James Webb Space Telescope: Status and Perspective

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JADES
JWST ADVANCED DEEP
EXTRAGALACTIC
SURVEY
1 µm
2 µm
4 µm

History of the Universe

adapted from NAOJ

Cosmology: Evolution of the Universe

General Relativity:

$$R_{\mu\nu} - \frac{1}{2}Rg_{\mu\nu} + \Lambda g_{\mu\nu} = \frac{8\pi G}{c^4}T_{\mu\nu}$$

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Cosmological Principle:
universe is uniformly isotropic and homogeneous when viewed on a large enough scale

$$\Longrightarrow ds^2 = -c^2dt^2 + a(t)^2\left(\frac{dr^2}{1-kr^2} + r^2d\Omega^2\right)$$ FLRW metric

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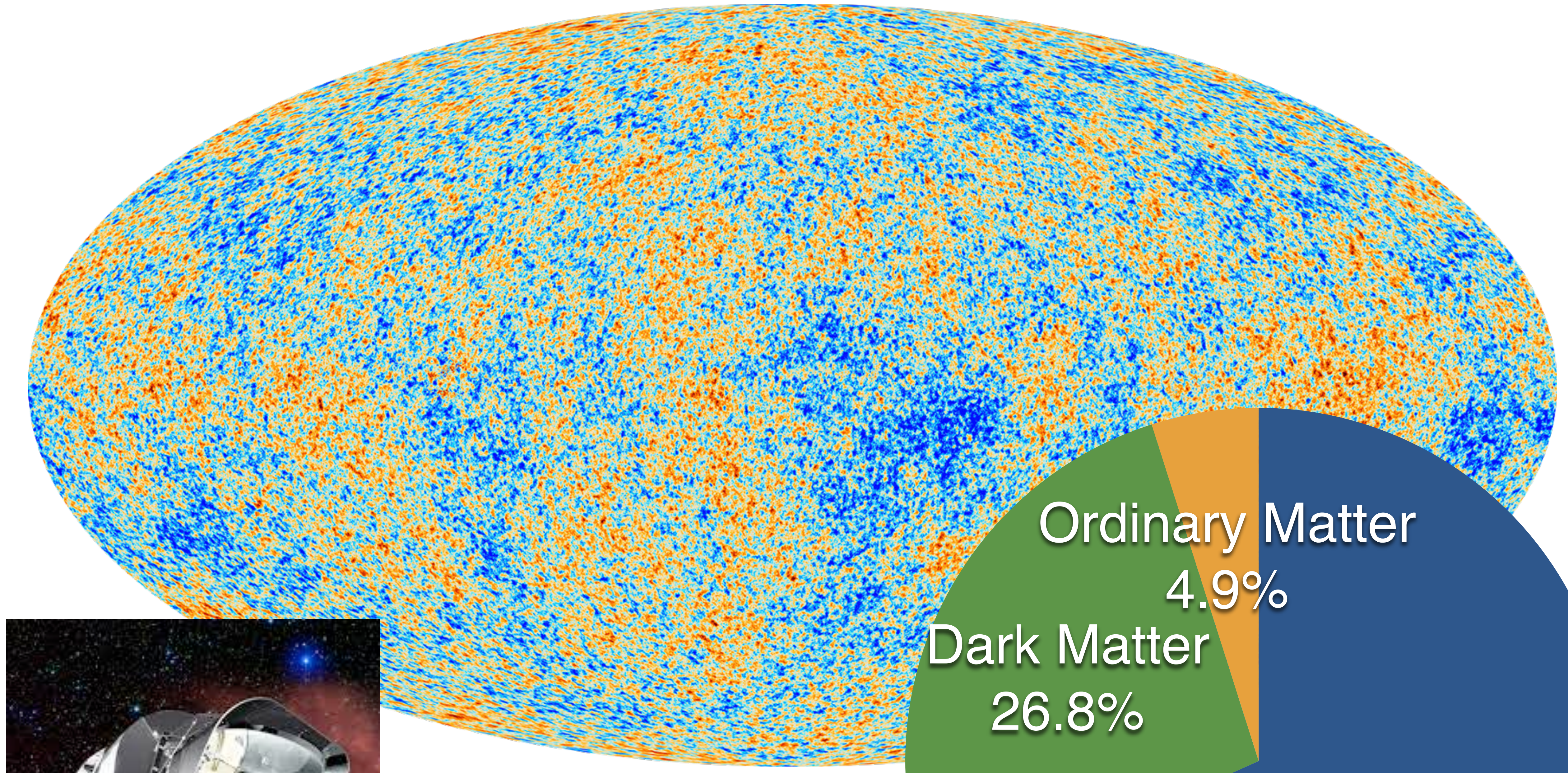
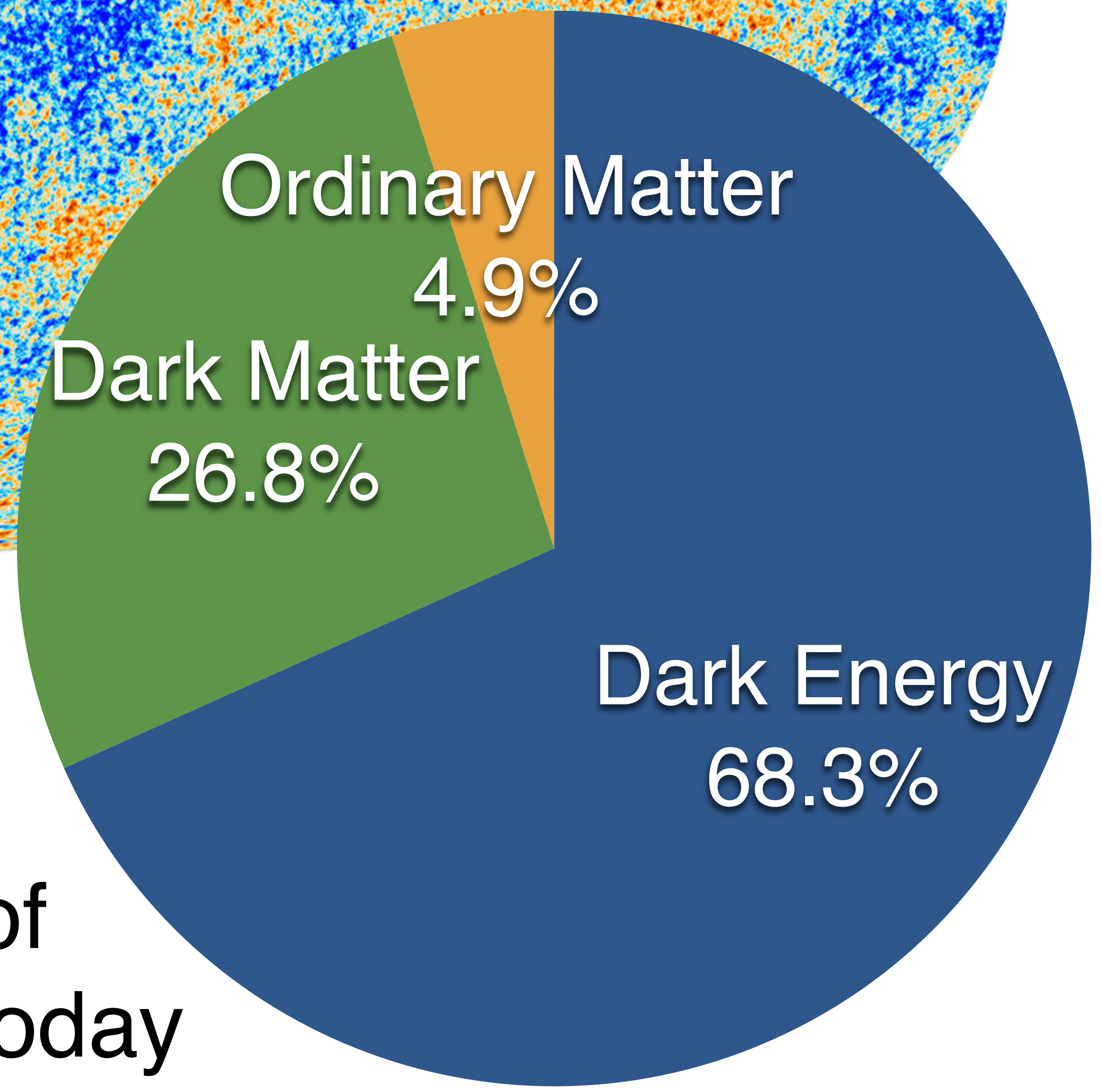
FLRW metric

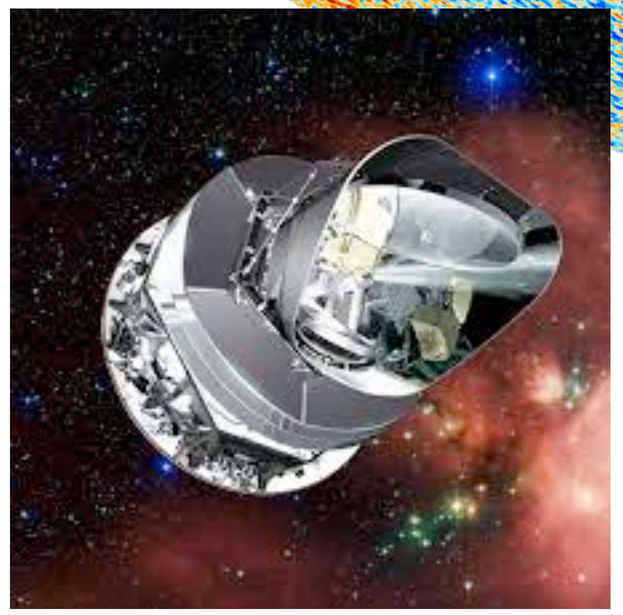
Scale factor a(t) depends on energy density of the Universe… need to measure the expansion of the Universe to infer its energy content via “standard rulers” (e.g., CMB, baryon acoustic oscillations [BAO]) or “standard candles” (e.g., supernovae).

Standard cosmological model (ΛCDM)

Cosmic Microwave Background (CMB)
the view of the universe 380,000 yr after the Big Bang

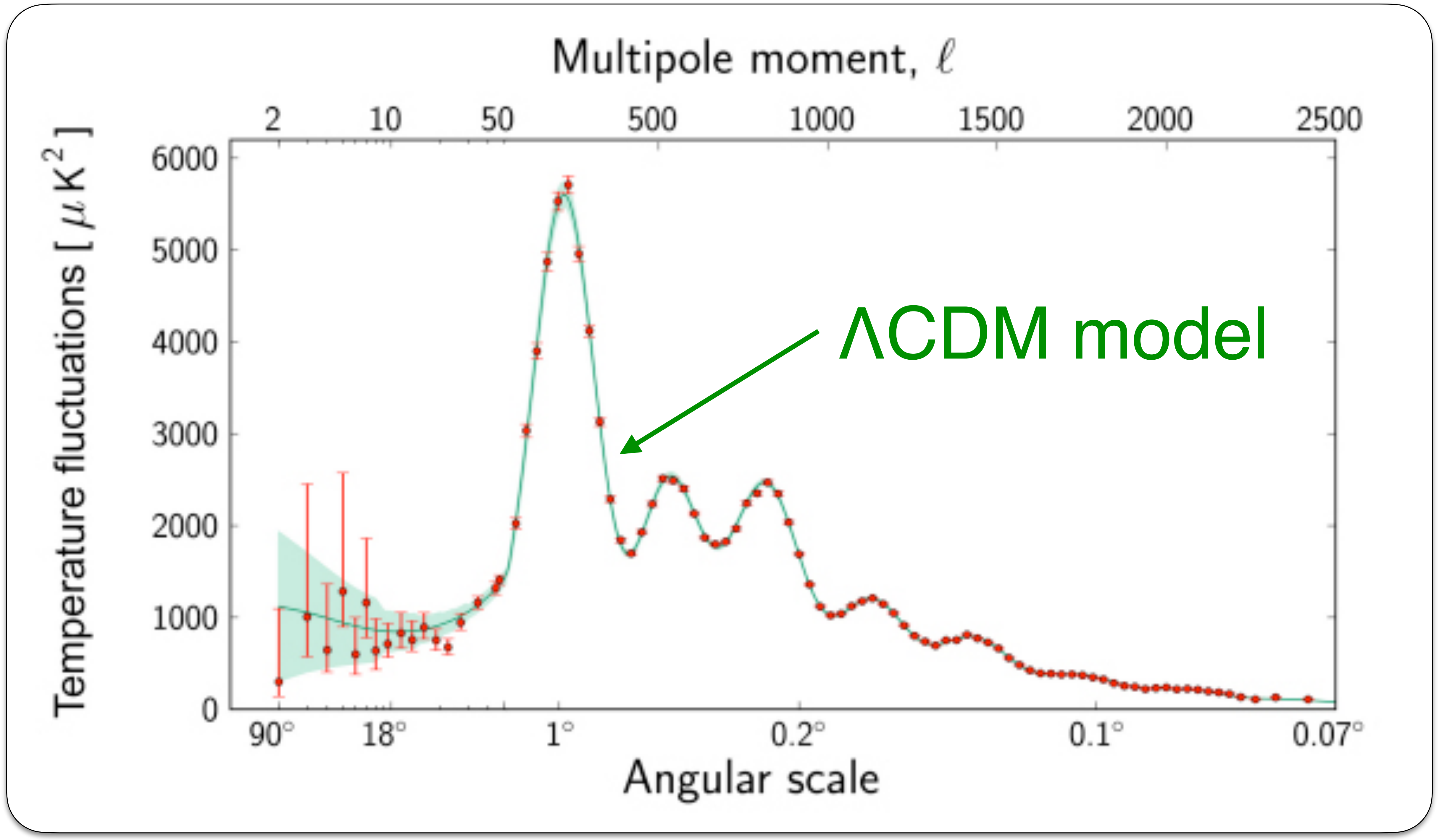






Planck Satellite

Composition of
the universe today



Planck Collaboration (2018)

➜ good understanding of the initial conditions
for galaxy evolution

Structure formation in ΛCDM

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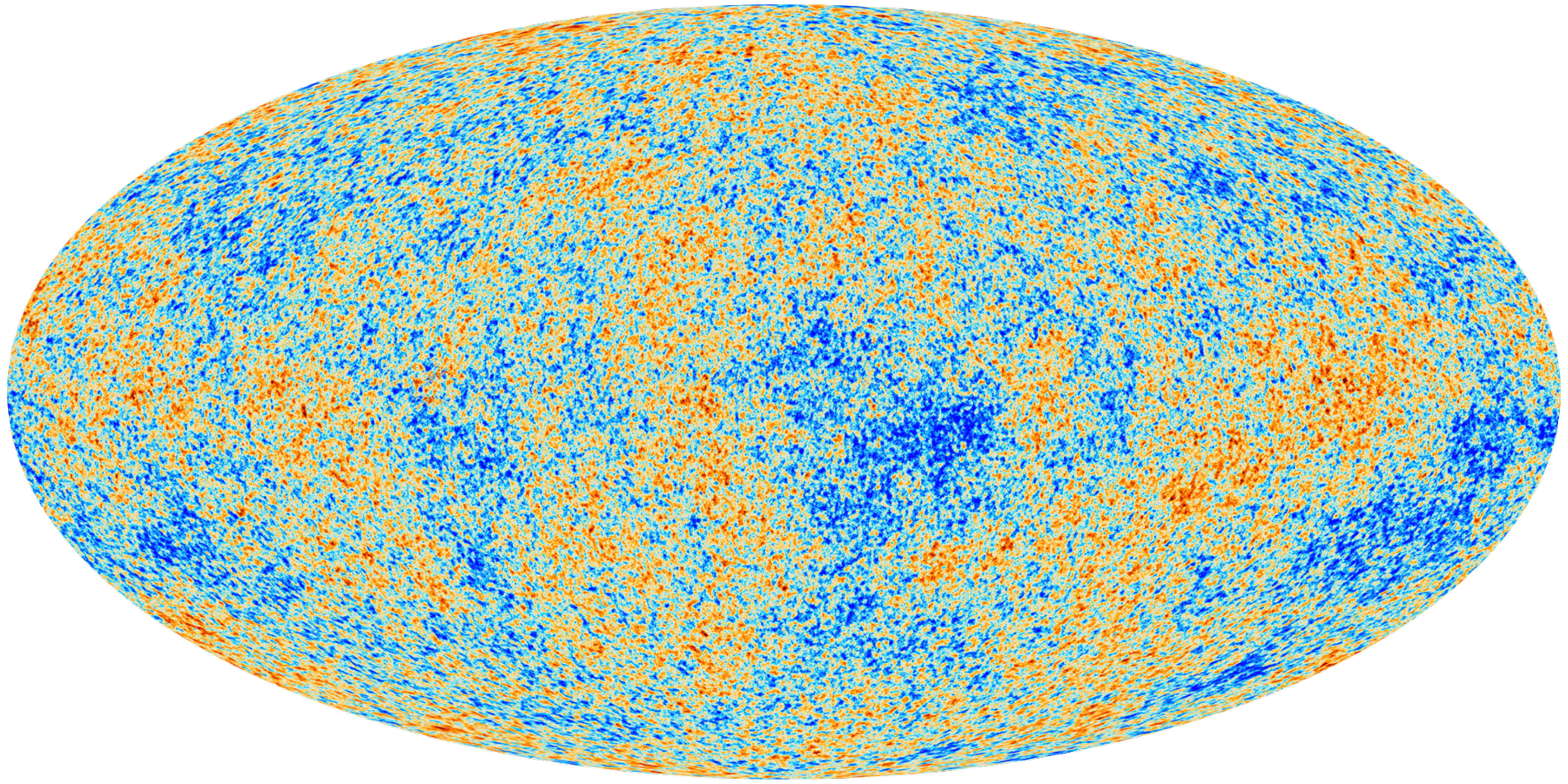

