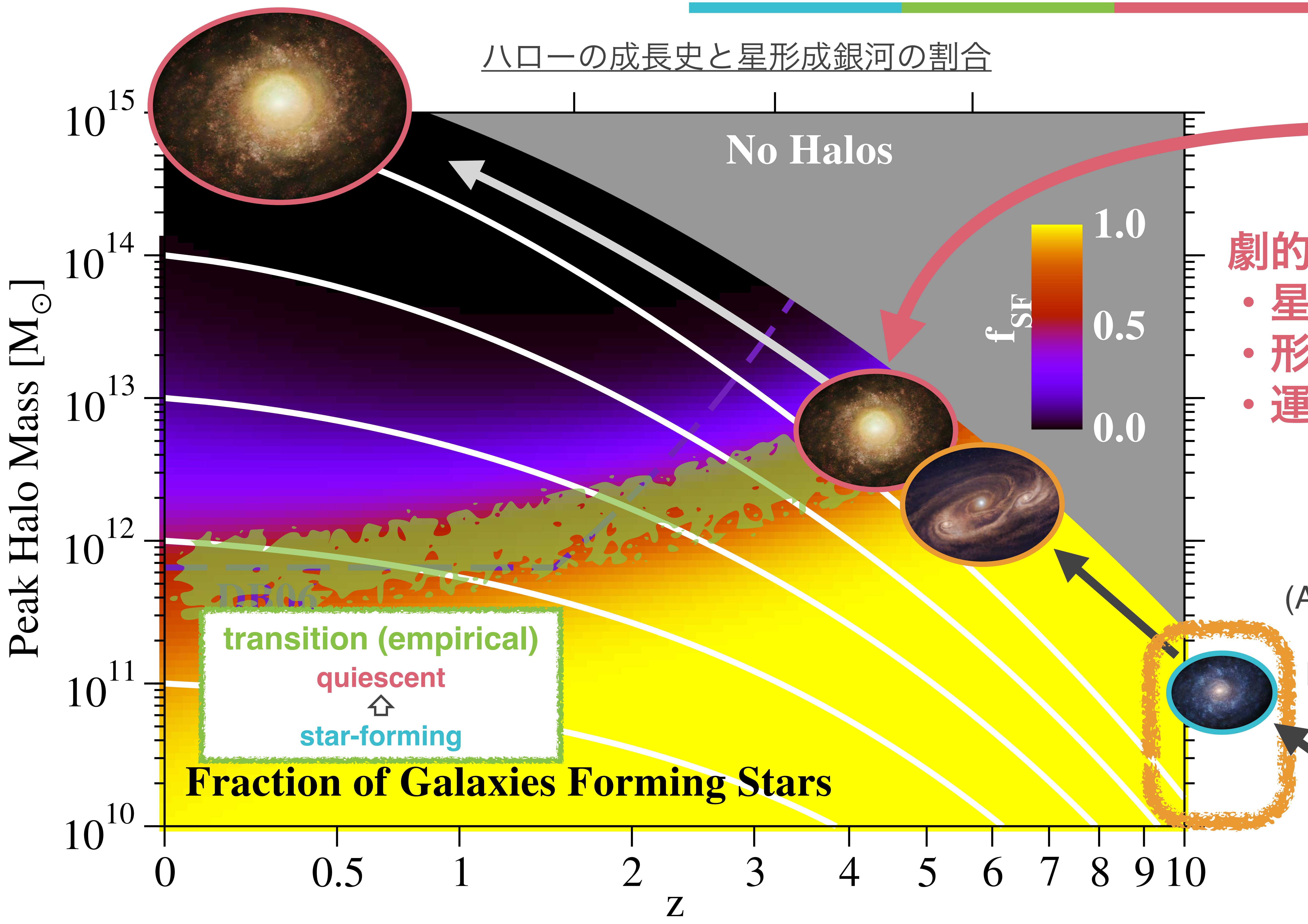
アルマ望遠鏡による遠方銀河観測

但木謙一
(北海学園大学)

Hokkai-
Gakuen
University

巨大銀河の進化 ⇄ 初代銀河の進化



巨大銀河の形成

劇的な変化
- 星形成活動
- 形態
- 運動

現在の最遠方銀河
z=11-13, logM*=8-9
(Arrabal Haro et al. 2023,
Bunker et al. 2023,
D'Eugenio et al. 2023)

初代銀河の誕生

Behroozi et al. 2019, ZINA DERETSKY/NATIONAL SCIENCE FOUNDATION/WIKIMEDIA COMMONS, Katrina Kenny & University of Adelaide

2022年7月12日に公開された画像の１つ
46億光年彼方の銀河団

NASA, ESA, CSA, STScI

arXiv > astro-ph > arXiv:2207.09434v1

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Astrophysics > Astrophysics of Galaxies

[Submitted on 19 Jul 2022 (this version), latest version 25 Oct 2022 (v2)]

Two Remarkably Luminous Galaxy Candidates at $z \approx 11 - 13$ Revealed by JWST

Rohan P. Naidu, Pascal A. Oesch, Pieter van Dokkum, Erica J. Nelson, Katherine A. Suess, Katherine E. Whitaker, Natalie Allen, Rachel Bezanson, Rychard Bouwens, Gabriel Brammer, Charlie Conroy, Garth Illingworth, Ivo Labbe, Joel Leja, Ecaterina Leonova, Jorryt Matthee, Sedona H. Price, David J. Setton, Victoria Strait, Mauro Stefanon, Sandro Tacchella, Sune Toft, John R. Weaver, Andrea Weibel

The first few hundred Myrs at $z > 10$ mark the last major uncharted epoch in the history of the Universe, where only a single galaxy (GNz11 at $z \approx 11$) is currently spectroscopically confirmed. Here we present a search for luminous $z > 10$ galaxies with $JWST$ /NIRCam photometry spanning $\approx 1 - 5\mu$m and covering 49 arcmin^2 from the public $JWST$ Early Release Science programs (CEERS and GLASS). Our most secure candidates are two $M_{\rm UV} \approx -21$ systems: GLASS-z13 and GLASS-z11. These galaxies display abrupt $\gtrsim 2.5$ mag breaks in their spectral energy distributions, consistent with complete absorption of flux bluewards of Lyman-α that is redshifted to $z \approx 13$ and $z \approx 11$. Lower redshift interlopers such as dusty quiescent galaxies with strong Balmer breaks would be comfortably detected at $> 5\sigma$ in multiple bands where instead we find no flux. From SED modeling we infer that these galaxies have already built up $\sim 10^9$ solar masses in stars over the $\lesssim 300 - 400$ Myrs after the Big Bang. The brightness of these sources enable morphological constraints. Tantalizingly, GLASS-z11 shows a clearly extended exponential light profile, potentially consistent with a disk galaxy of $r_{50} \approx 0.7$ kpc. These sources, if confirmed, join GNz11 in defying number density forecasts for luminous galaxies based on Schechter UV luminosity functions, which require a survey area $> 10\times$ larger than we have studied here to find such luminous sources at such high redshifts. They extend evidence from lower redshifts for little or no evolution in the bright end of the UV luminosity function into the cosmic dawn epoch, with implications for just how early these galaxies began forming. This, in turn, suggests that future deep $JWST$ observations may identify relatively bright galaxies to much earlier epochs than might have been anticipated.

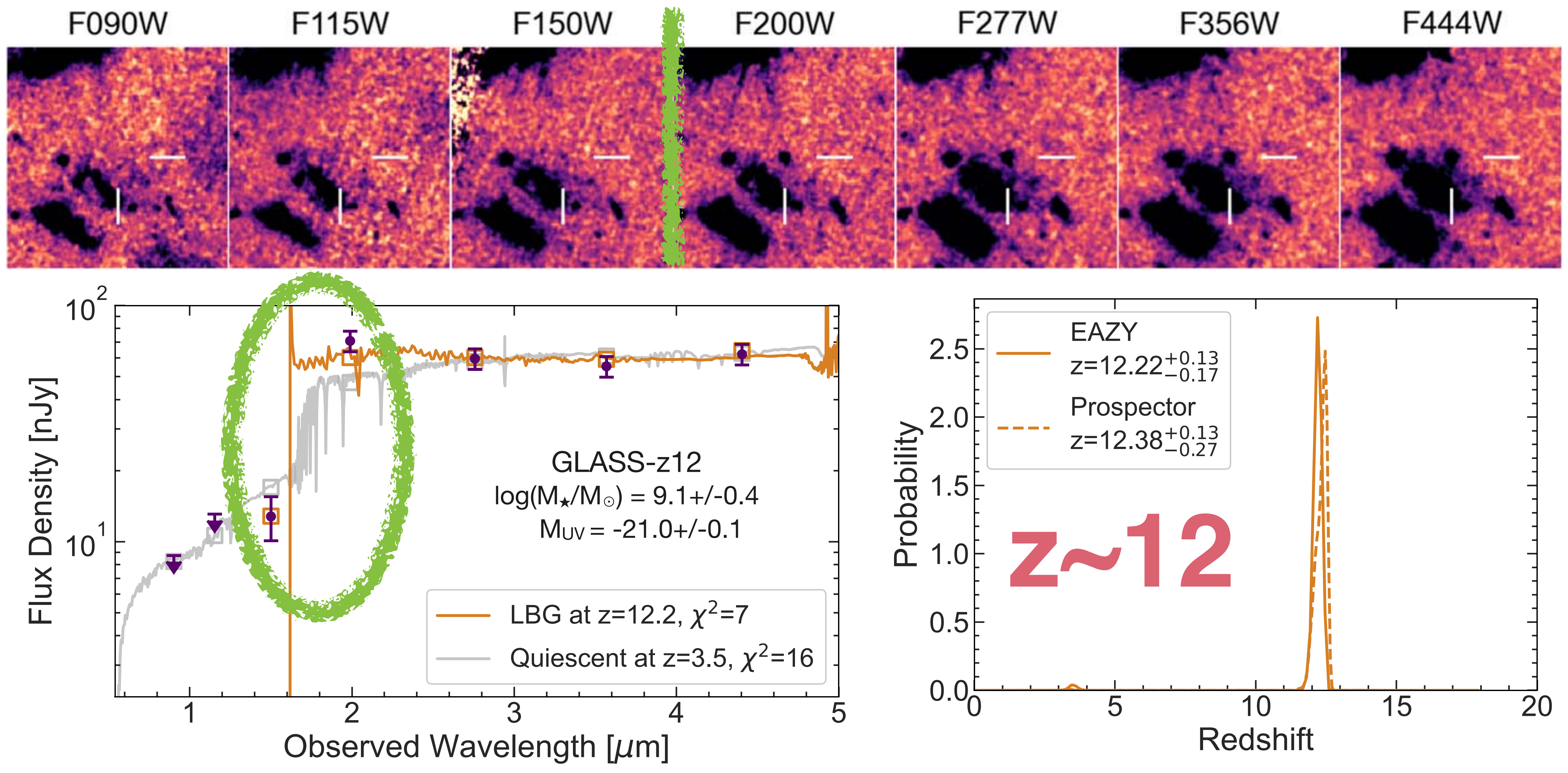
Comments: Submitted to ApJL. Figs. 1 and 2 summarize the candidates, Fig. 3 places the brightness of these systems in context, Fig. 4 shows the morphology, Fig. 5 explores implications for the UVLF. Comments warmly welcomed

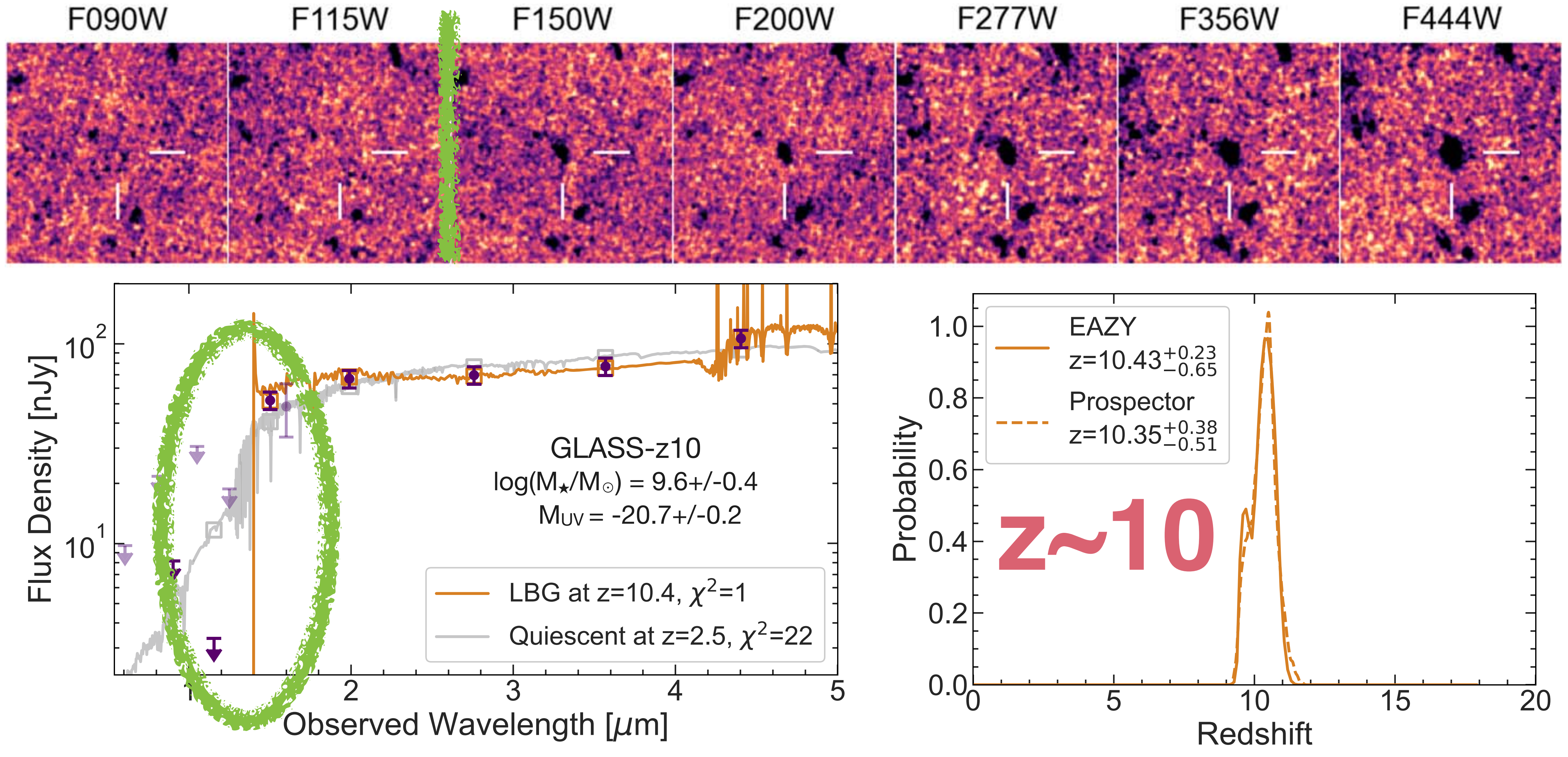
Subjects: **Astrophysics of Galaxies (astro-ph.GA)**

Cite as: arXiv:2207.09434 **[astro-ph.GA]**

すでに215の論文で引用されている

01 [OIII] 88 μm Line Emission



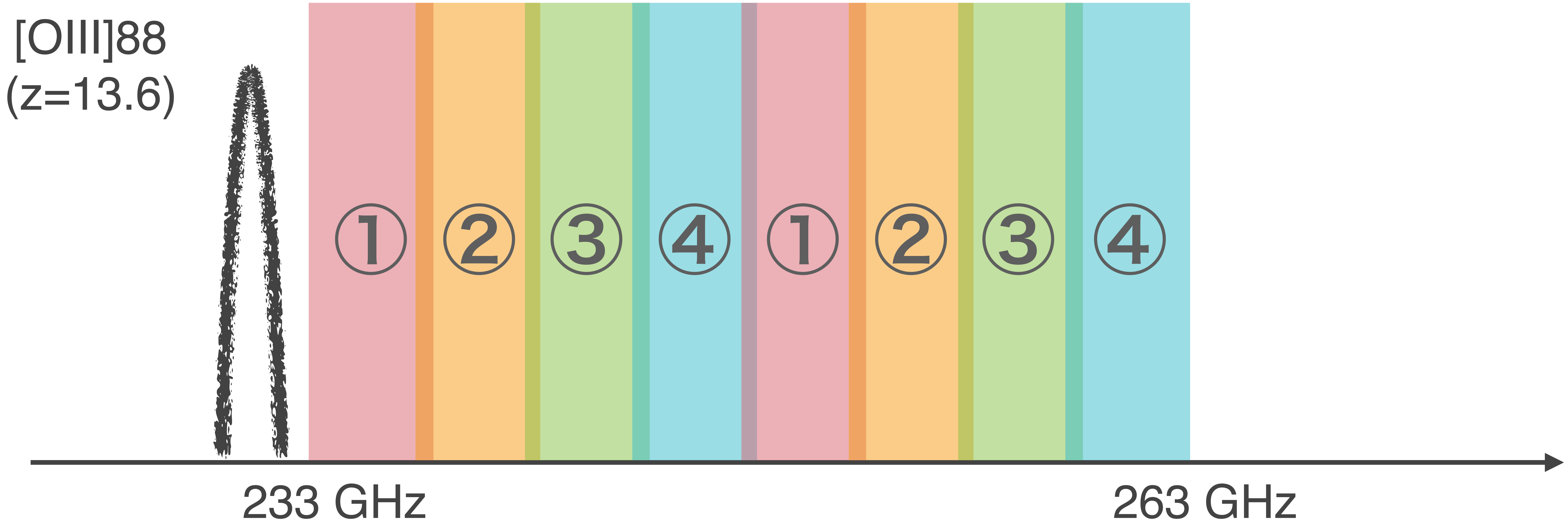


2021.A.00020.S	Confirmation of a z = 12.3 galaxy candidate	Tom J L C Bakx	EA	10
COIs	Jorge Zavala;			
Abstract	We ask for 16 hours of ALMA band 6 time to acquire the spectroscopic redshift of a robust bright galaxy candidate at z=12.3 identified in the Early Release Science Programs of the JWST. If confirmed, this galaxy would be the highest-redshift galaxy known to date and will provide strong constraints on the UV luminosity function and on galaxy formation models. We combine four spectral tunings to form a contiguous frequency coverage across redshifts 11.9 to 13.5 (covering more than 90% of the redshift probability distribution of the source), targeting the doubly-ionized Oxygen [OIII] emission. Meanwhile, these observations will provide strong constraints on the dust emission (down to an obscured fraction of 1) and internal ISM conditions (including metallicity) of a galaxy observed ~350Myr after the Big Bang. Through this high-reward proposal, ALMA will uniquely provide the essential and complementary perspective on one of the key goals of the JWST mission.			

2021.A.00023.S	A Pilot Study for the Far-IR Confirmation of the Oldest Galaxies Observed by JWST	Ilsang Yoon	NA	10
COIs	Chris Carilli; Min S. Yun; Caitlin C.M. Casey; Intae Jung; Jonathan T Letai; Steven L Finkelstein; Casey Papovich; Eric J. Murphy; Seiji Fujimoto;			
Abstract	We propose ALMA observation of the recently discovered galaxy candidate, GLz11 at z=10.74, from the JWST ERS program. JWST will routinely discover these early galaxies and can do a census of similar z>10 galaxies to understand the first galaxy formation. ALMA is the only instrument with the sensitivity to detect the FIR continuum and fine structure from such an object, and has a strong synergy with the JWST observation to study the high-redshift galaxy formation. The observation of FIR SED including cooling line is very important to measure the spectroscopic redshift and constrain the physical parameters from SED modeling in terms of constraining dust content to break the age-dust degeneracy. Our program will observe the FIR peak of GLz11 with spectral window set up covered by 3 Science Goals such that 88.63micron [OIII] emission line is included in the sufficient redshift range (z=10.30-11.21) for spectroscopic redshift confirmation. The proposed observation has the very real potential to both verify a key science program for the JWST by confirming an extreme redshift galaxy, and demonstrate the importance of ALMA in the JWST era for studying the first galaxies in the Universe.			

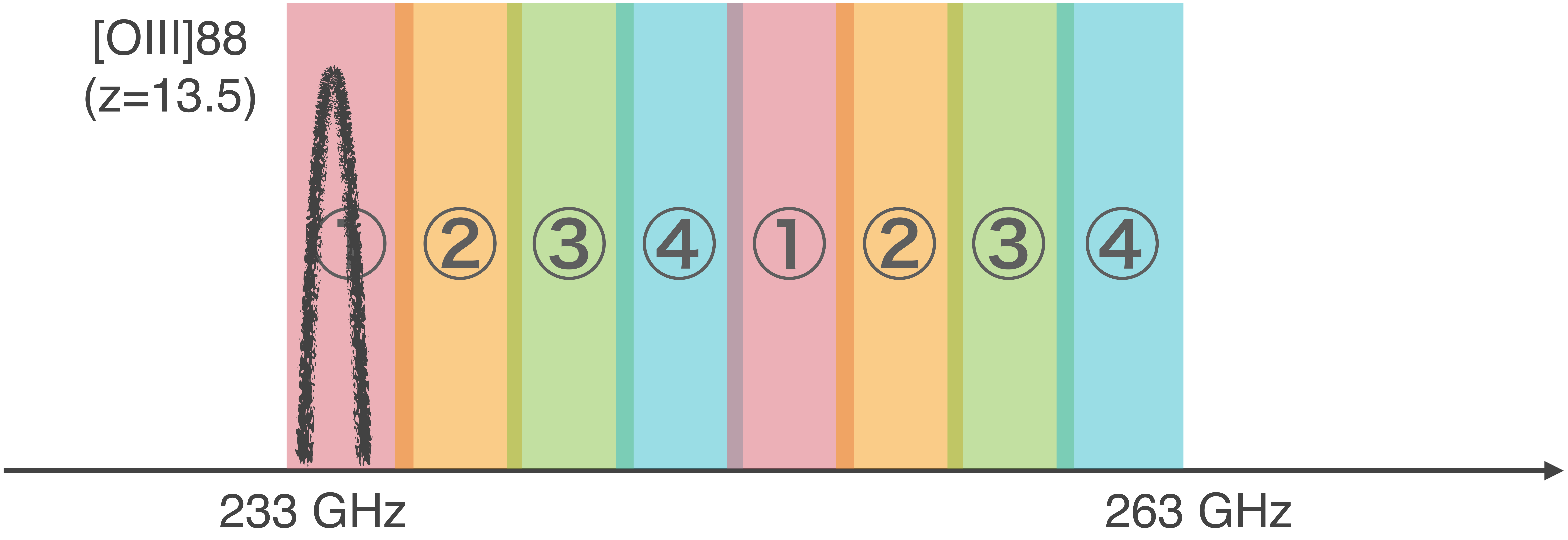
Naidu et al. 2022

01 [OIII] 88 μm Line Emission



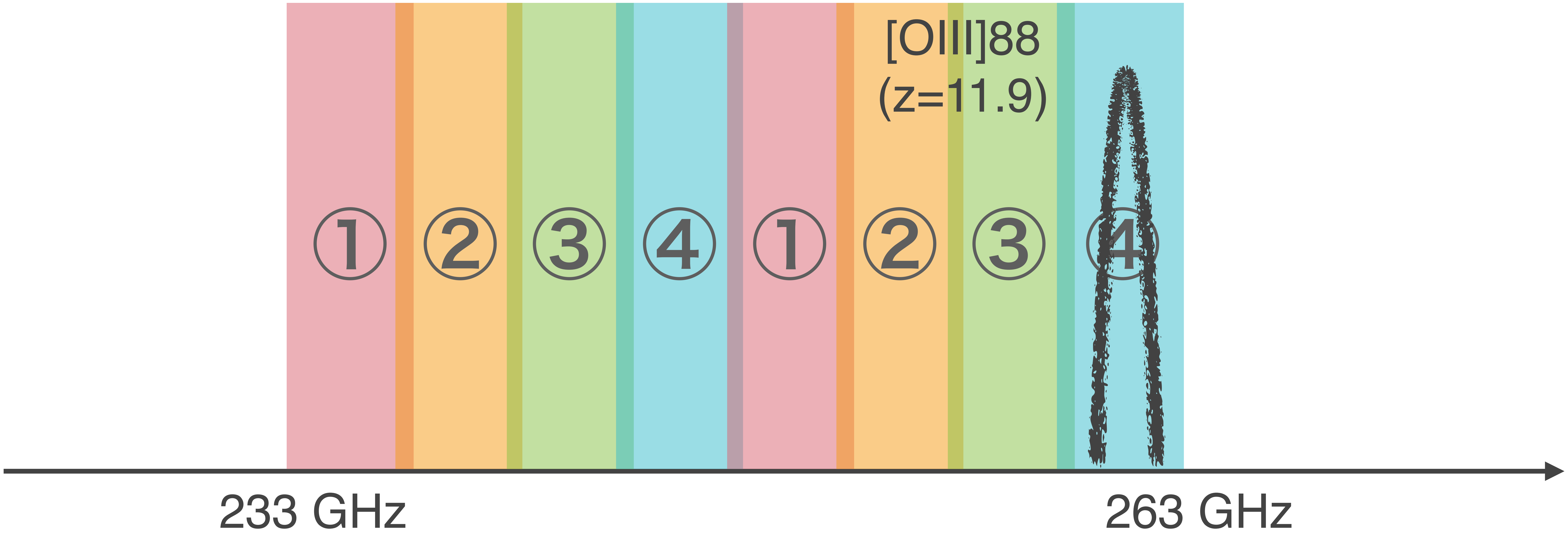
One ALMA observation does not provide data at 233-263 GHz.
(z=11.8-13.6)

01 [OIII] 88 μm Line Emission



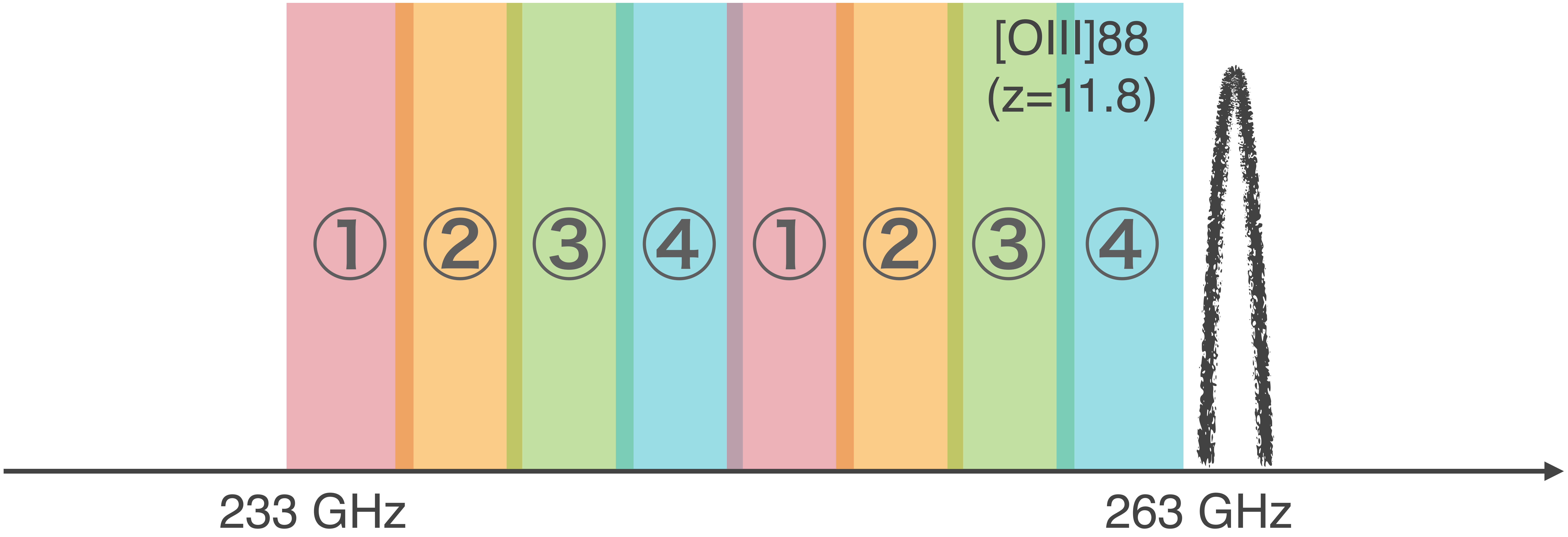
One ALMA observation does not provide data at 233-263 GHz.
(z=11.8-13.6)

01 [OIII] 88 μm Line Emission



Single ALMA observation does not provide a spectrum at 233-263 GHz.
(z=11.8-13.6)

01 [OIII] 88 μm Line Emission

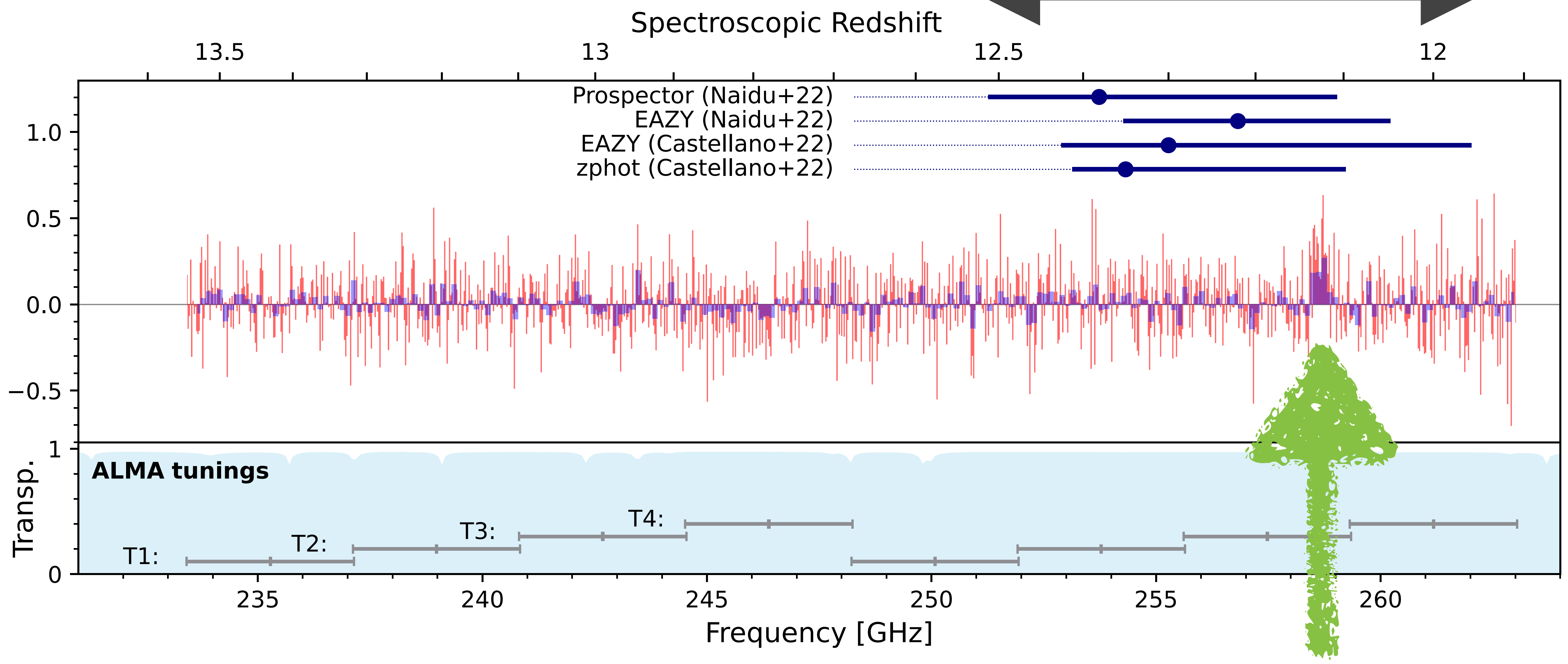


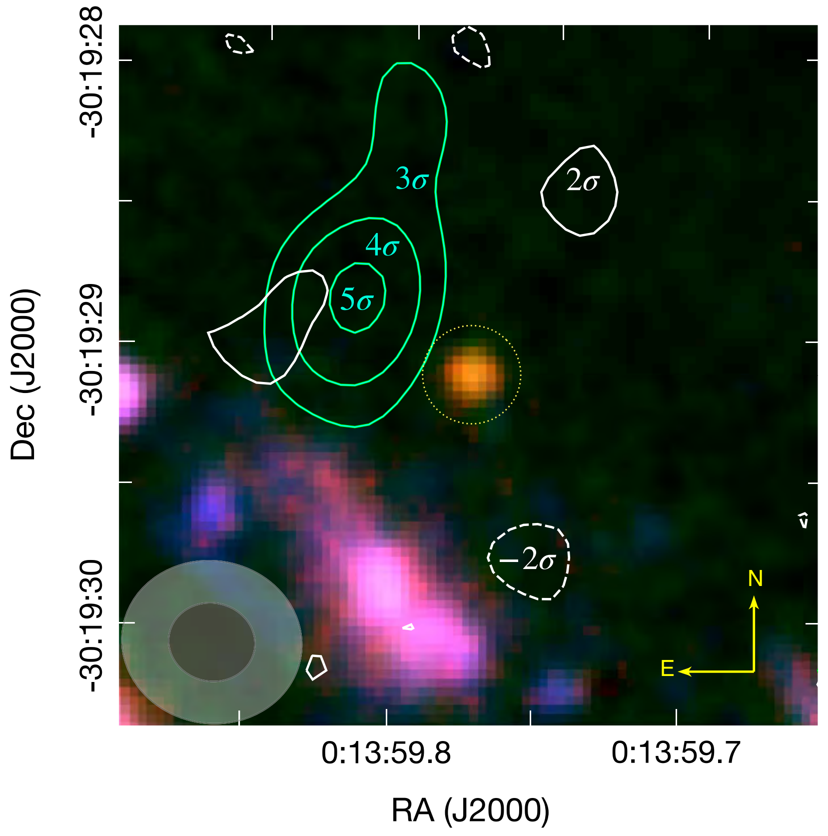
One ALMA observation does not provide data at 233-263 GHz.
(z=11.8-13.6)

