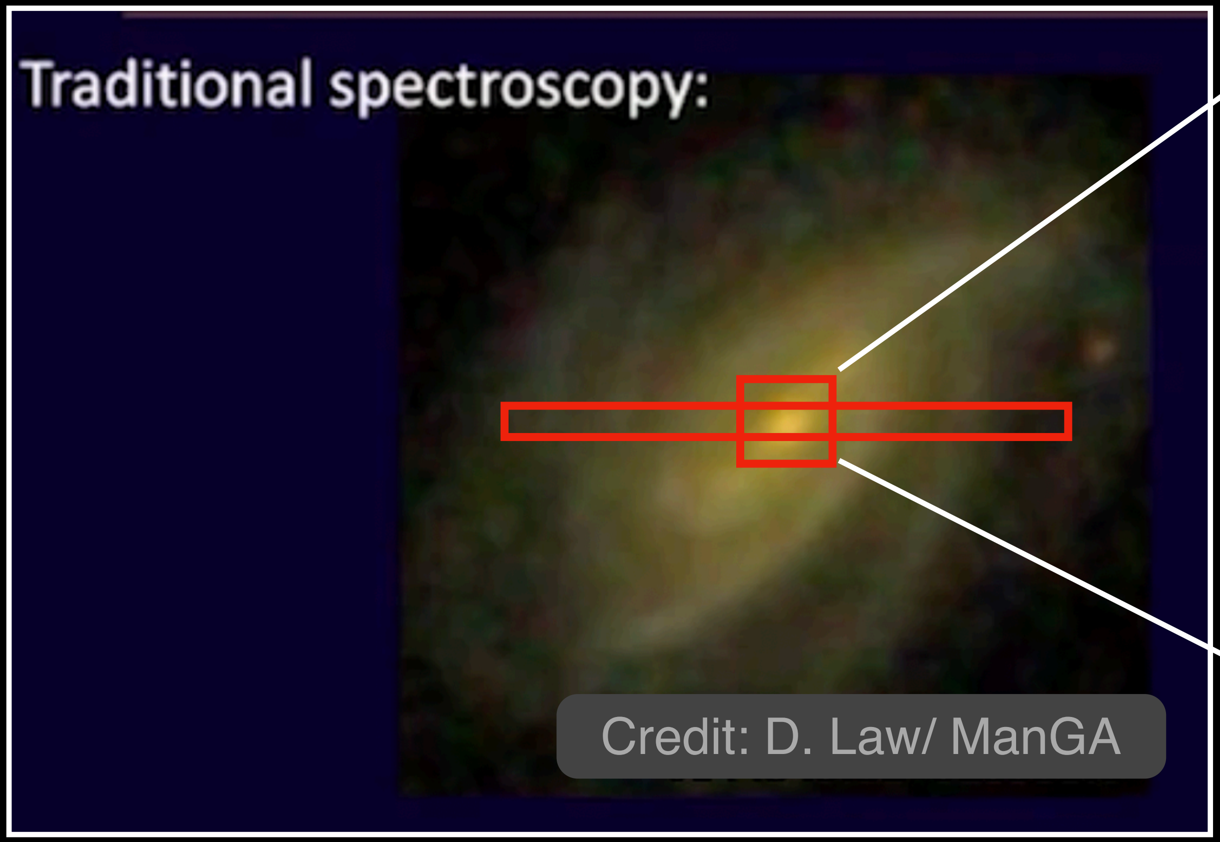

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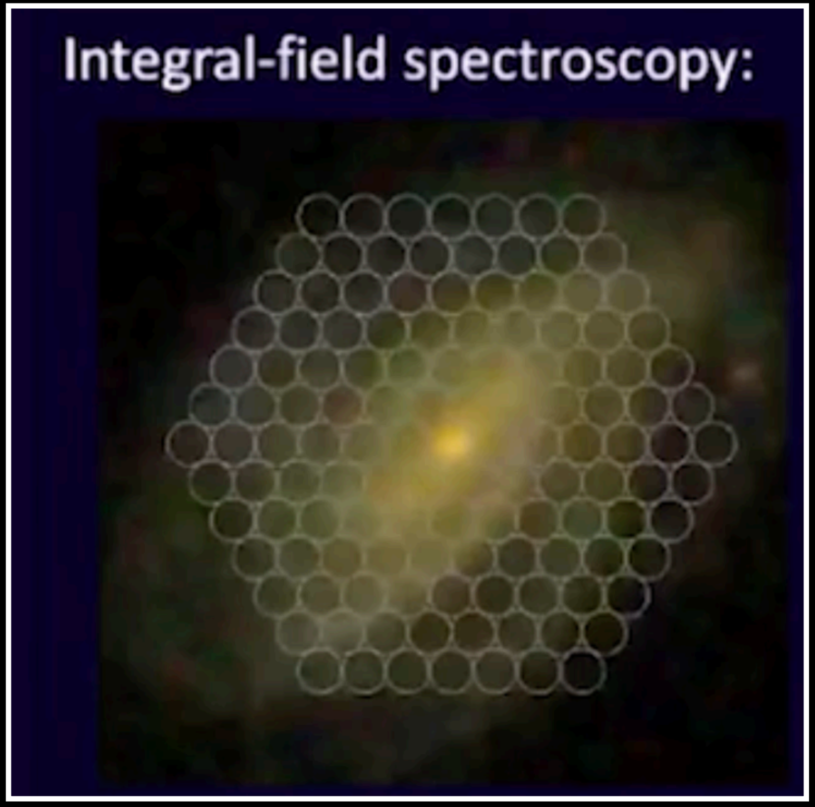