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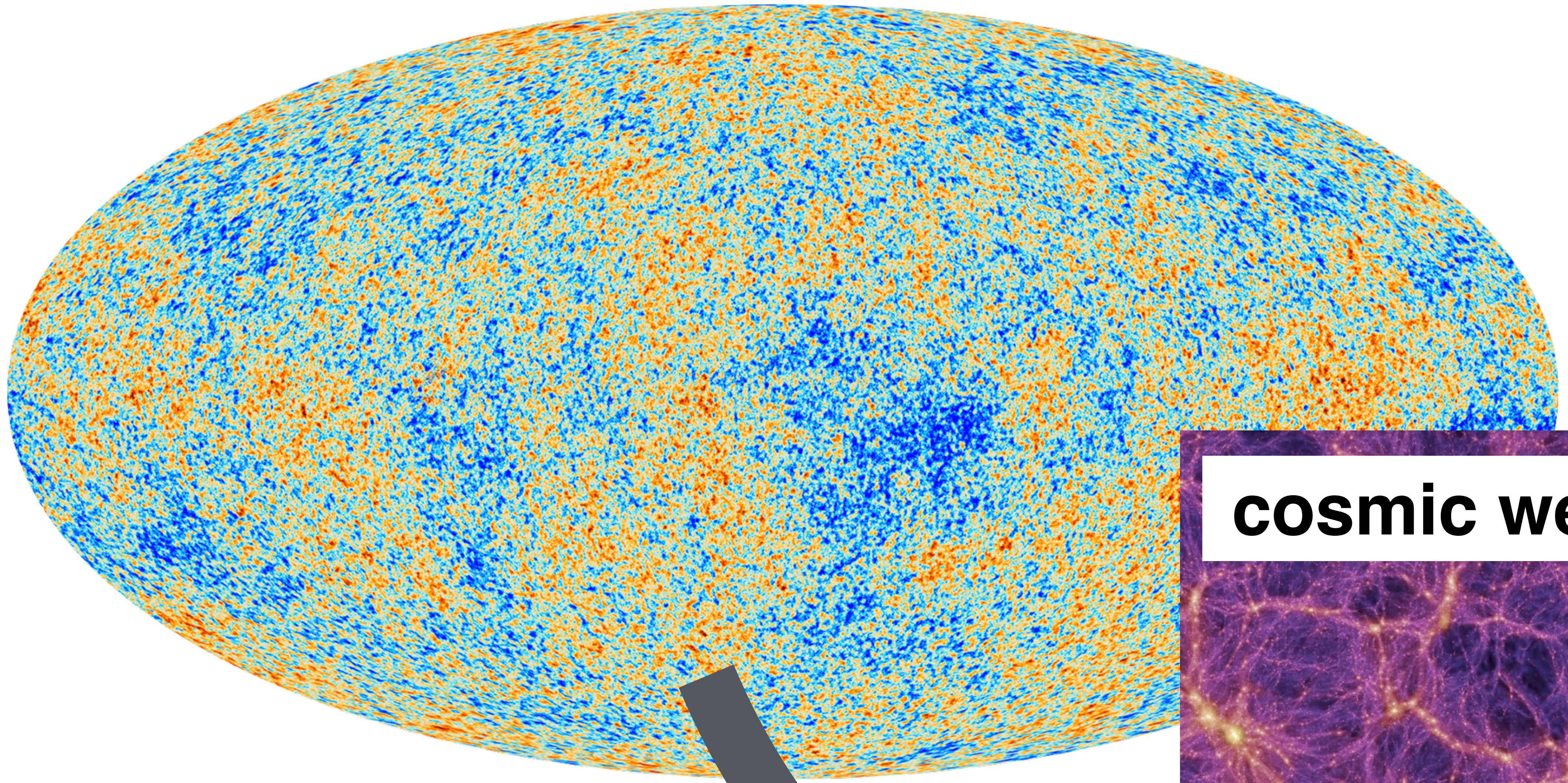
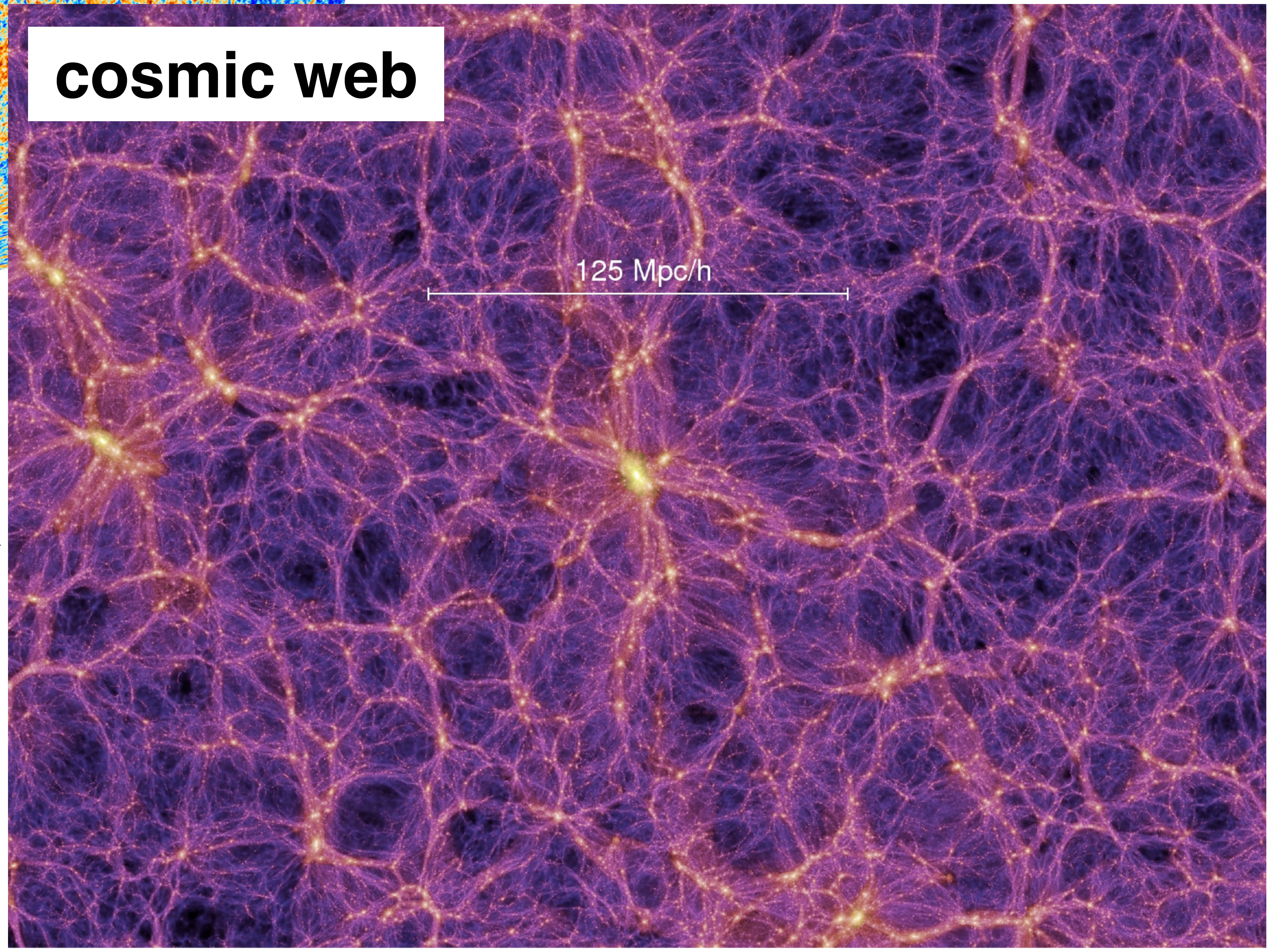


dark matter fluctuations
➜ formation of haloes



Springel et al. (2005)

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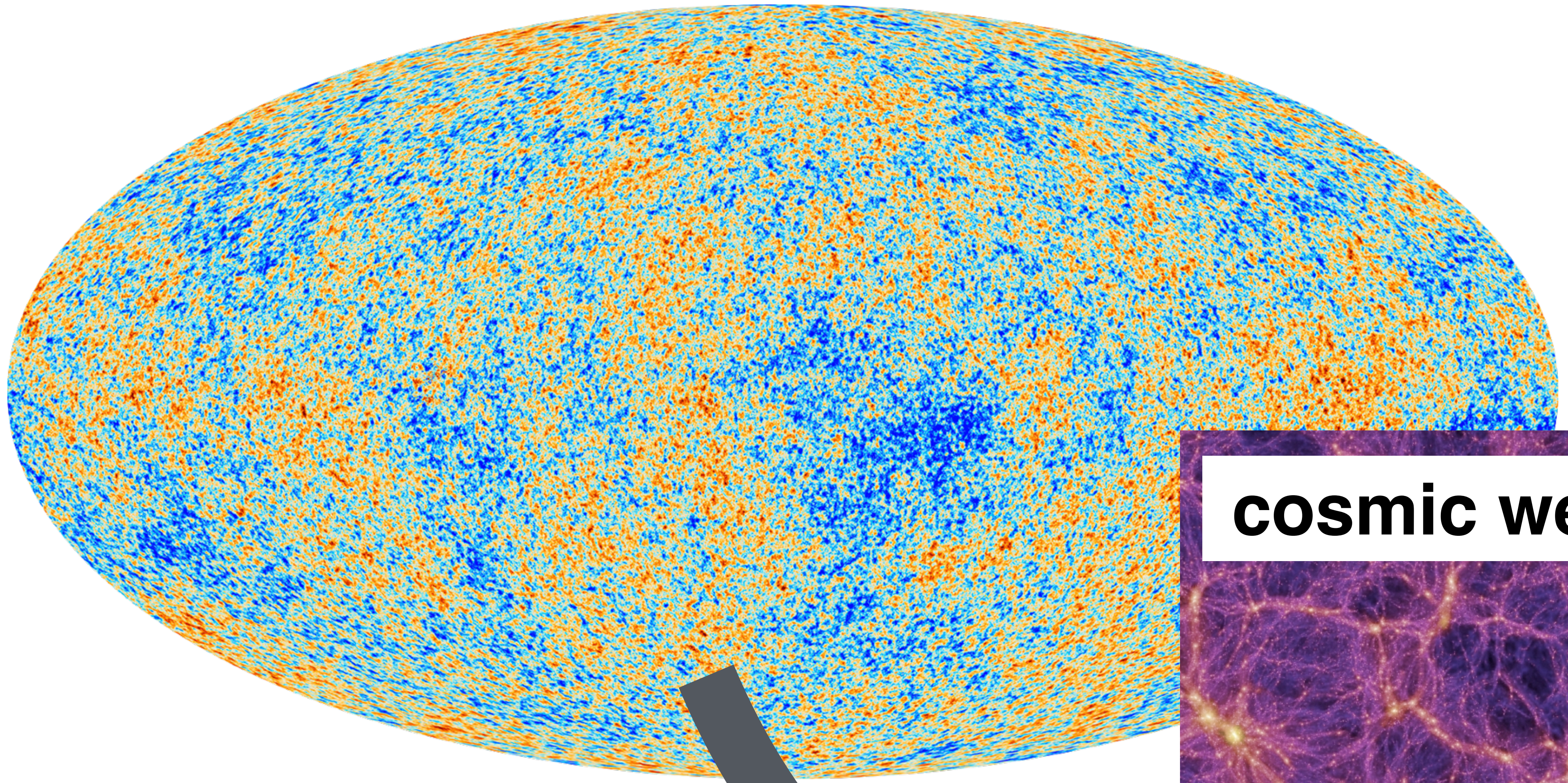

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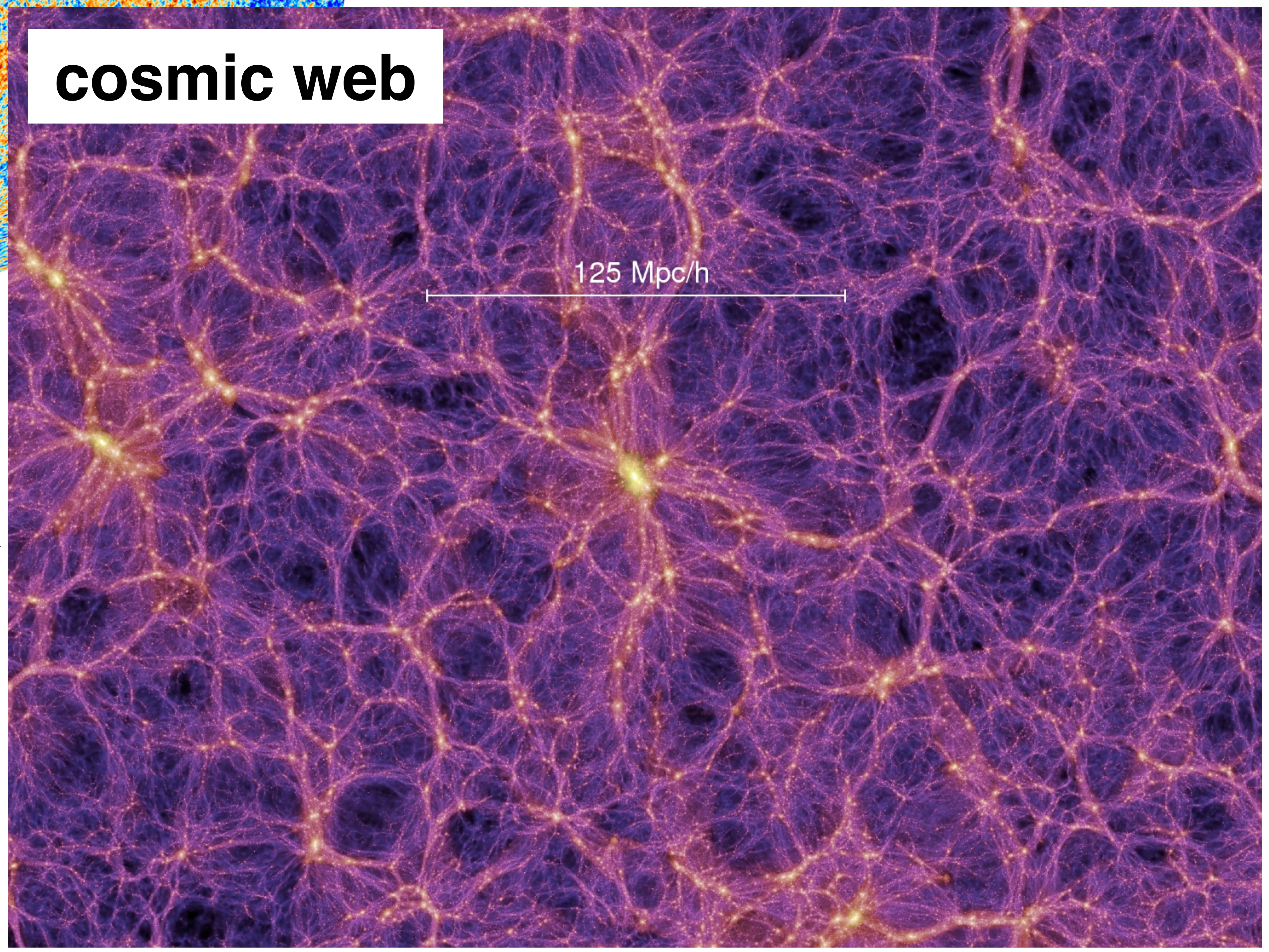
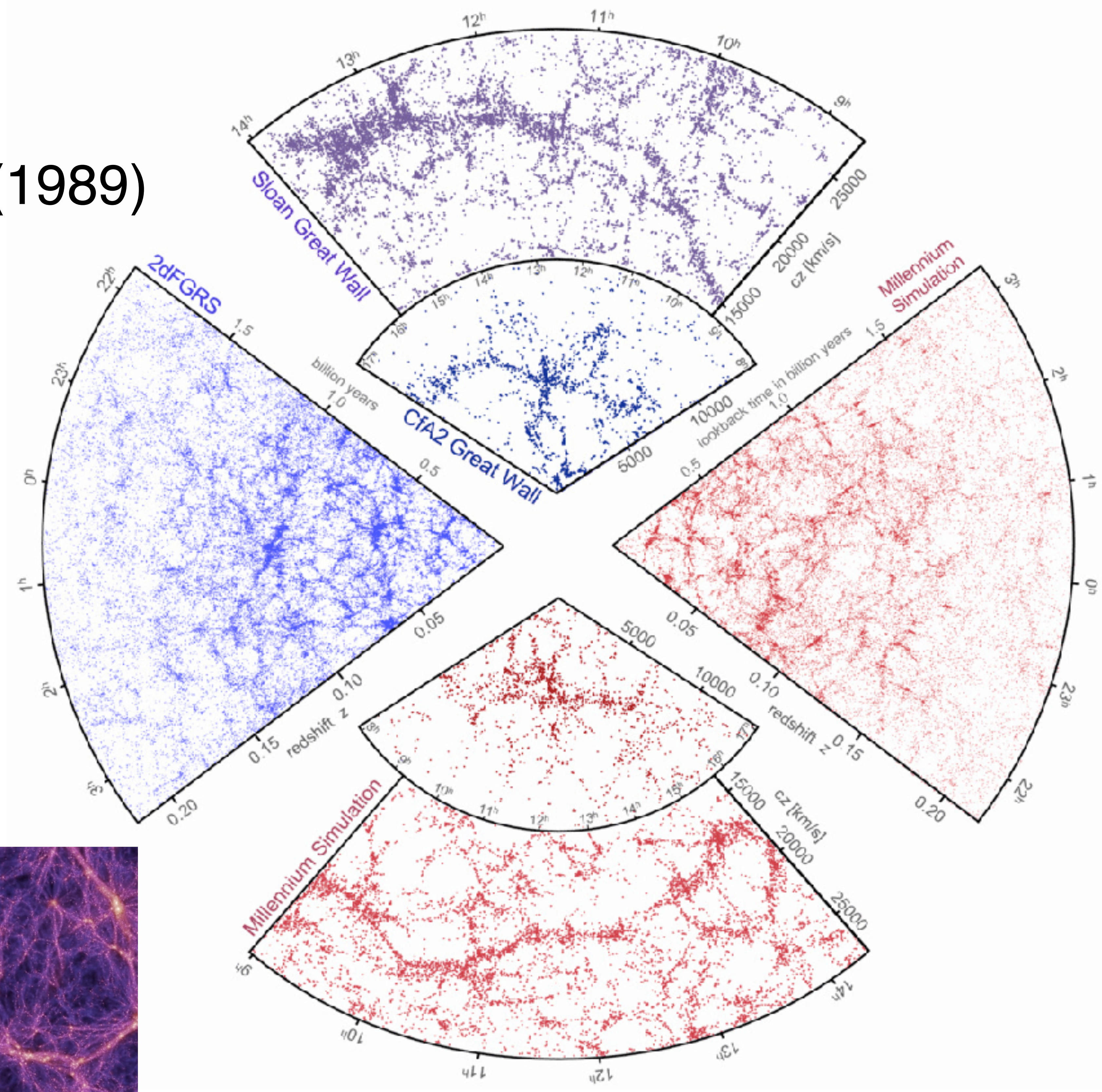


Springel et al. (2005)

Geller & Huchra (1989)



