Dust Properties and IR Observations
(at cosmic noon)

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Dall-E

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Comunidad de Madrid
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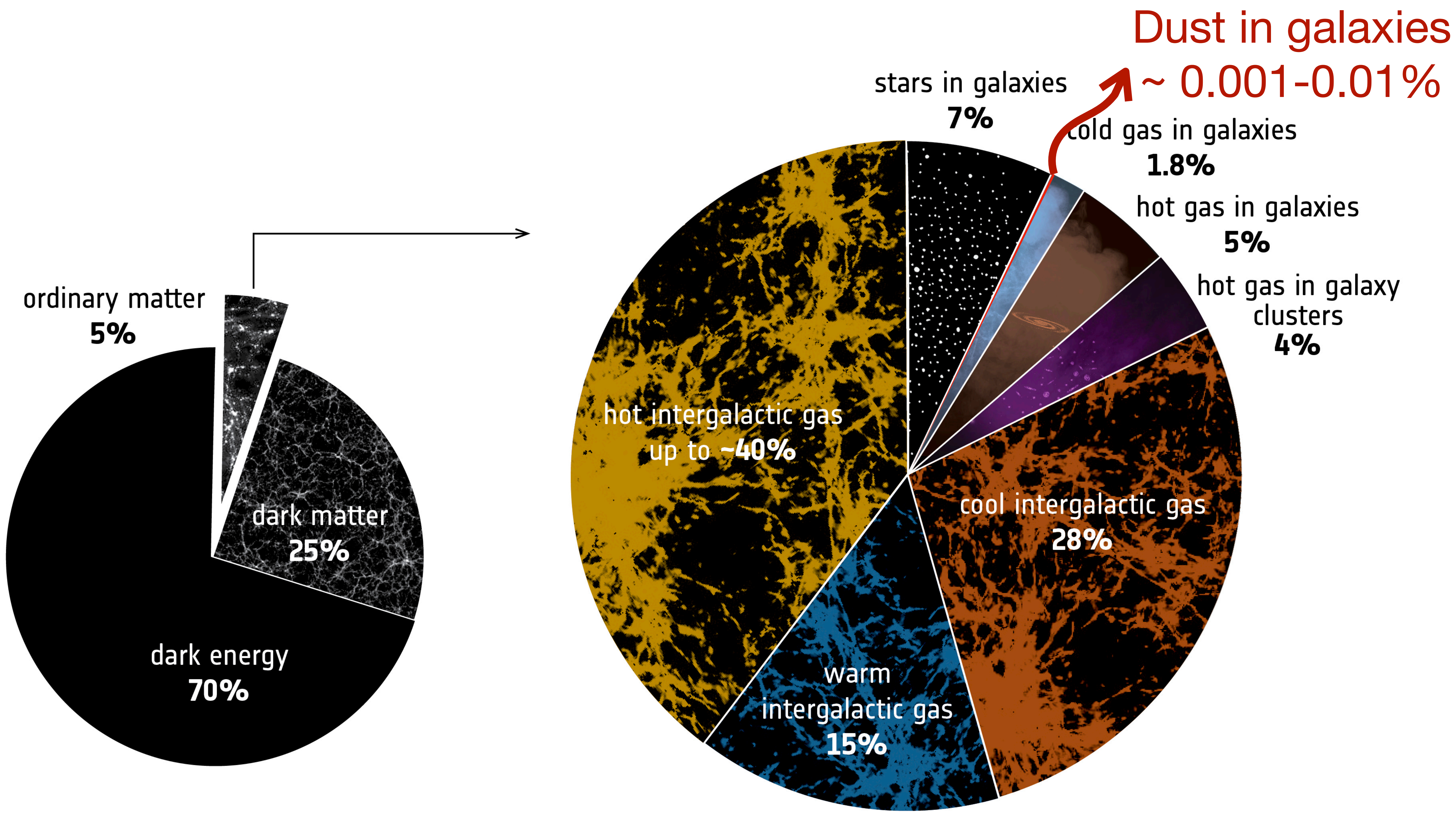
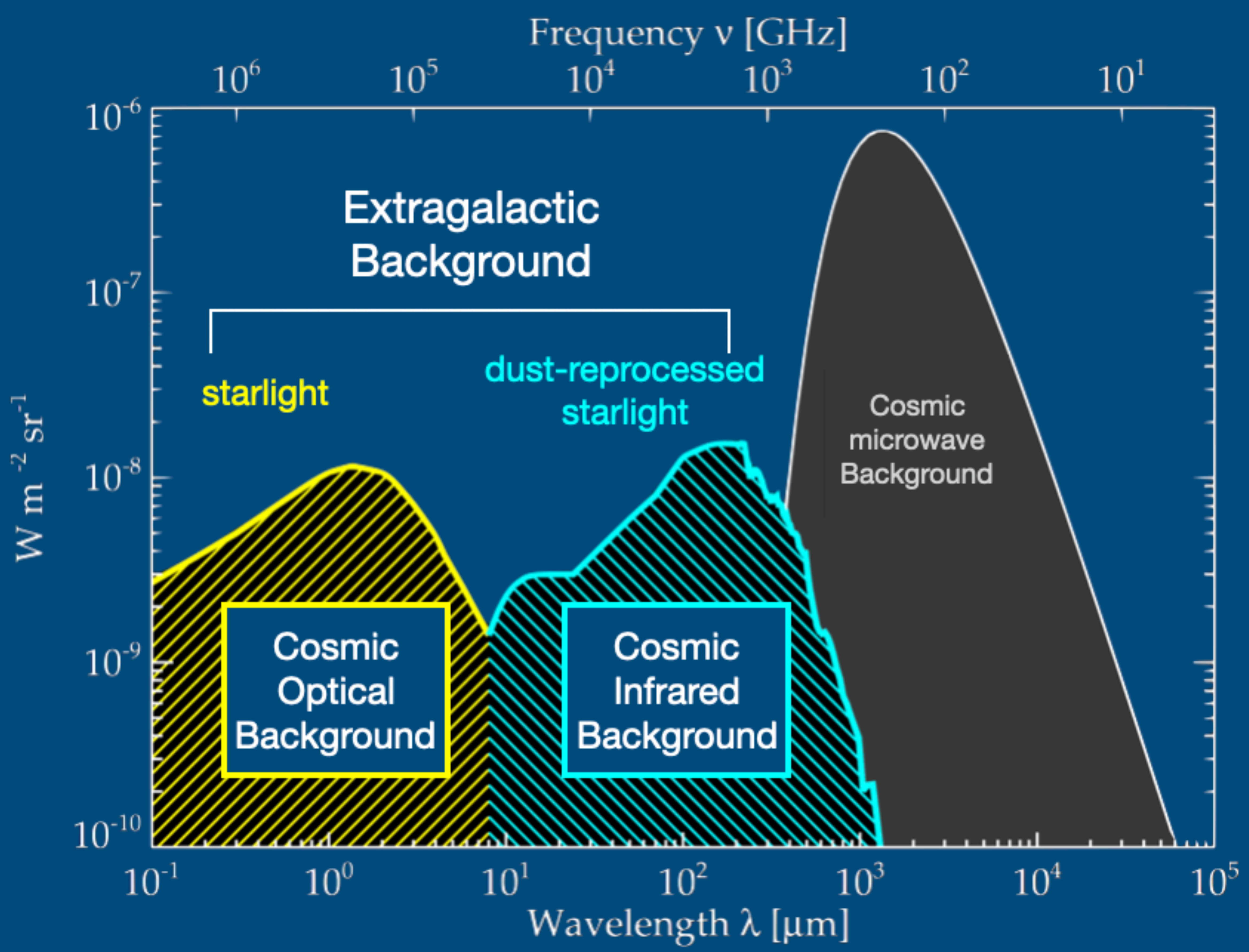
DUST IS NEGLIGIBLE BY MASS, BUT…