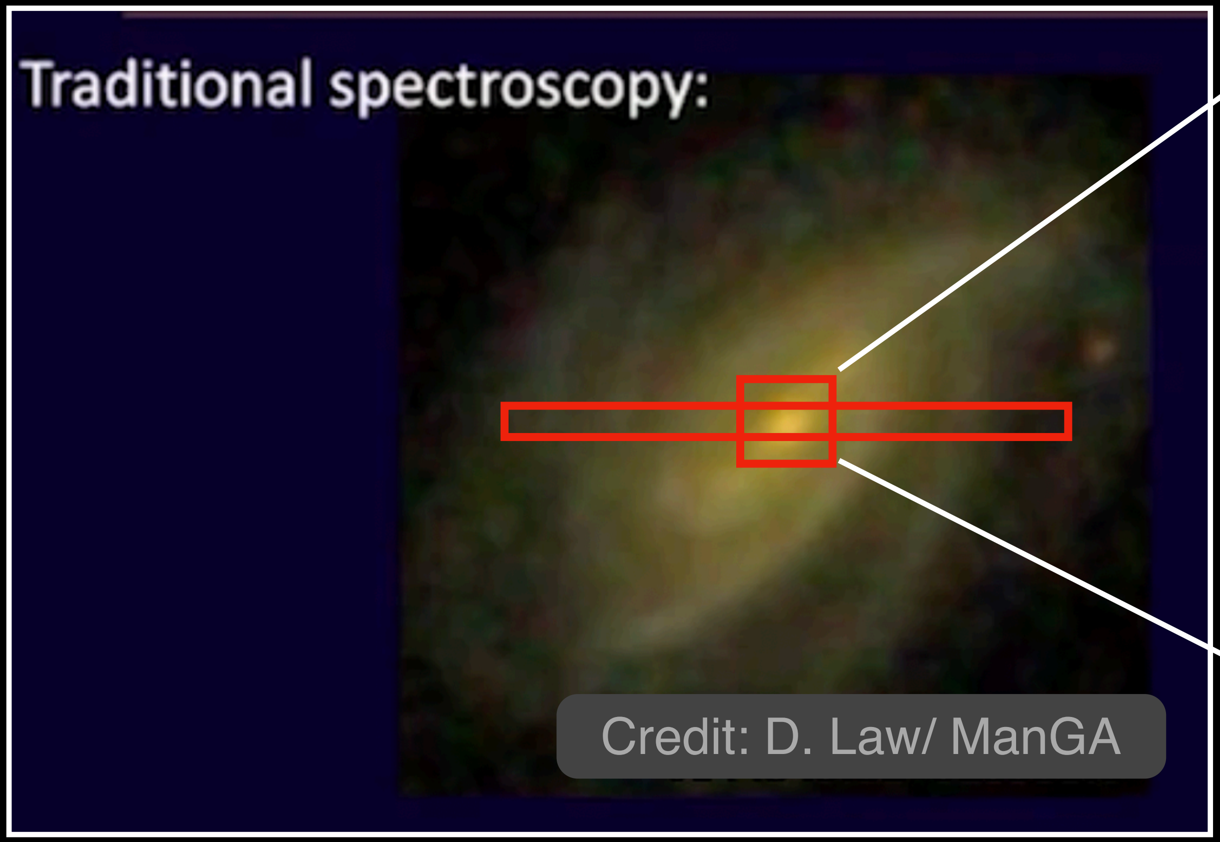

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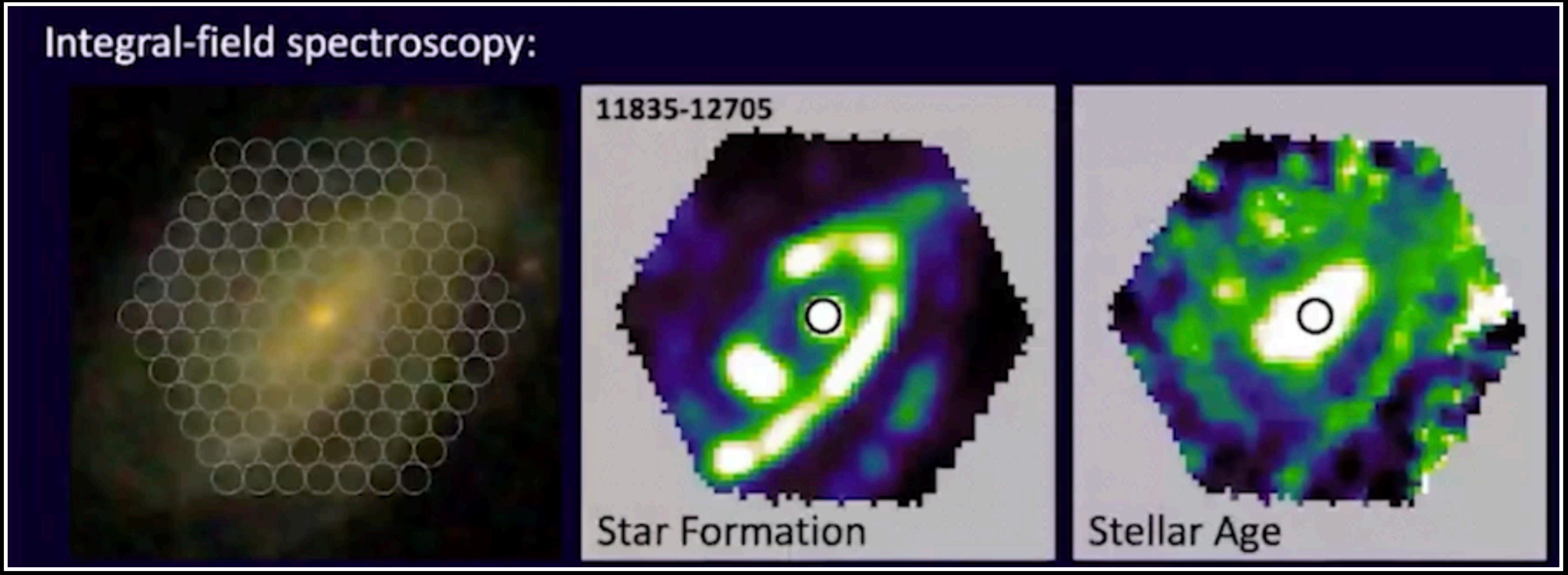
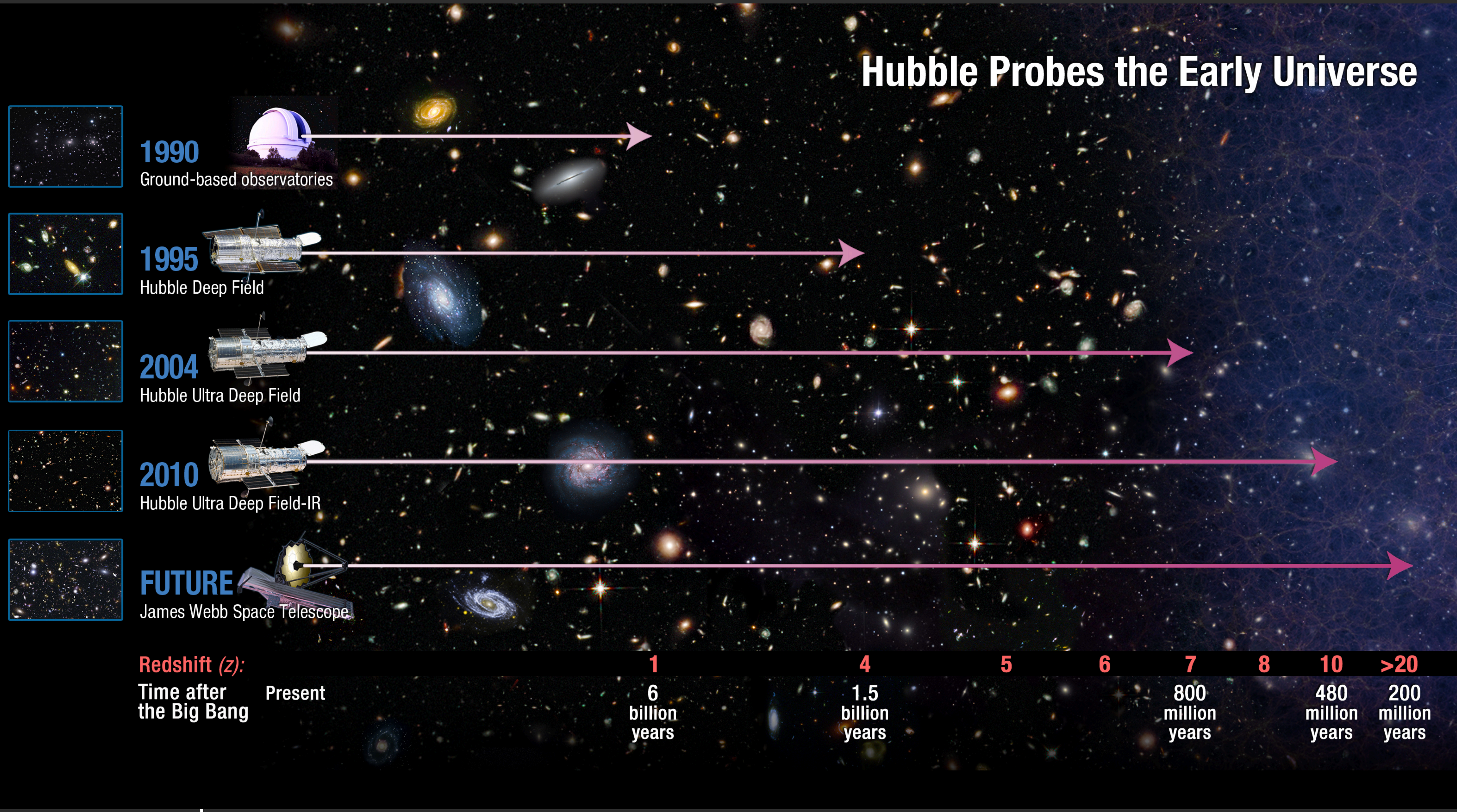
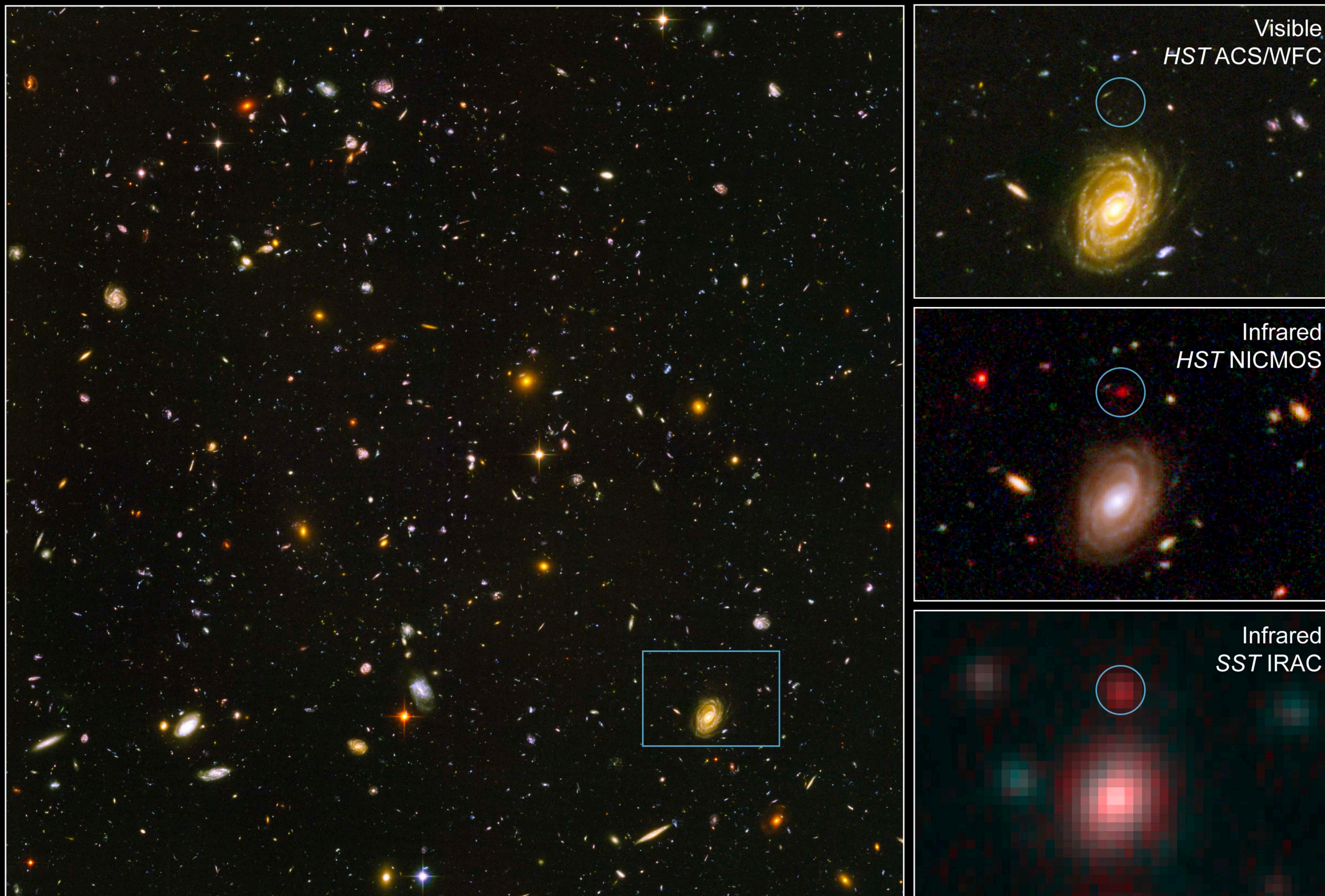


After launch deployment & commissioning

James Webb Space Telescope



Most distant galaxy discovered so far…



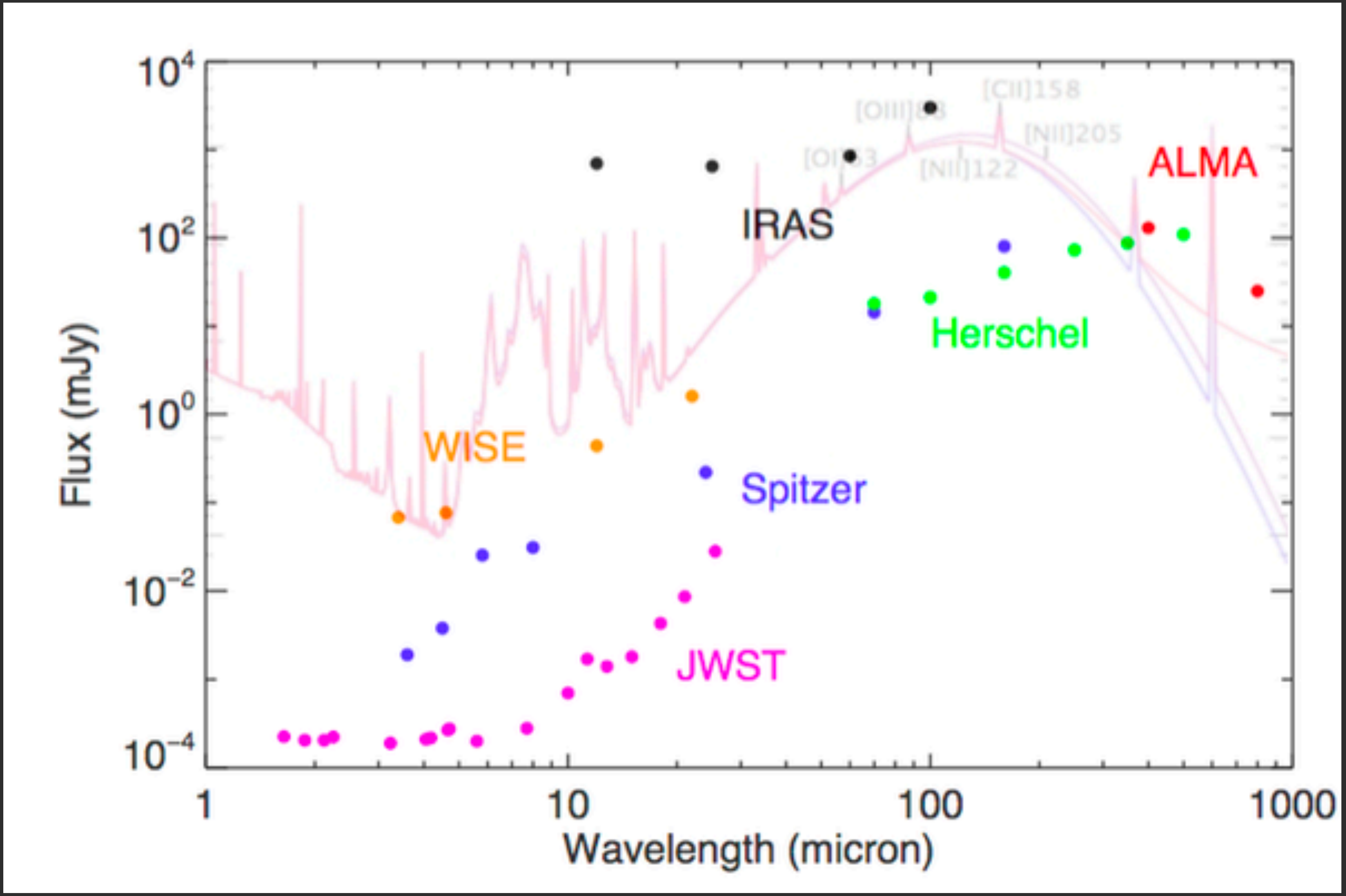
Distant Galaxy in the Hubble Ultra Deep Field • HUDF-JD2

Hubble Space Telescope ▪ ACS/ WFC

NASA, ESA, and B. Mobasher (STScI/ESA)

STScI-PRC05-28

James Webb Space Telescope



Worlds outsides our Solar system
EXOPLANETS

What are the building blocks of planets?

