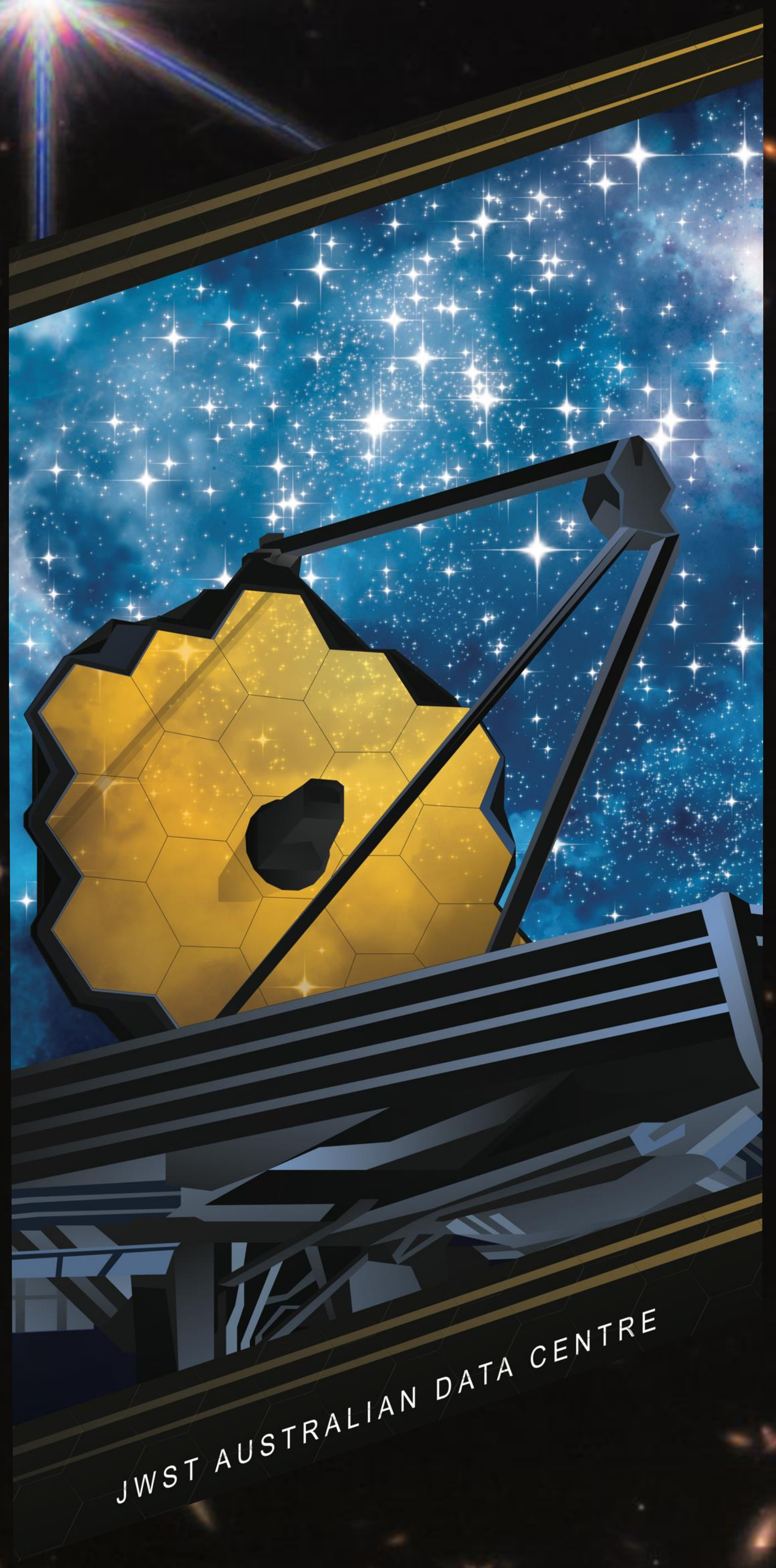
Space 2.0 views of the high redshift** universe



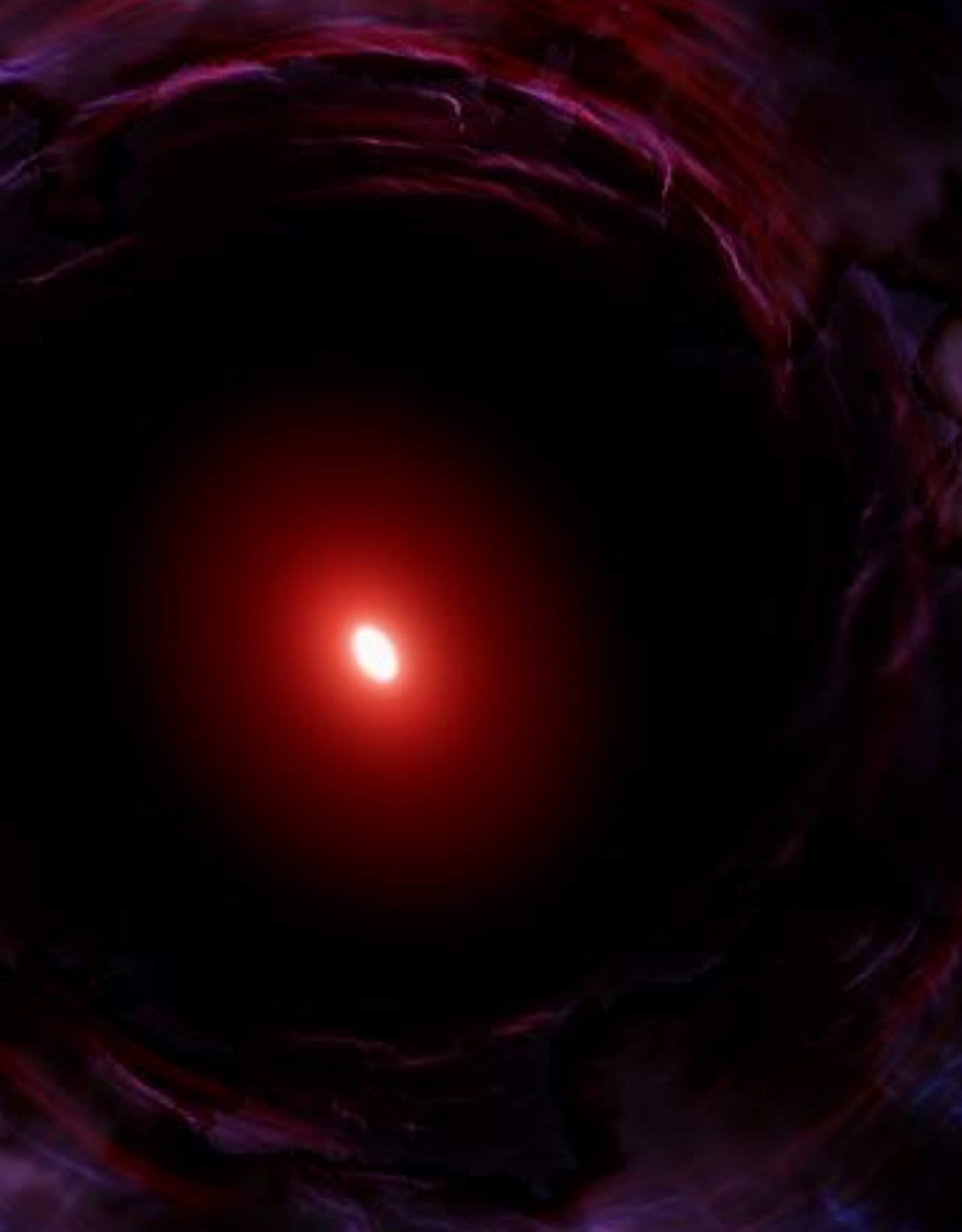
Karl Glazebrook

SWINBURNE
CENTRE FOR ASTROPHYSICS AND SUPERCOMPUTING

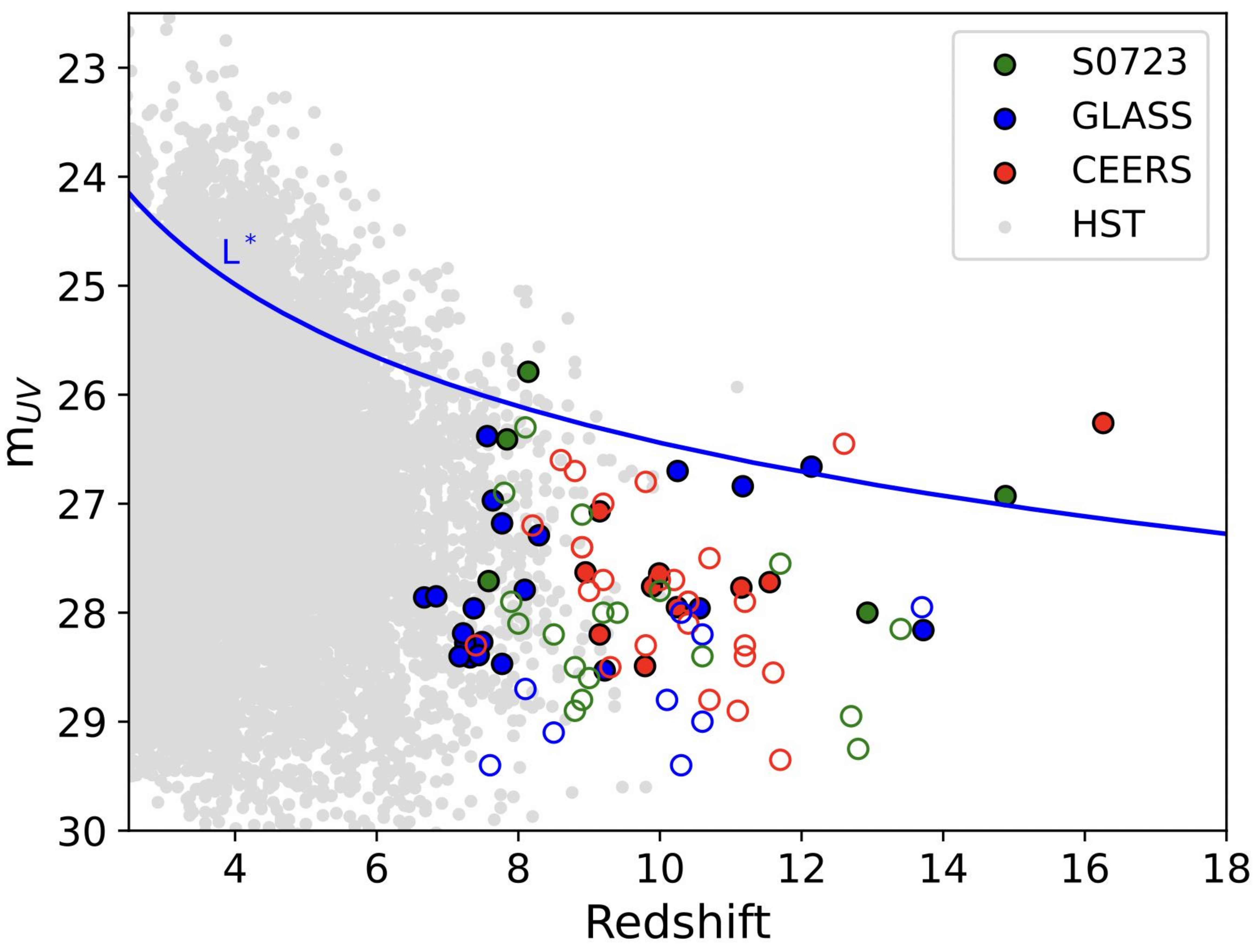
**$z \gtrsim 5$

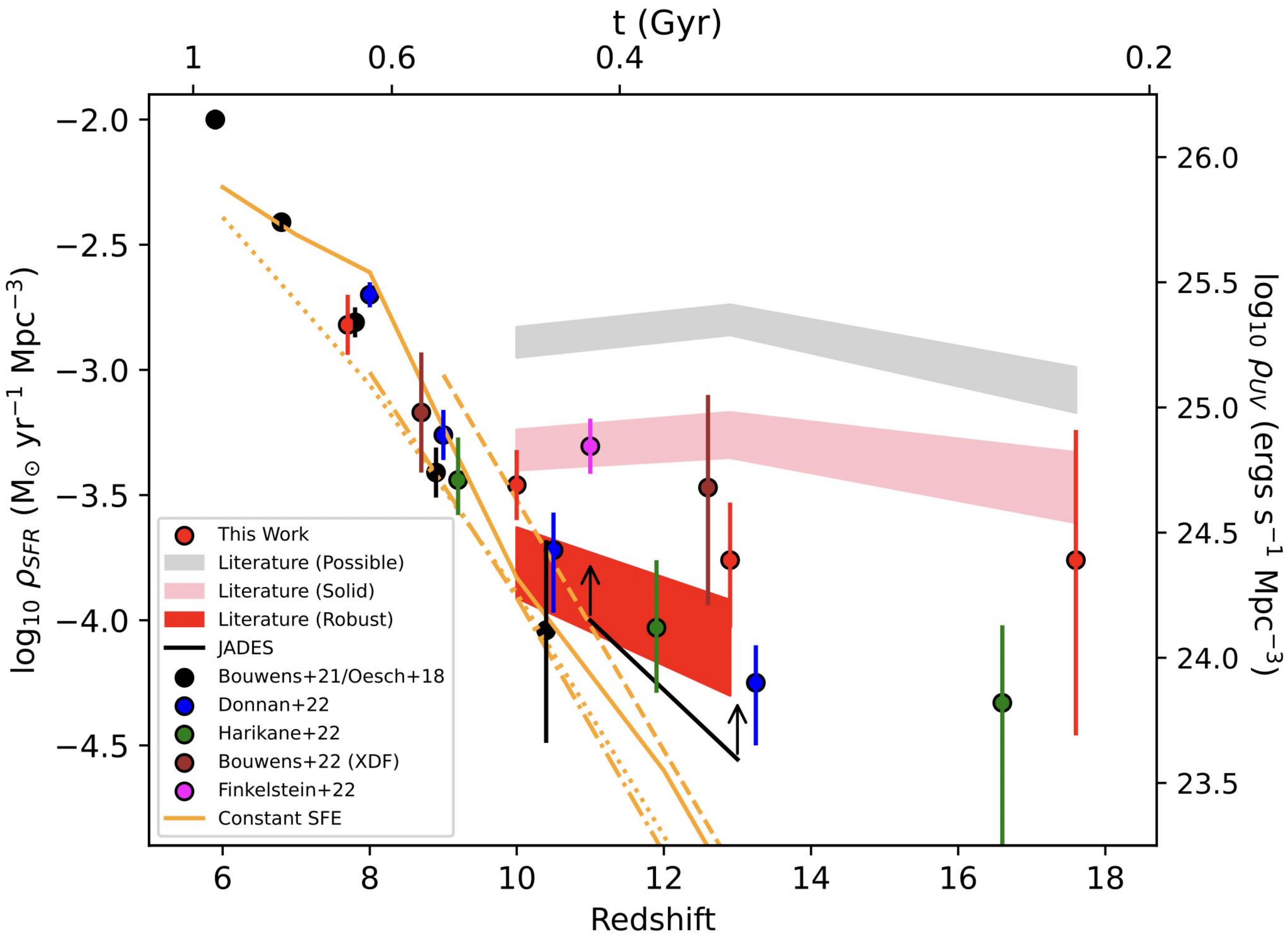
Outline

- Weird stuff JWST is finding at high-z (z>5) & it's incredible sensitivity
- Science motivations for new space *wide field* NIR spectroscopic surveys at z>5 (rare objects in the early universe)
- Thoughts on 'Space 2.0' approaches to this and opportunities for Australia



