The Physical Properties of Galaxies in the First 700 Million Years as Revealed by JWST

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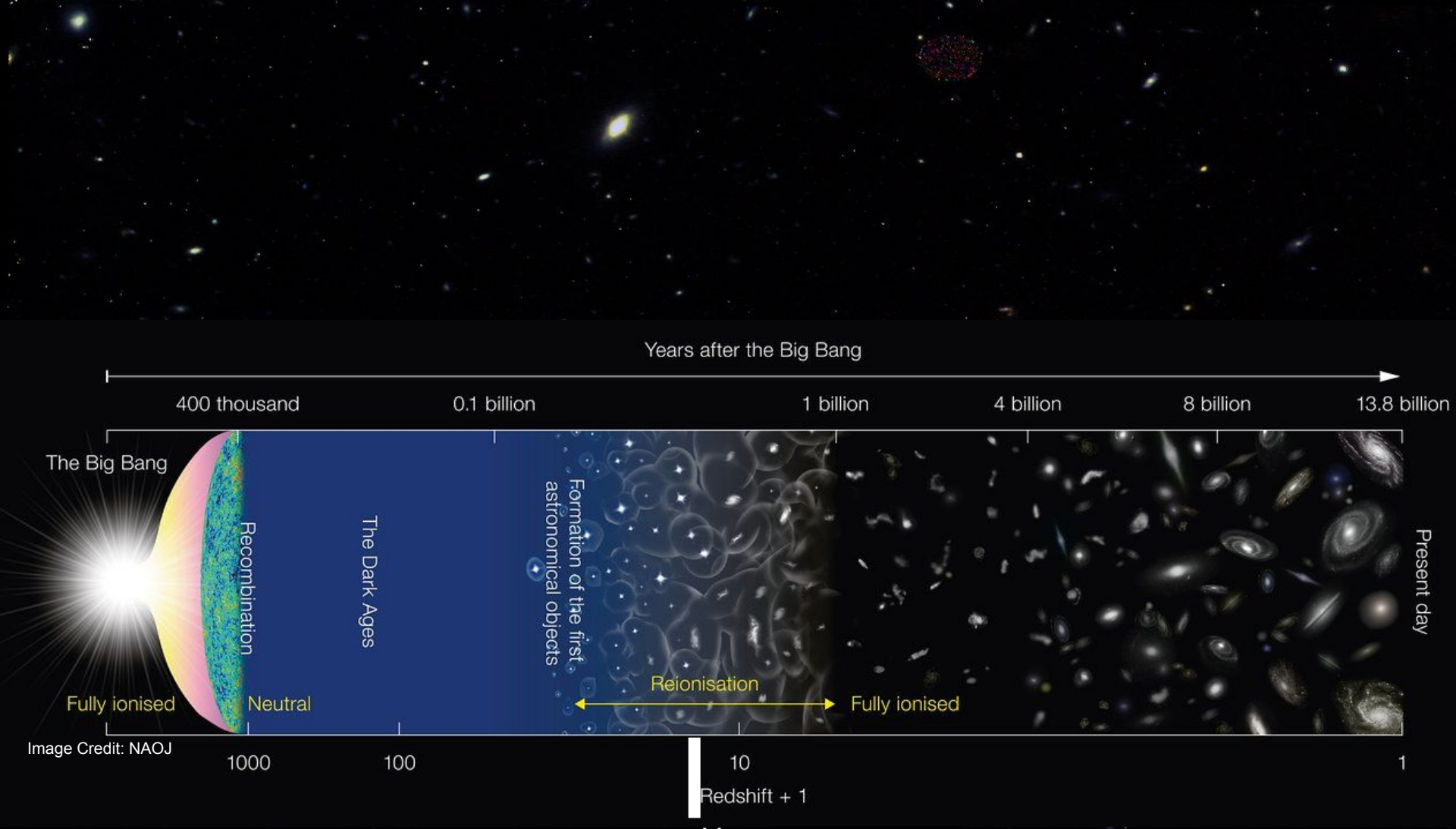
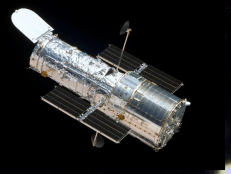
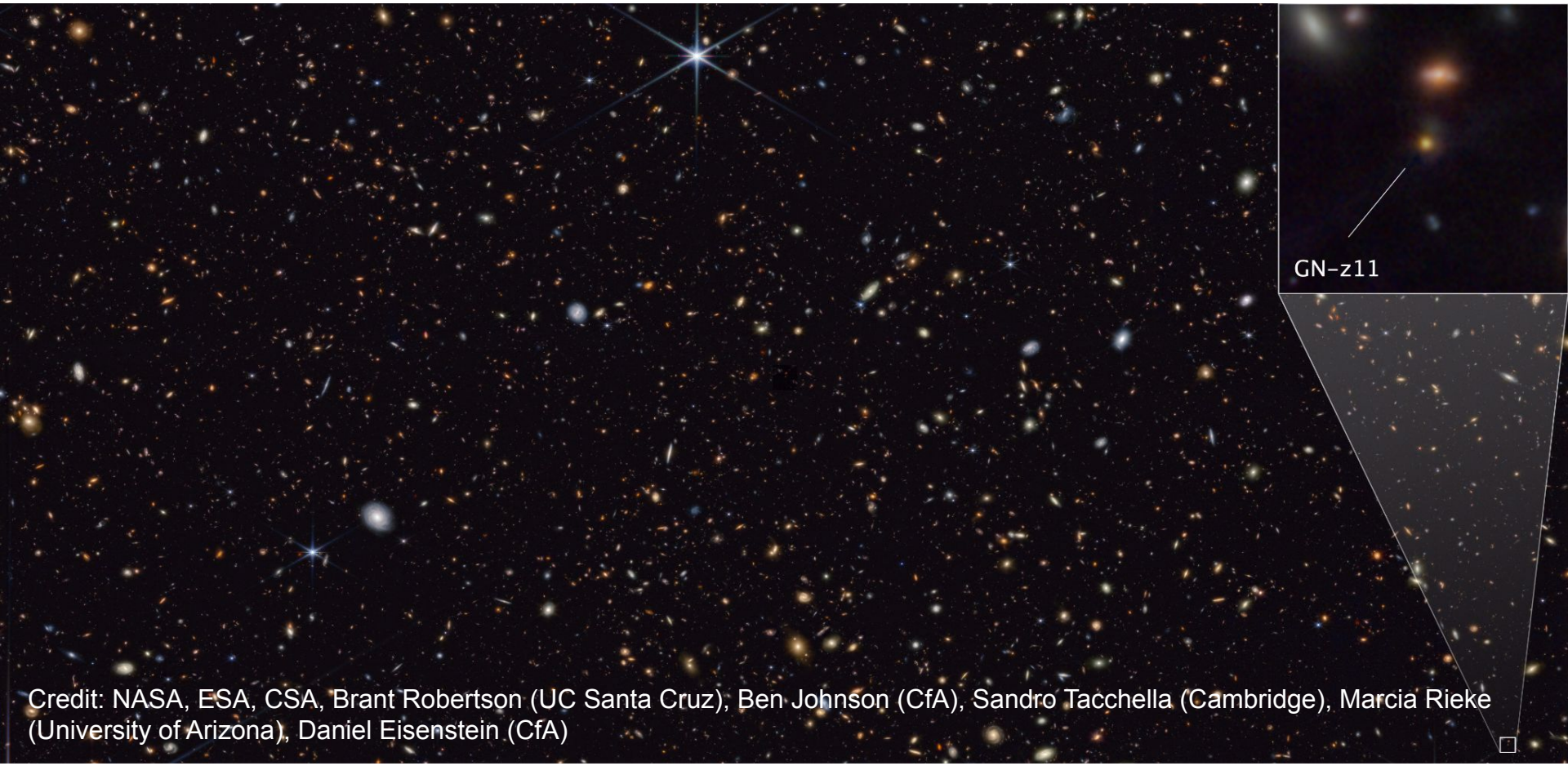