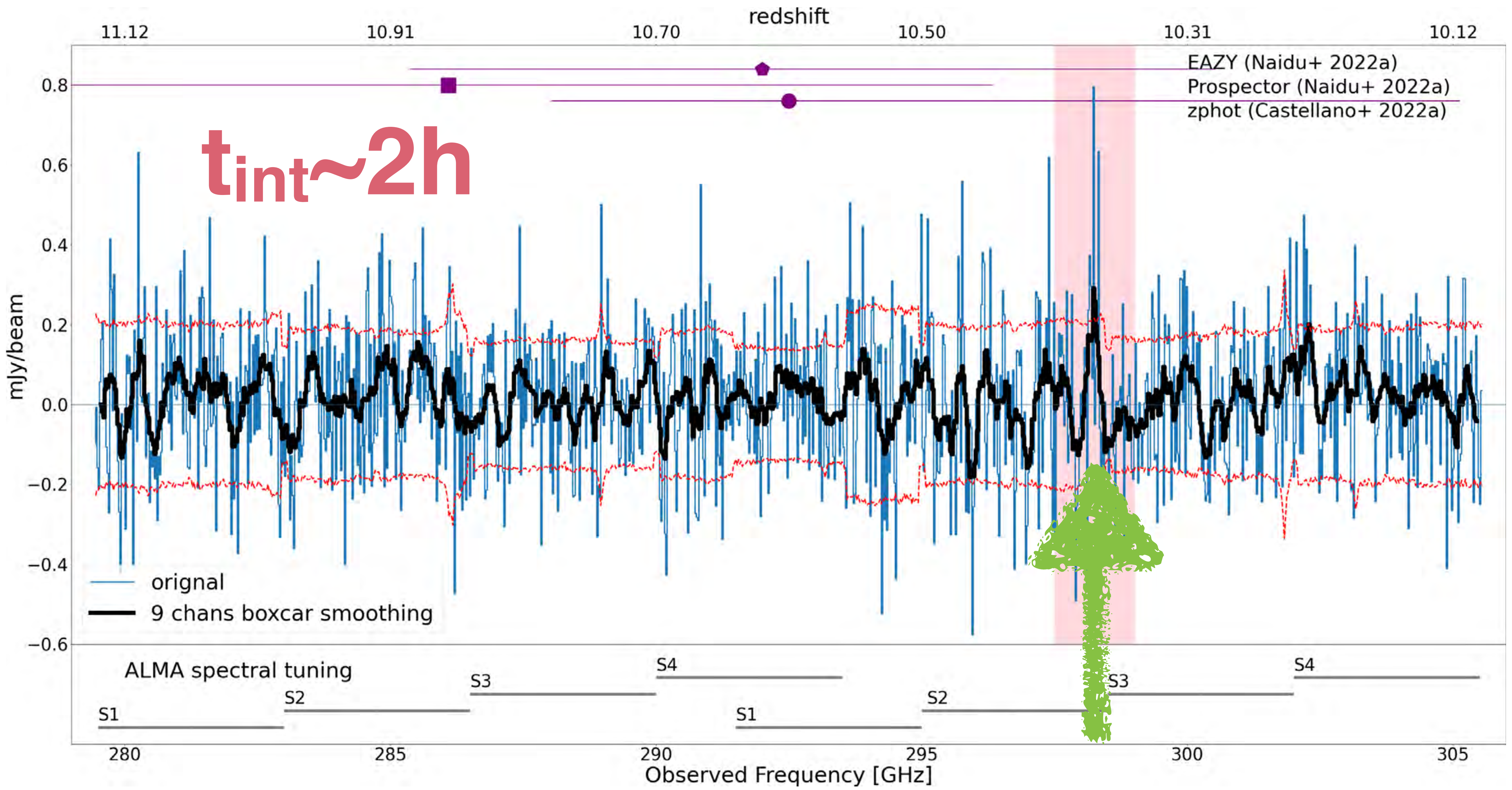
01 [OIII] 88 μm Line Emission

Phot-z

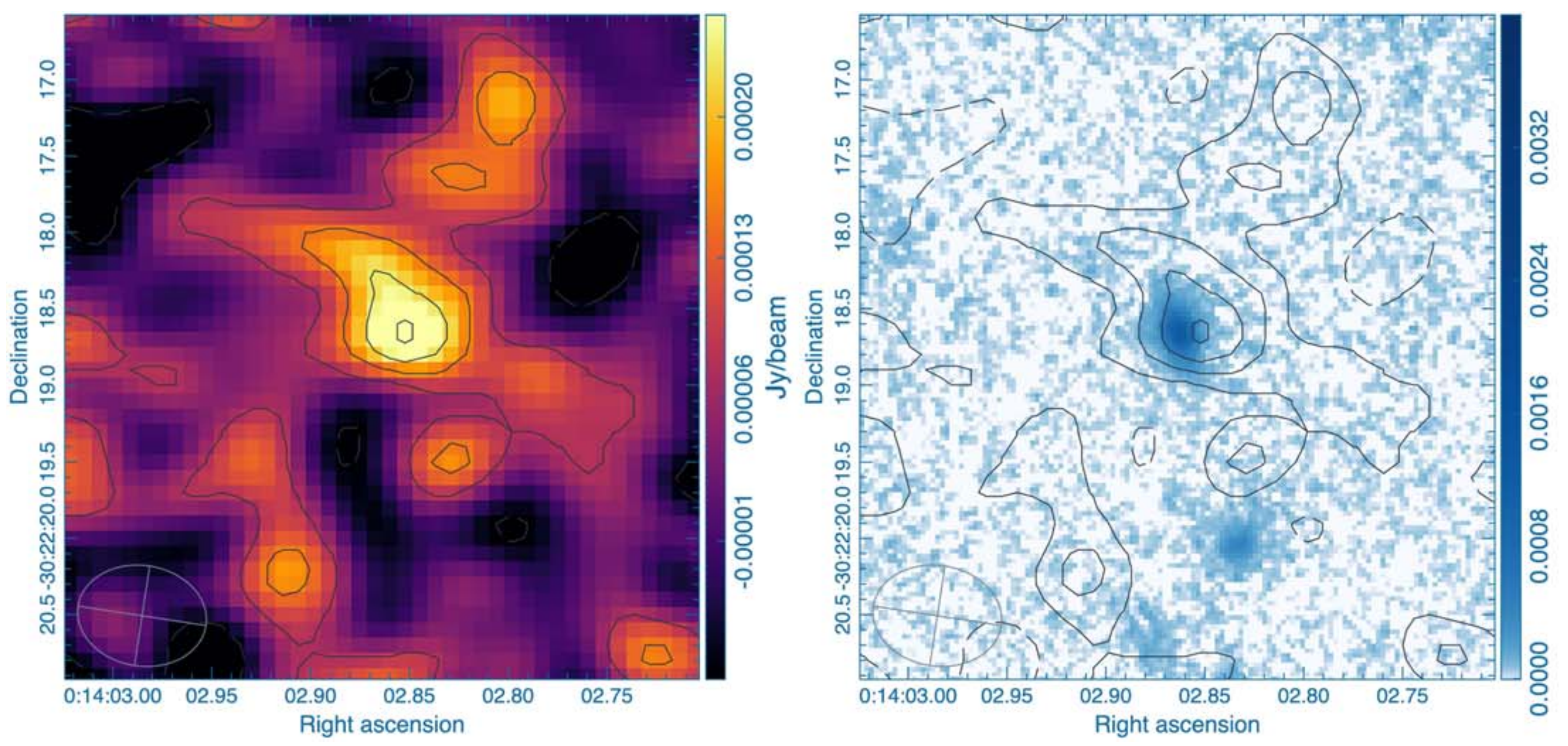
t_{int}~2h







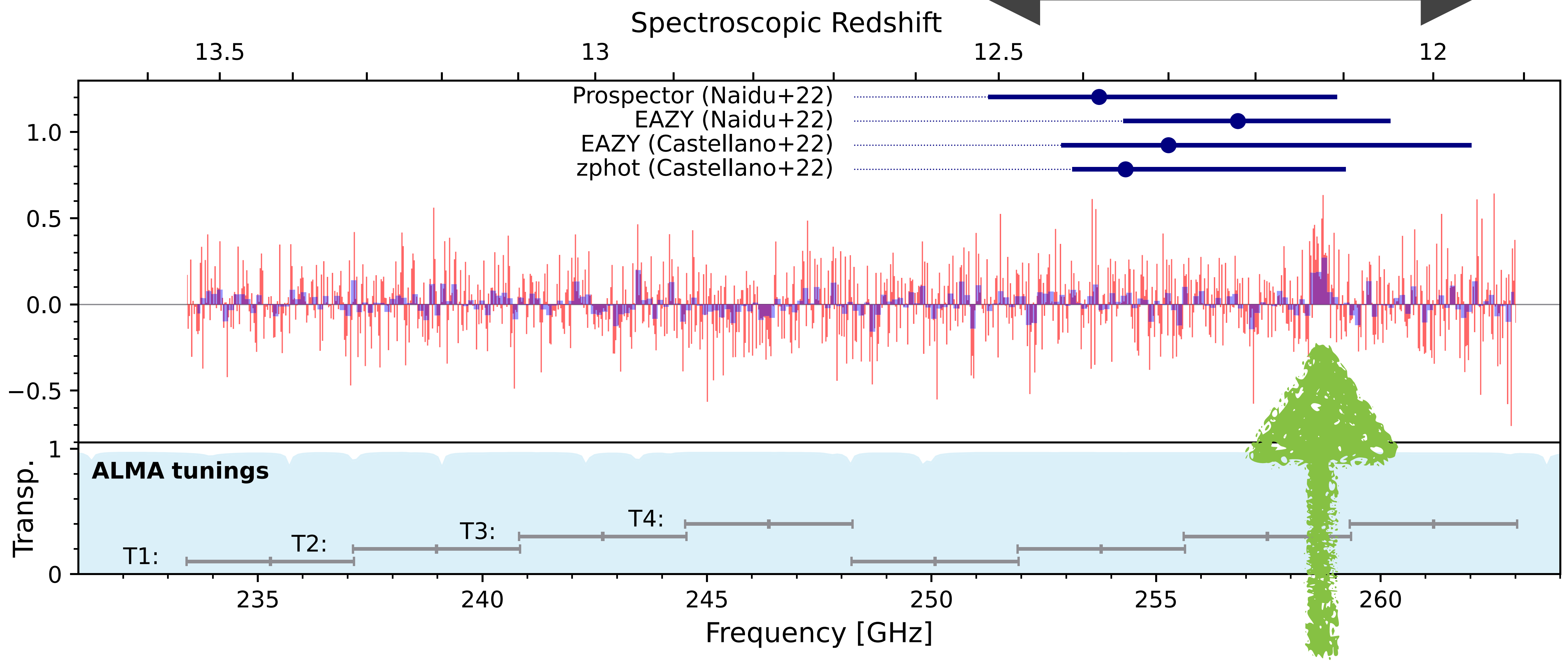
t_{int}~2h

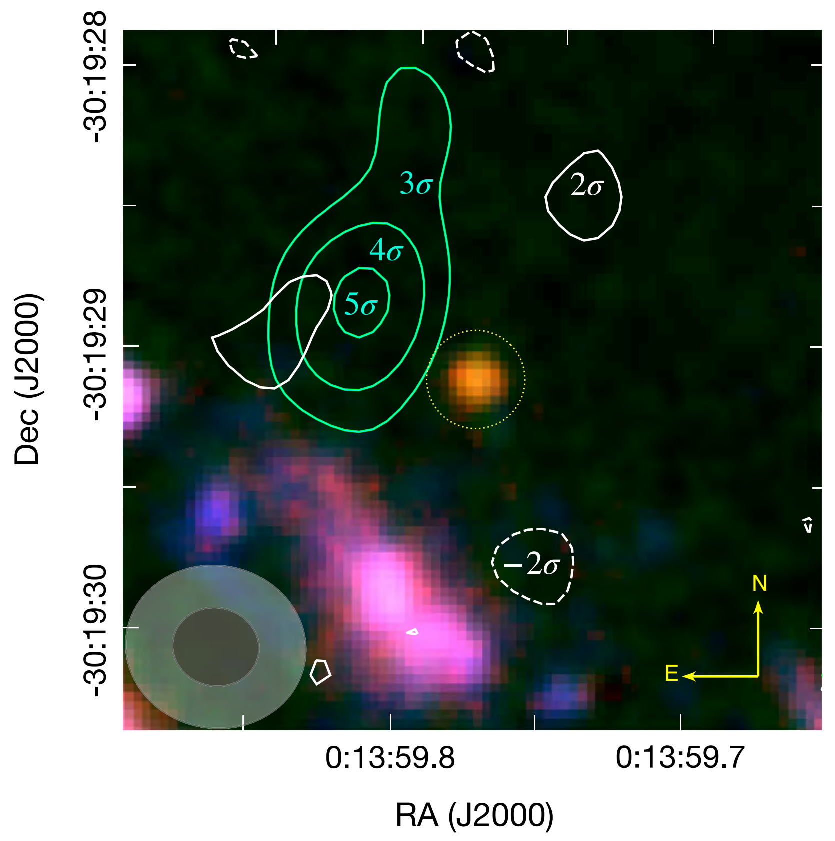


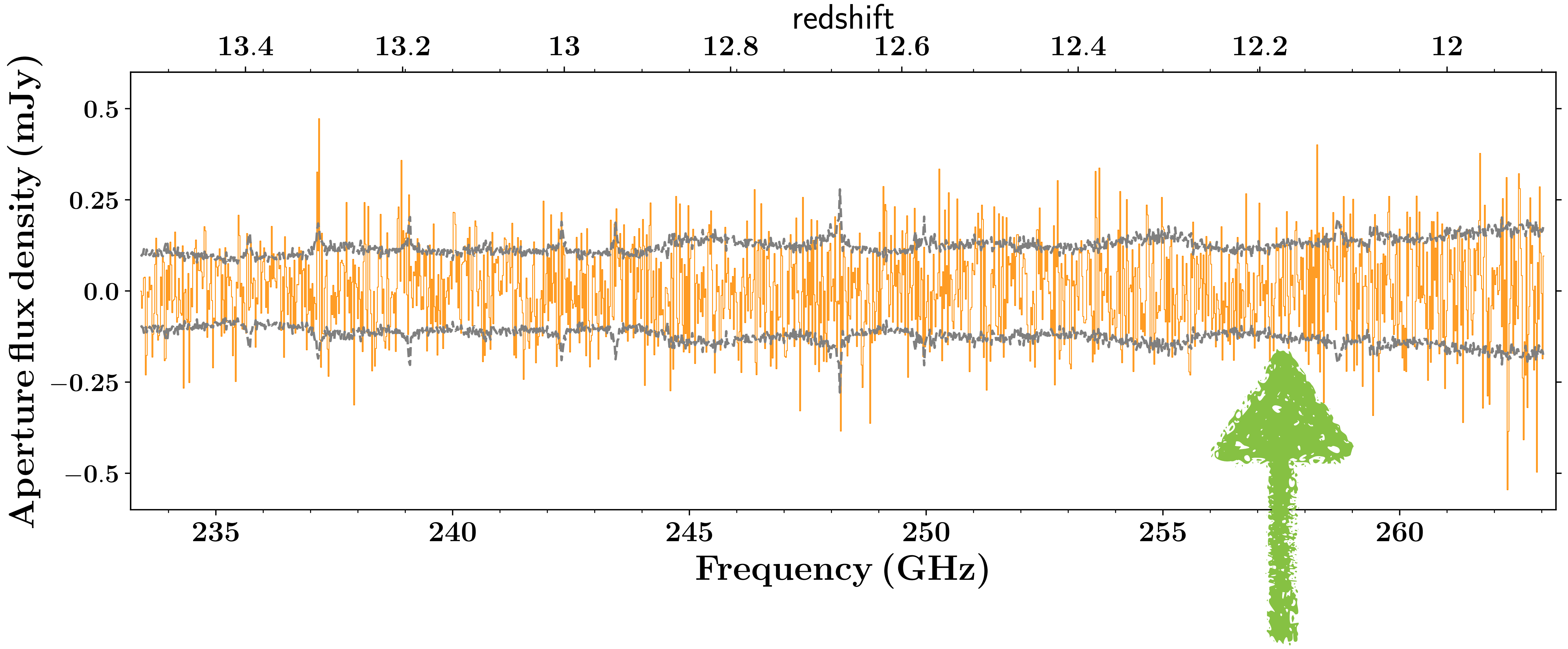
01 [OIII] 88 μm Line Emission

t_{int}~2h

Phot-z







Bakx et al. 2023

Popping et al. 2023

01 [OIII] 88 μm Line Emission

Search MAST for JWST

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EDIT SEARCH | Target= 0:13:59.76 -30:19:29.1 Radius= 3 arcseconds Data Type(s)= SPECTRUM, MEASUREMENTS Instrument(s)= NIRSPEC, NIRISS Columns= Dataset, Product Levels, Target Name, RA (J2000), Dec (...

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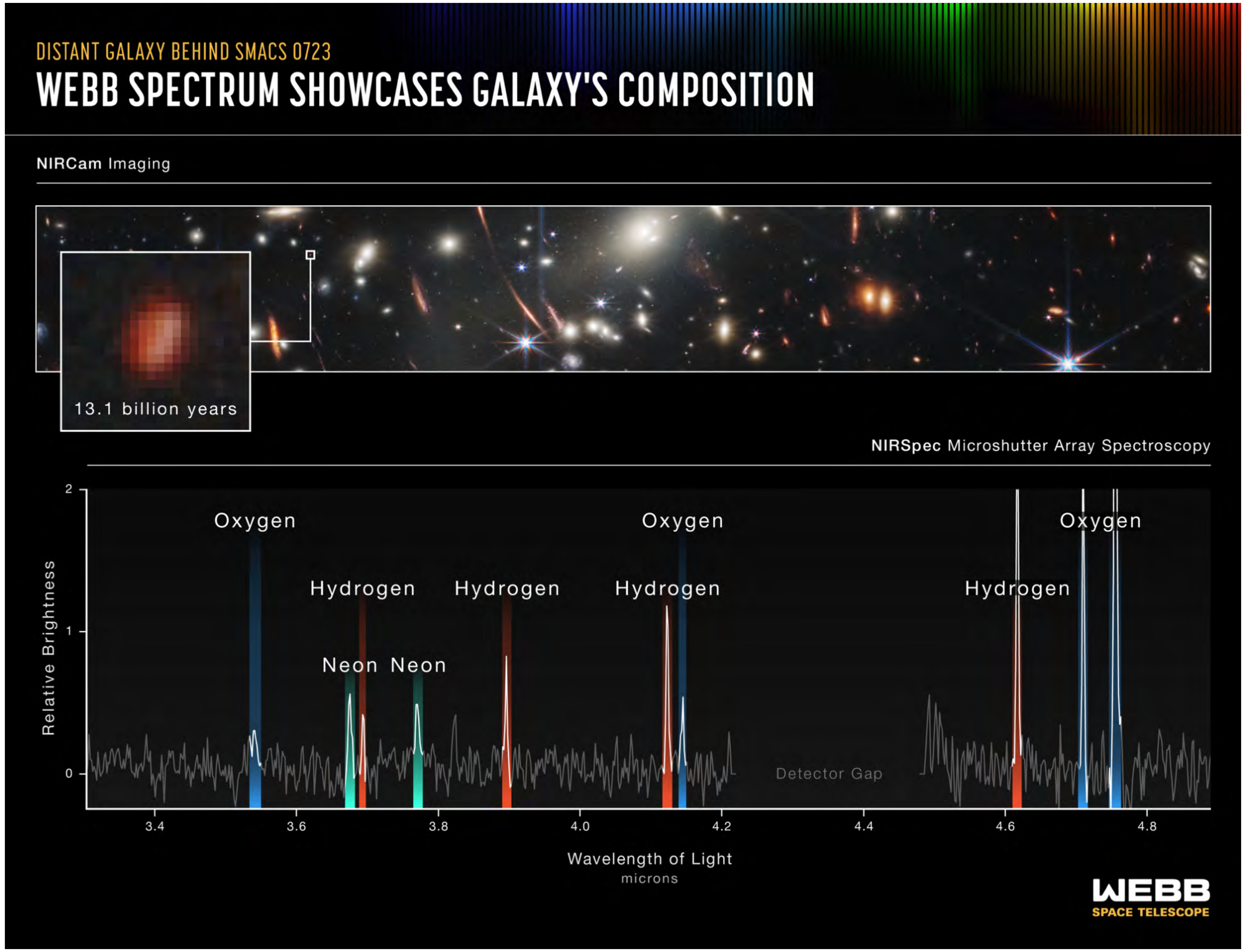
JWST could be a more powerful redshift machine.

