THE KAVLI FOUNDATION

UNIVERSITY OF CAMBRIDGE

Black hole growth and galaxy quenching with JWST: new discoveries and old questions

Leiden 2-4-2025

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erc UKRI Science and Technology Facilities Council

Three main topics

Quiescent galaxies

Nascent SMBHs

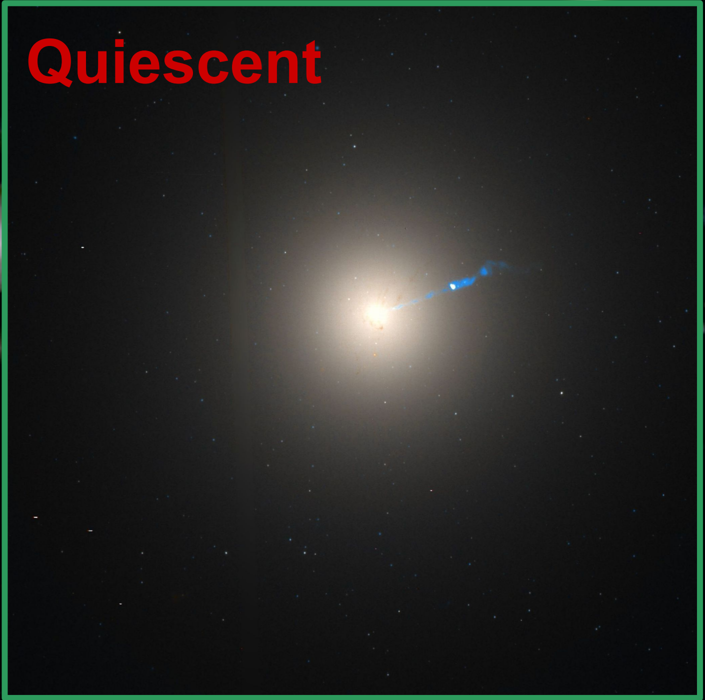
Dust at high-z

For massive galaxies, we need to look at z>2

All massive quiescent galaxies stopped forming stars at high z

Star forming

Quiescent



Frow JWST we learned:

- Gas is removed
- Neutral-gas outflows
- Link with AGN
- ~70K dust

[M77: NASA, ESA & A. van der Hoeven. M87: NASA]

For massive galaxies, we need to look at z>2

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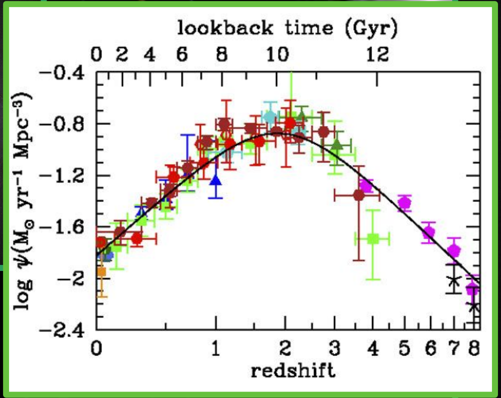
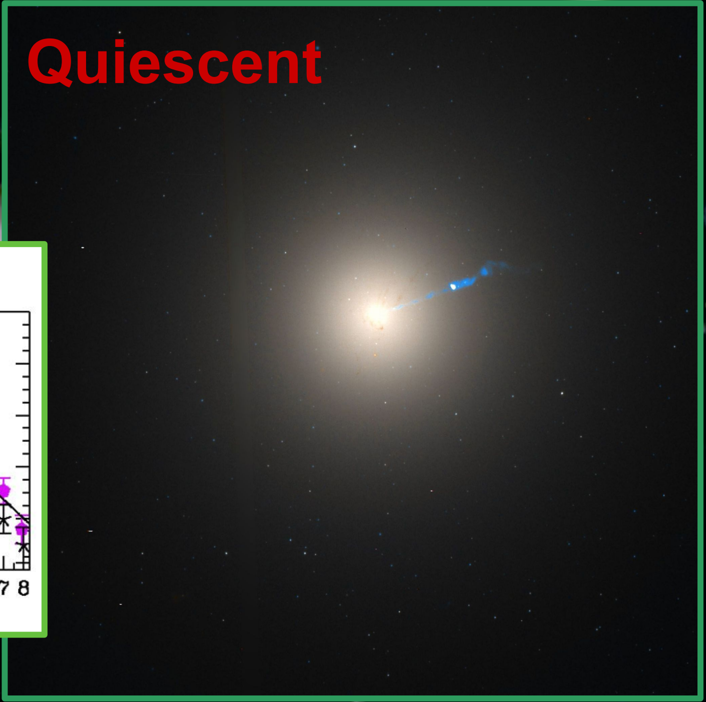
Star forming



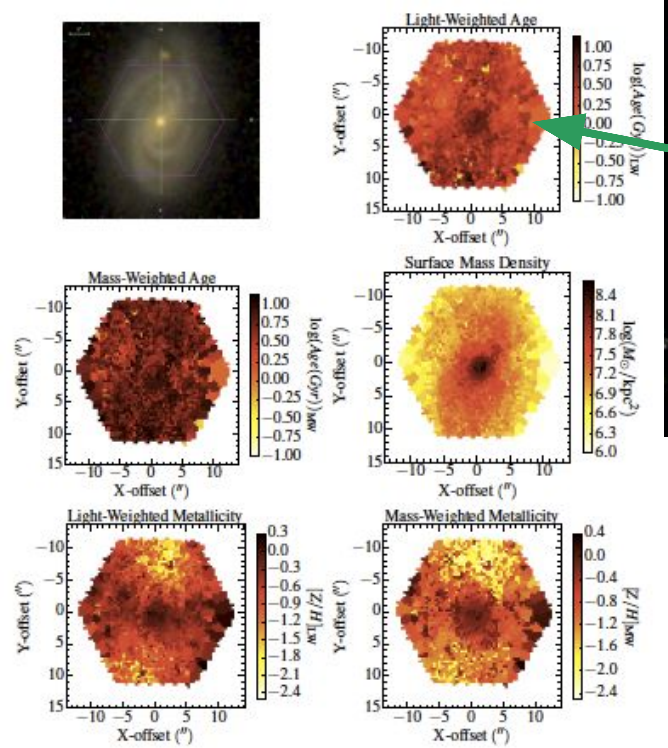
Quiescent



PSB galaxies may be an alternative path (not for everything)

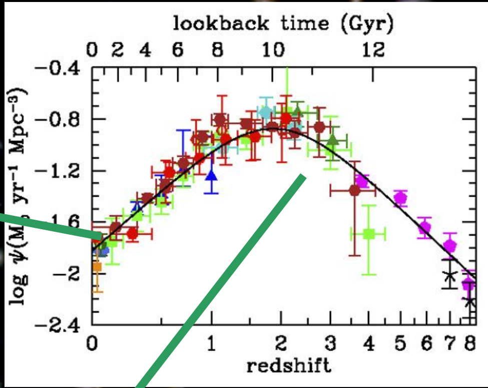
[M77: NASA, ESA & A. van der Hoeven. M87: NASA. Madau & Dickinson (2014)]

Before Webb, only possible for emission lines

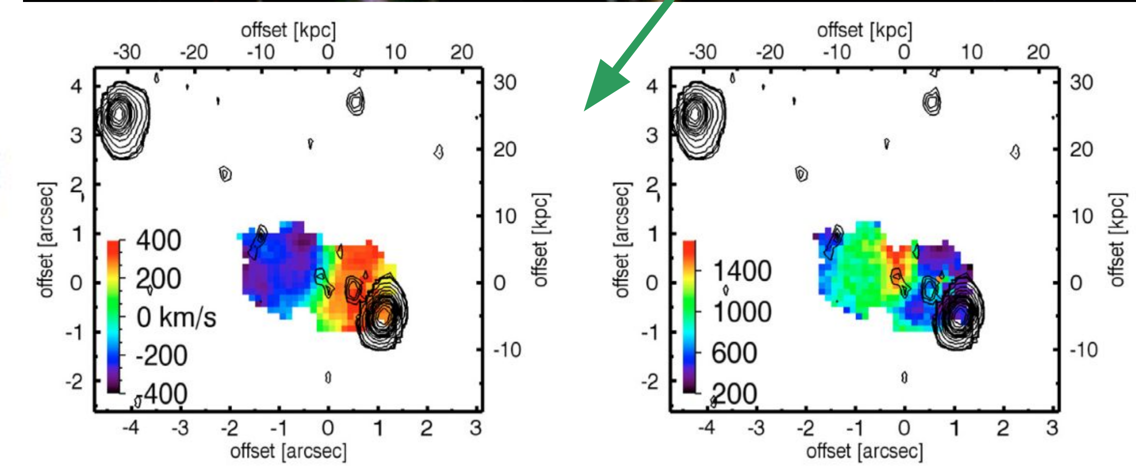


[Neumann+2022]

We could study outflows only at high-z, but quenching (via stellar populations) only at low z.



(Madau+Dickinson 2014)

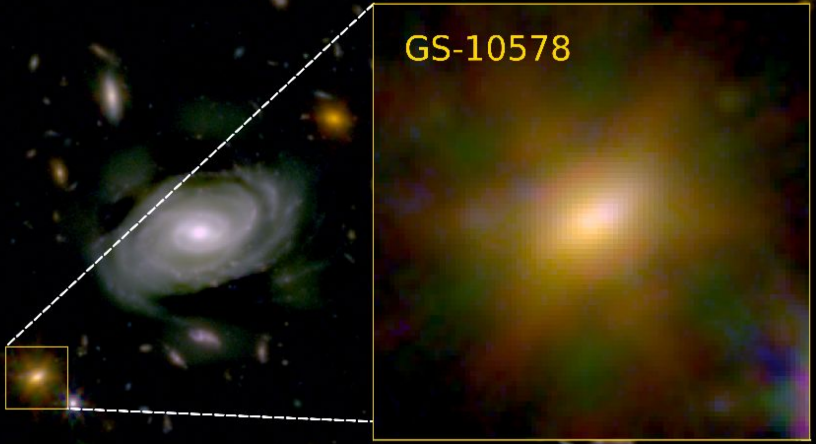


[Nesvadba+2008]

Quiescent galaxies with JWST

Studying massive galaxies near in time to when they became quiescent

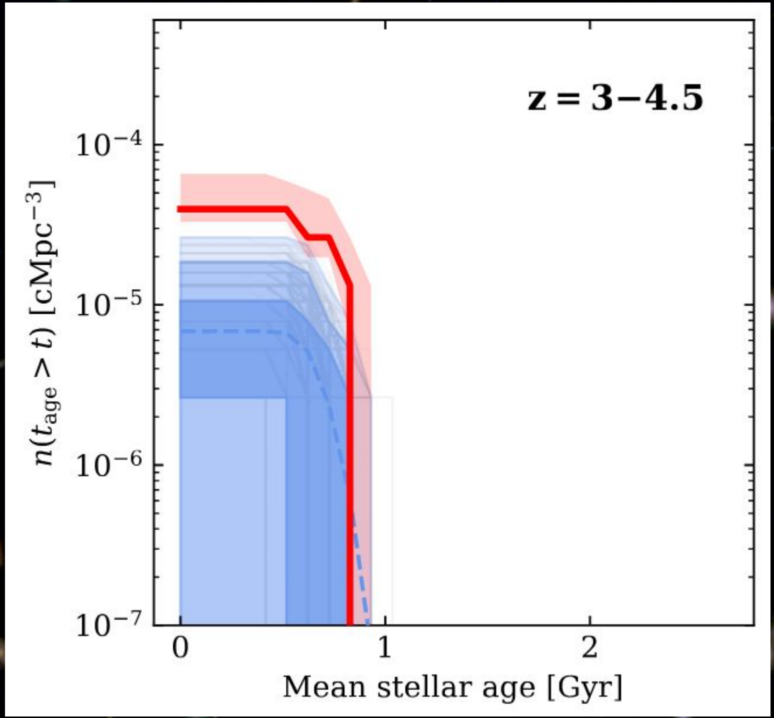
- Less time for passive evolution
- Less time available to spread AGN activity



One of the JWST quiescent galaxies, demonstrating its compactness: 0.2-arcsec resolution is required to study their structure.