Credit: ESA, Nicastro+2018 Nature

CIB constitutes half of the Extragalactic Background

- *half* of the electromagnetic content of the Universe from galaxies processes

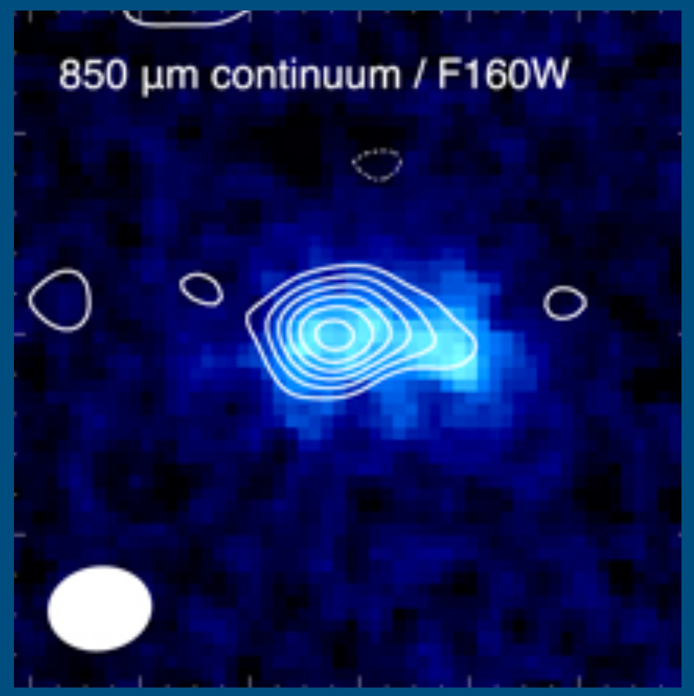


Dole et al. 2006