Image Credit: NAOJ

z=11



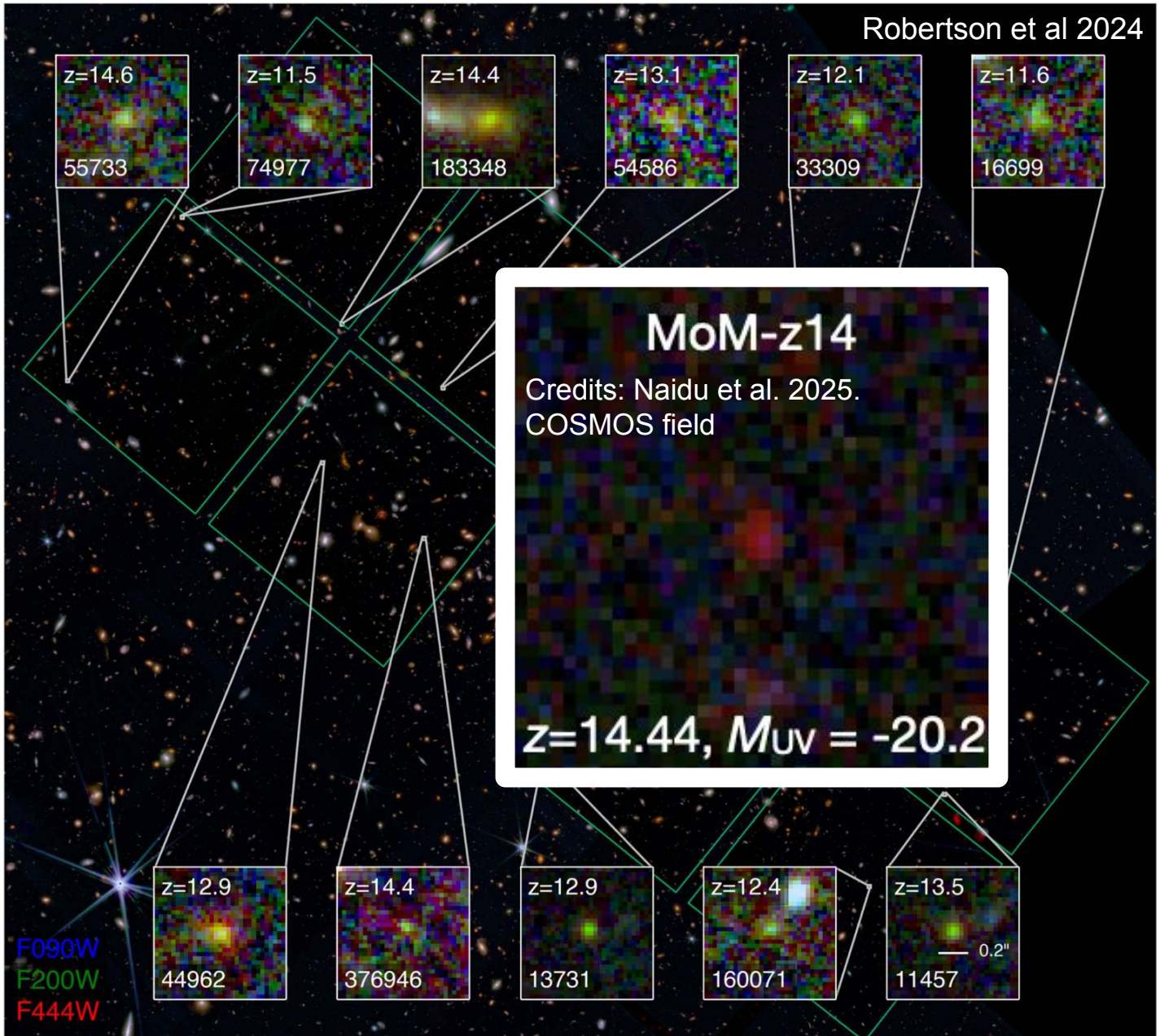
First results with JWST

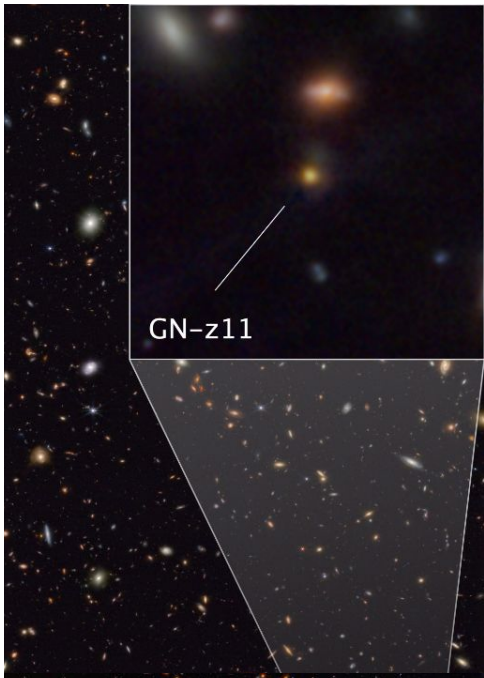


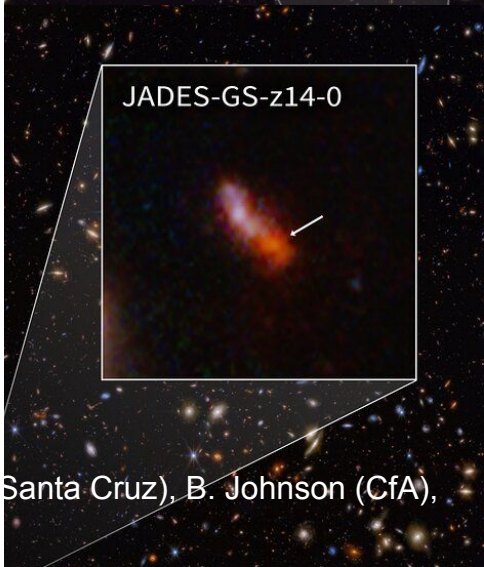
Credit: NASA, ESA, CSA, Brant Robertson (UC Santa Cruz), Ben Johnson (CfA), Sandro Tacchella (Cambridge), Marcia Rieke (University of Arizona), Daniel Eisenstein (CfA)

First results with JWST

First results with JWST







Santa Cruz), B. Johnson (CfA),

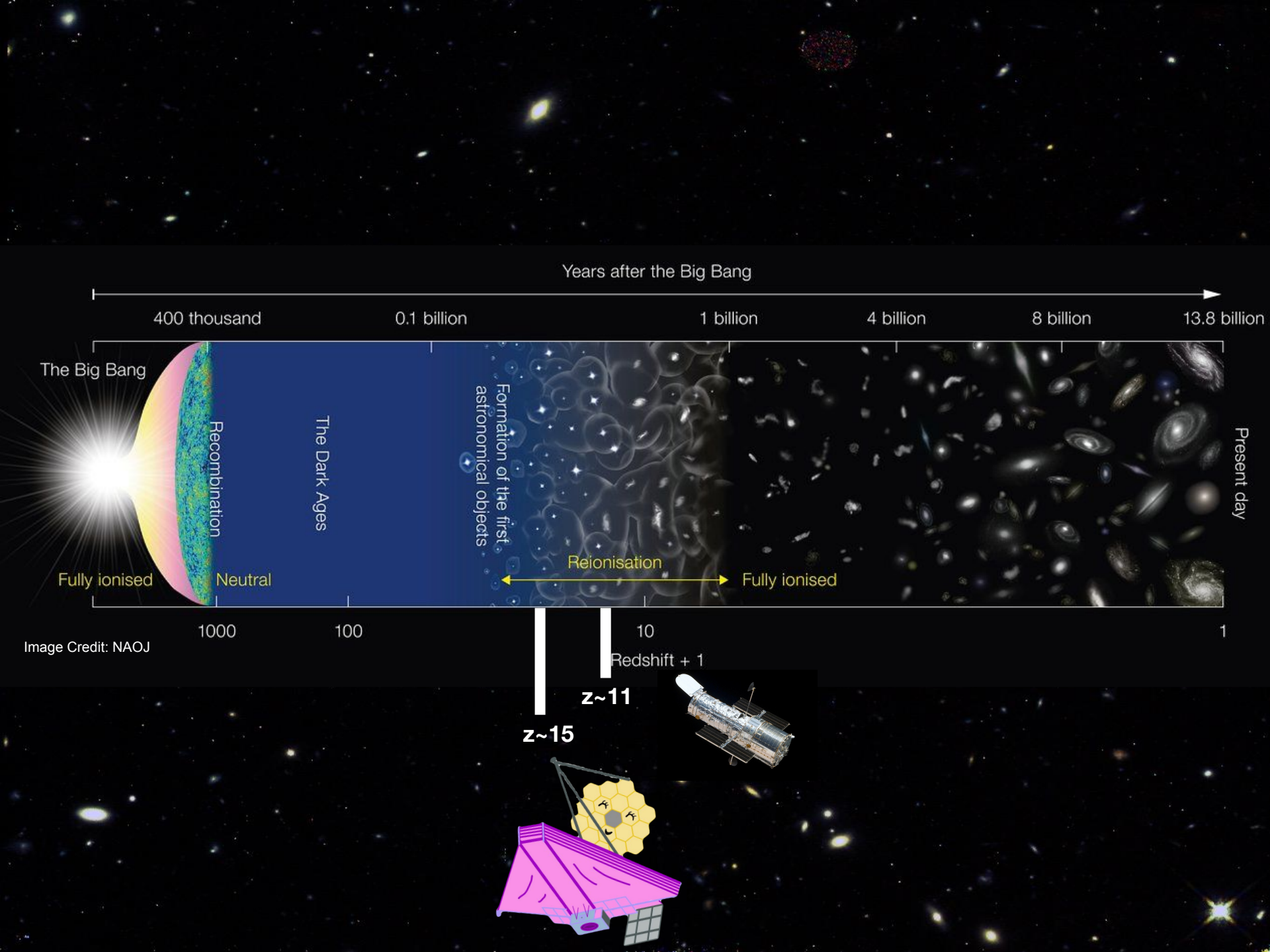


Image Credit: NAOJ

Puzzle of the Blue Monsters

Blue monsters: very UV-bright ($M_{UV} < -20$, $\square < -2.0$) galaxies at z>10.

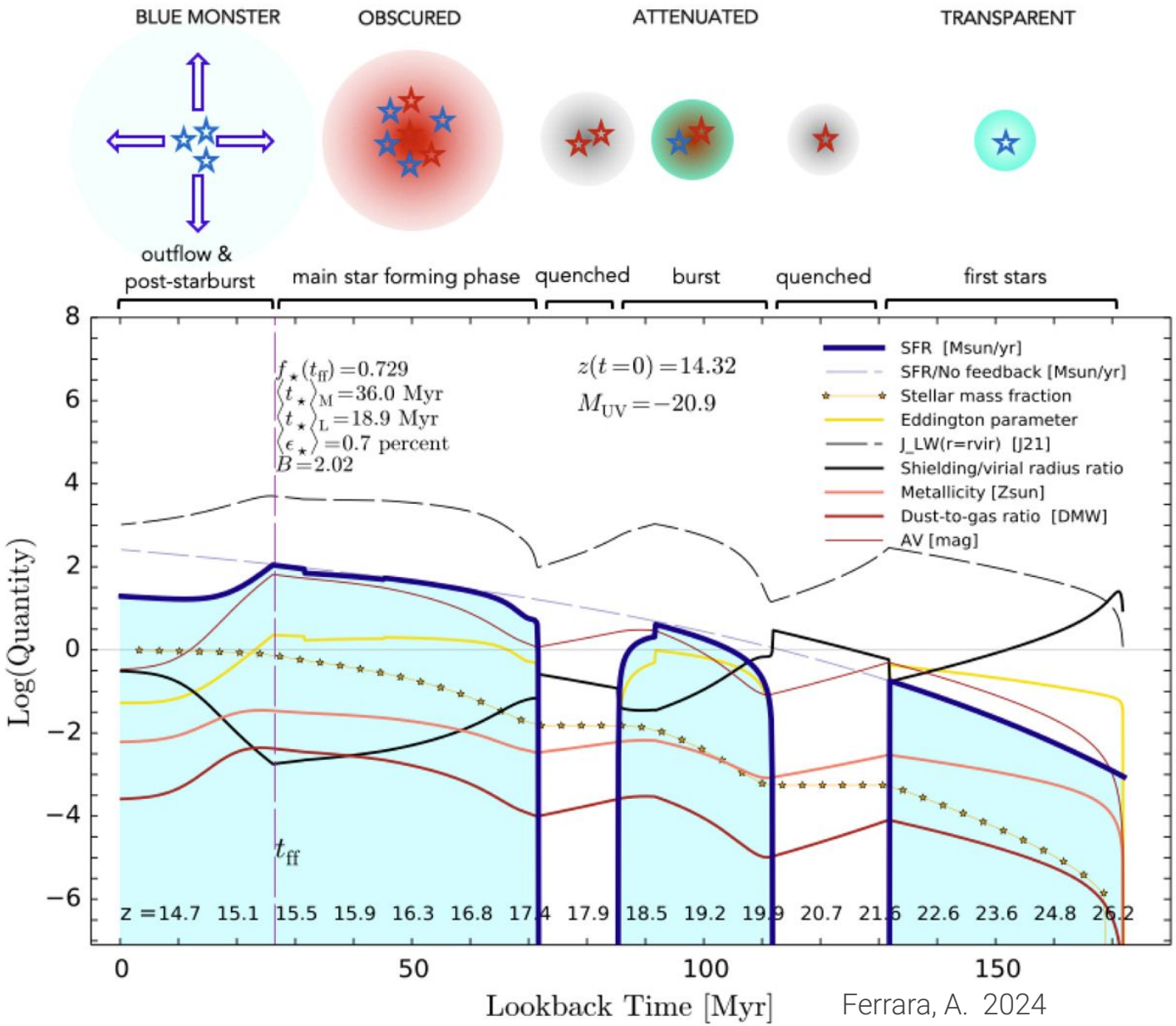
Theories in the literature try to explain the formation of these blue monsters (e.g. Fiore+23, Ziparo+23, Ferrara 24,25) with a combination of:

(1) lack of dust.