Correctly predicts the large-scale structure of the Universe

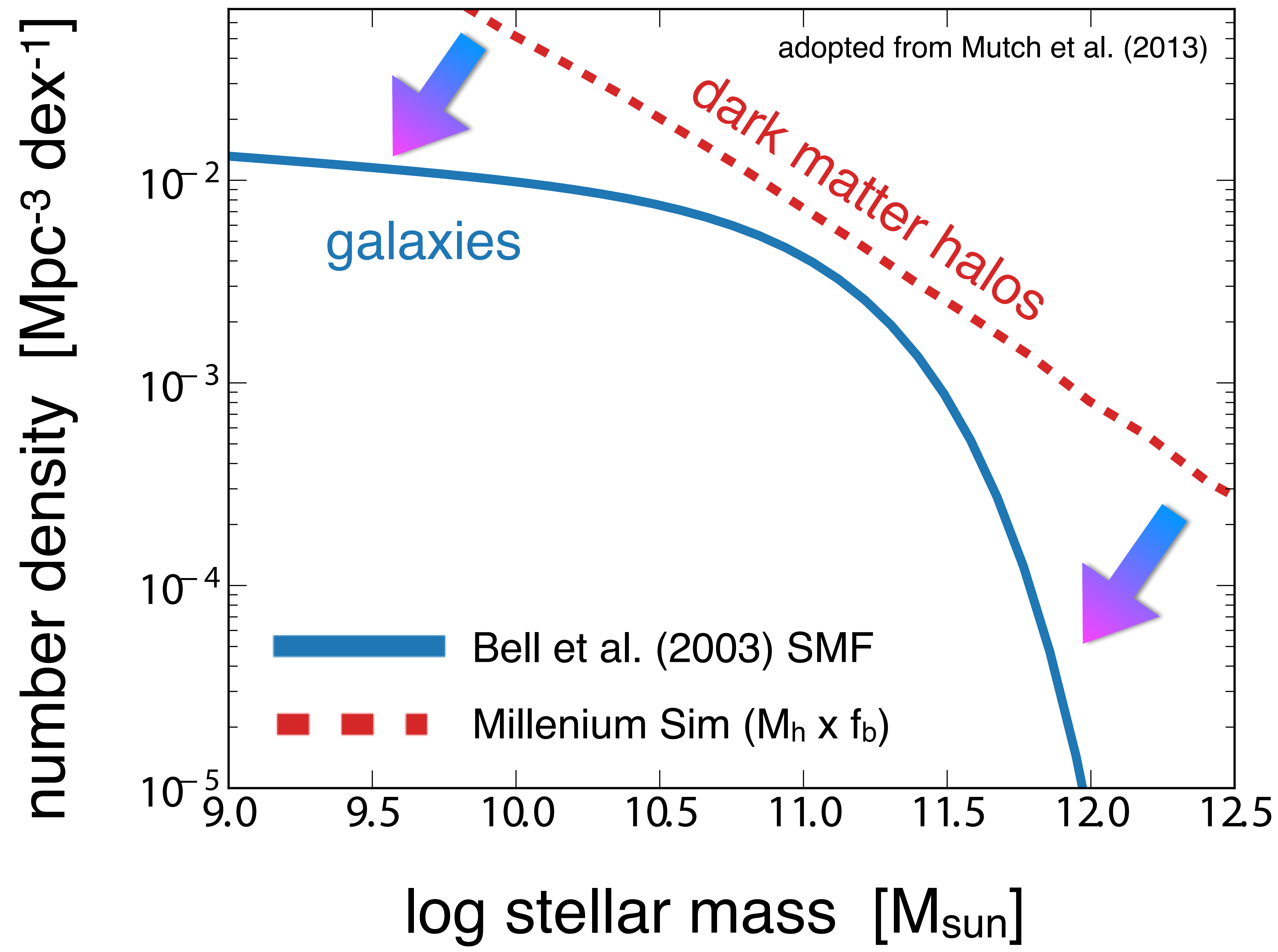

cosmic web (~Gpc)
125 Mpc/h
1 pc = 3 ly = 3x10^16 m

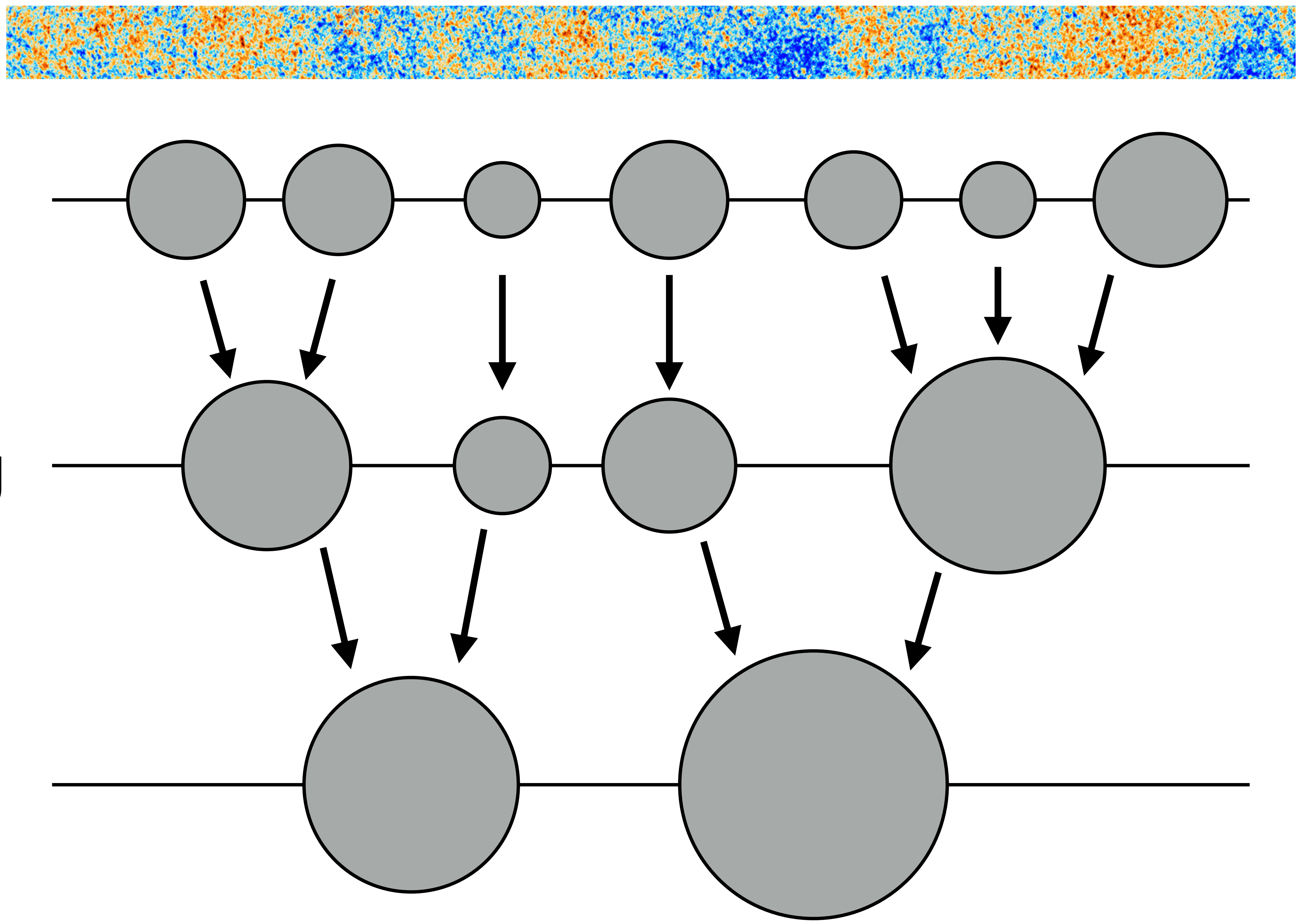
cosmic web (~Gpc)
125 Mpc/h
star formation (~pc)
dark matter halos (~Mpc)
galaxies (~kpc)
black holes (0.01pc)
1 pc = 3 ly = 3x10^16 m


cosmic web (~Gpc)
125 Mpc/h
formation and diffusion of cosmic rays
formation of stars molecular clouds
gas flow & cooling
supernova explosions
magnetic fields
stellar winds
interstellar medium
black hole activity
radiation fields
black hole growth
star formation (~pc)
dark matter halos (~Mpc)
galaxies (~kpc)
black holes (0.01pc)
1 pc = 3 ly = 3x10^16 m

Paradigm of galaxy formation

1) Growth of dark matter fluctuations
2) Baryons “follow” dark matter, cool and form stars
3) Feedback from stars and black holes prevent overcooling



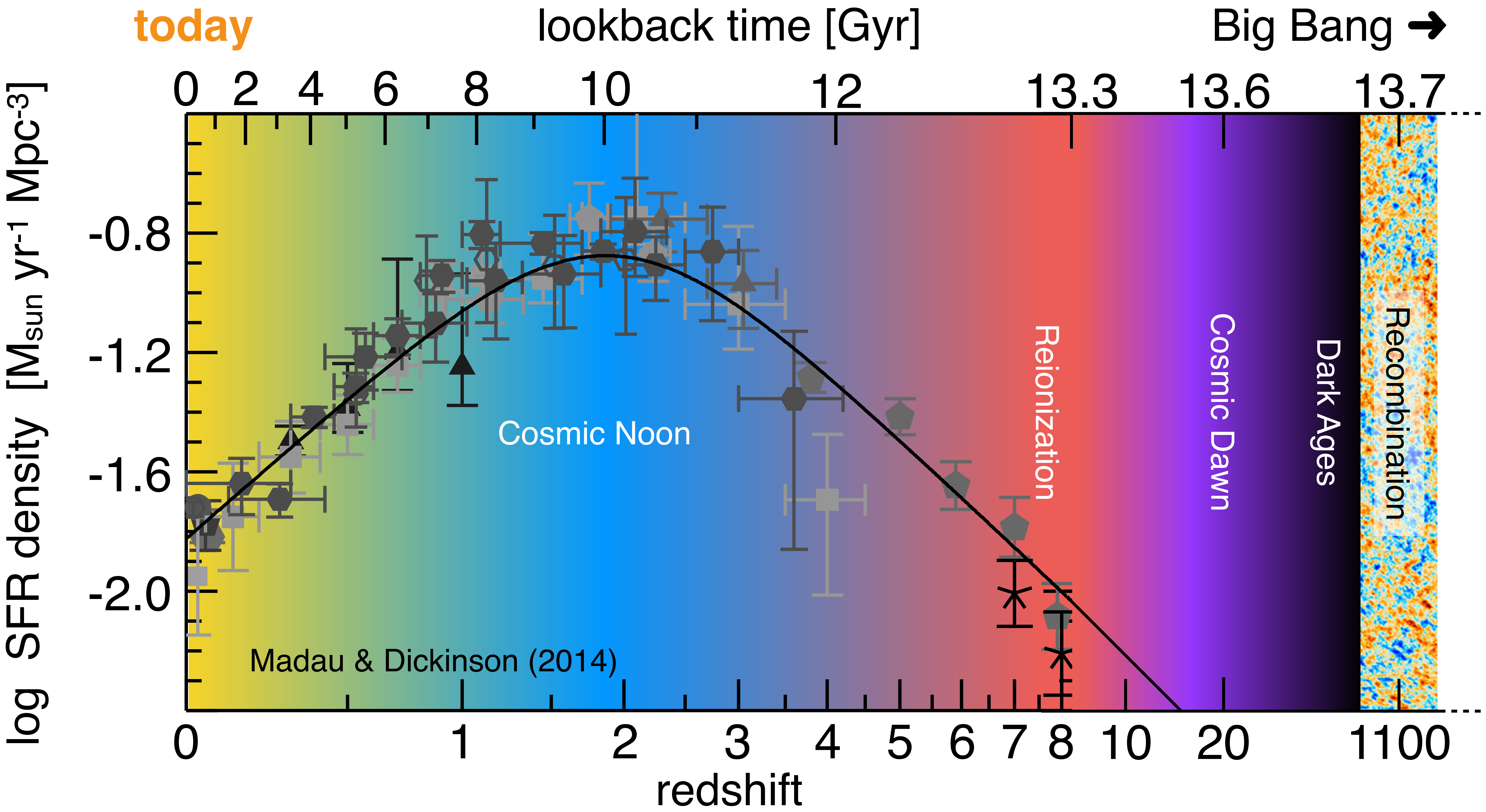


galaxies probe dark matter via structure formation (and via lensing and DM-baryon interactions)

➜ baryonic physics cannot be ignored

➜ galaxy growth needs to be regulated, i.e. inefficient star formation at low and high halo masses

Star formation in the Universe



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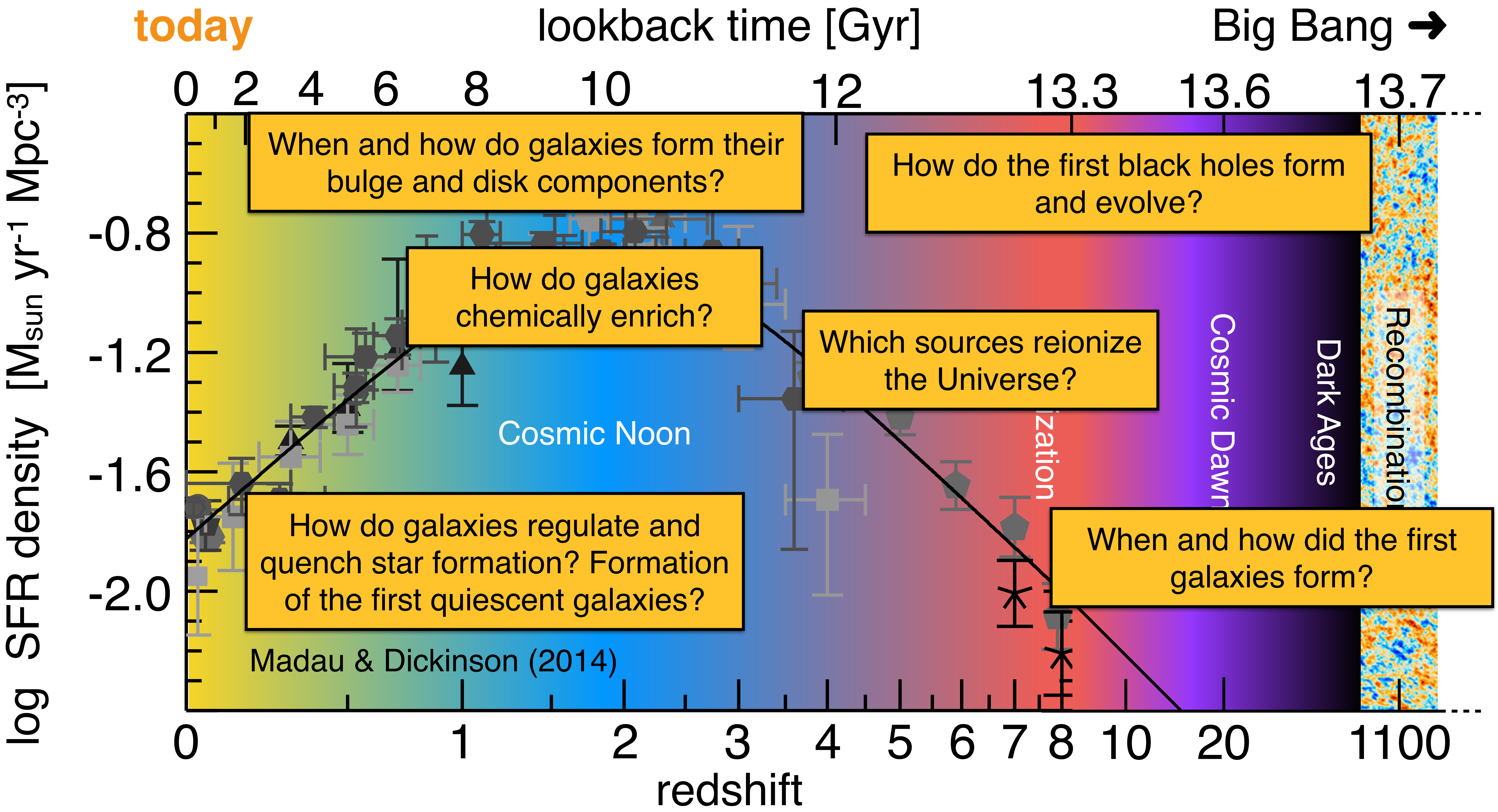

James Webb Space Telescope (JWST) the next generation space telescope

- mission duration: >10 years
- cost: 10 billion US-$
- 4 science instruments
  - NIRCam (0.6-5 µm)
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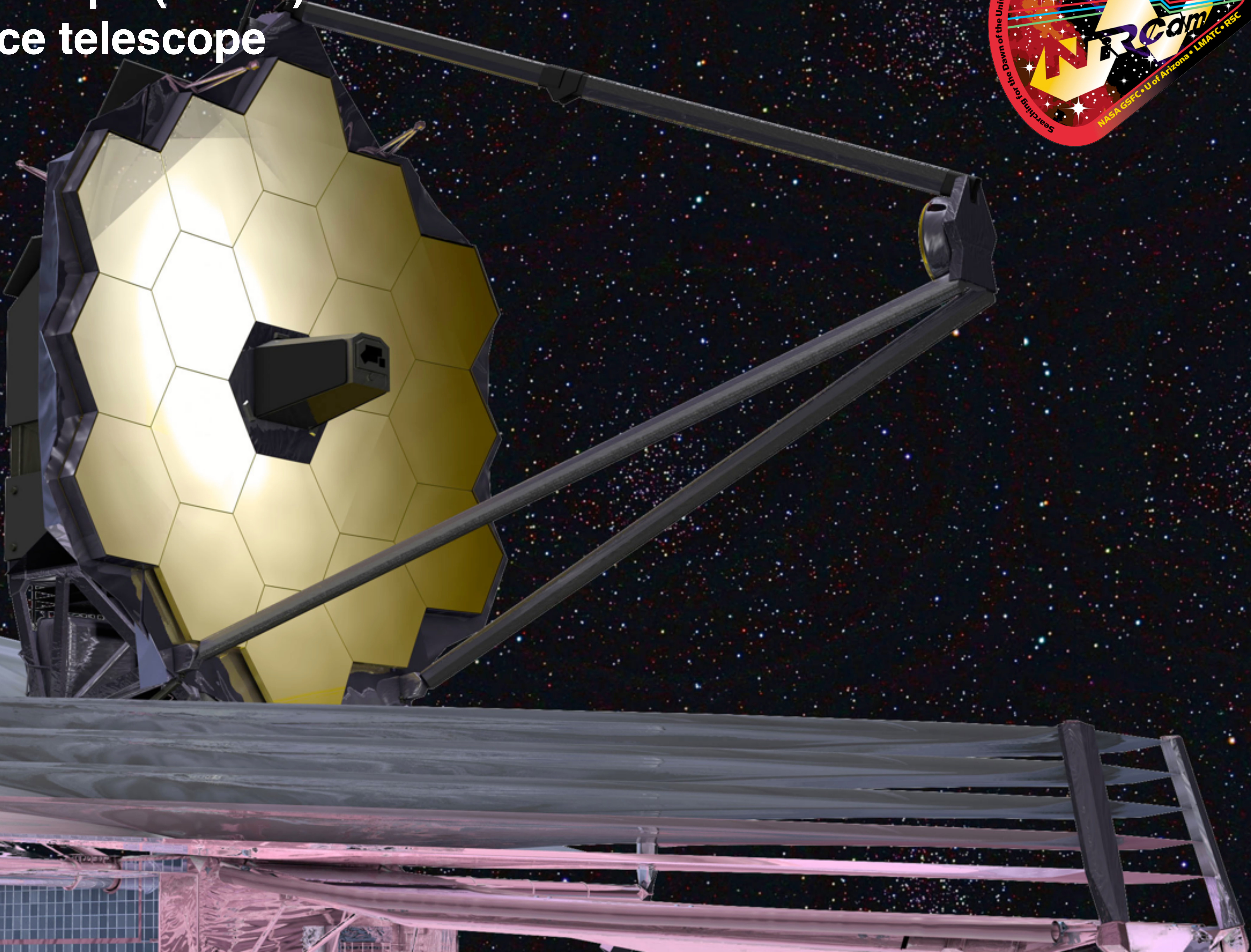
  - MIRI (5-30 µm)
  - NIRISS (0.6-2.5 µm)
- I am team member of the NIRCam science team



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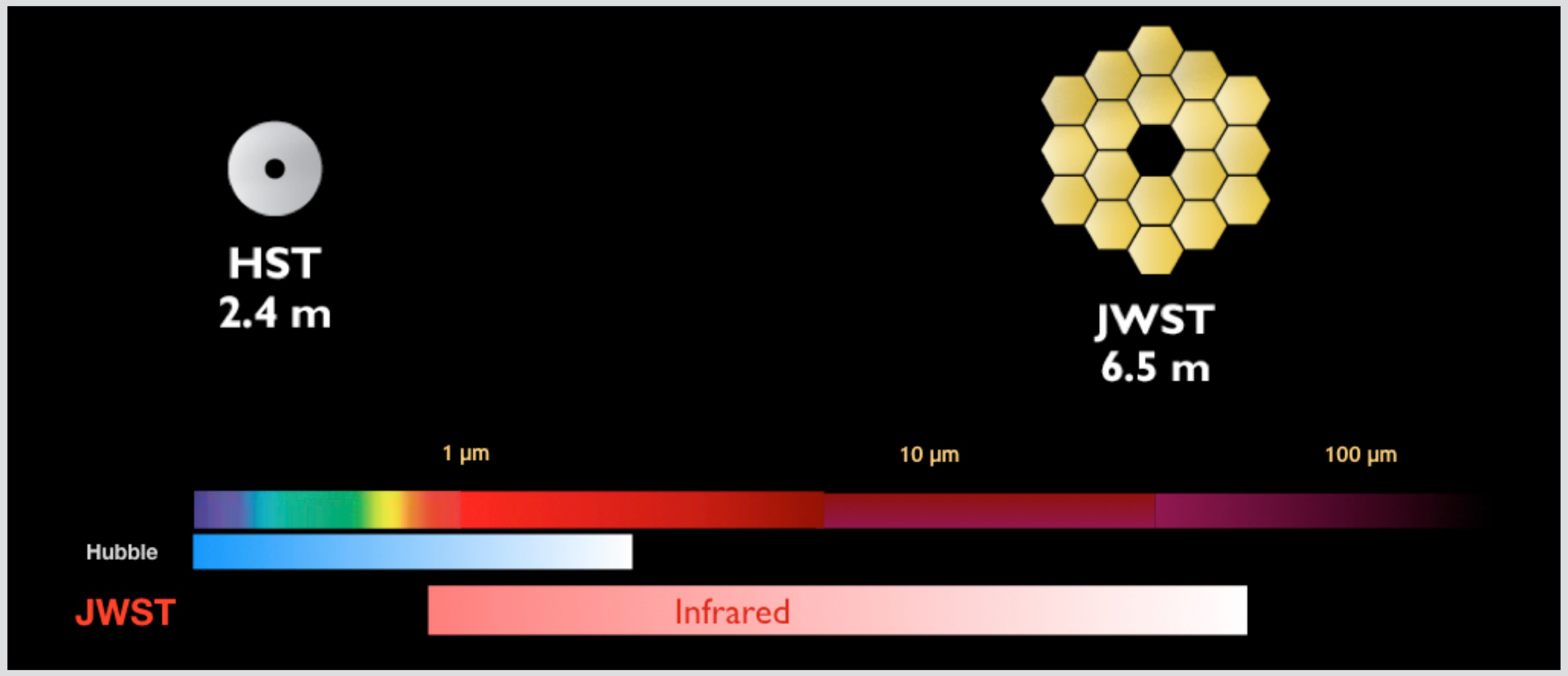
+ spectroscopy!