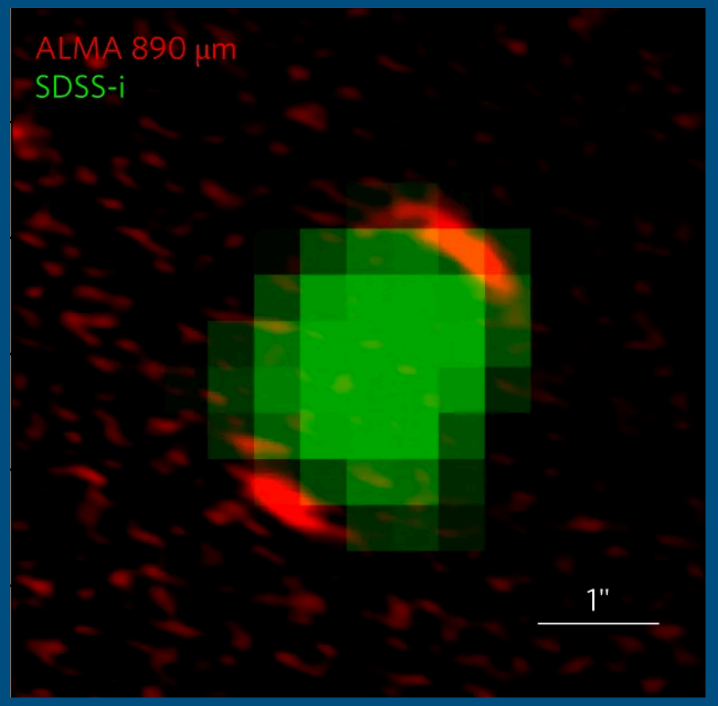
OBSERVED OUT TO VERY HIGH REDSHIFTS

in emission

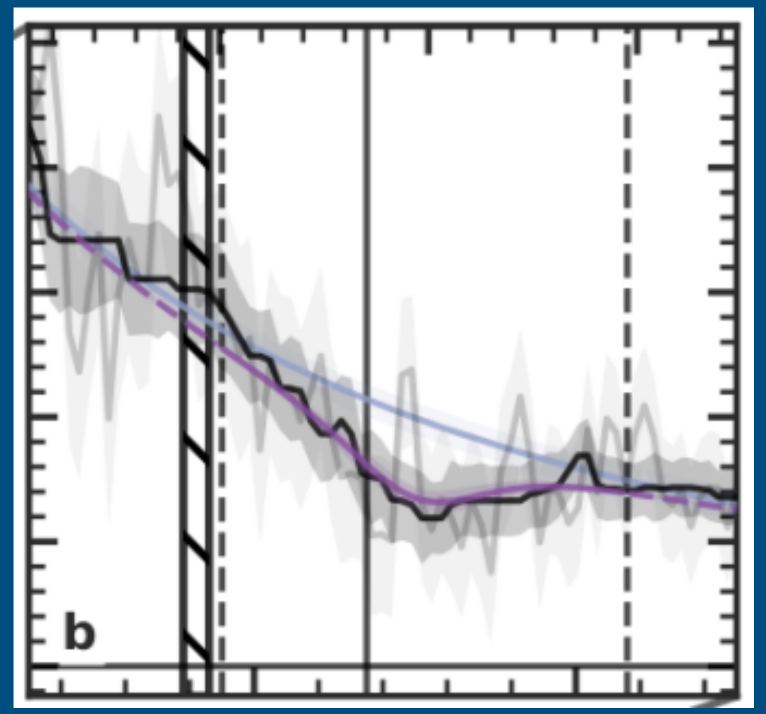
and absorption



z=8.31
Tamura+2019



z=6.02
Zavala+2018



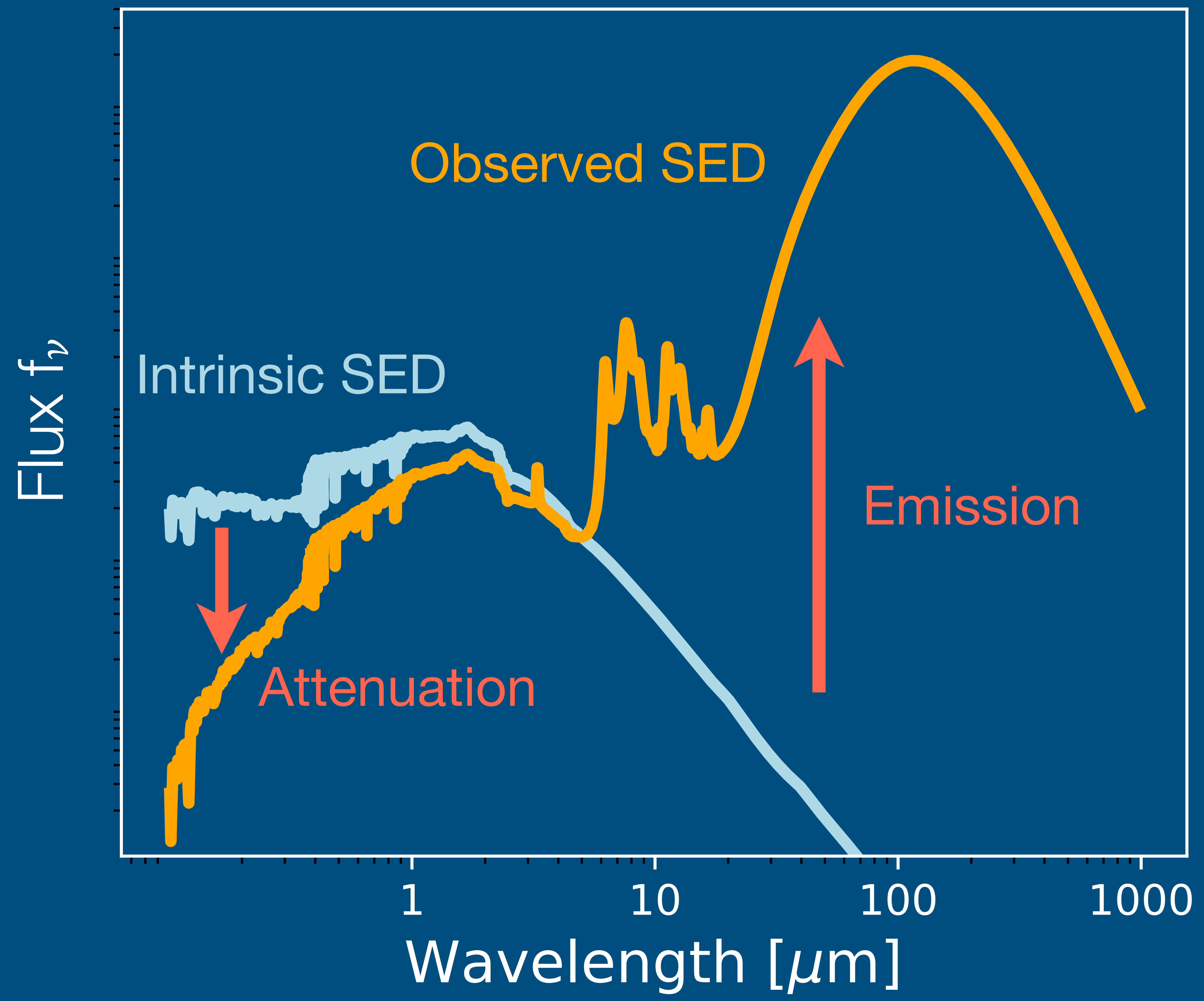