HUDF [The JADES Collaboration]

An overabundance of massive, quiescent galaxies of 10x (rel. to simulations)



[Baker, Lim, et al. (2024)]

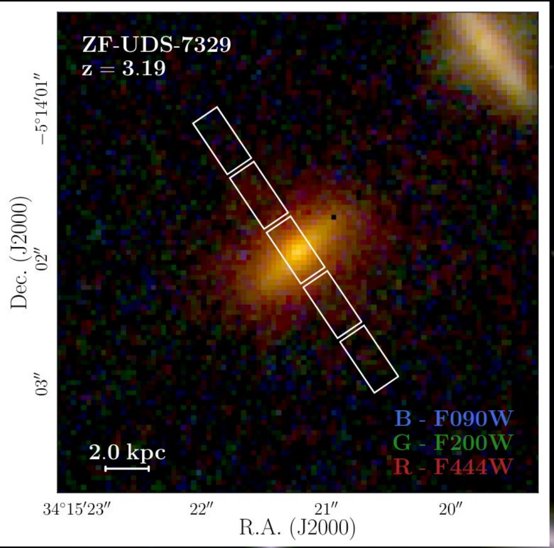
They also provide:

Info on AGN-driven quenching (Lagos et al. 2024)

→ 30% have AGN (Baker, Lim et al. (2024)

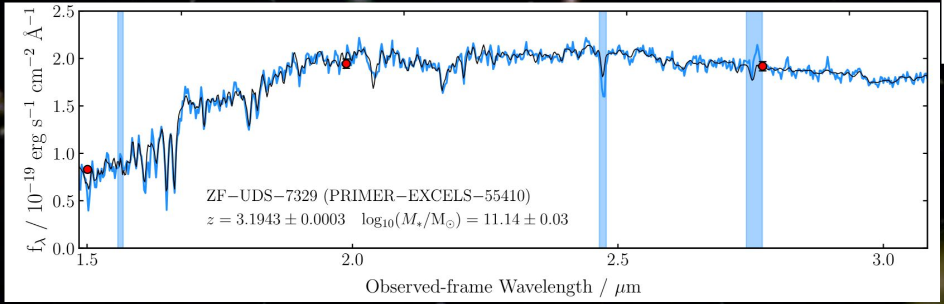
[Straatman et al. 2014; Schreiber et al. 2015, 2018; Merlin et al. 2019; Valentino et al. 2020; Shahidi et al. 2020; Carnall et al. 2020; Gould et al. 2023; Weaver et al. 2023; Carnall et al. 2023b; Valentino et al. 2023; Nanayakkara et al. 2024a,b; Long et al. 2023; Alberts et al. 2023, Xie et al. 2024, Remus & Kimmig 2024].

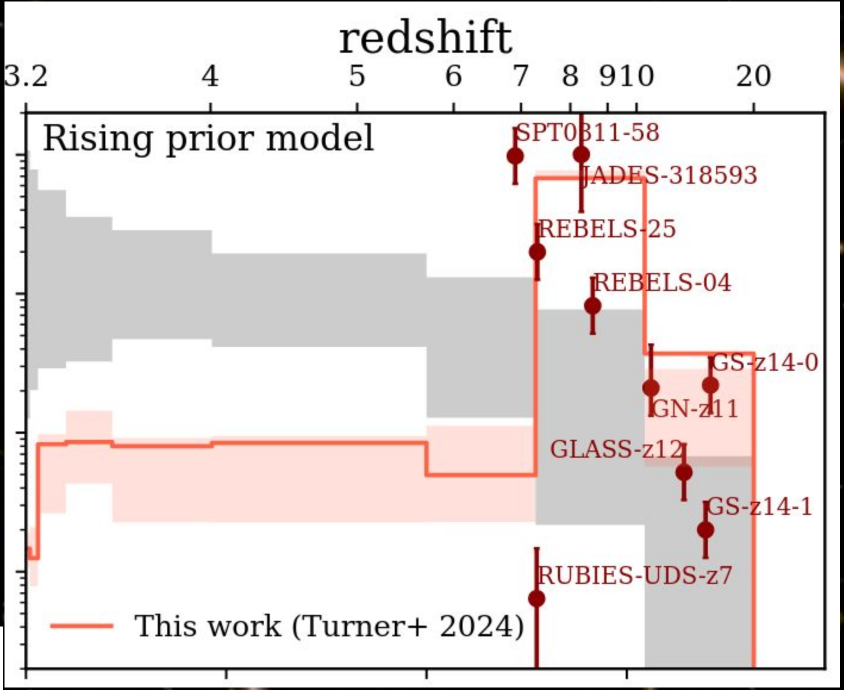
Massive z=3 quiescent galaxy formed by z~7



JWST can study the SFH of these quiescent galaxies

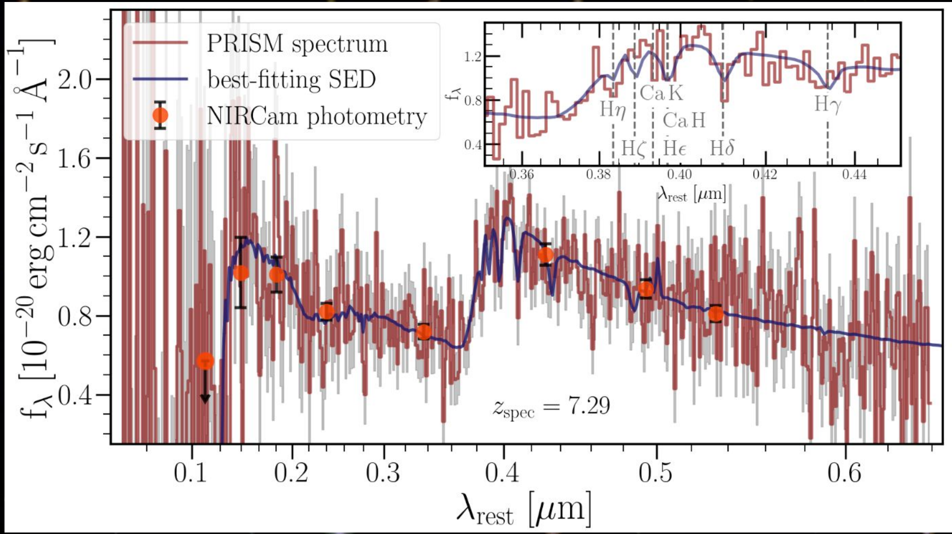
ZF-UDS-7329 z~3.2 [Glazebrook+2024]

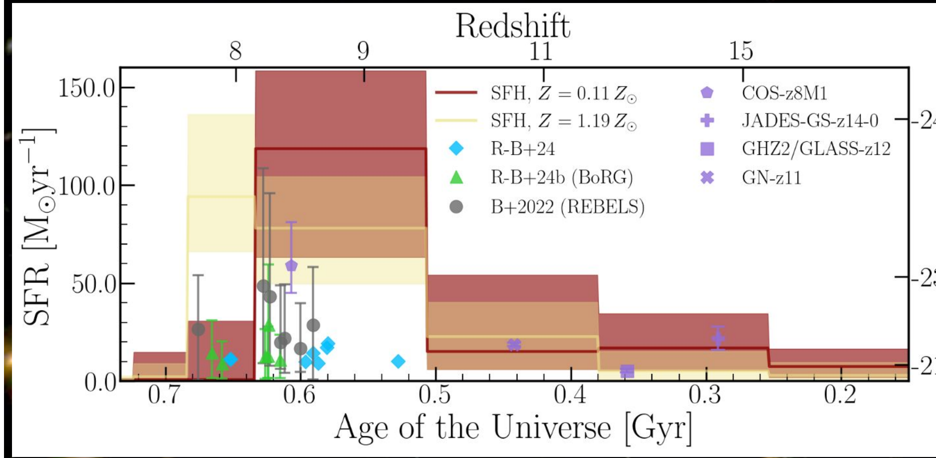




- extremely rapid formation
- baryon conversion efficiency ϵ~1 (Glazebrook+2024, de Graaff+2024, Carnall+2024)

A massive, quenched galaxy at z=7.3



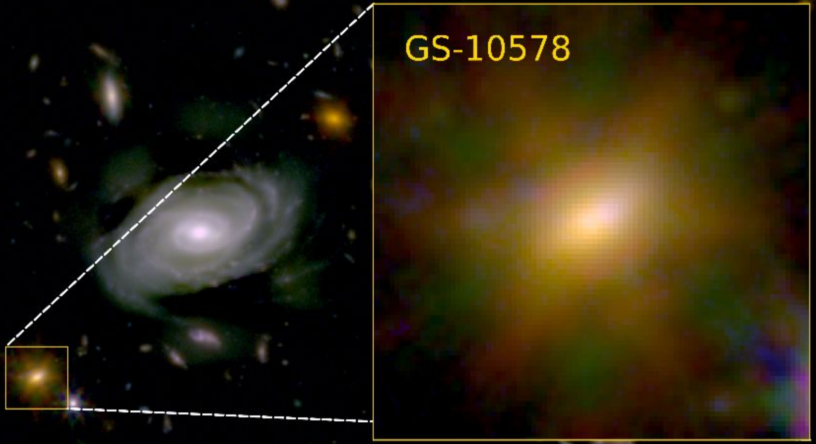


SFH tell us the truth: we are uncovering the early quenching progenitors!

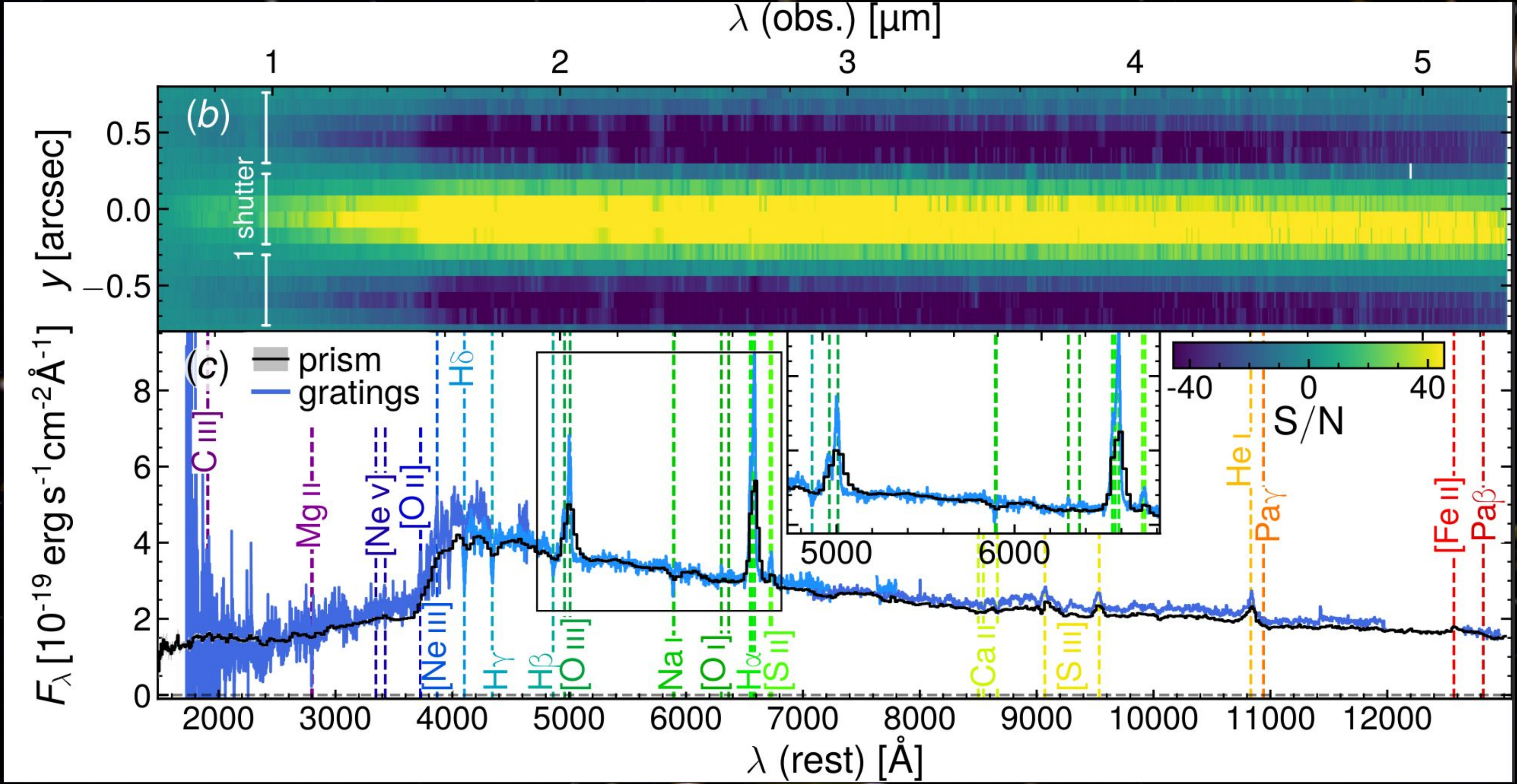
RUBIES-UDS-QG-z7 at z=7.3
[Weibel+2024]