#1 Numbers of z>10 star forming galaxies





Bouwens+2022

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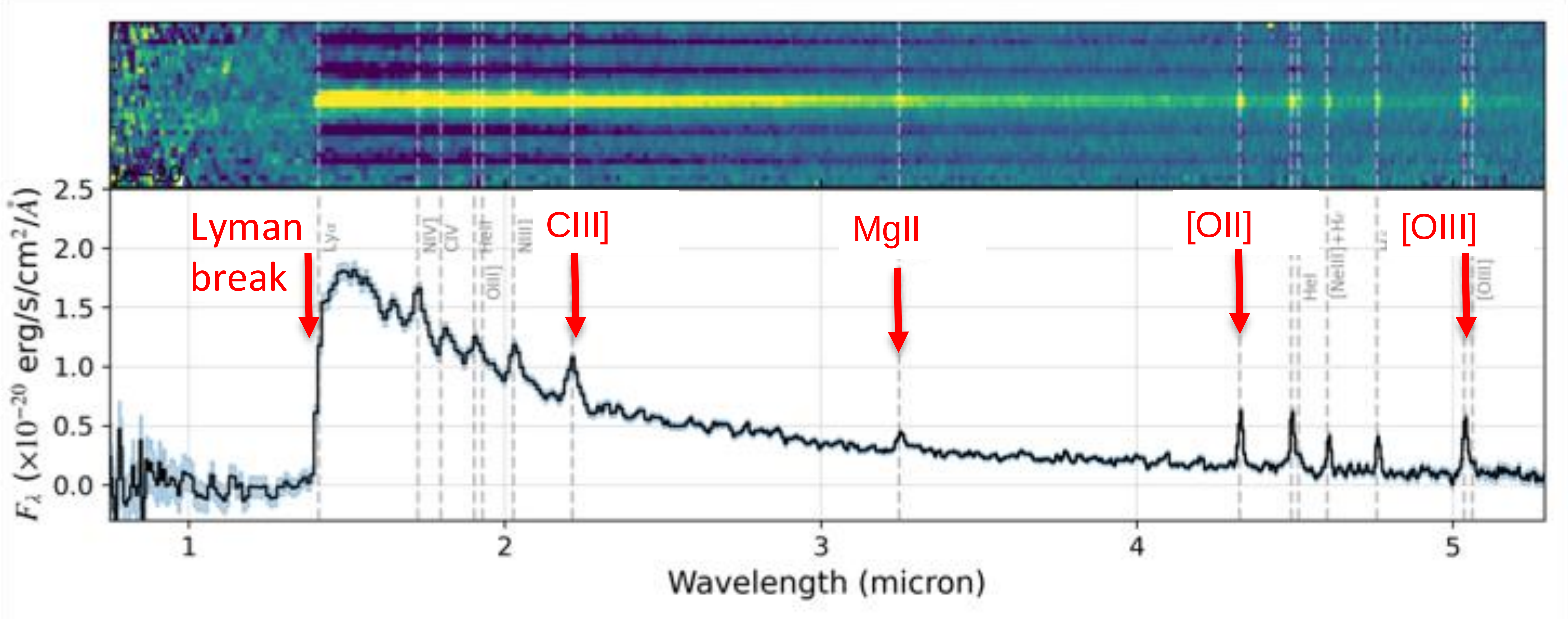
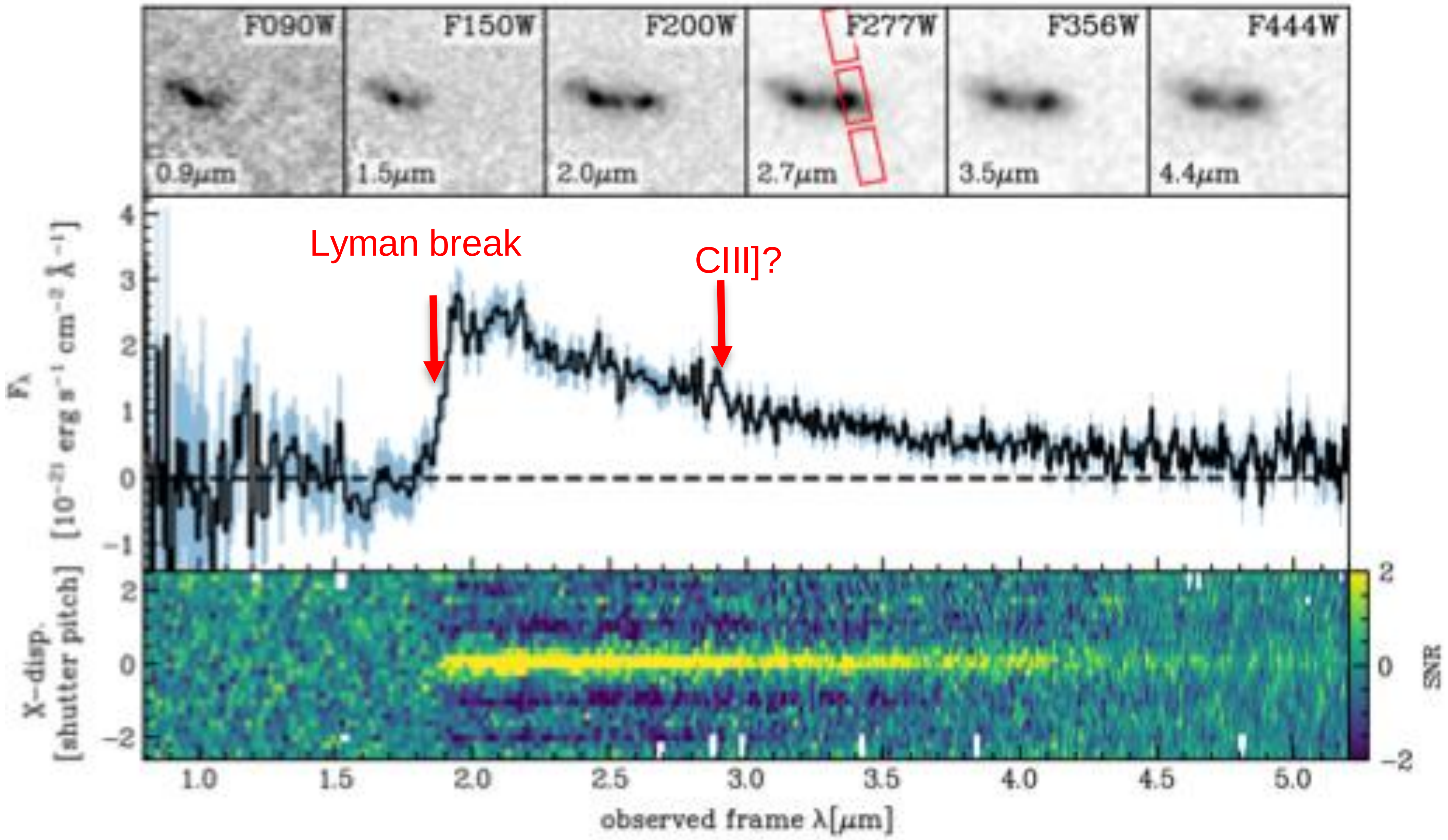
Spectroscopy of super-luminous z>10 galaxies





Bunker et al 2022; Carniani et al 2024

GN - z11:

Originally claimed via HST Lyman break (Oesch et al 2016)

z_{spec}= 10.60
M_{UV} ~ -21.5
radius ≈ 100pc
M* ~ $10^{8.7}$ $M_\odot$
SFR ~ 25 $M_\odot$ yr^{-1}

JADES-GS-z14.0: current record holder

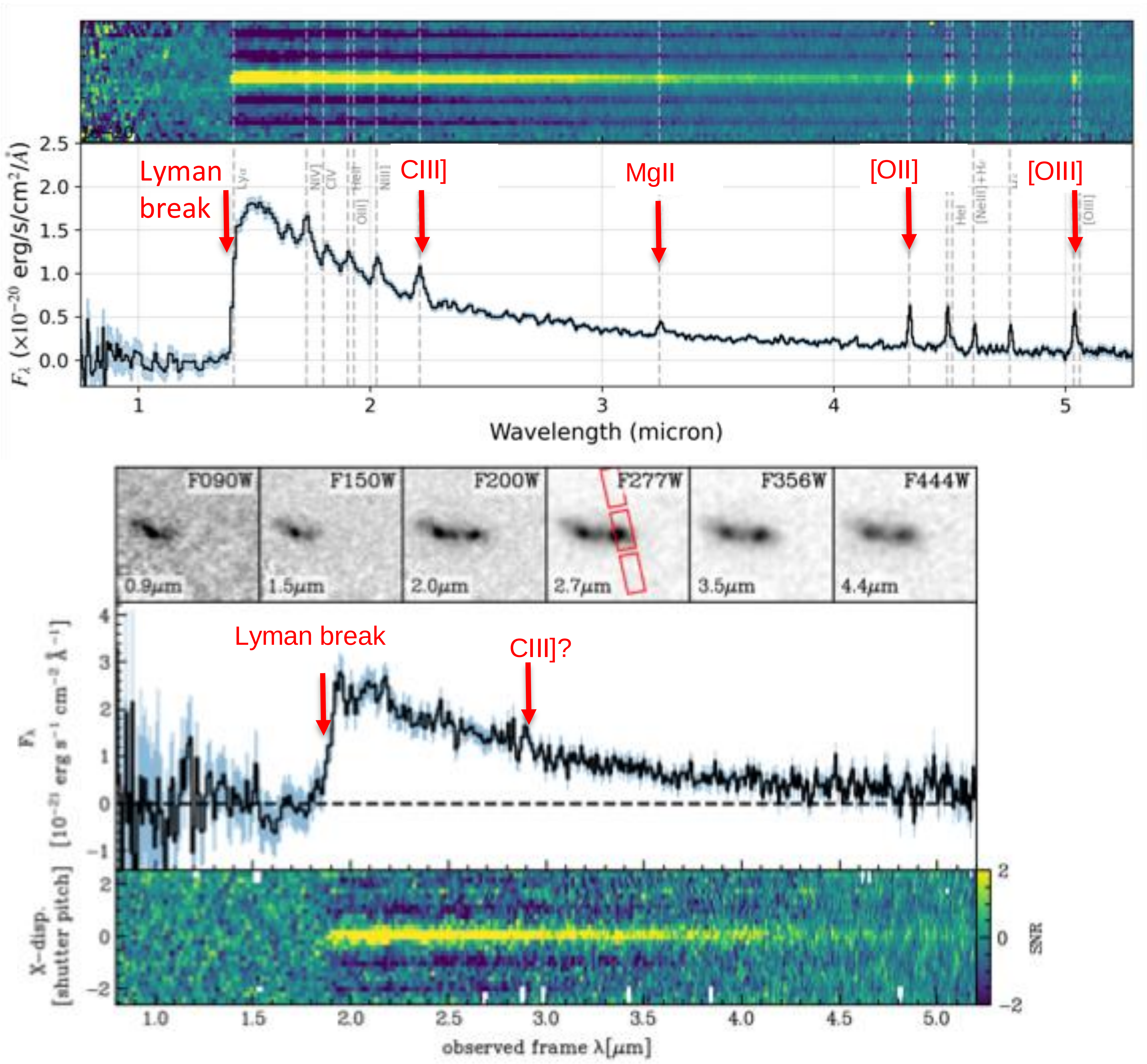
Originally disfavoured by the JADES team as it's 0.4 arcsec from a foreground z~3.5 galaxy, but perseverance paid off!

z_{spec}= 14.32
M_{UV} ~ -20.81
radius ≈ 200pc
M* ~ $10^{8.7}$ $M_\odot$
SFR ~ 20 $M_\odot$ yr^{-1}

See also: Curtis-Lake+22, Arrabal Haro+23, Harikane+23, Wang+23, Atek+23, Hainline+24

[Slide by Richard Ellis, IAU 2024]

Spectroscopy of super-luminous z>10 galaxies



Bunker et al 2022; Carniani et al 2024

Key questions:

What are their abundance? (Need > handfuls)

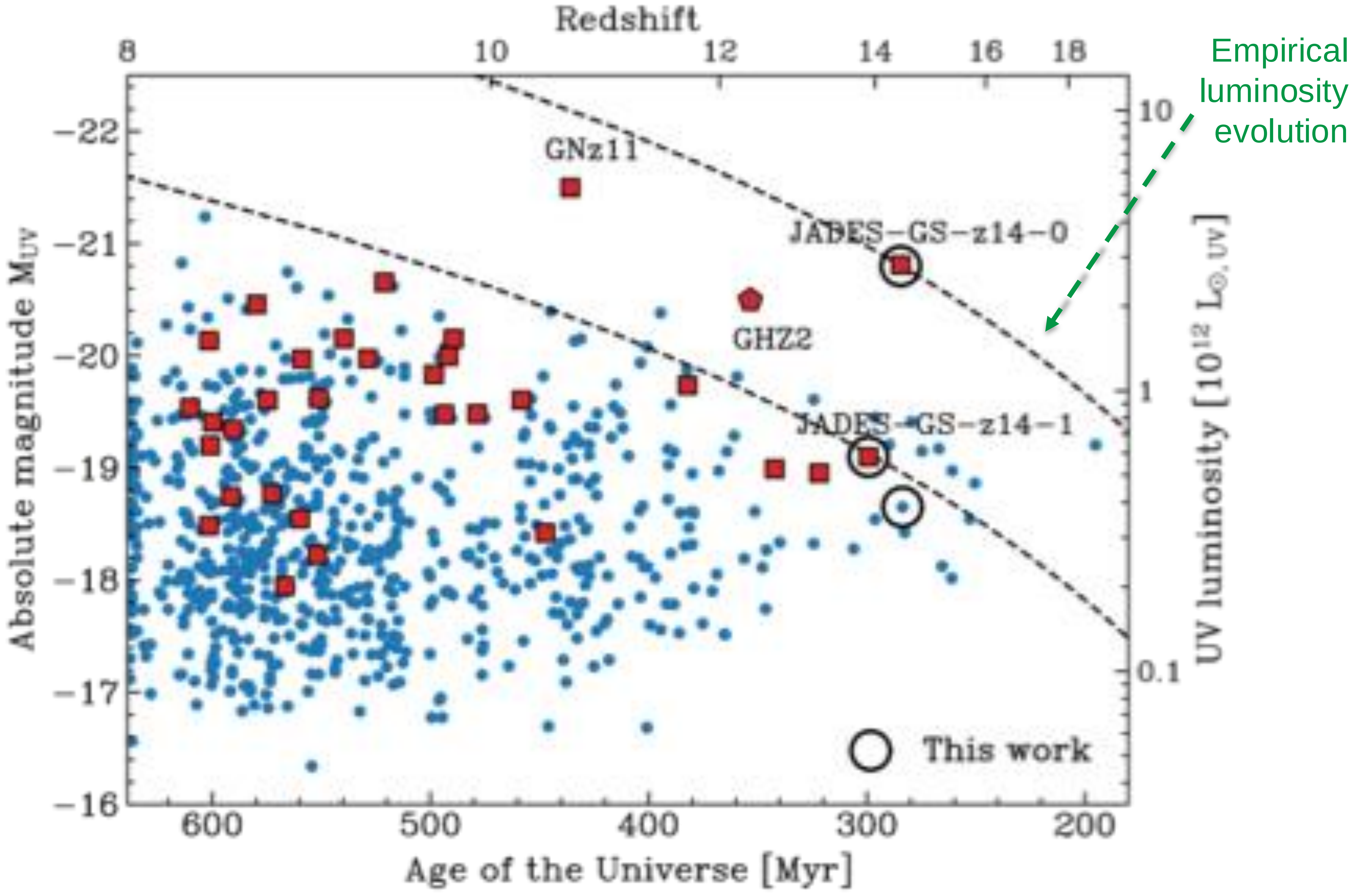
What are their stellar masses? (Need mid-IR ~20μm photometry)

What is their dark matter halo masses (need clustering - thousands of galaxies)

See also: Curtis-Lake+22, Arrabal Haro+23, Harikane+23, Wang+23, Atek+23, Hainline+24

What's going on?

The discovery of four spectroscopically-confirmed z>10 super-luminous galaxies in such small cosmic volumes is a tantalising indication that **new time-specific physical processes are responsible,** perhaps related to the onset of cosmic dawn



Carniani et al 2024

Many explanations!

- **ejected dust?**
- (Ferrara+23)

- **ineffective feedback?**
(Dekel+23)

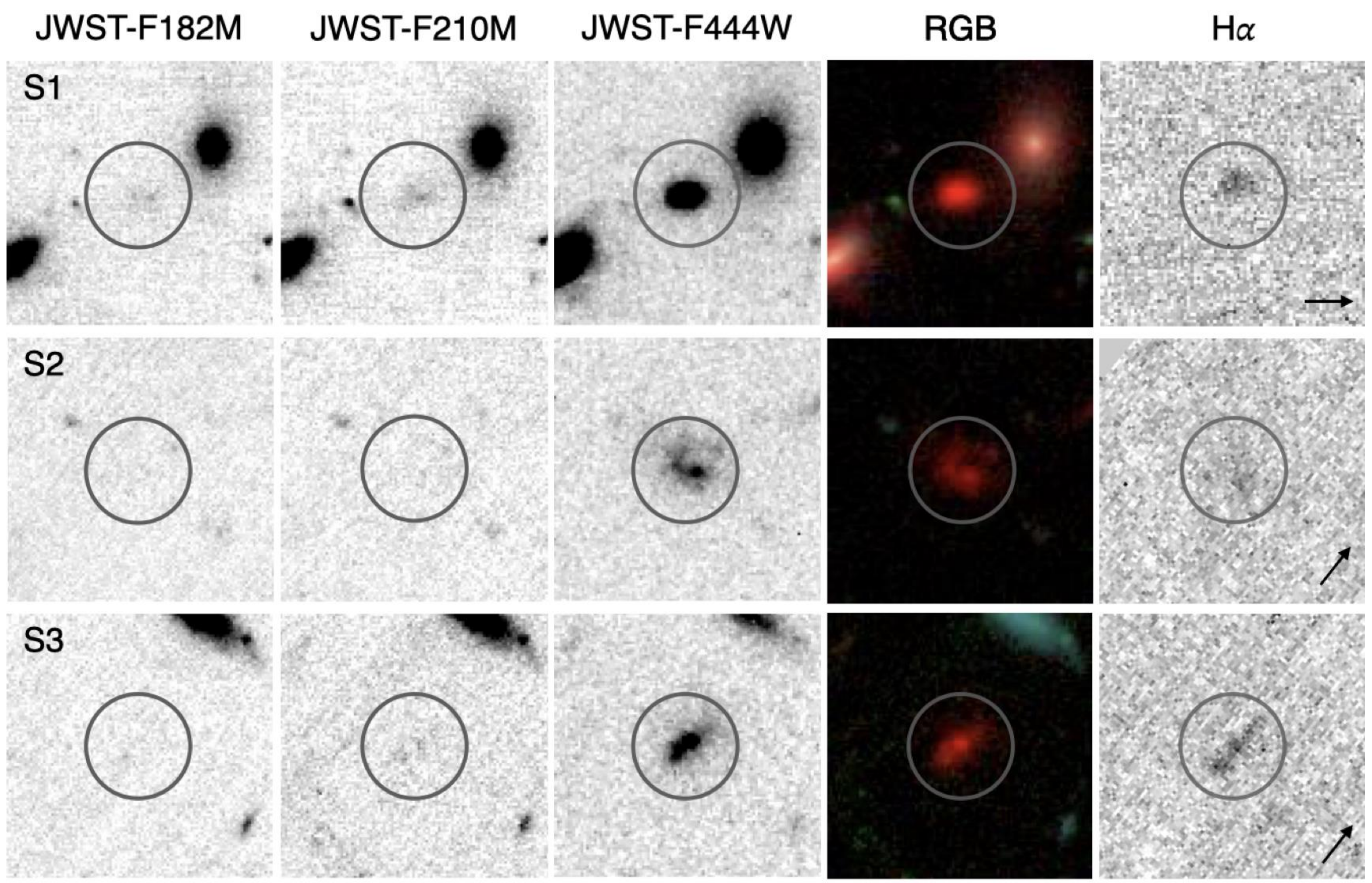
- **biased detection via bursty SF?**
- (Shen+23,24, Gelli+24,Kravtsov+24)