Can we find a water on a planet in habitable zone?

How did life develop on Eart

Do comets and other icy & dusty bodies contain clues to our origin?

How first galaxies formed?

What is a role of aromatic molecules (PAH) in dust formation?

How many smaller distant galaxies we miss?

What is the metallicity of distant galaxies?

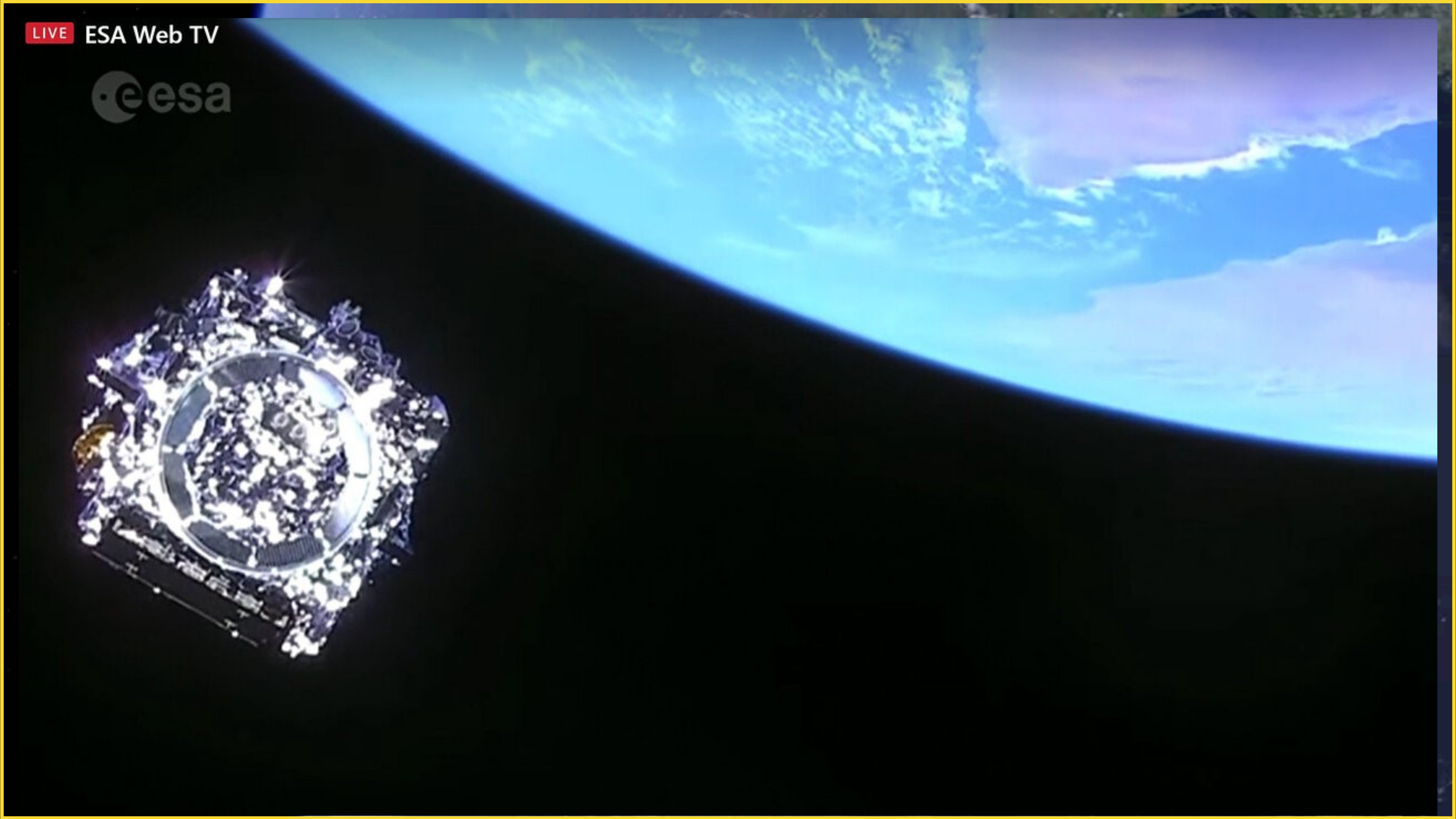
Co-evolution of galaxies and black holes over cosmic times…

Black holes

Spectra of the bright stars around black holes (MUSE instrument on VLT).
More massive BHs cause stars to move faster.
This effect is reflected in the spectra —> spectral lines are broader if the stars are moving faster.