(2) very recent starburst when observed.

(3) nature of the emission (hard ionization from stellar population vs. AGN).

The Blue Monsters



Ferrara, A. 2024

Puzzle of the Blue Monsters

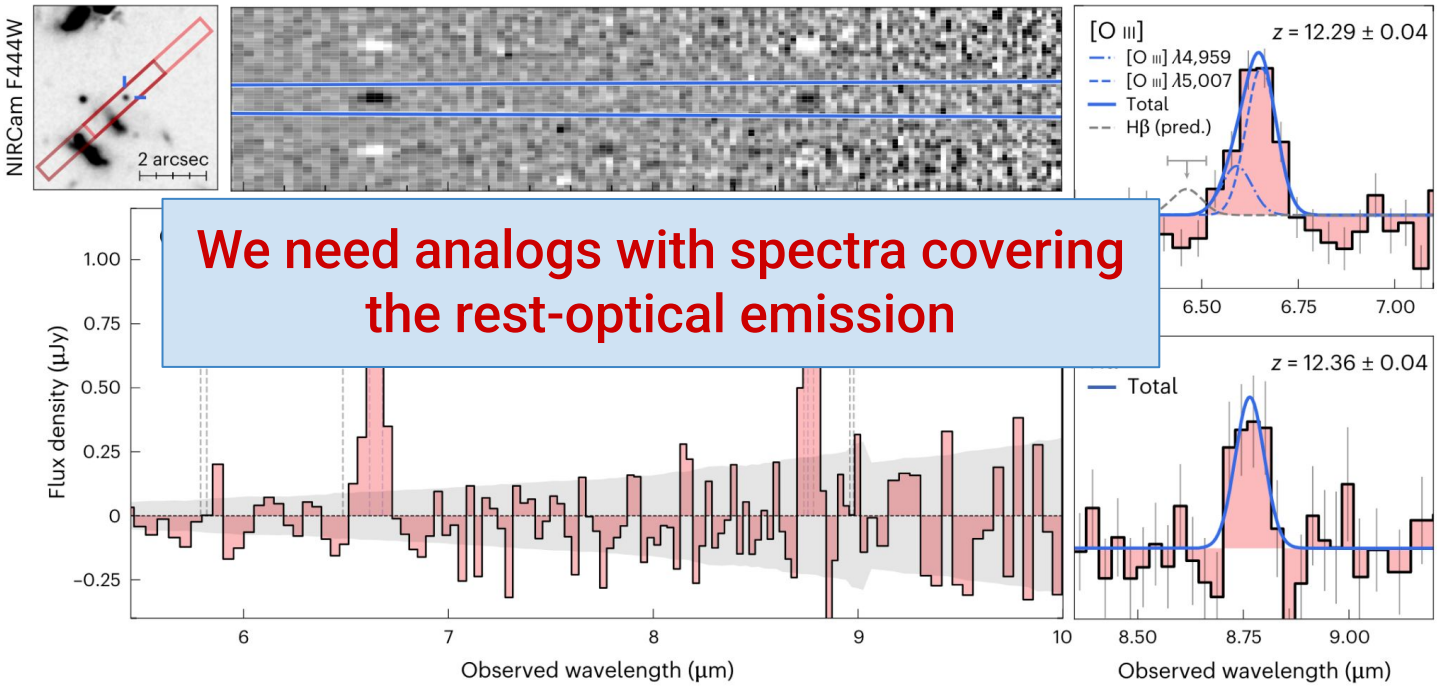
Blue monsters: very UV-bright ($M_{UV} < -20$, □ < -2.0) galaxies at z>10.

- Most of these blue monsters are still photometric findings. **We need spectra!**

Puzzle of the Blue Monsters

Blue monsters: very UV-bright (M_{UV} < −20, □ < −2.0) galaxies at z>10.

- Most of these blue monsters are still photometric findings. **We need spectra!**
- At z > 10 we can observe nicely the rest-UV, but the rest-optical becomes challenging!
  - Rest optical → Nebular emission lines to study stellar populations.
  - MIRI would get H□ and [OIII] but at **is expensive and lower resolution.**

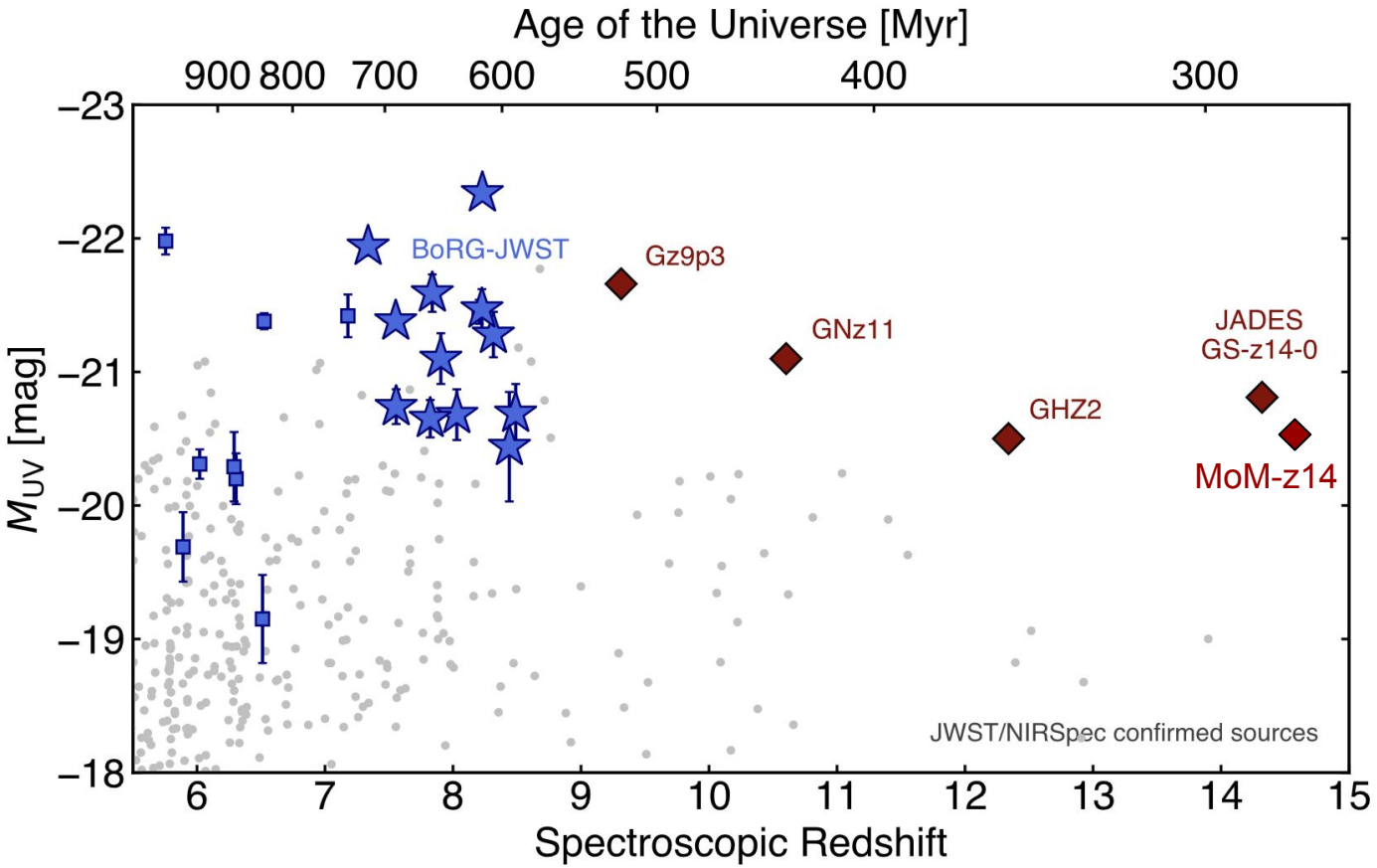


We need analogs with spectra covering the rest-optical emission

Zavala. J. A. et al 2024

The BoRG-JWST Galaxies are Analogs to Blue Monsters

- z>9 spectroscopically confirmed Blue Monsters.
- BoRG-JWST galaxies using NIRSpec PRISM R~100



Modified from Roberts-Borsani G., Bagley M., Rojas-Ruiz, S. et al. 2025

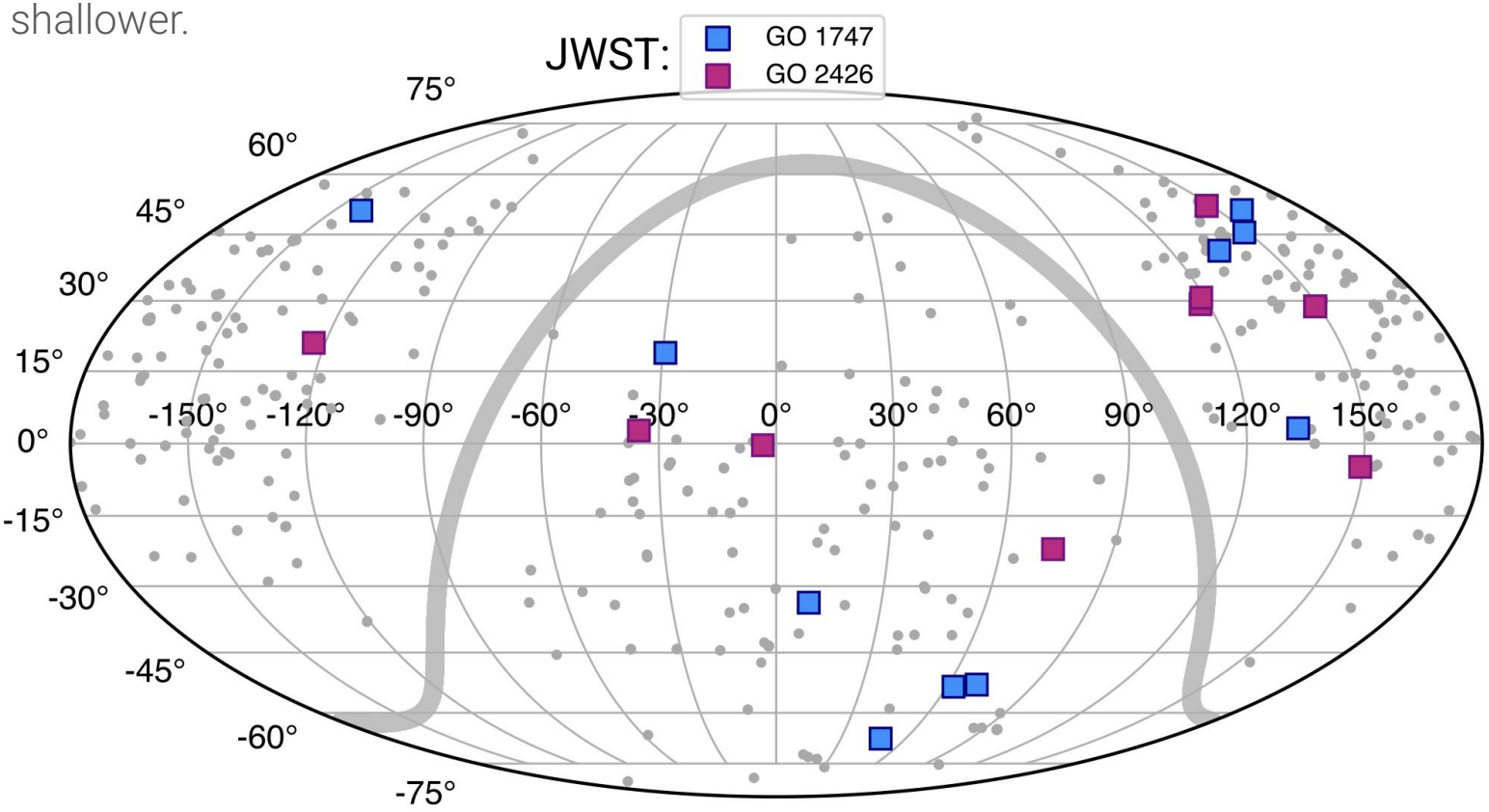
BoRG-JWST Survey: Representative sample of UV-bright Galaxies