01 [OIII] 88 μm Line Emission

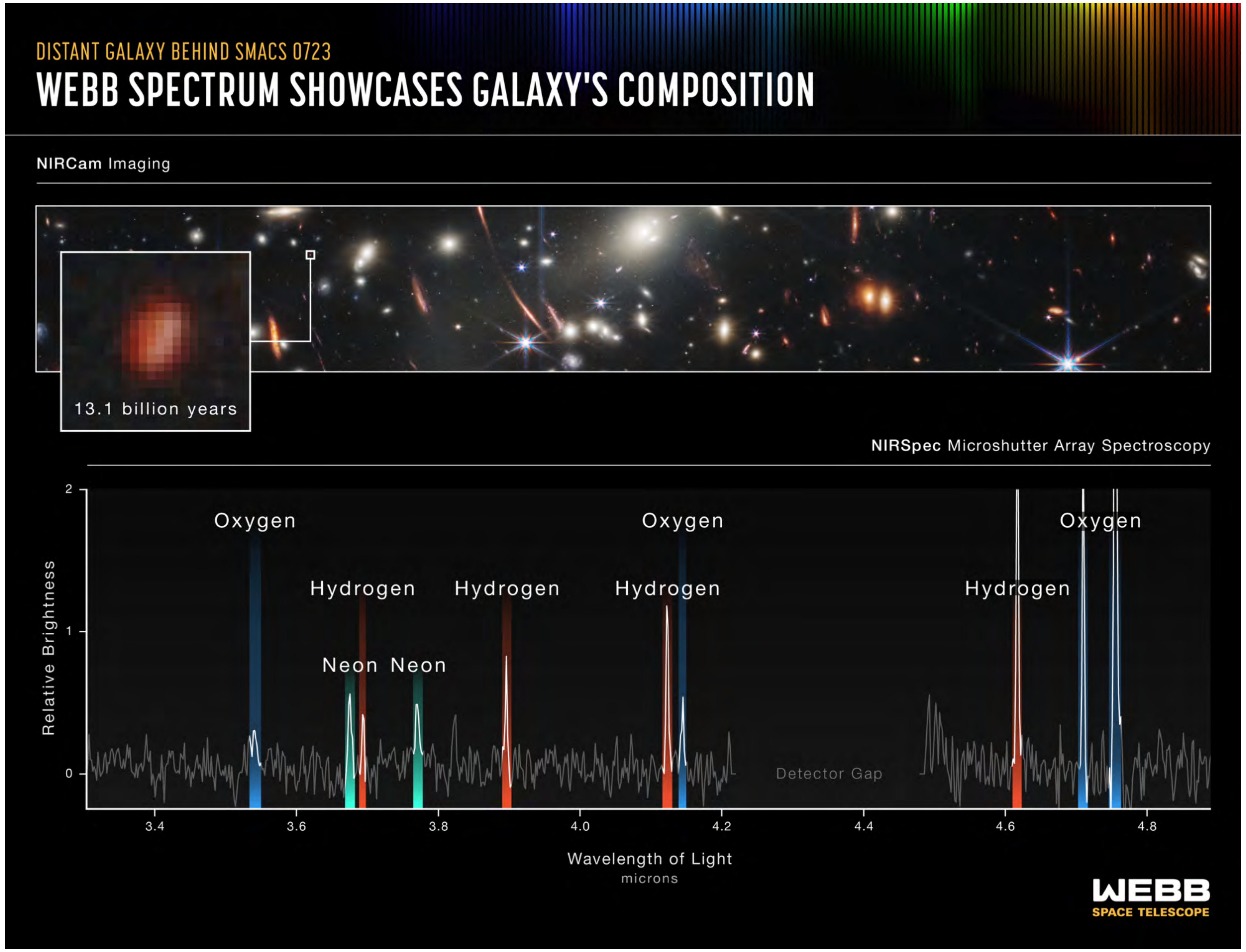
confirmation of spectroscopic redshift



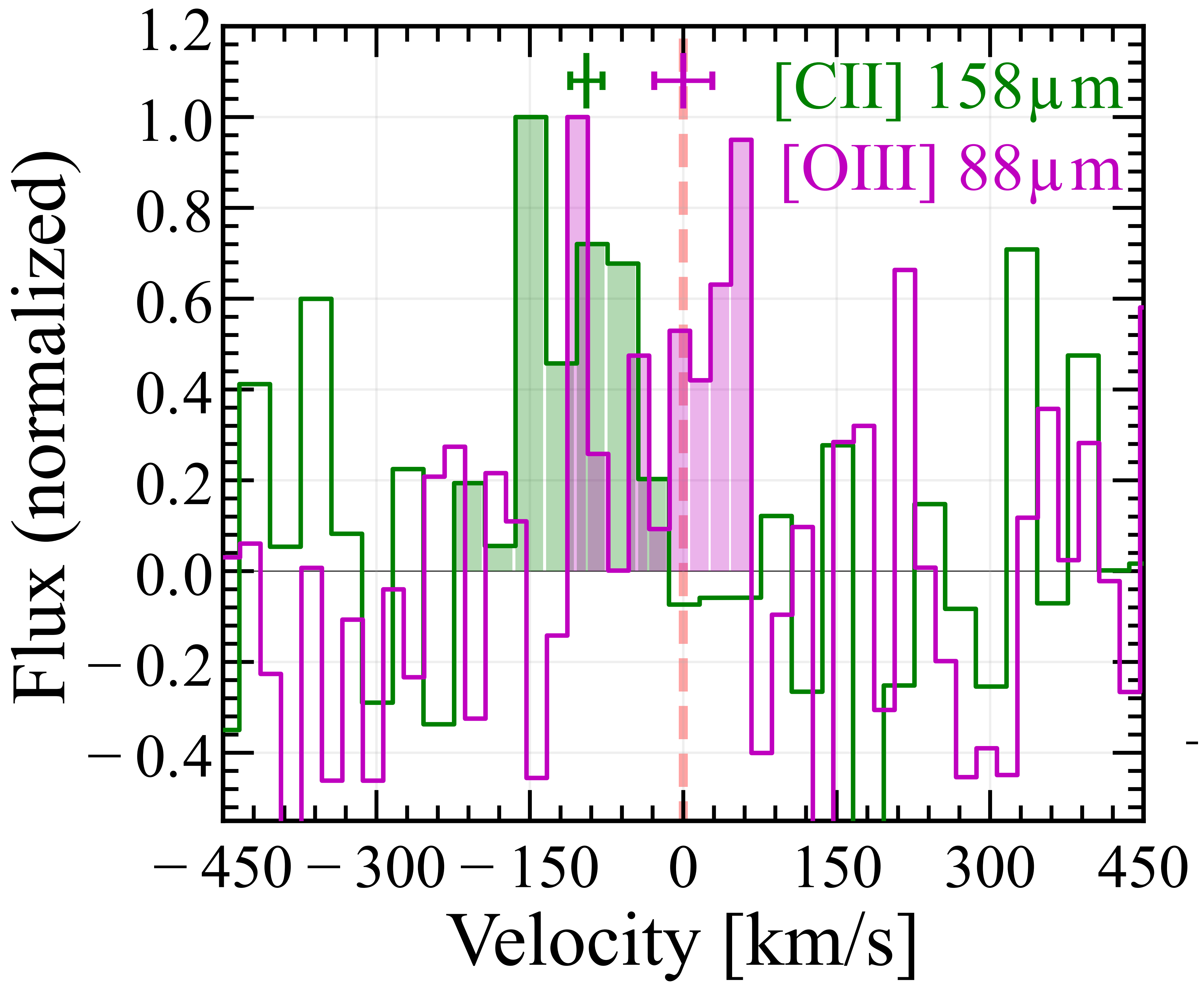
ALMA observations

01 [OIII] 88 μm Line Emission

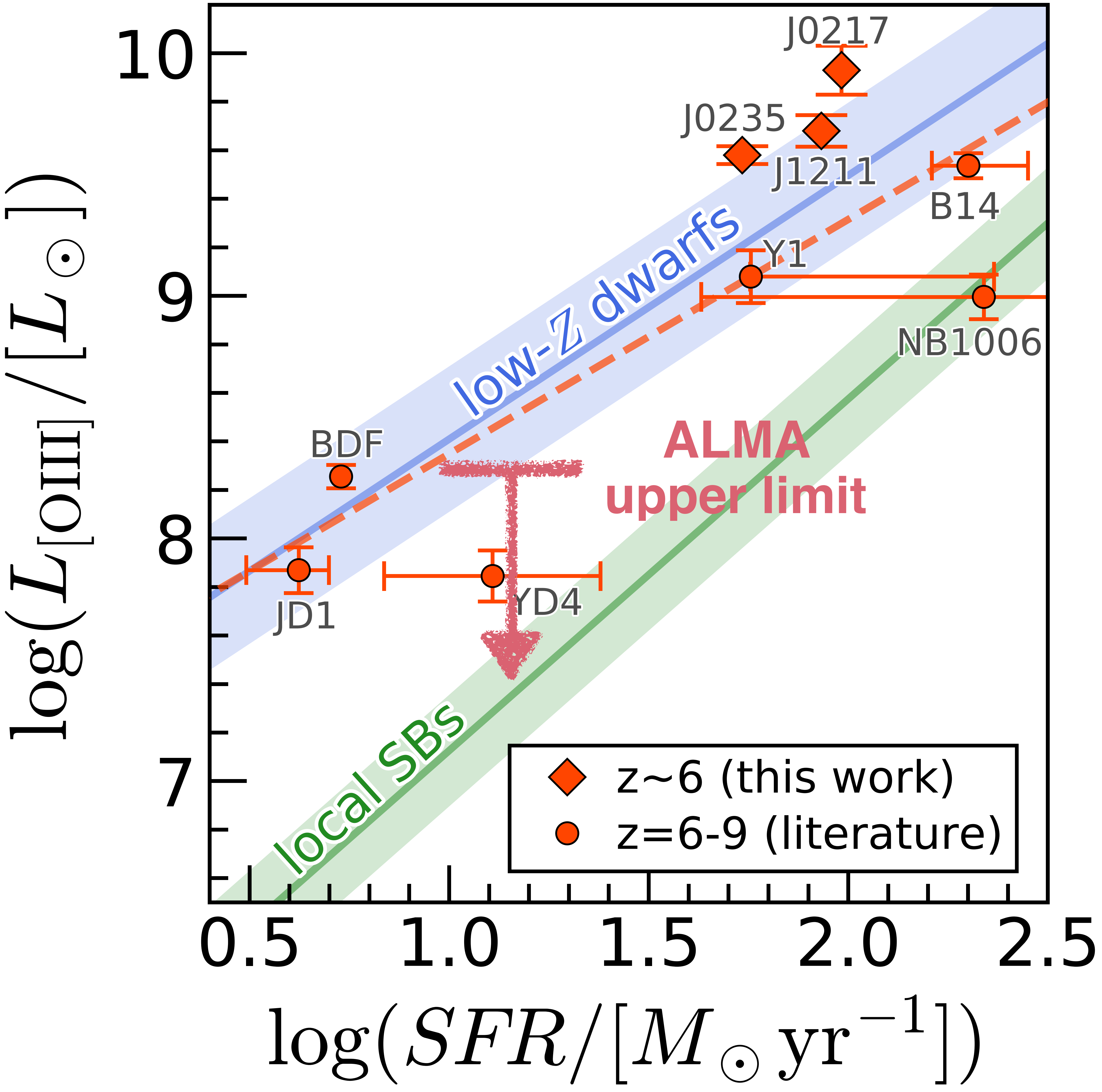
confirmation of spectroscopic redshift



ALMA observations

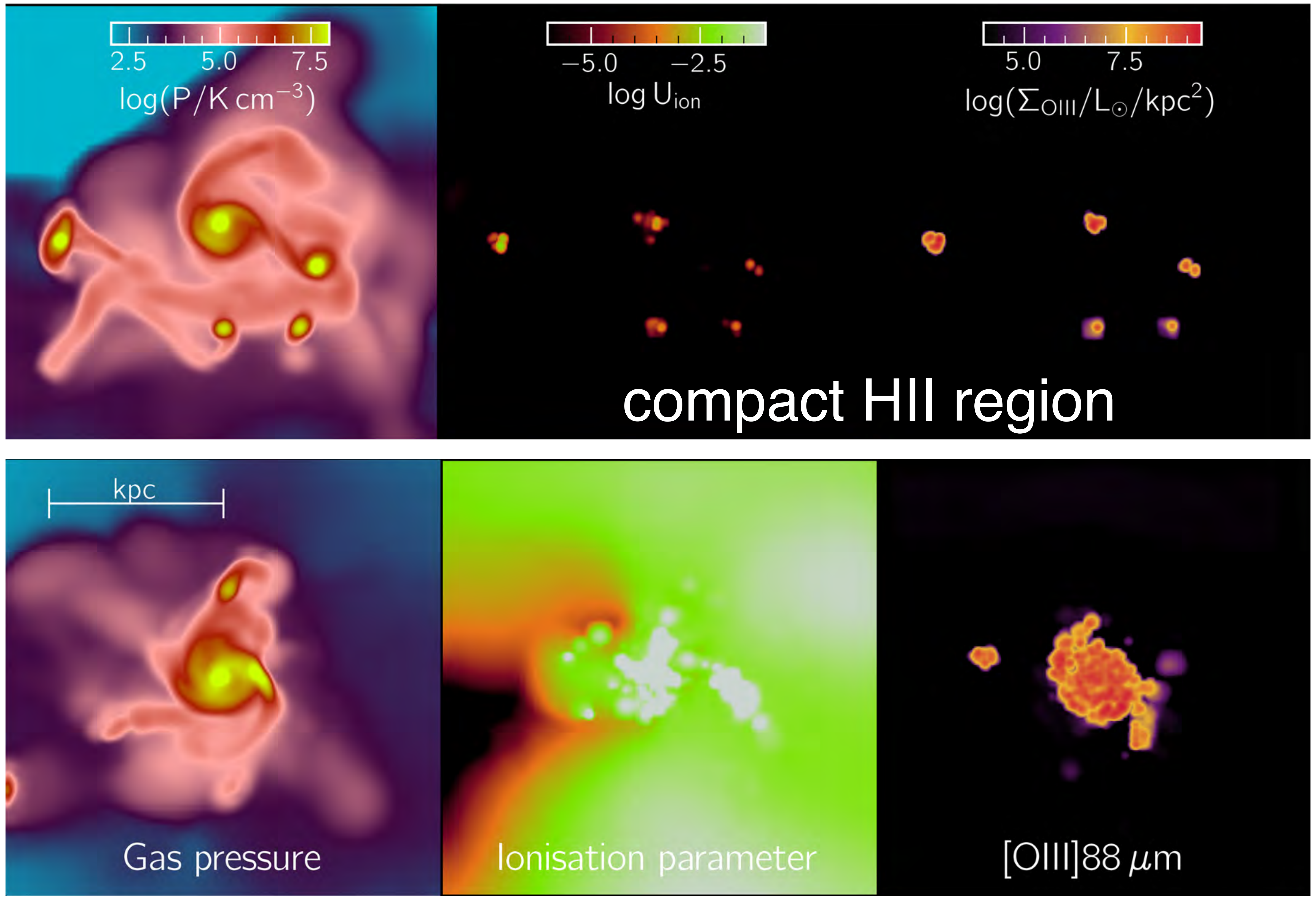


01 [OIII] 88 μm Line Emission



Why is [OIII] emission weak?

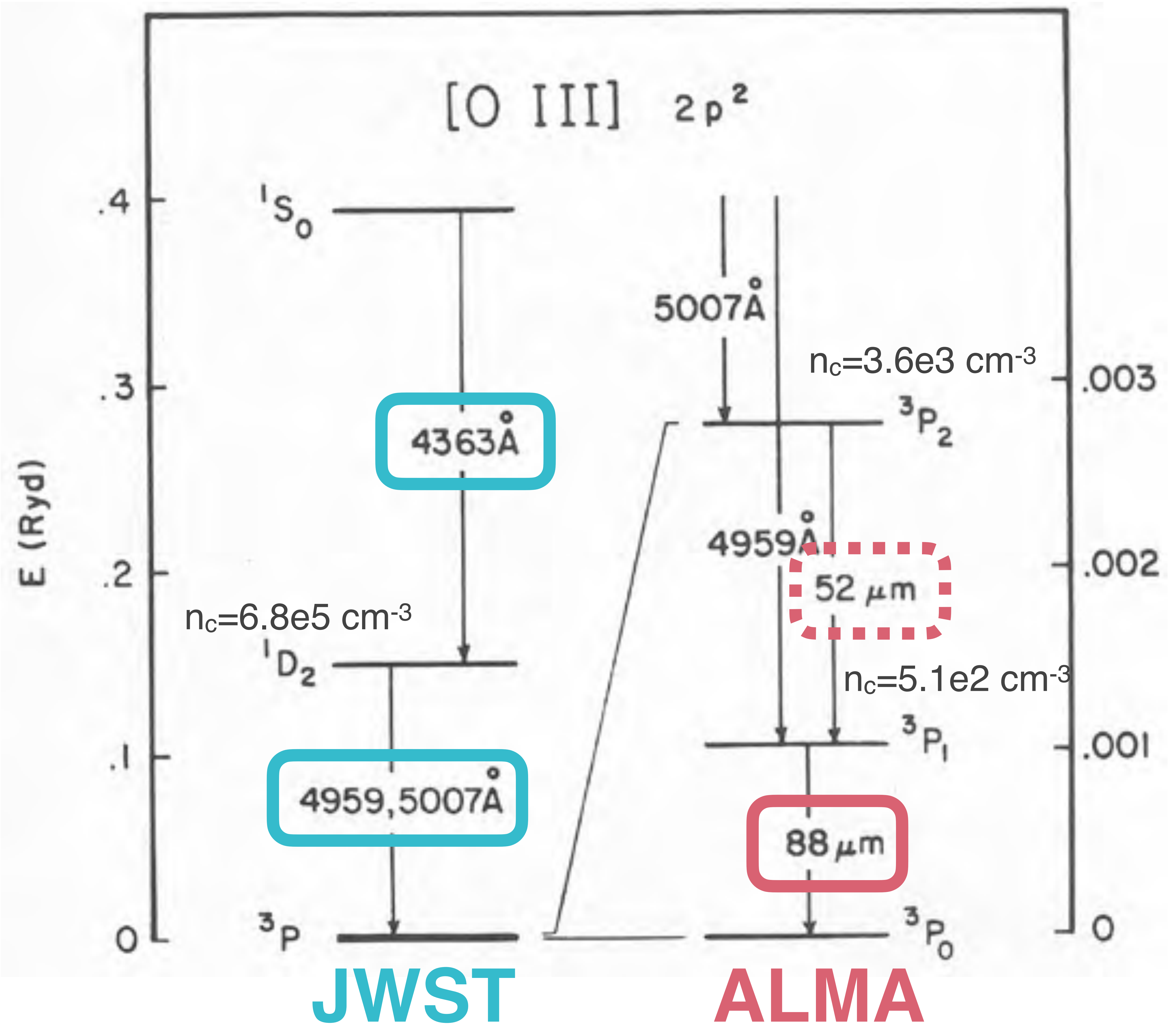
- low metal
- high gas density
- **low ionization parameter**



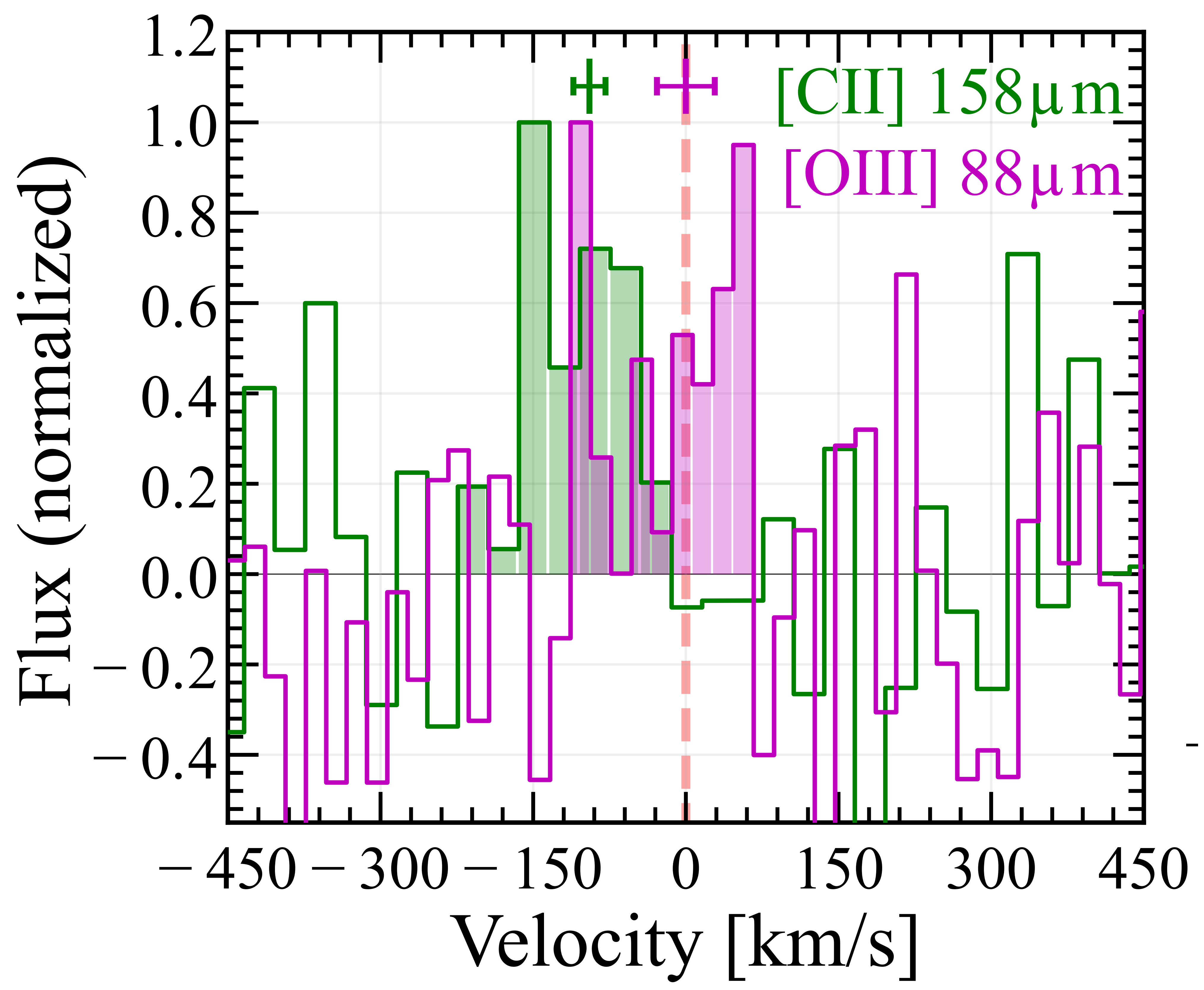
Harikane et al. 2020

SERRA: Kohandel et al. 2023

01 [OIII] 88 μm Line Emission



ALMA observations



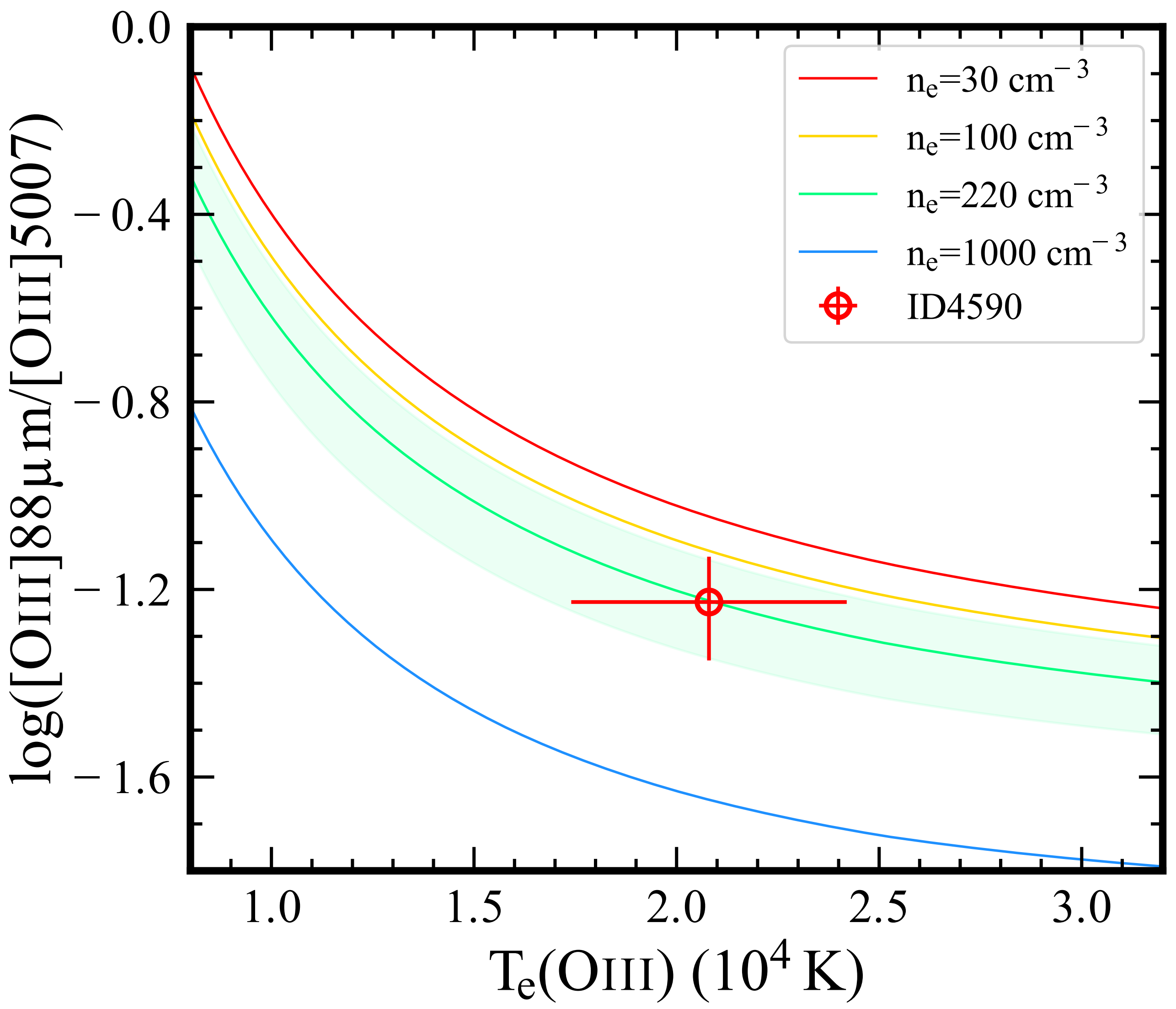
Dinerstein et al. 1995

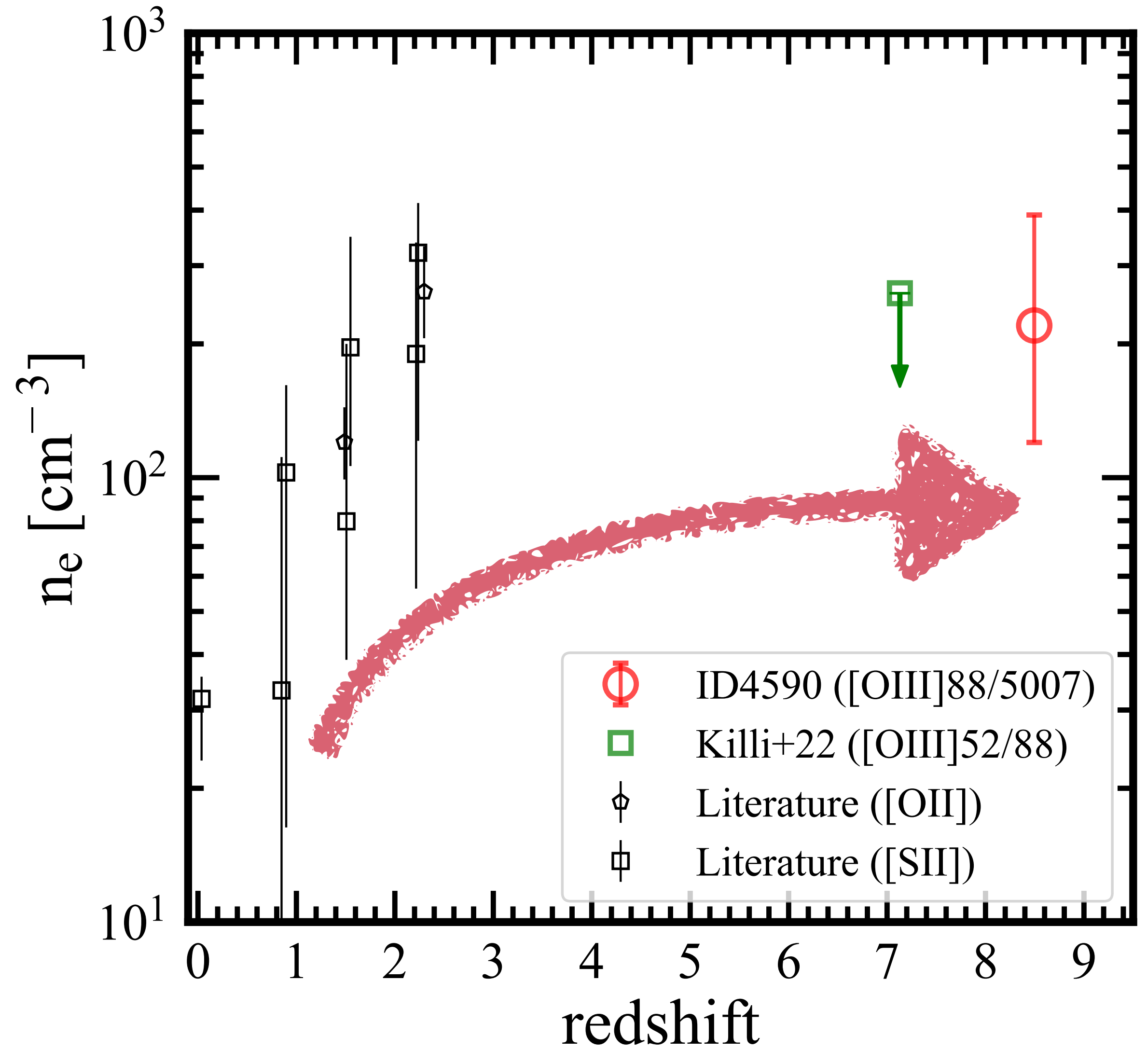
Fujimoto et al. 2022, arXiv:2212.068

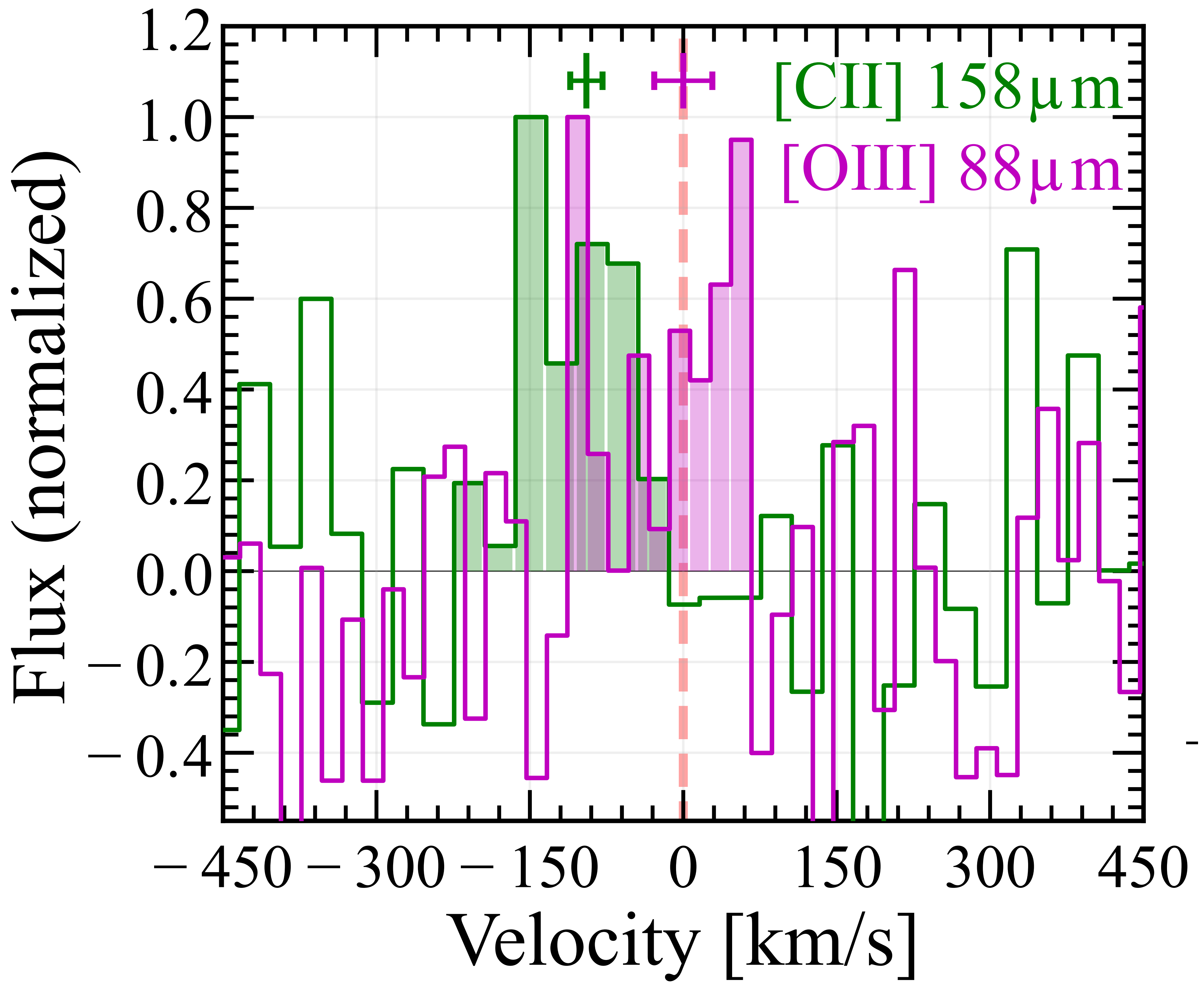
01 [OIII] 88 µm Line Emission

ALMA observations

high electron density (n_e~200 cm^{-3})







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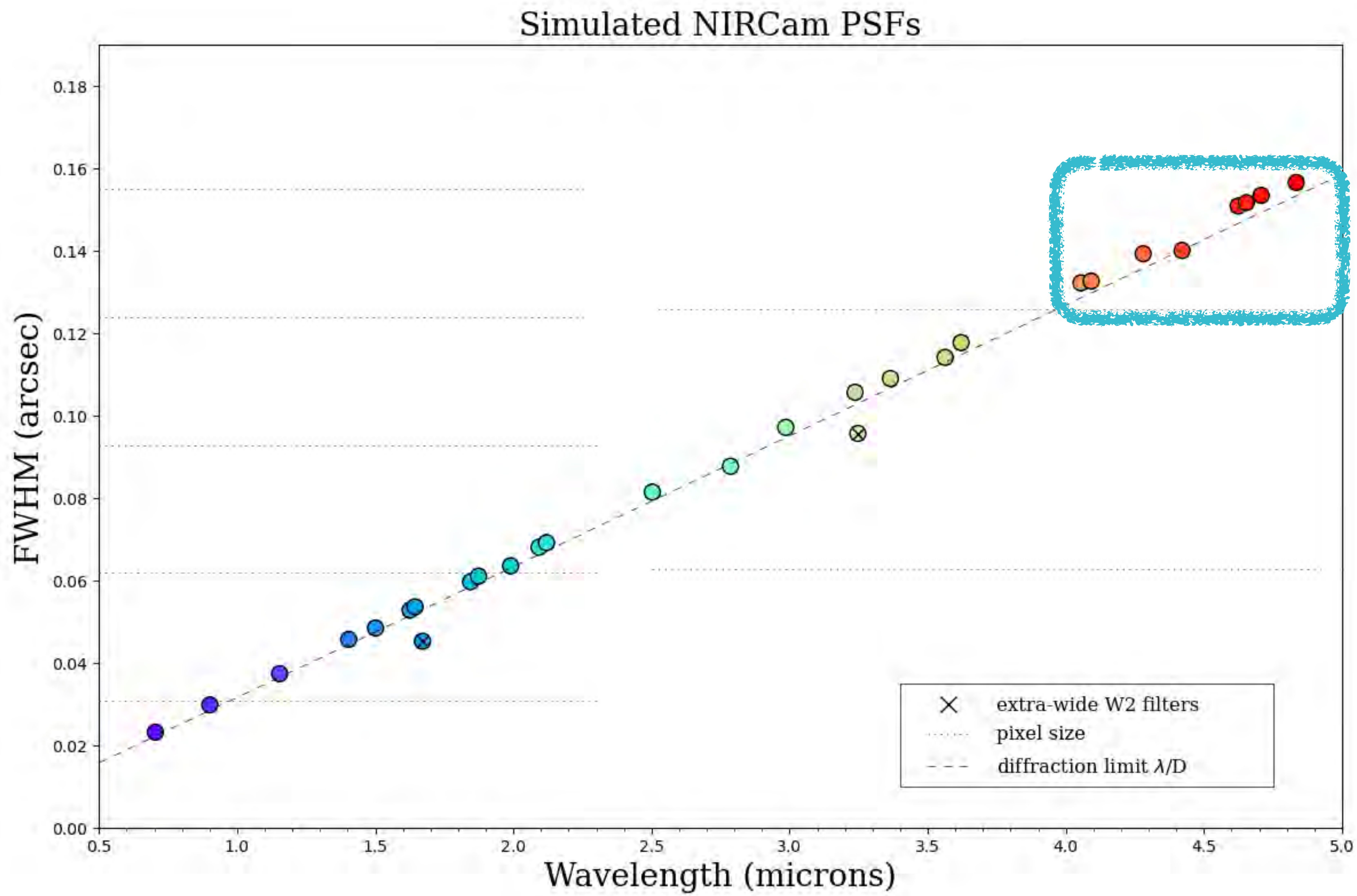


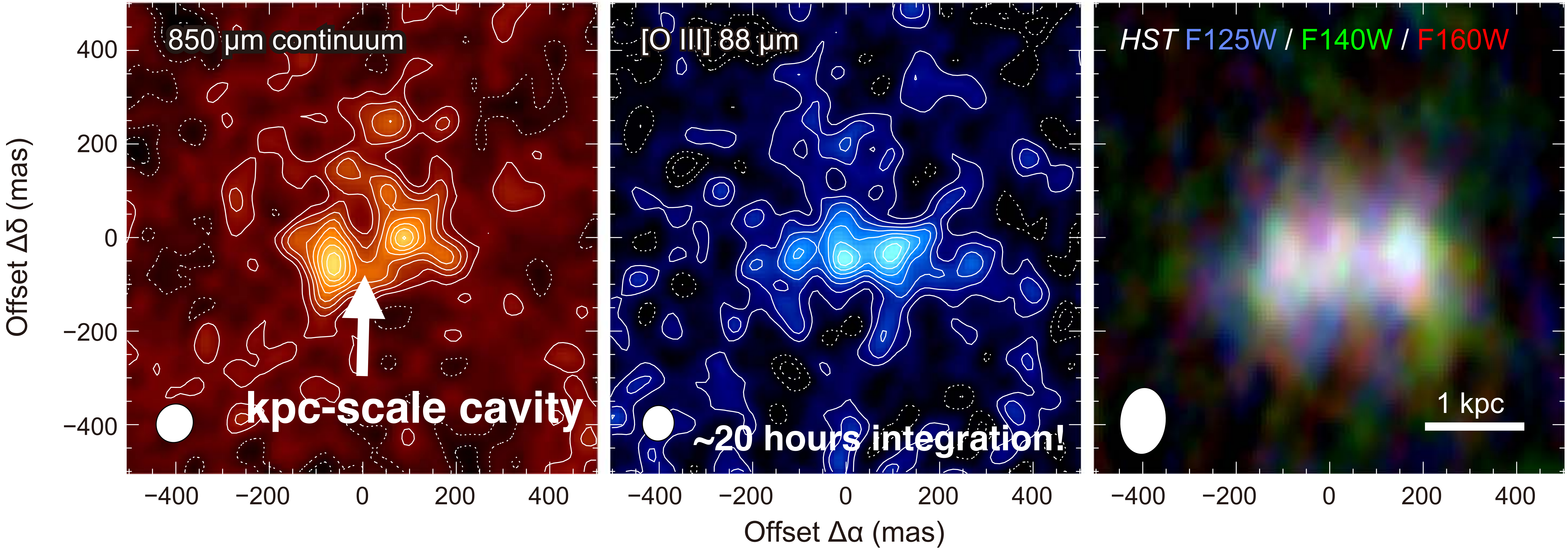
JWST resolution ~0.15″ (700pc)