Most distant galaxy discovered so far…

After launch deployment & commissioning

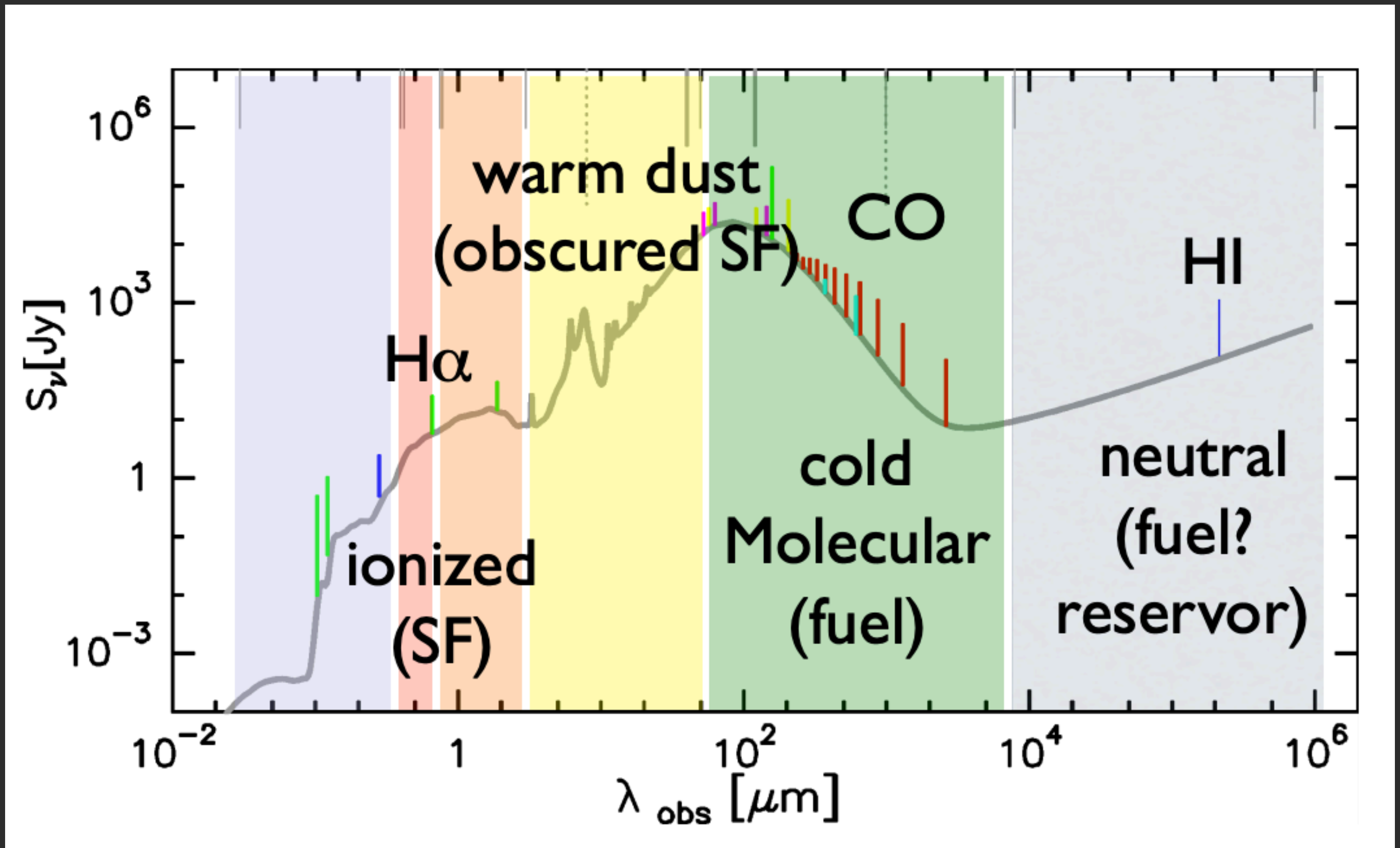


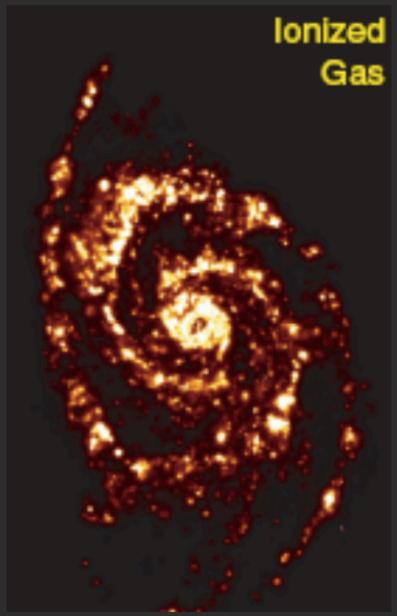
JWST as spectral machine

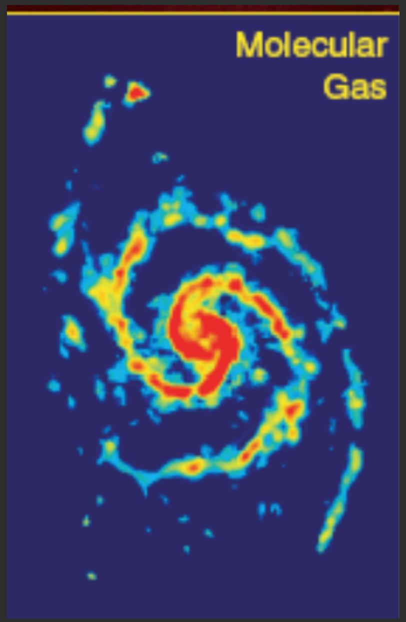
Science we expect

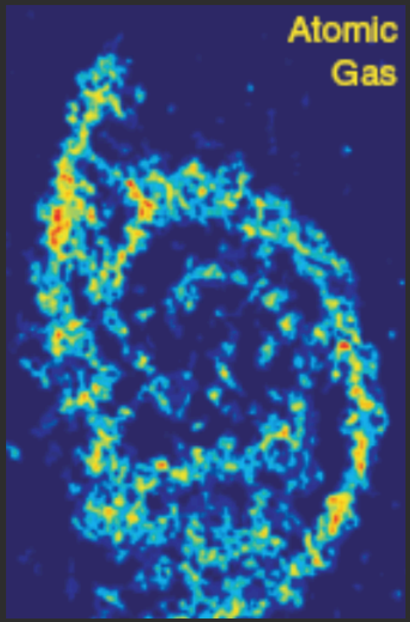
Early Release Science programs			
Name	**PI**	**Category**	**Science Observation Time (hours)**
Radiative Feedback from Massive Stars as Traced by Multiband Imaging and Spectroscopic Mosaics	Olivier Berne	Stellar Physics	8.3[262]
IceAge: Chemical Evolution of Ices during Star Formation	Melissa McClure	Stellar Physics	13.4[263]
Through the Looking GLASS: A JWST Exploration of Galaxy Formation and Evolution from Cosmic Dawn to Present Day	Tommaso Treu	Galaxies and the IGM	24.3[264]
A JWST Study of the Starburst-AGN Connection in Merging LIRGs	Lee Armus	Galaxies and the IGM	8.7[265]
The Resolved Stellar Populations Early Release Science Program	Daniel Weisz	Stellar Populations	20.3 [266]
Q-3D: Imaging Spectroscopy of Quasar Hosts with JWST Analyzed with a Powerful New PSF Decomposition and Spectral Analysis Package	Dominika Wylezalek	Massive Black Holes and their Galaxies	17.4[267]
The Cosmic Evolution Early Release Science (CEERS) Survey	Steven Finkelstein	Galaxies and the IGM	36.6[268]
Establishing Extreme Dynamic Range with JWST: Decoding Smoke Signals in the Glare of a Wolf-Rayet Binary	Ryan Lau	Stellar Physics	6.5[269]
TEMPLATES: Targeting Extremely Magnified Panchromatic Lensed Arcs and Their Extended Star Formation	Jane Rigby	Galaxies and the IGM	26.0[270]
Nuclear Dynamics of a Nearby Seyfert with NIRSpec Integral Field Spectroscopy	Misty Bentz	Massive Black Holes and their Galaxies	1.5 [271]
The Transiting Exoplanet Community Early Release Science Program	Natalie Batalha	Planets and Planet Formation	52.1[272]
ERS observations of the Jovian System as a Demonstration of JWST's Capabilities for Solar System Science	Imke de Pater	Solar System	9.3[273]
High Contrast Imaging of Exoplanets and Exoplanetary Systems with JWST	Sasha Hinkley	Planets and Planet Formation	18.4[274]