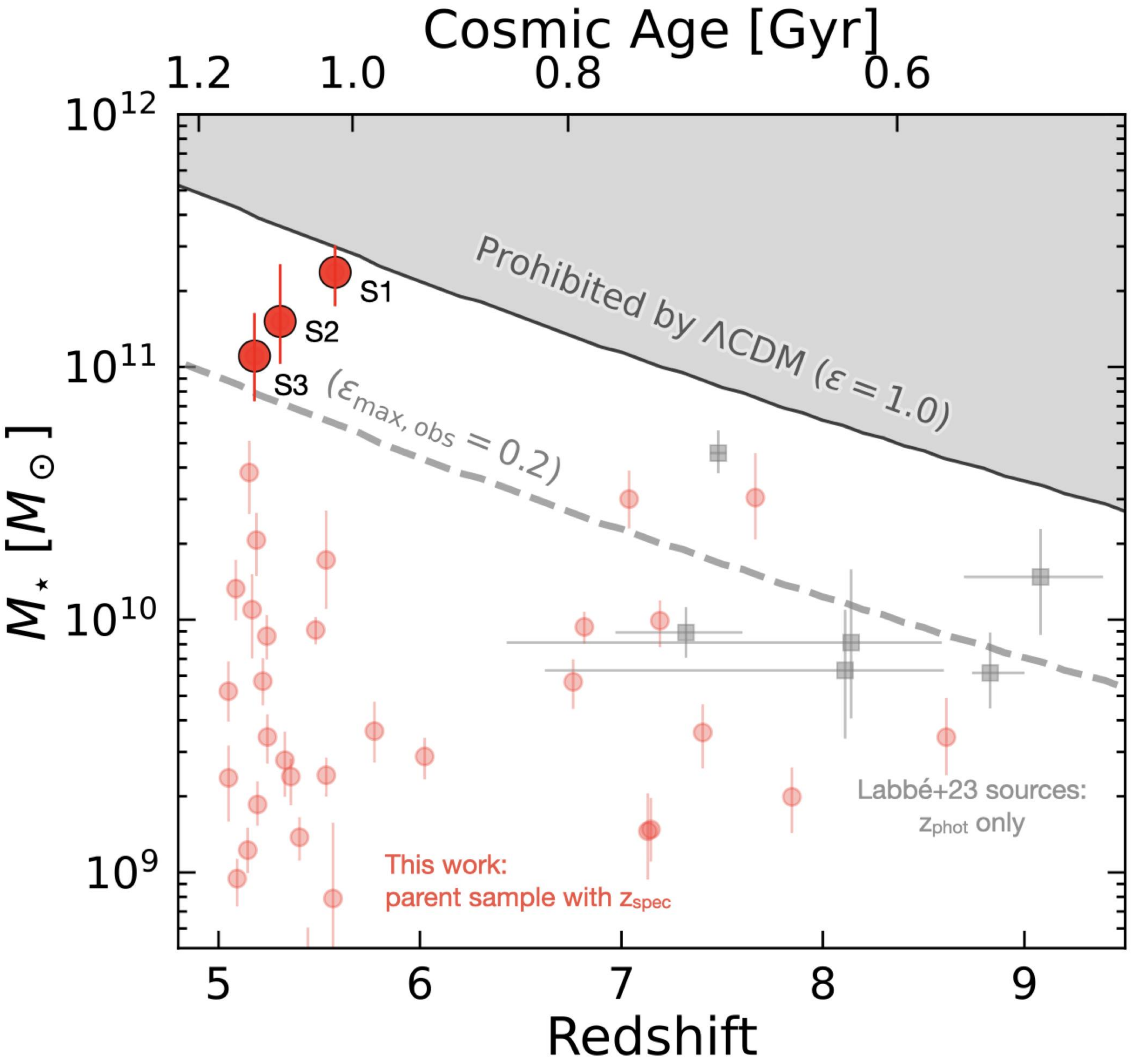
- **Very massive stars?**
(Harikane+23, Menon+24, Schaerer+24))

[Slide by Richard Ellis, IAU 2024]

#2 Massive optically dark SFGs

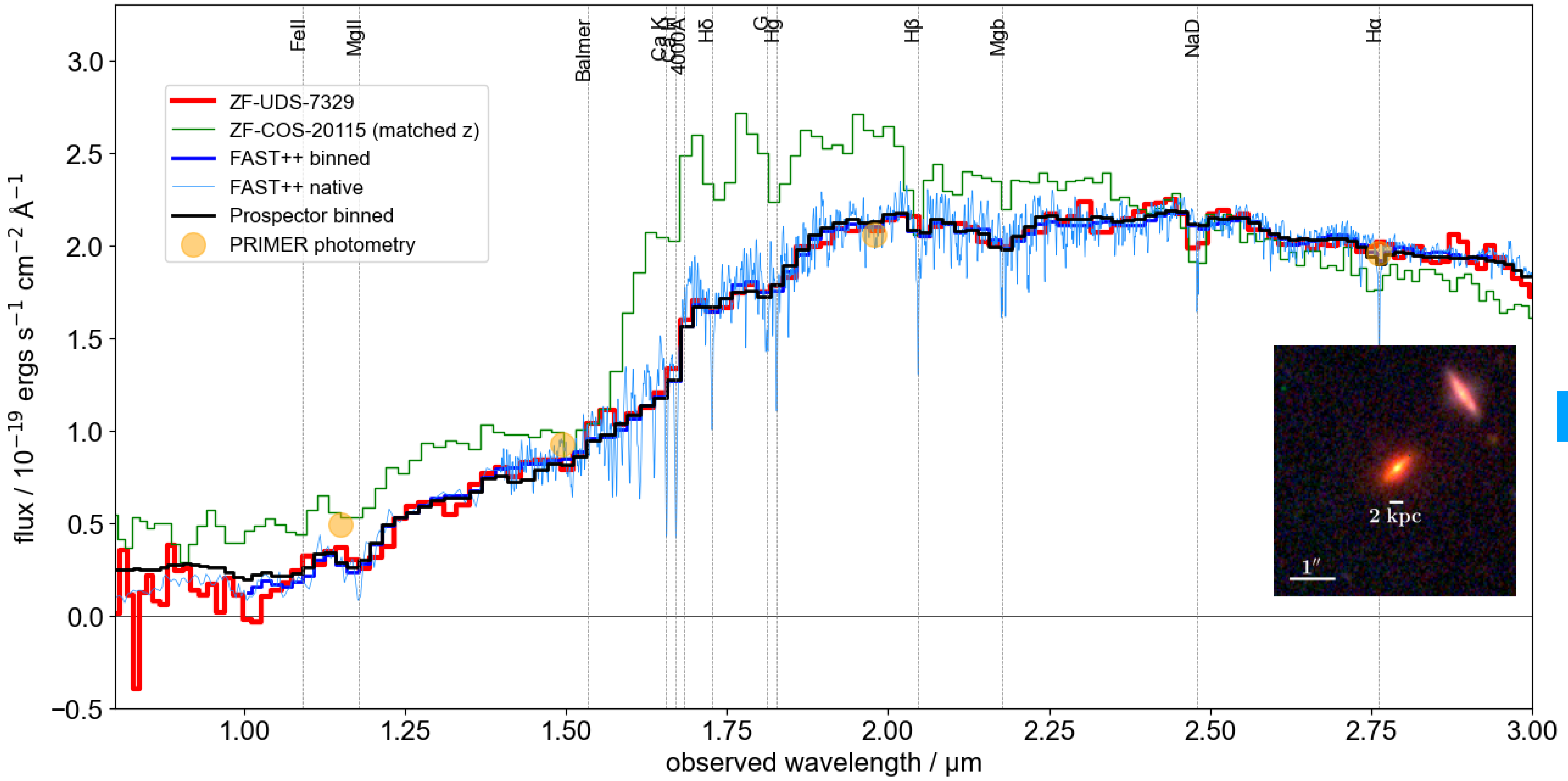
Xiao+2024 (FRESCO slitless survey)

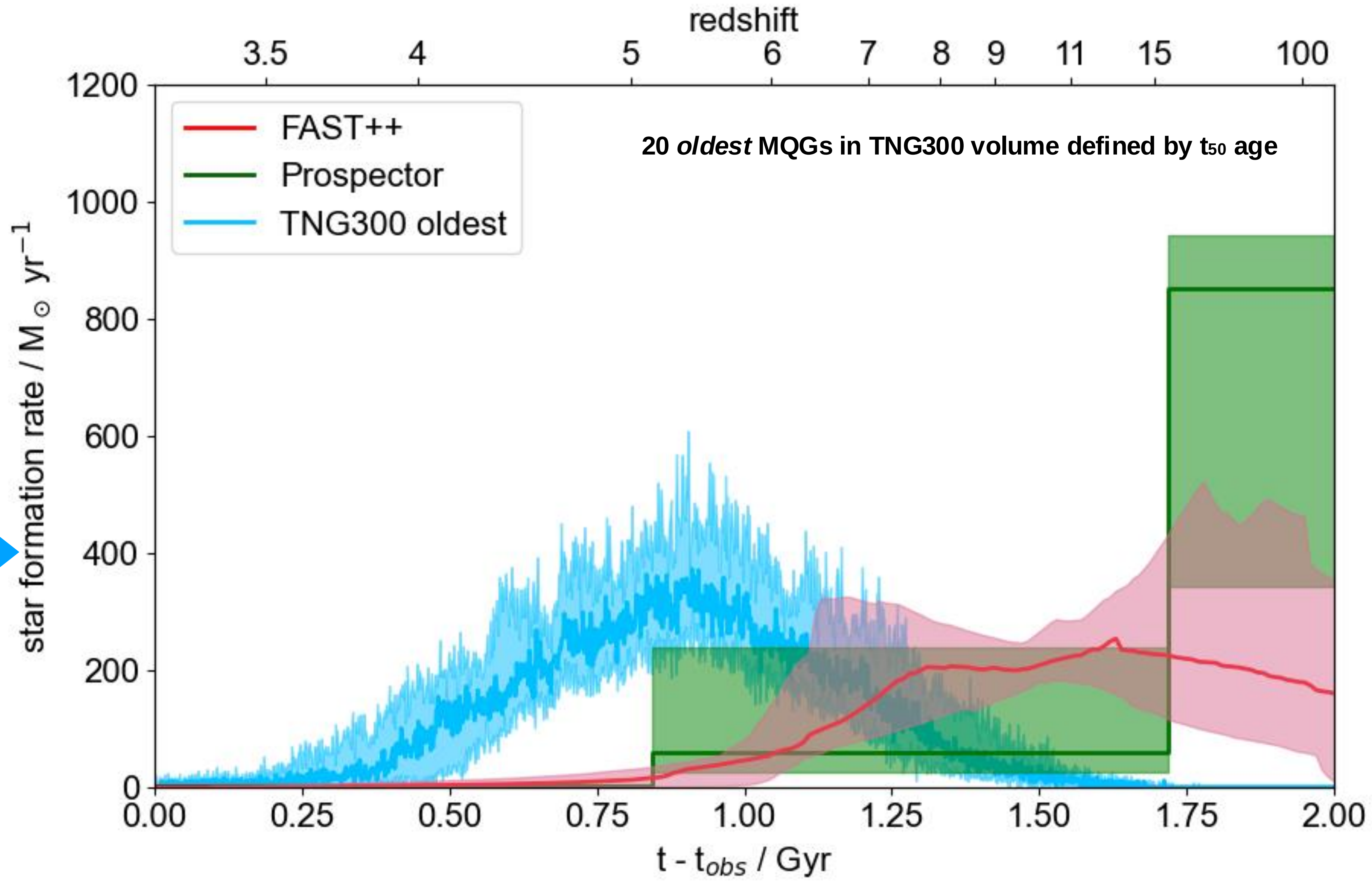




Need 50% baryons→stars

#3 A massive old galaxy at z=3.2





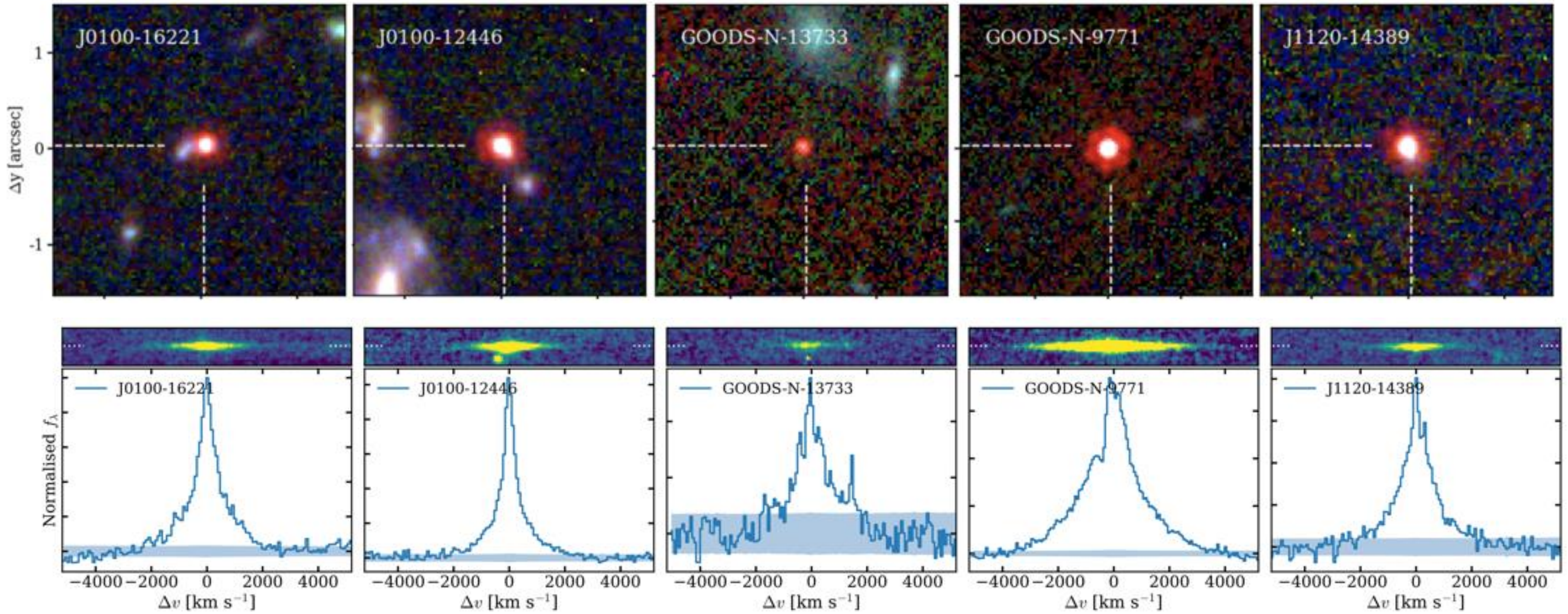
Glazebrook et al. 2024: "*Forms at z~11, no ΛCDM halos exist to host it even if 100% of baryons→stars*" (paraphrasing myself…)

Karl Glazebrook, SUT

Pushing standard models to the limits…

- Carnall et al. 2024: *'However, these objects roughly align with the most massive galaxies expected under the assumption of 100 per cent conversion of baryons'*
- De Graaff et al. 2024: *'…implies a high efficiency of star formation of ϵ >0.2, and the low-metallicity model even suggests that the galaxy is converting baryons to stars with near-perfect efficiency.'*
- Turner e t al.2024: *'The inferred SFH is consistent with a high stellar fraction f_* ~100% at z=7–12 implying an extremely high integrated star-formation efficiency'*
- Xiao et al. 2024: *'would require, on average, about 50% of the baryons in their halos to be converted into stars– two to three times higher than even the most efficient galaxies at later times'*

#4 Another surprise: Little Red Dots - Dust-obscured AGN?