Dissection of GS-10578: a massive, quenched galaxy at z=3

In collaboration with Pablo Pérez-Gonzàlez

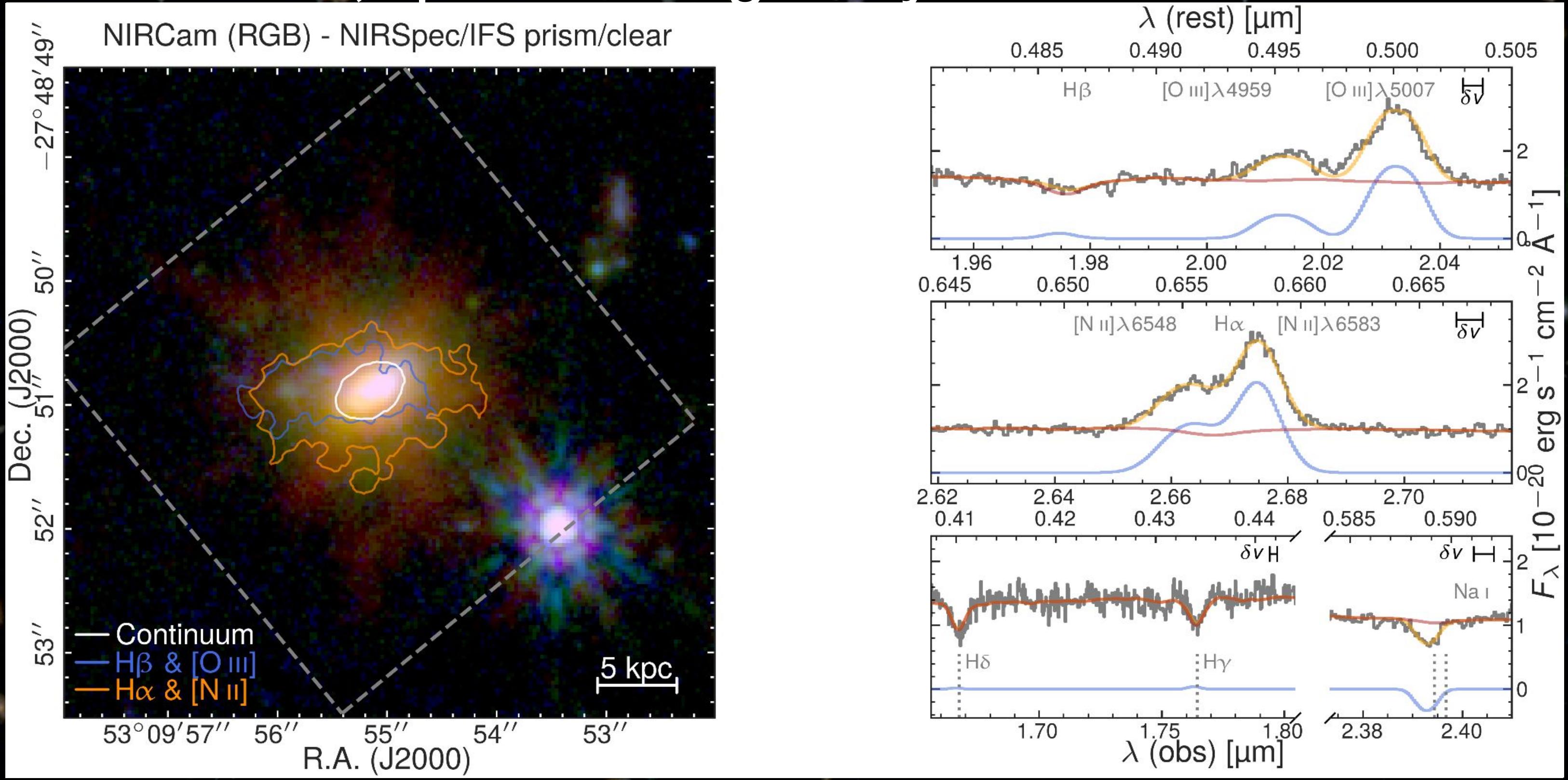


Post-starburst spectrum from JADES DR3



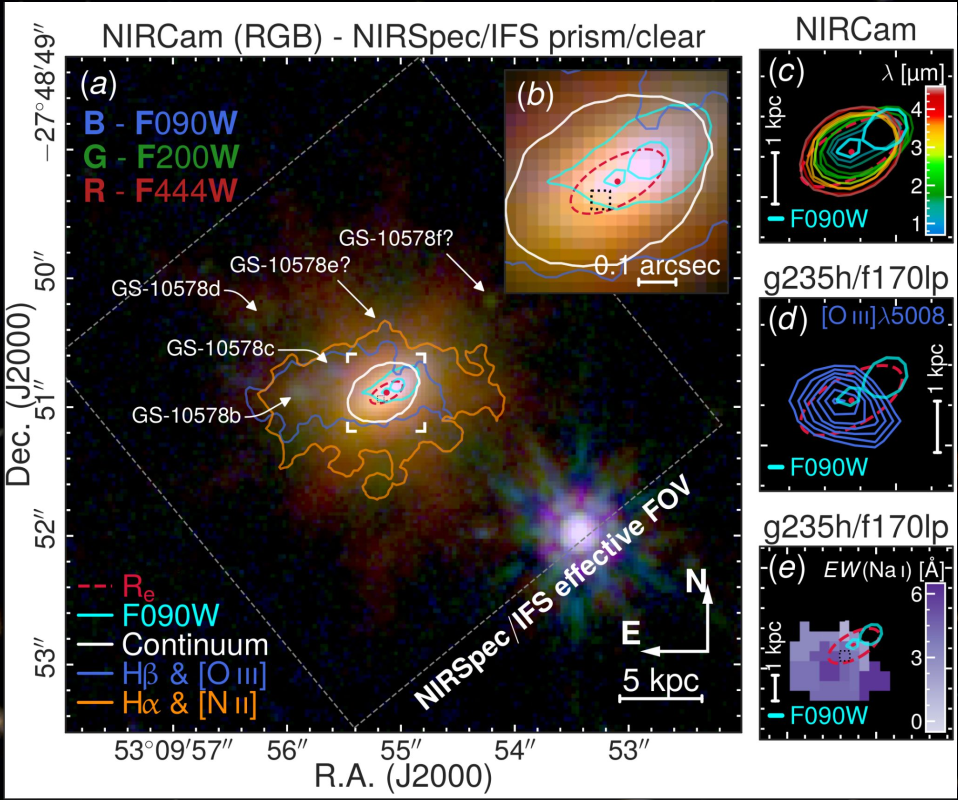
[D'Eugenio et al. (2024)]

A massive, quenched galaxy at z=3

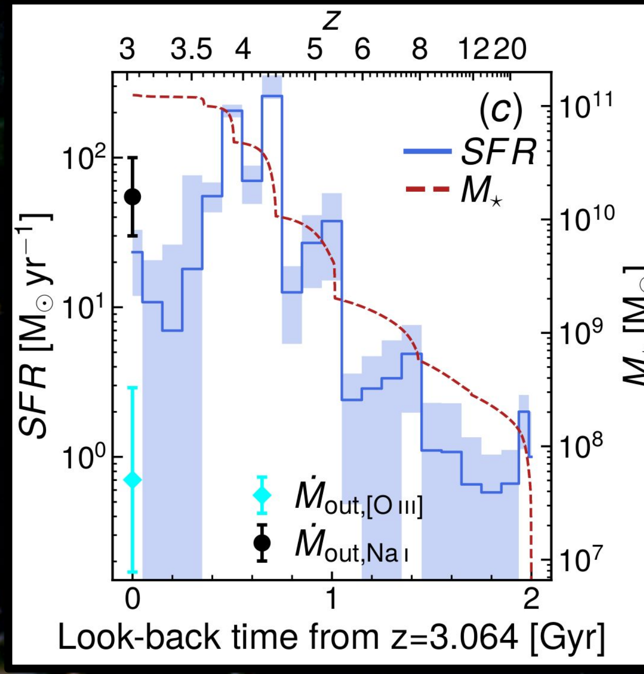


NIRSpec reveals very broad emission lines (top, middle), stellar absorption (bottom, left), and ISM blueshifted absorption (bottom, right)