Star-formation markers

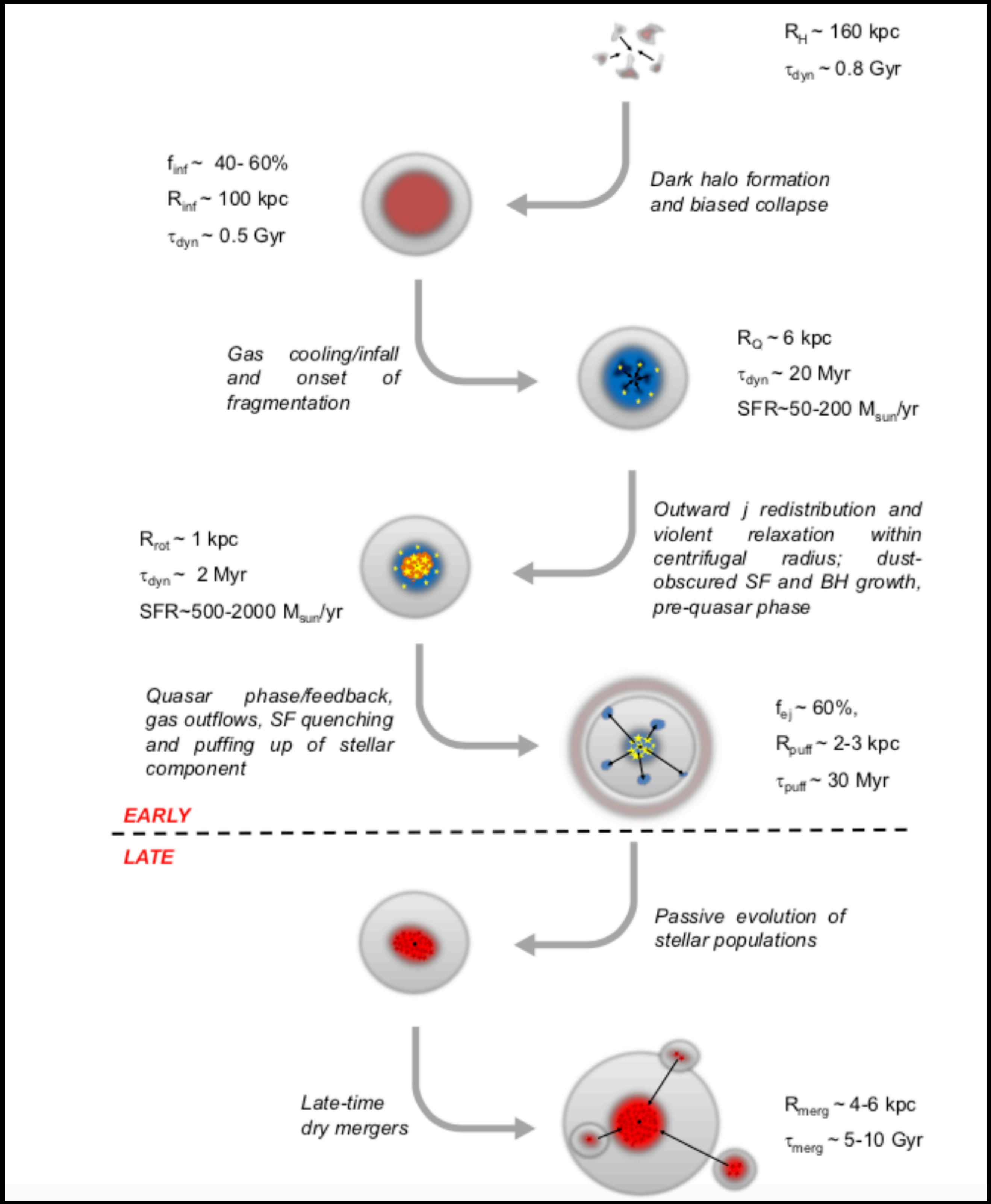




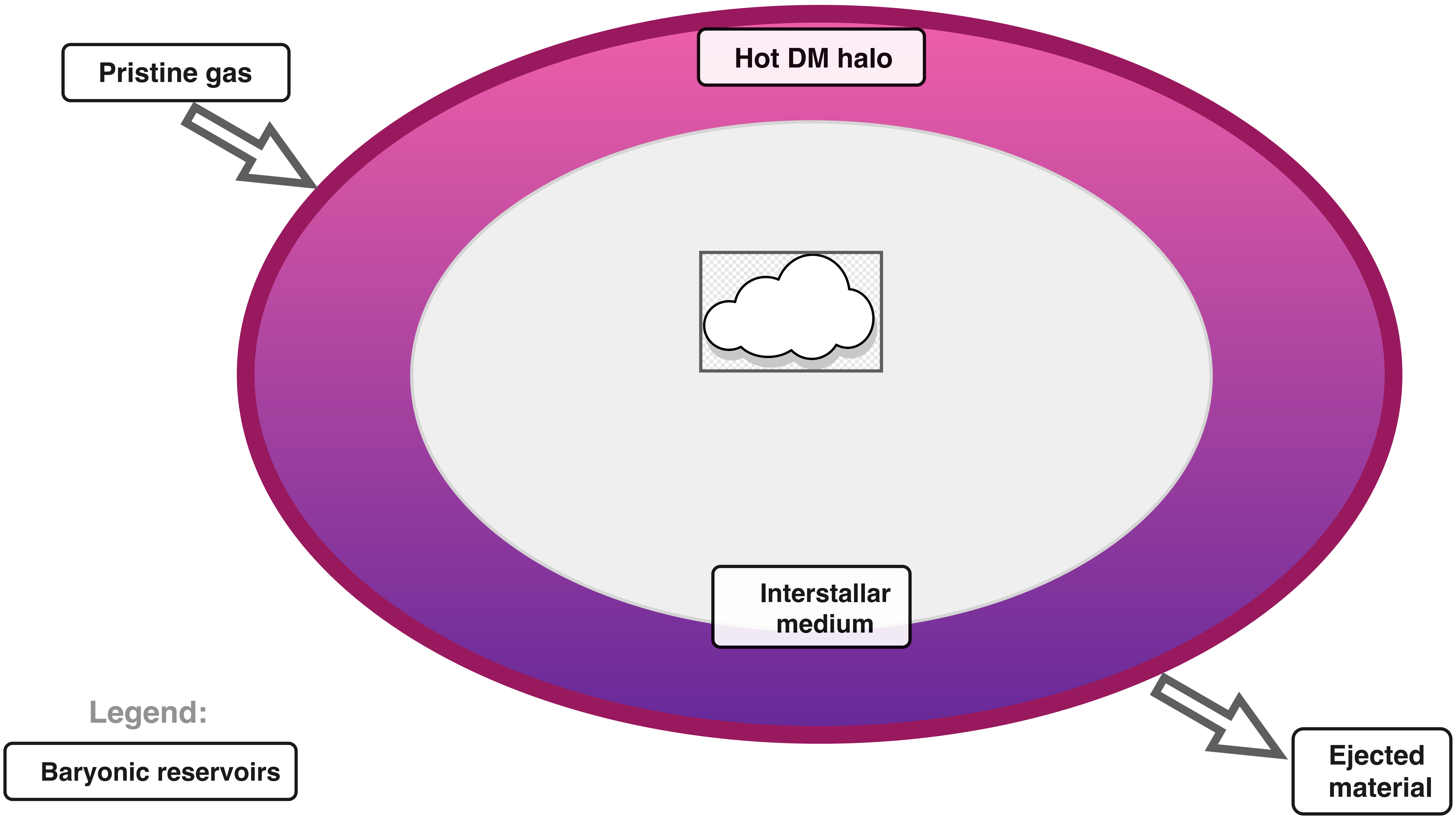




Evolution of dusty galaxies
interplay of SF and SMBH



Interplay of metals, gas, stars and dust in galaxy evolution



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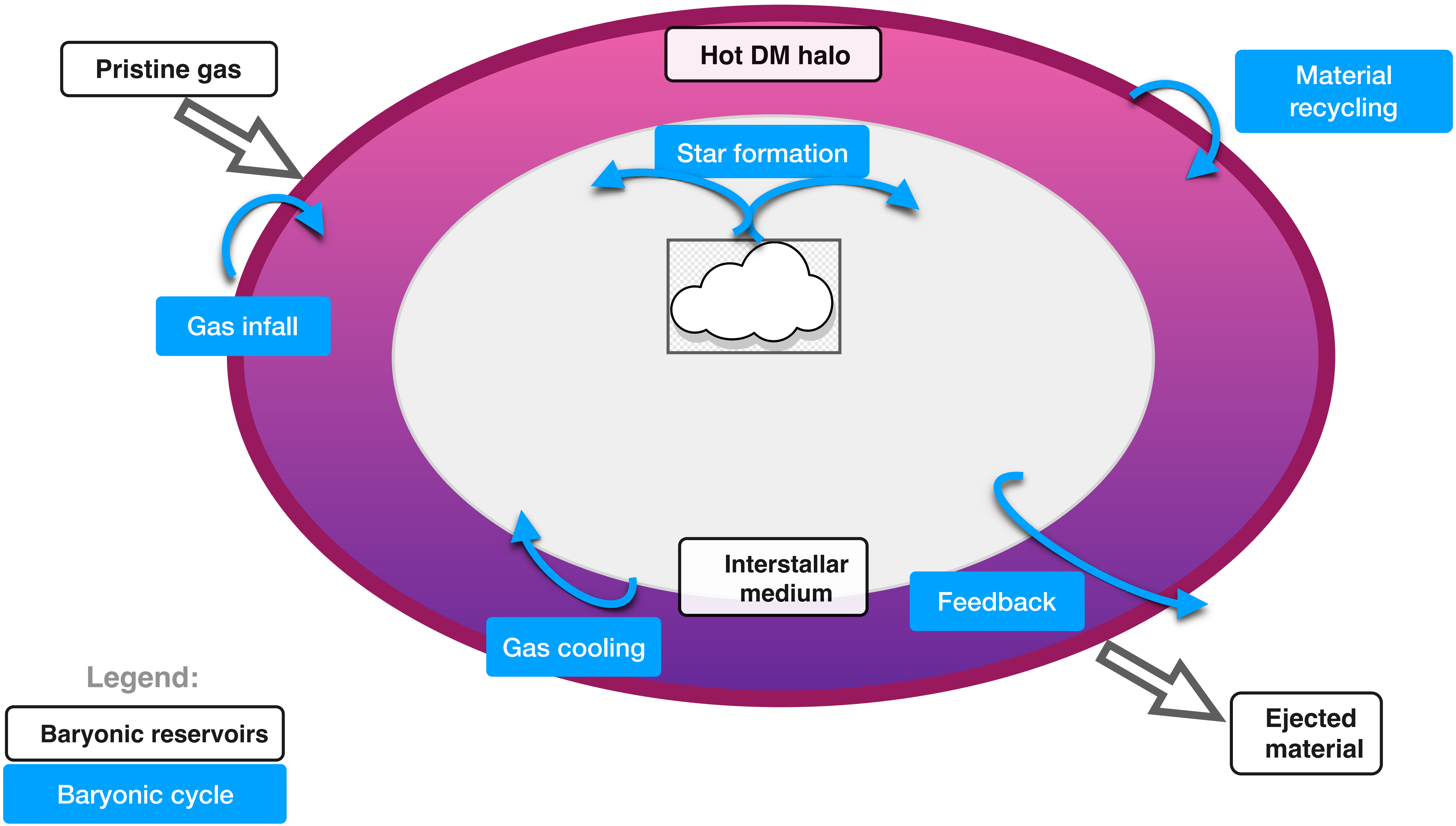
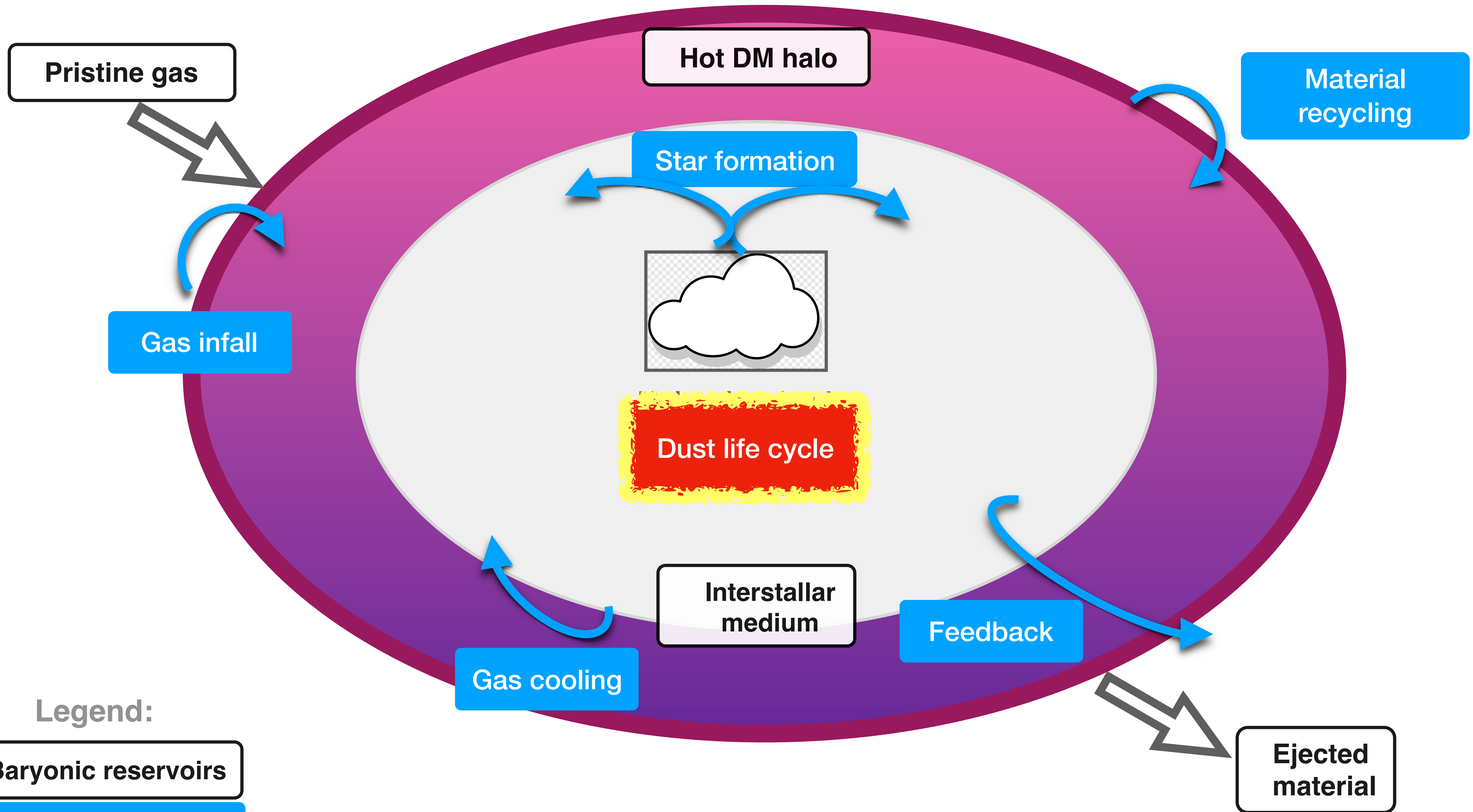
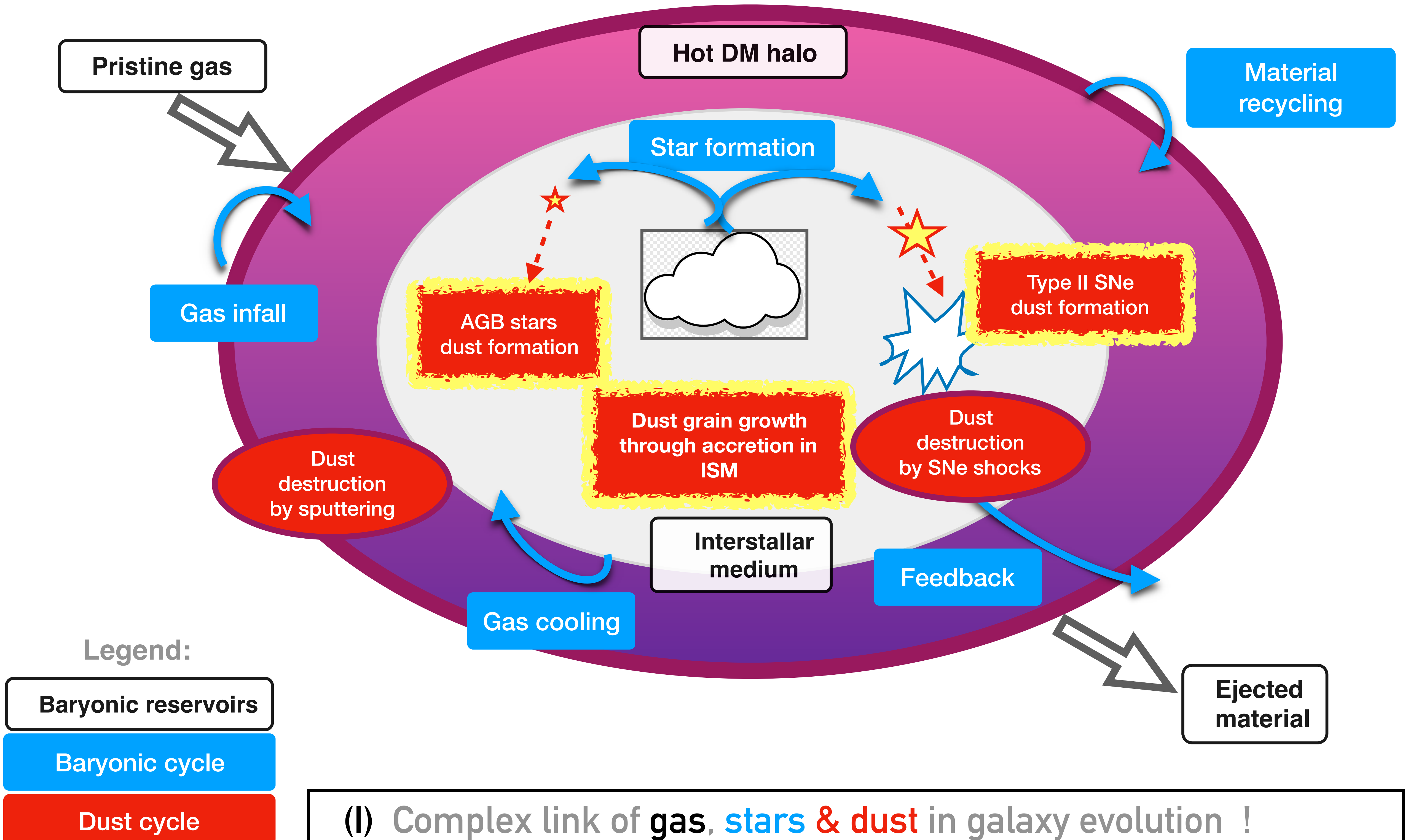


Interplay of metals, gas, stars and dust in galaxy evolution



Legend:

Interplay of metals, gas, stars and dust in galaxy evolution

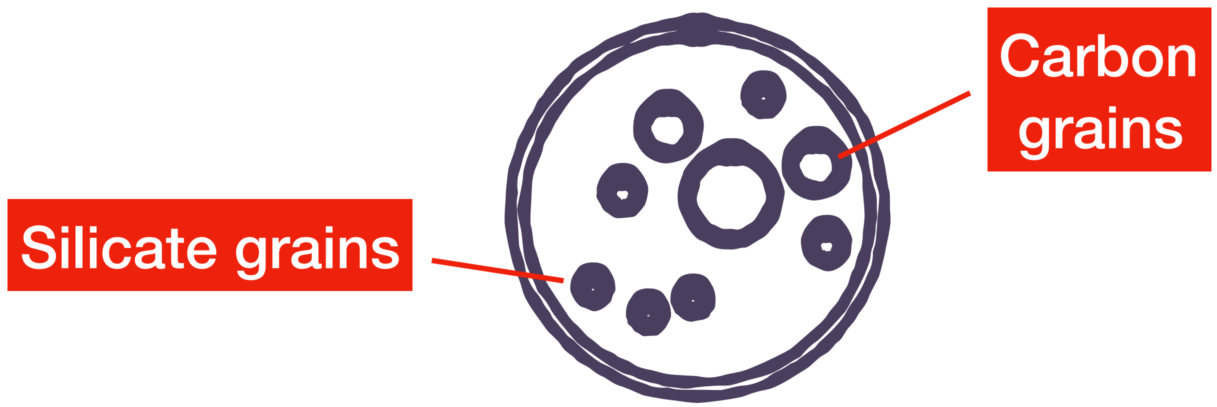


(I) Complex link of gas, stars & dust in galaxy evolution !

(II) Measure of different **dust production/destruction** processes !

Why studying dust and metals over cosmic times?

Evolution of ISM from the early to the local Universe



Interstellar dust particles

- Solid particles of size 0.3 um<r<0.3 nm
- Made of heavy elements (mainly O, C, Si, Mg, and Fe)
- Mixed with the gas in the ISM.
- Accounting for only 1% of ISM mass…
- … but, they have a radical impact on galaxies!!!