ALMA resolution ~0.07″ (300pc)

https://jwst-docs.stsci.edu

01 [OIII] 88 μm Line Emission

z=8.3 galaxy

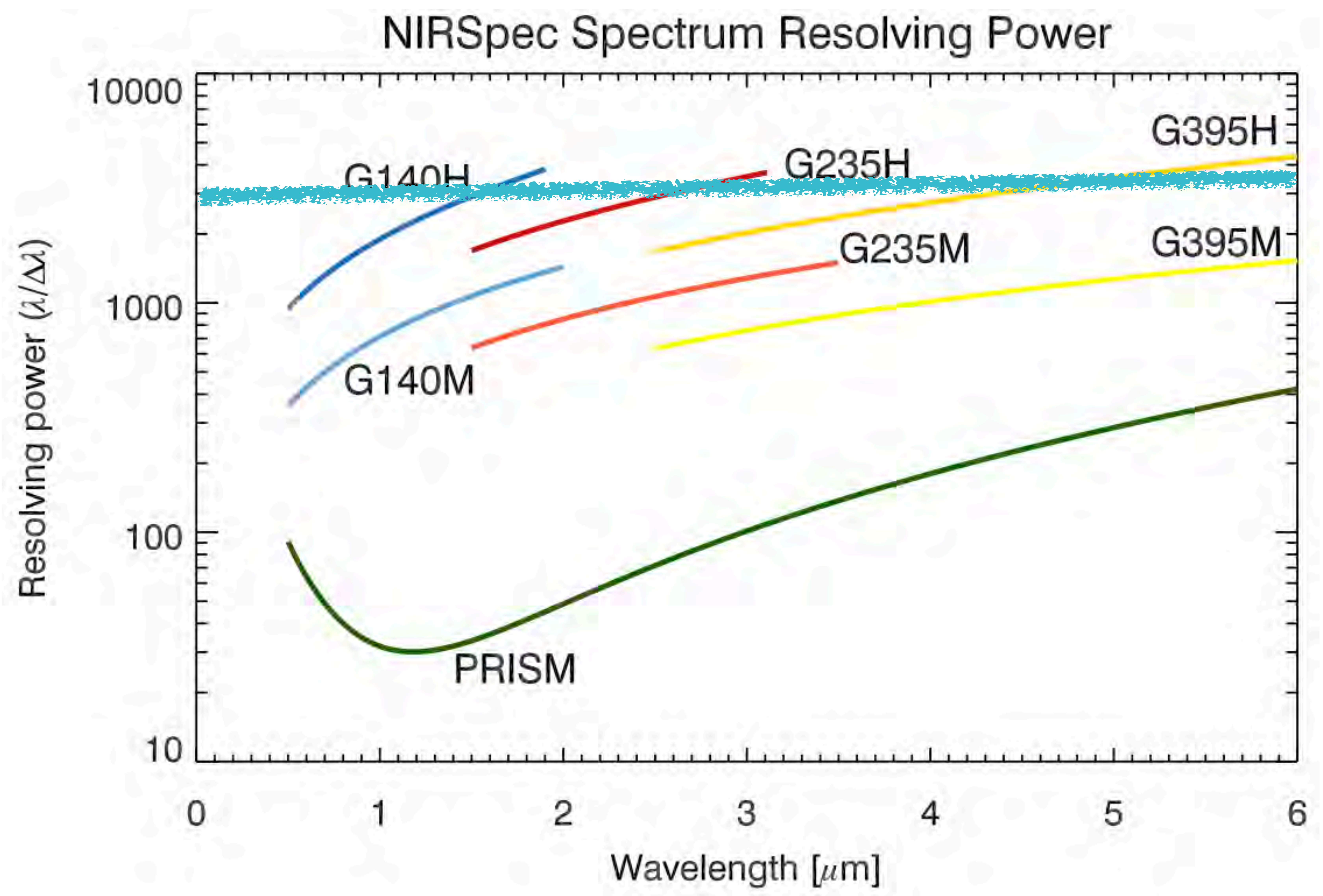


>1 kpc scale: well-mixed geometry of multiphase ISM

<1 kpc scale: different distribution

Tamura et al. 2023

01 [CII] 158 μm Line Emission

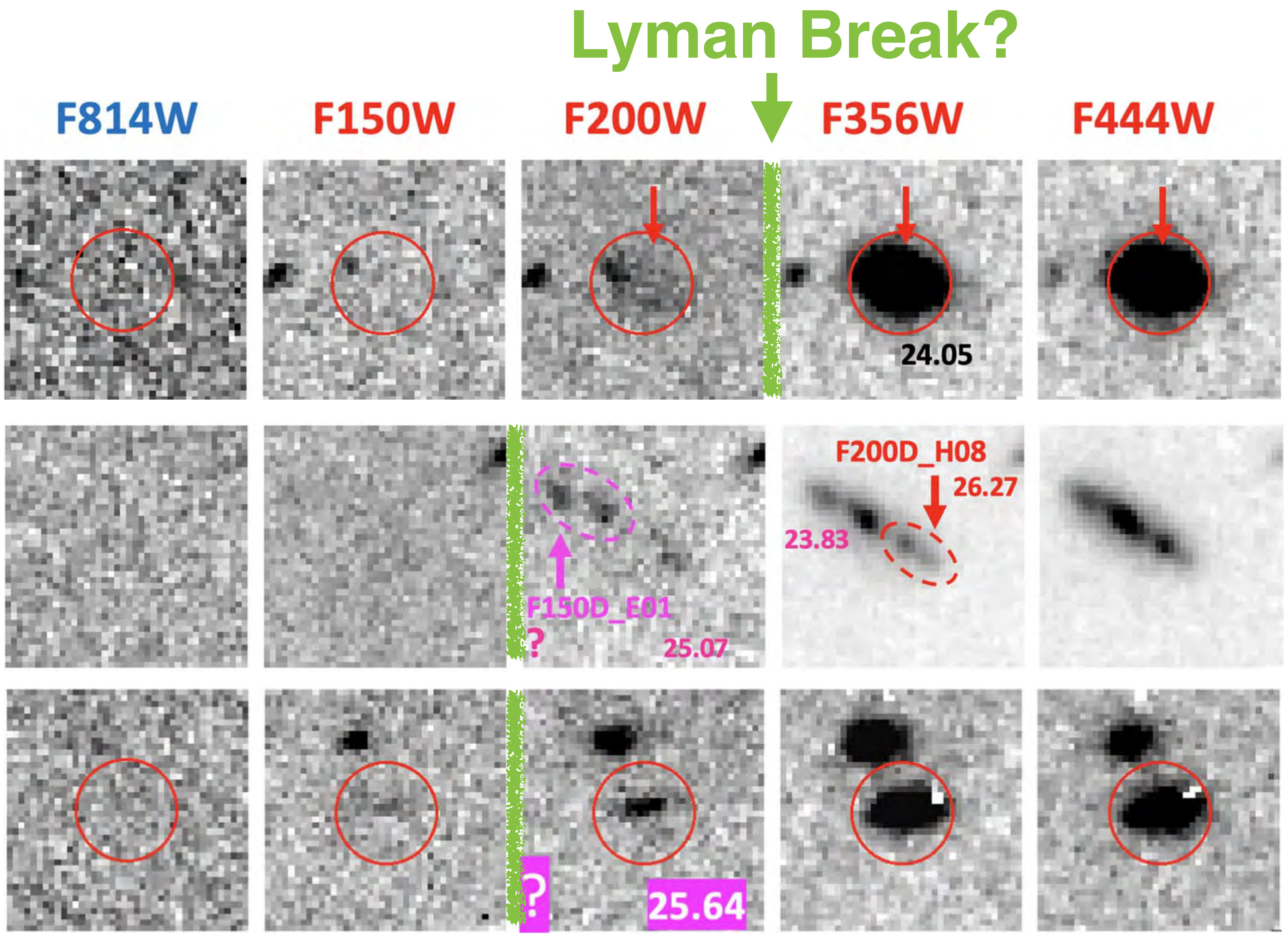


JWST resolution ~100 km/s

ALMA resolution ~10 km/s

https://jwst-docs.stsci.edu

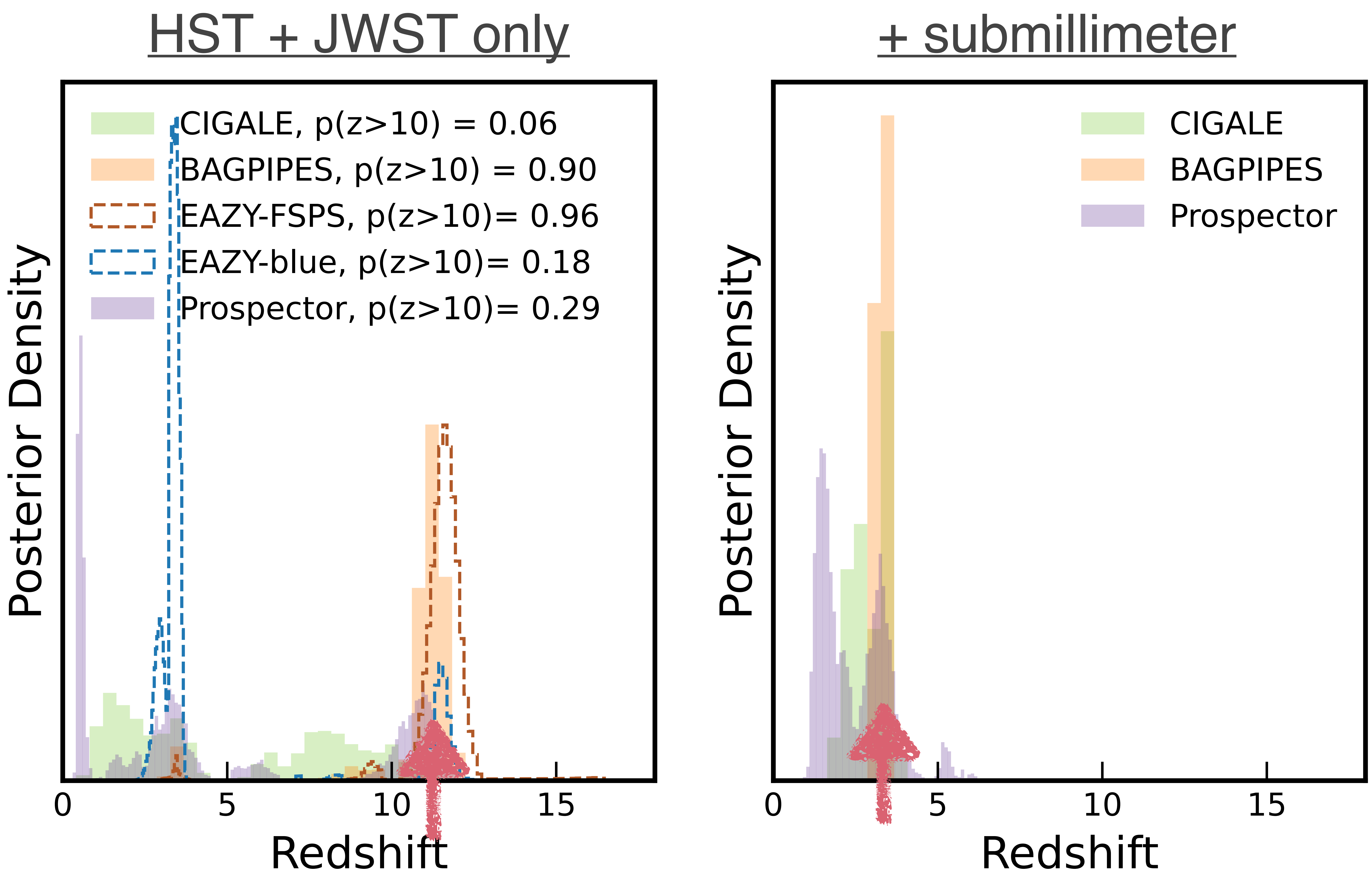
01 Dust Continuum Emission



Yan et al. 2023

Meyer et al. 2023

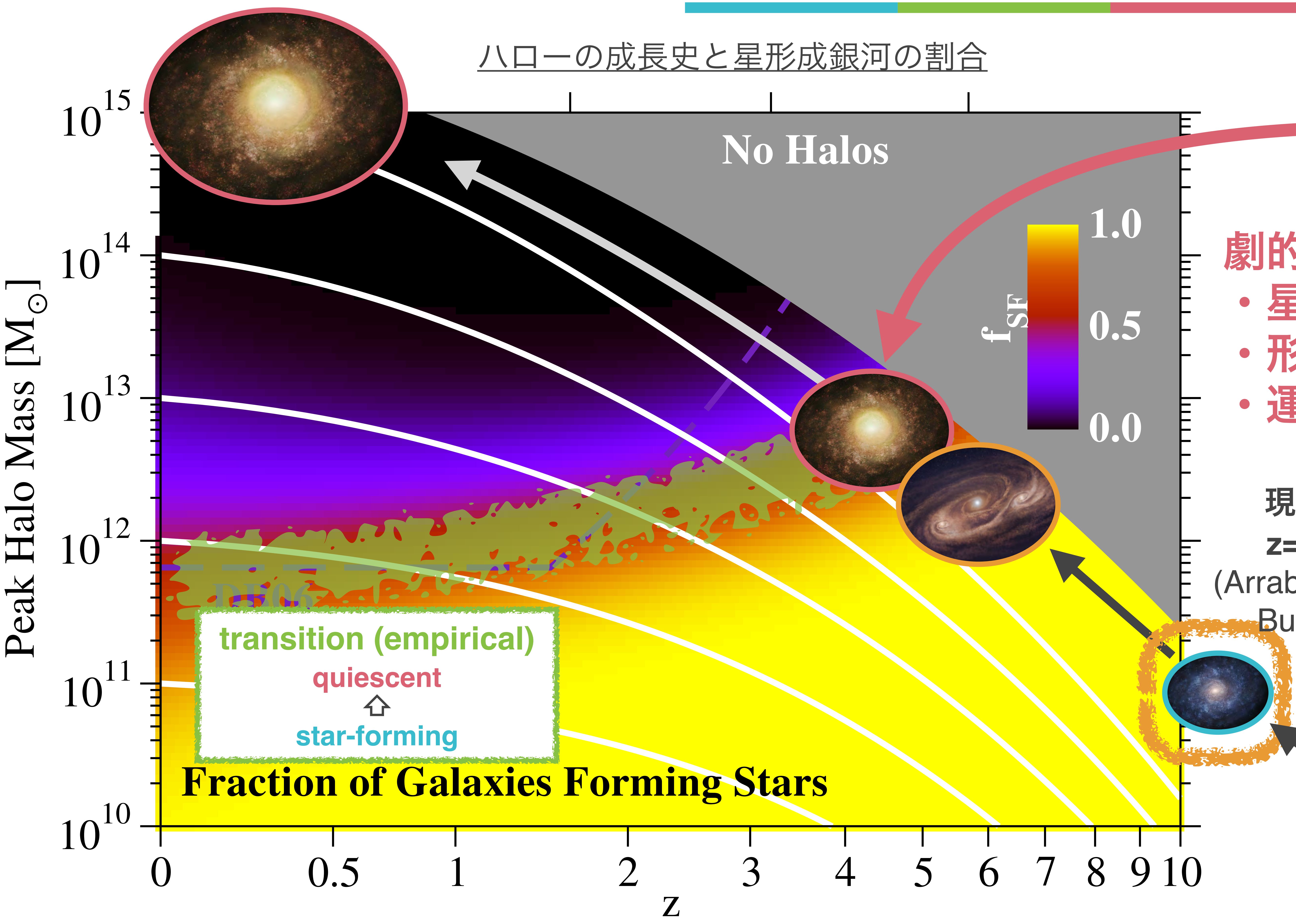
01 Dust Continuum Emission



Meyer et al. 2023

巨大銀河の進化 ⇄ 初代銀河の進化

ハローの成長史と星形成銀河の割合



巨大銀河の形成

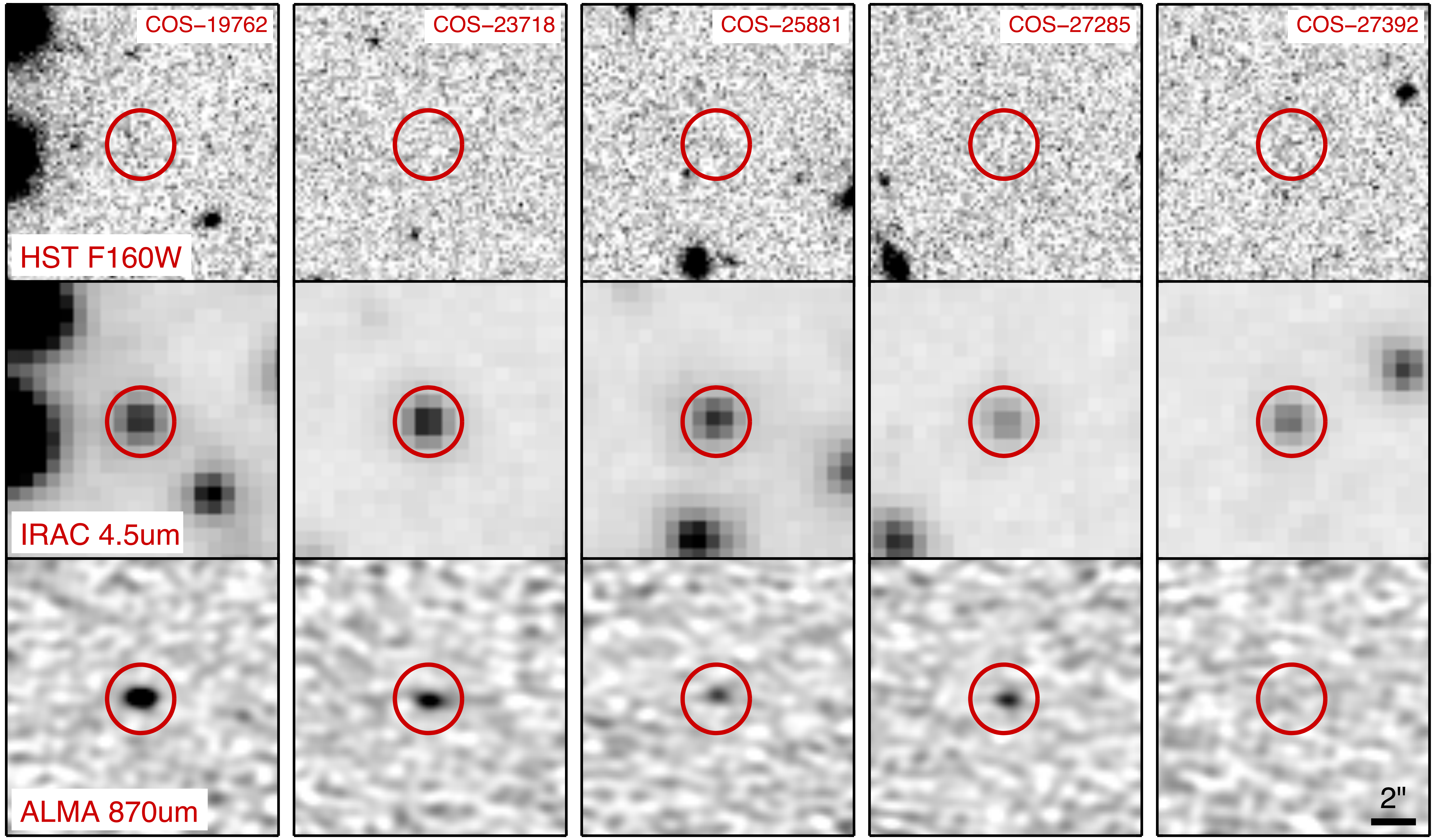
劇的な変化
- 星形成活動
- 形態
- 運動

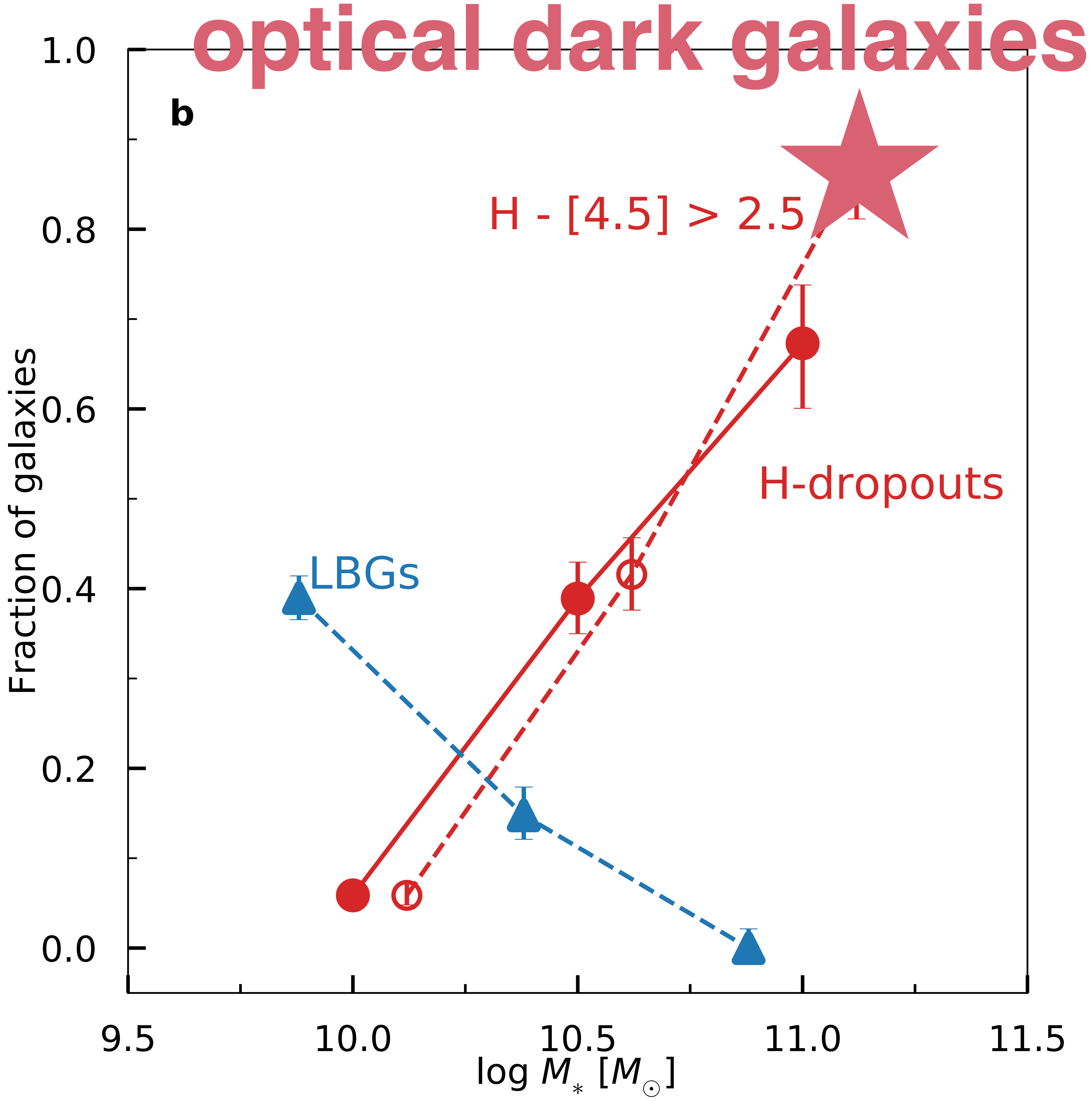
現在の最遠方銀河
z=11-12, logM*~9
(Arrabal Haro et al. 2023, Bunker et al. 2023)

初代銀河の誕生

Behroozi et al. 2019, ZINA DERETSKY/NATIONAL SCIENCE FOUNDATION/WIKIMEDIA COMMONS, Katrina Kenny & University of Adelaide

02 Optically Dark Galaxies

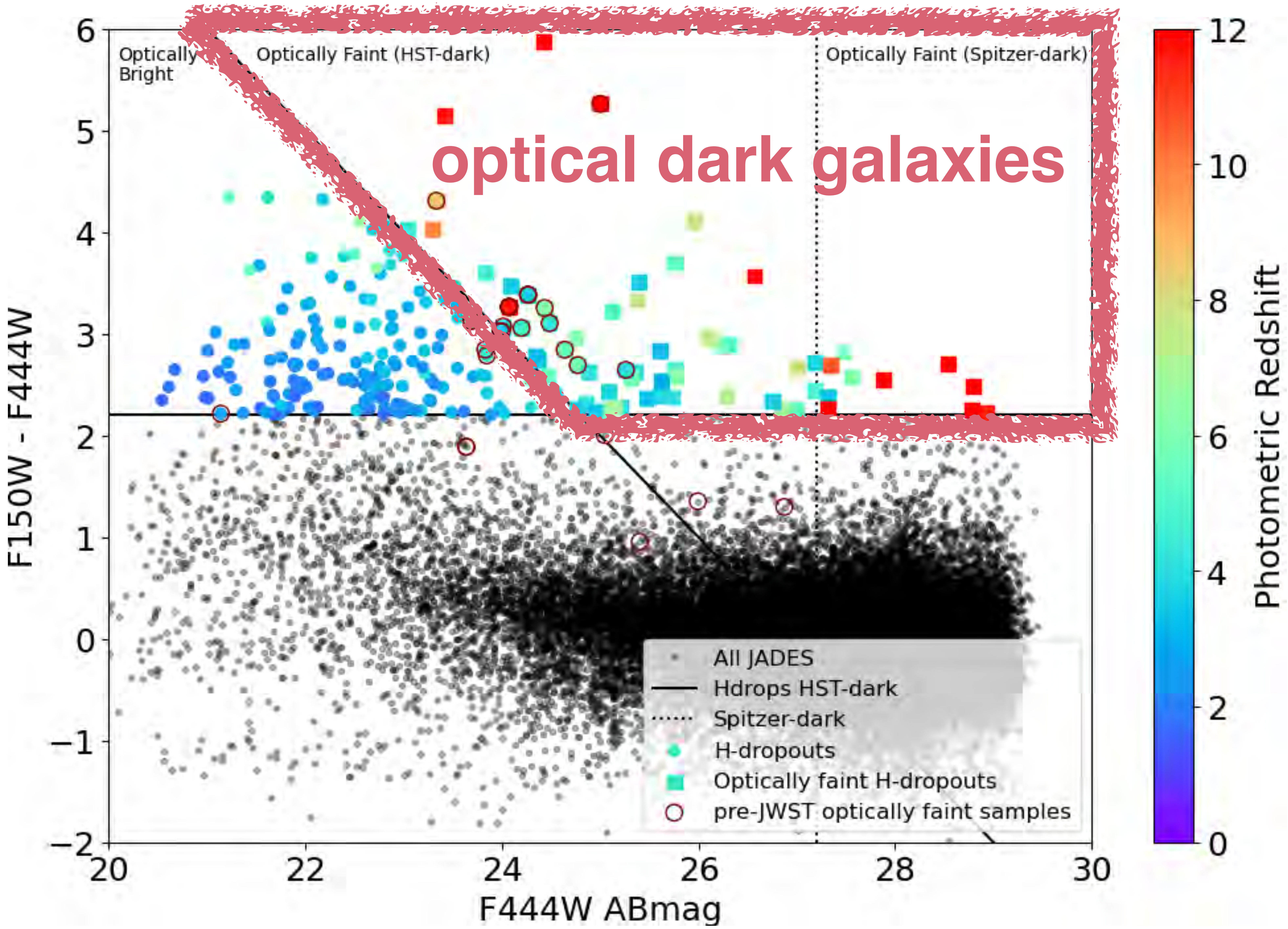




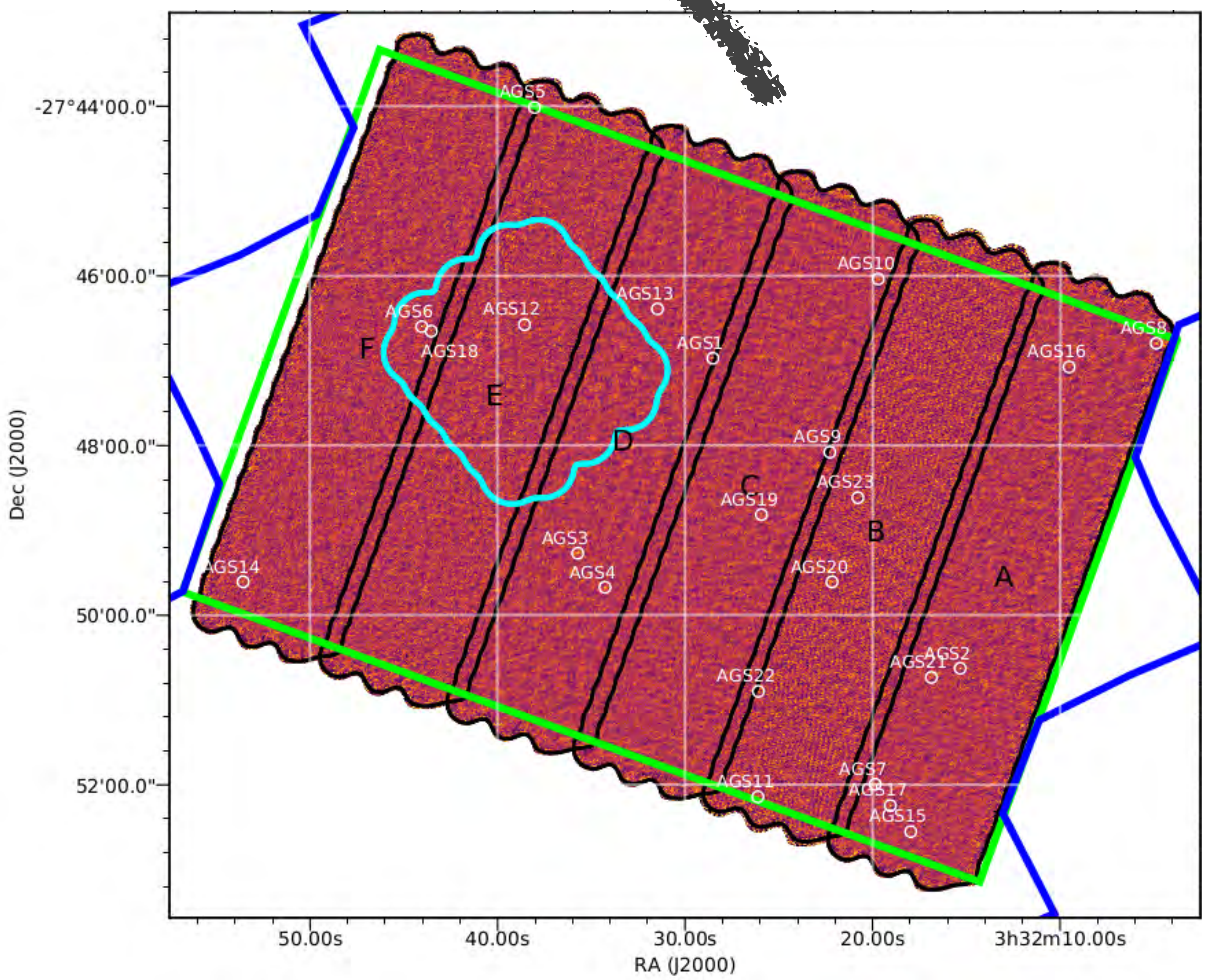
Previous HST surveys might have missed ~90% of massive galaxies