z=6.71
Witstok, Shivaei+2023

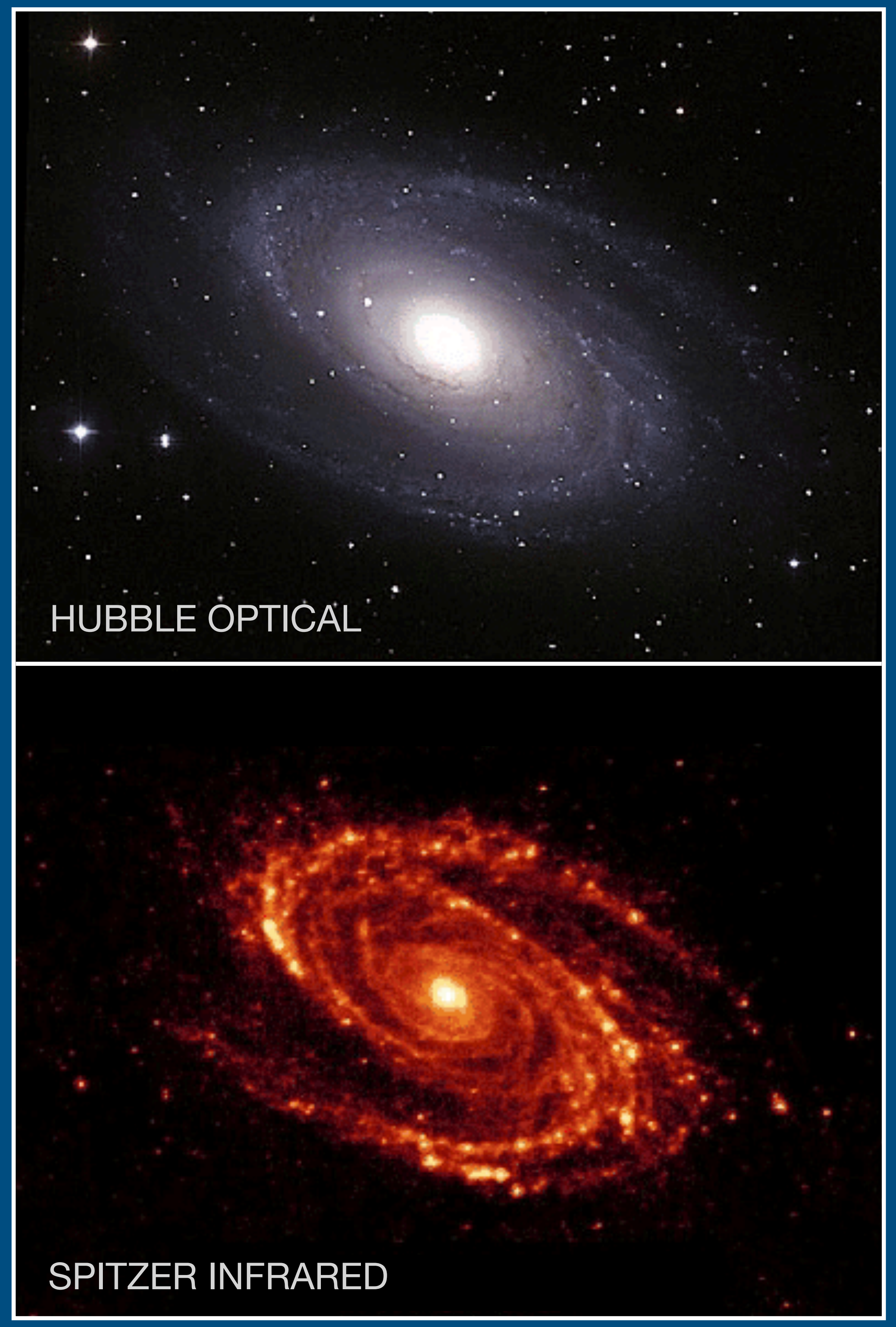
KEY ROLES IN ISM PHYSICS AND CHEMISTRY

- Star formation
- Molecule formation (e.g., H_2)
- ISM cooling and heating
- Gas dynamics