NIRCam 2-4μm colour images

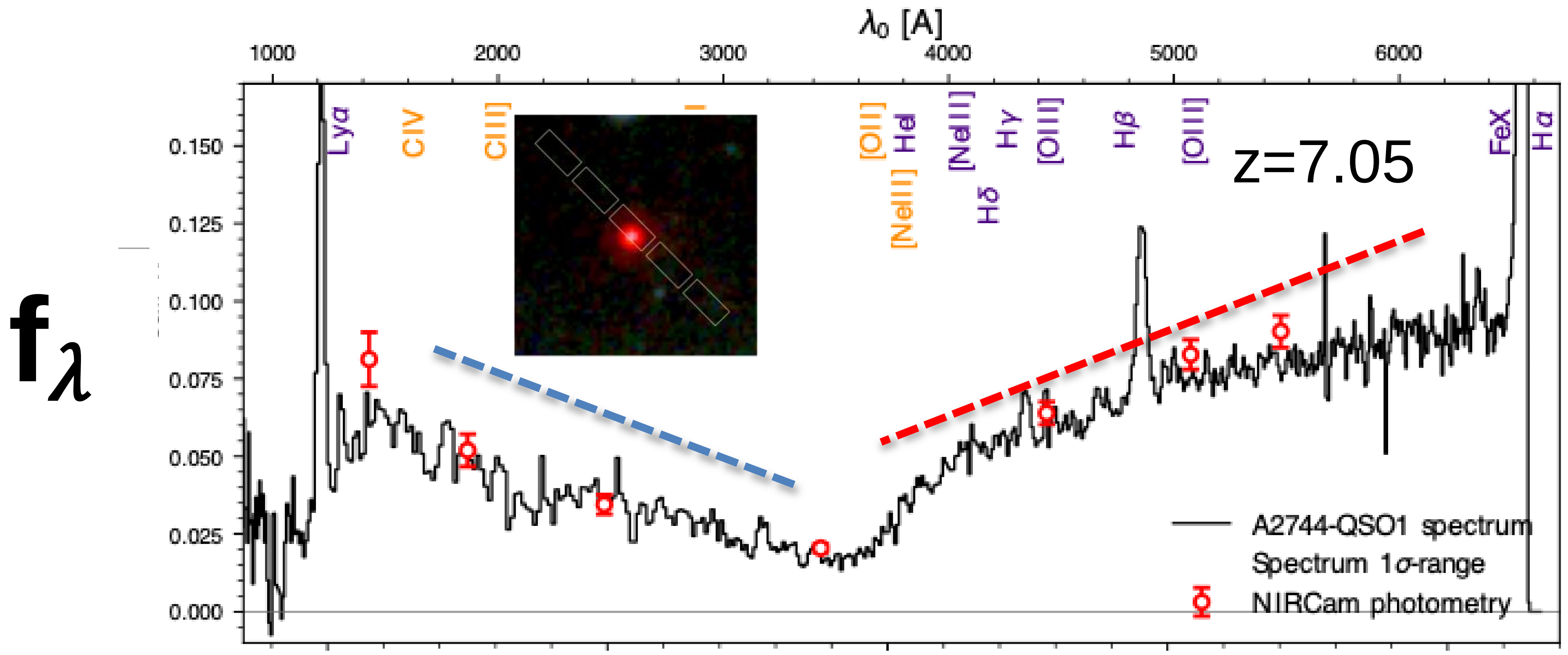
NIRCam 3-5μm slitless grism Hα

Matthee et al (2023): Hα-selected sample at 4.2<z<5 finds majority are compact **"little red dots"** with broad lines (1200-3700 km s^{-1}) suggesting a hitherto unknown population of dust-attenuated AGN. Broad Hα component is consistent with fraction of flux in point source

Greene et al (2023): Spectra of 17 compact red sources finds 11 broad line AGN with 4.5<z<8.5 (60%). Adopting **red optical + blue UV colour selection** yields 80% success rate for locating AGN.

BUT! Williams et al (2023), Pérez-González et al (2024) claim a dusty AGN hypothesis overpredicts MIRI data and SED is more consistent with an old stellar population. Such systems would have high stellar masses ~ 10^{11} $M_\odot$

β_{UV} = -2 β_{opt} = +1



Lensed LRD μ~3 r<30pc – no host galaxy?

Furtak et al(2023)

[Slide by Richard Ellis, IAU 2024]

Little Red Dots - Dust-obscured AGN?

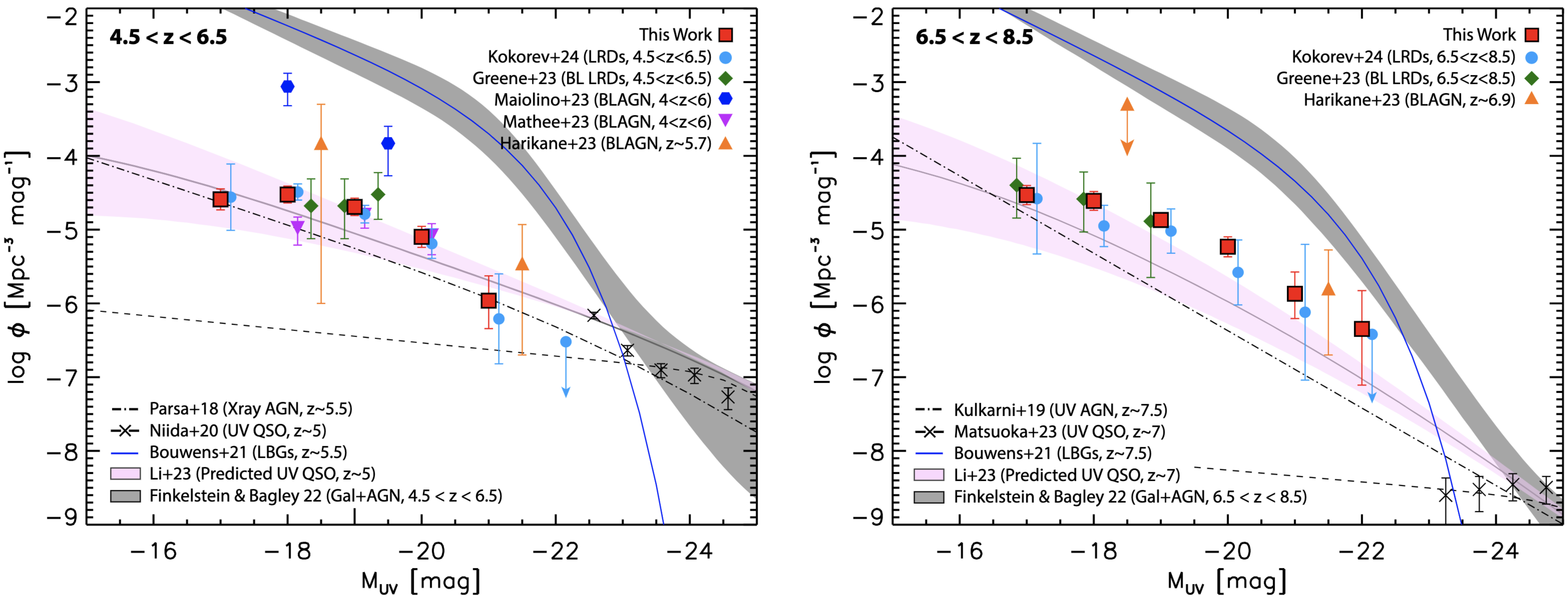


Figure 8. The UV luminosity function of our sample measured at rest-frame 1450Å in two redshift bins: $4.5 < z < 6.5$ (*left*) and $6.5 < z < 8.5$ (*right*). We find good agreement with previous photometric and spectroscopic compilations of LRDs (Matthee et al. 2023; Greene et al. 2023; Kokorev et al. 2024). We find LRDs are ~ 4 and ~ 10 times more numerous at $M_{\rm UV} = -19$ than X-ray AGN at $z \sim 5$ (Parsa et al. 2018) and UV-selected AGN at $z \sim 7$ (Kulkarni et al. 2019), respectively. We also note fair agreement with the model predictions of Li et al. (2023).

More exotic models…

The Excess of JWST Bright Galaxies: a Possible Origin in the Ground State of Dynamical Dark Energy in the light of DESI 2024 Data

N. Menci[1], A. A. Sen[2], M. Castellano[11,2]

of the ROYAL ASTRONOMICAL SOCIETY

MNRAS **533,** 3923–3936 (2024) https://doi.org/10.1093/mnras/stae1932
Advance Access publication 2024 September 13

Early galaxies and early dark energy: a unified solution to the hubble tension and puzzles of massive bright galaxies revealed by *JWST*

Xuejian Shen [1★], Mark Vogelsberger [1,2], Michael Boylan-Kolchin [3], Sandro Tacchella [4,5] and Rohan P. Naidu[1†]

[1] Department of Physics & Kavli Institute for Astrophysics and Space Research, Massachusetts Institute of Technology, Cambridge, MA 02139, USA

A smooth filament origin for prolate galaxies "going bananas" in deep JWST images.

Alvaro Pozo,[1] Tom Broadhurst,[2,1,3] Razieh Emami,[4] Philip Mocz,[5,6] Mark Vogelsberger,[7] Lars Hernquist,[4] Christopher J. Conselice,[8] Hoang Nhan Luu,[1] George F. Smoot,[1,9,10,11] and Rogier Windhorst[12]

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[8] *Jodrell Bank Centre for Astrophysics, University of Manchester, Oxford Road, Manchester, UK*
[9] *Department of Physics and Institute for Advanced Study, The Hong Kong University of Science and Technology, Hong Kong*
[10] *Paris Centre for Cosmological Physics, APC, AstroParticule et Cosmologie, Universit ́e de Paris, CNRS/IN2P3, CEA/lrfu, 10, rue Alice Domon et Leonie Duquet, 75205 Paris CEDEX 13, France emeritus*
[11] *Physics Department, University of California at Berkeley, CA 94720, Emeritus*
[12] *School of Earth and Space Exploration, Arizona State University, Tempe, AZ 85287-1404, USA*

ABSTRACT

We compare the abundant prolate shaped galaxies reported in deep JWST surveys, with the predicted *stellar* appearance of young galaxies in detailed hydro-simulations of three main dark matter contenders: Cold (CDM), Wave/Fuzzy (ψDM) and Warm Dark Matter (WDM). The observed galaxy images closely resemble the elongated stellar appearance of young galaxies predicted by ψDM and

The Astrophysical Journal Letters, 937:L30 (7pp), 2022 October 1 https://doi.org/10.3847/2041-8213/ac927f

Accelerating Early Massive Galaxy Formation with Primordial Black Holes

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Observations of Galaxies at $z \gtrsim 10$ Allow to Test Cosmological Models with Features in the Initial Power Spectrum

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[1] *P.N. Lebedev Physical Institute, Astro Space Center, Moscow, 117997 Russia*
[2] *National research centre Kurchatov institute, Moscow, Russia*

The initial power spectrum of density perturbations, generated during the inflationary epoch, is now constrained by observations on scales $\lambda > 5$ Mpc and has a power-law form. The peculiarities of the inflationary process can lead to the appearance of non-power-law contributions to this spectrum, such as peaks. The exact size and shape of the peak cannot

New galaxy UV luminosity constraints on warm dark matter from JWST

Bin Liu[1], Huanyuan Shan[1,2,3] and Jiajun Zhang[1,2,3]

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ABSTRACT

We exploit the recent *James Webb Space Telescope* (JWST) determination of galaxy UV luminosity functions over the redshift range $z = 9 - 14.5$ to derive constraints on warm dark matter (WDM) models. The delayed structure formation in WDM universe

Can Early Dark Energy be Probed by the High-Redshift Galaxy Abundance?

Liu, Weiyang,[1,2★] Zhan, Hu,[1,3] Gong, Yan,[1,2] and Wang, Xin[1,2]
[1] *Key Laboratory of Space Astronomy and Technology, National Astronomical Observatories, Chinese Academy of Sciences, Beijing, 100101, China P.R.*
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Accepted XXX. Received YYY; in original form ZZZ

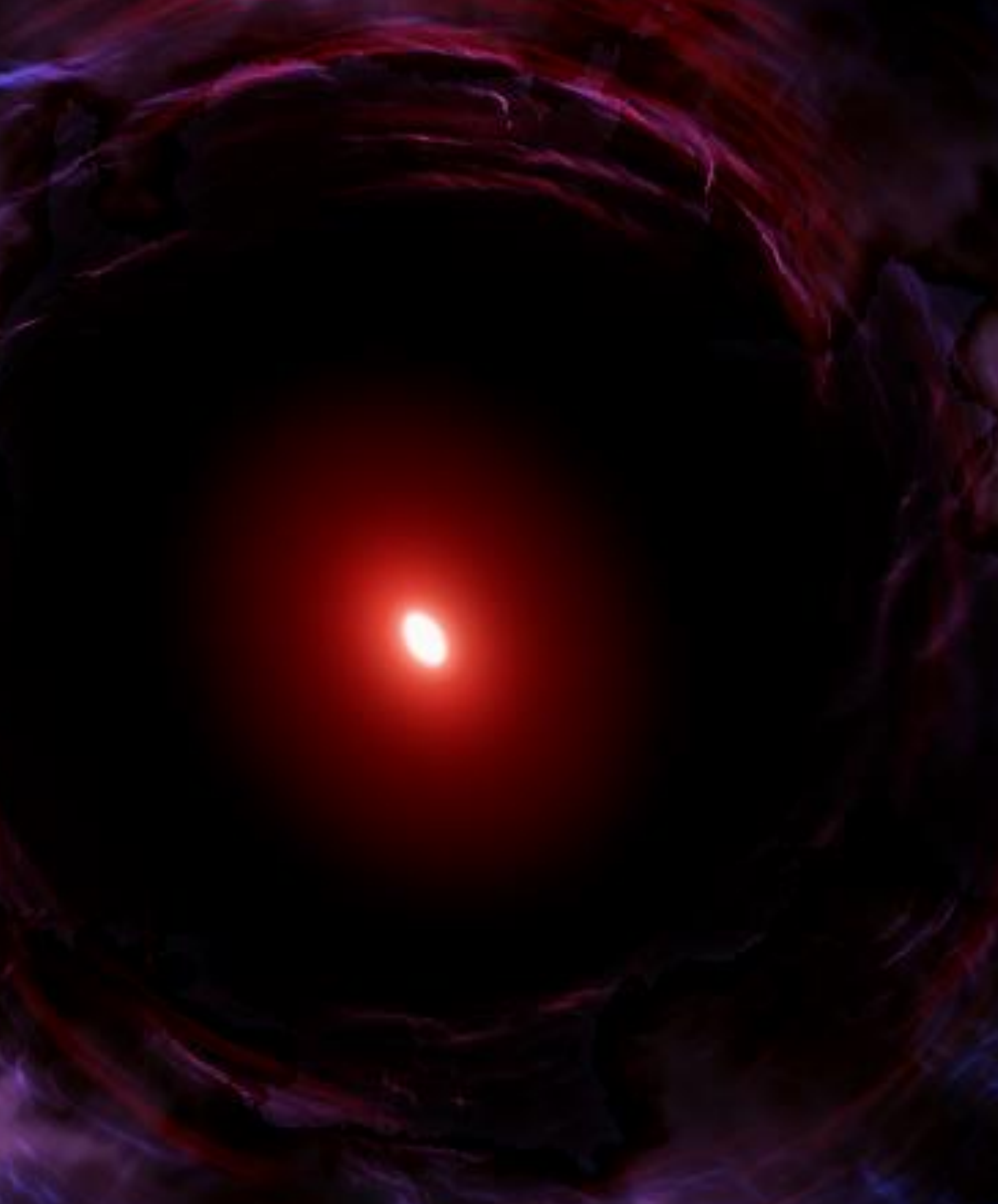
ABSTRACT
The Hubble tension and σ_8 tension are two of the major issues of the standard Λ Cold Dark Matter (ΛCDM) model. The analysis of the Cosmic Microwave Background (CMB) data acquired by the Atacama Cosmology Telescope (ACT) and the large-scale

Warm dark matter constraints from the *JWST*

Pratika Dayal [1★] and Sambit K. Giri [2]
[1] *Kapteyn Astronomical Institute, University of Groningen, PO Box 800, 9700 AV Groningen, The Netherlands*
[2] *Nordita, KTH Royal Institute of Technology and Stockholm University, Hannes Alfvéns väg 12, SE-10691 Stockholm, Sweden*

Common themes

- Rare populations (per arcmin^2) either forming or appearing at z>5
- Big uncertainties about stellar mass, dark matter content and halo abundances
- JWST samples are at most ‘tens of spectra’
- JWST spectra are amazing