Search for galaxies in:

- ➔ Deep areas, or
- ➔ Many independent pointings are robust against cosmic variance, but shallower.

● **SuperBoRG + WISP Hubble Surveys**

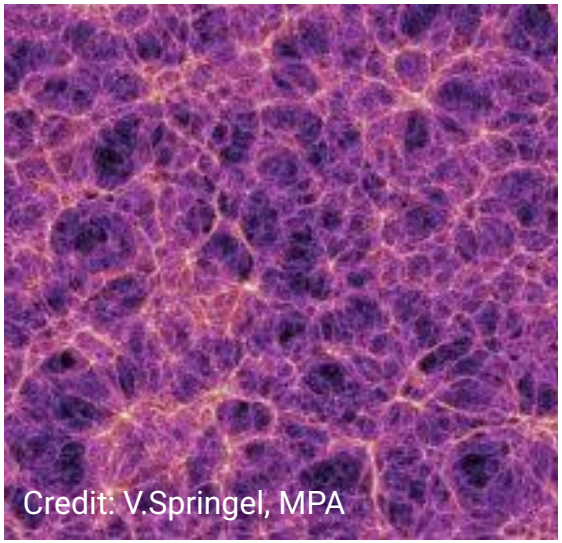
361 independent sight lines!
~1640 arcmin^2 or ~0.4 deg^2

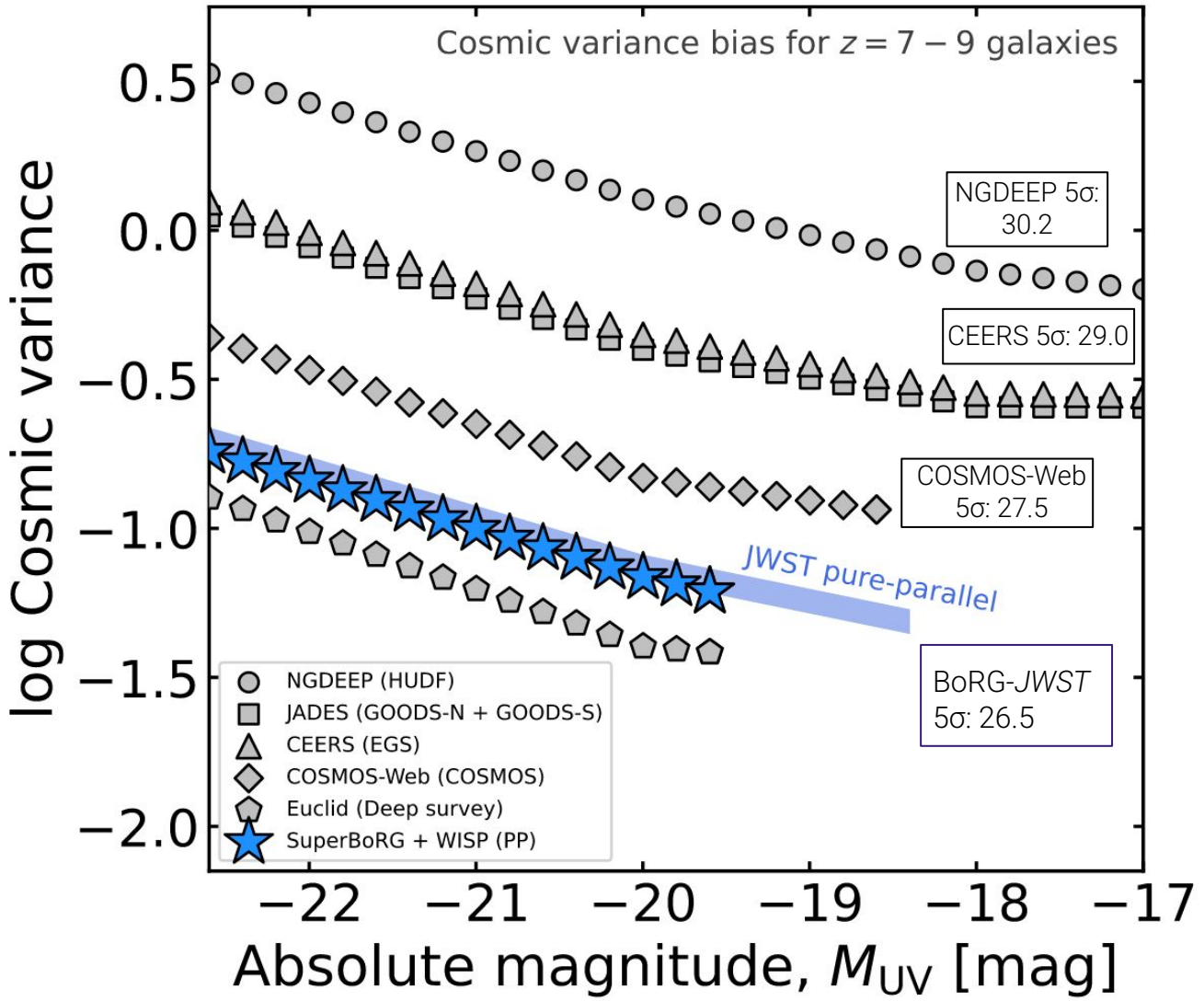


Roberts-Borsani G., Bagley M., Rojas-Ruiz, S. et al. 2025

BoRG-JWST Survey: Representative sample of UV-bright Galaxies

- BoRG-JWST Survey is robust against cosmic variance!
- We have a representative sample of the z~8-9 galaxy population.


Credit: V.Springel, MPA



Credit: Roberts-Borsani G., Bagley M., Rojas-Ruiz, S. et al. 2025

BoRG-JWST Galaxies as Ideal Analogs to Blue Monsters

We investigate the rest-UV and -optical emission lines to test the theory:

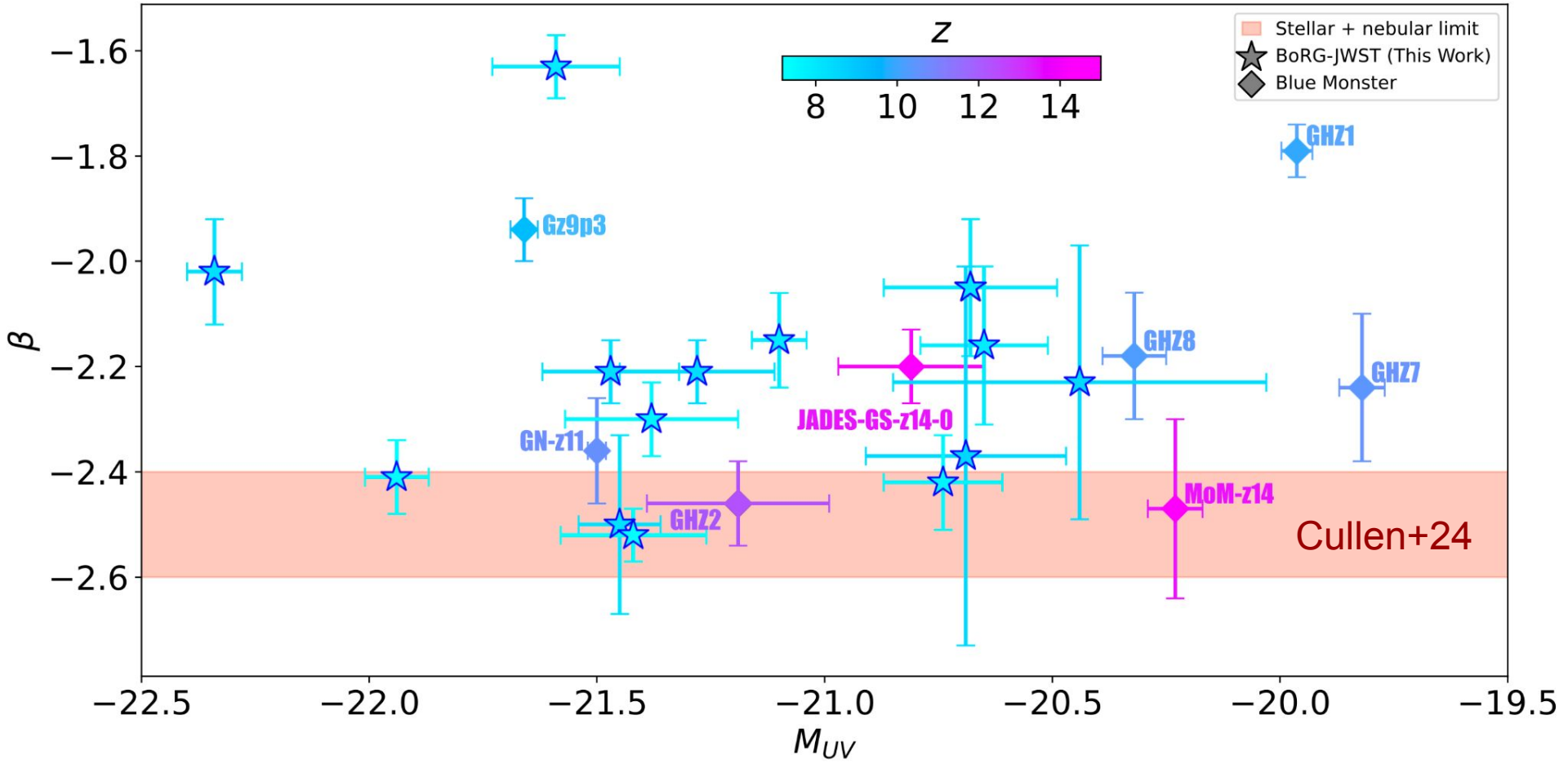
1) Galaxies lack dust.