Wang et al. 2019

02 Optically Dark Galaxies



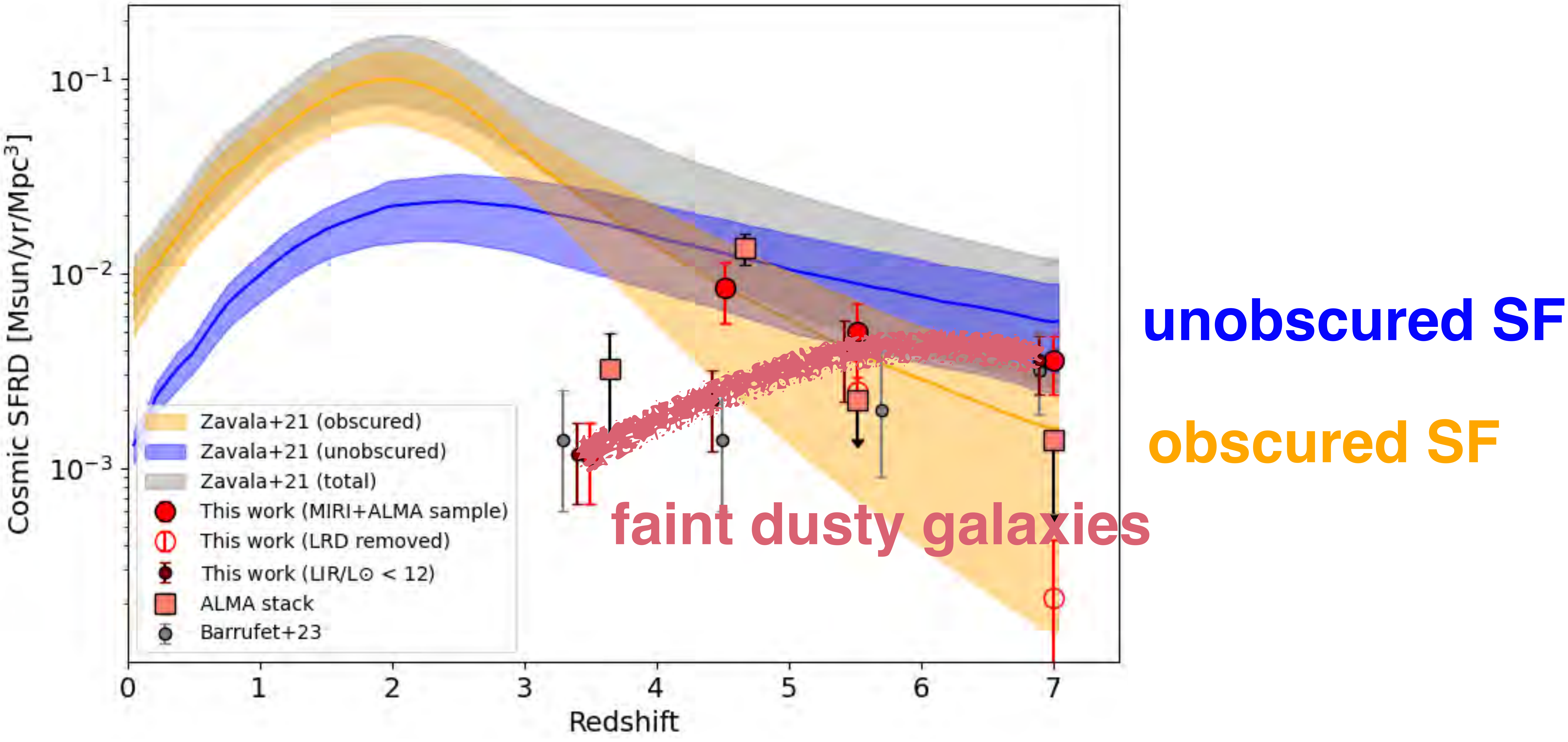
covering optically dark galaxies identified in ALMA blind surveys



Williams et al. 2023

Franco et al. 2018

02 Optically Dark Galaxies

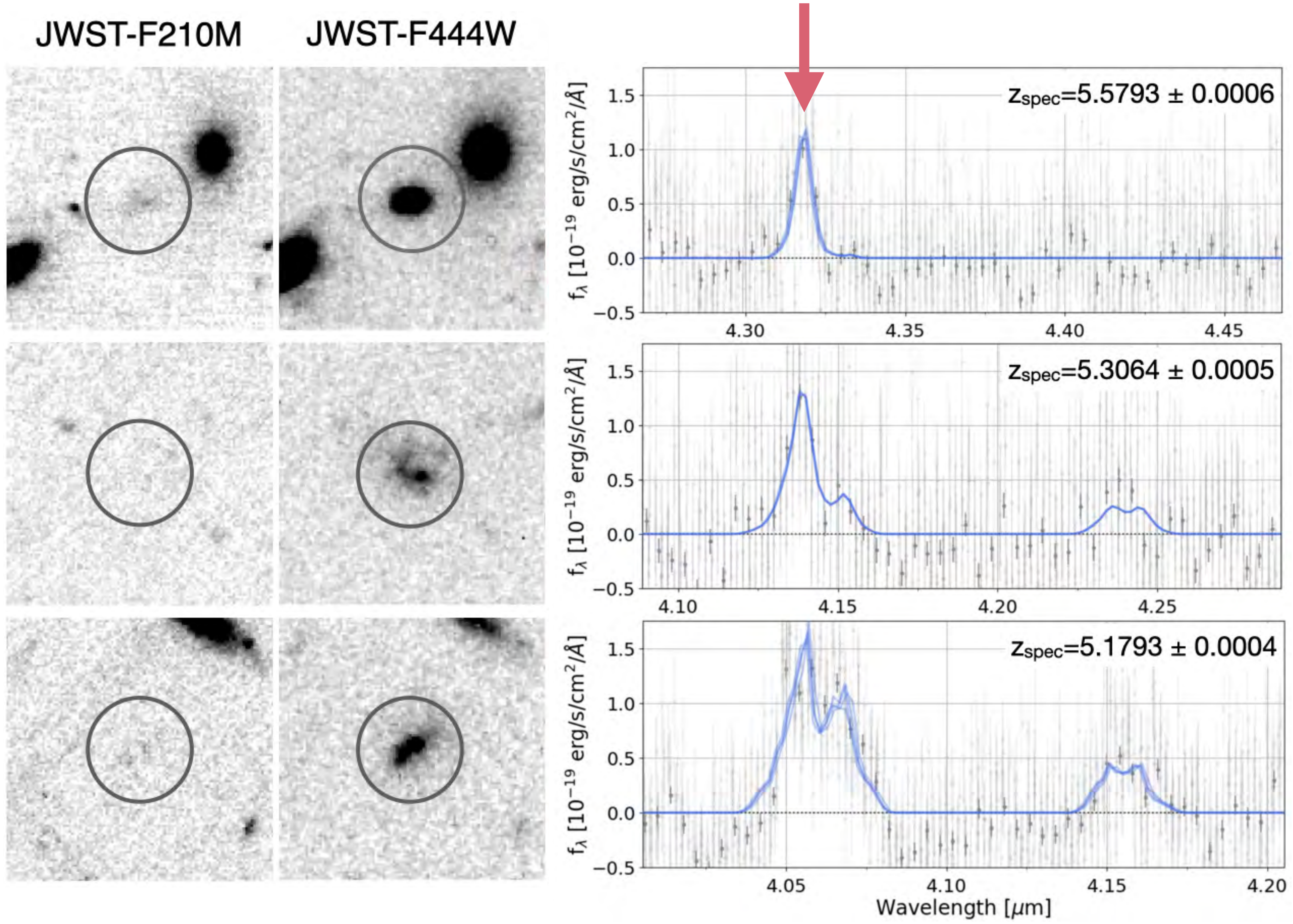


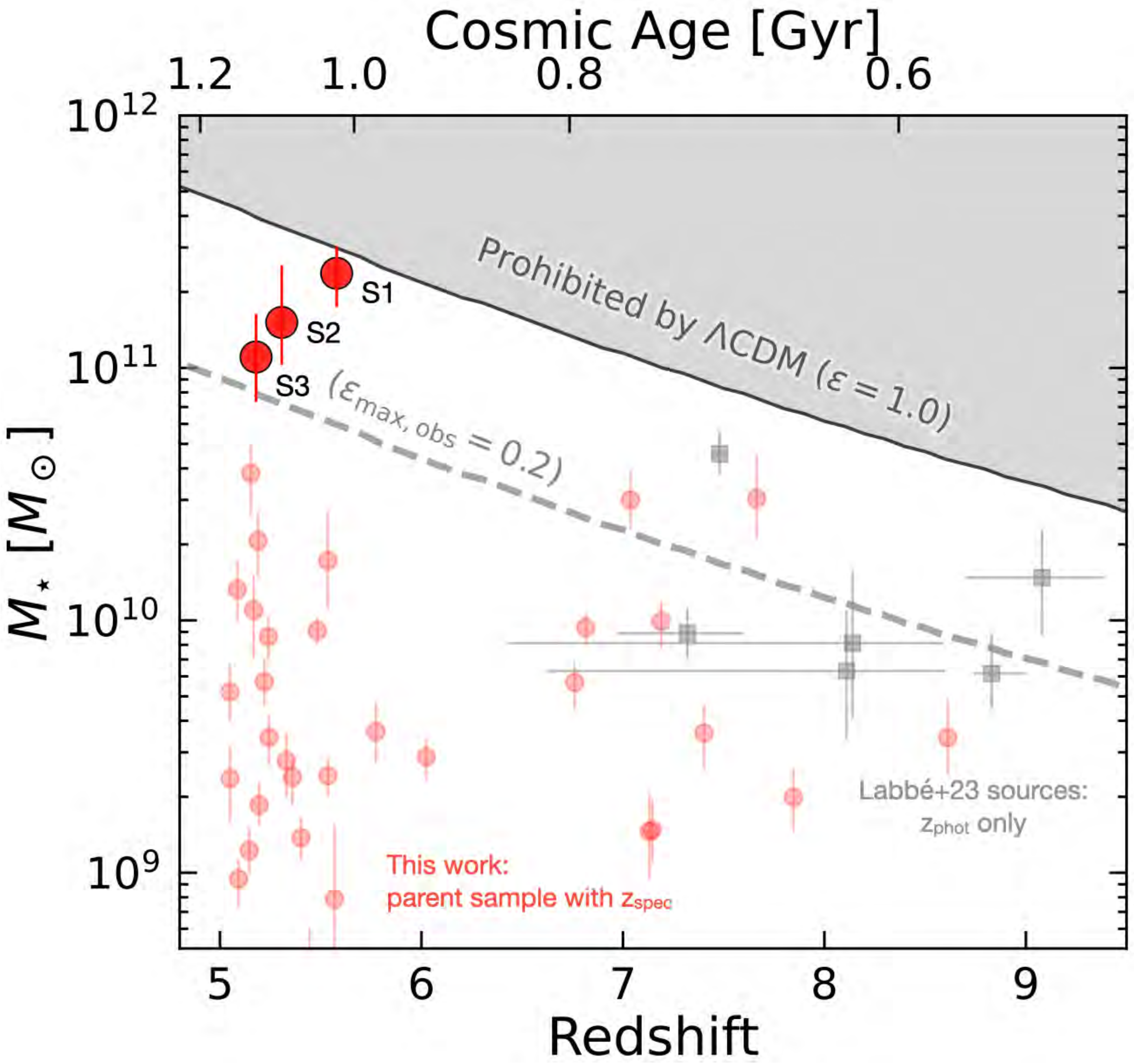
Faint dusty galaxies contribute to cosmic SFRD at z>5

Williams et al. 2023

02 Optically Dark Galaxies

Hα emission

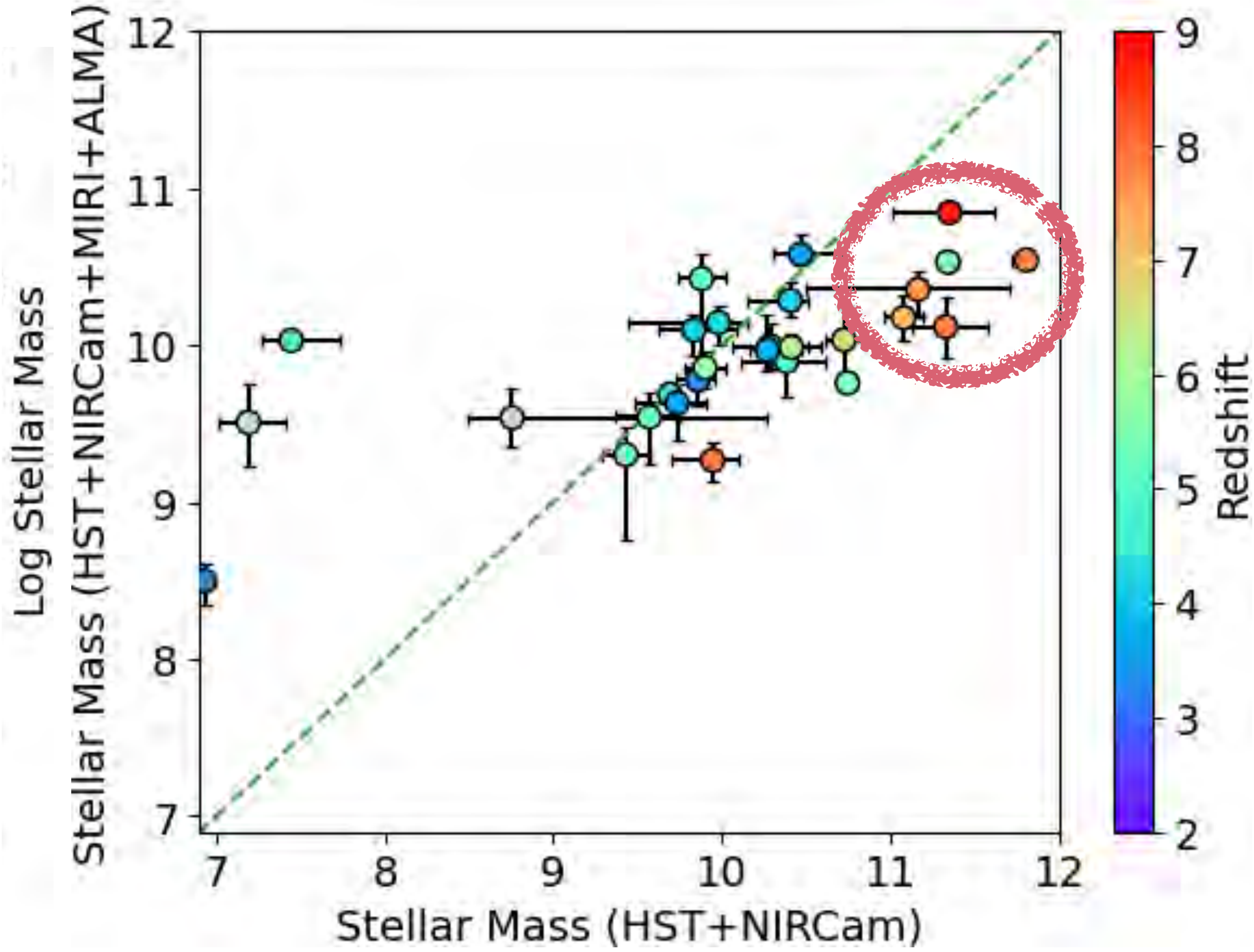


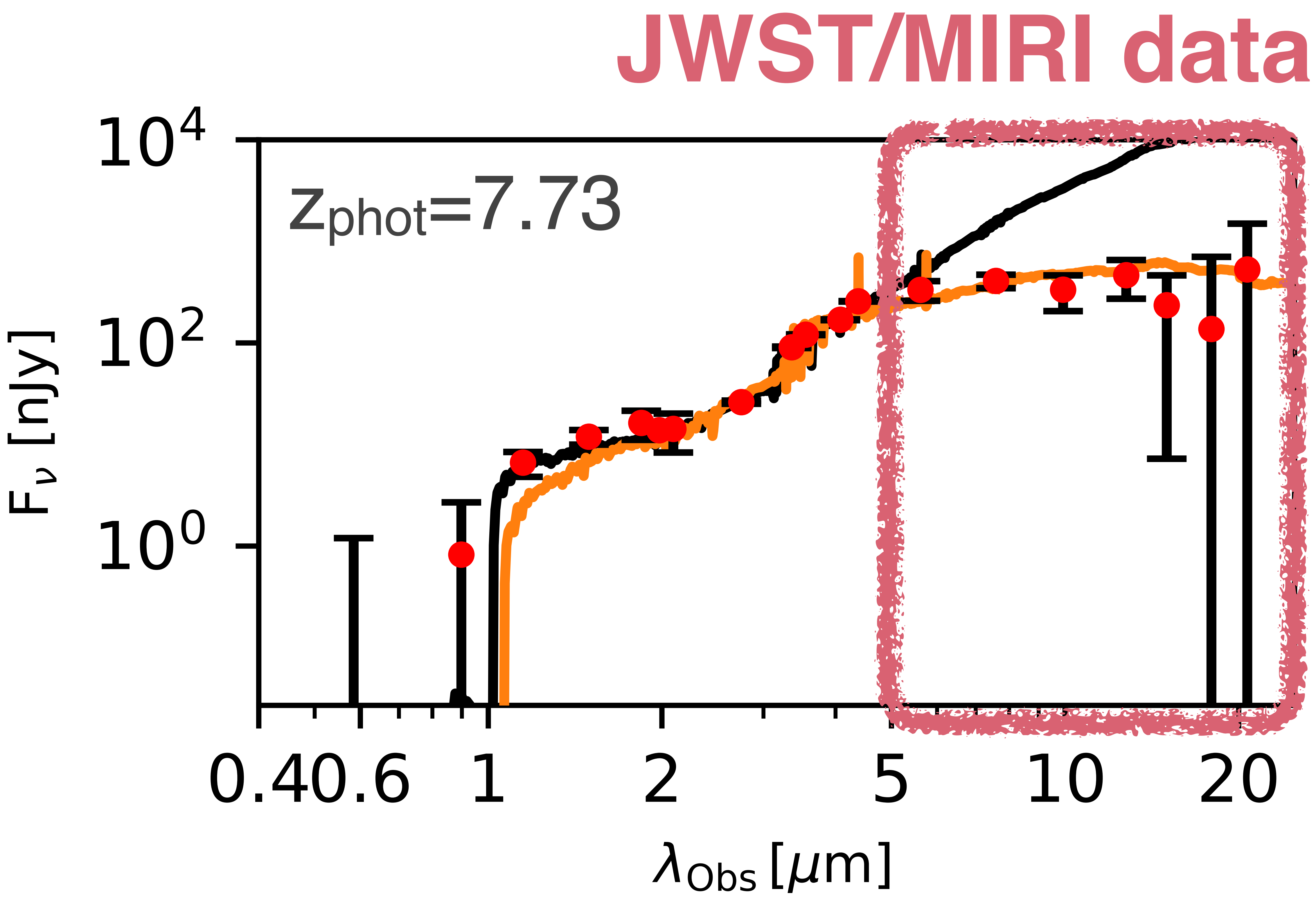


About 50% of the barons are converted into stars.

Xiao et al. 2023, submitted to Nature

02 Optically Dark Galaxies



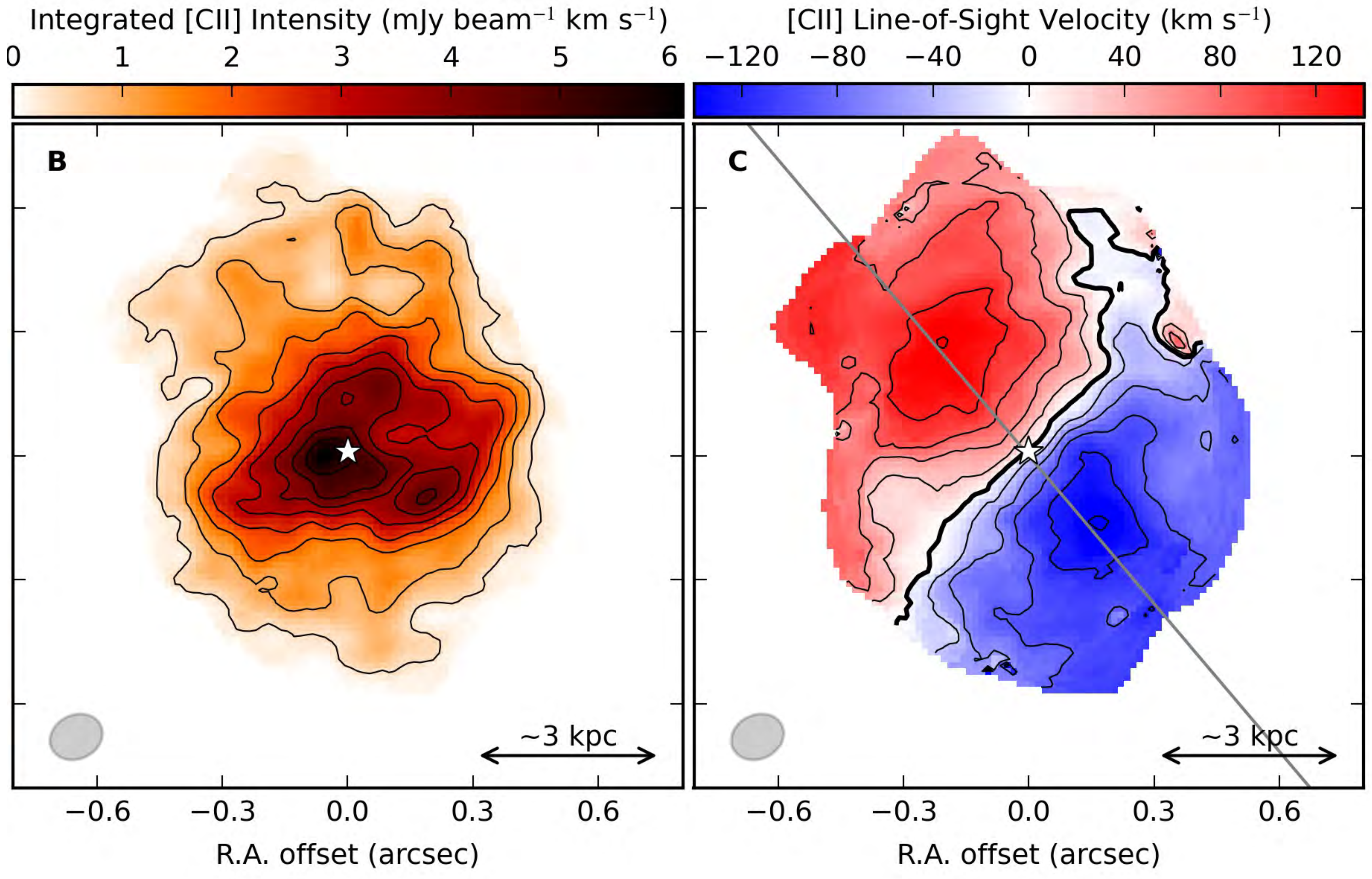


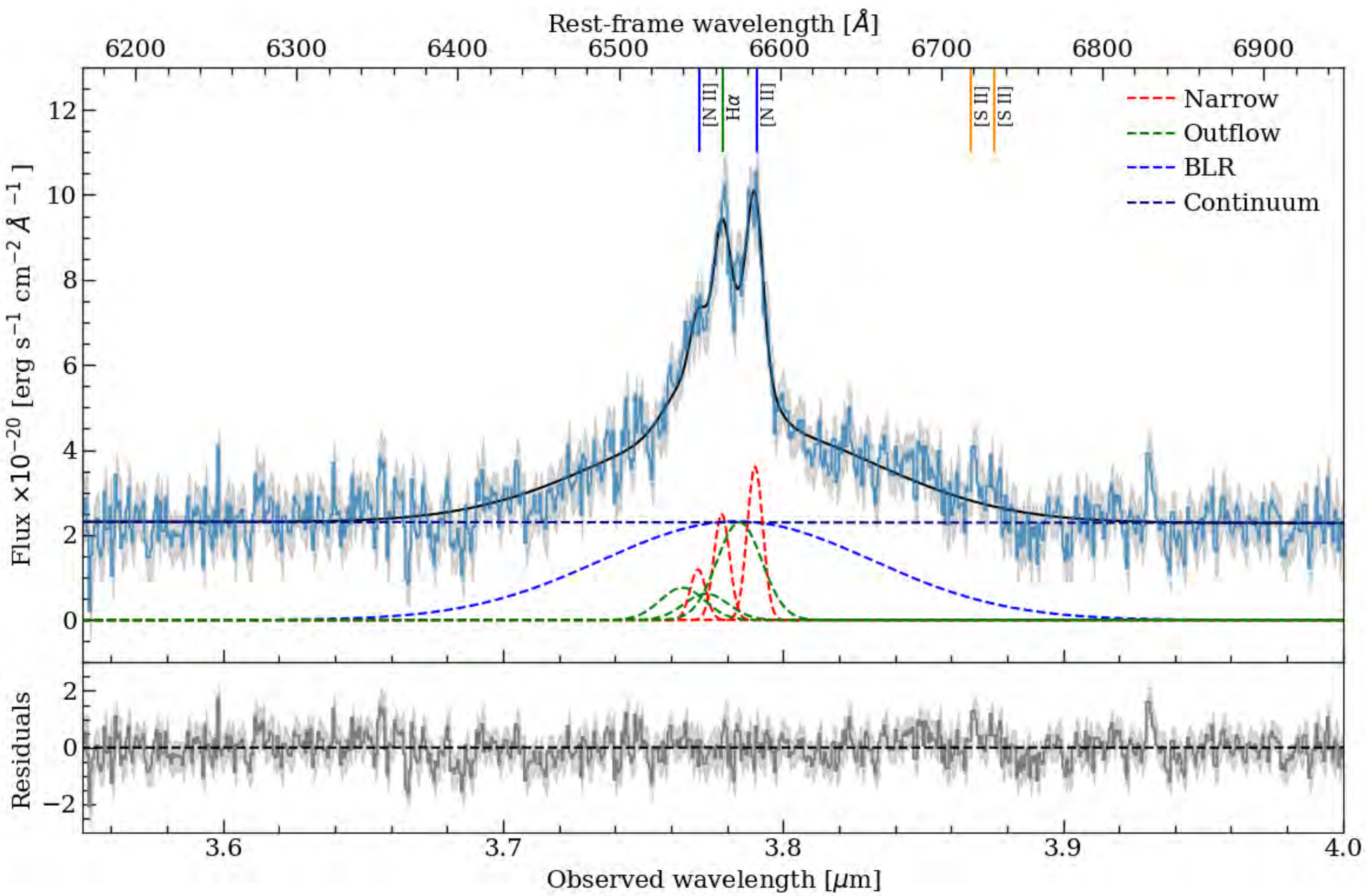
stellar masses are overestimated for red sources

Williams et al. 2023

02 Optically Dark Galaxies

ALESS 073.1 at z=4.8 (submillimeter bright galaxy)





ALMA [CII] observations

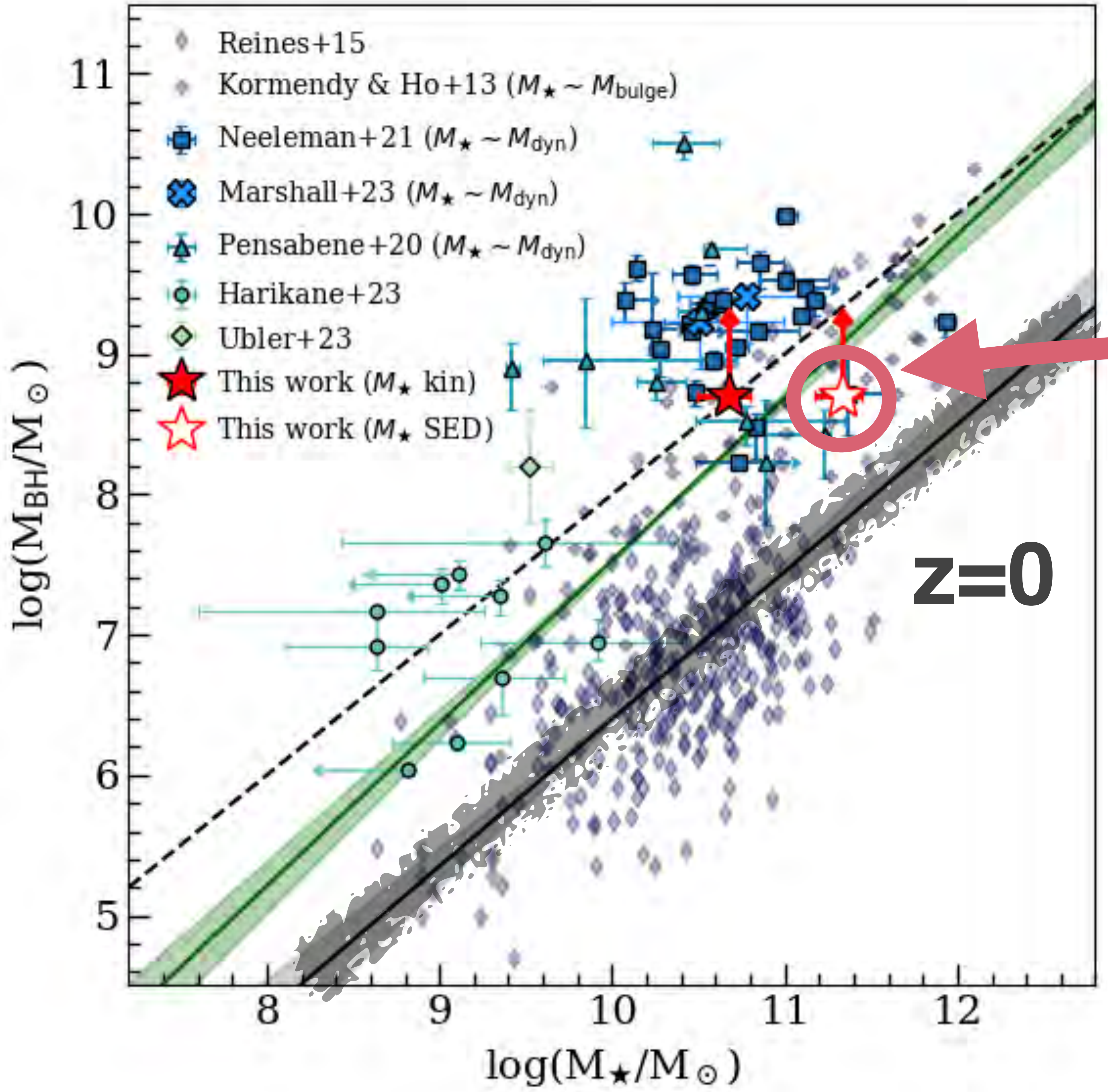
JWST Hα observations

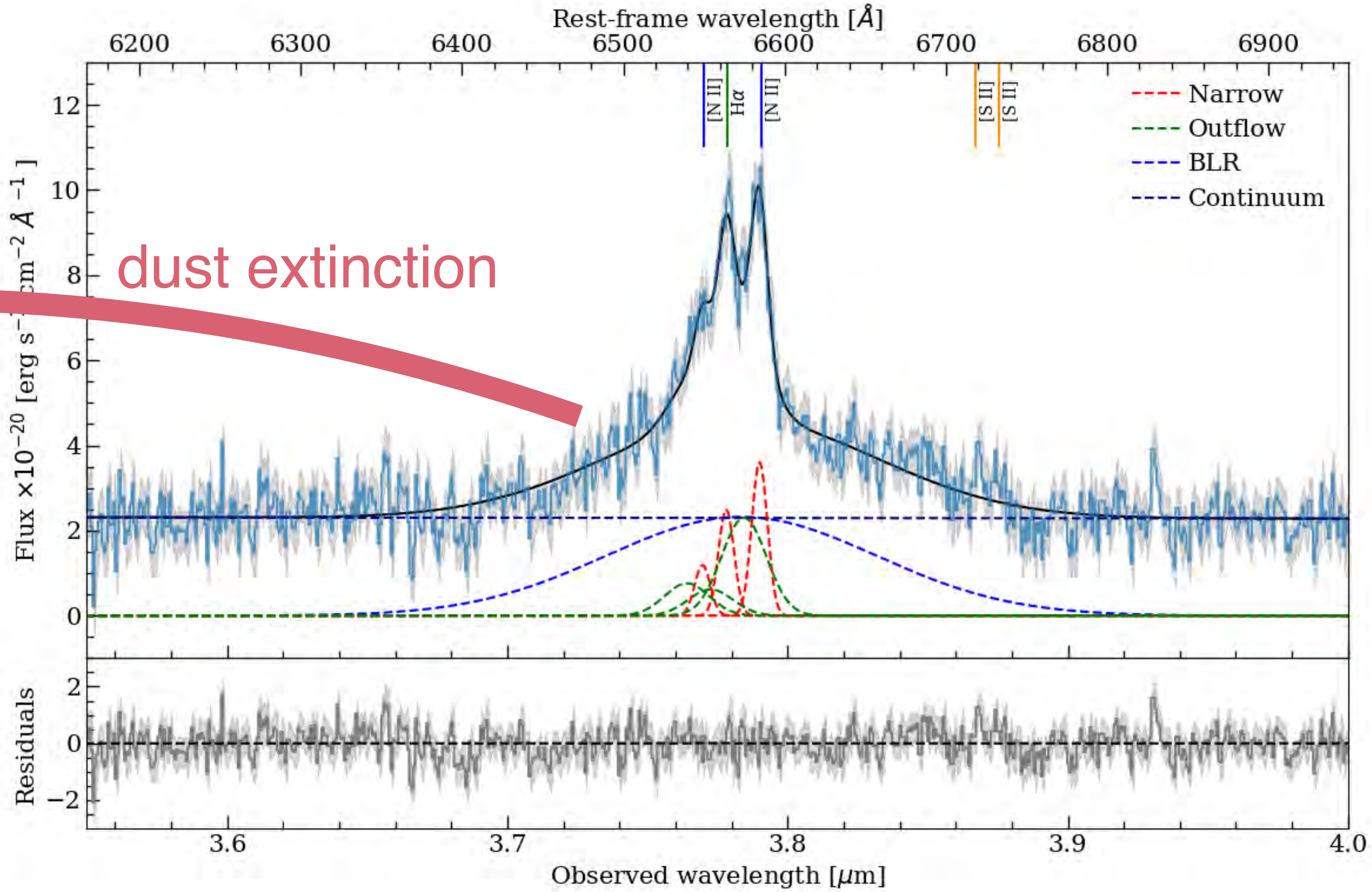
Lelli et al. 2021

Parlanti et al. 2021

02 Optically Dark Galaxies

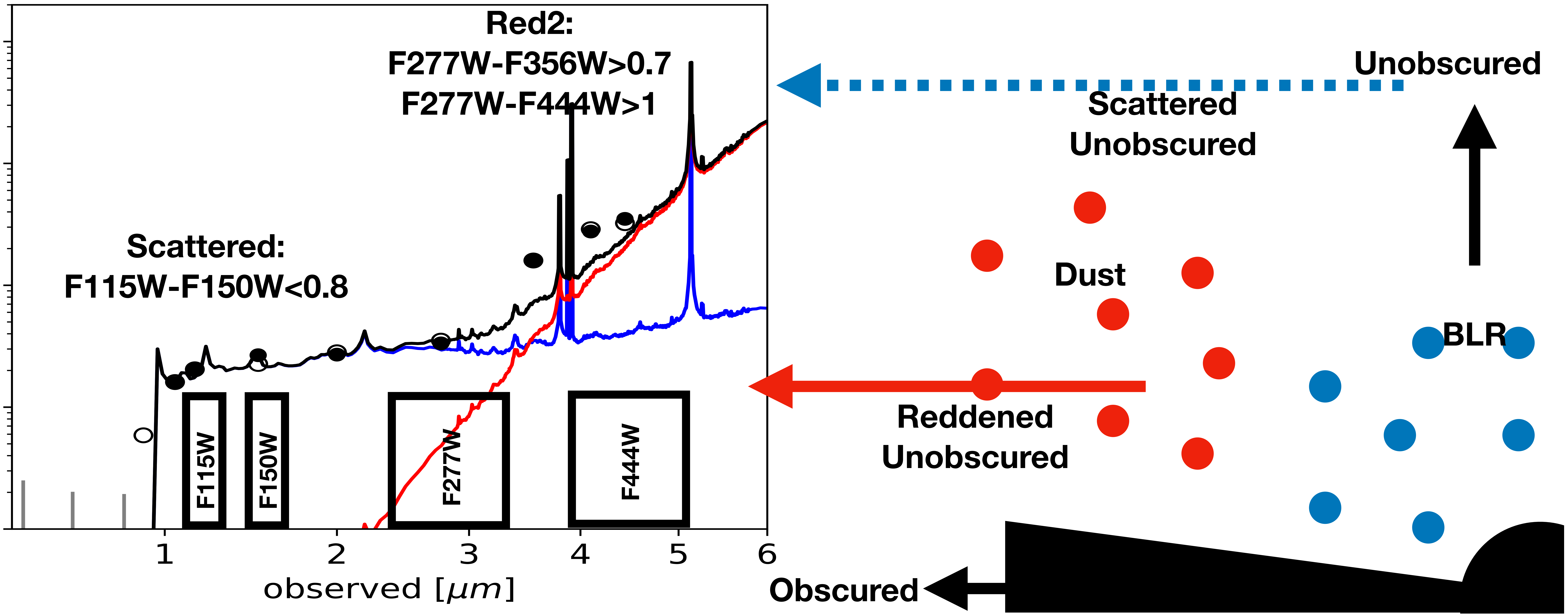
ALESS 073.1 at z=4.8 (submillimeter bright galaxies)