Always expected

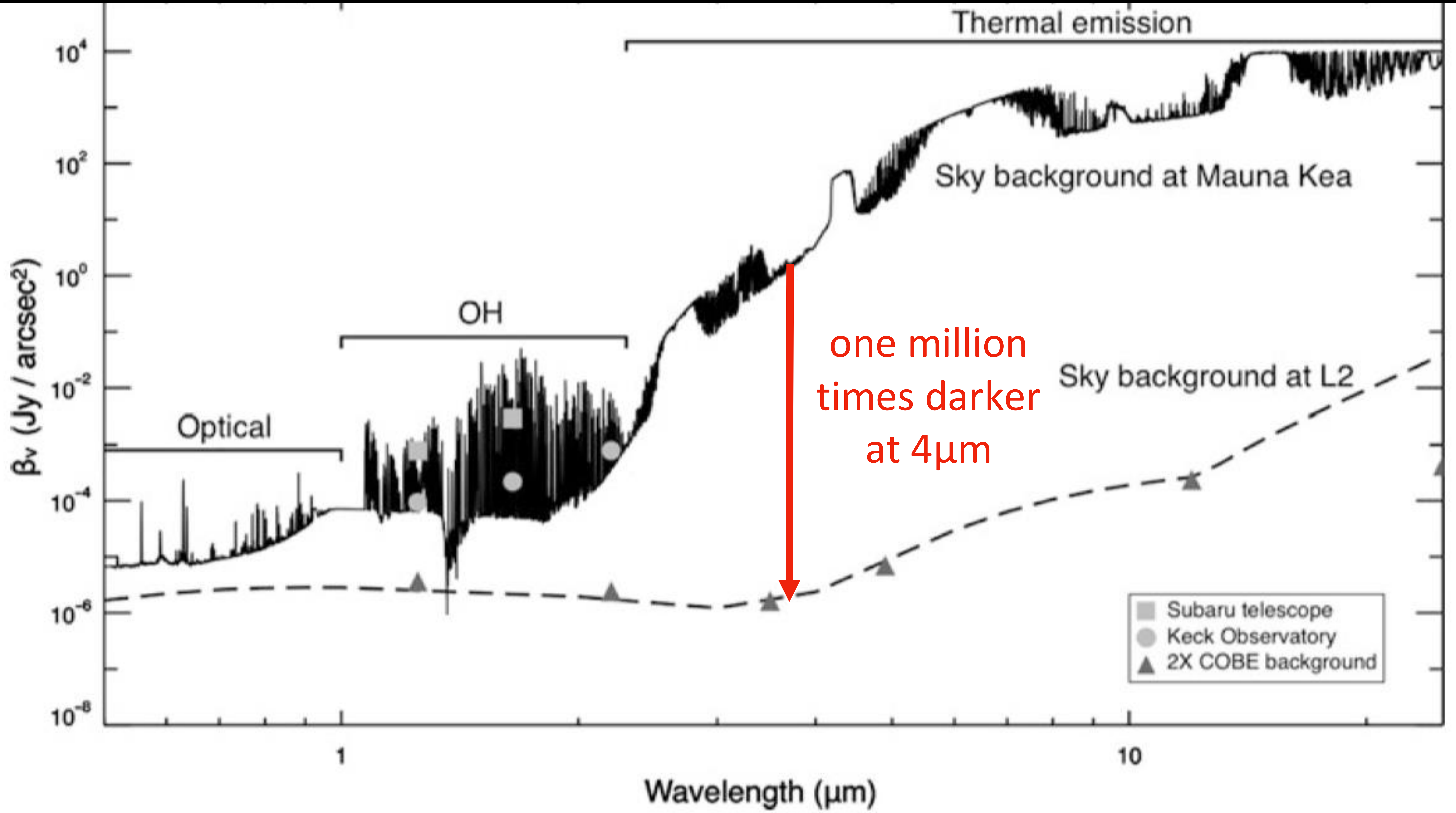
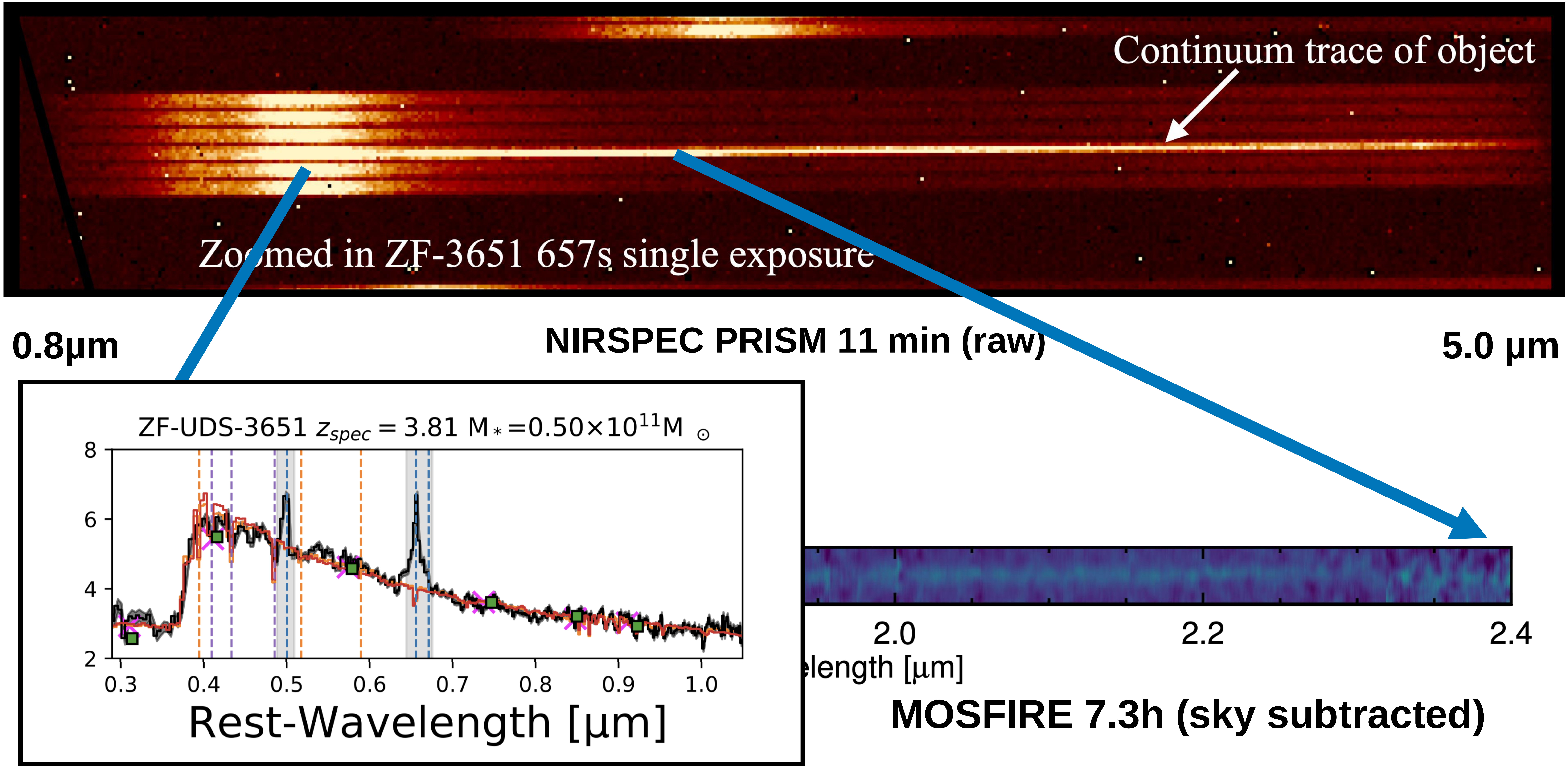


Fig. 9-3

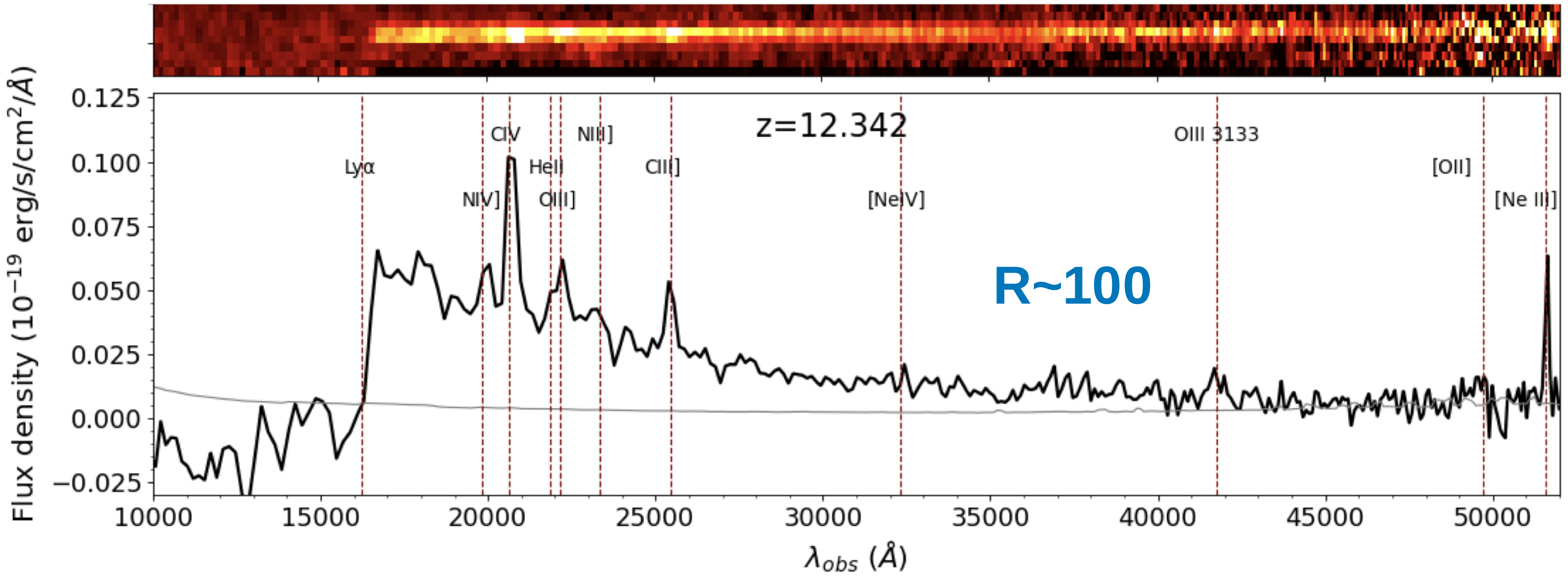
Typical "dark time" visible and infrared background emission for a ground-based telescope as measured at Mauna Kea (Hawaii). An estimate of the background for a cryogenically cooled telescope at L2 is shown for comparison (After Gillet and Mountain 1998)

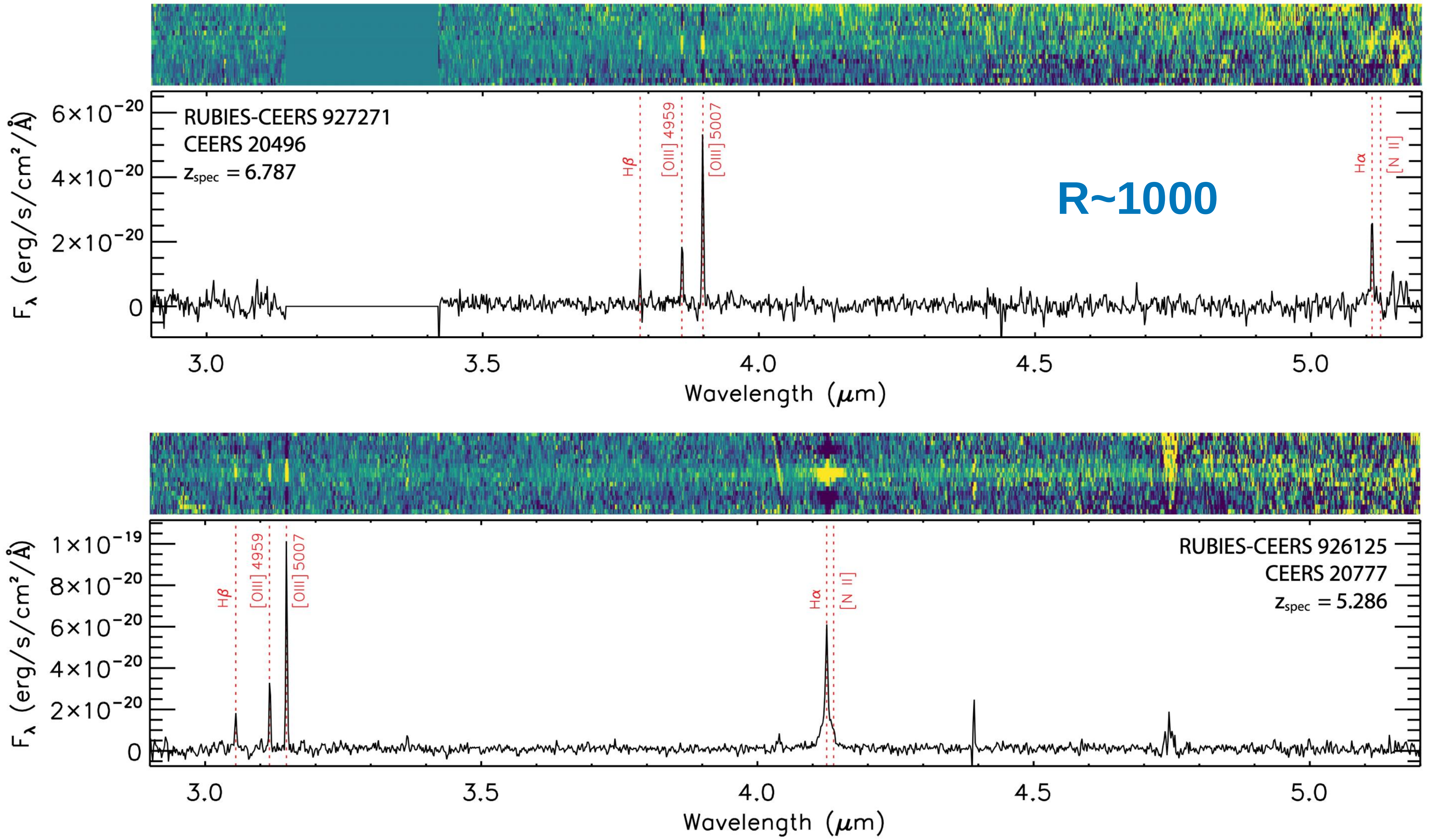
JWST spectra: R=100–400

(Nanayakkara et al. 2024)

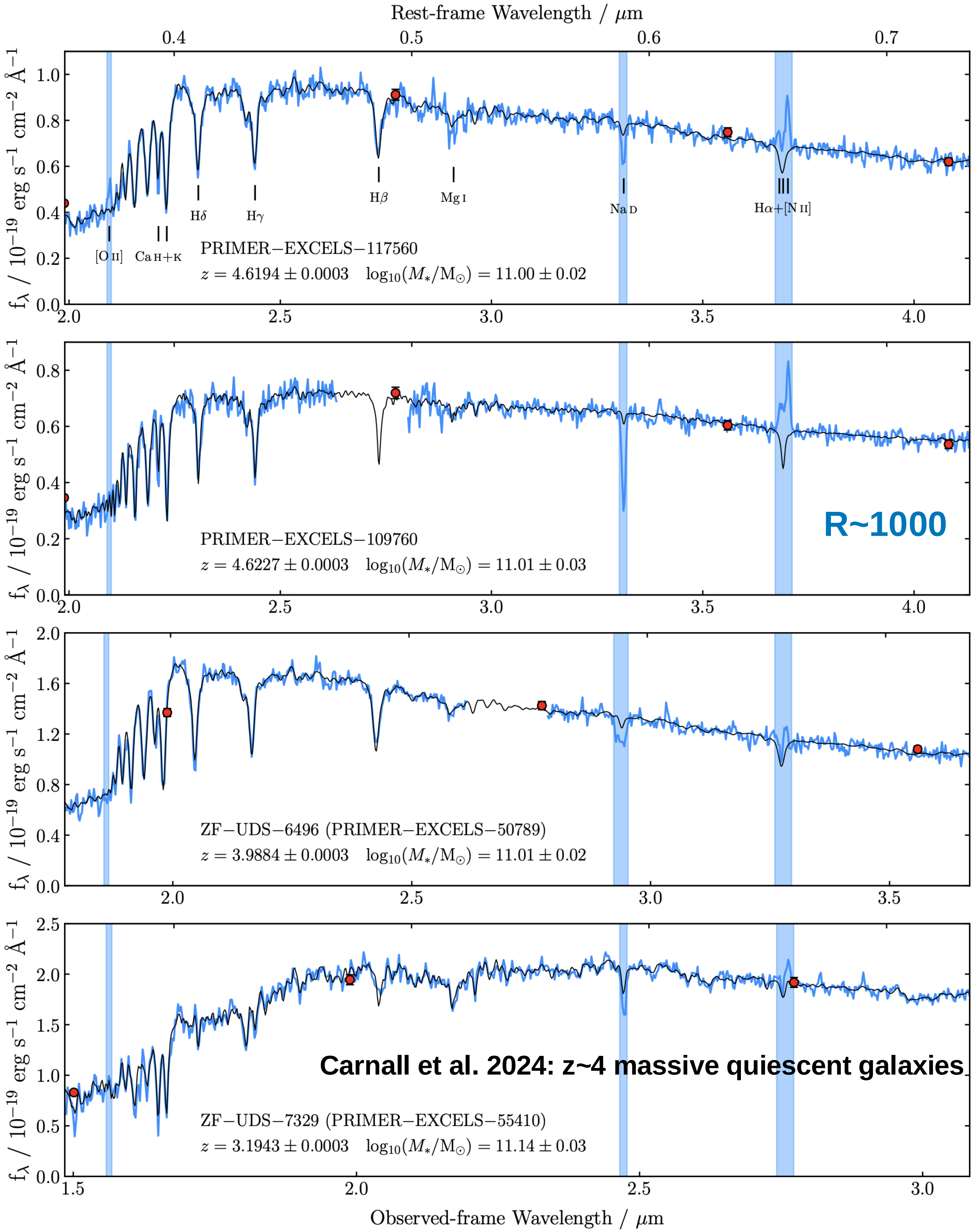


Castellano et al. 2024: z~12 LBG





Kocevski et al. 2024: 5<z<10 AGN

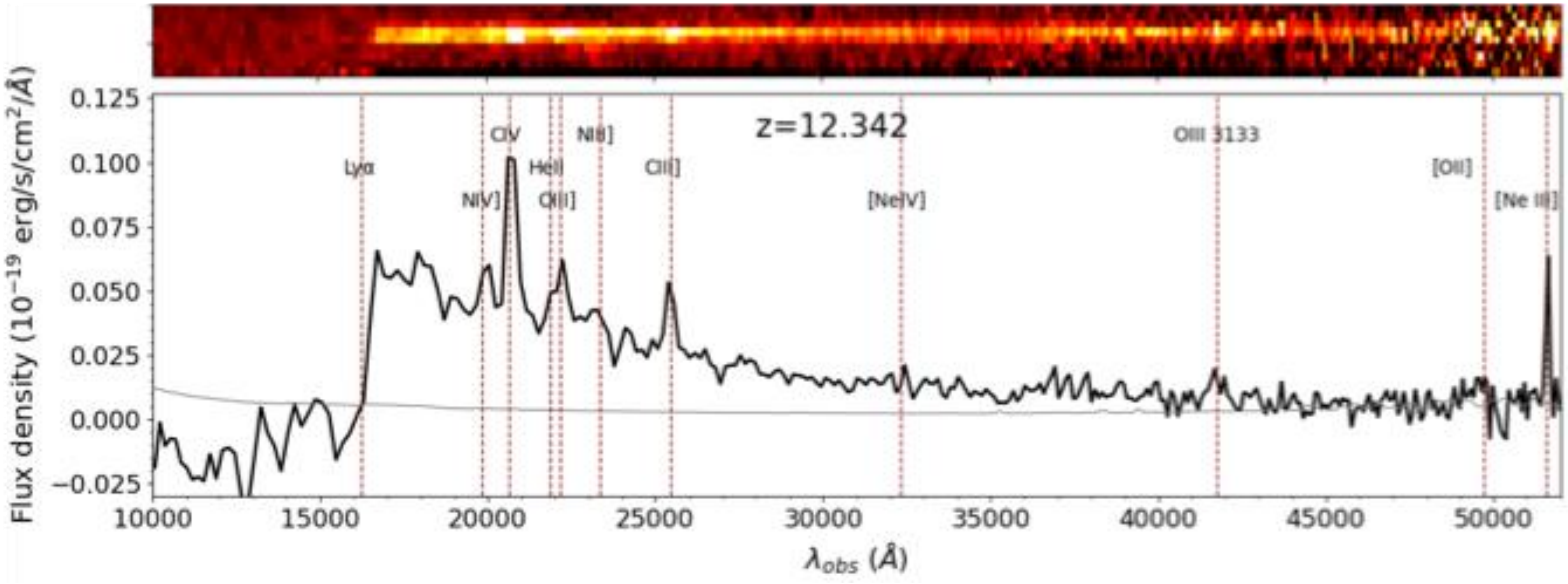


Carnall et al. 2024: z~4 massive quiescent galaxies

Highlight 3 – Chemical Evolution

JWST has opened up the prospects of tracing evolution of the gas-phase metallicity.