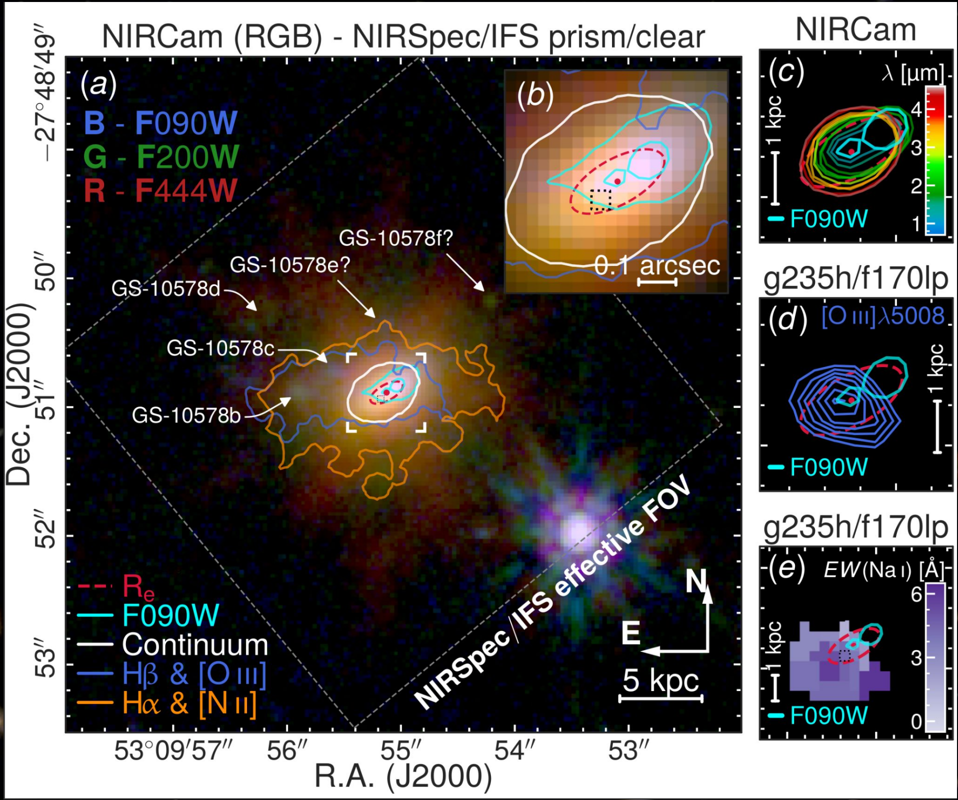
A massive, quenched galaxy at z=3

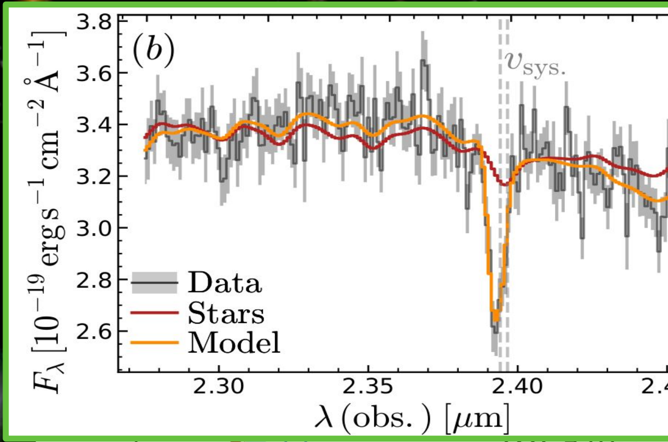


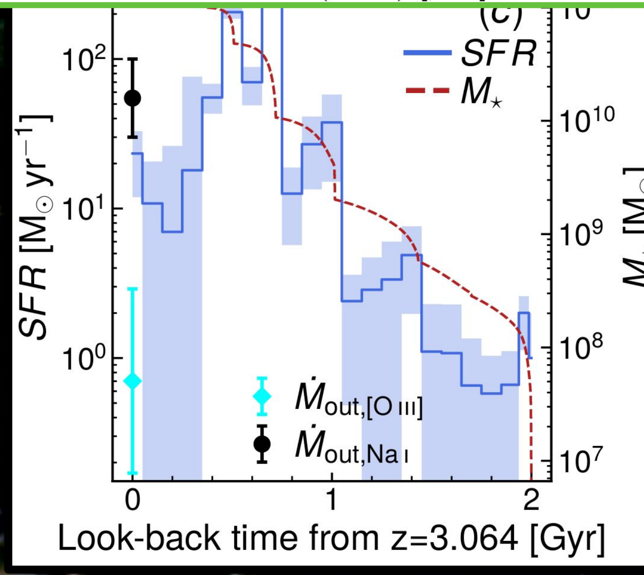
The galaxy is quenched (SFH below), yet it is still embedded in ionized gas (blue and orange contours to the left)



A massive, quenched galaxy at z=3



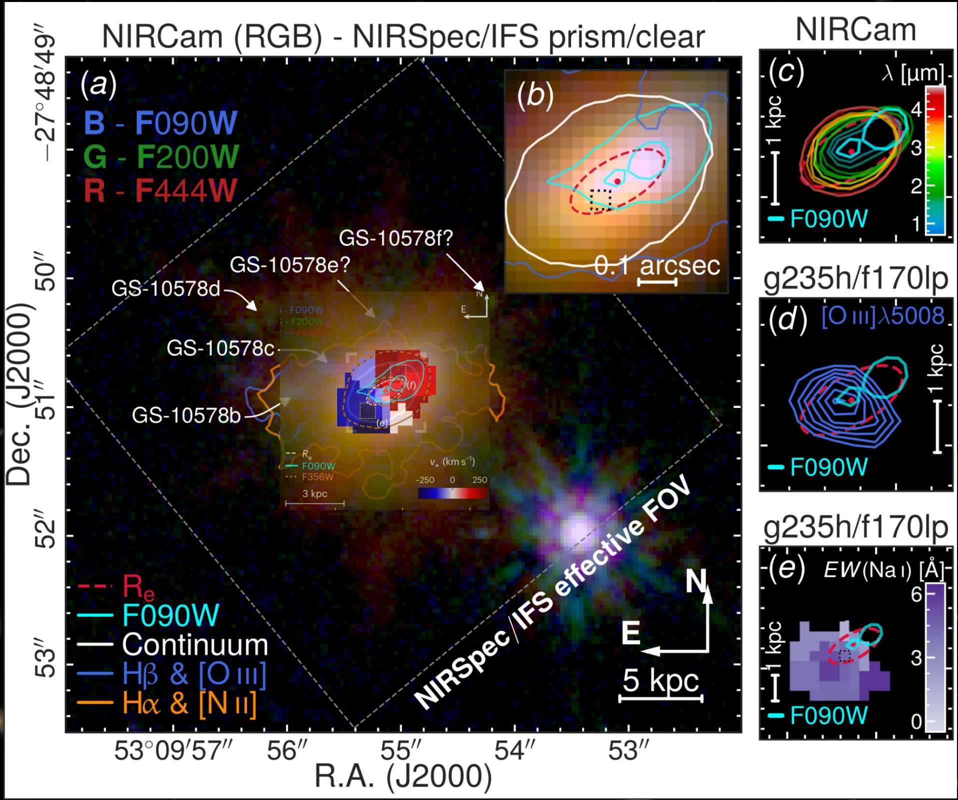


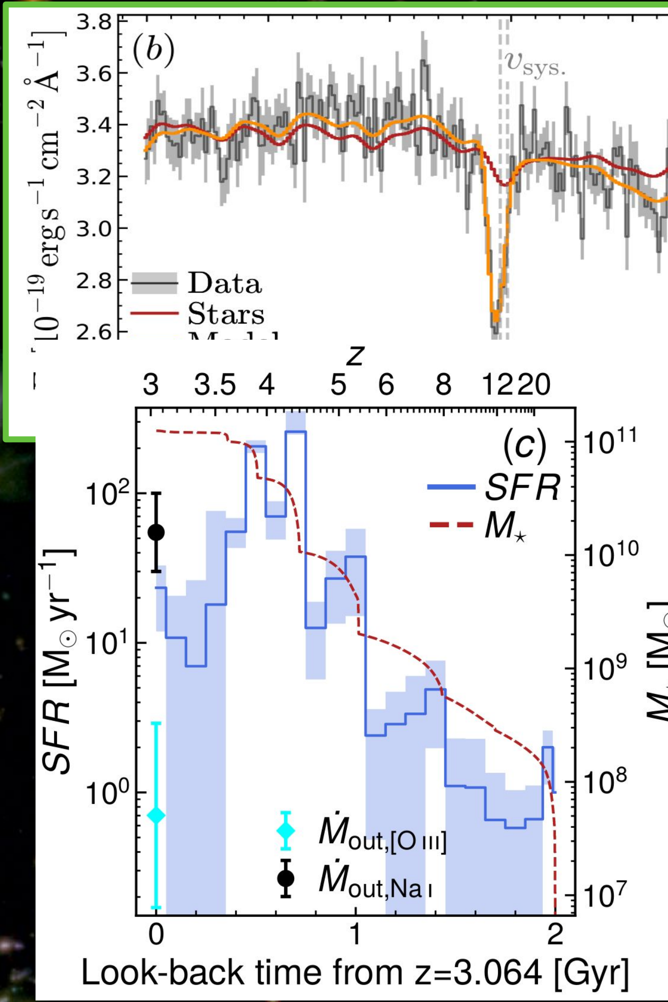


Powerful neutral-gas outflows (top right spectrum, orange)

(see also Belli et al. 2024, Davies et al. 2024)

A massive, quenched galaxy at z=3





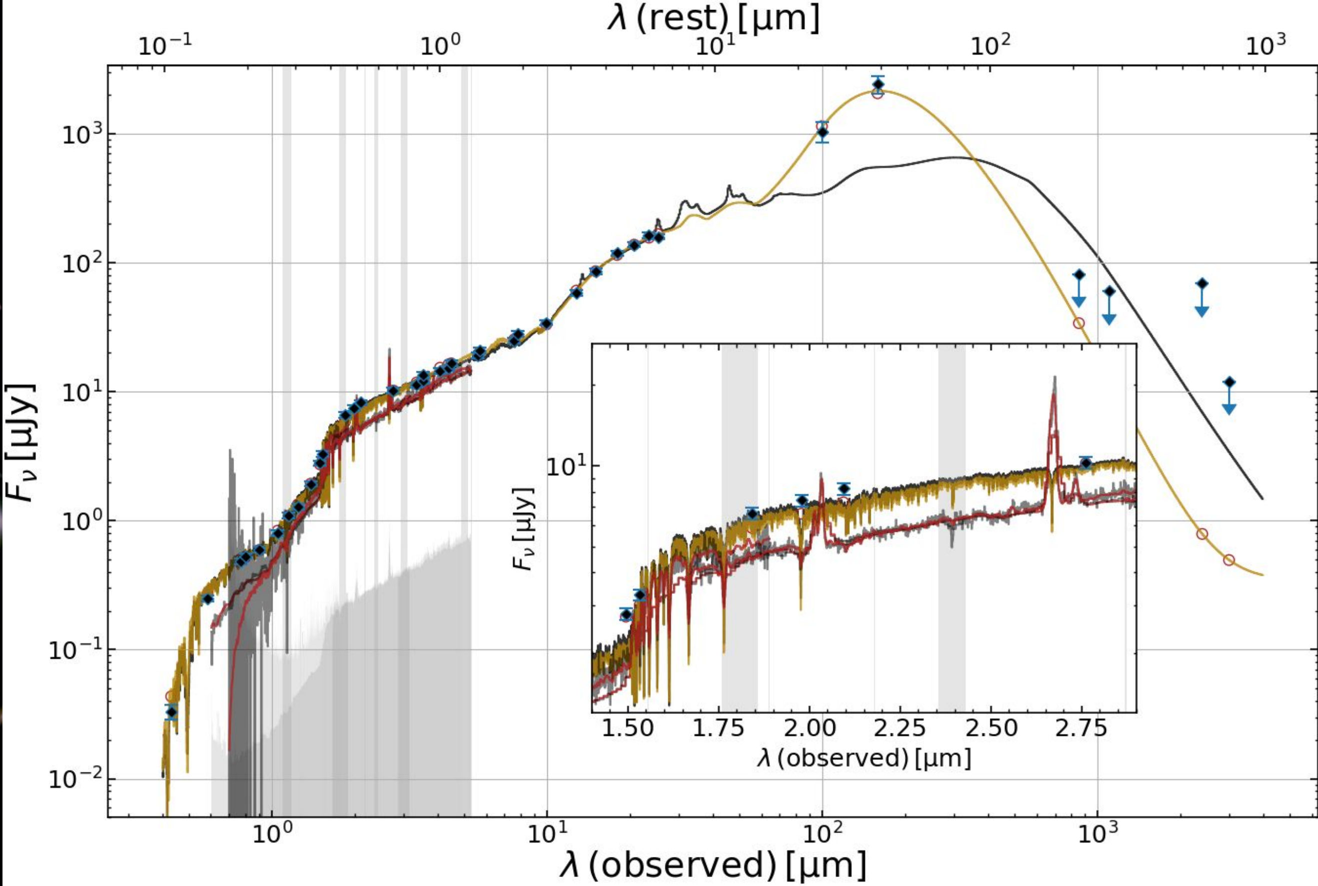
These outflows have high mass loading (right, black point), capable of stopping star formation (cf. [OIII] outflow)