Extragalactic Surveys in Cycle 1 & 2

List of surveys (incomplete):

JADES (GTO; Eisenstein+23a)
JADES Origins Field (GO; Eisenstein+23b)
JEMS (GO; Williams, Tacchella+23)

PEARLS (GTO; Windhorst+23)

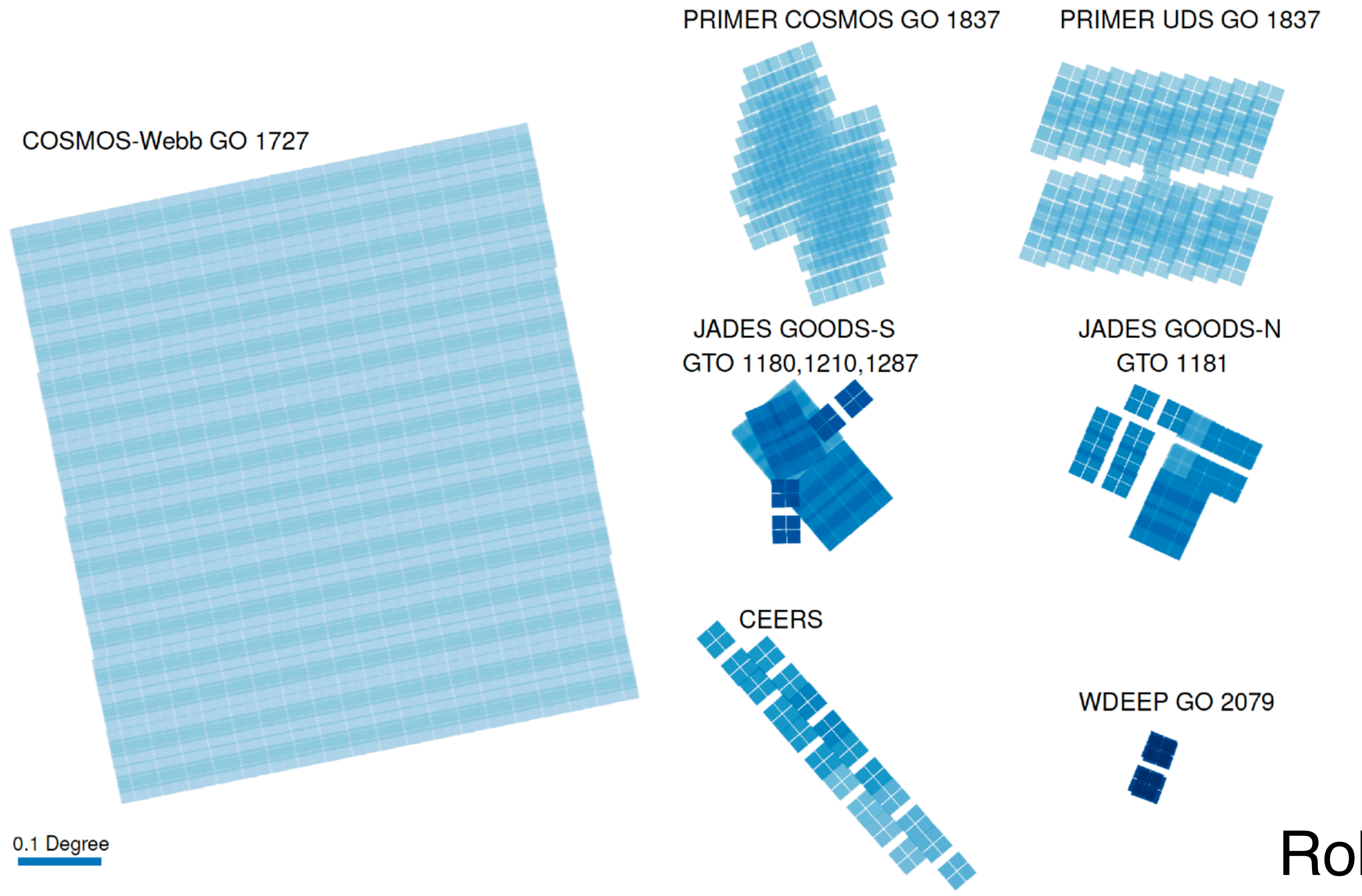
CEERS (ERS; Finkelstein+ in prep.)

GLASS (ERS; Treu+23)

COSMOS-Web (GO; Casey+23)

NGDEEP (GO; Leung+23)

UNCOVER (GO; Bezanson+22)



Robertson (2022)

➜ large diversity of pointings, depths, filters
(and spectroscopic component)

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Synergy photometry & spectroscopy (Eisenstein+23)

DR: Rieke+23, Bunker+23, D'Eugenio+24, Eisenstein+24

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DR: Rieke+23, Bunker+23, D'Eugenio+24, Eisenstein+24

<u>in Cambridge:</u> Maiolino (NIRSpec) & Tacchella (NIRCam)


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SURVEY
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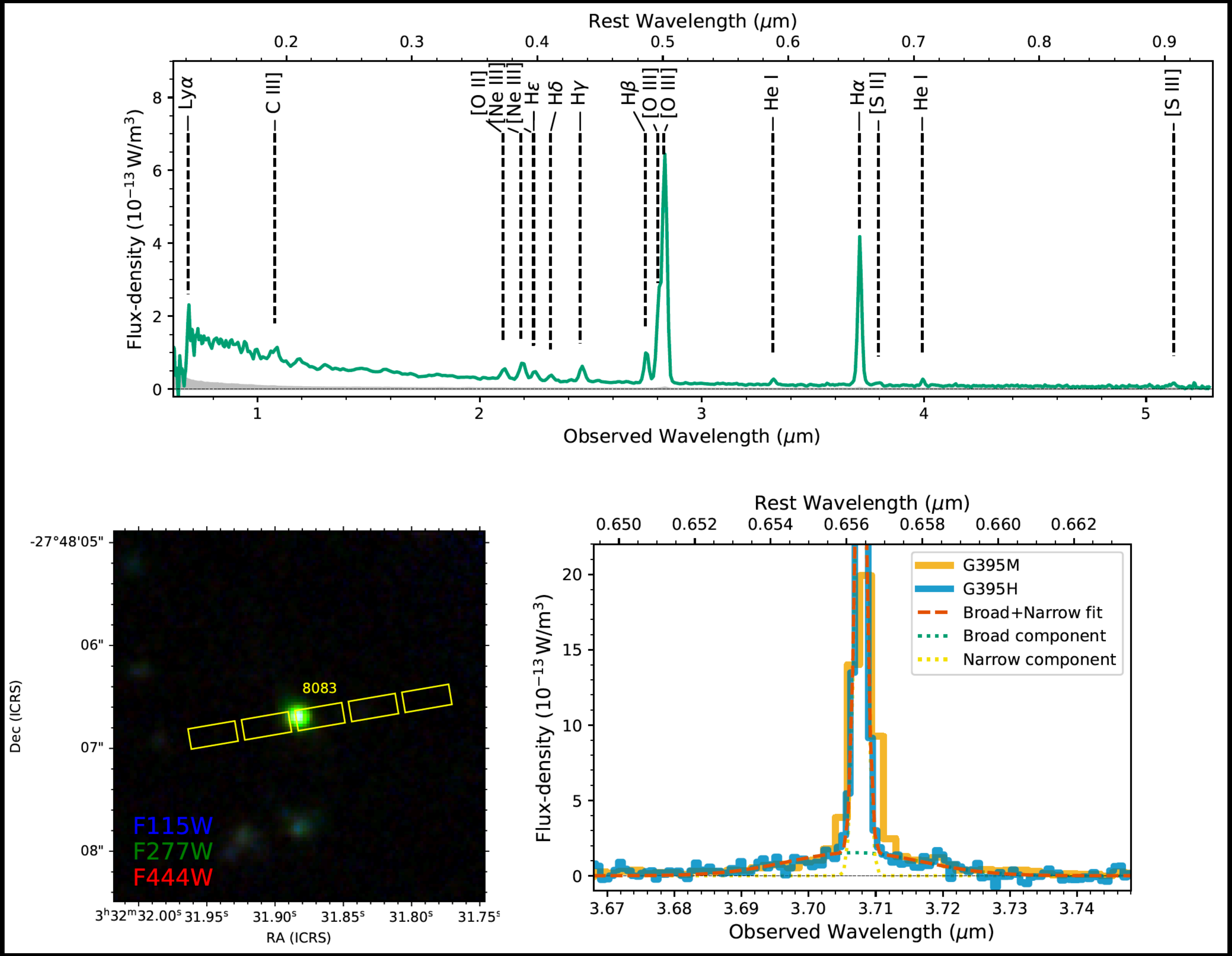
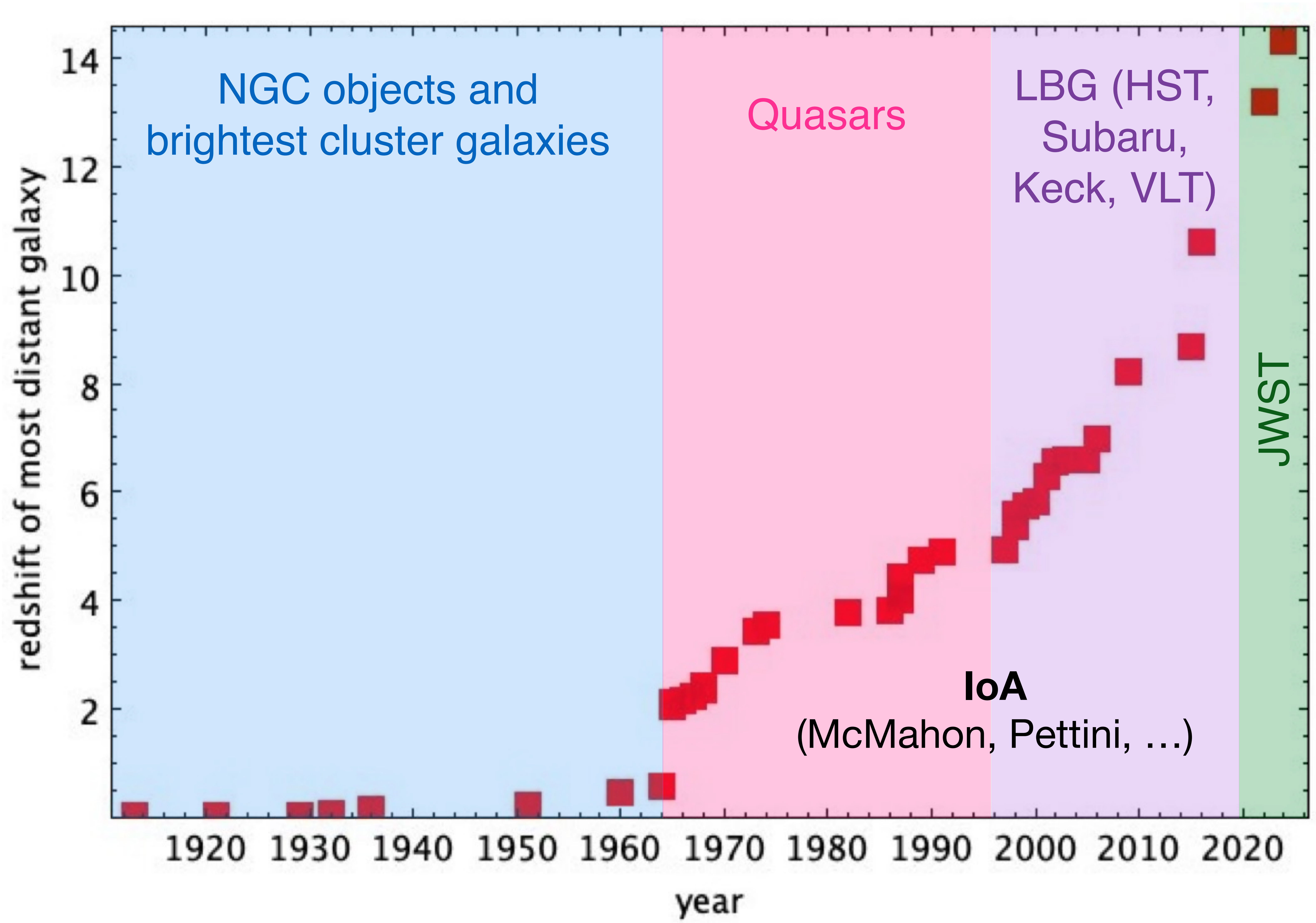
JADES · JWST ADVANCED DEEP EXTRAGALACTIC SURVEY ·
JADES NIRCam
3"
F090W F200W F444W
JADES (Eisenstein+ 2023)

Example spectra for a z = 4.65 galaxy from the JADES Deep/HST observations



JADES (Eisenstein+ 2023)

Redshift frontier with JWST



JADES team
adopted from S. Carniani

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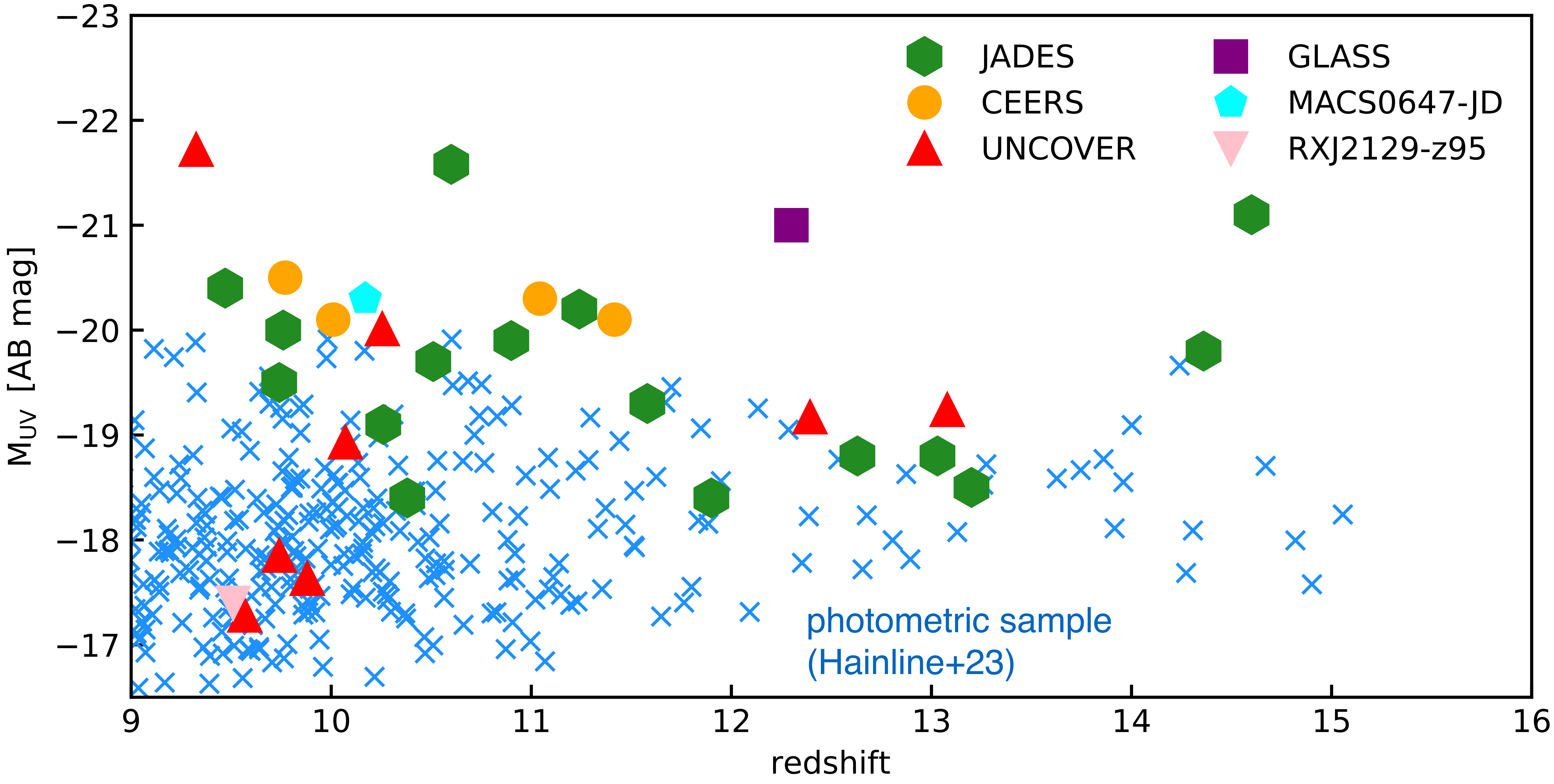
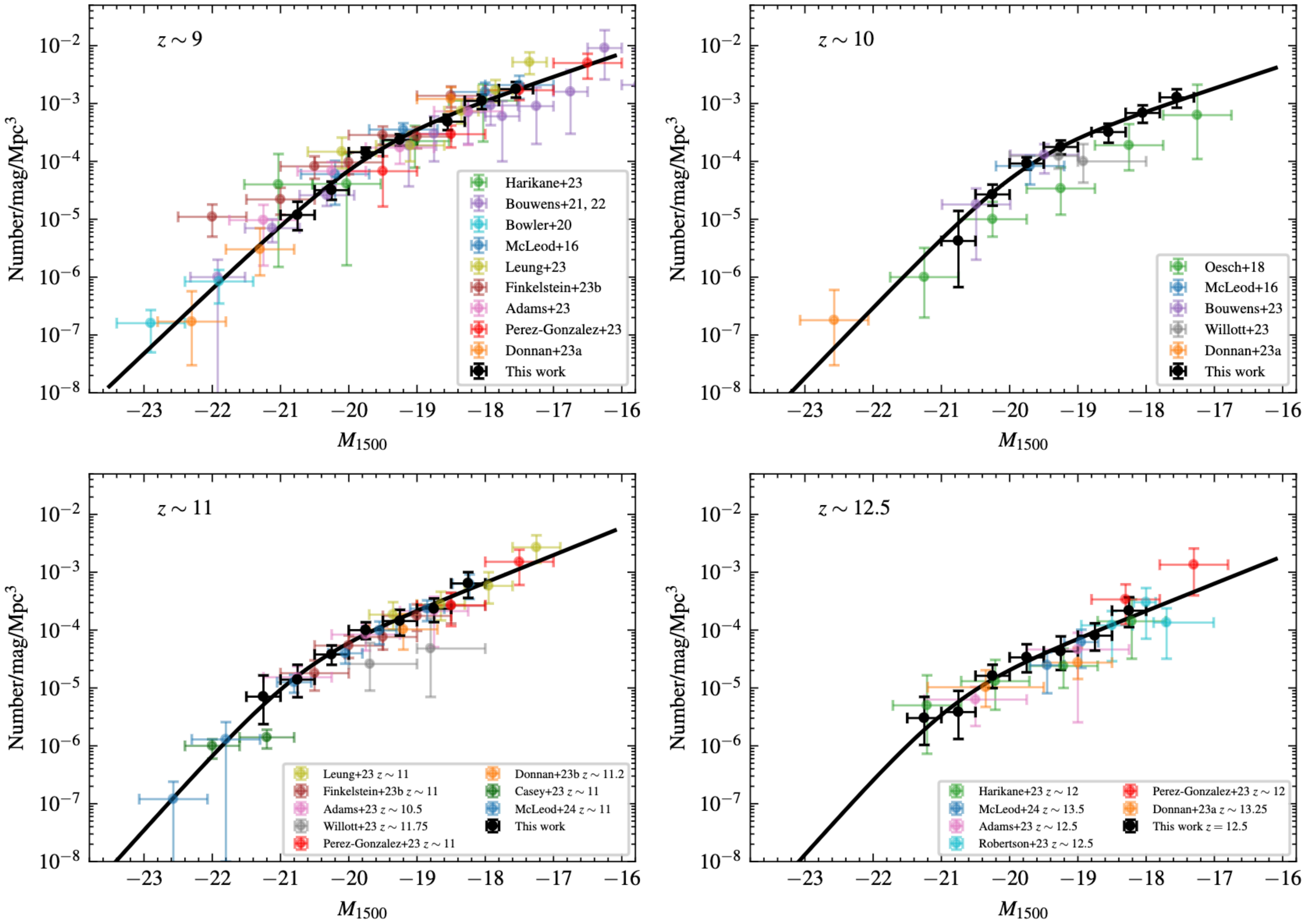