GHz2: z=12.34 mildly lensed μ=1.3 NIRSpec prism 15 ksec exposure
Strong CIV, no [Ne V] AGN unlikely; dense gas



GHz2 z=12.3 (above): M* ~ 5. 10_8 $M_\odot$, SFR ~ 5 $M_\odot$ yr-1 Z_{gas}~3-7% solar

GN-z11 z=10.6 (atypical case): M* ~ 5. 10^8 $M_\odot$, SFR ~ 35 $M_\odot$ yr^{-1} Z_{gas}~10% solar

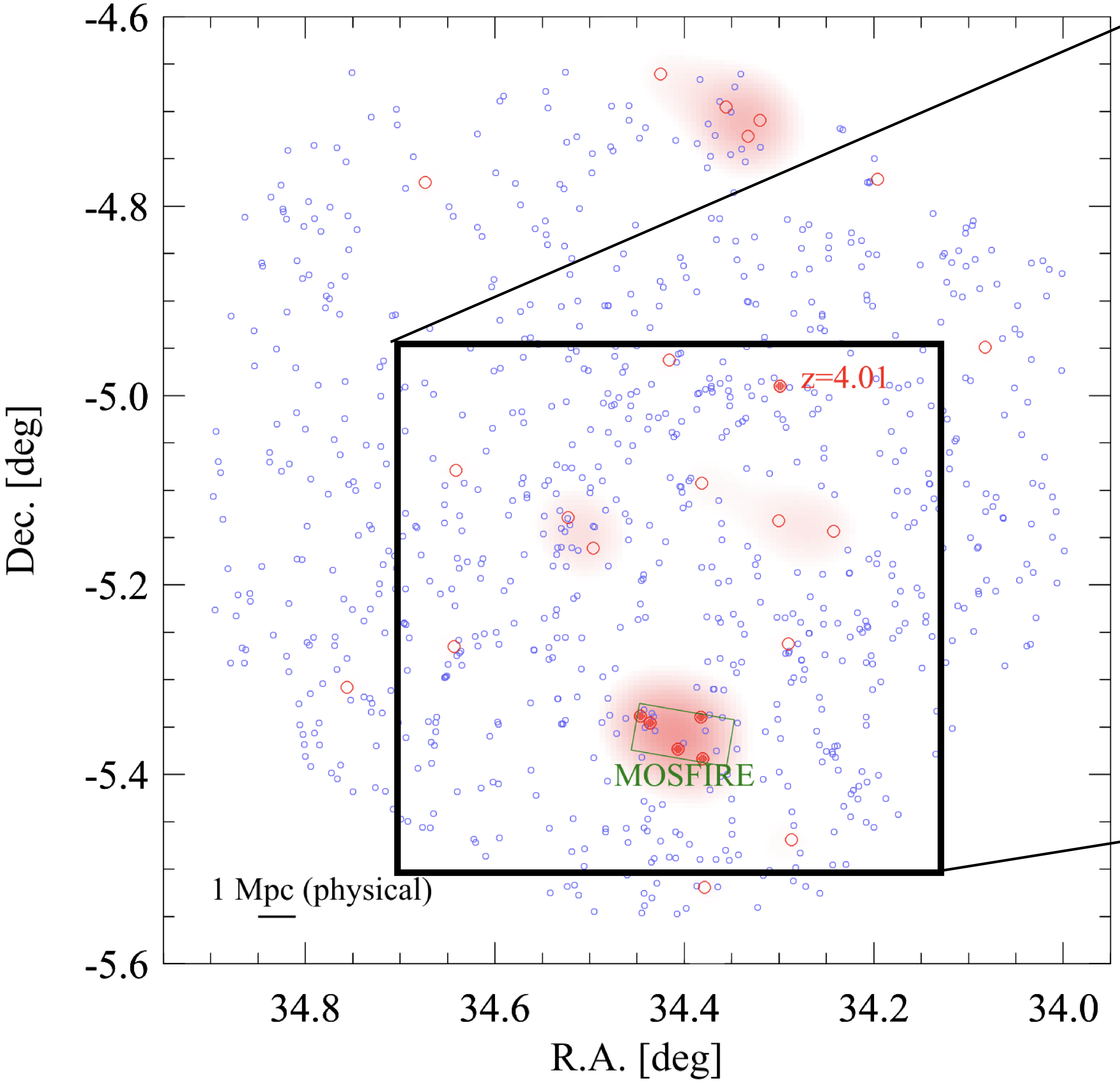
Curtis-Lake et al z>10 sample: M* ~ 1-4. 10^8 $M_\odot$, SFR ~ 10-150 $M_\odot$ yr^{-1} Z_{gas}~1-4% solar

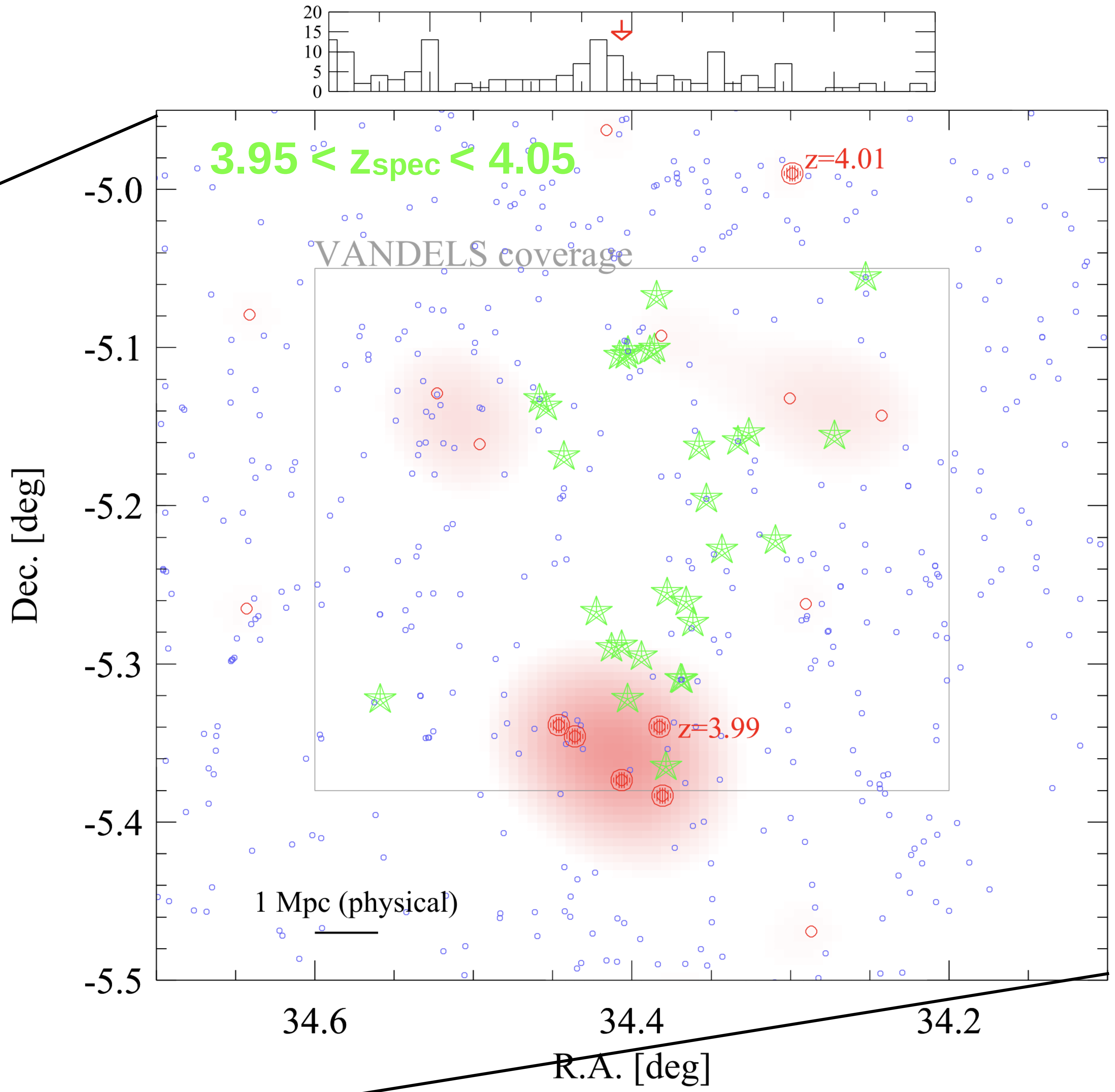
Castellano et al 2024 **[Slide by Richard Ellis, IAU 2024]**


Clustering…

Clustering

Tanaka et al. 2024 z=4.01 protocluster in SXDS field
5 QGs within 1 pMpc



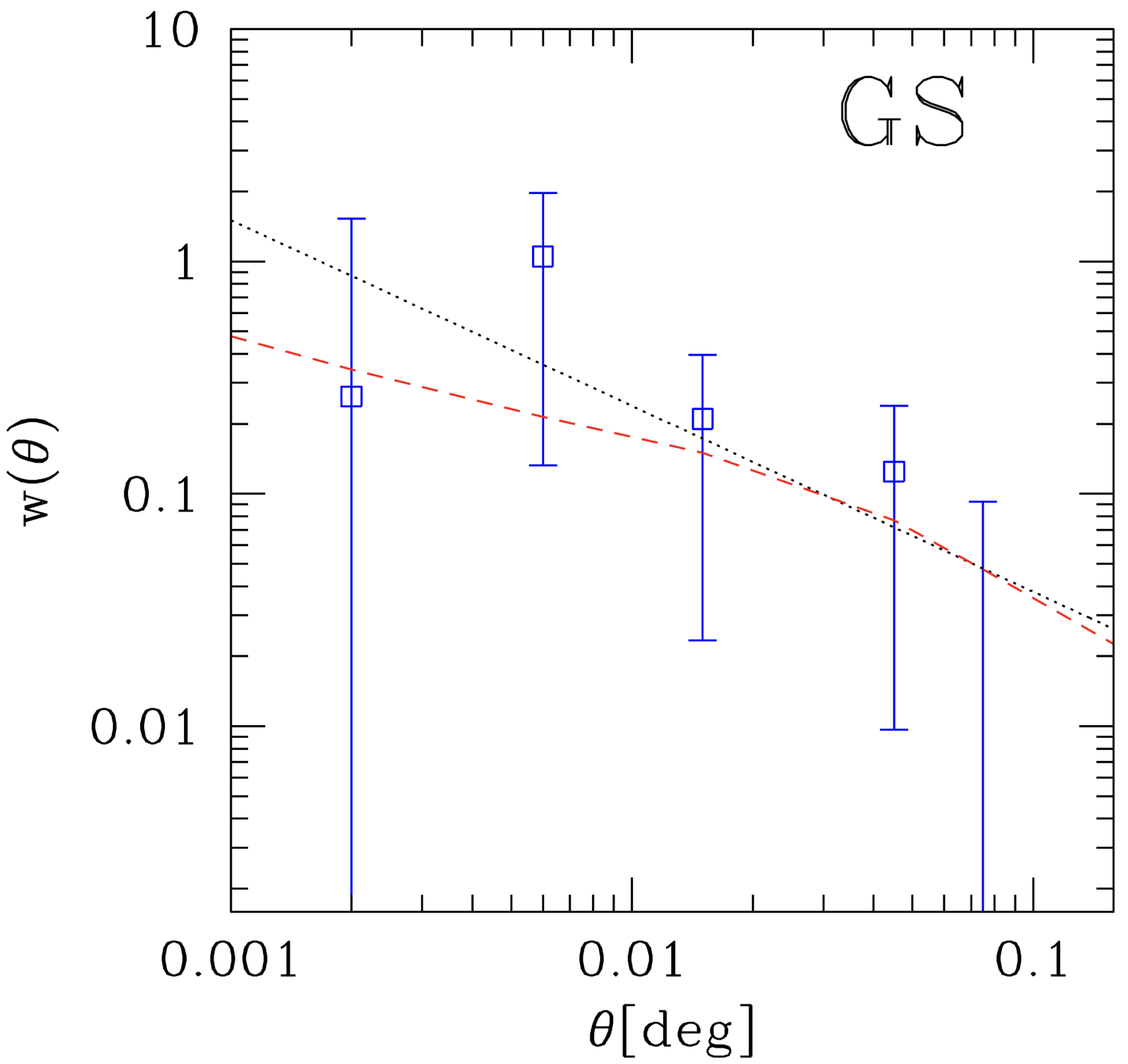


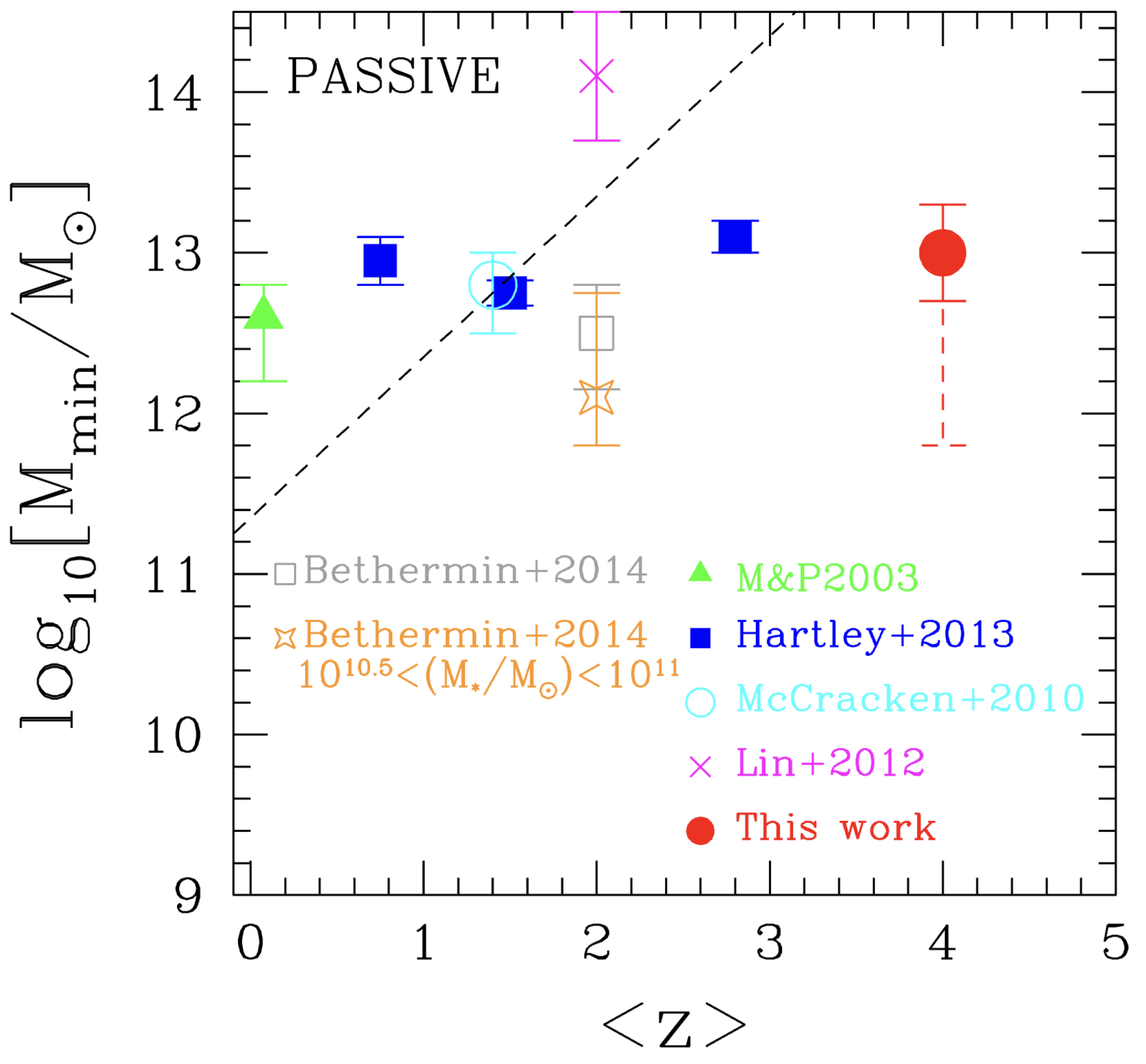
Halo mass > 1E13 Msun from QG stellar mass