2) Stochastic star formation (starburst when observed).

3) AGN vs. strong star-forming contribution to their luminosity.

The BoRG-JWST Galaxies are Analogs to Blue Monsters: 1) Lack of dust

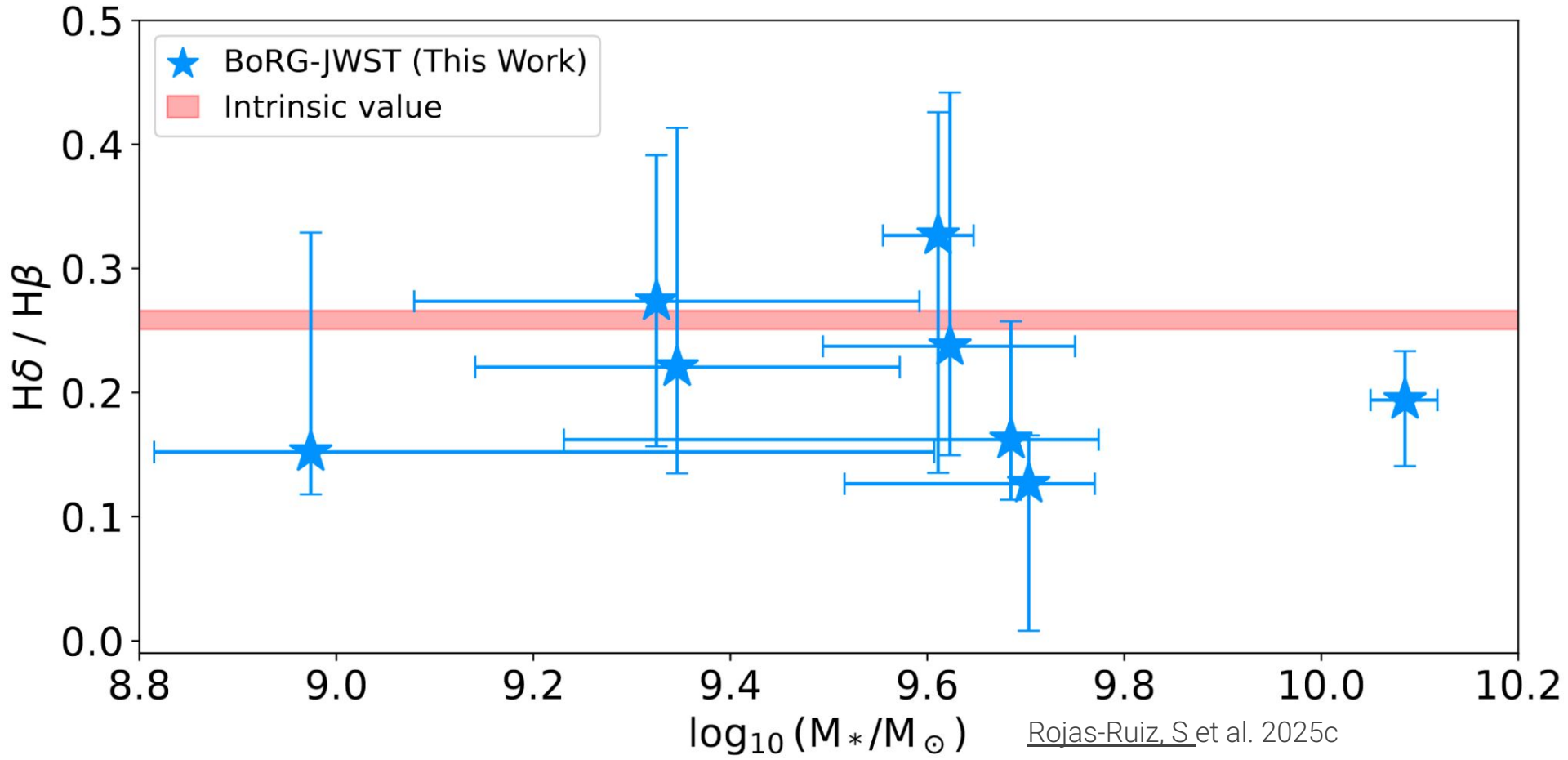
- Very blue UV beta slopes (□ < -2.0) but within limit of stellar and nebular emission.



Rojas-Ruiz, S. et al. 2025c

The BoRG-JWST Galaxies are Analogs to Blue Monsters: 1) Lack of dust

- Balmer decrement evaluation shows little dust attenuation for BoRG-JWST galaxies and within intrinsic limit (Hδ/H□ ~ 0.26)!
- H□ information not available for most Blue Monsters.

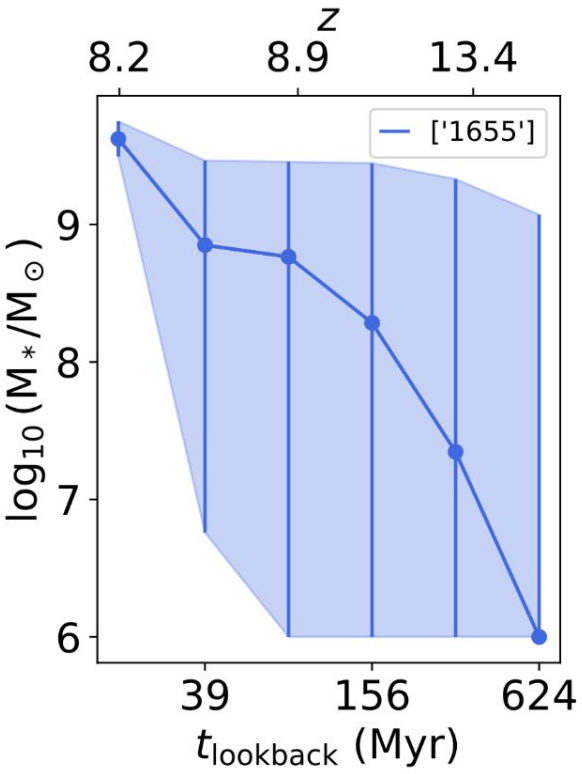


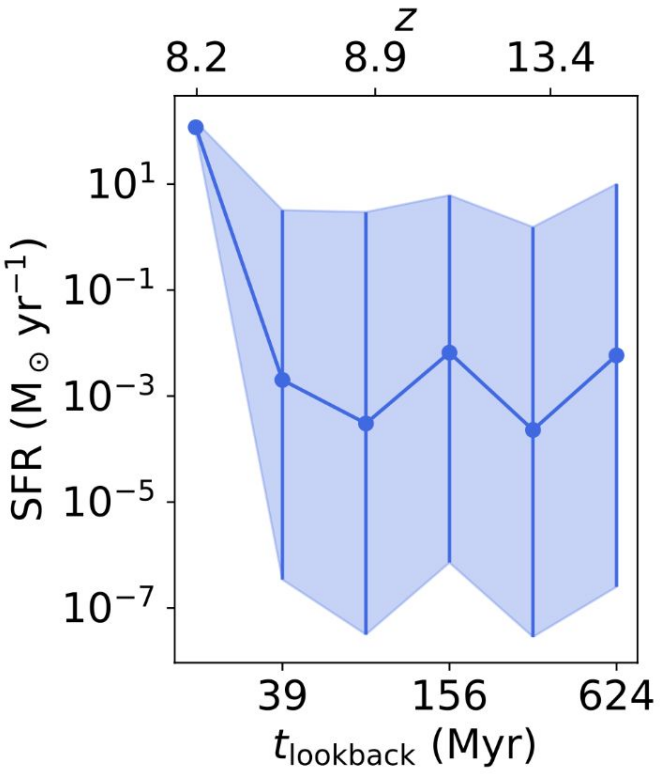
Rojas-Ruiz, S et al. 2025c

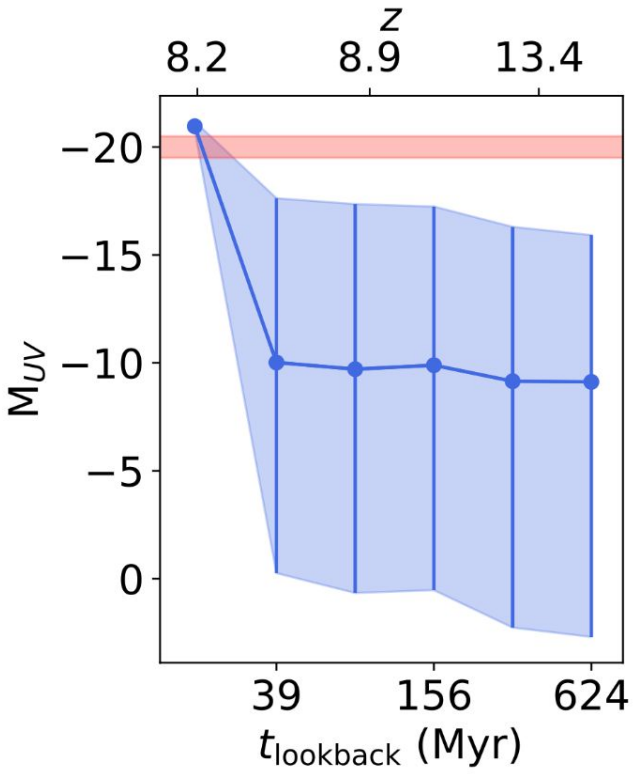
The BoRG-JWST Galaxies are Analogs to Blue Monsters: 2) Bursty star formation

- Use SED fitting code **gsf** (Morishita+19,+24) and find evidence for burstiness in all the 14 BoRG-JWST galaxies!
- This evolution may explain why we are finding more UV-bright galaxies at z > 10.