Abundance of galaxies in the first 500 Myr



bright-end of UV LF remarkably constant

Donnan+24

Over-abundance of galaxies in the first 500 Myr

- large number of groups constrained the UV LF and luminosity density at z>8:
  Finkelstein+22; Castellano+22; Naidu+23; Adams+23; Atek+23; Austin+23; Donnan+23; Hainline+23; Harrikane+23; McLeod+23
- bright-end of UV LF remarkably constant, with luminosity density >2× larger than using constant star formation efficiency models

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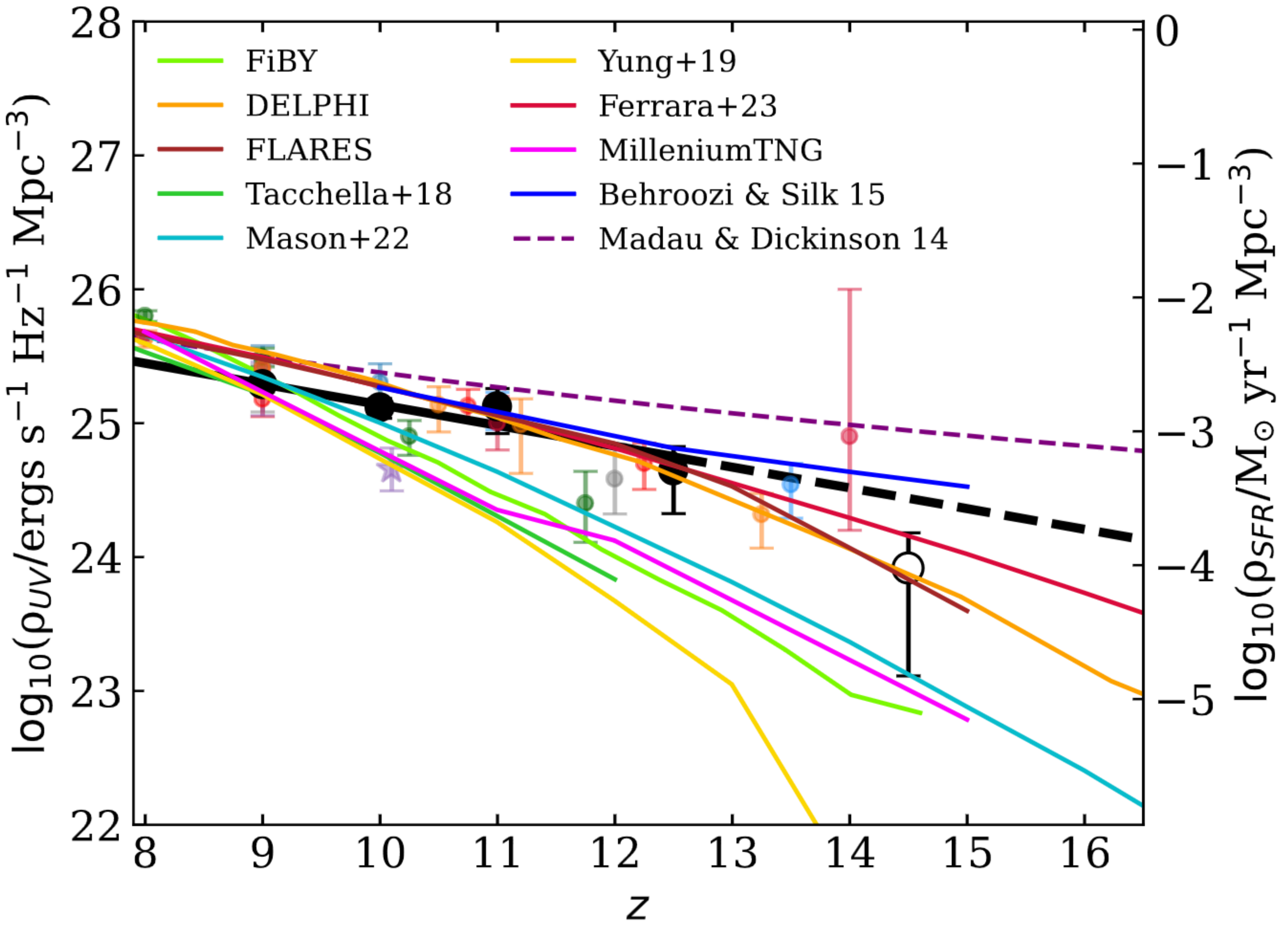

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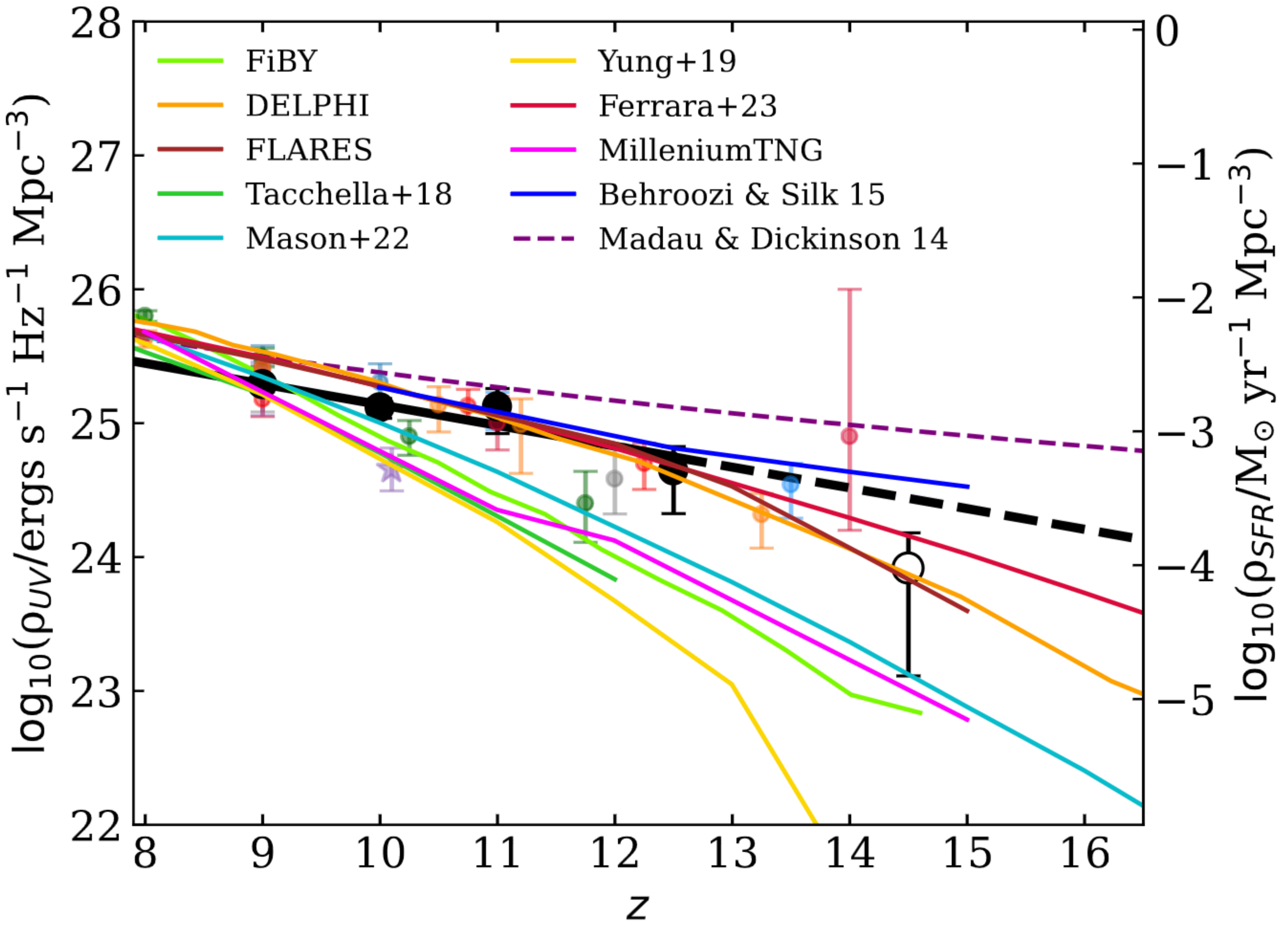
- Challenges:
  - selection techniques: same data ➜ different candidates!
  - comparison to models

Donnan+24



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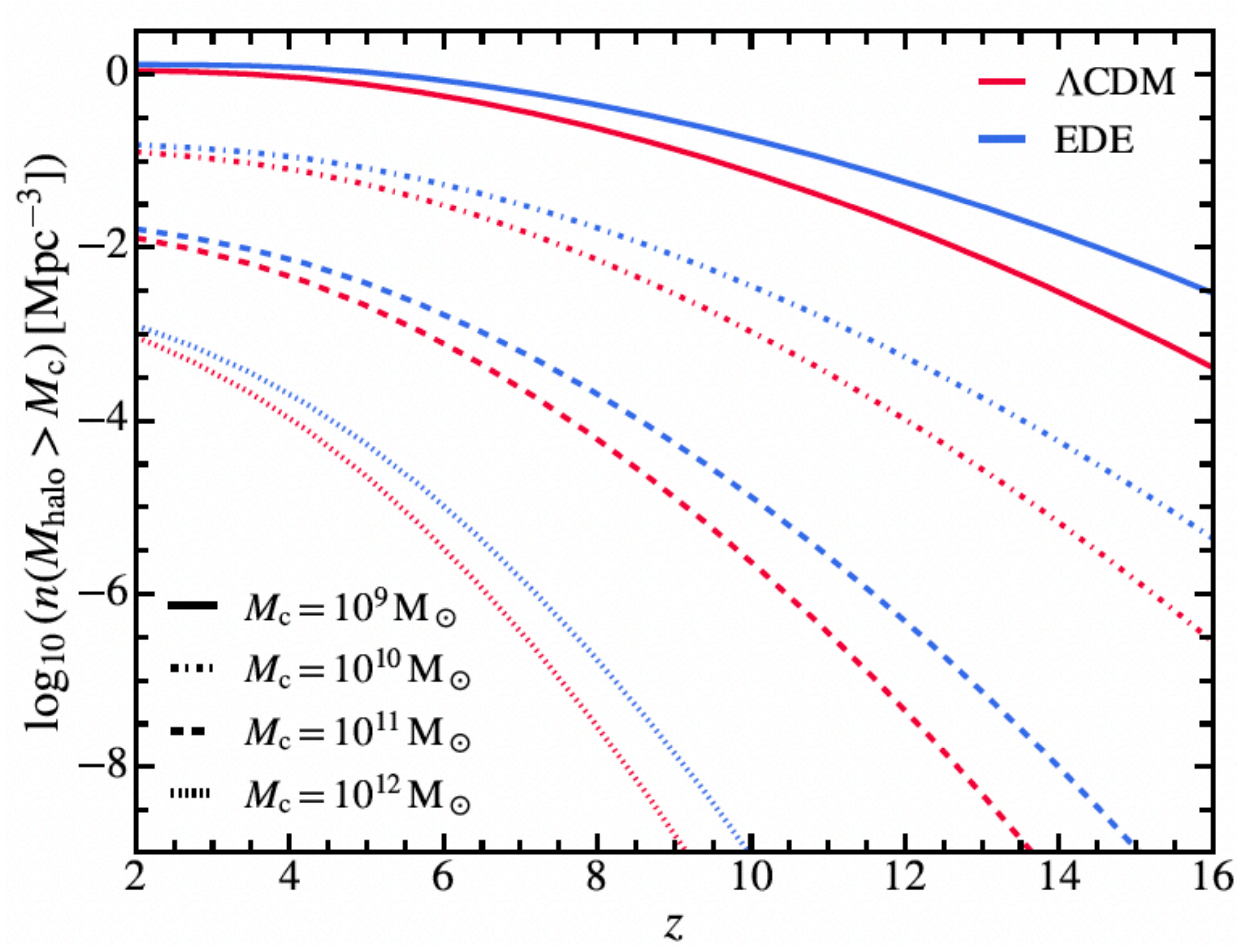
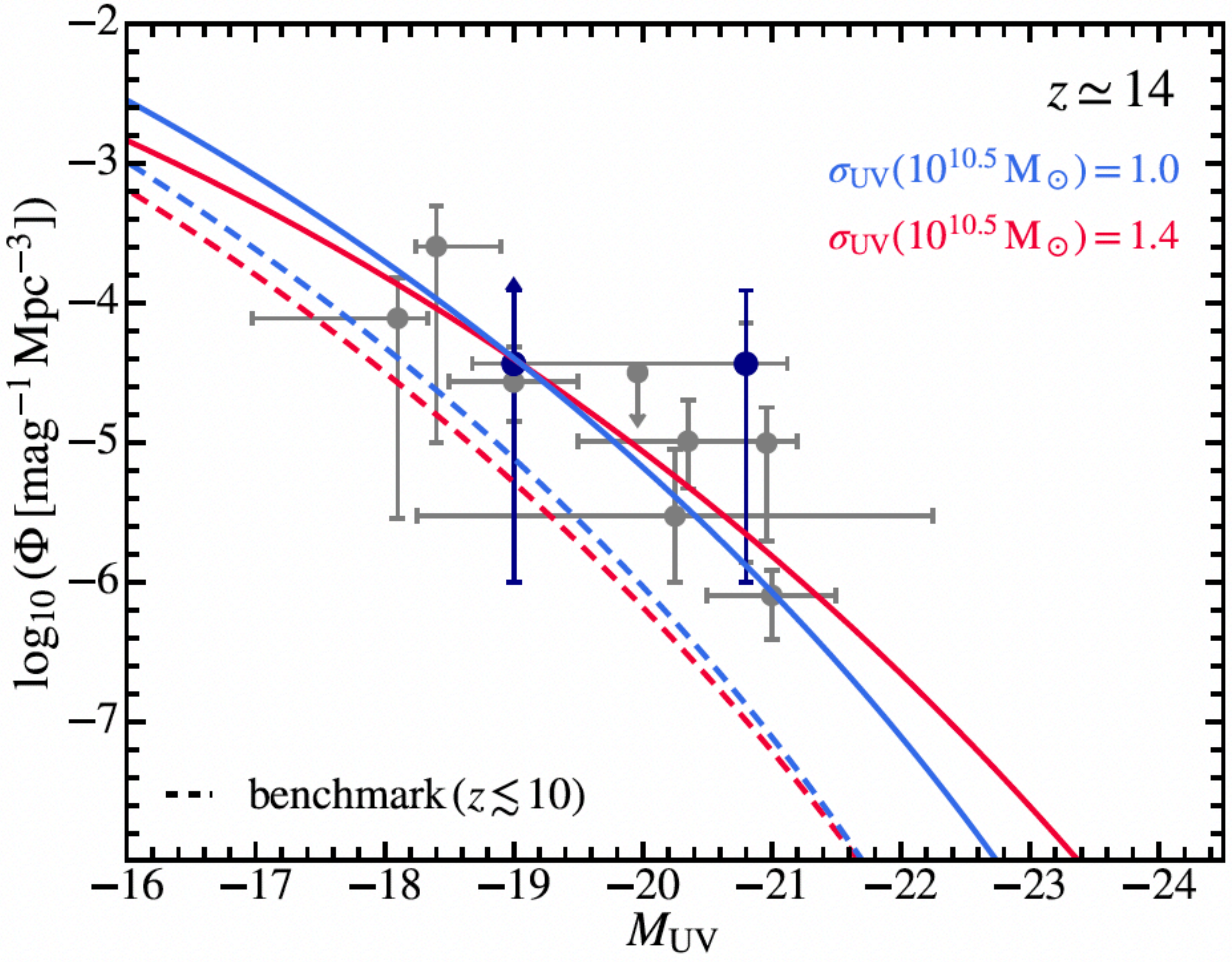
  ➜ but degeneracy with baryonic physics (Khimey, Bose & Tacchella 21)