Why studying dust and metals over cosmic times?

Dust

Increases the formation of H_2

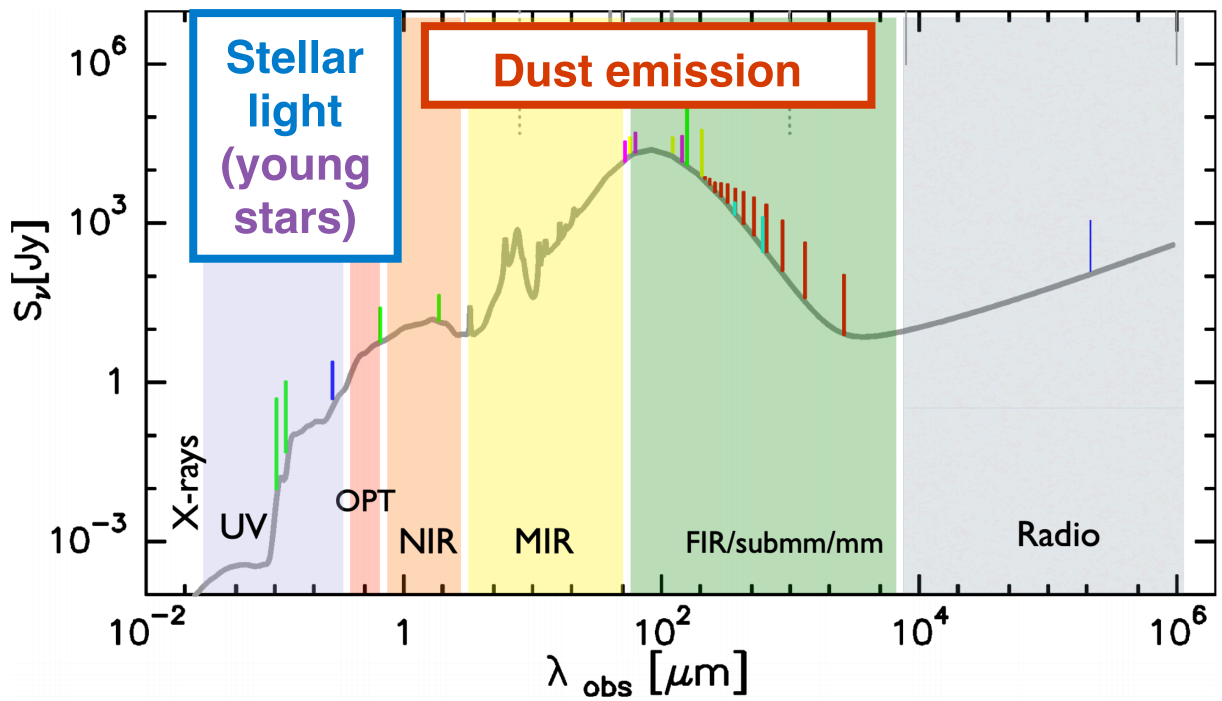
(hydrogen forming onto surfaces of interstellar dust grains)

Additional cooling channel for gas

(role in increaing star-forrmation)

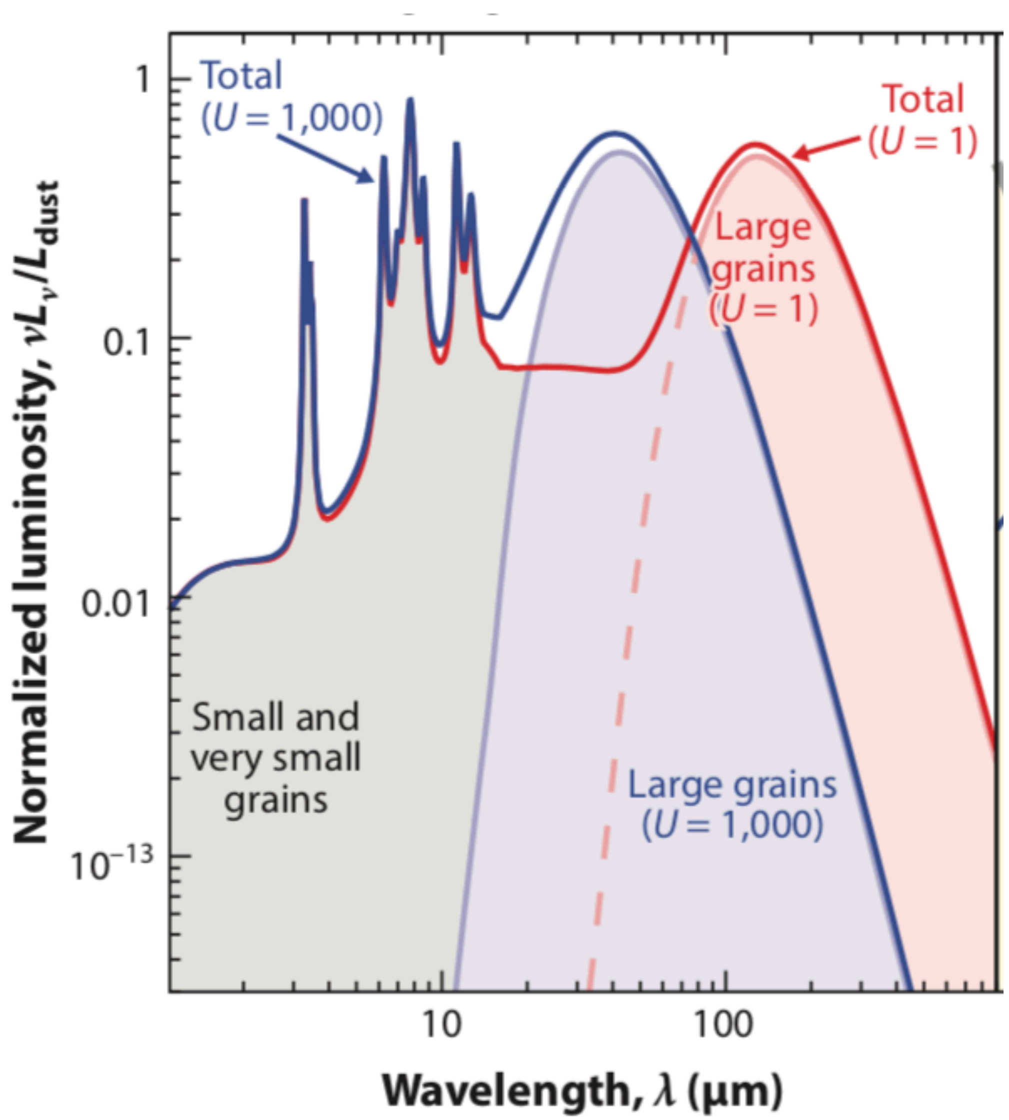
Dust contributes to the metals in CGM

Affecting galaxy spectral energy distribution (SED)
(Dust grains absorb stellar radiation in the ultraviolet (UV) and re-emit in far-IR)



Dust, its spectral energy distribution (SED) and beyond…

Dust emission = combination of various meachanisms



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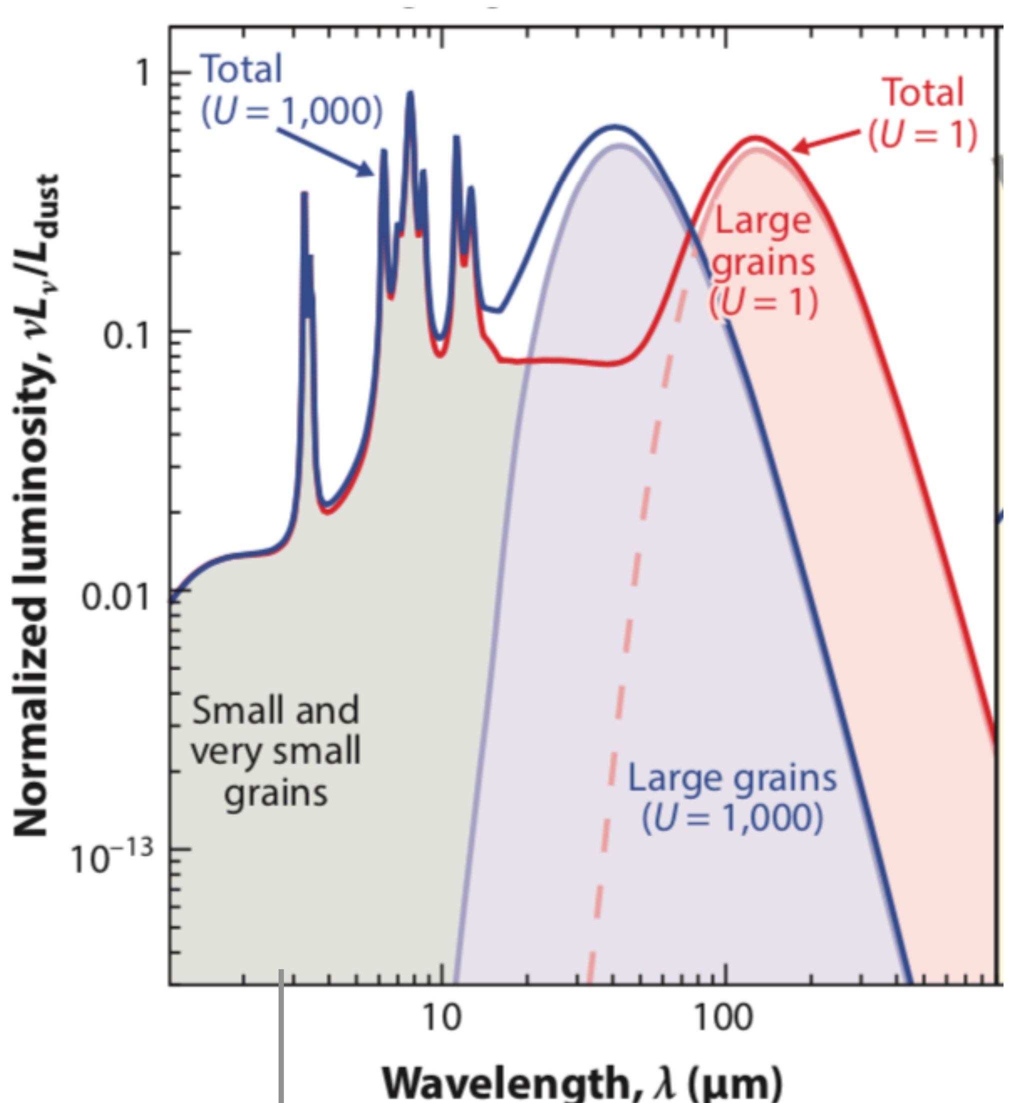
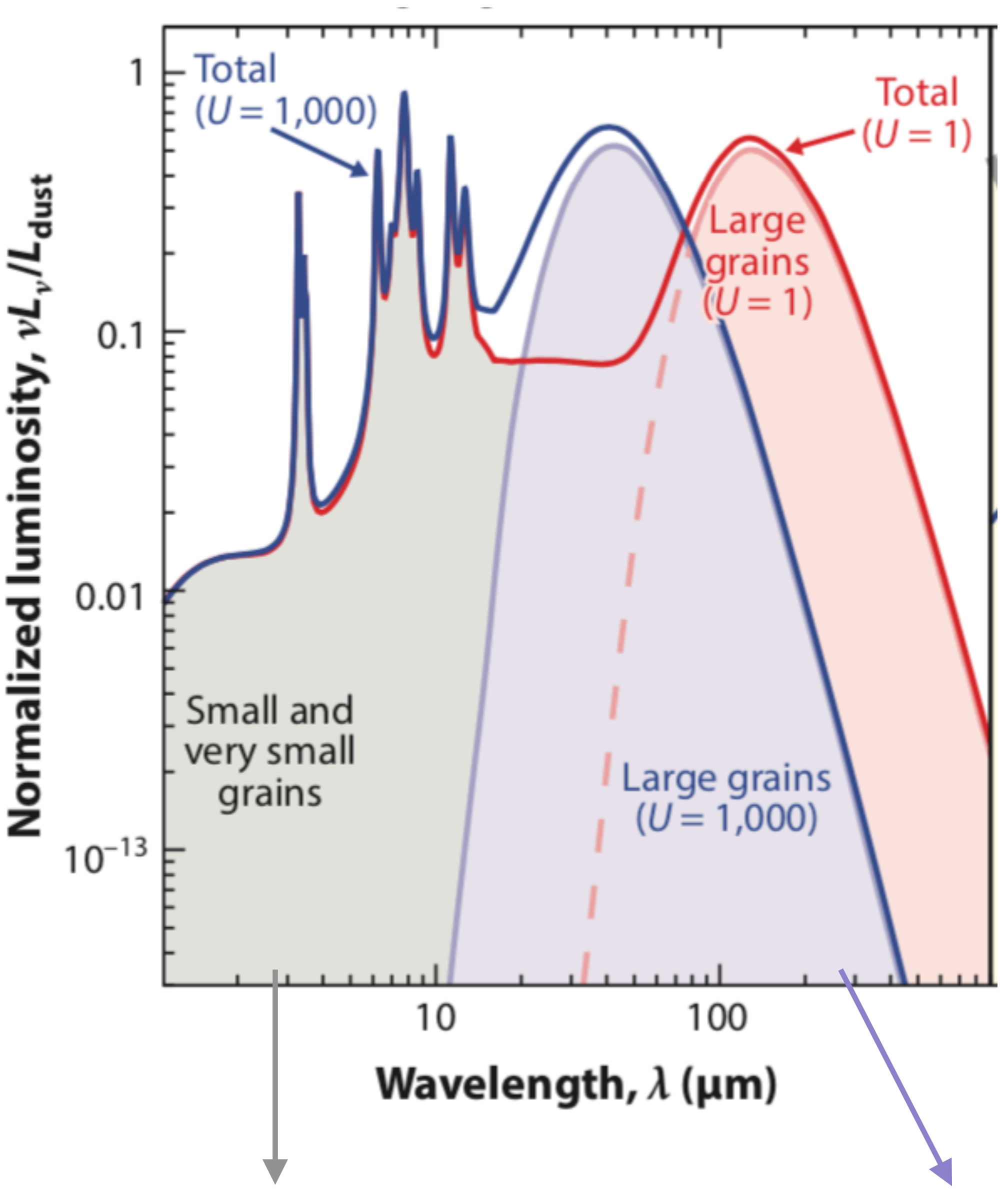