BoRG 1655, z = 8.030





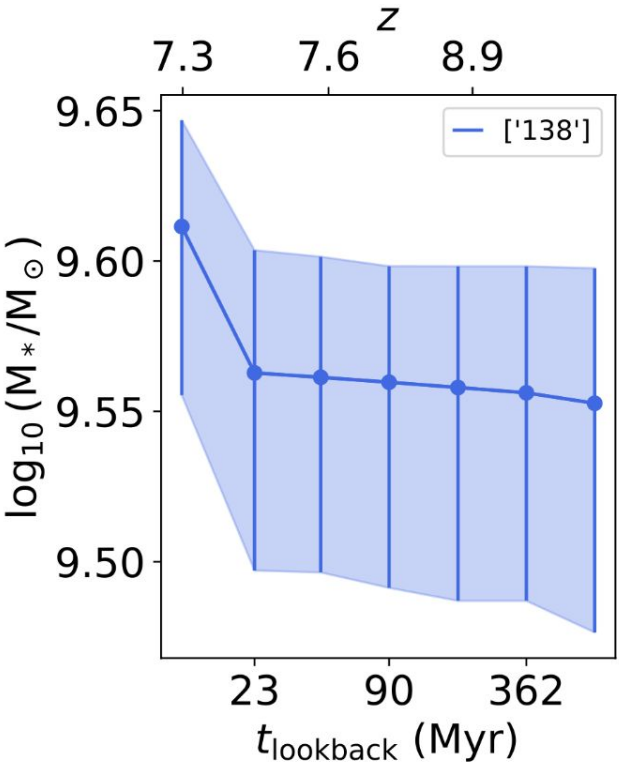


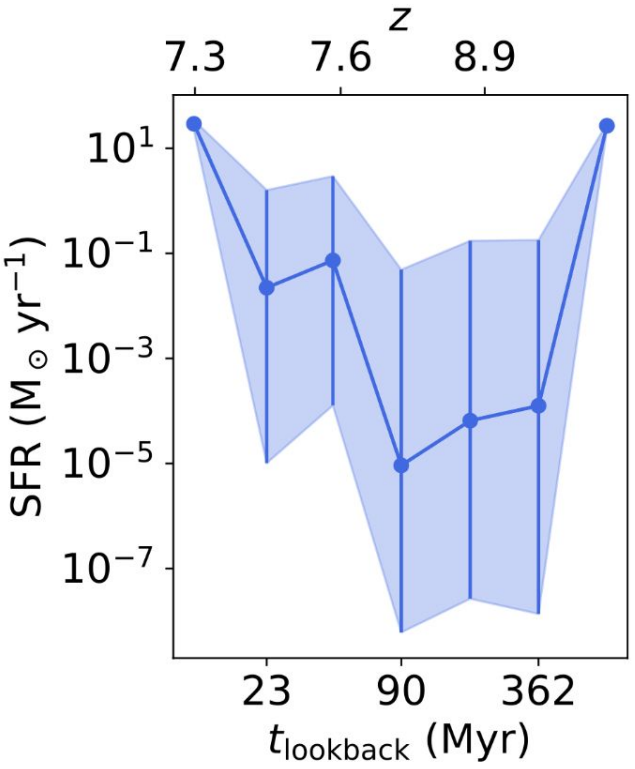
Rojas-Ruiz, S et al. 2025c.

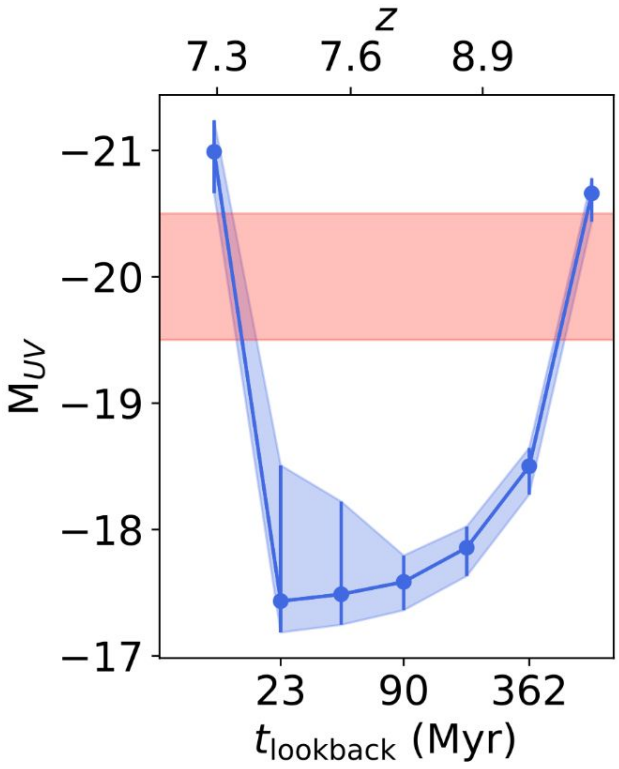
The BoRG-JWST Galaxies are Analogs to Blue Monsters: 2) Bursty star formation

- Evidence for burstiness in all 14 BoRG-JWST galaxies!
- This evolution may explain why we are finding more UV-bright galaxies at z > 10.
- Burst episodes repeated in 7 galaxies which we called “Blue Zombies”.

BoRG 138, z = 7.179

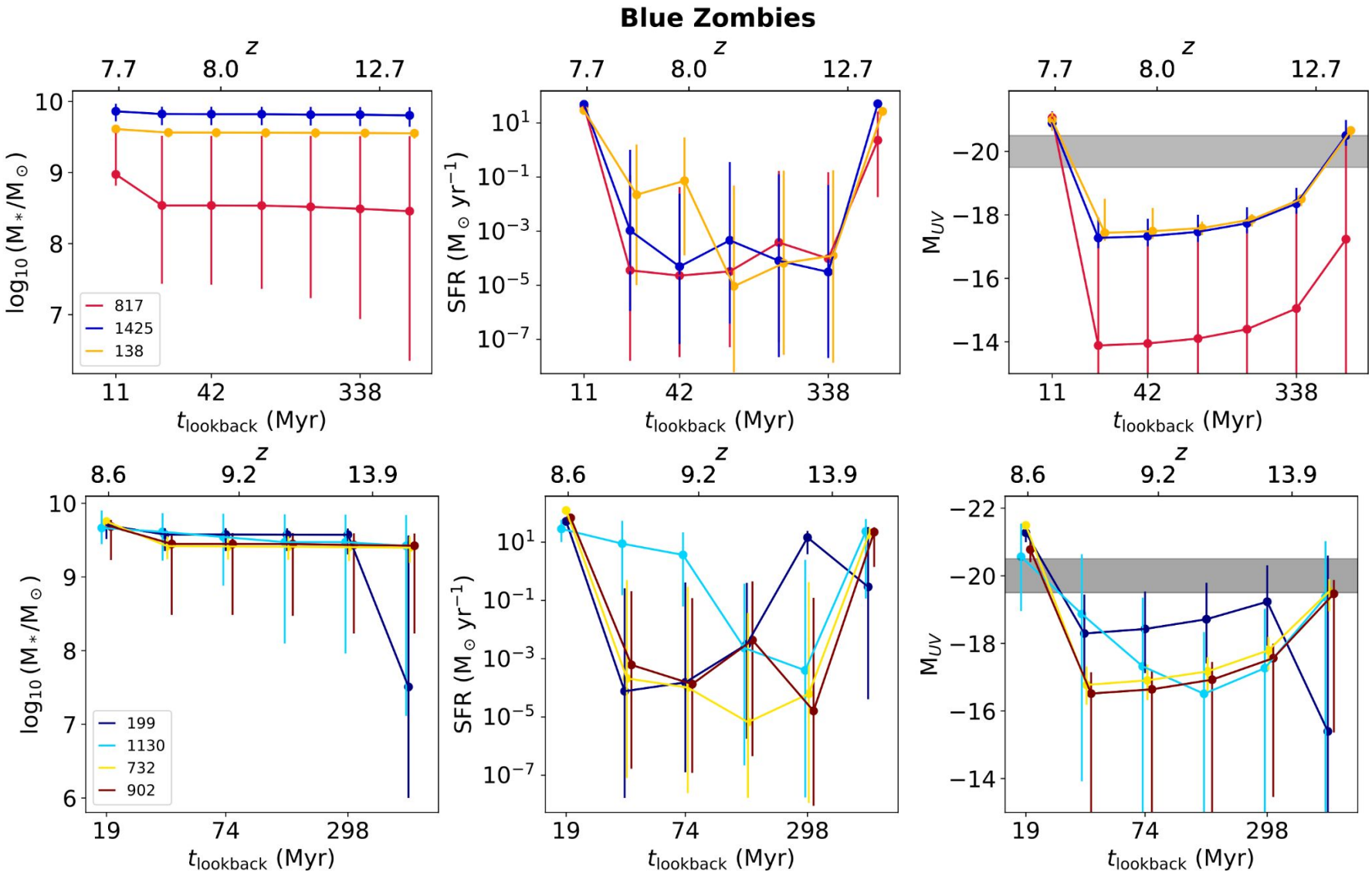






Rojas-Ruiz, S et al. 2025c.

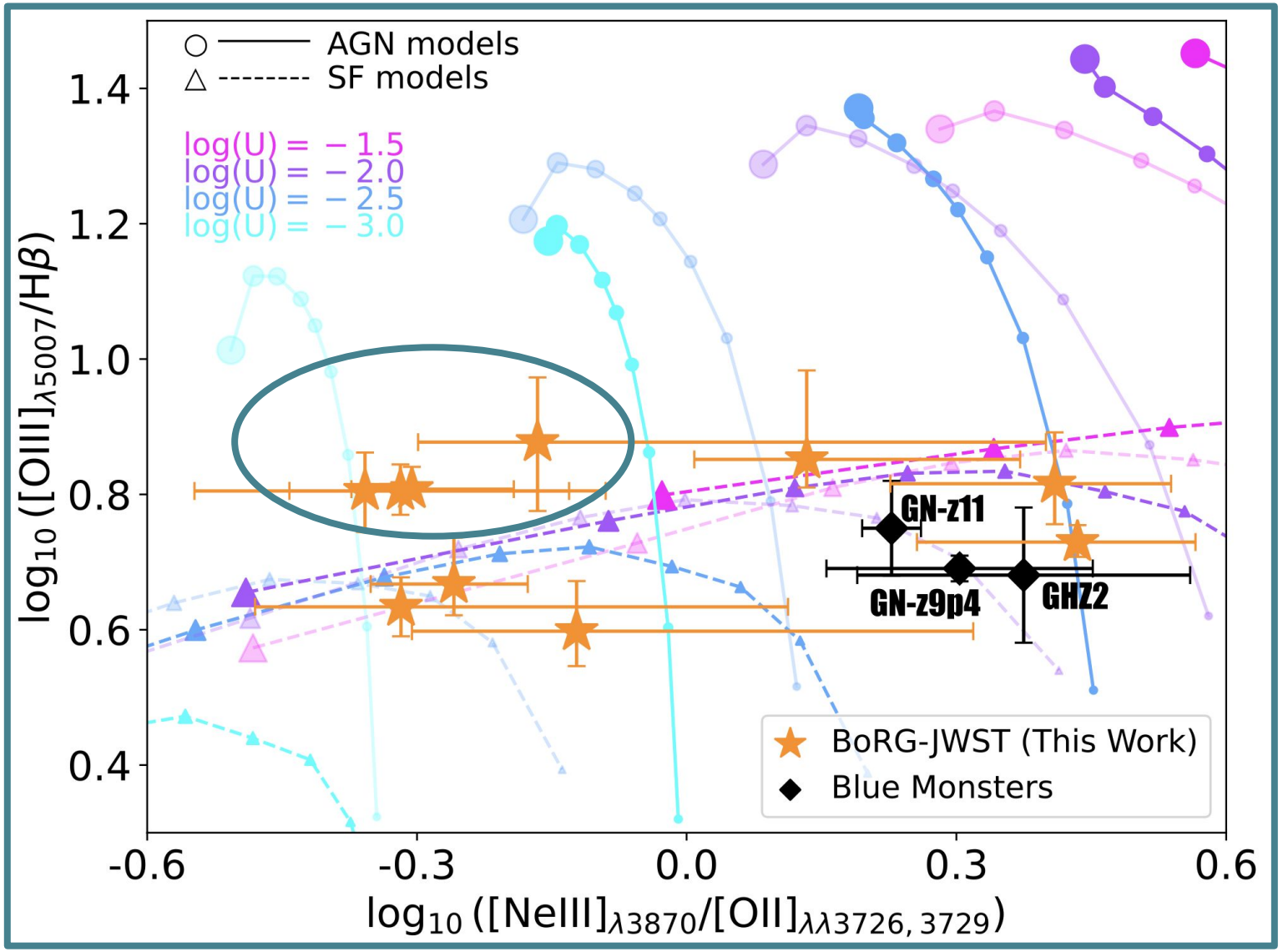
The BoRG-JWST Galaxies are Analogs to Blue Monsters: 2) Bursty star formation