Comparison with TNG300: no such structure or close pairs at z=4.01

Clustering and Dark Halo Mass

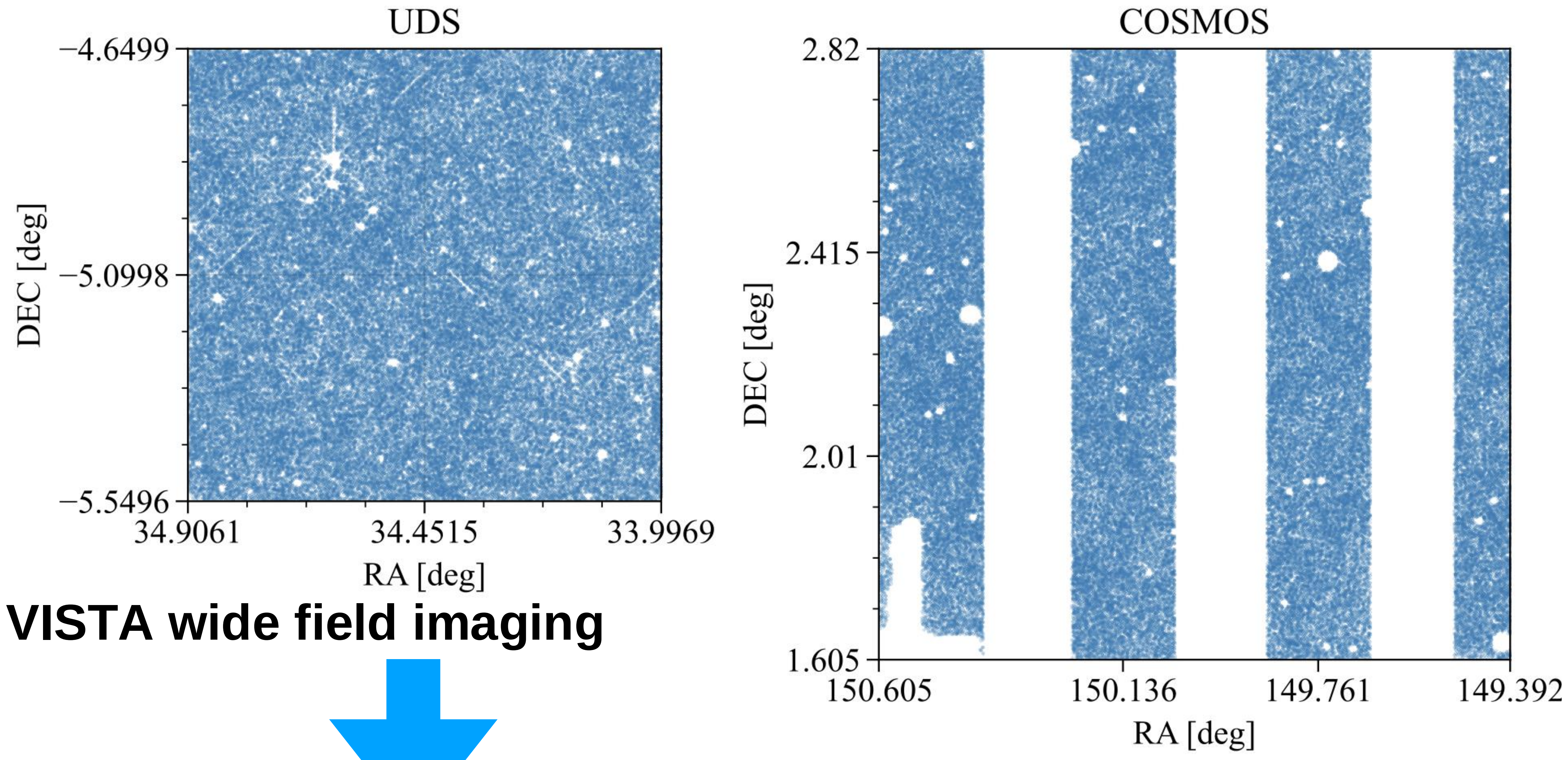
Magliocchetti et al. 2023 3<z<5
mean log M* ~ 10.4



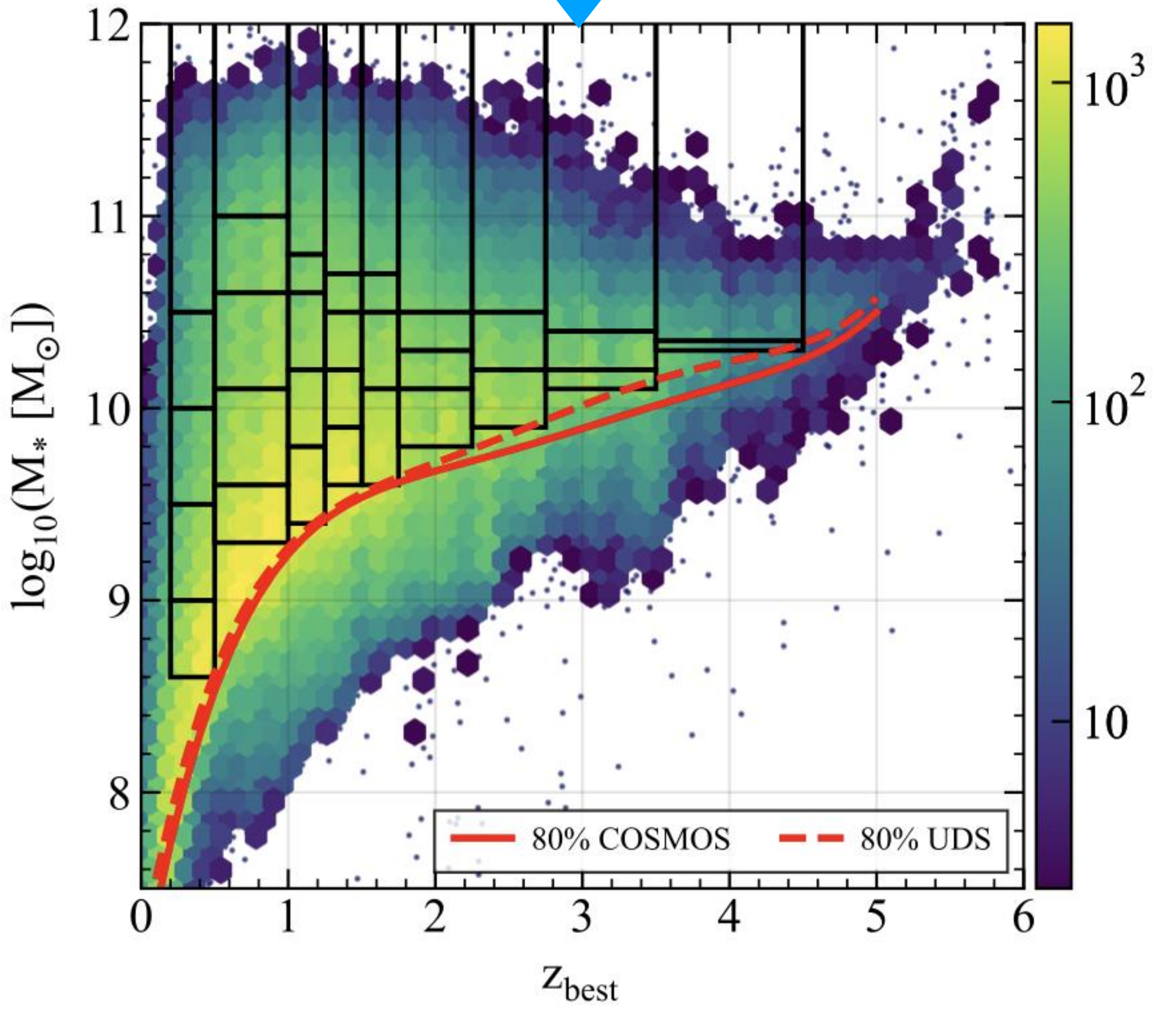


r_0 ~ 12 Mpc

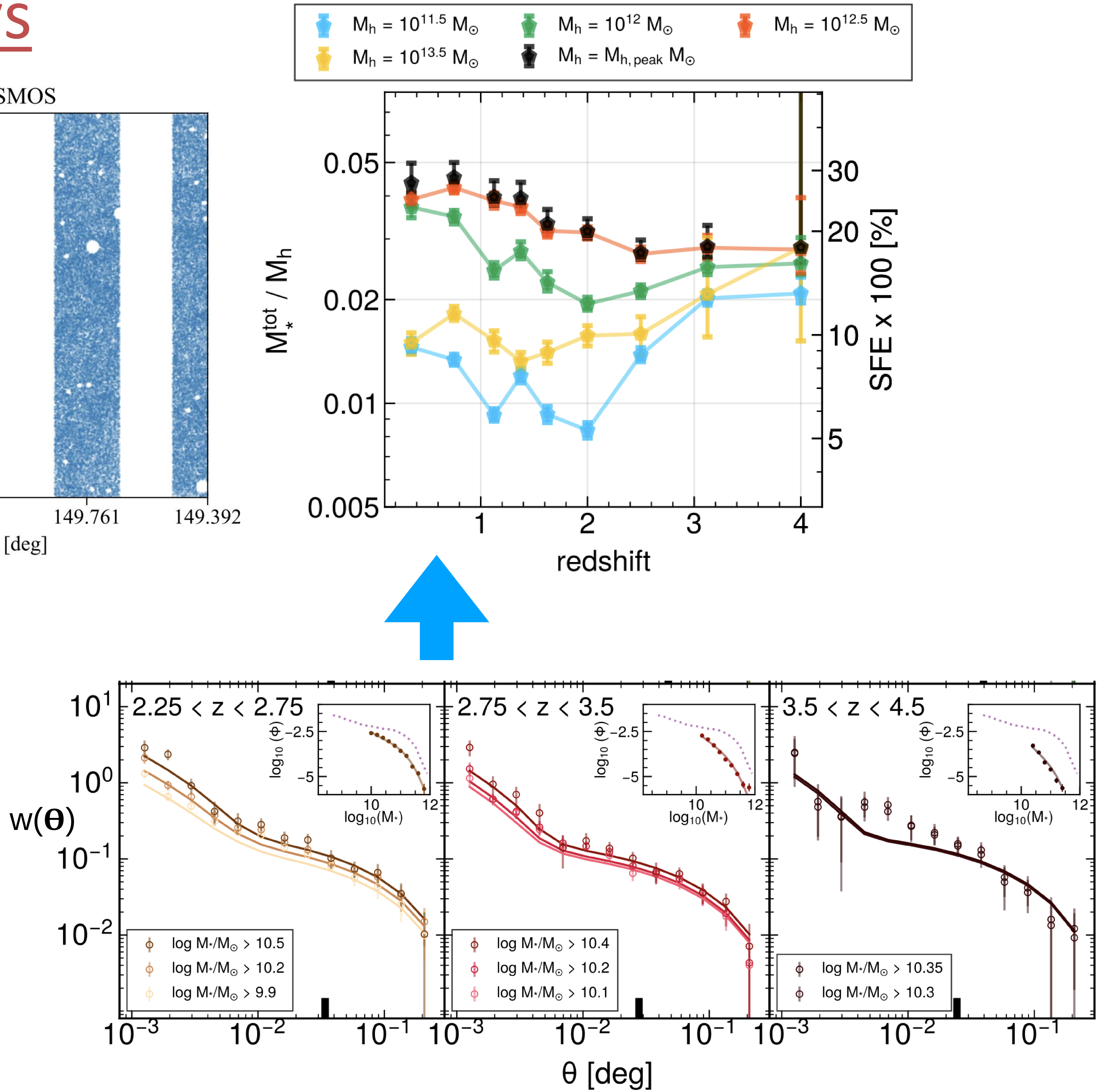
Wide field photo-z surveys



VISTA wide field imaging

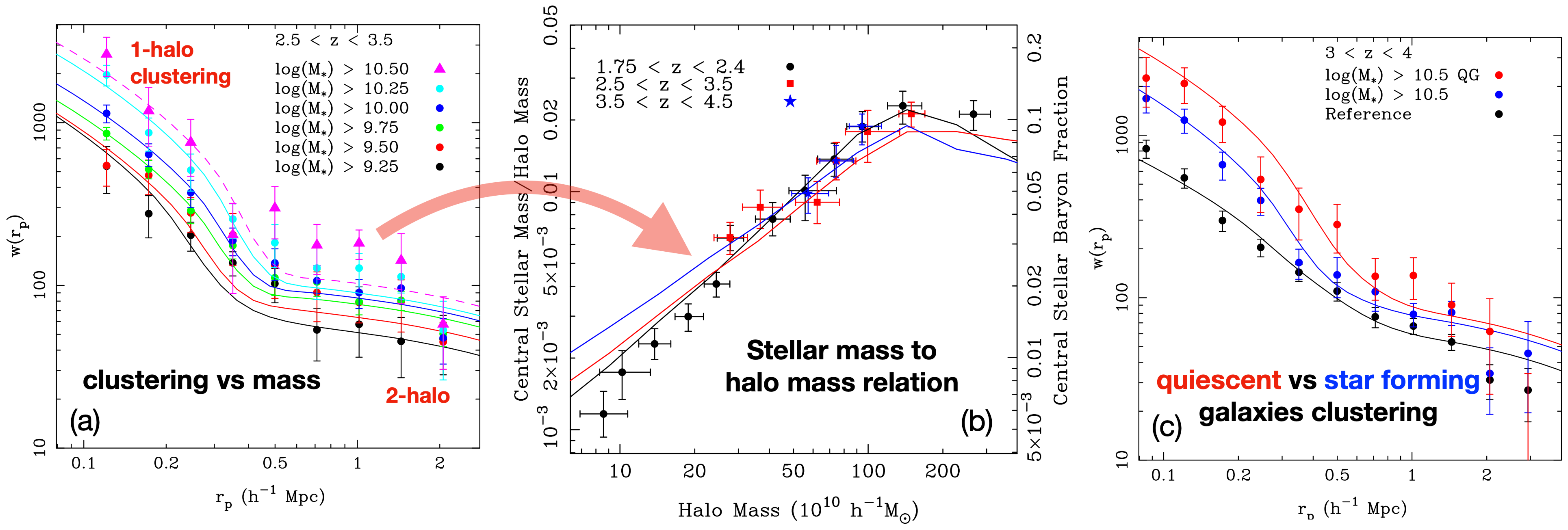


Zaidi et al (incl. KG) 2024



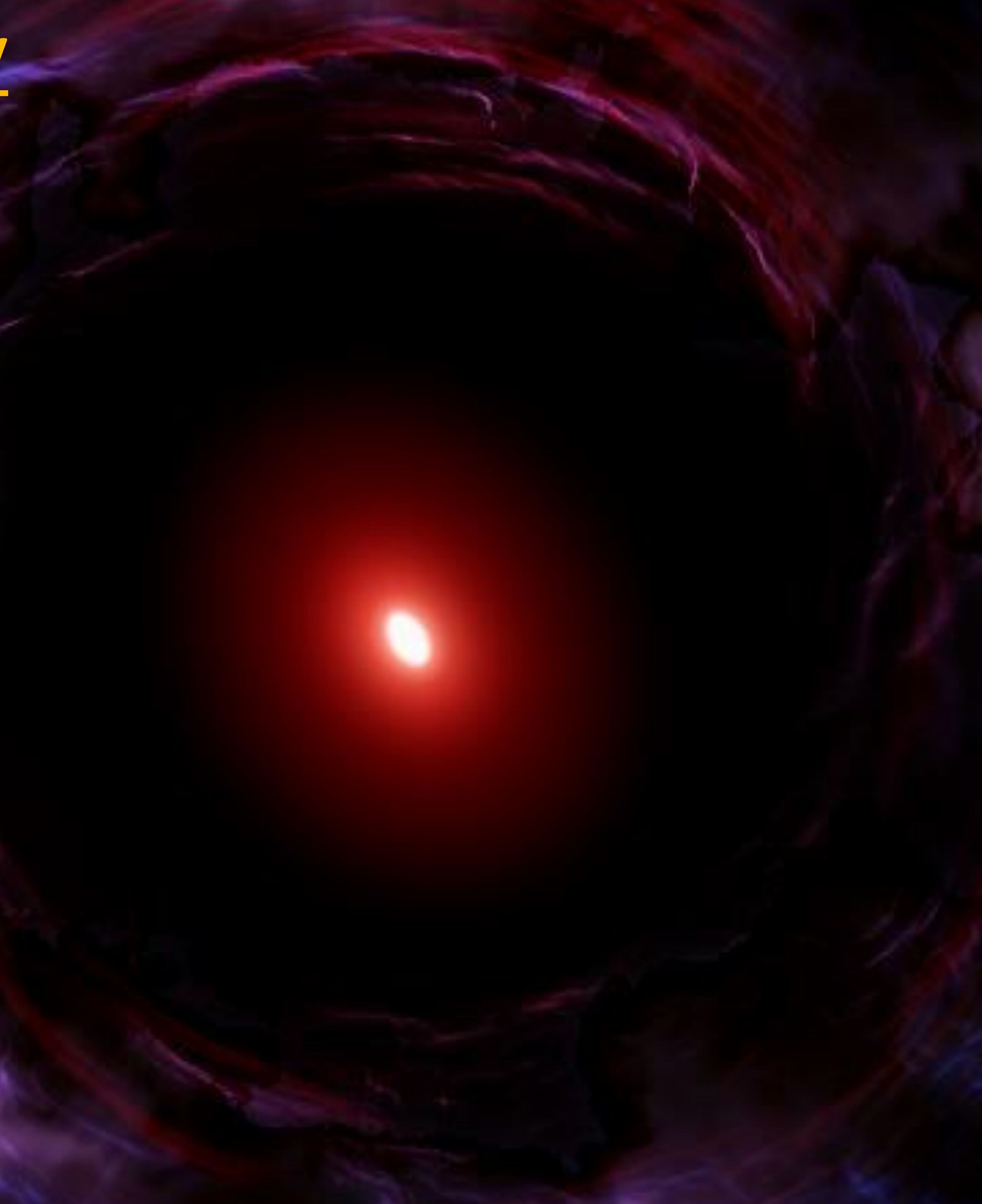
The growth of baryons in the cosmic DM web