A massive, quenched galaxy at z=3

JWST + ALMA + Herschel:

- Obscured AGN
- Massive
- No ongoing SF (<3 M/yr)

…yet relatively high dust temperature, >70 K



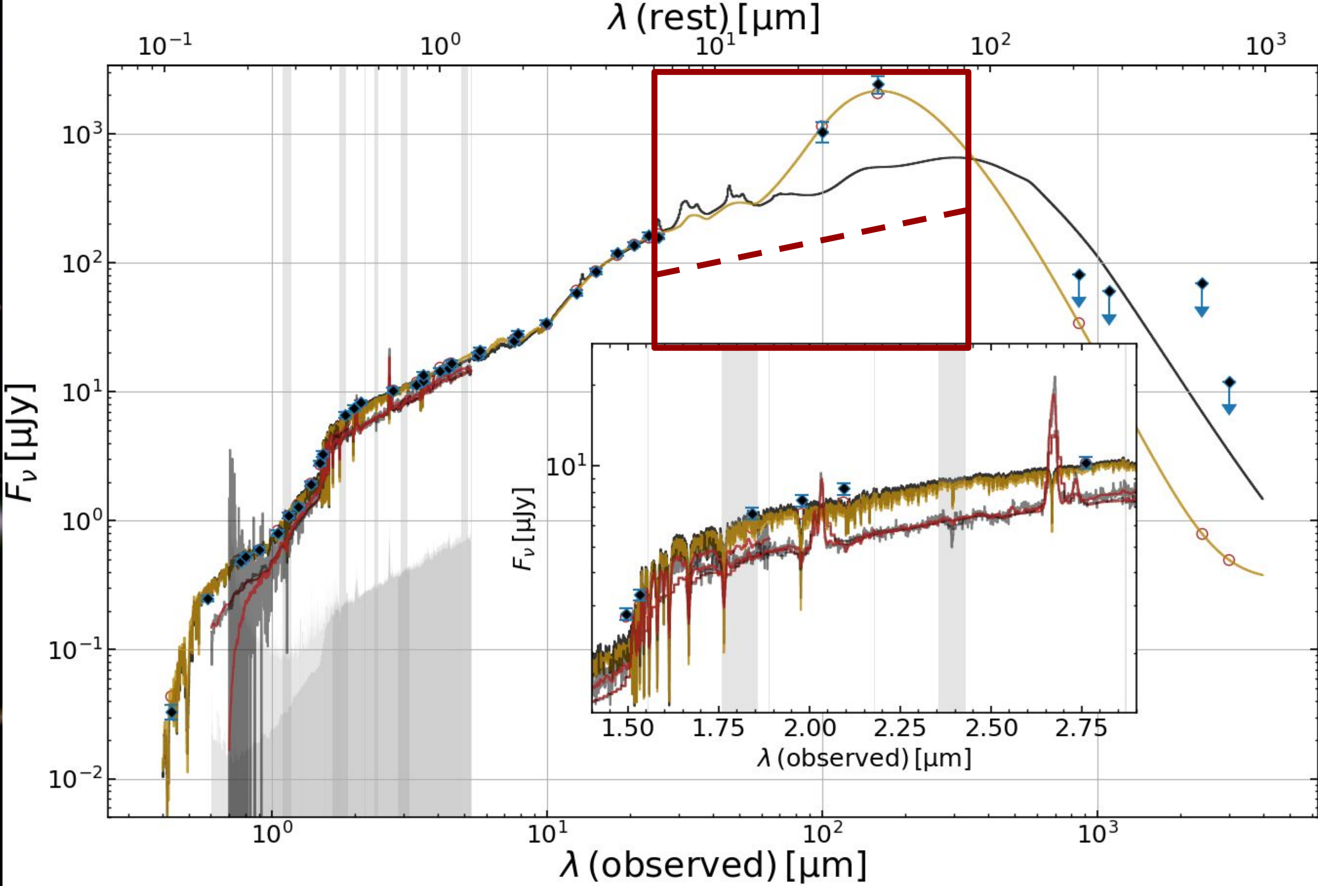
A massive, quenched galaxy at z=3

JWST + ALMA + Herschel

- Obscured AGN
- Massive
- No ongoing SF (<3 M/yr)

…yet relatively high dust temperature, >70 K

Going 1 dex lower than Herschel, we reach the typical massive galaxy at z=3



Are outflows quenching galaxies?

Open questions:

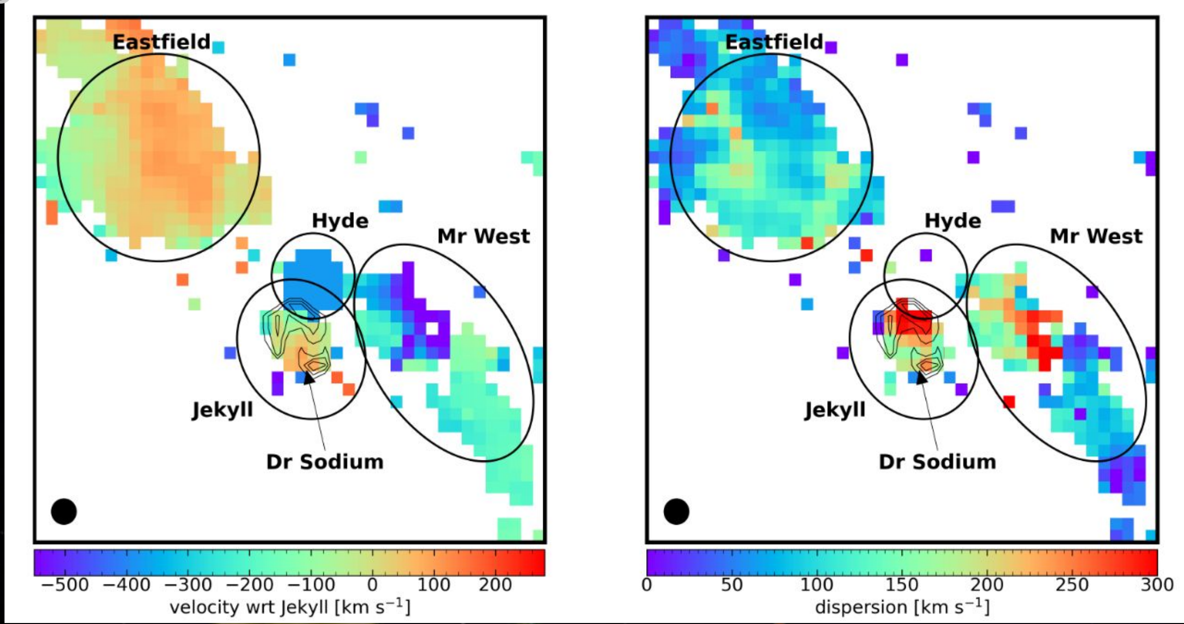
Certainly no1t single episodes, but could be the cause.

What happens to the cold molecular gas?

'Voorwerpen' or tides?

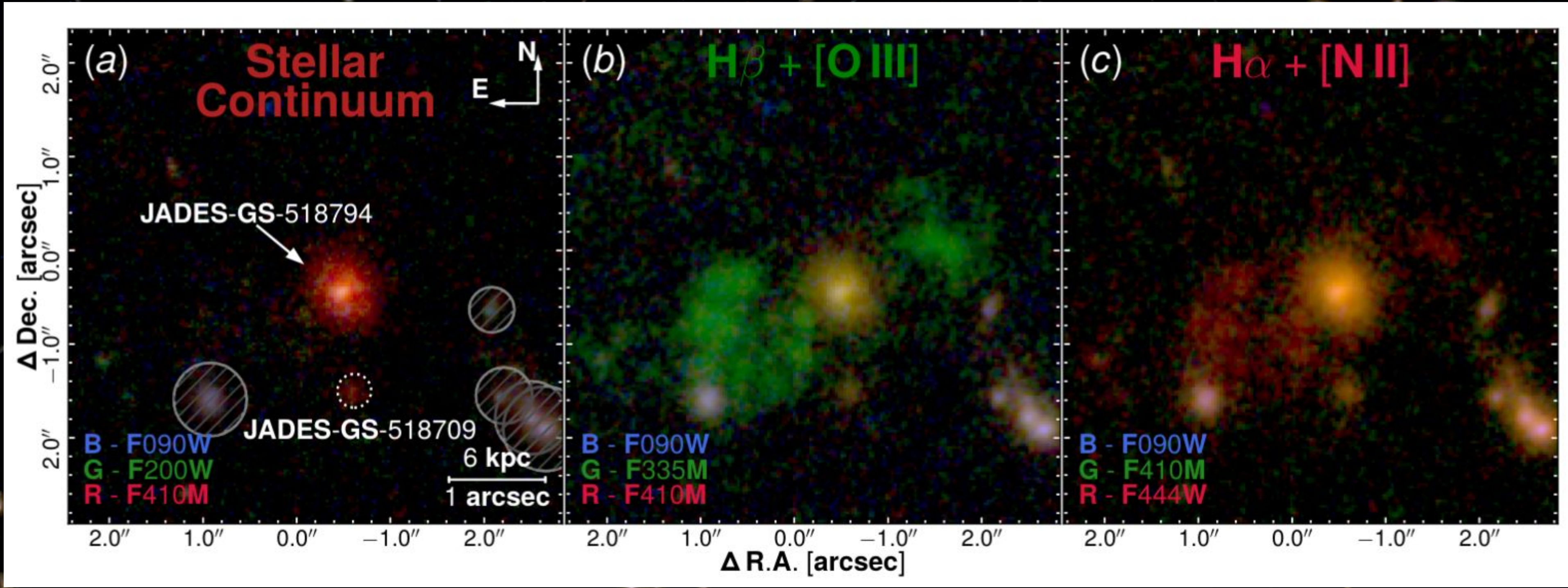
High duty cycle -> Many progenitors are AGN (and even QSO Onoue+2024)

Another massive quiescent galaxy (Jekyll) with extended ionized gas (Eastfield and Mr West)



[Perez-Gonzalez et al. (2024)]

The effects of feedback on host galaxies: outflows

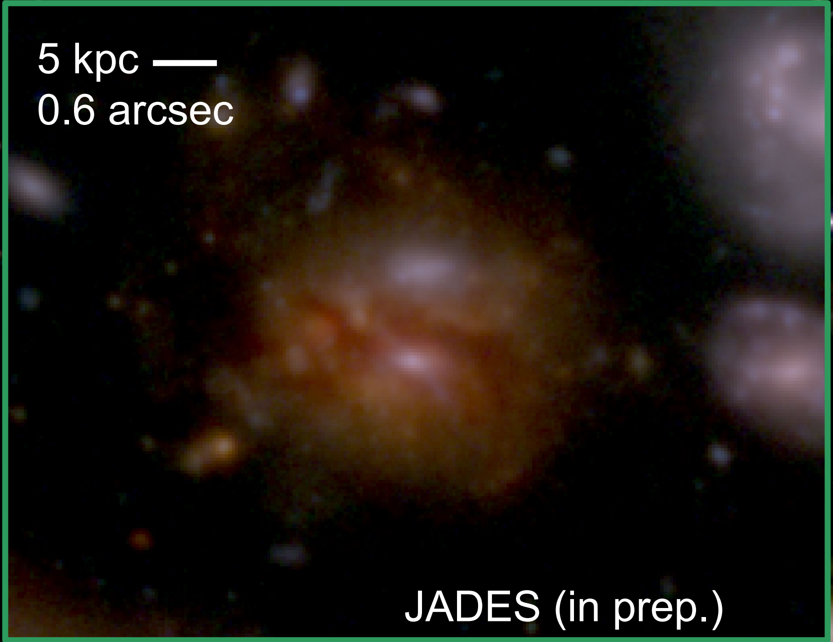


Even NIRCam is demonstrating its ability to catch outflows, in this case a quasar-like nebula around a clearly non-quasar central galaxy

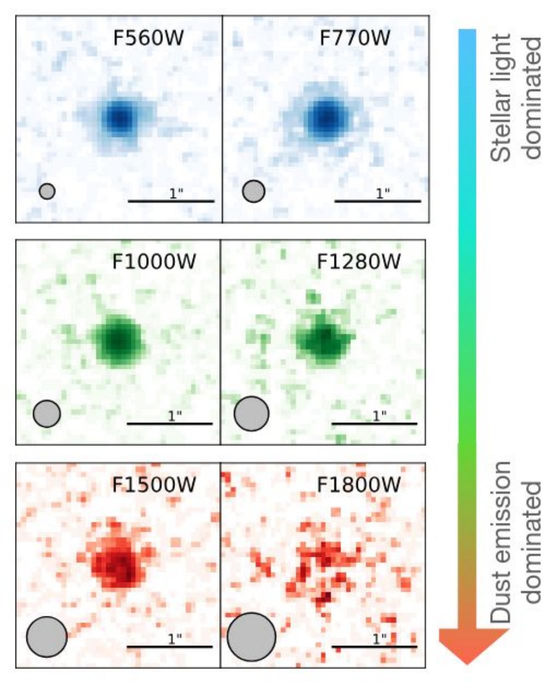
[D'Eugenio et al. (2025d)]

We have compelling evidence of dust removal

Evidence of dust at large galactocentric distance from Submm galaxy, via excess of reddened background sources.