Rojas-Ruiz, S et al. 2025c.

The BoRG-JWST Galaxies are Analogs to Blue Monsters: 3) AGN vs. SF nature

Dual AGN and SF nature of BoRG galaxies??



Rojas-Ruiz et al. 2025c

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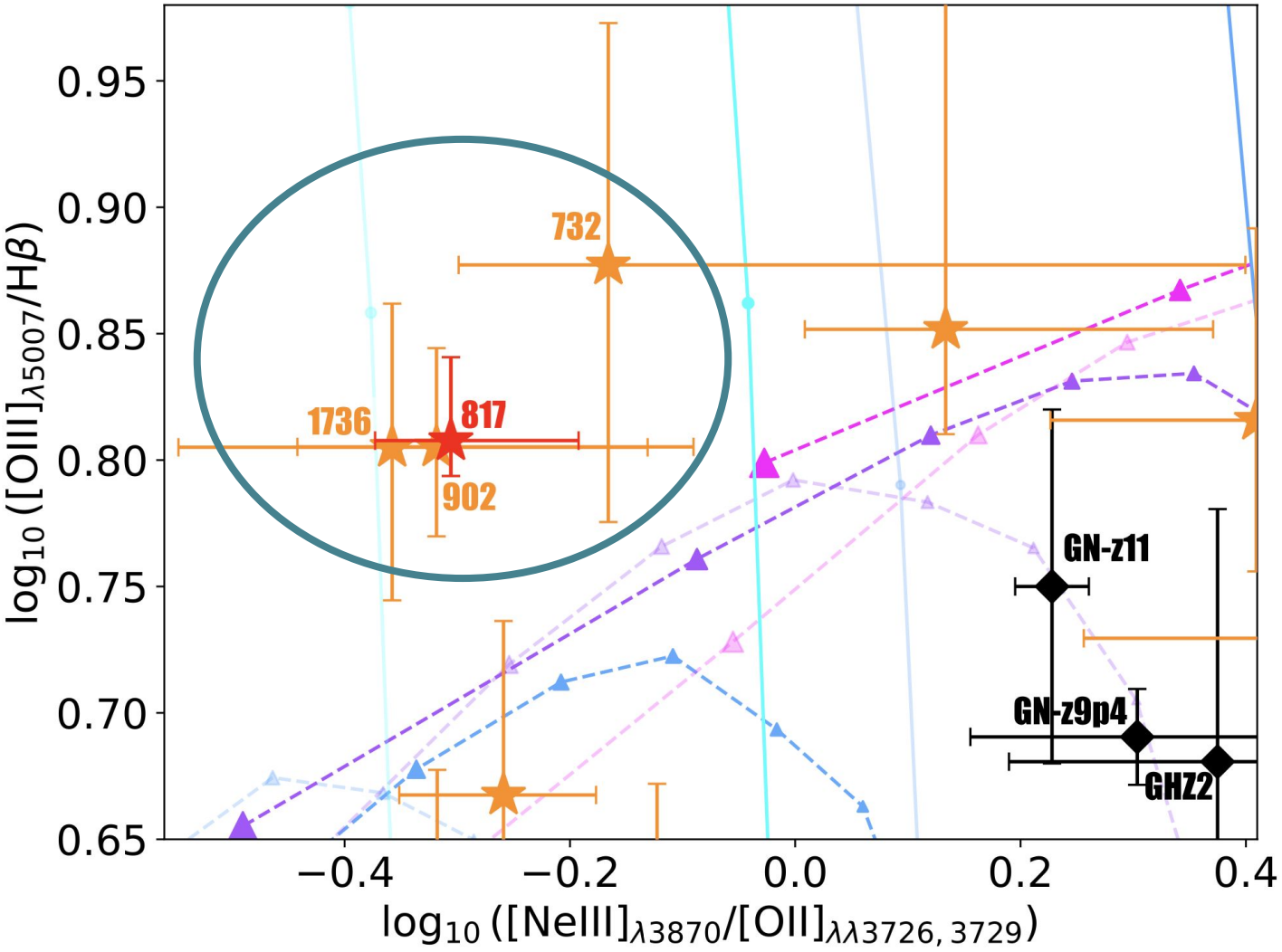


- Galaxies 2426_1736, 1747_902, 1747_817, and 1747_732 are restricted to the AGN models, only 817 has >3-sigma confidence levels.

Rojas-Ruiz et al. 2025c.

BoRG-JWST Galaxies are Truly Ideal Analogs to Blue Monsters

We investigate the rest-UV and -optical emission lines to test the theory:

1) Galaxies lack dust.

2) Stochastic star formation (starburst when observed).

3) Emission from AGN vs. stellar population.

Investigate AGN emission in JWST NIRSpec Data

Challenge: Distinguishing AGN or Star-Forming galaxy.

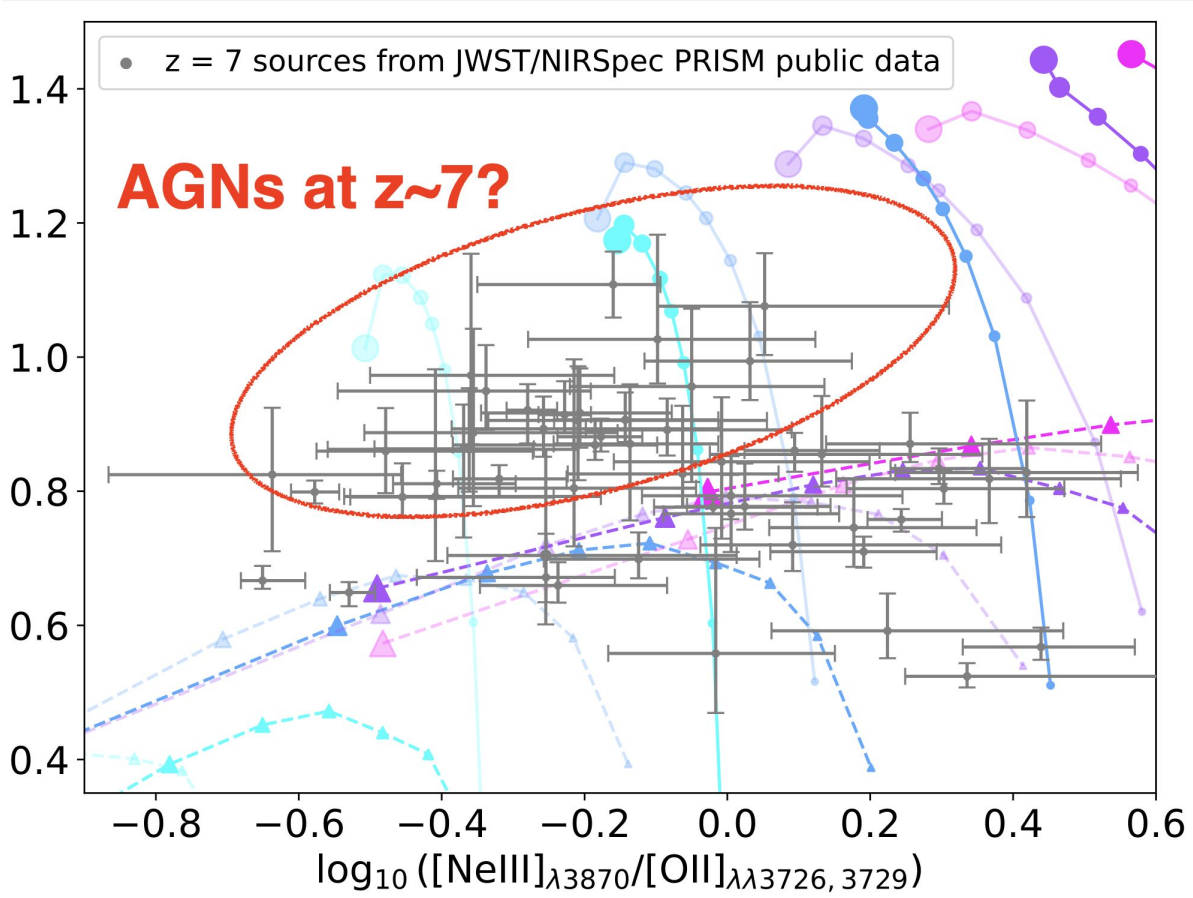
Data: 1,364 sources with NIRSpec spectra coming from major JWST Legacy Surveys such as GLASS, JADES, CANUCS, RUBIES, CEERS, BoRG-JWST, etc.

Methodology:

1) Traditional OHNO Diagnostic

Investigate AGN emission in JWST NIRSpec Data

Undergraduate student at UCLA:
Isaiah Mills Terry



Rojas-Ruiz, Mills Terry et al. in prep.