dust-obscured AGN

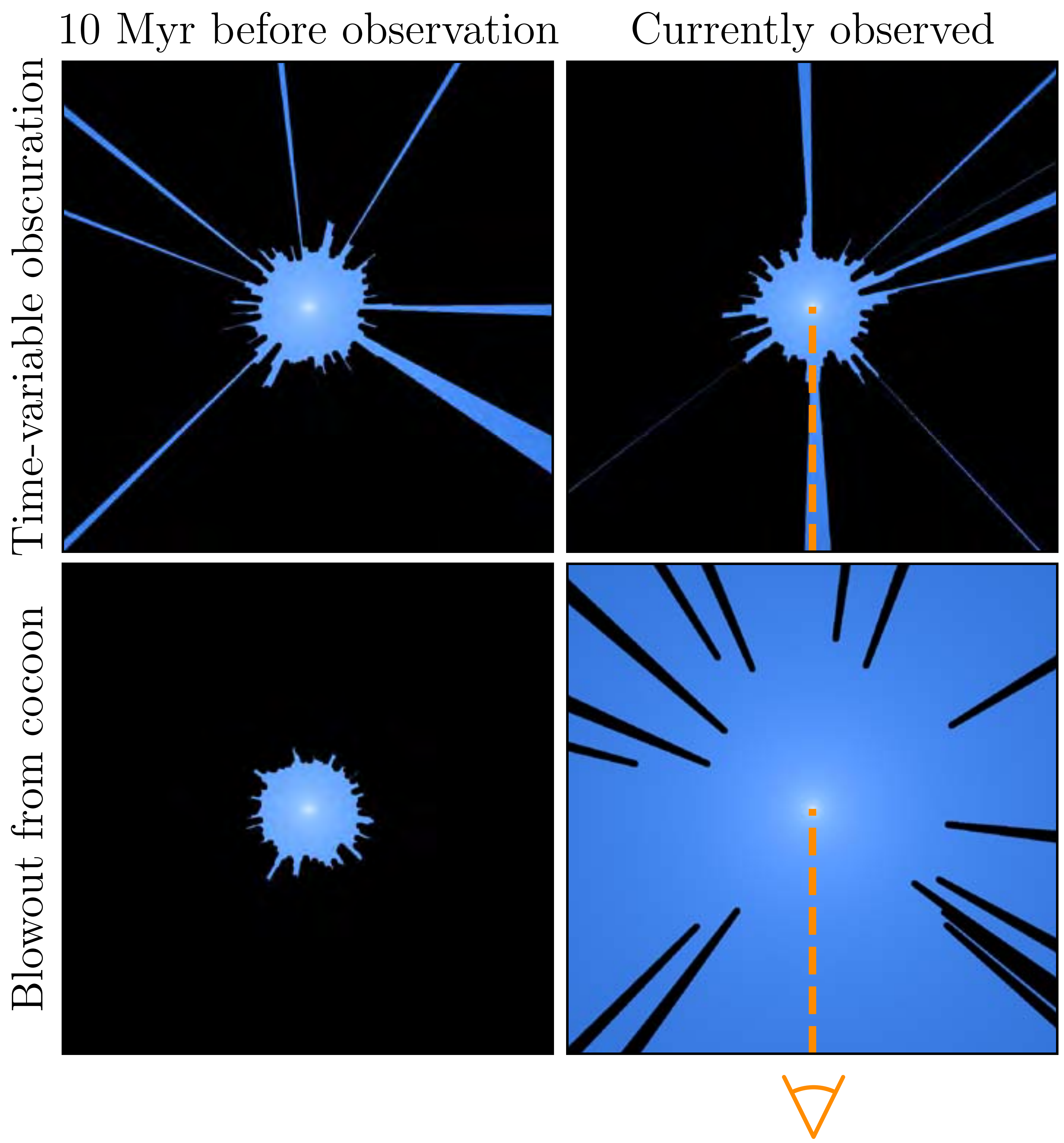
03 Dust Obscured AGN



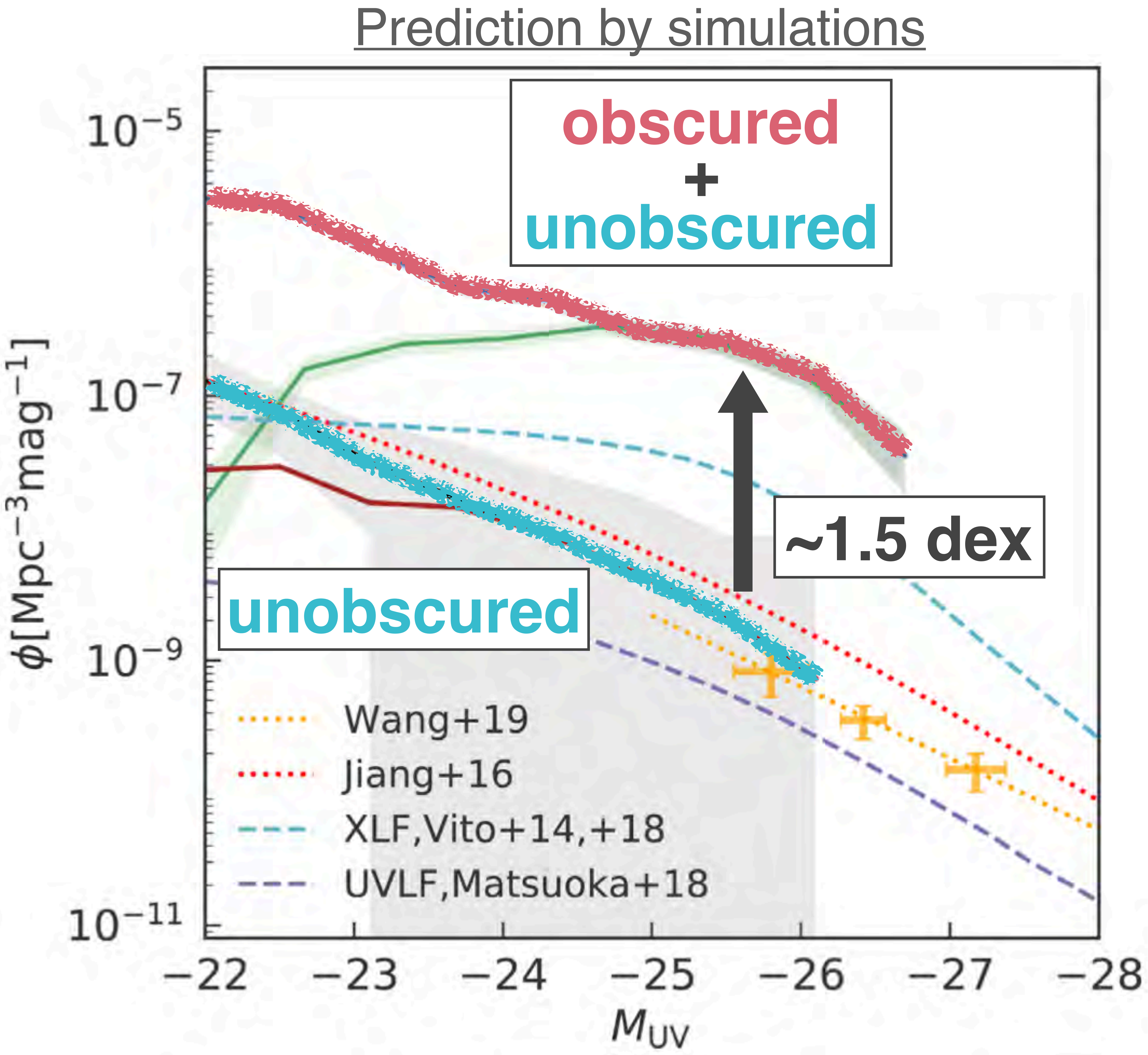
JWST discovered many dust-obscured AGNs

Fujimoto et al. 2022, Kocevski et al. 2023, Barro et al. 2023, Labbe et al. 2023

03 Dust Obscured AGN



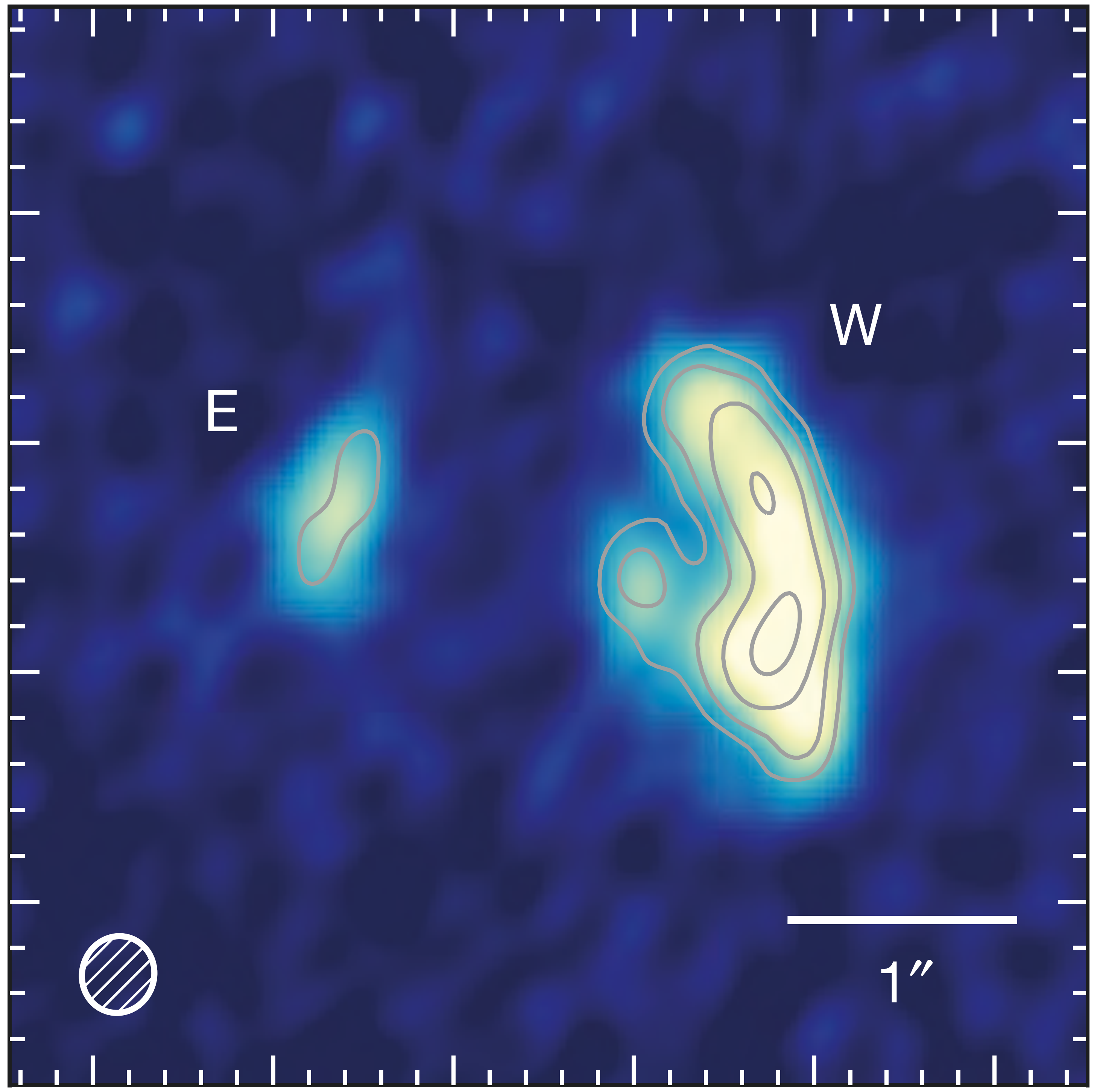
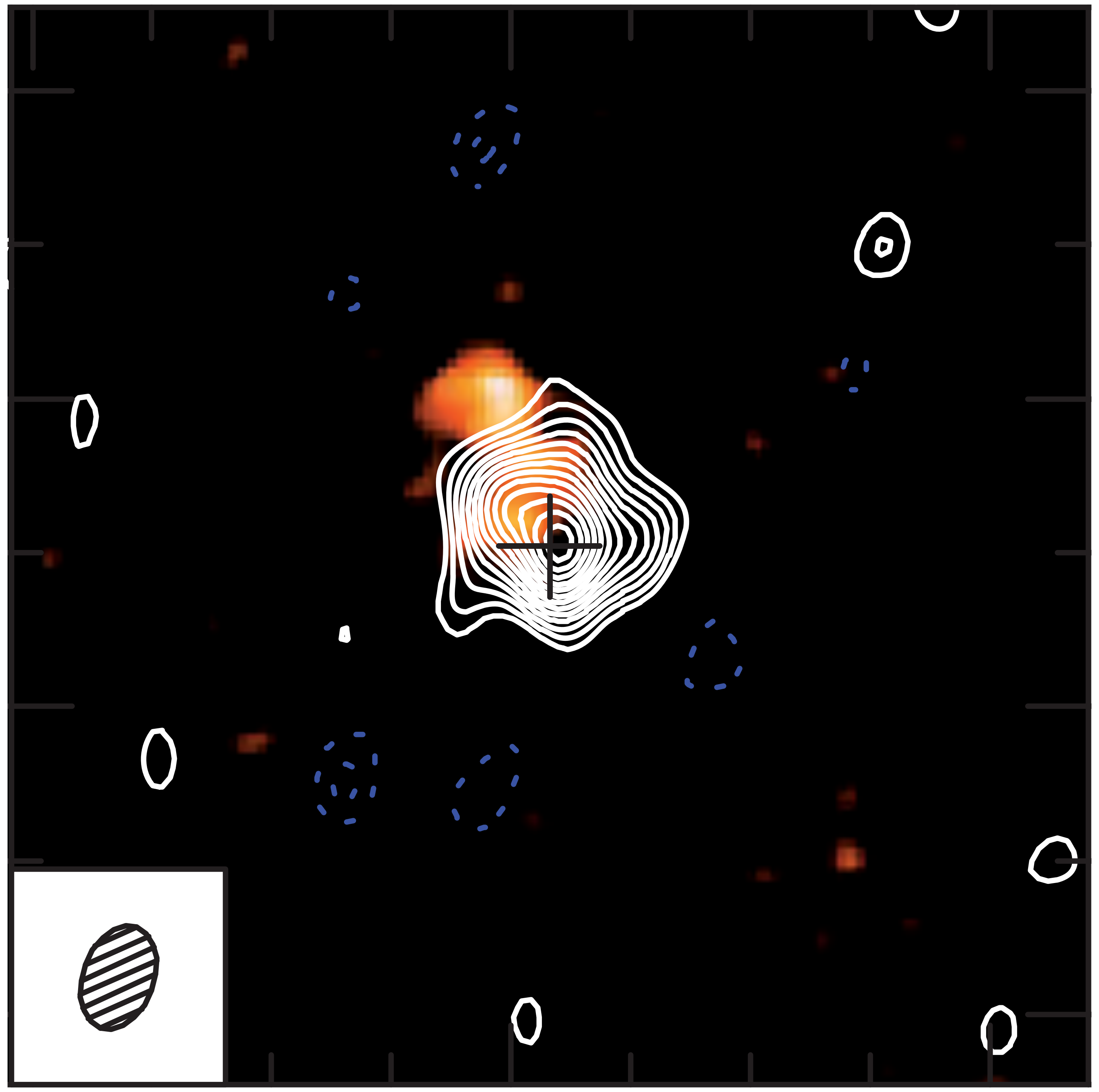
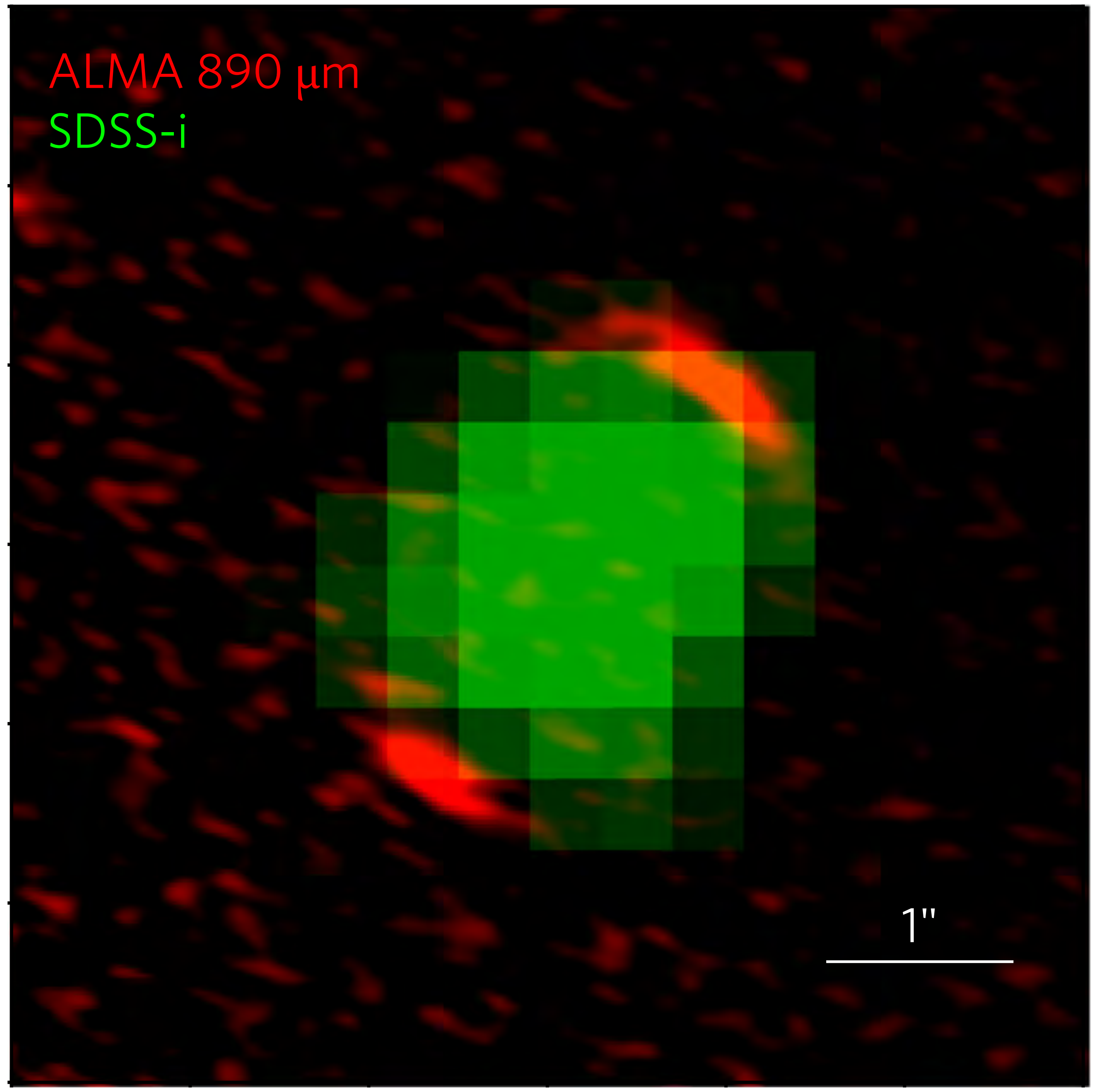
obscured quasar **unobscured quasar**



Davies et al. 2019

Ni et al. 2020

03 Dust Obscured AGN

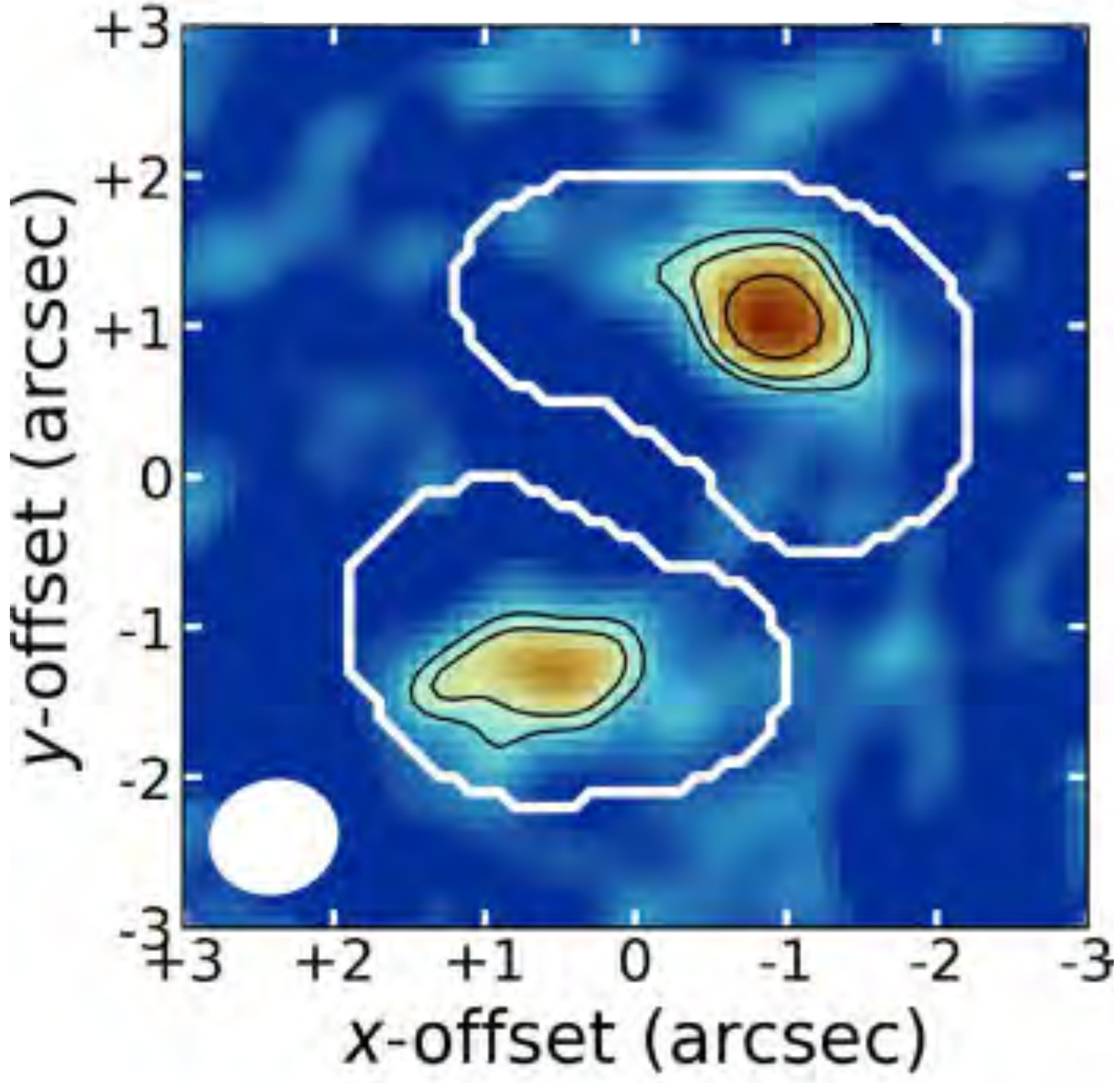
SPT0311-58 at **z=6.9** (Marrone+18)	HFLS3 at **z=6.3** (Riechers+13)	G09-83808 at **z=6.0** (Zavala+18)
		