Evidence of a hot-dust ring in a massive, quiescent galaxy with a Type-1 AGN (z=4.7)



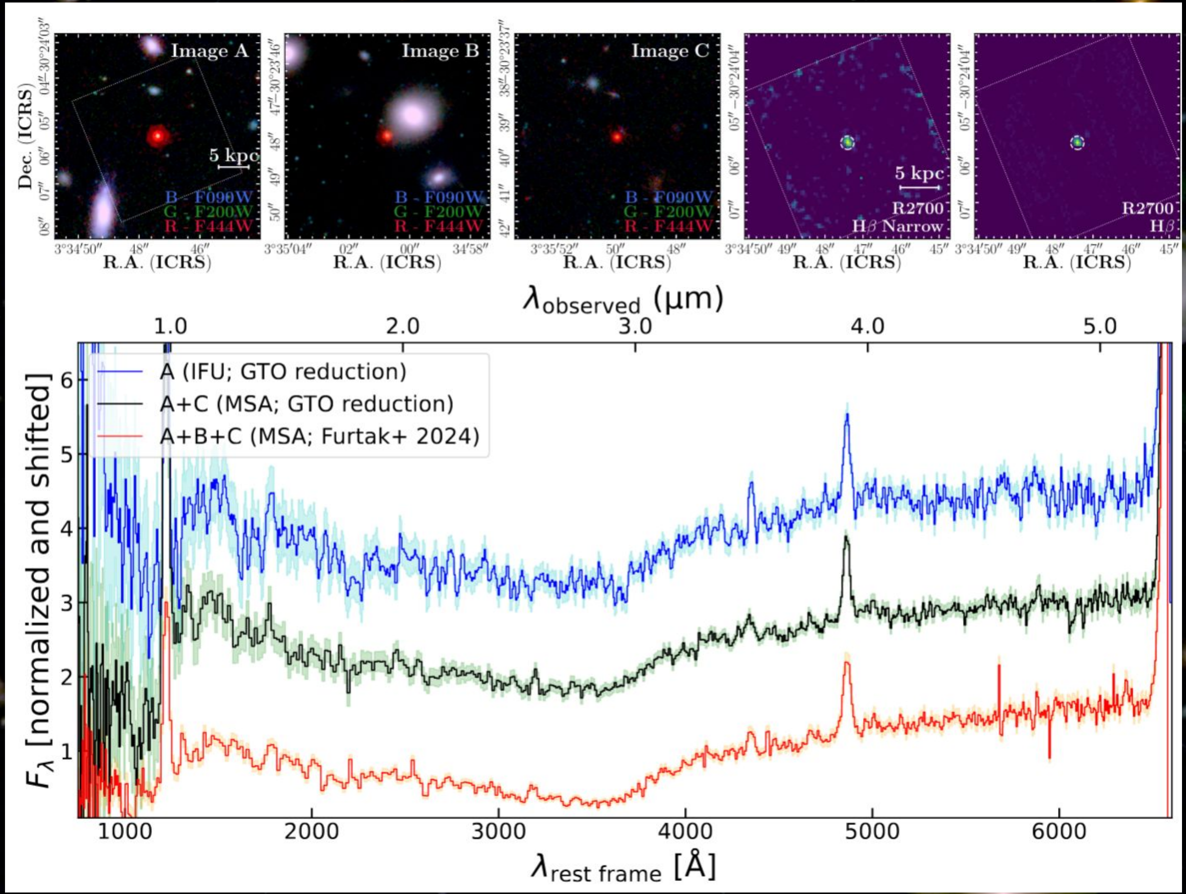
Ji et al. (2024)

New things and open questions

- Neutral gas outflows capable of stopping star formation are common
- Some certainly powered by AGN
- Quiescent galaxies with no molecular gas
- ISM/dust removal seen in action

- Heavily obscured star formation
- Missing progenitors
- Statistics on dust content
- Heavily obscured AGN
- Dust removal

LRDs and Nascent SMBHs



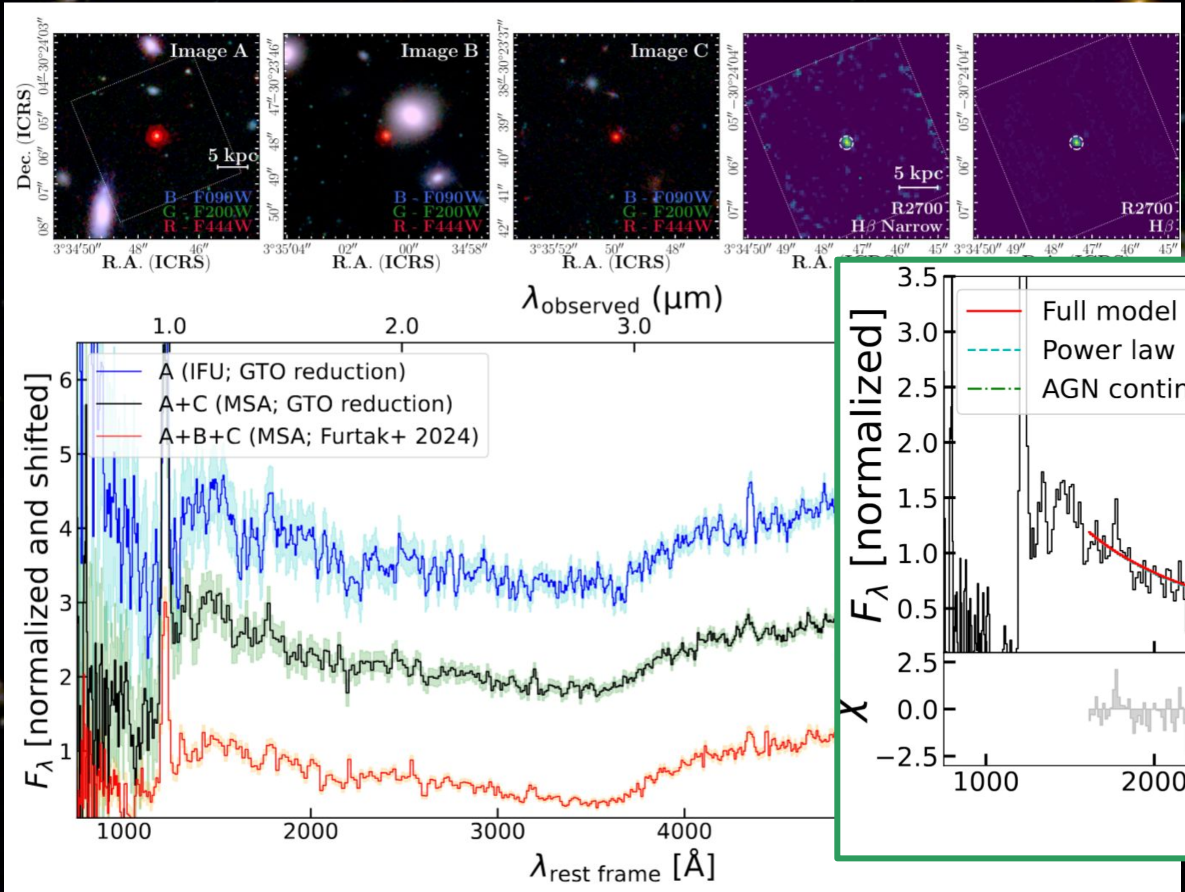
Inayoshi & Maiolino (2025)
Ji et al. (2025)
Naidu et al. (2025)

Balmer breaks at high-z can be driven by dense gas near the AGN,

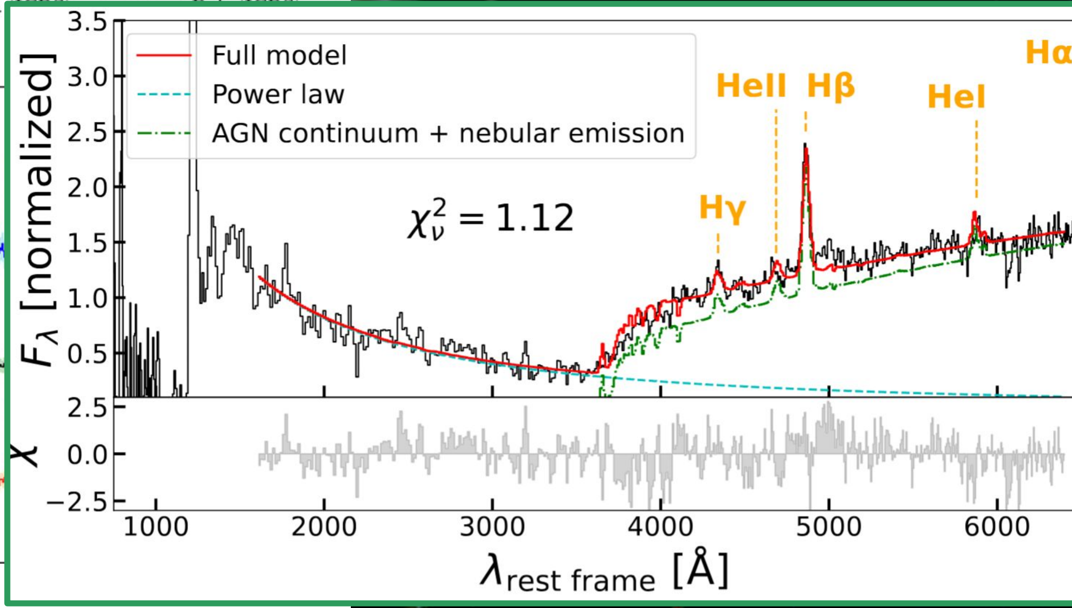
Initially, these breaks were interpreted as stellar, leading to overmassive, early galaxies and “Universe breakers”

[Ji et al. (2025)]

Variable optical continuum and EW(H□)