Investigate AGN emission in JWST NIRSpec Data

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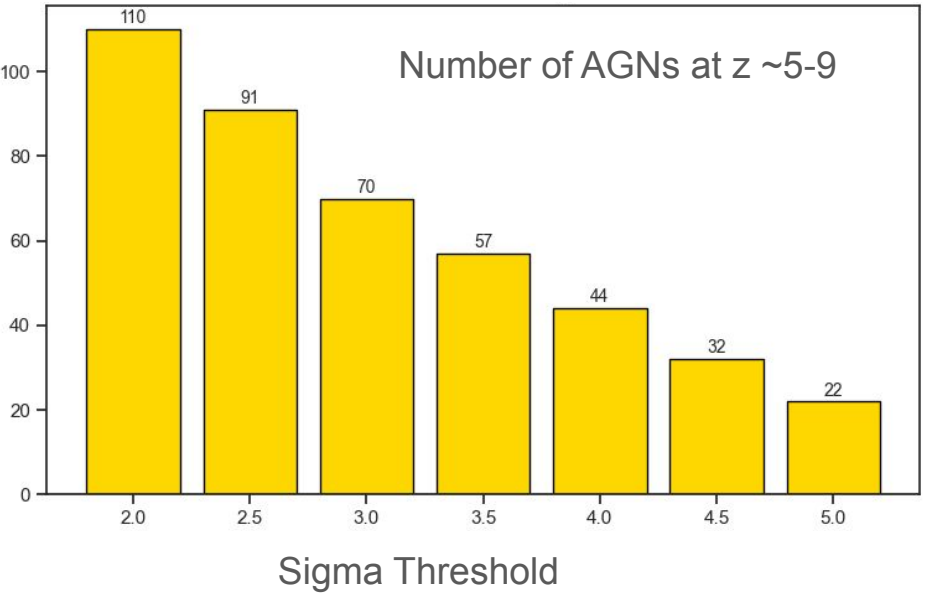
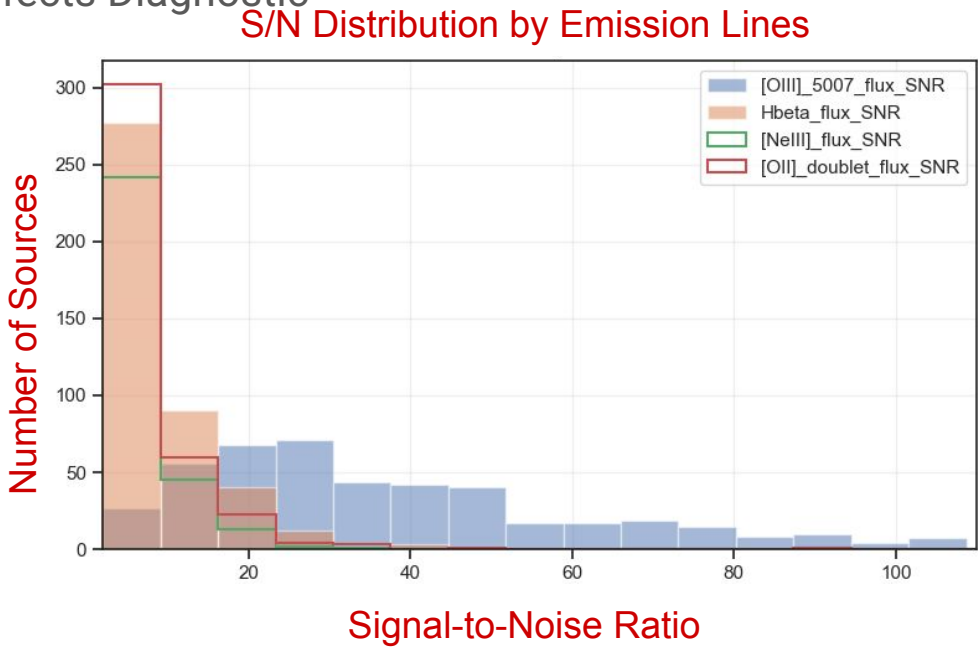
Methodology:

1) Traditional OHNO Diagnostic: Poor SNR affects Diagnostic





Rojas-Ruiz, Mills Terry et al. in prep.

Undergraduate student at UCLA: Isaiah Mills-Terry

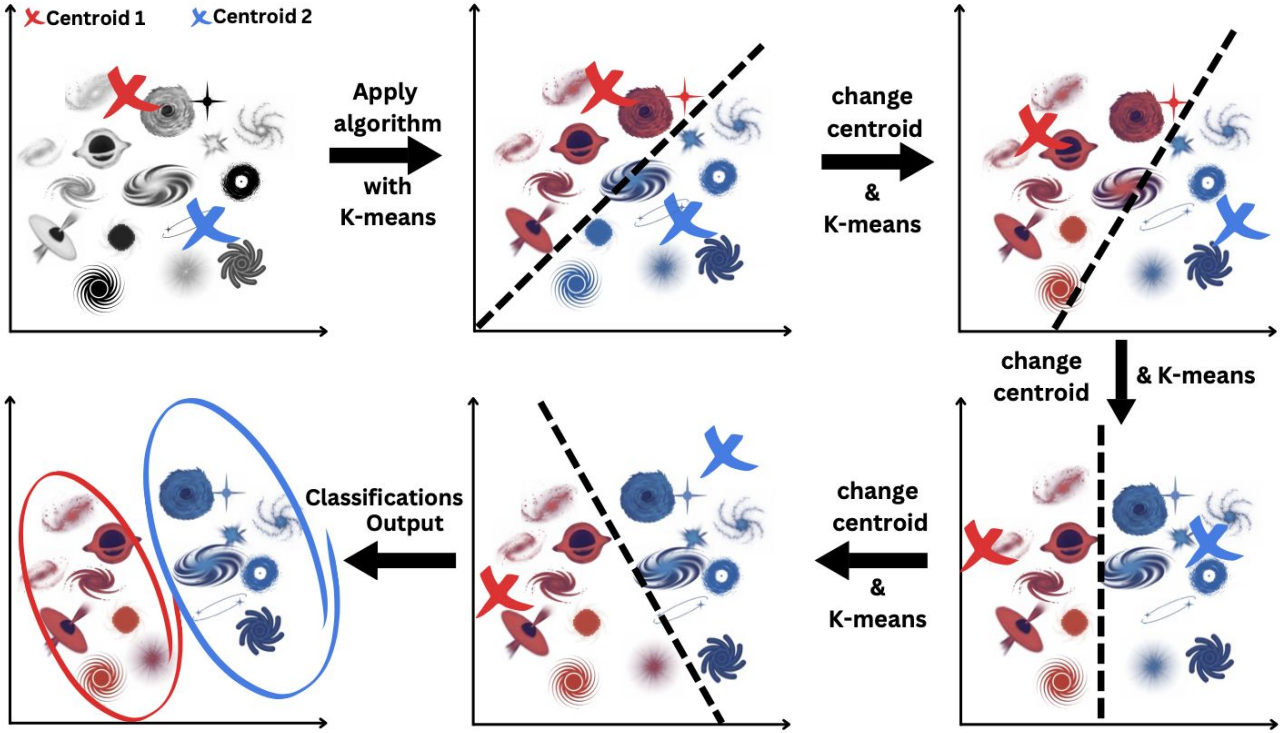
Investigate AGN emission in JWST NIRSpec Data

Challenge: Distinguishing AGN or Star-Forming galaxy.

Data: 1,365 sources with NIRSpec spectra coming from major JWST Legacy Surveys such as GLASS, JADES, CANUCS, RUBIES, CEERS, etc.

Methodology:

1) Traditional OHNO Diagnostic: Poor SNR affects OHNO diagnostic, MIRI would be inefficient.
2) Machine Learning Methods: Classify AGNs and assign confidence level with probabilities



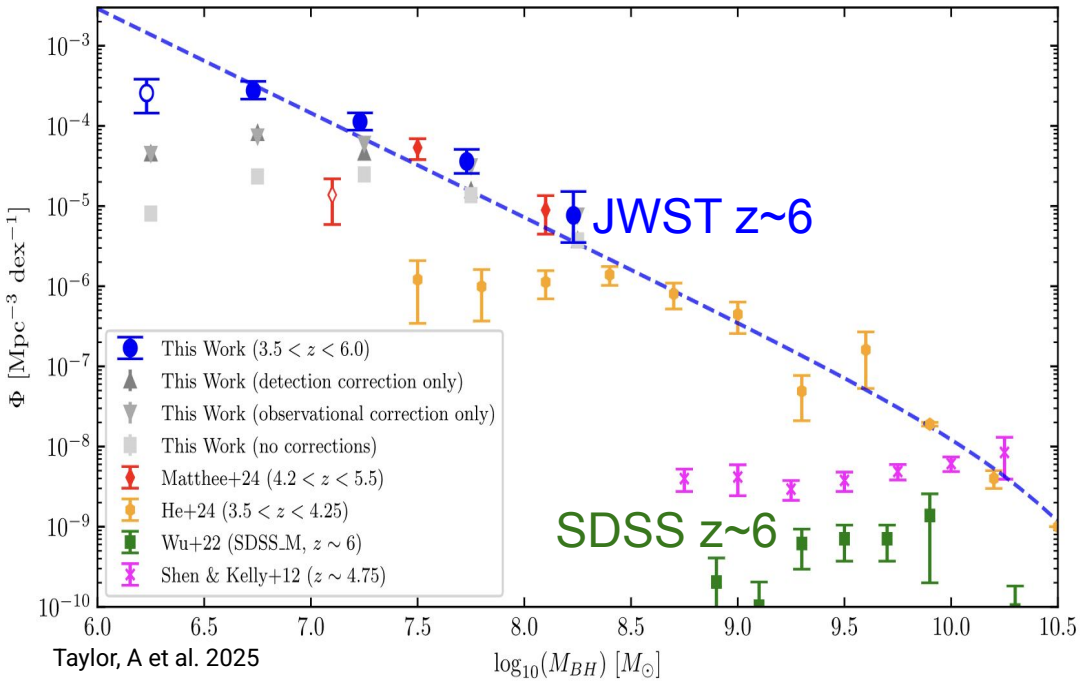
Introduce more 'features' besides the OHNO ratios:

- multiwavelength data (X-rays to radio).
- JWST Photometry.

Rojas-Ruiz et al. in prep.

Investigate Black Holes Mass Function with classified AGNs

Current picture of the BH mass function



Taylor, A et al. 2025

Synergy with large-scale survey observations

- Rubin's high-resolution imaging will allow better AGN diagnostics using machine learning.
- Find several million AGNs at $z > 4$, with ~1,000 AGNs at $6 < z < 7$.
- Build the BH mass function to fill in the gap, explain any discrepancies, and potentially solve mysteries like the "Little Red Dots" from JWST.

SUMMARY

BoRG-JWST Galaxies provide a key opportunity to explore early galaxy evolution.

- Provide a **representative sample** of the galaxy population at z=7-9 through the independent sightline observations that **overcomes cosmic variance.**
- **Confirm a higher abundance of bright galaxies** in the UVLF at z~8, alleviating tensions with z > 10 galaxy findings.
- **Ideal analogs** of the z > 10 Blue Monster galaxies with **poor dust content and stochastic episodes of star formation.**
- The nature of emission from **SF galaxy or AGN cannot be distinguished** with available rest-optical emission lines.
    - **Machine learning methods could robustly classify** SF galaxyies / AGNs with quantified confidence level.