Over-abundance of galaxies in the first 500 Myr

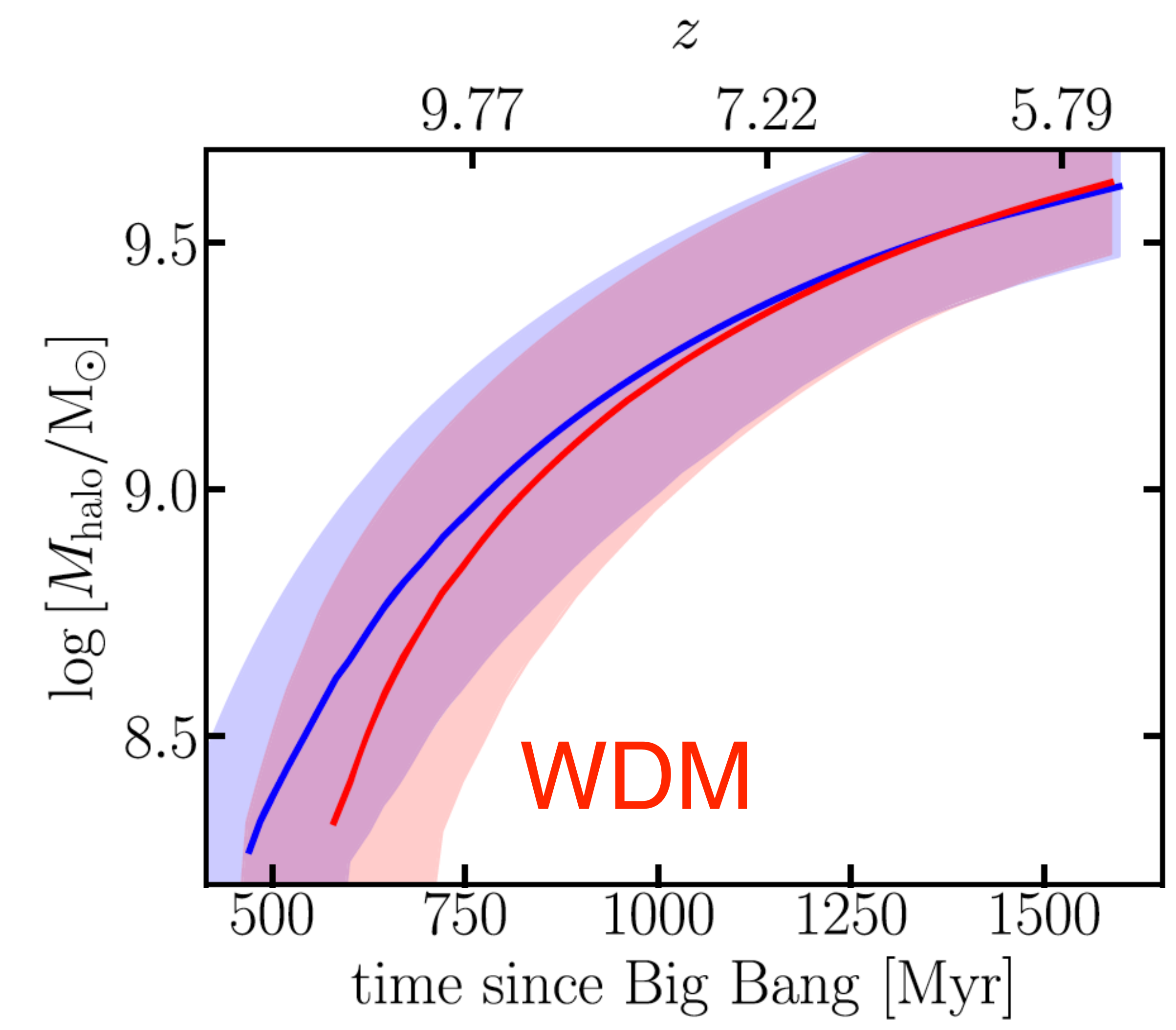
- Hubble tension (see review by Abdalla+ 22):
  discrepancy between inferences of the current expansion rate of the Universe based on CMB and directly measuring the expansion locally from supernovae
- increased expansion at early times is “Early Dark Energy” (EDE) can solve the Hubble tension…
  … and it also increases the number of dark matter halos



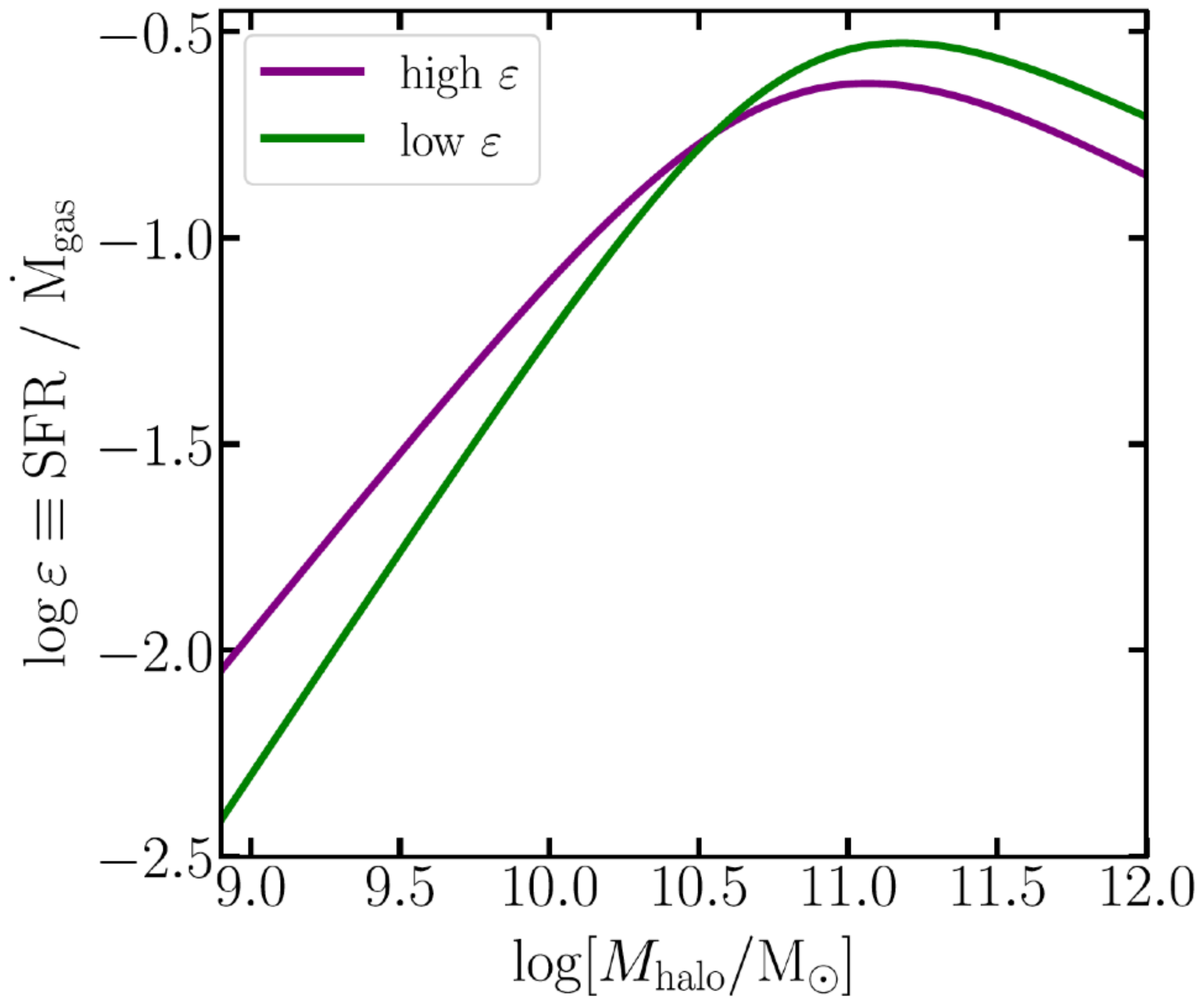


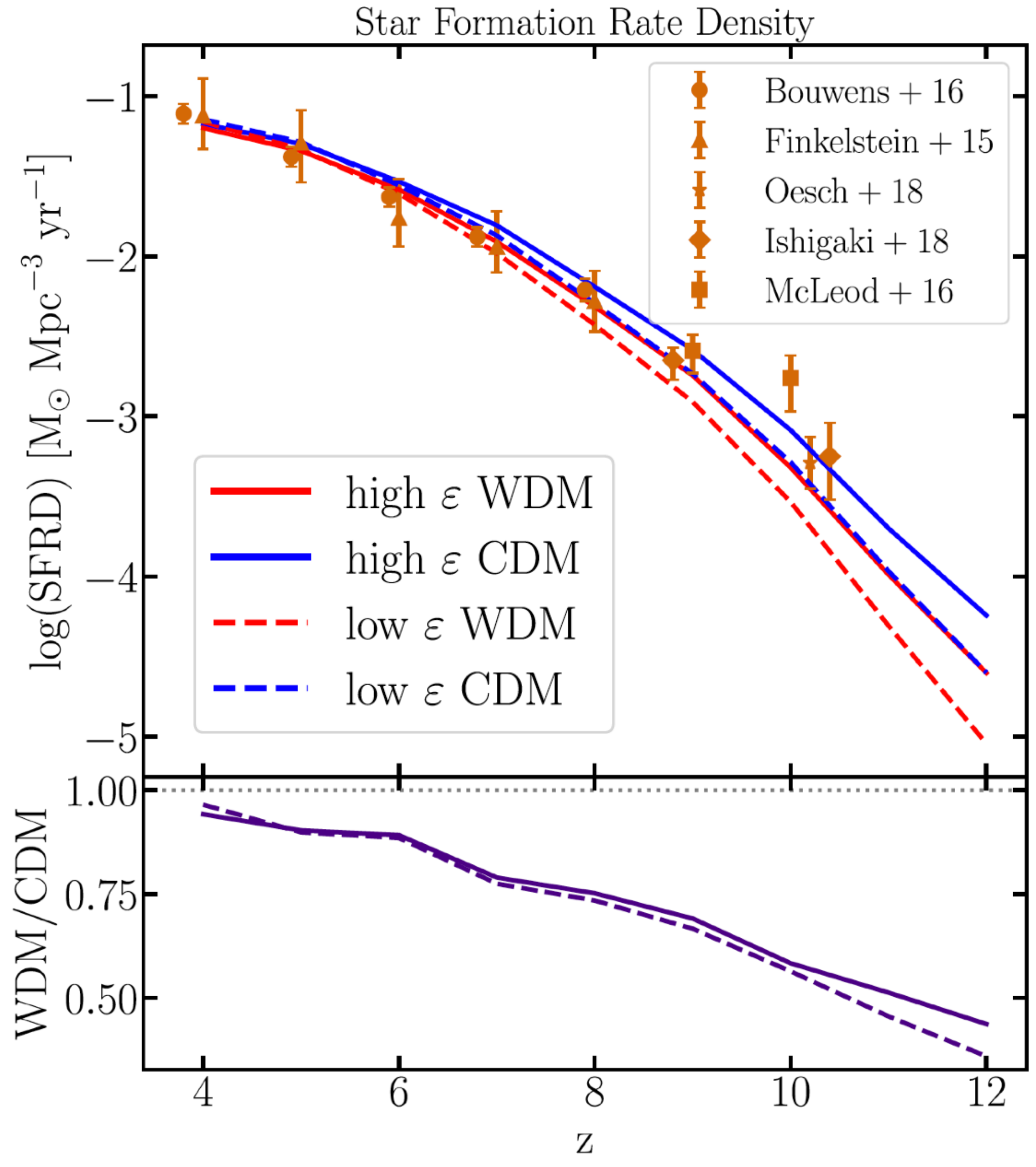
Khimey, Bose & Tacchella (2021)

Over-abundance of galaxies in the first 500 Myr



- Explore the impact of Warm Dark Matter (WDM) on the first galaxies
- WDM: 7 keV sterile neutrino
- Vary star-formation efficiency in low mass dark matter halos





Our results suggest that it is challenging to constrain the nature of dark matter, because their is a degeneracy between the baryonic physics and the dark matter model!

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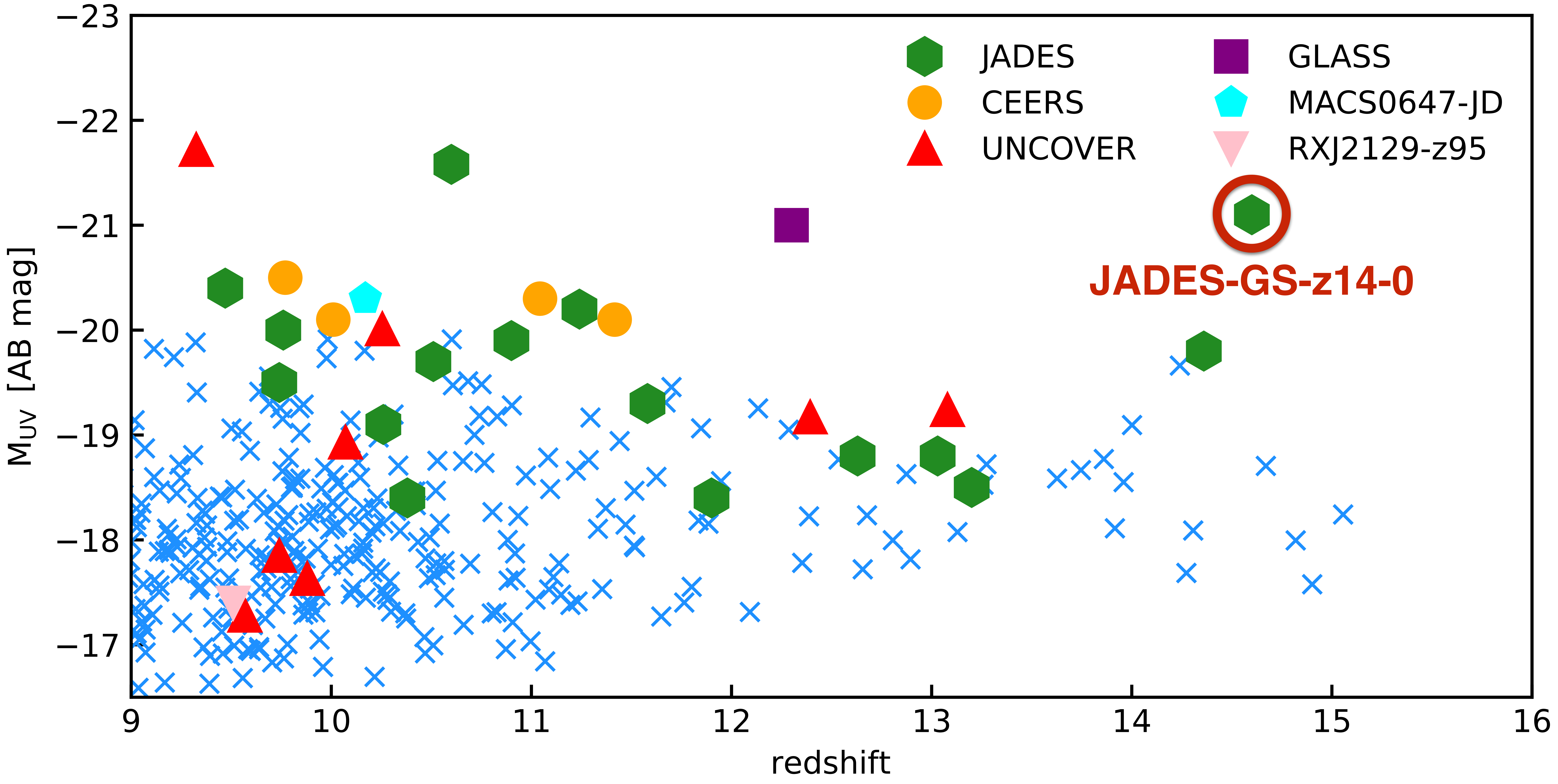
  - vary initial mass function (IMF) at high redshifts (Inayoshi+22; Cueto+24; Trinca+24; Ventura+24)
  - non stellar sources (e.g. AGN; dark stars; Inayoshi+22; Trinca+24; Hegde+24; Ilie+23)

Frontiers with JWST



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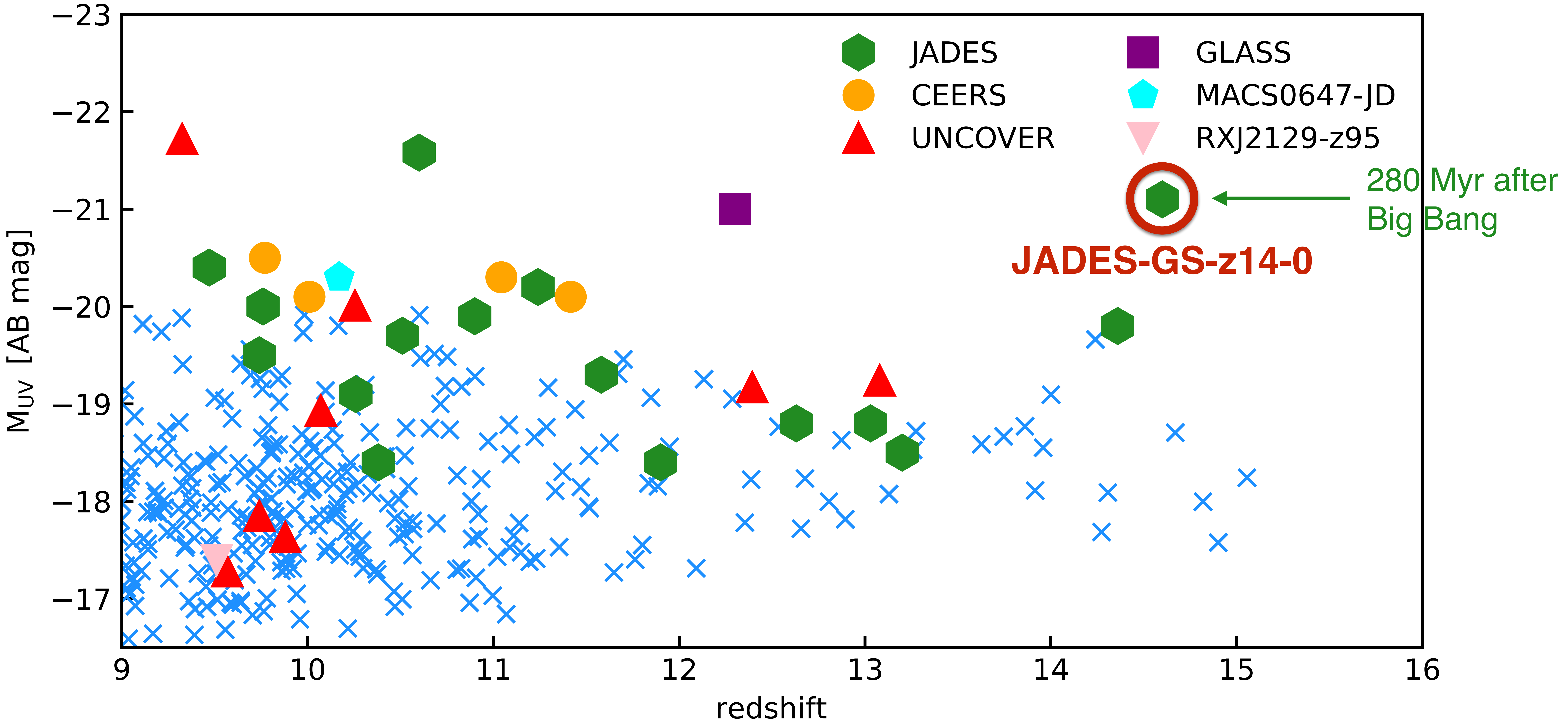
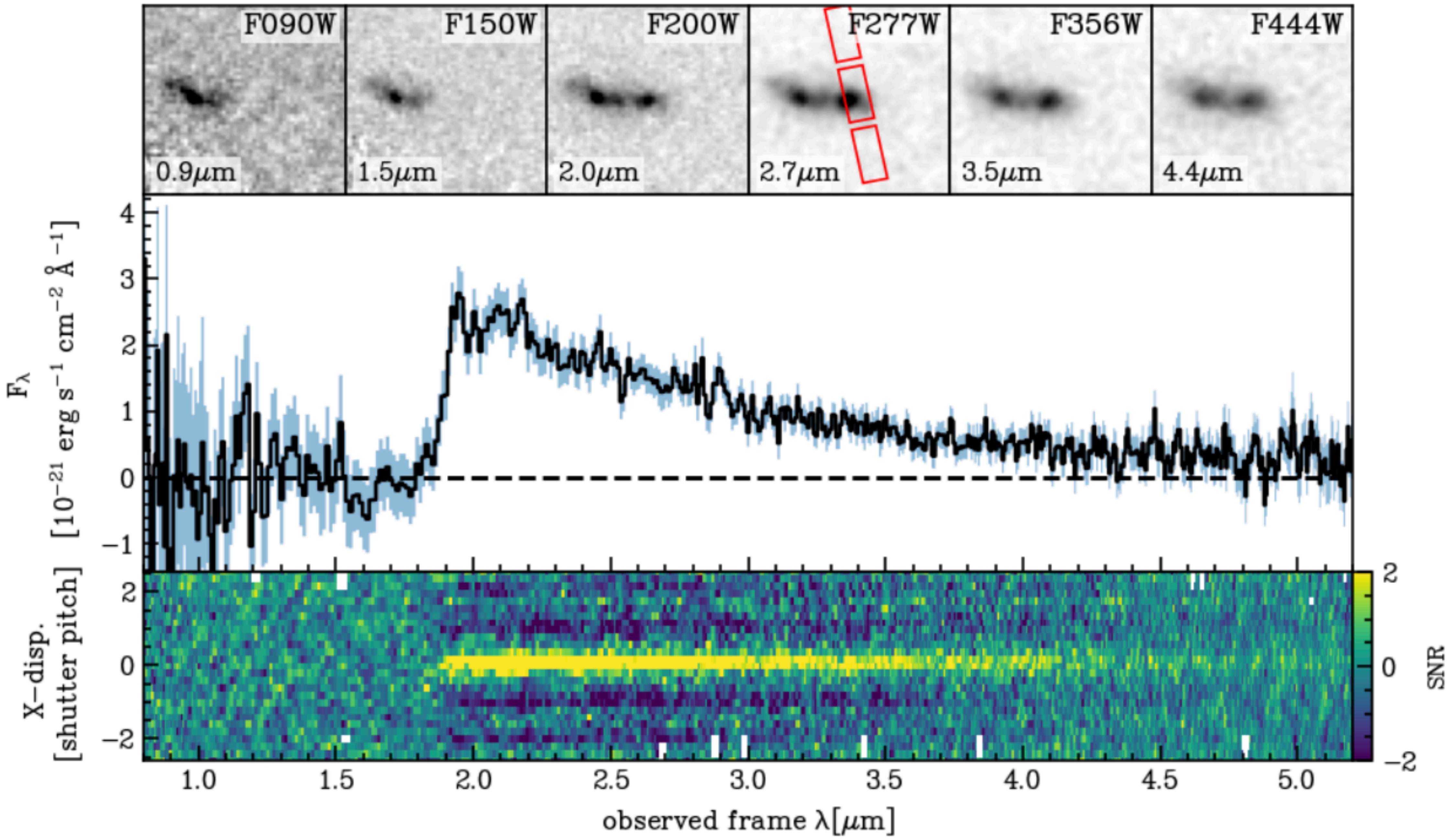