PAH emission

(PDR regions illuminated by UV-bright stars; contribute up to 10% of the total IR luminosity)

Dust, its spectral energy distribution (SED) and beyond…

Dust emission = PAH features + Diffusse emission



PAH emission

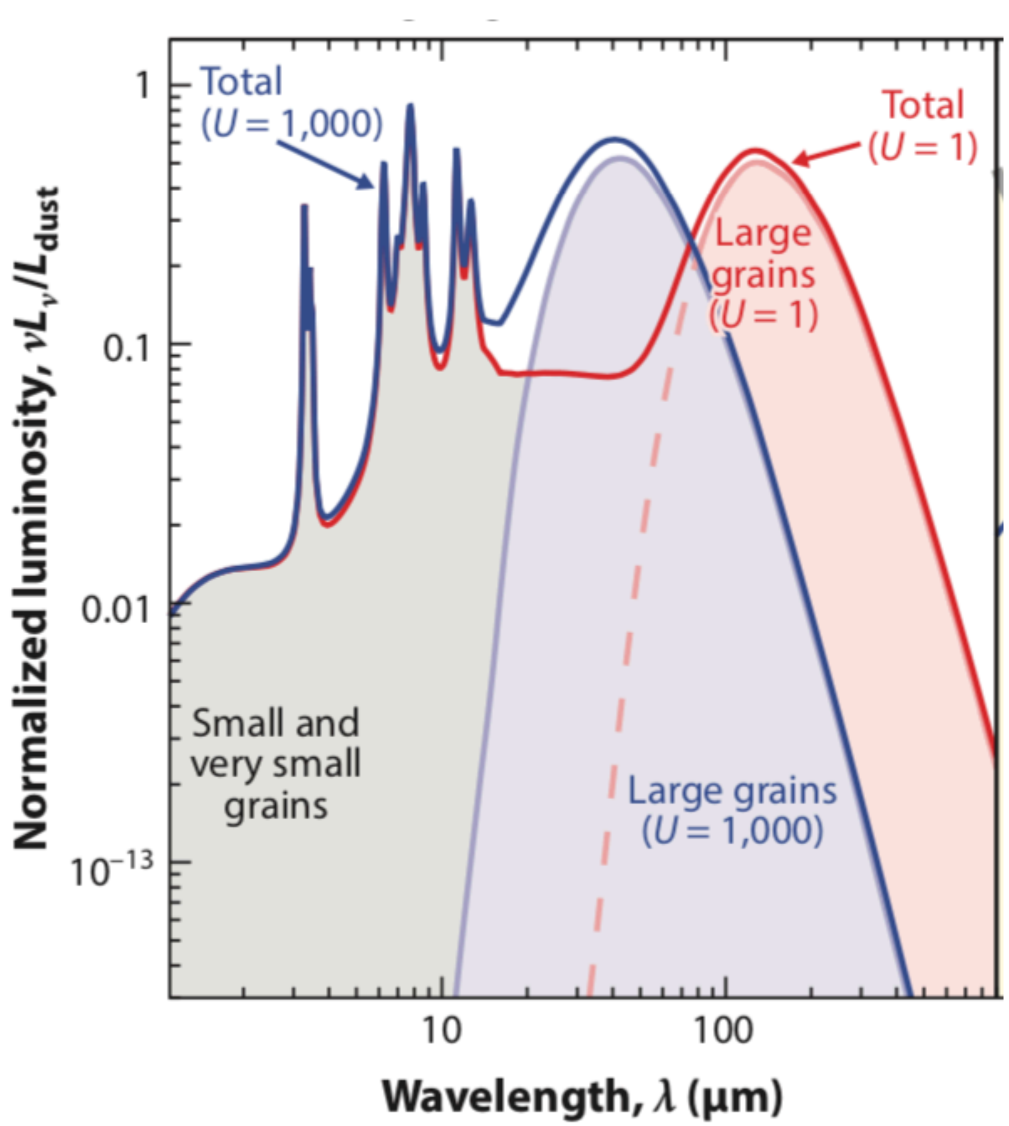
(PDR regions illuminated by UV-bright stars; contribute up to 10% of the total IR luminosity)

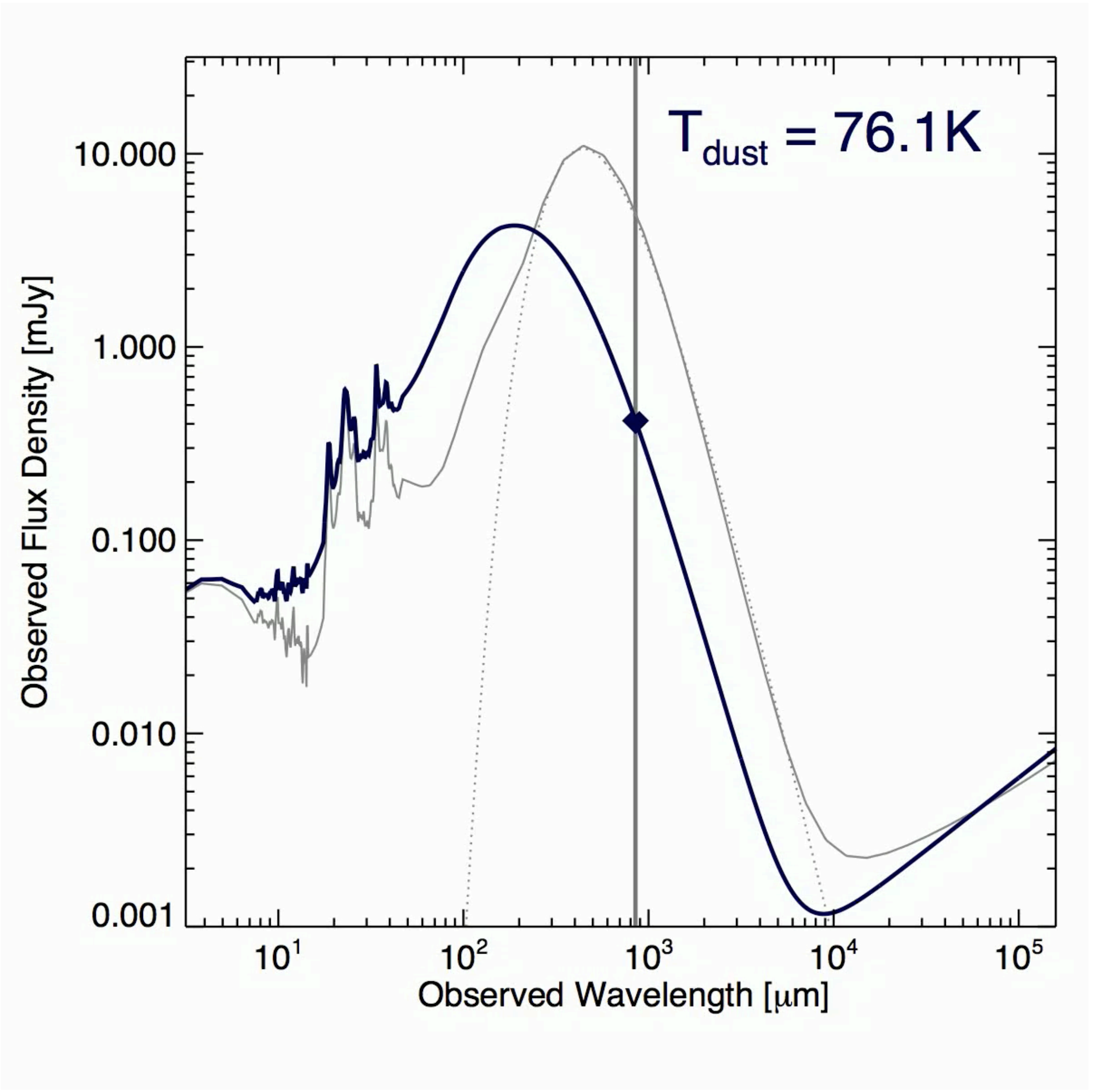
Diffuse emission

(majority of dust, mostly larger grains, heated by constant radiation field)