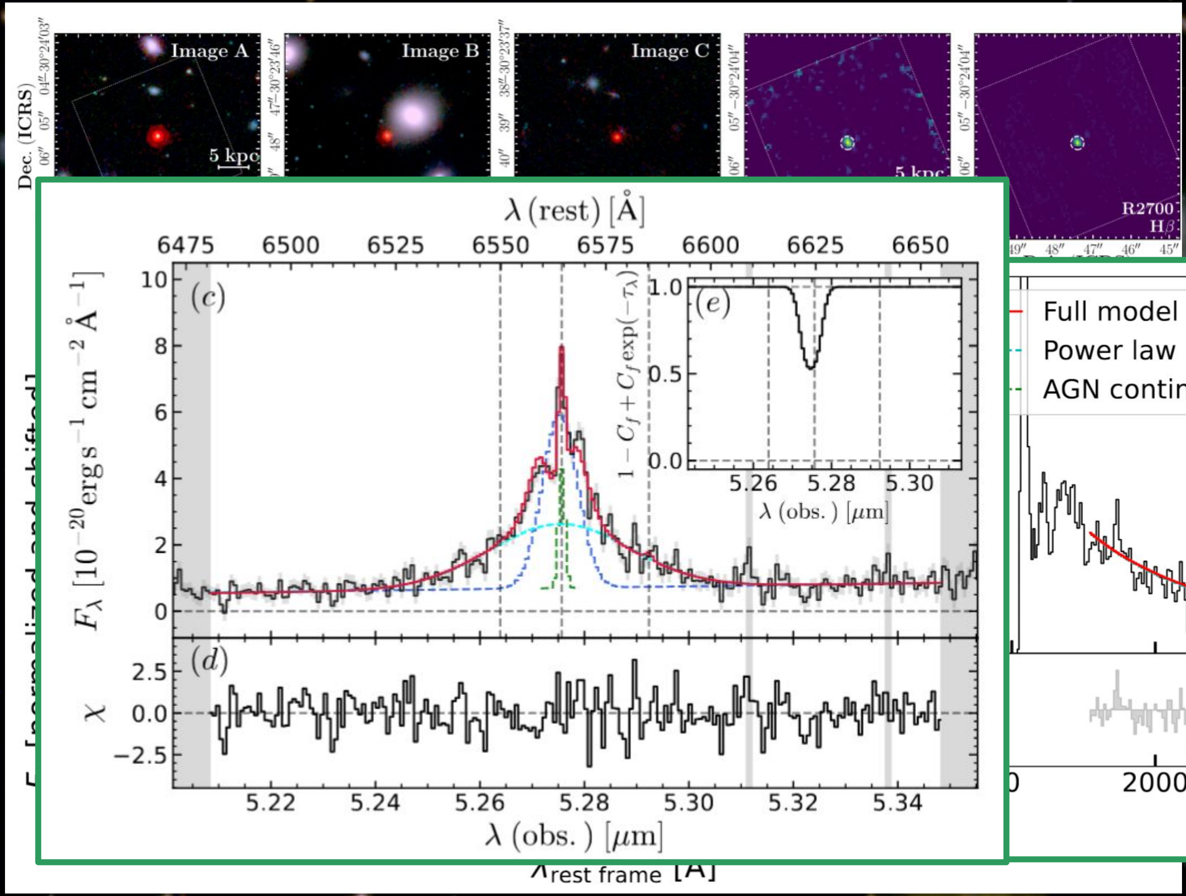
No stellar model can fit such a **strong and smooth** break so we (red line), because in stars smoo implies weak break (not so in AG

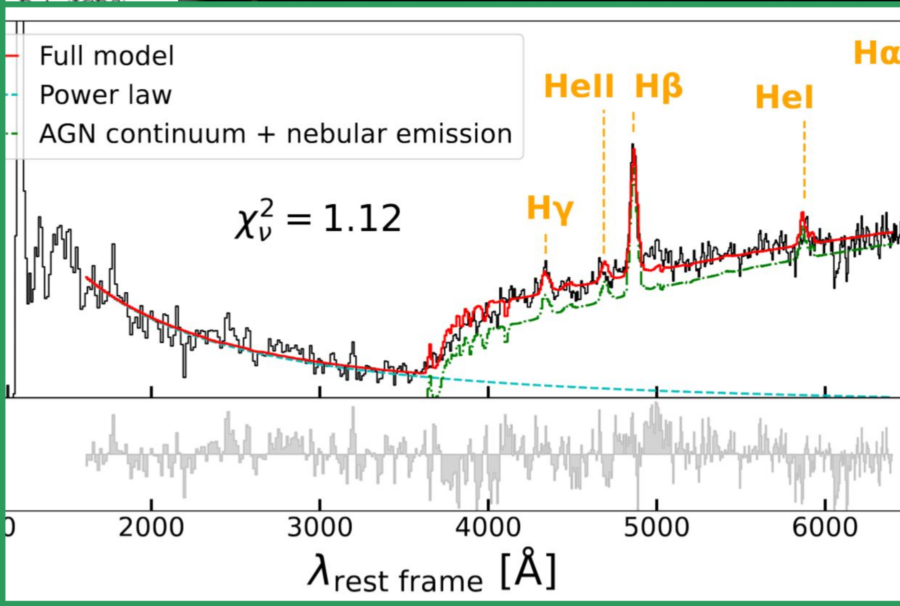


[Ji et al. (2025)]

Link between Balmer Break and line absorption

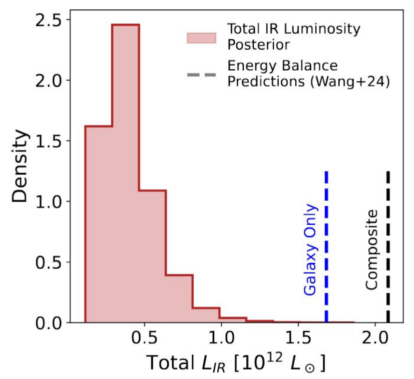
The AGN model requires stronger-than-stellar Hα absorption: also found later (left)





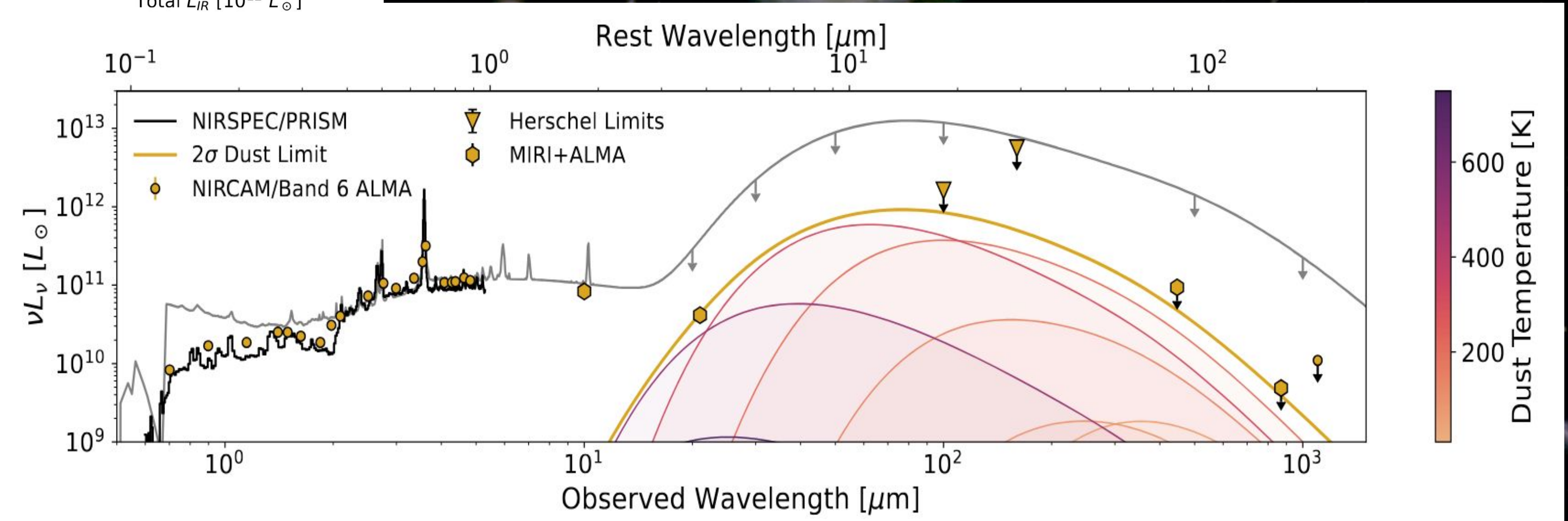
[Ji et al. (2025). D'Eugenio et al. (2025c)]

MIR and FIR constraints

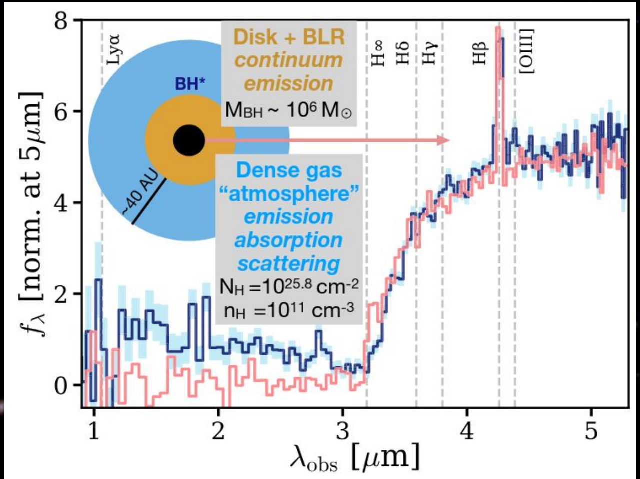


Weak or no detections imply the missing UV light (relative to normal, unobscured AGN) is not absorbed by dust. Since "blue LRDs" are rarer, this suggests most of the UV is absorbed by HI (also making the Balmer break)

[Setton et al. (2025)]

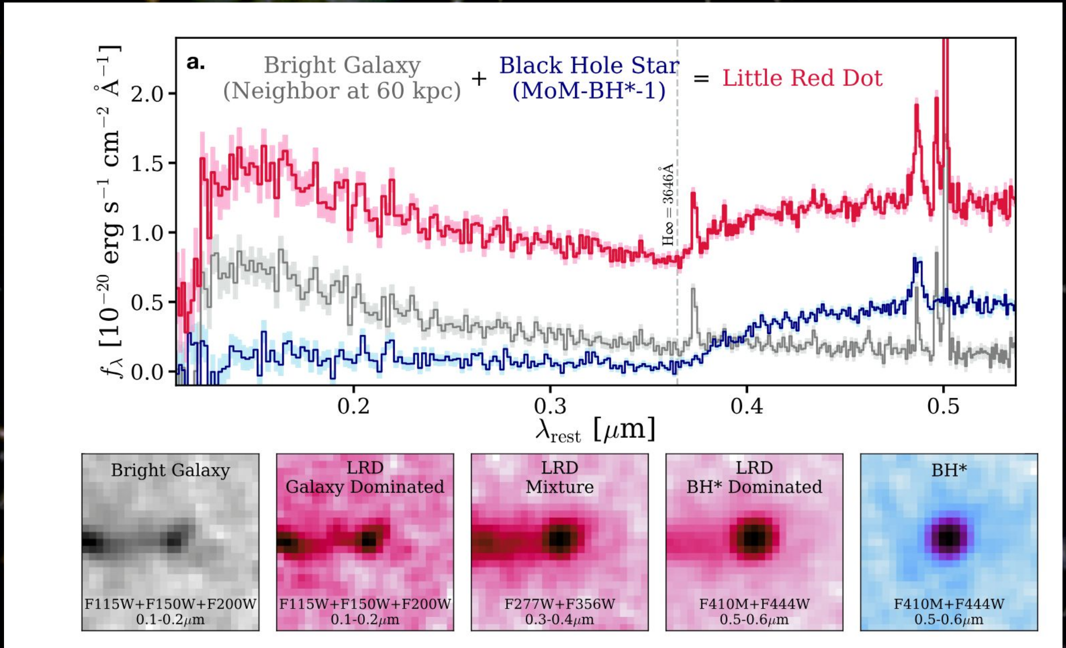


Black-Hole Star (Naidu et al. 2025)