JADES Origins Field (JOF)

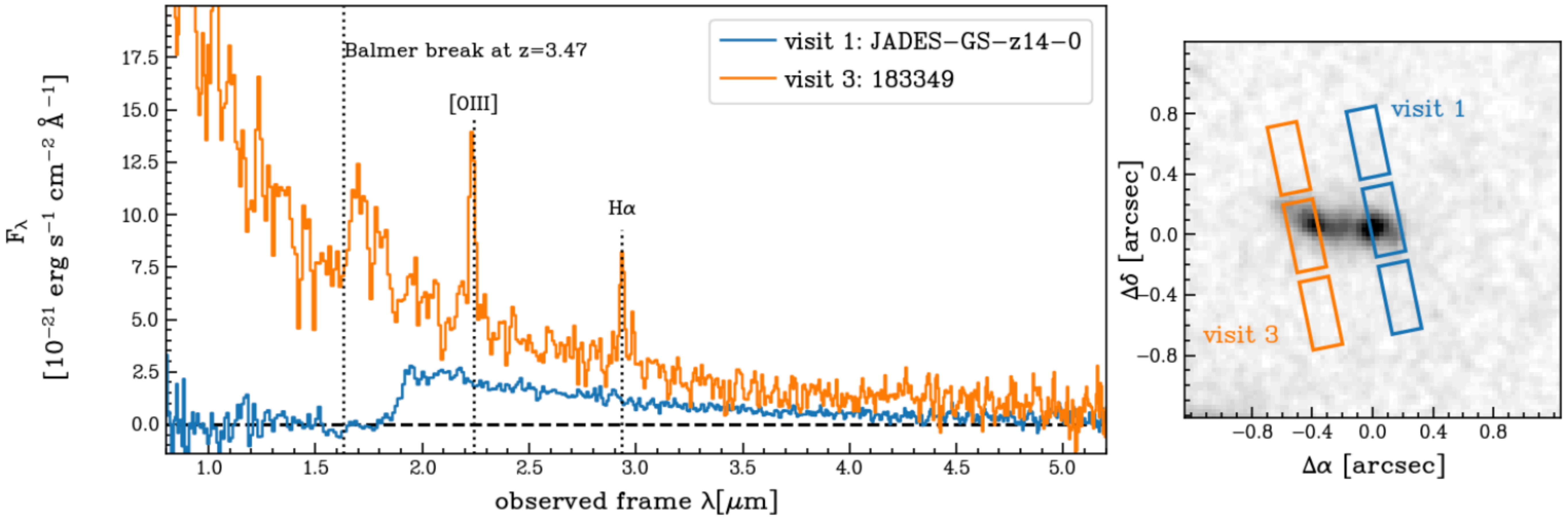
Robertson, Johnson, Tacchella+24

JADES-GS-z14-0: most distant galaxy

Carniani+24, Nature



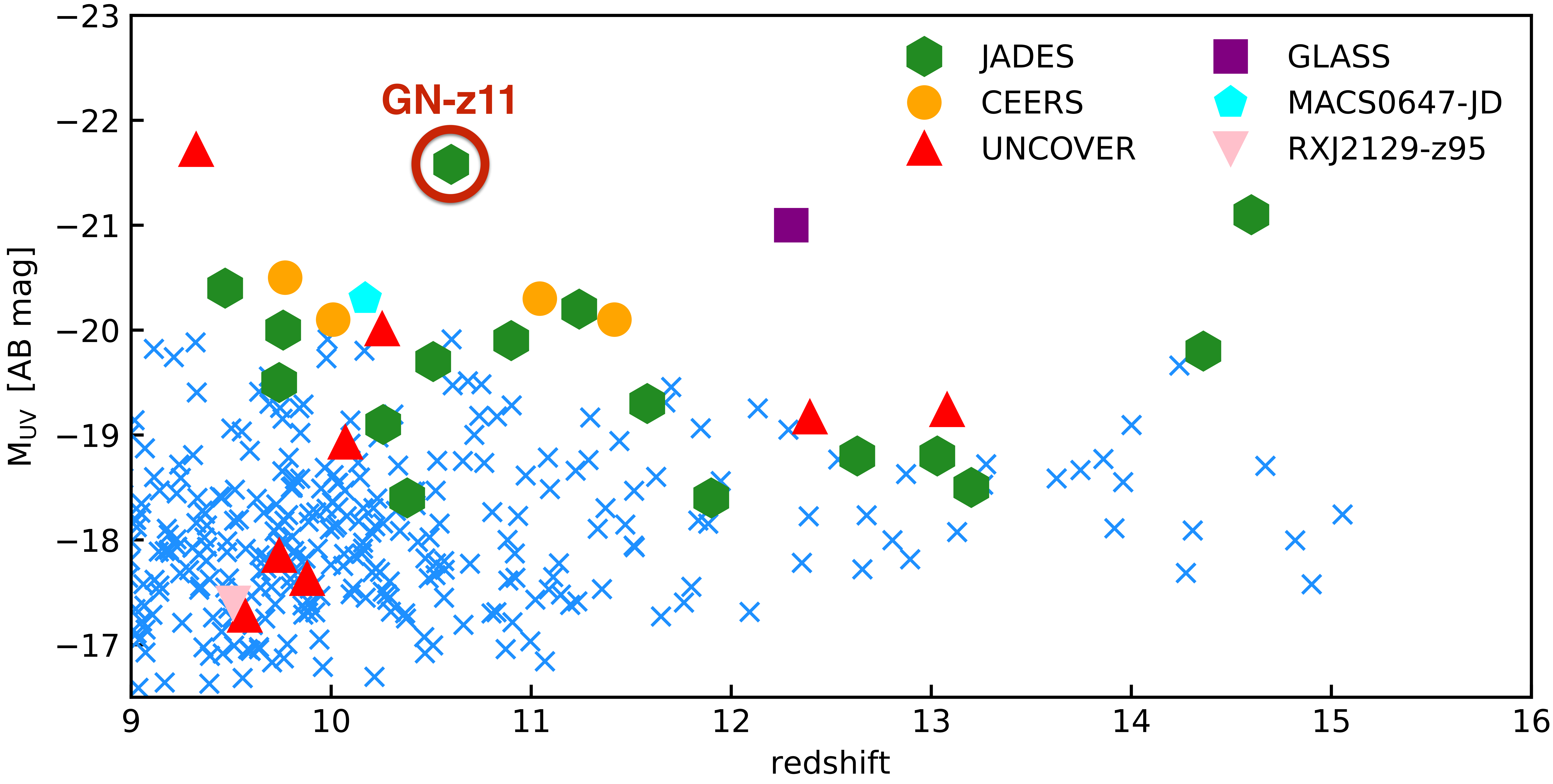
redshift z=14.32 via Lyman break (damping wing!)



neighbouring galaxy is clearly at a different redshift

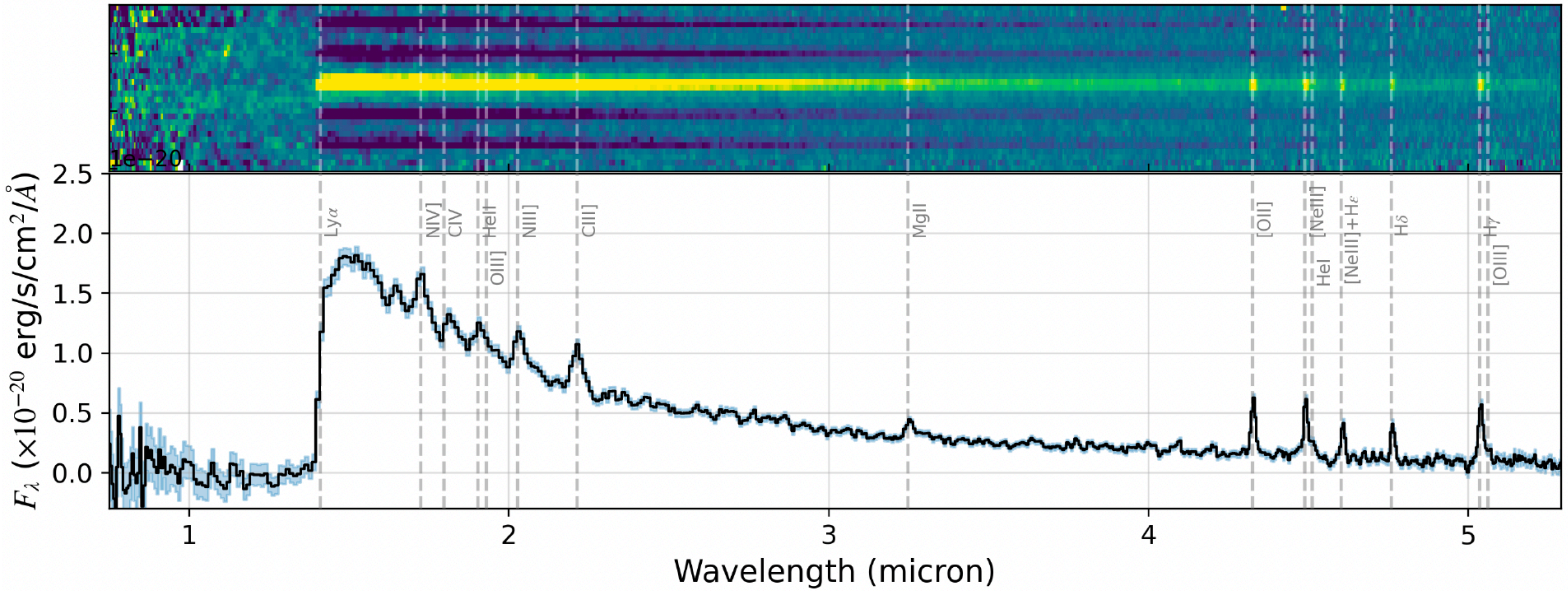
➜ extended (~200 pc), no indication for an AGN!

Frontiers with JWST



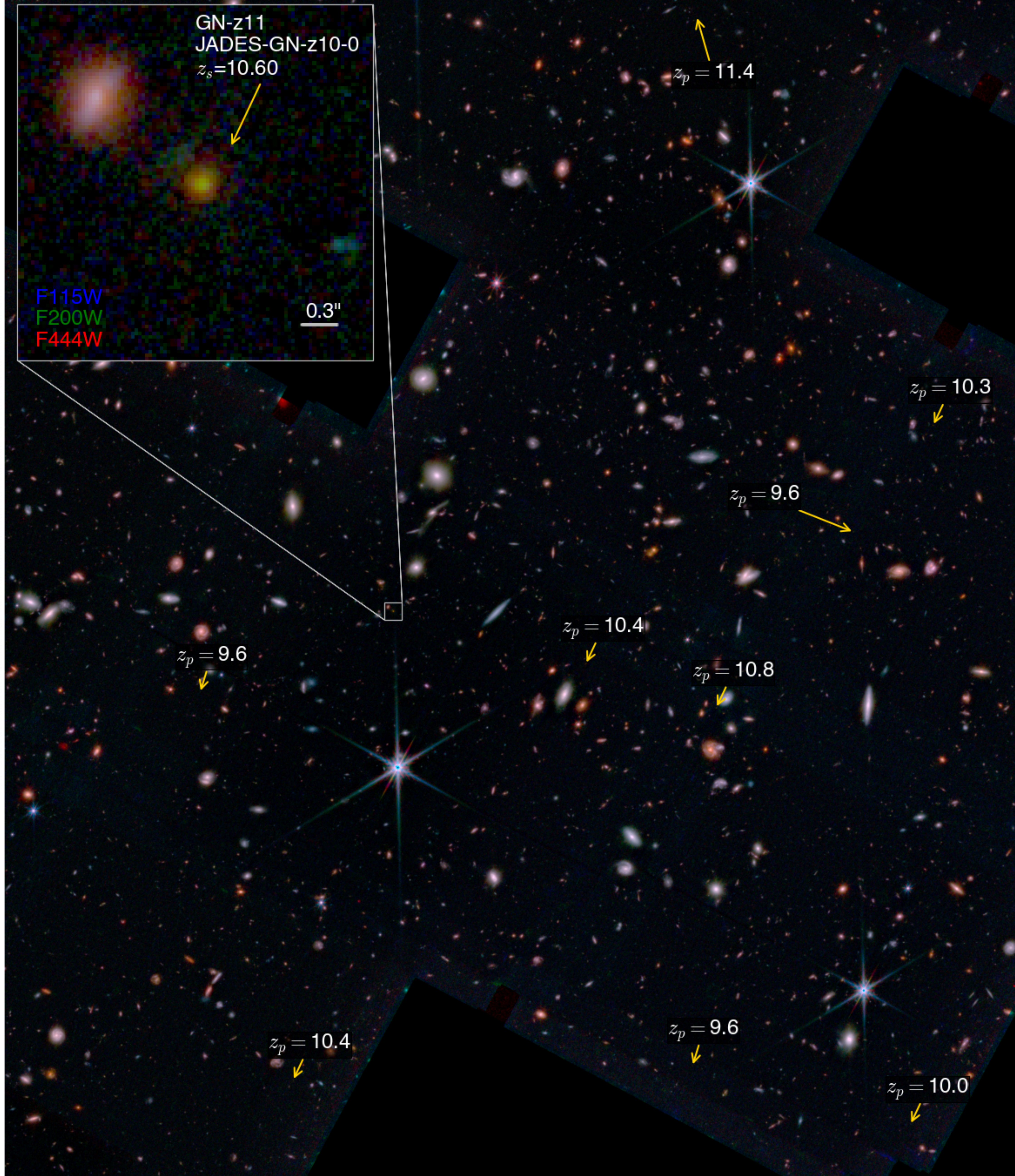
Nature of GN-z11

Bunker+ (2023)



GN-z11 is at z=10.60!