Dust, its spectral energy distribution (SED) and beyond…

Dust emission = PAH features + Diffusse emission

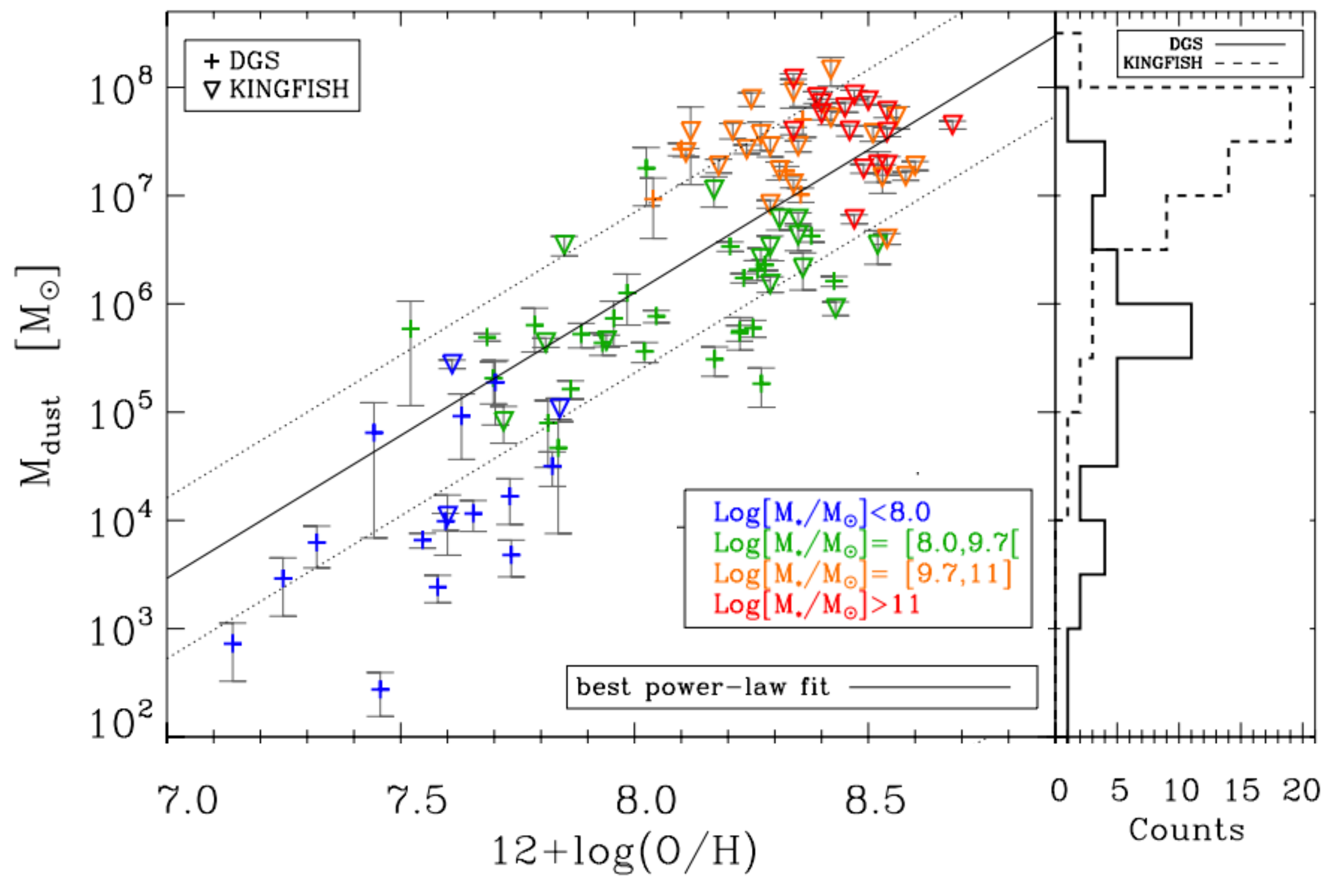




$$\langle U \rangle \propto \frac{L_{\rm IR}}{M_{\rm dust}} \propto \frac{M_{\rm mol}^{\frac{1}{s}-1}}{Z(M_\star, SFR)}$$

Why studying dust-metallicity relation at high-z (z>2)

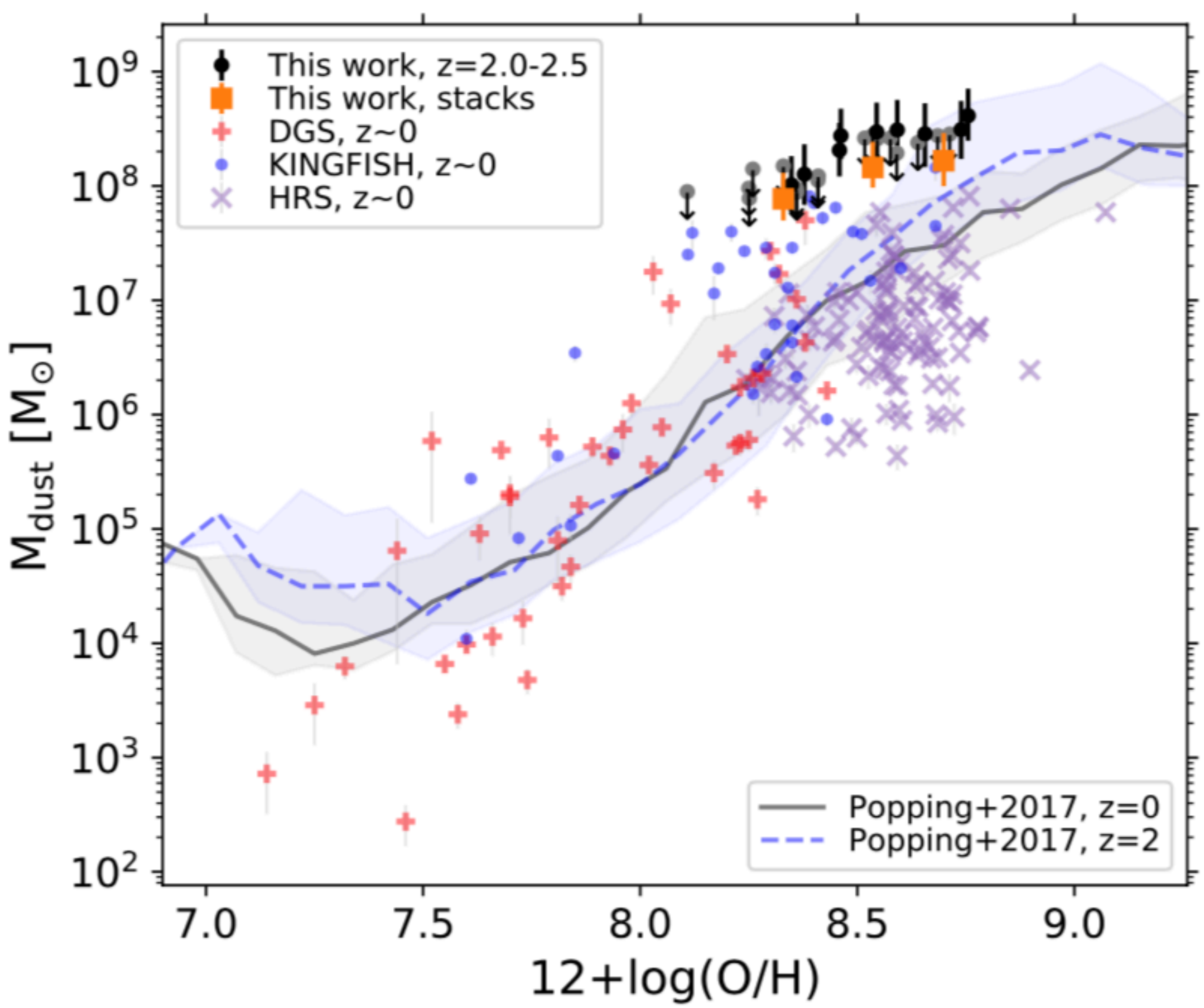
Relation between dust mass and metallicity established only for local samples or for a handful of very massive samples up to z~2.3



dust-metallicity relation @z~0
(Rémy-Ruyer + '15)

Dust, its spectral energy distribution (SED) and beyond…

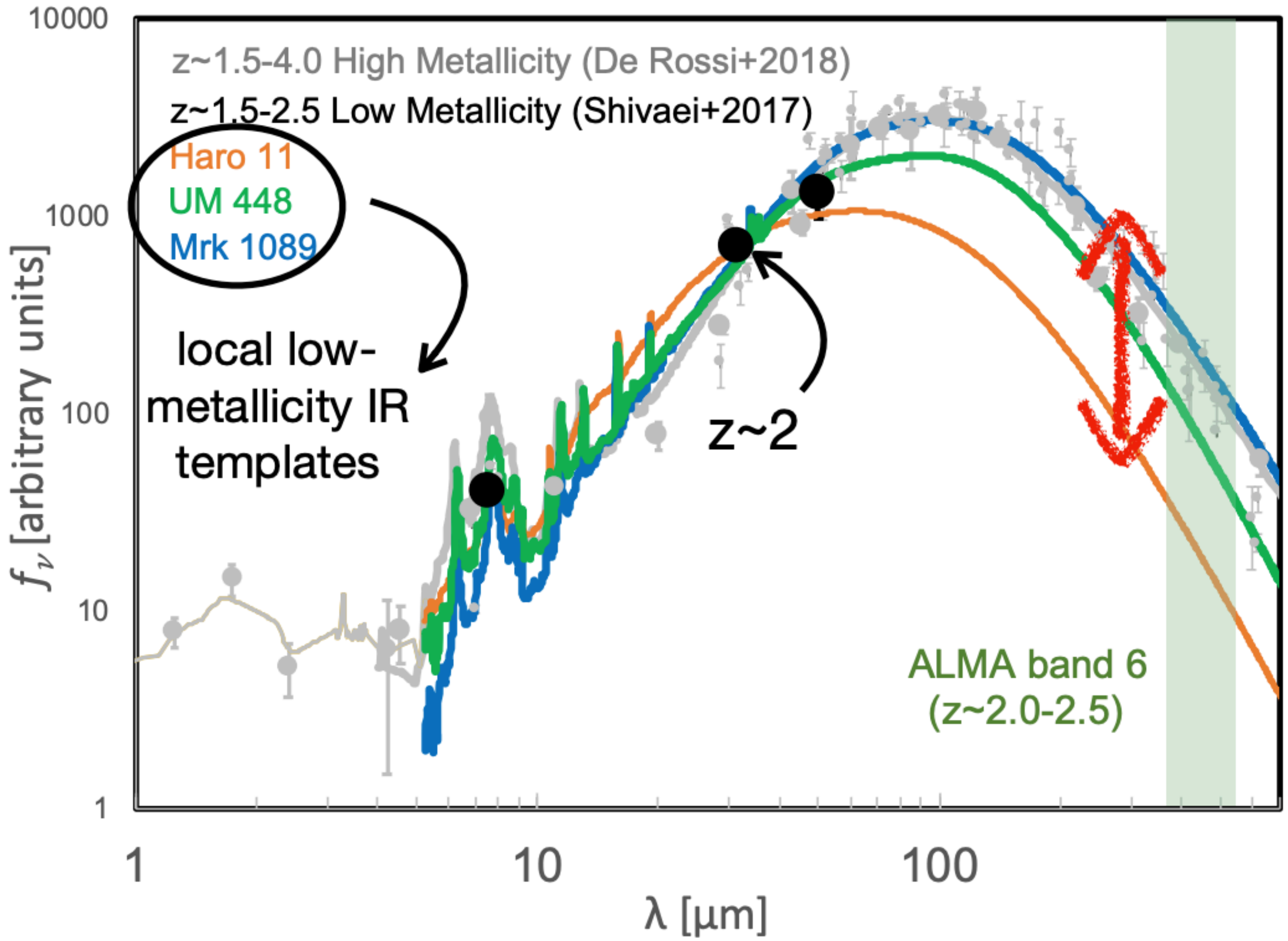
Dust mass at z~2 order of magnitude higher than at z~0
➡ tension with models! (e.g. they need to account for higher gas masses or SFE)



sSFR-metallicity relation @z~2
(Shivaei + '22)

Dust, its spectral energy distribution (SED) and beyond…

To predict dust SED at high-z, one needs to correct overestimation for far-IR part
➡ JWST + ALMA come into the game!



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