[Naidu et al. (2025)]

With recent claims of HI covering factor~1, suggesting a spherical geometry (i.e. a "Black-Hole Star"; BH*)

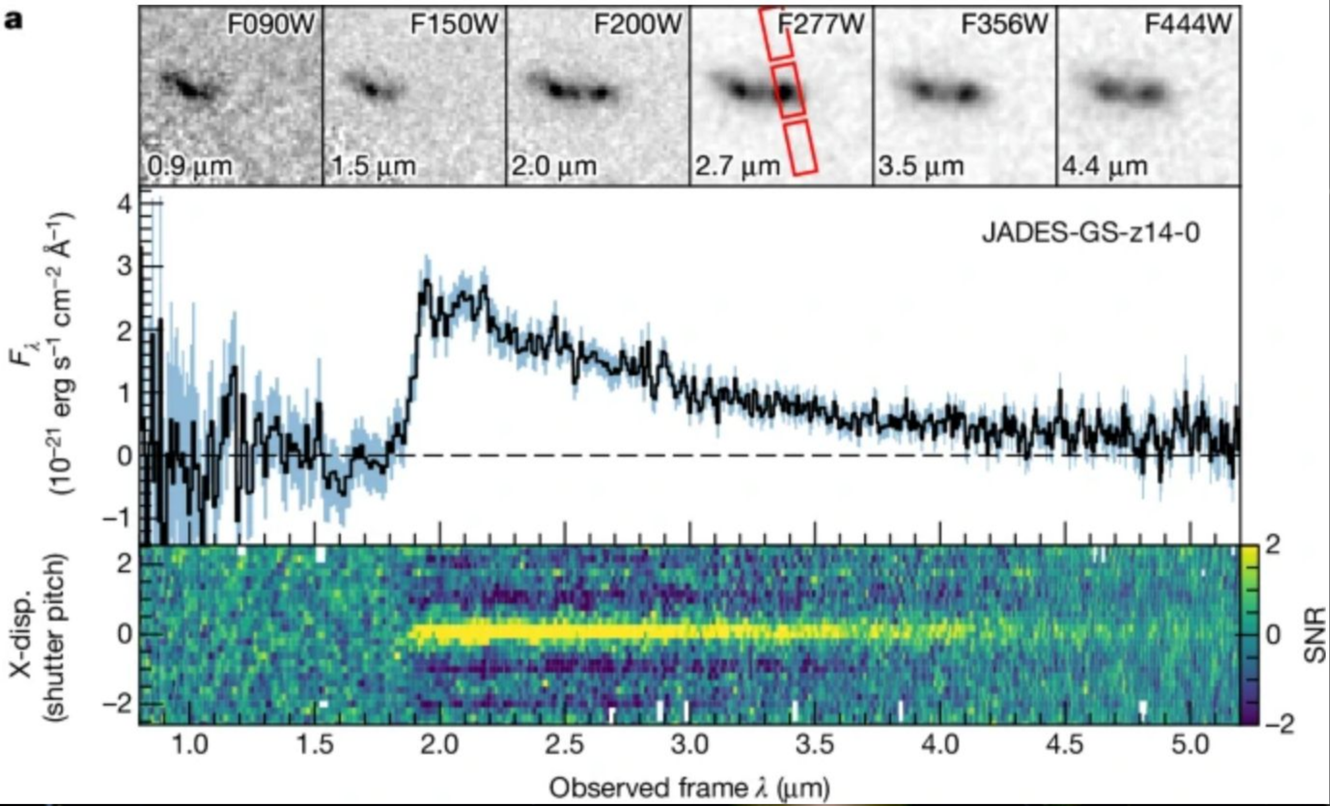


LRDs would arise from different mix of BH*'s and host galaxies).

Rest-frame MIR constraints crucial.

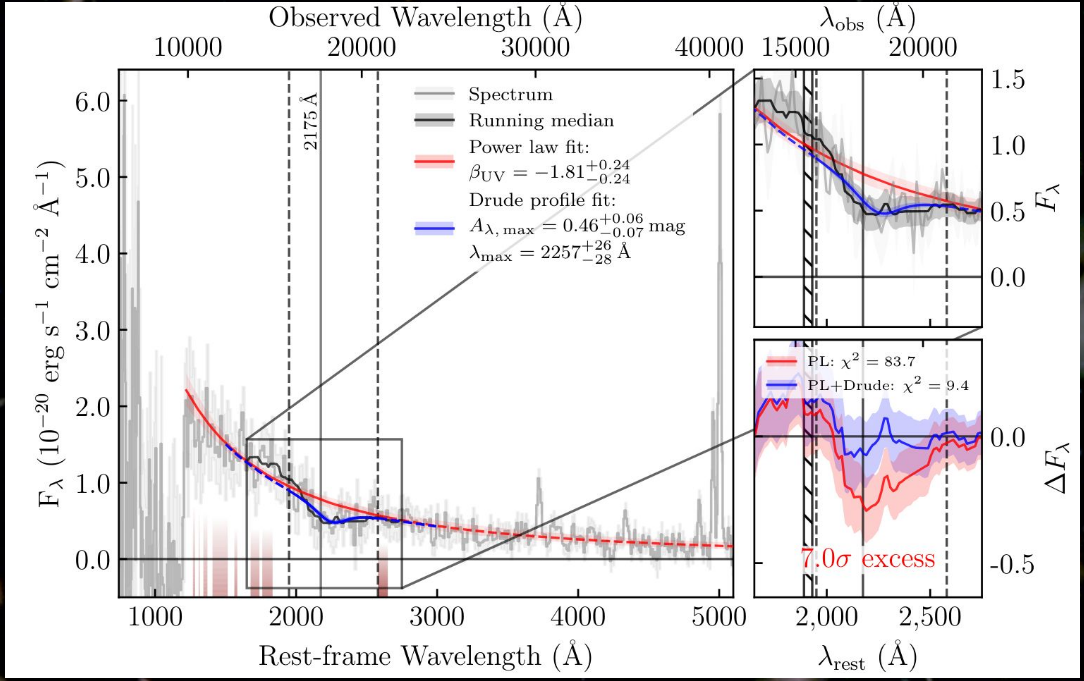
Dust in high-z galaxies

Evidence of dust in the SED shape of even the earliest known galaxies
GS-z14-0 (most distant known) already has Av>0



[Carniani et al. (2024)]

UV-bump at z=7



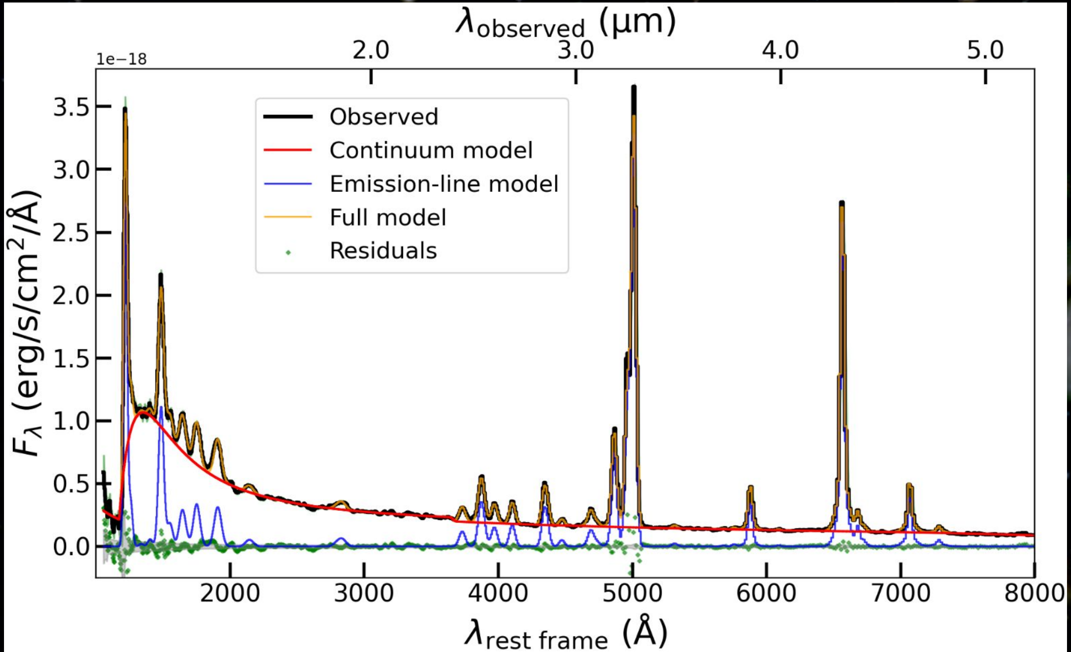
[Ormerod et al. (2025)]

This includes direct evidence for the UV absorption ‘bump’ at 2,175 Å

Implies the existence of carbonaceous dust well into the first billion year.

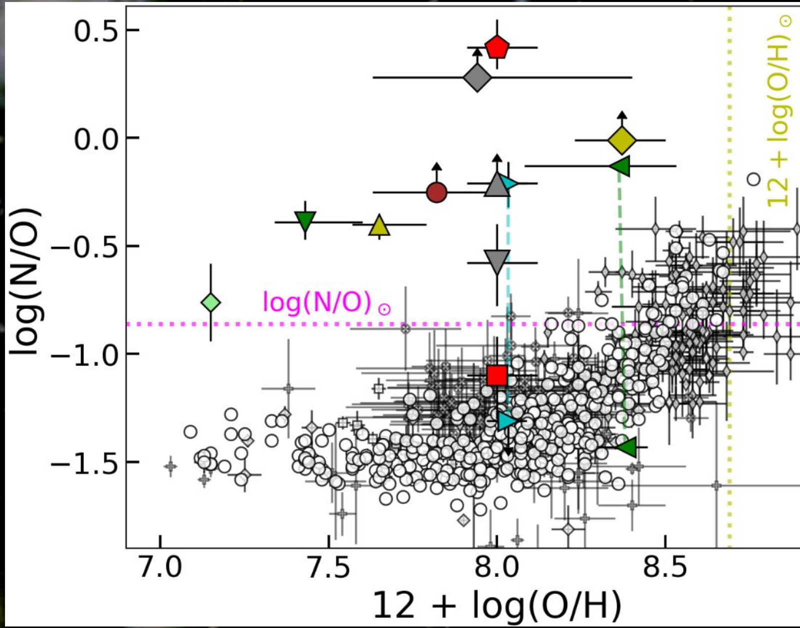
Dust was more abundant and earlier than we thought.

A nitrogen-loud and chemically stratified galaxy at z=5.6



[Ji et al. (2024)]

Many galaxies display anomalous abundance patterns, such as abnormally high C/O and , especially, high N/O



This may be due to chemical stratification, with the centre much more rich in N than the galaxy. FIR emission lines are crucial to understand multi-zone metallicity.

Summary

- Dust properties (and morphology?) to study quenching in massive, quiescent galaxies
- Search for progenitors
- MIR/FIR properties of LRDs/BH*s
- Dust emission in z>7 galaxies.

Thank you!

Technical capabilities wishlist

Two science cases: massive galaxy quenching and LRDs.
If PRIMA not approved: something that replaces PRIMA

If PRIMA approved:
Arcsec resolution: 0.2” (resolve massive, compact galaxies, resolve hosts of LRDs)
Interferometry: necessary due to resolution above
Spectral range: as blue in MIR as technically possible, to 350 um (high-z hot AGN dust, [OIII]88um at z=3). Reaching longer wavelengths would be even more compelling for Reionization science.
Spectral resolution: R~5,000 would cover typical JWST galaxies.
Field of View: no less than 3 arcsec (extent of CGM around