… and possibly not alone:
9 galaxies out to ~5 cMpc transverse
➜ massive dark-matter halo (~8x10[10] M☉)



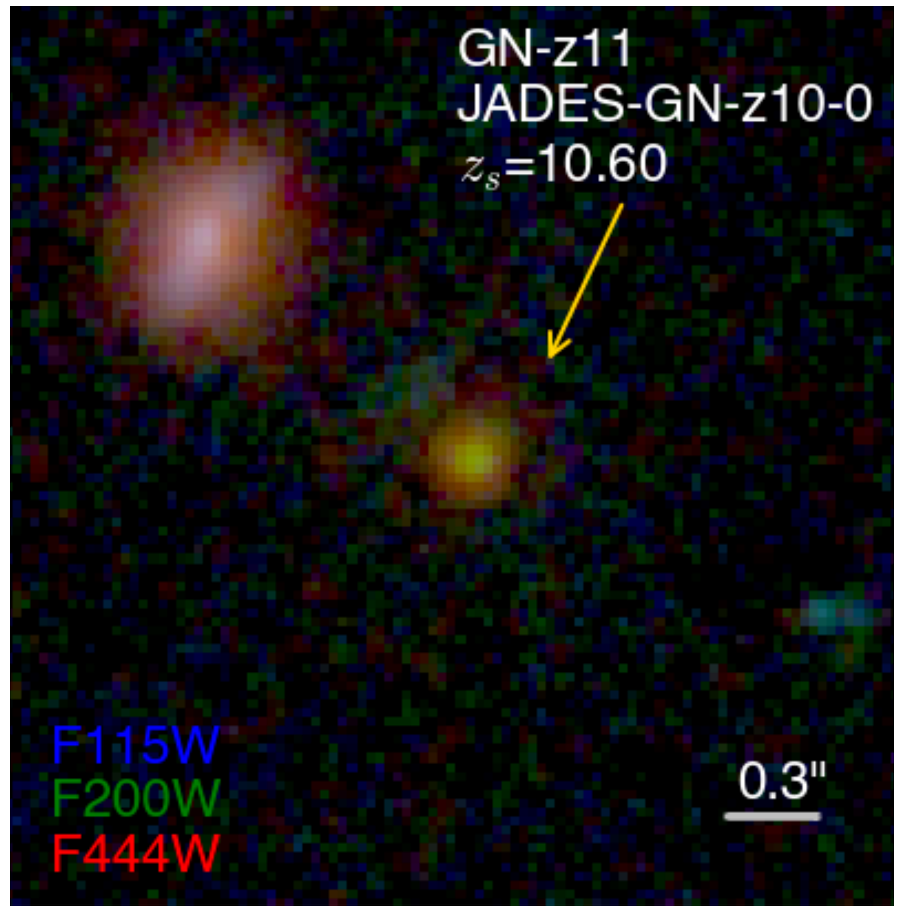
Tacchella+ (2023)

Nature of GN-z11

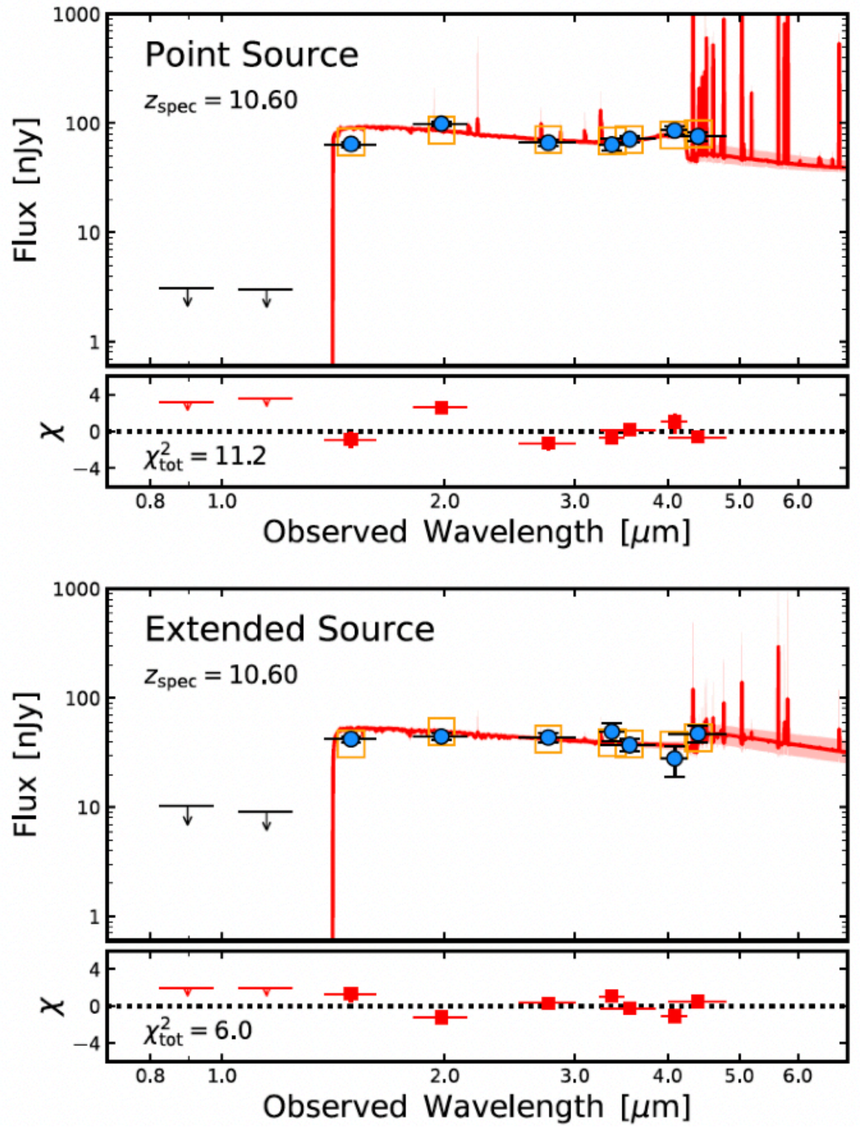
- Compact, but can decompose light into point source + extended component

➜ **luminosity** is dominated by central point source , while the **stellar mass** is dominated by the extended component ("outshining")

➜ nuclear star-burst; bulge/core/GC formation?



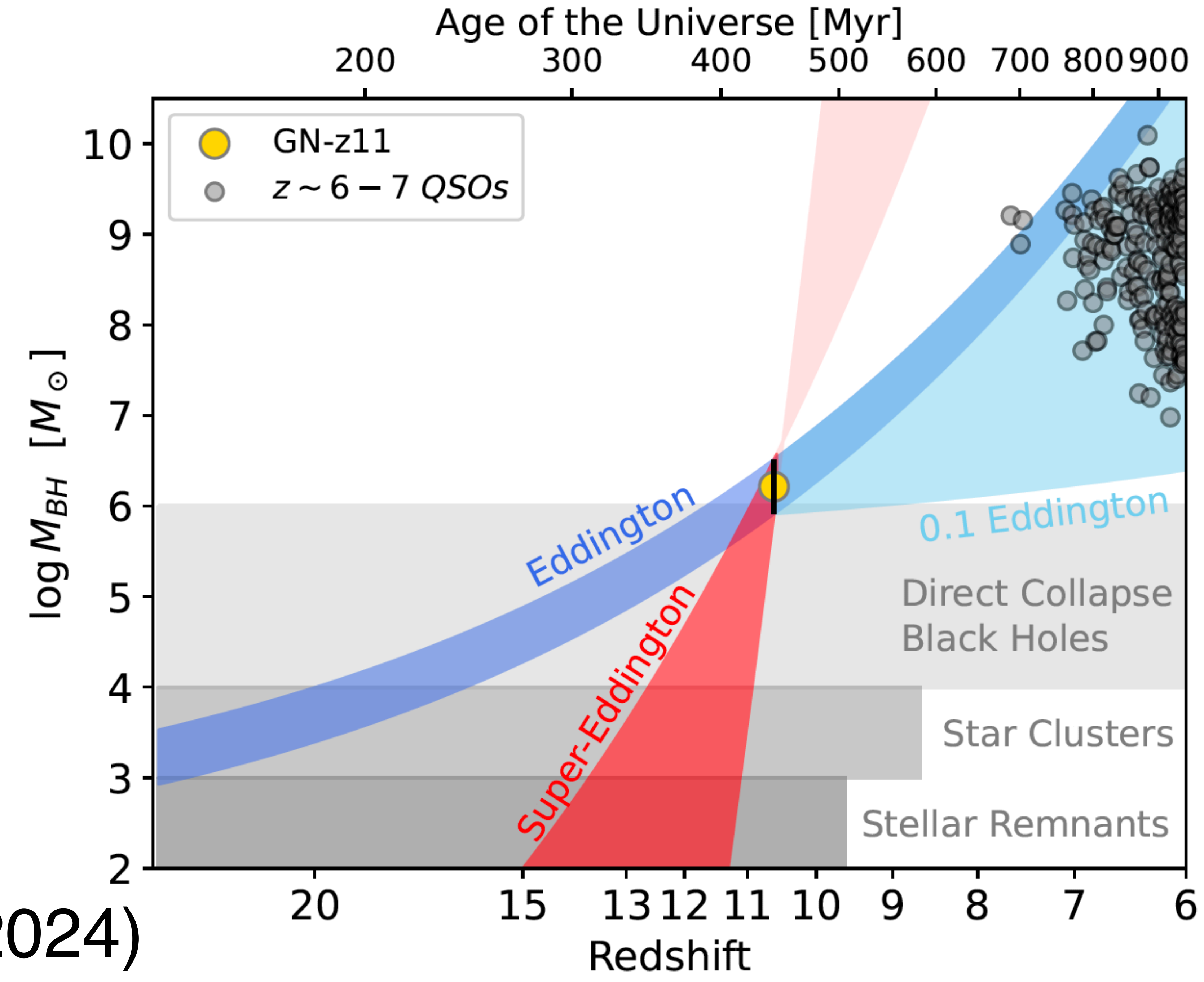
Tacchella+ (2023)



- But GN-z11 also host an accreting black hole!

➜ central point source is an AGN

➜ several spectral features (CIV1549; continuum spectral slope; density implied from permitted lines) point to Broad Line Region of AGN

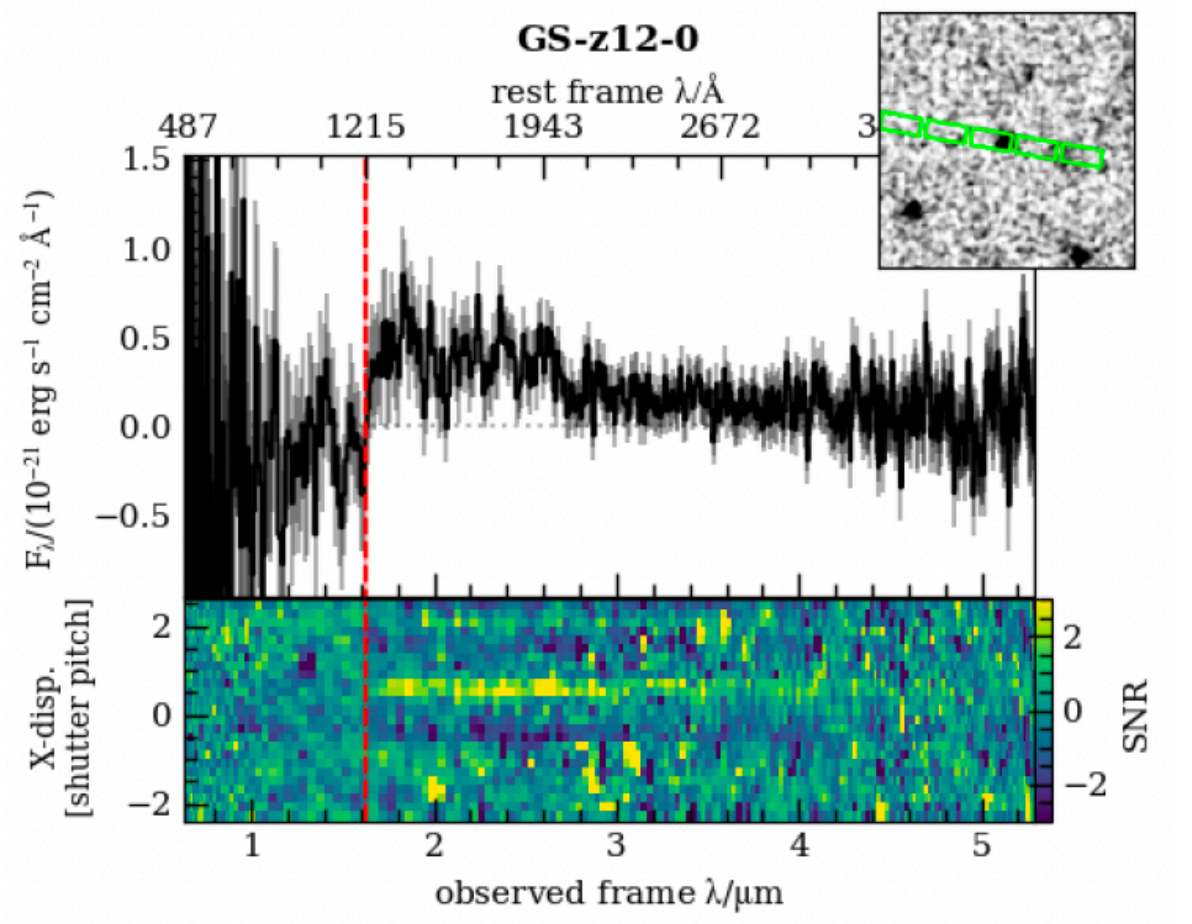


Maiolino+ (2024)

Dark stars?

Curtis-Lake, Carniani+ (2023)
Robertson, Tacchella+ (2023)

- Dark Stars, powered by dark matter (DM) heating rather than by nuclear fusion, and can become super massive (~10^6 $M_\odot$)
- Ilie+ (2024): high-z objects discovered with JWST are consistent with a super-massive dark star interpretation, thus identifying the first dark star candidates
- But better data revealed emission lines in the spectrum, inconsistent with dark stars



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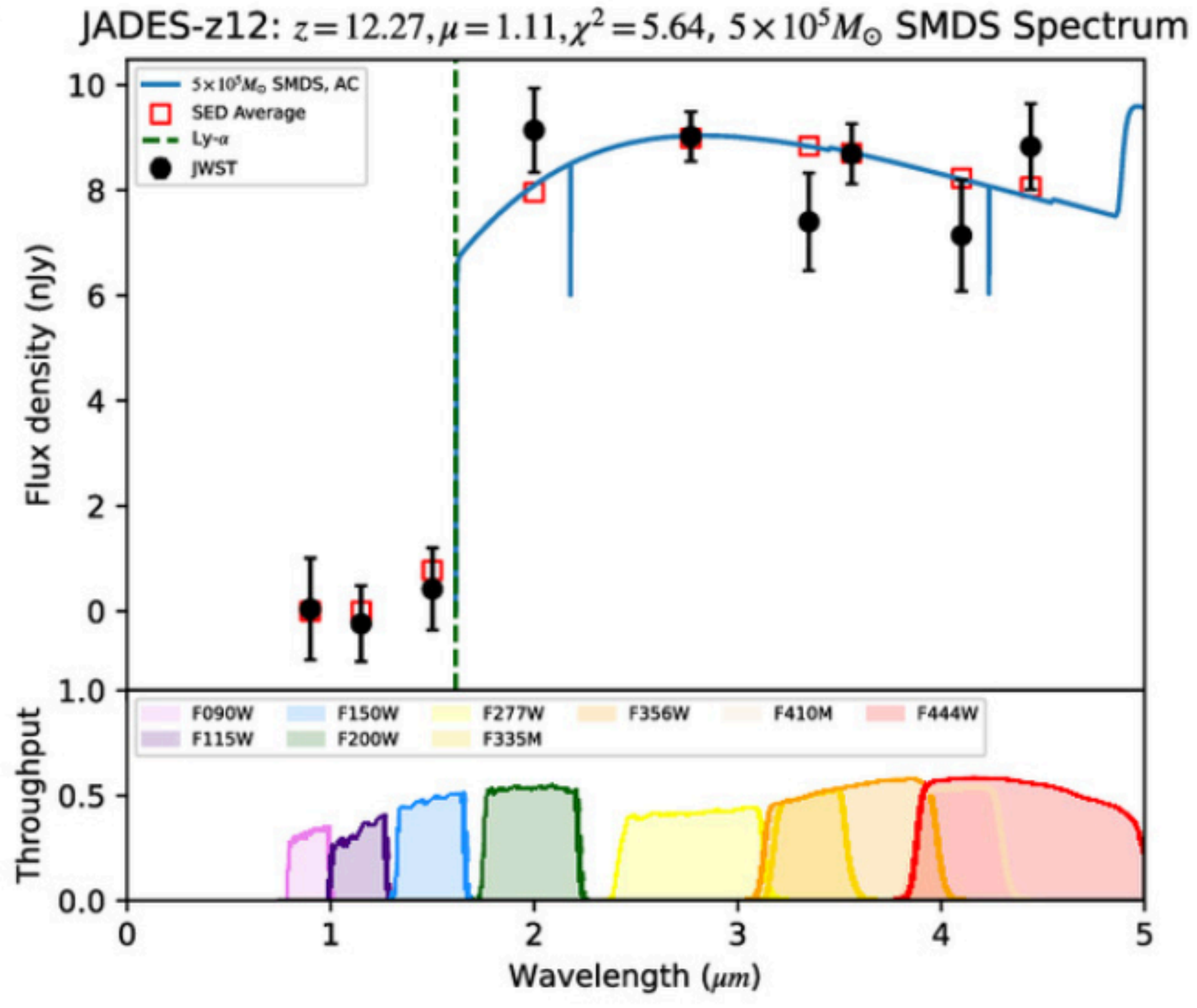
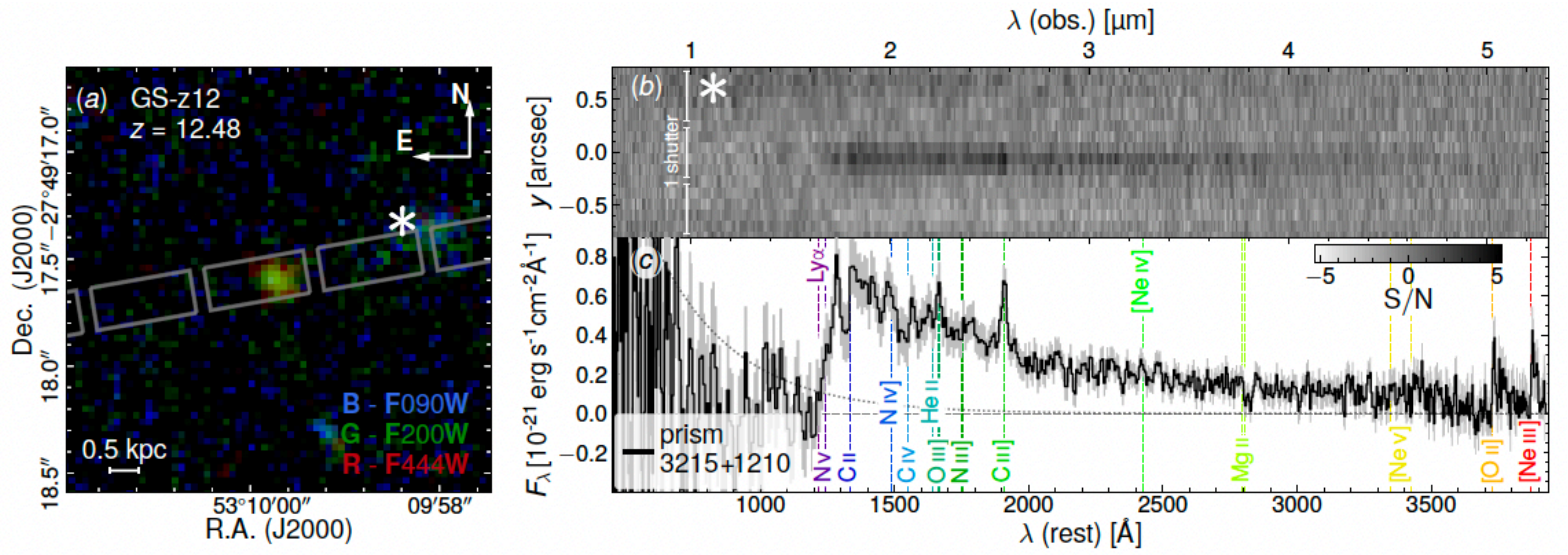


JADES-GS-z12-0 as a SMDS



D'Eugenio+ (2024)

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  - increase the scatter between halos and UV (Shen [incl ST]+ 23; Mason+23; Kravtsov & Belokurov 24)
  - vary initial mass function (IMF) at high redshifts (Inayoshi+22; Cueto+24; Trinca+24; Ventura+24)
  - non stellar sources (e.g. AGN; dark stars; Inayoshi+22; Trinca+24; Hegde+24; Ilie+23)

➜ z>10 galaxies are diverse: sizes, attenuation, SFR, AGN, intense star formation

Conclusions

- JWST delivers exquisite data
  ➜ first time that we can do high-resolution (NIR) spectroscopy in space
- JWST surprised us: more UV bright galaxies in the early universe, galaxies with accreting black holes, massive quiescent galaxies, mature systems with dense cores…
- Over-abundance of UV bright galaxies:
  ➜ could explain with changing cosmological model (f.e. Early Dark Energy), but “baryonic” solutions are more reasonable
  ➜ galaxies are complicated systems… need to understand first the internal working of those before putting constraints on cosmology