SIMULATIONS for the JWST OutThere 1<z<4 redshift survey (~50,000 objects)



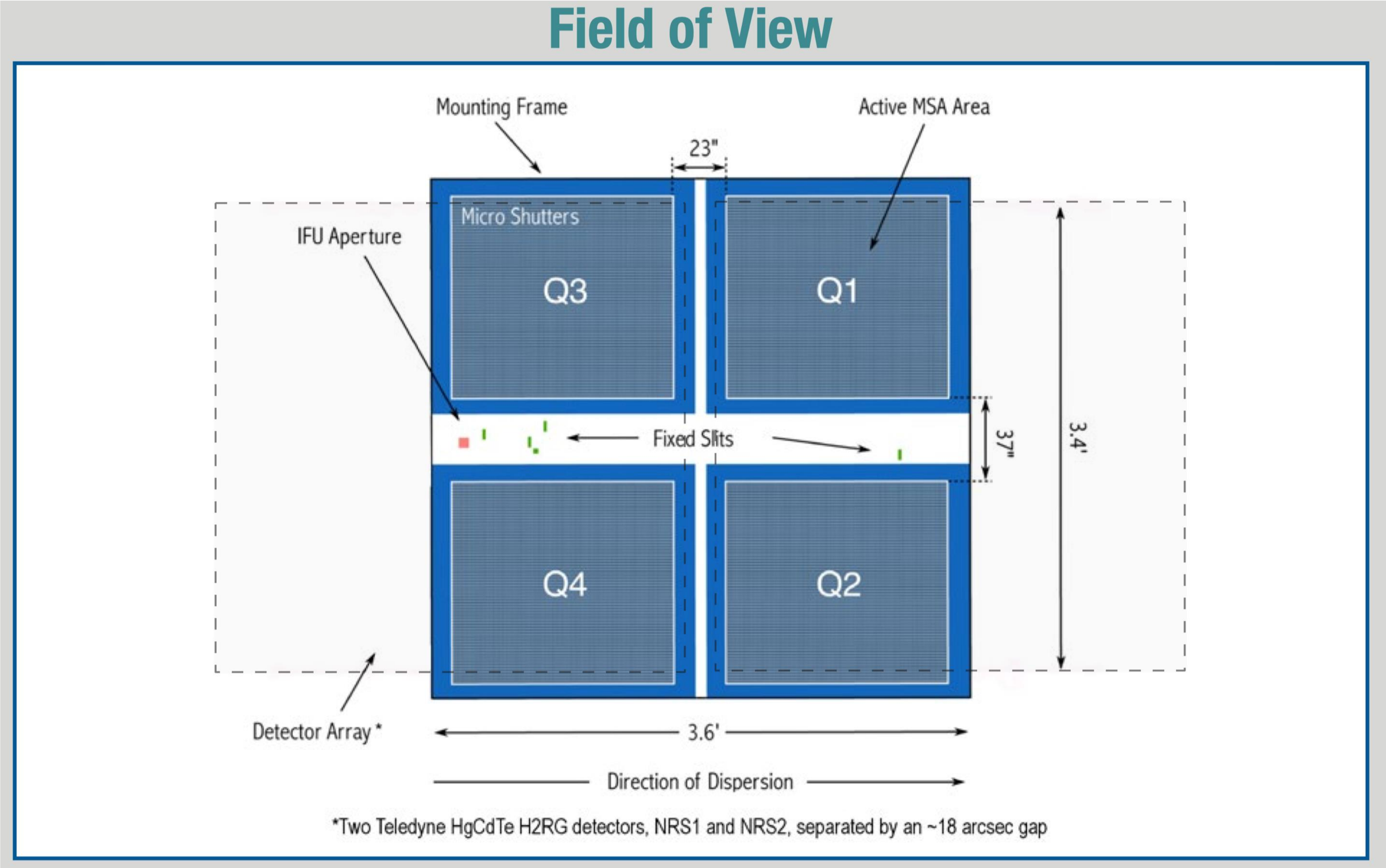
Wide field space spectroscopy

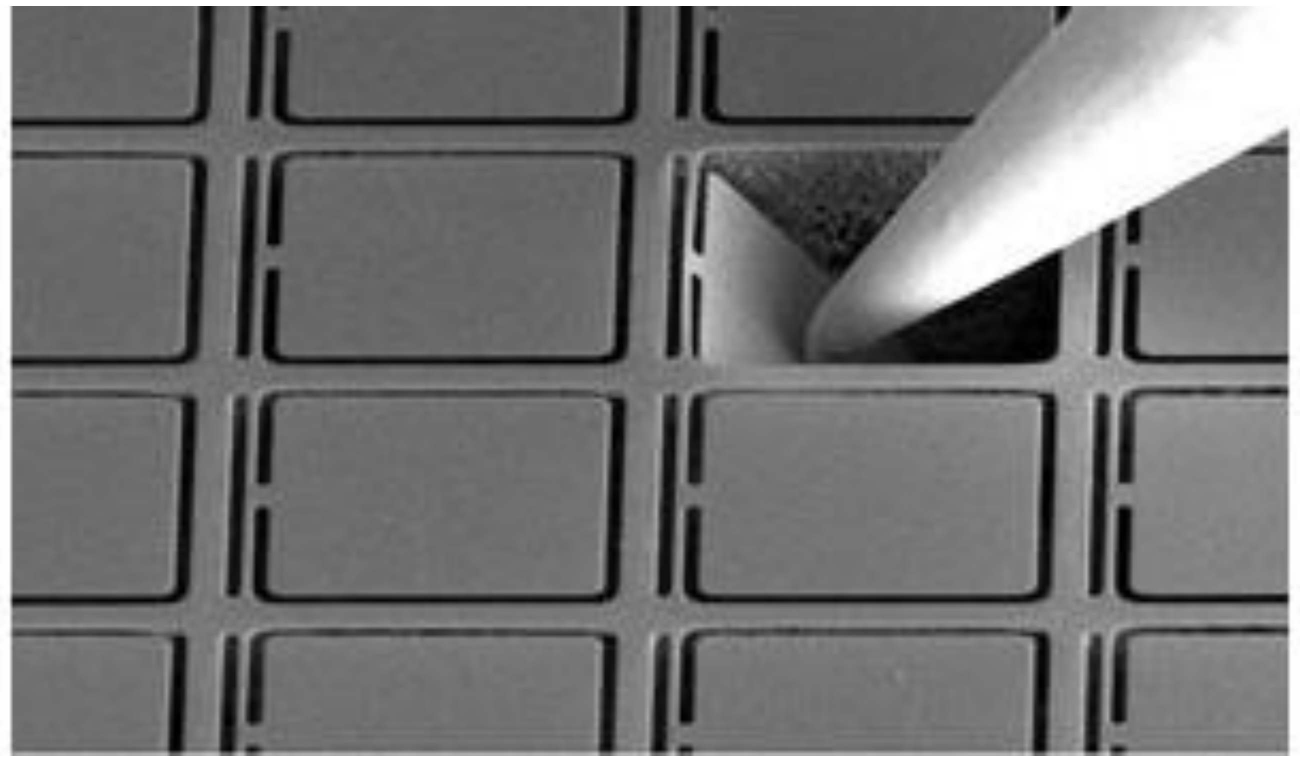
- Rare populations **need wide field targeting and clustering measures**: probe dark matter halos in early universe (new physics?)
- Smaller mirror wider field could have same AΩ as JWST: but many more examples of rare objects per shot ~ 1000 deg^{-2}



Euclid – 1m mirror, 0.7 deg FOV 600M EUR mission

JWST NIRSPEC



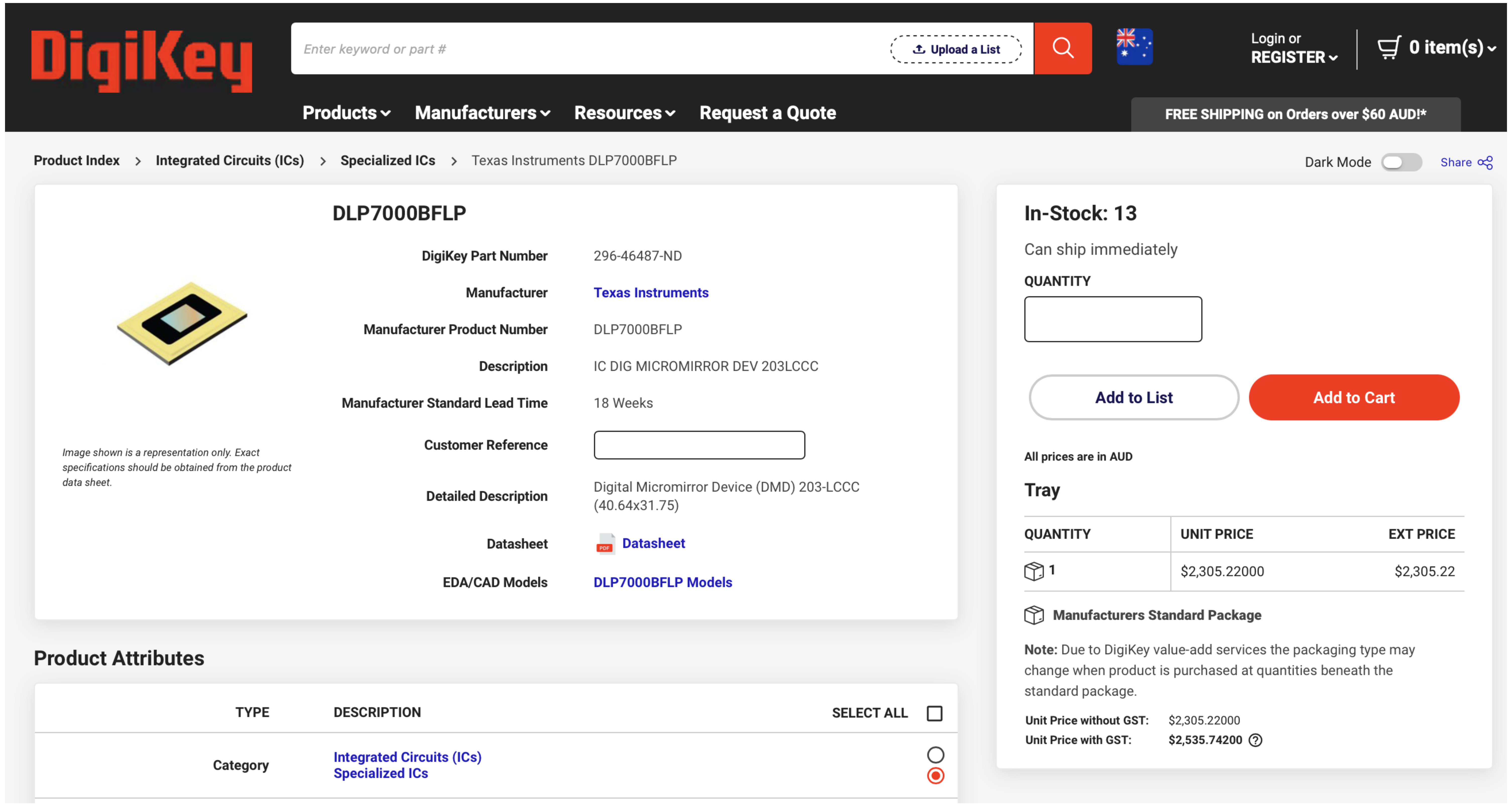


250,000 100μm x 200μm 'Micro Shutter Array'

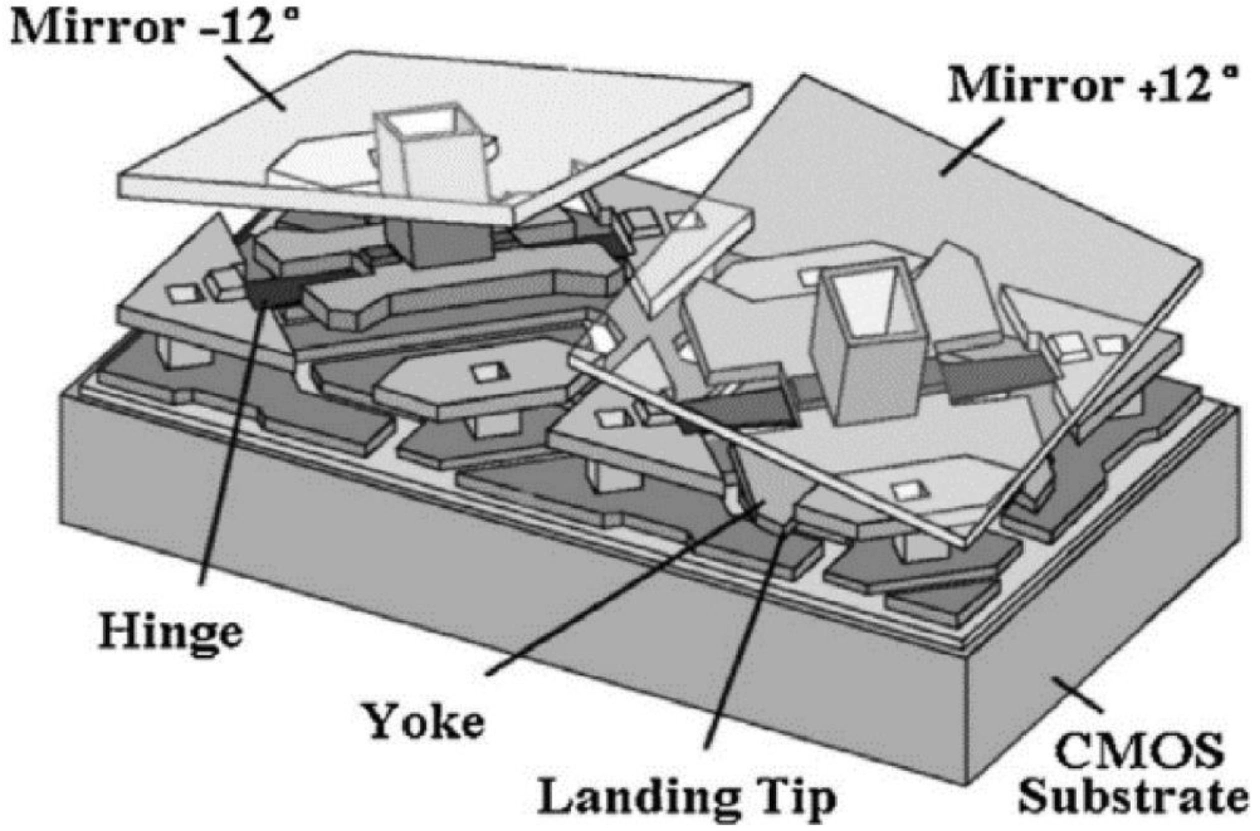
- A 1m telescope with a 20 arcmin FOV ≈ 6.5m telescope with 3 arcmin FOV
- Say 1m (0.6 arcs PSF at 3μm) with f/15 would give the same physical size focal plane (~7cm) as MSA for 20 arcmin
- Fast beams (e.g. f/5) would result in a very compact focal plane (0.3 arcsec=10μm)
- Plenty of input imaging (Euclid/Roman NIR surveys)

Design thoughts

- 1–2m telescopes, proven heritage ground/space
- Slits ~500x more sensitive than slitless, and much cleaner data
- Space X claims 100 kg to LEO for several million $.
- c.f. Euclid (~2000 kg, 1.2m f/20.4) – Space X charged $70M (Falcon 9 launch)
- What about slit technology?



- 1024x768 device 13µm pitch
- 12º mirror tilt
- Would need 4x4 array
- Space?
- Matched detector would be 4096x4096



Final thoughts

- Space 2.0 – launch often and break things. Budget for several missions!
- Could start small?
- A lot of the key discoveries of JWST only needed < 1 hour spectroscopic exposures!
- Wide field: NIR slit spectroscopy is my favourite idea – test early formation of galaxies in DM halos, and exotic DM models.
- Tons of other applications in galaxy evolution/cosmology.
- Test DMD in space (or other novel slit tech) would be the first step.