$S_{870,obs}$=**35 mJy**	$S_{870,obs}$=**33 mJy**	$S_{870,obs}$=**36 mJy**
$S_{870,int}$=**16 mJy**, $L_{IR,int}=33\times10^{12}$ L_{sun}	$S_{870,int}$=**33 mJy**, $L_{IR,int}=42\times10^{12}$ L_{sun}	$S_{870,int}$=**4 mJy**, $L_{IR,int}=4\times10^{12}$ L_{sun}

extreme outliers

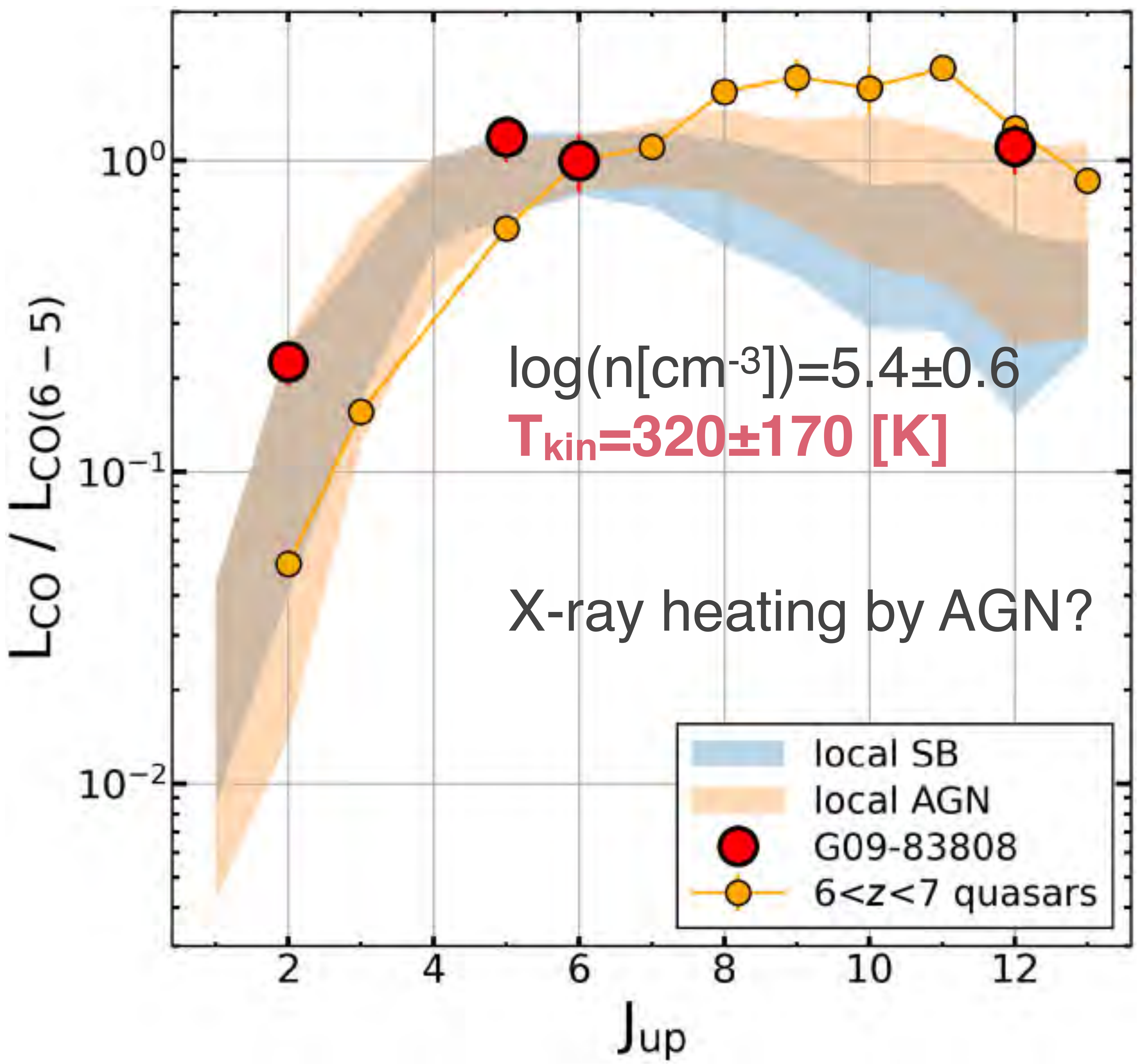
more common population

03 Dust Obscured AGN

CO J=12-11 line observations



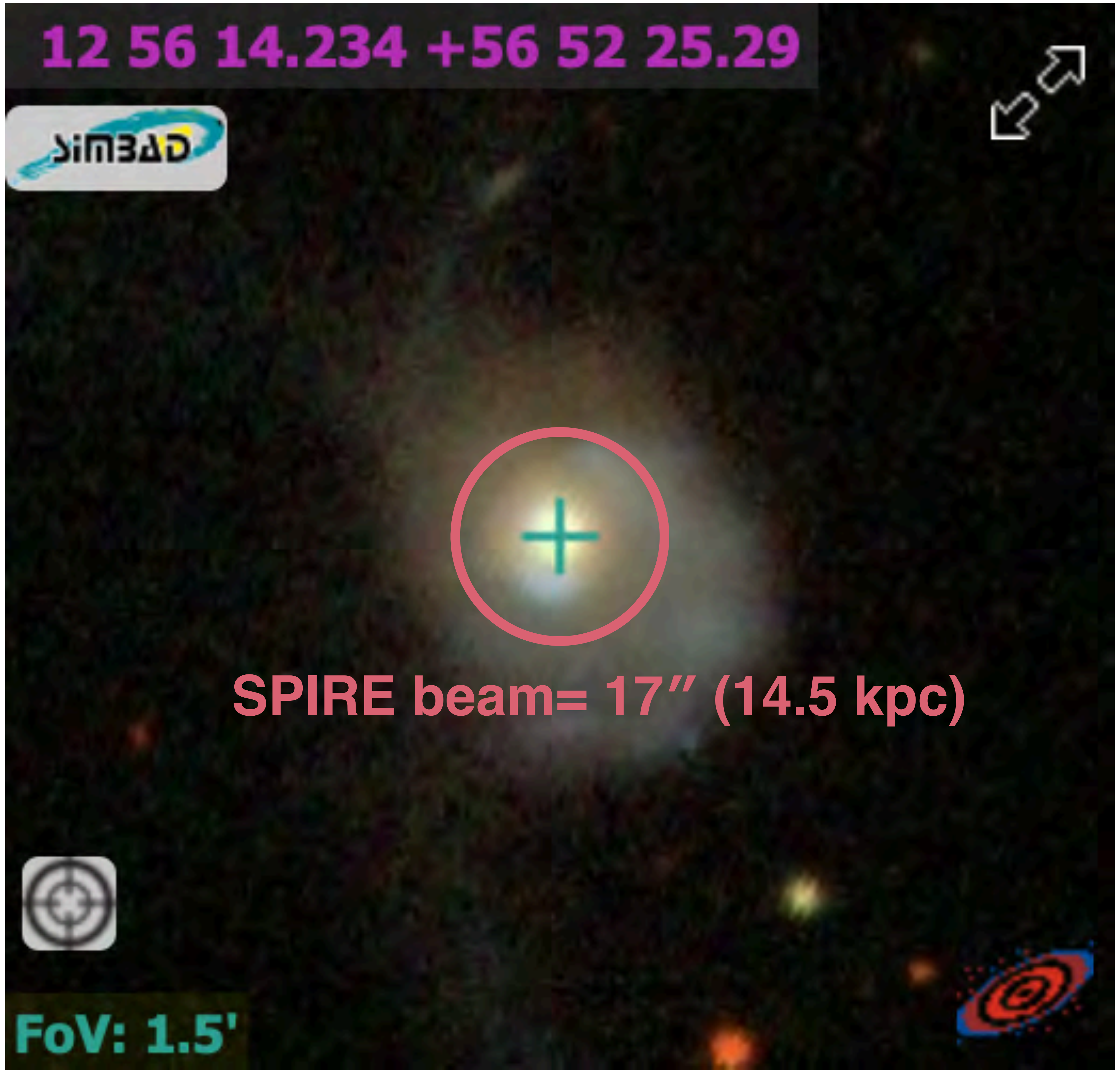
CO spectral energy distributions



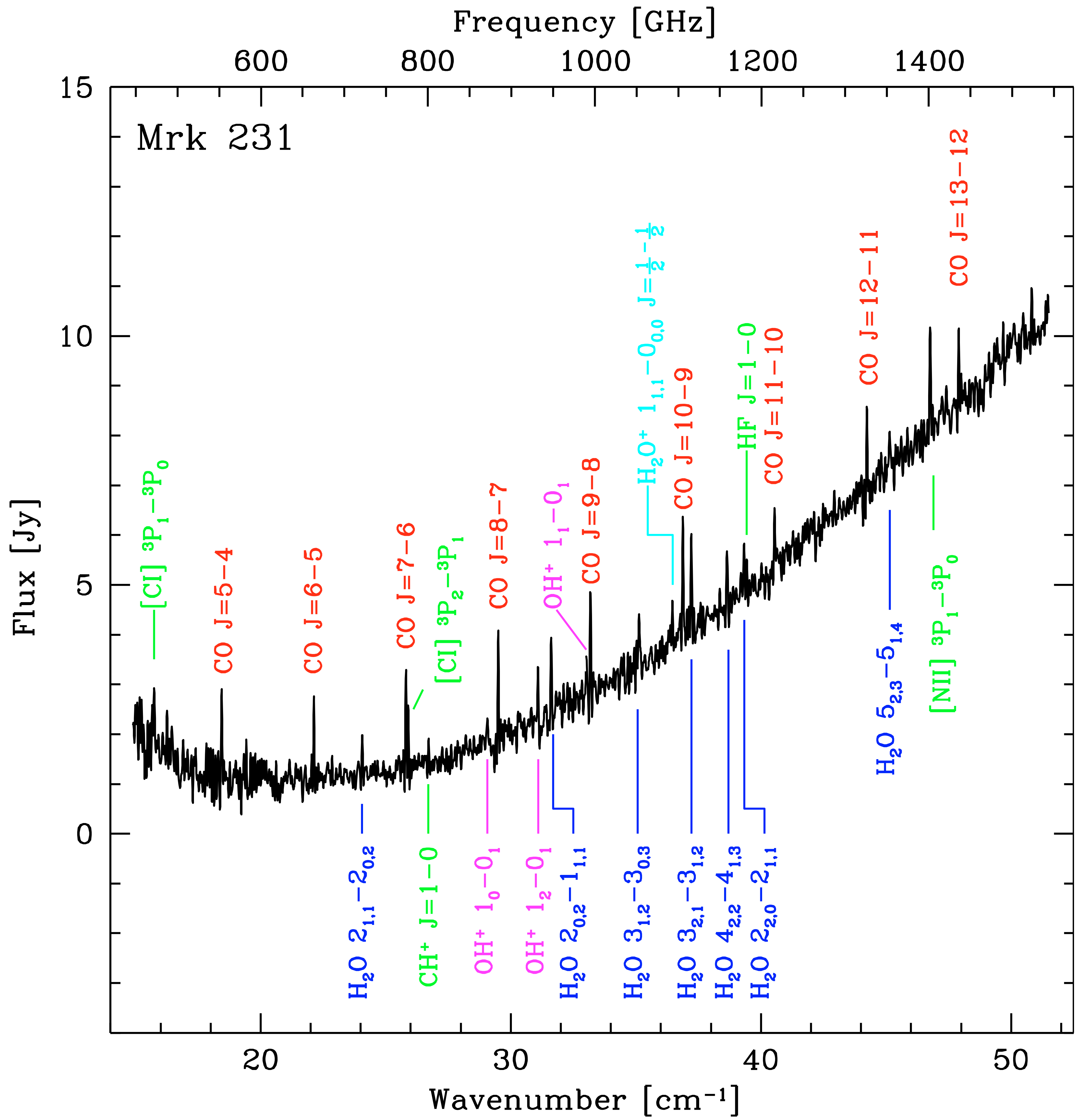
Tsujita et al. 2022

03 Dust Obscured AGN

SDSS image of Mrk231



SPIRE spectrum of Mrk231



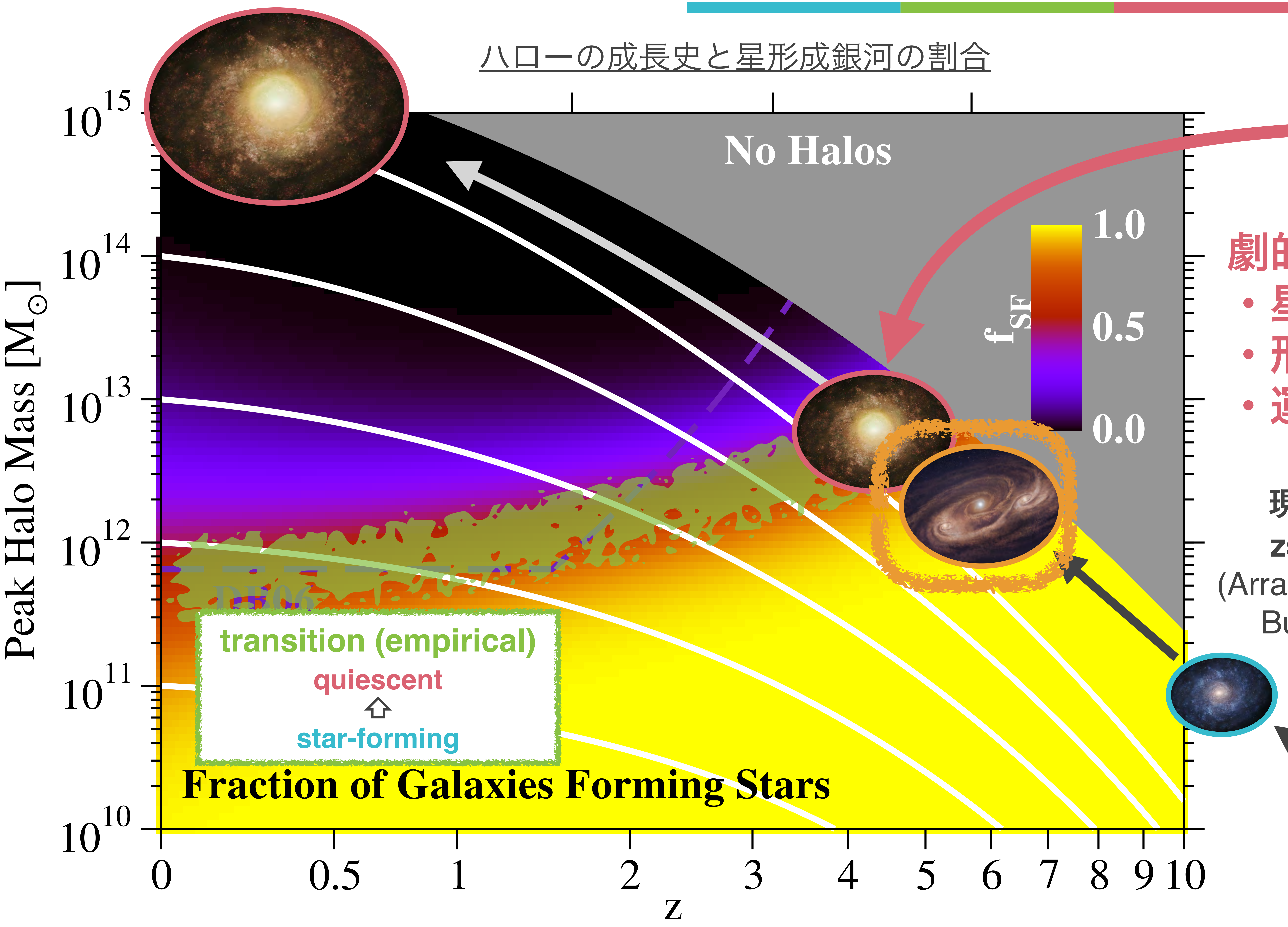
van der Werf et al. 2010

03 Dust Obscured AGN

Models of CO spectral energy distributions

Vallini et al. 2019

巨大銀河の進化 ⇄ 初代銀河の進化



巨大銀河の形成

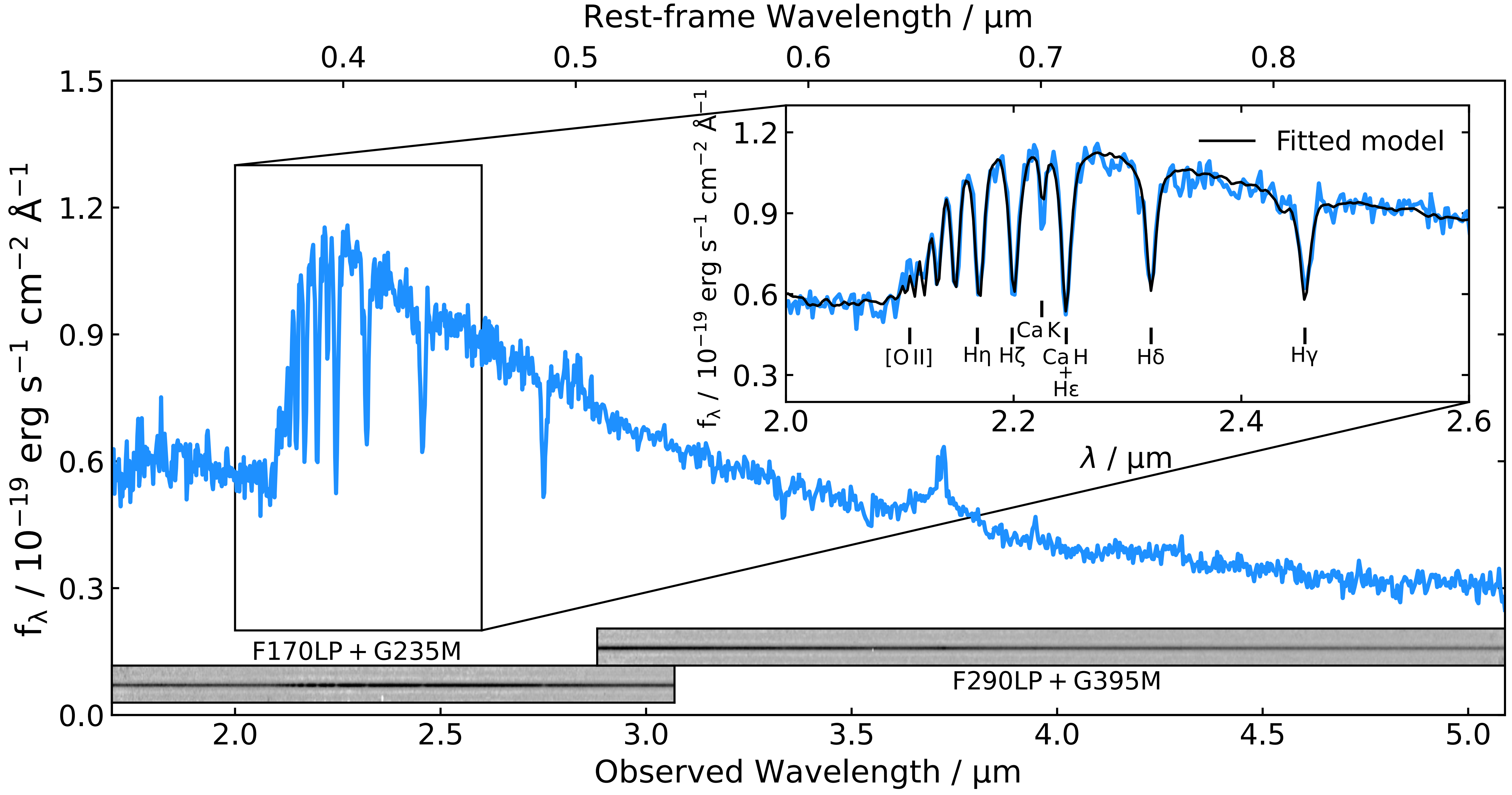
劇的な変化
- 星形成活動
- 形態
- 運動

現在の最遠方銀河
z=11-12, logM*~9
(Arrabal Haro et al. 2023, Bunker et al. 2023)

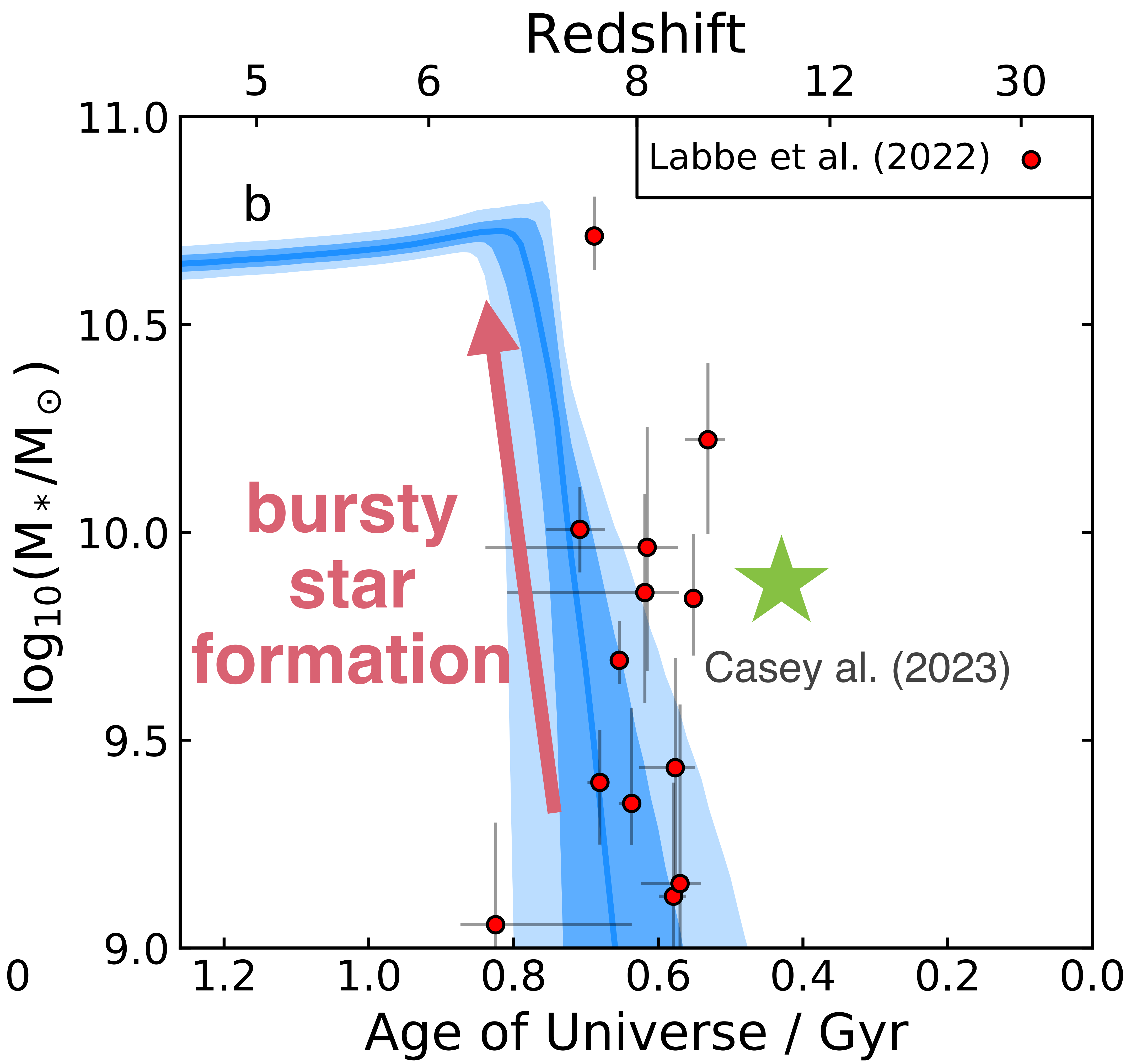
初代銀河の誕生

Behroozi et al. 2019, ZINA DERETSKY/NATIONAL SCIENCE FOUNDATION/WIKIMEDIA COMMONS, Katrina Kenny & University of Adelaide

04 Massive Quiescent Galaxies

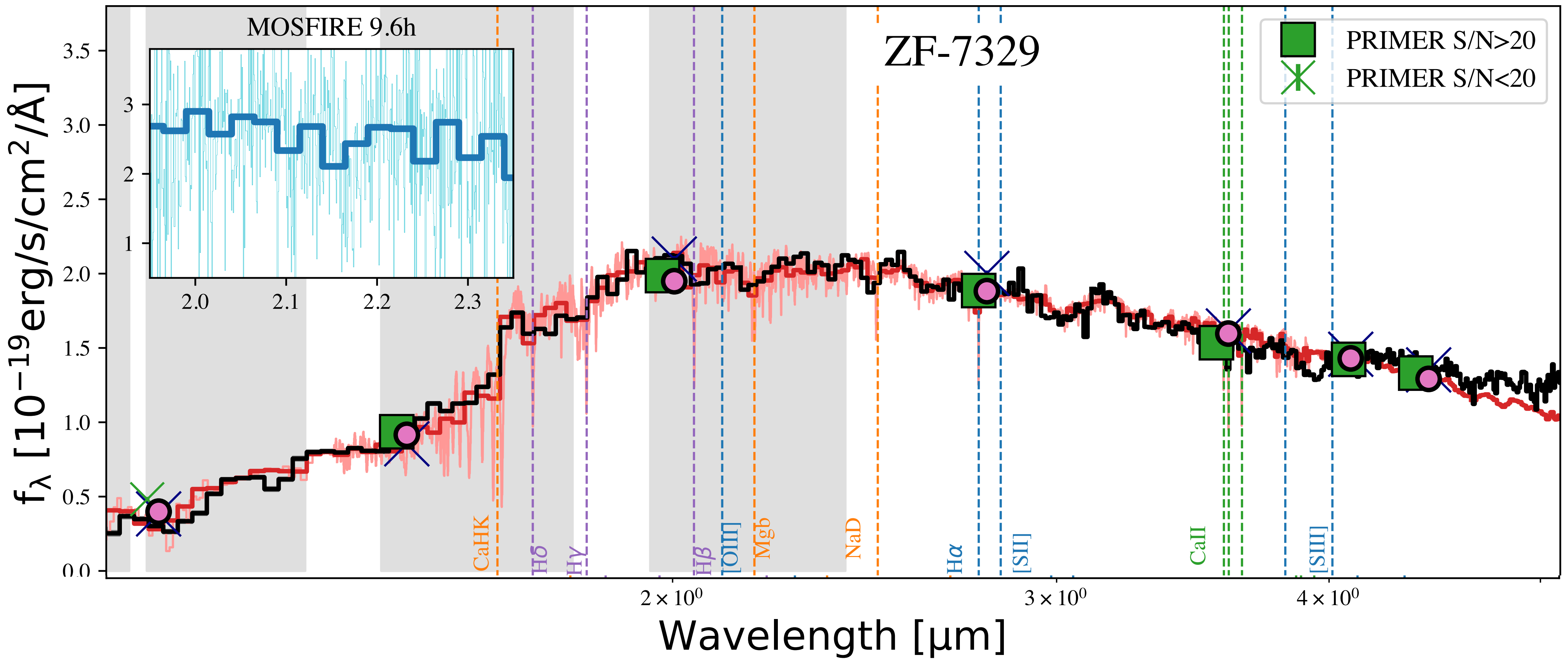


z=4.66, logM*~10.6



Carnall al. 2023

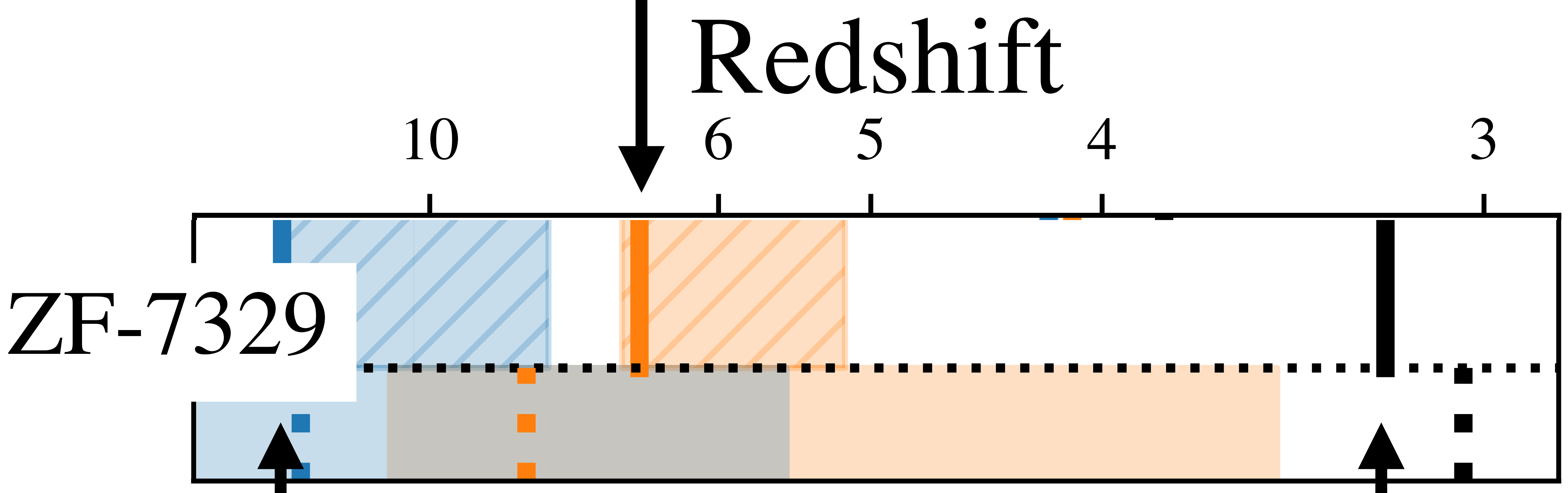
04 Massive Quiescent Galaxies



z=3.21, logM*~11

星形成活動を止めた時期

(z~7)



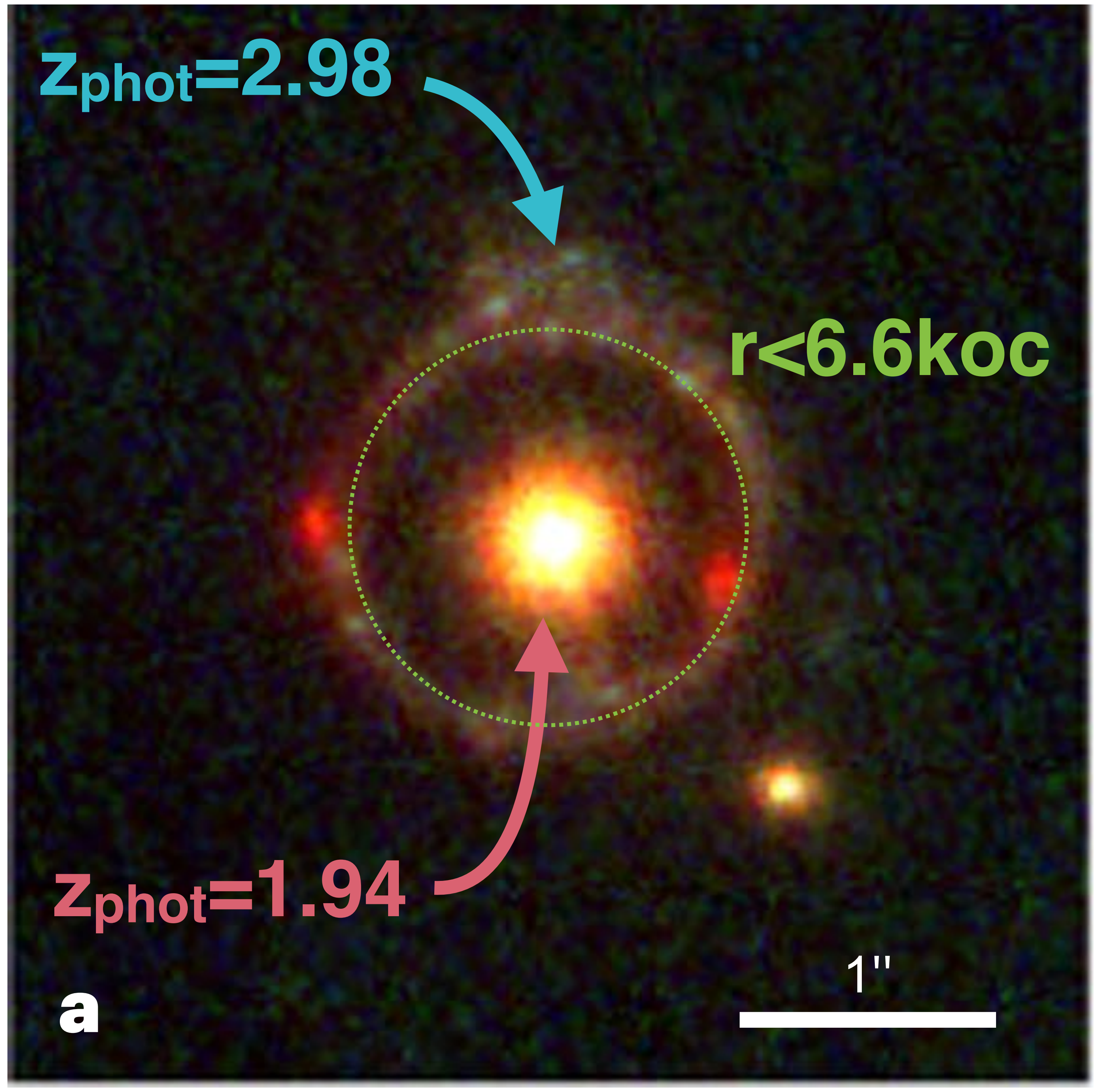
星質量の50%が形成した時期

(z~10, logM*~10.7)

観測した時期

（z=3.21）

04 Massive Quiescent Galaxies



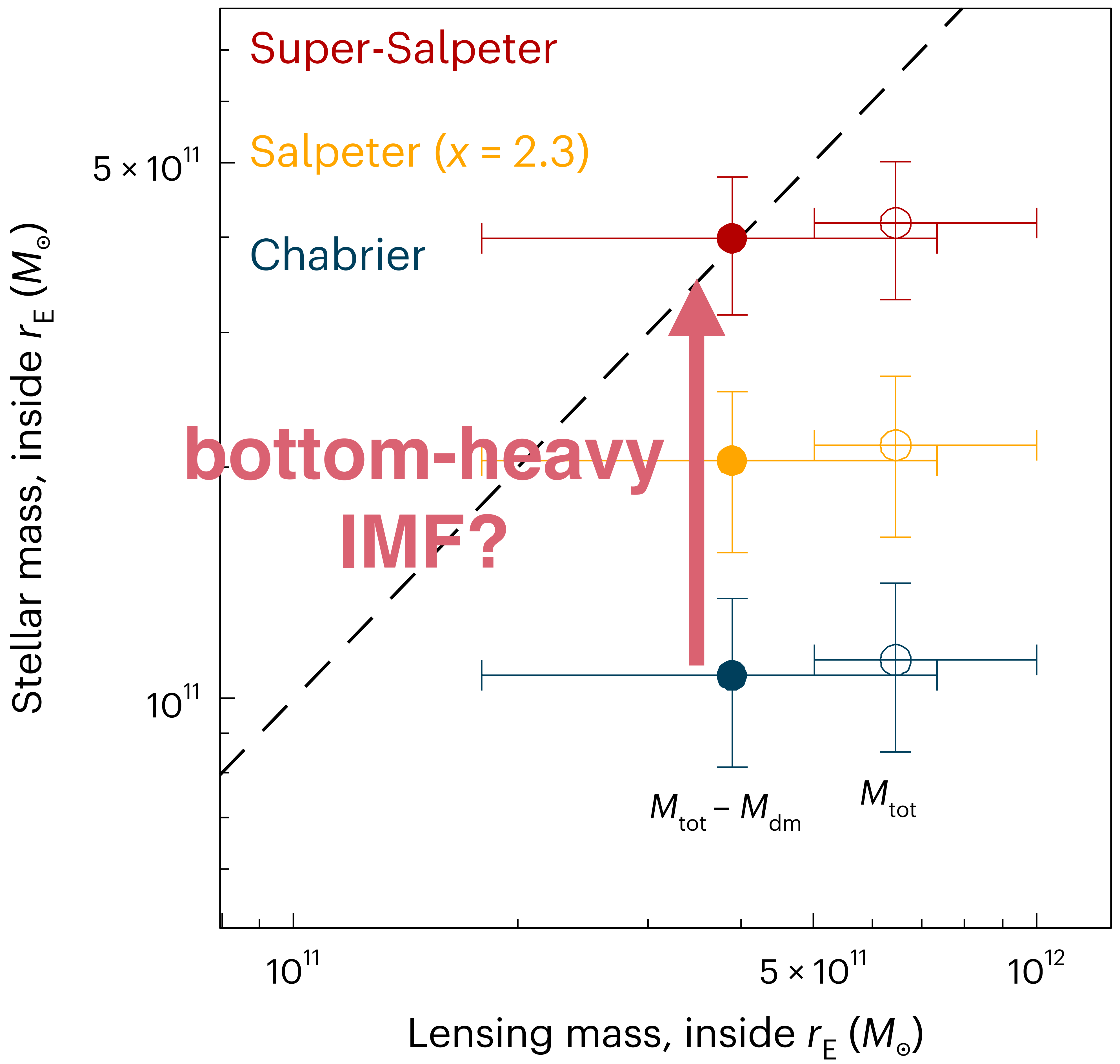
COSMOS-Web data

$$M_{\rm stars} = 1.1^{+0.2}_{-0.3} \times 10^{11} M_\odot$$

- M_{star}-M_{halo} relation
- NFW profile

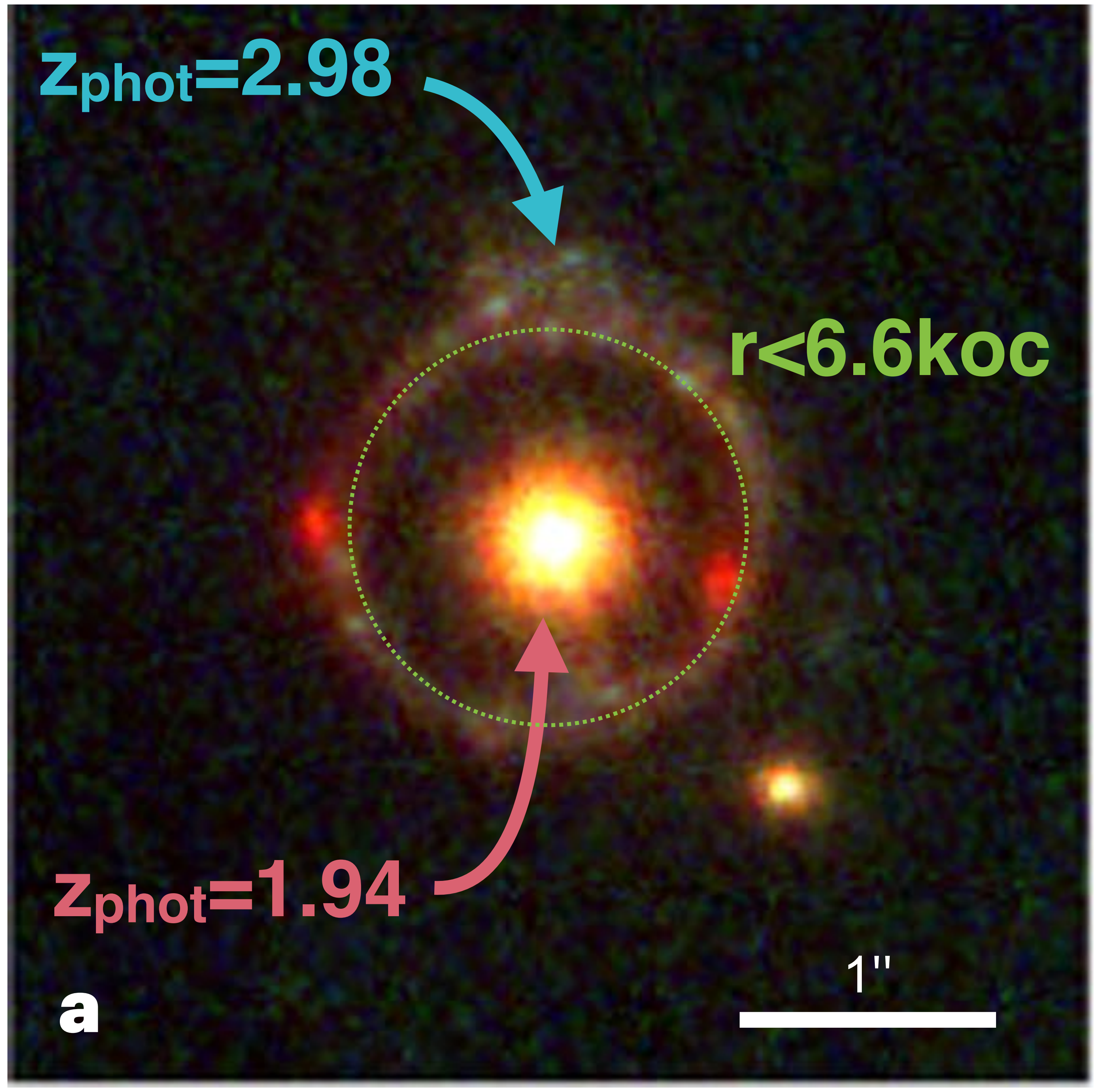
$$M_{\rm dm} = 2.6^{+1.6}_{-0.7} \times 10^{11} M_\odot$$

$$M_{\rm lens} = 6.5^{+3.7}_{-1.5} \times 10^{11} M_\odot$$

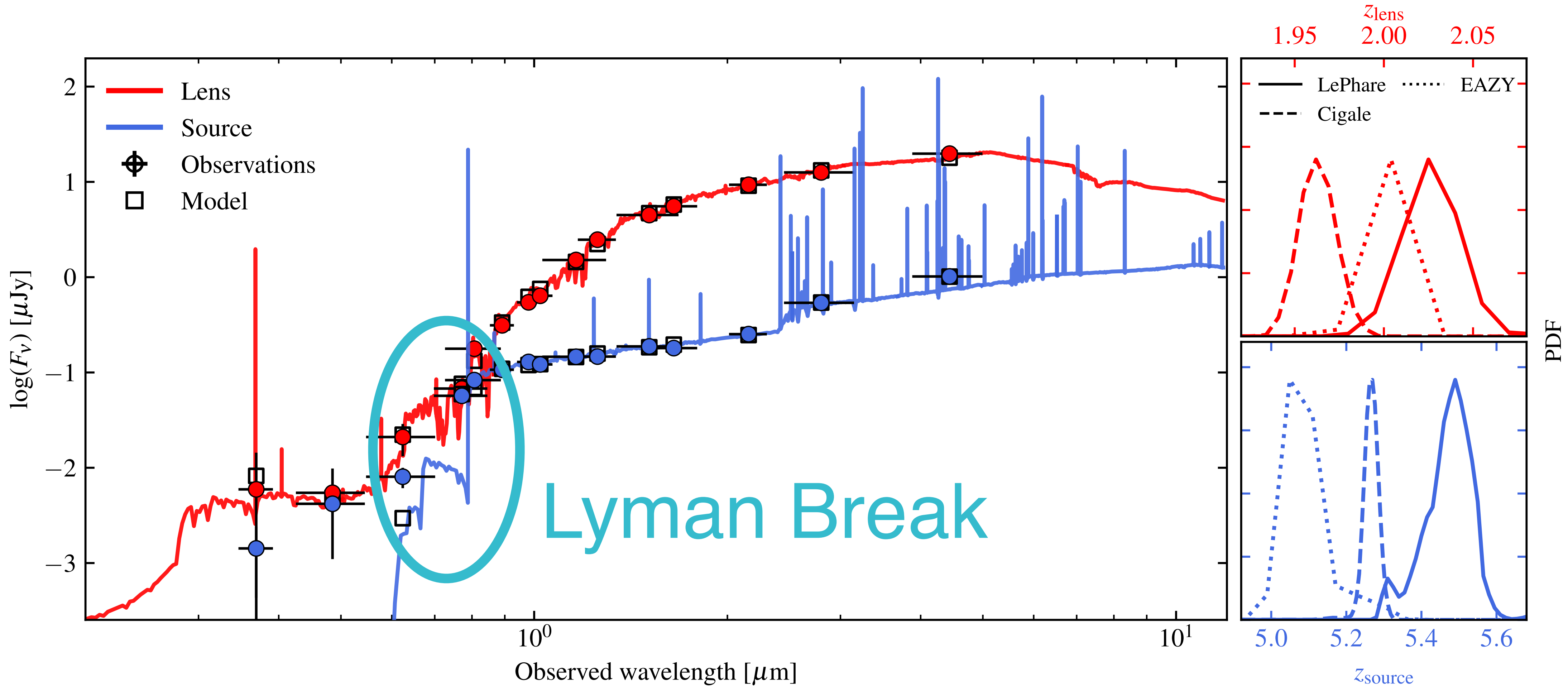


van Dokkum et al. 2023, Nature Astronomy

04 Massive Quiescent Galaxies



COSMOS-Web data



If the background source is at **z~5**, M_{lens}~3.7×10^11 M_{sun}

$$M_{\rm stars} = 1.1^{+0.2}_{-0.3} \times 10^{11}\, M_\odot$$

- M_{star}-M_{halo} relation
- NFW profile

$$M_{\rm dm} = 2.6^{+1.6}_{-0.7} \times 10^{11}\, M_\odot$$

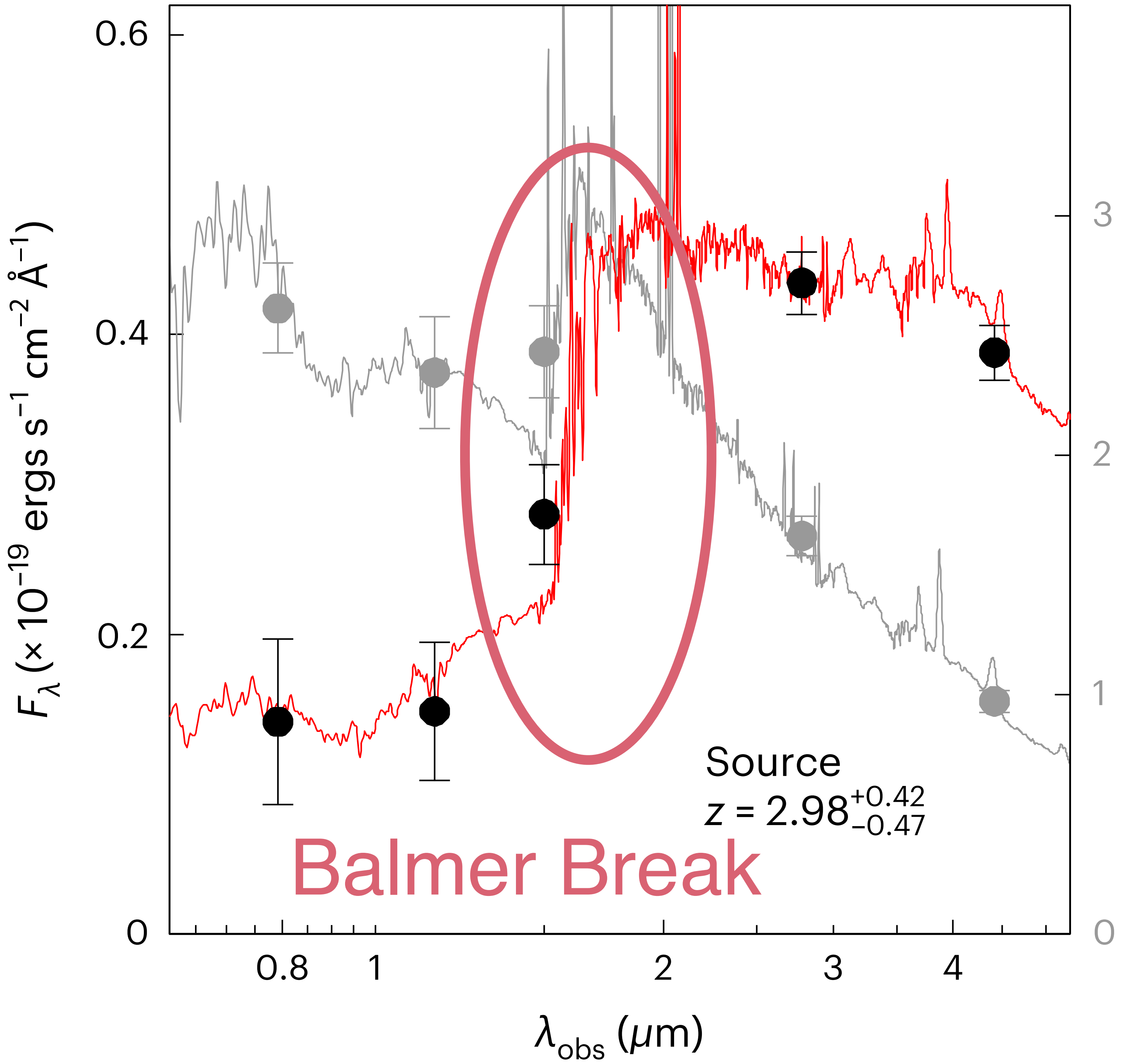
$$M_{\rm lens} = 6.5^{+3.7}_{-1.5} \times 10^{11}\, M_\odot$$

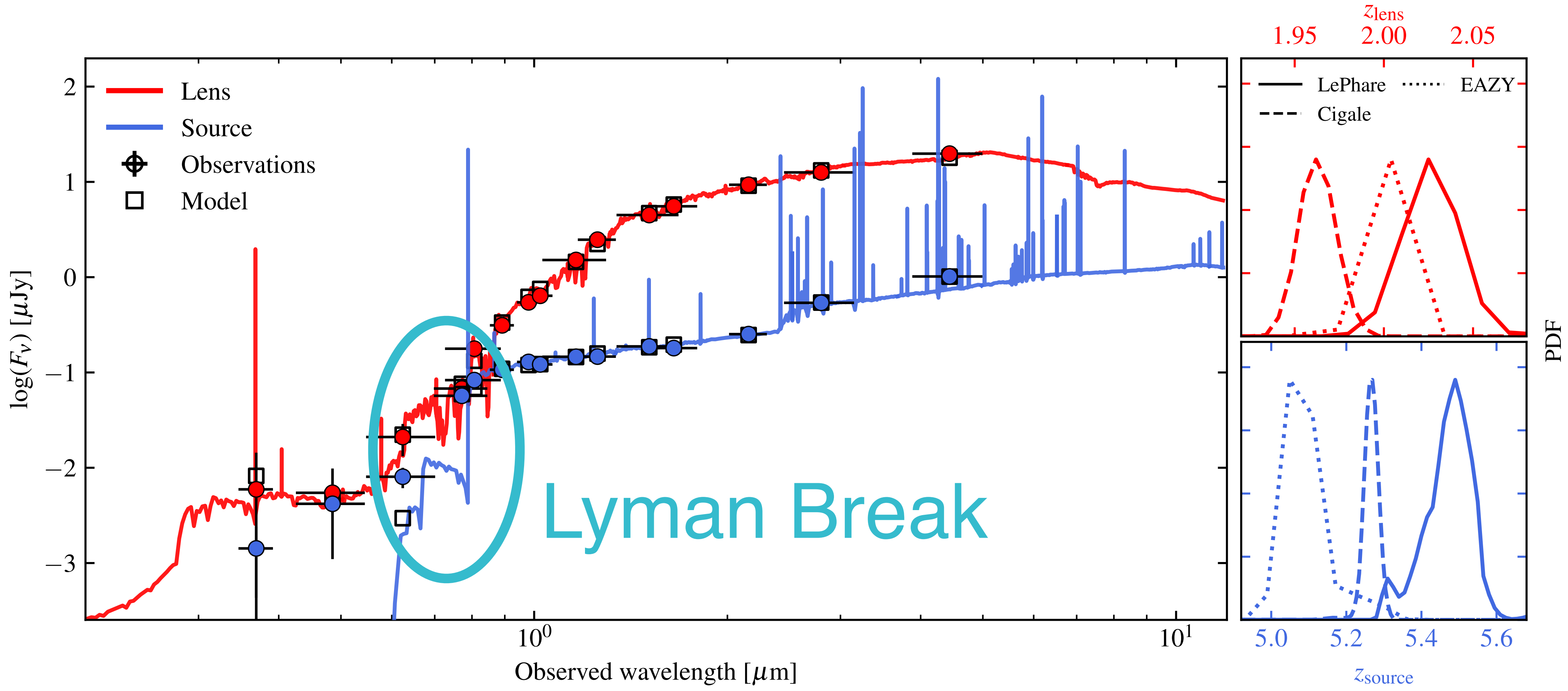
no need to change the IMF or the DM halo profile

van Dokkum et al. 2023, Nature Astronomy

Mercier et al. 2023, submitted (COSMOS-Web team)

04 Massive Quiescent Galaxies





If the background source is at **z~5**,

$M_{lens} \sim 3.7 \times 10^{11} M_{sun}$

no need to change the IMF or the DM halo profile

$$M_{stars} = 1.1^{+0.2}_{-0.3} \times 10^{11} M_\odot$$

- M_{star}-M_{halo} relation
- NFW profile

$$M_{dm} = 2.6^{+1.6}_{-0.7} \times 10^{11} M_\odot$$

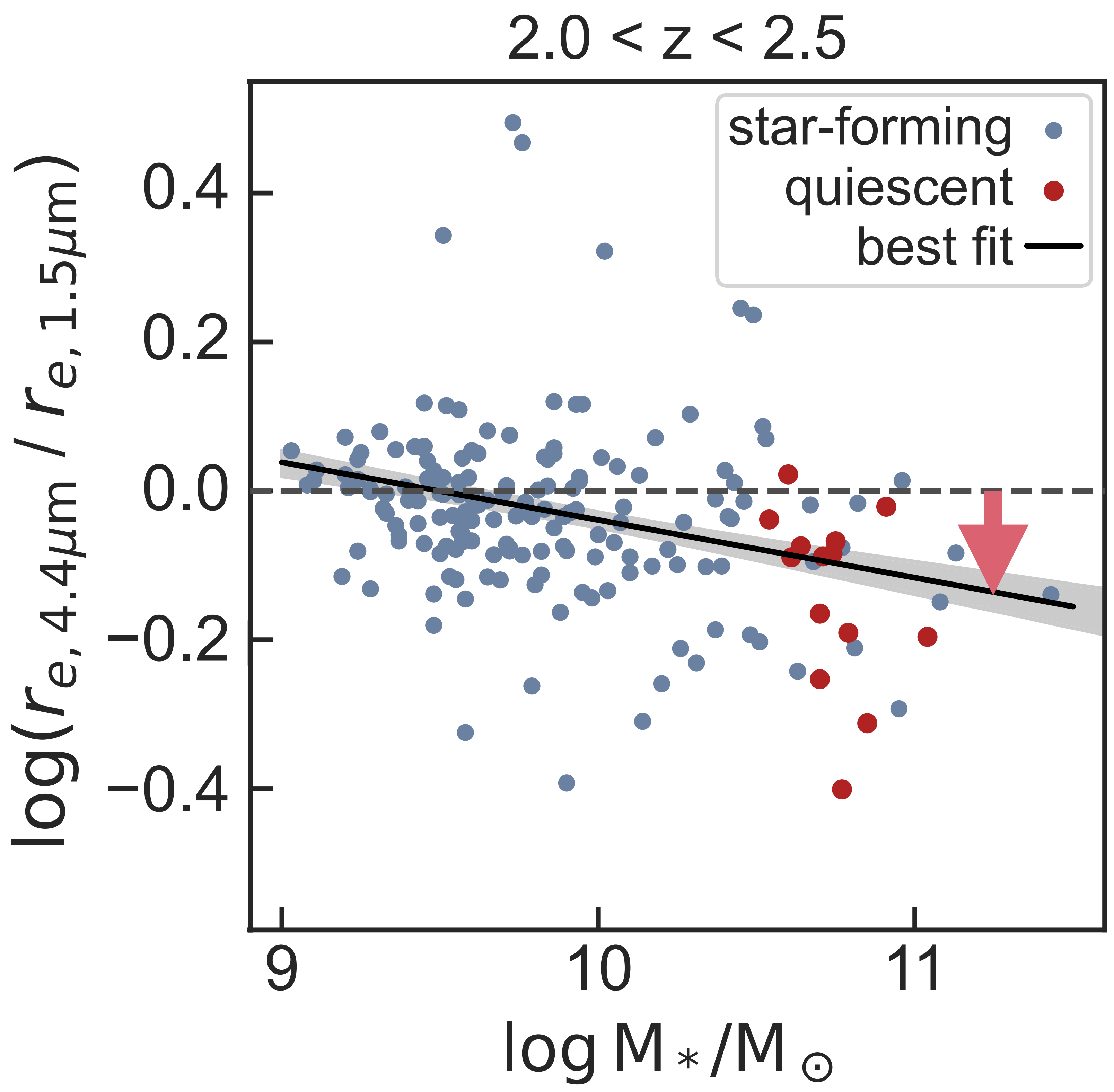
$$M_{lens} = 6.5^{+3.7}_{-1.5} \times 10^{11} M_\odot$$

van Dokkum et al. 2023, Nature Astronomy

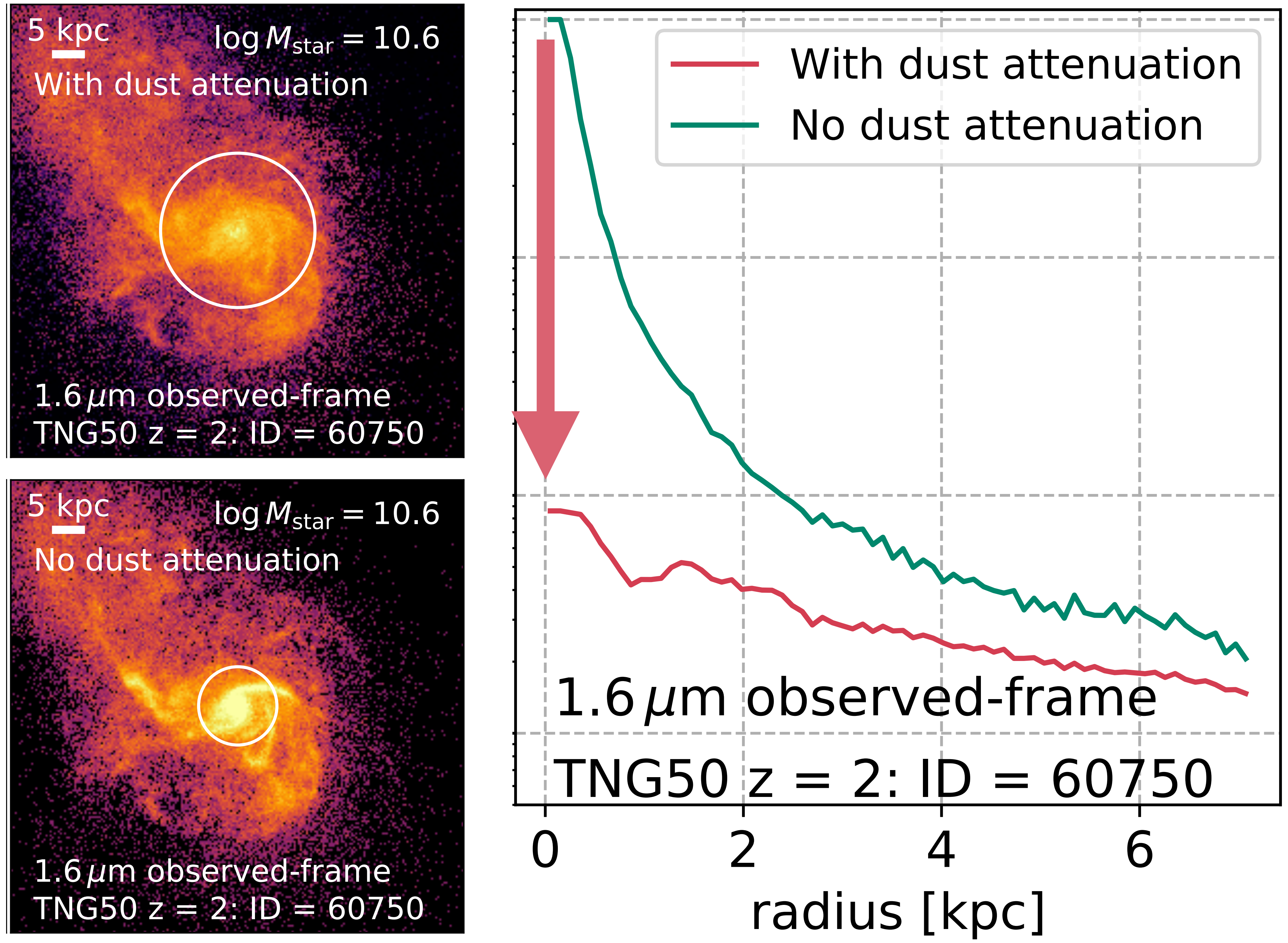
Mercier et al. 2023, submitted (COSMOS-Web team)

04 Massive Star-forming Galaxies

observations



simulations



$r_{e,1.5\mu m}$: HST size at the rest-0.5 μm

$r_{e,4.4\mu m}$: JWST size at the rest-1.5 μm

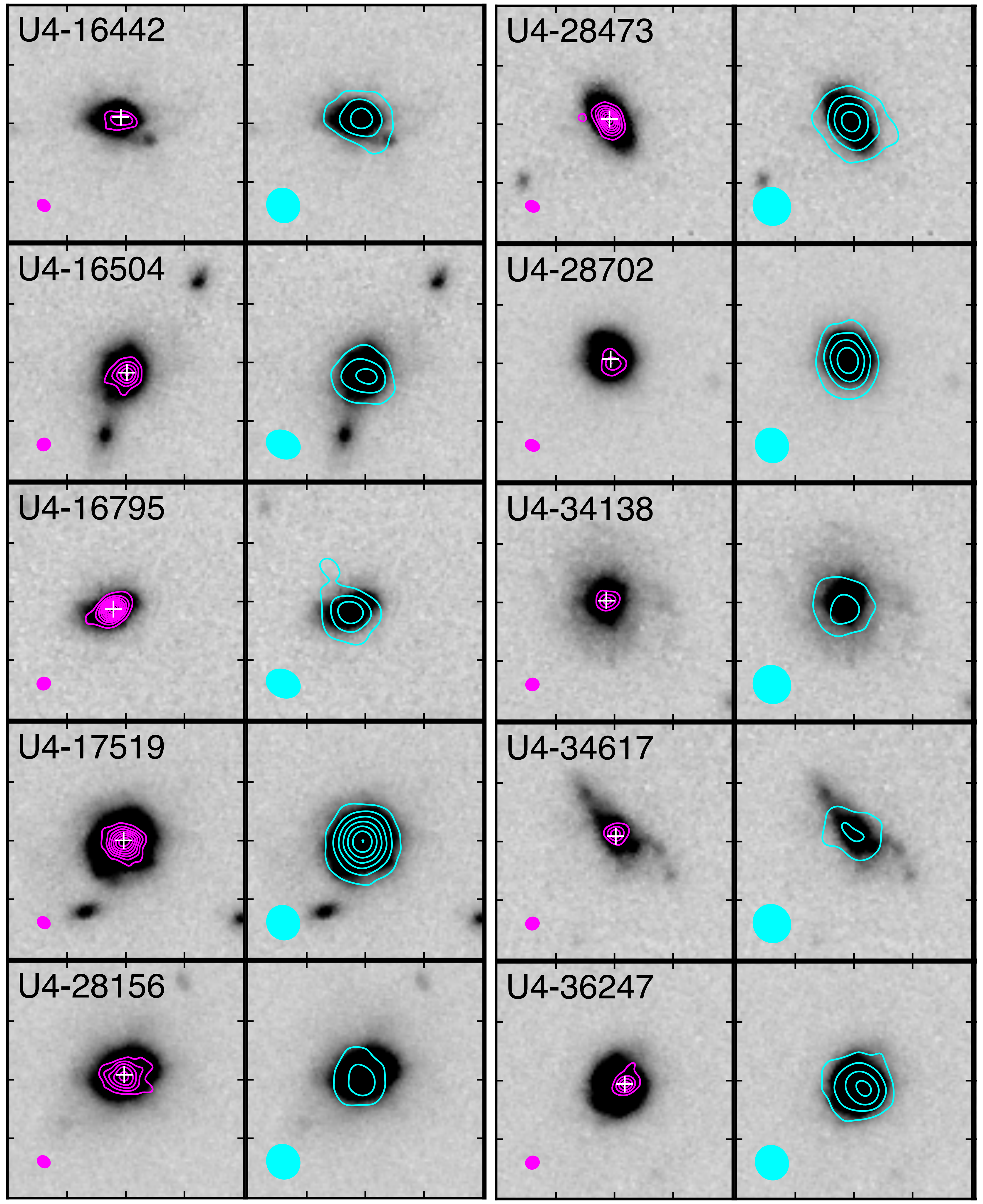
HST sizes are overestimated due to radial gradients in stellar age, metal, dust attenuation

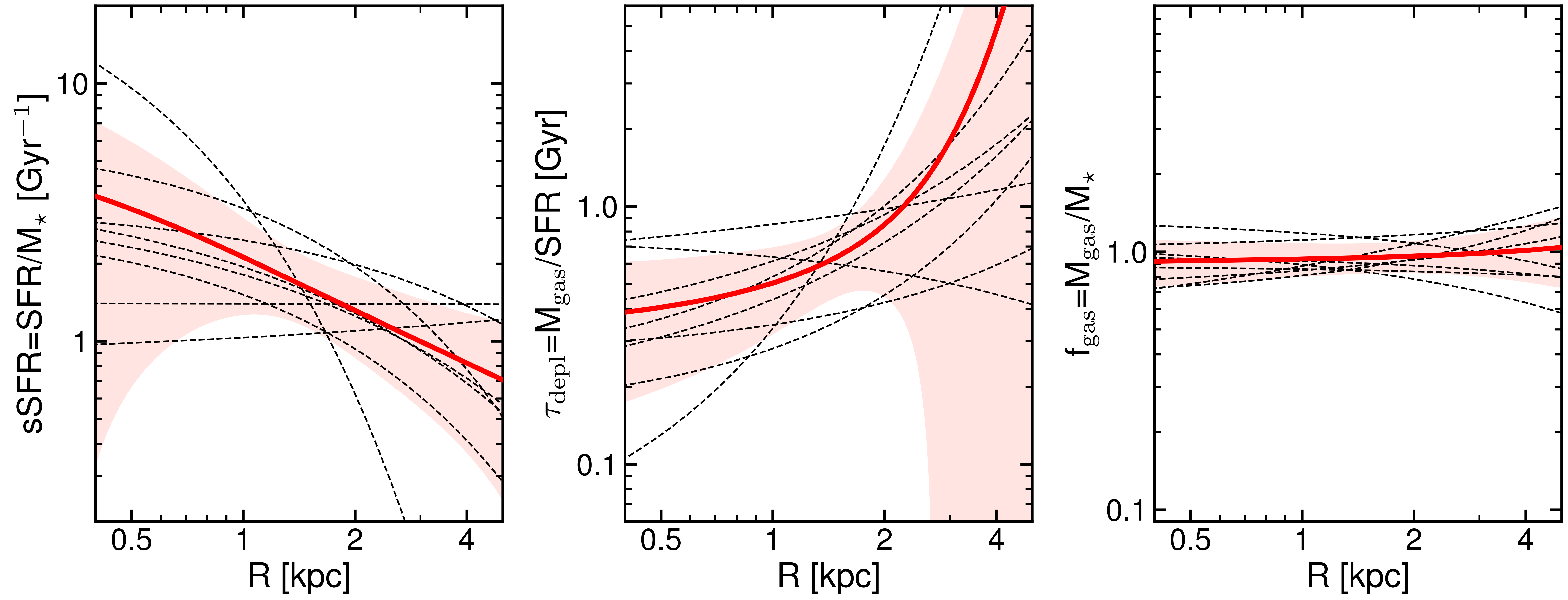
Suess et al. 2022

Popping et al. 2022

04 Massive Star-forming Galaxies

04 Massive Star-forming Galaxies





Tadaki et al. 2023

Summary

01 [OIII] 88 μm Line Emission

02 Optically Dark Galaxies

03 Dust Obscured AGN

03 Massive Quiescent Galaxies