Image credit: NASA, ESA, and S. Beckwith (STScI) and the HUDF Team

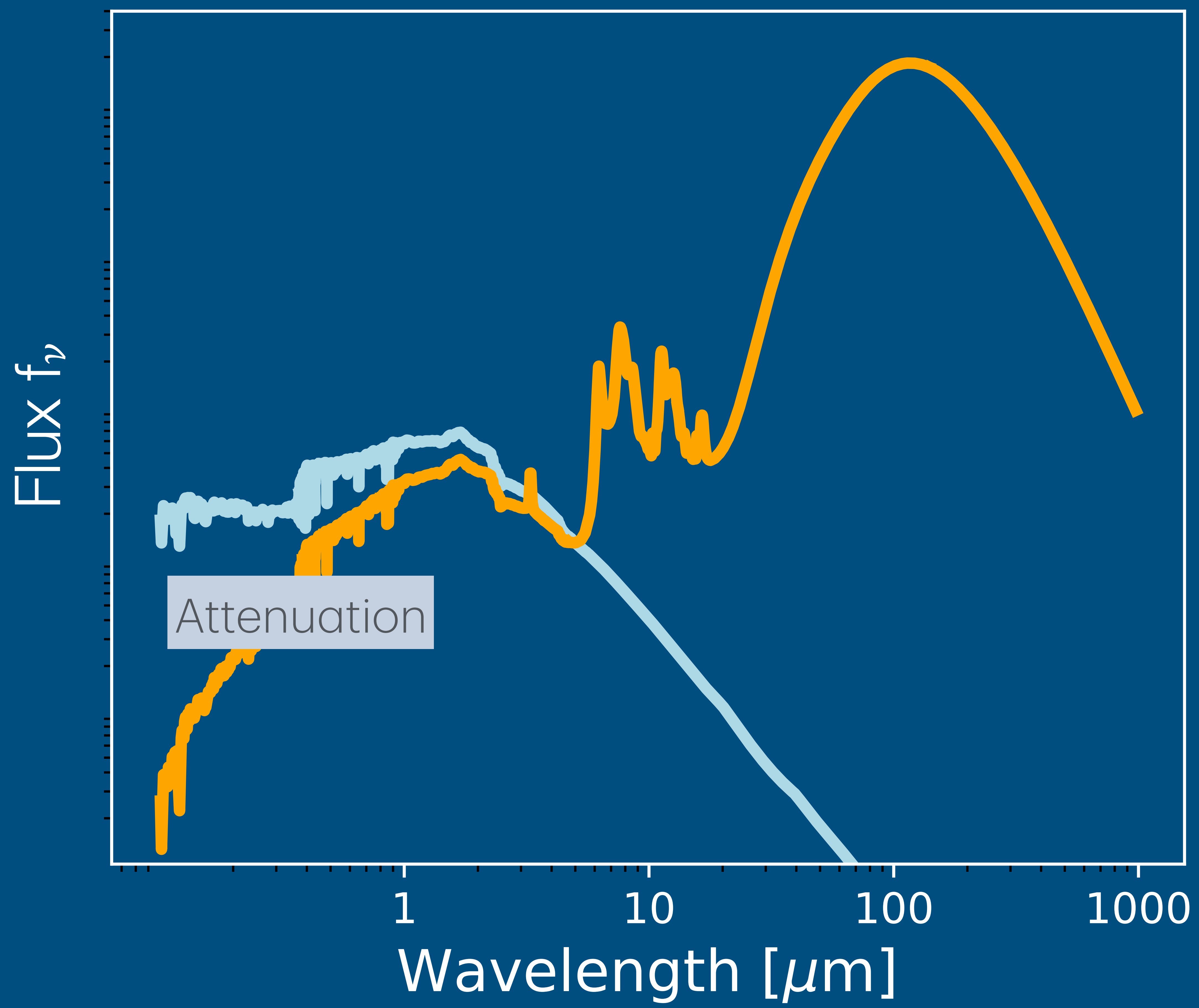
Changes the view of galaxies from UV to sub-mm





M81. Credits:NASA/JPL/ESA

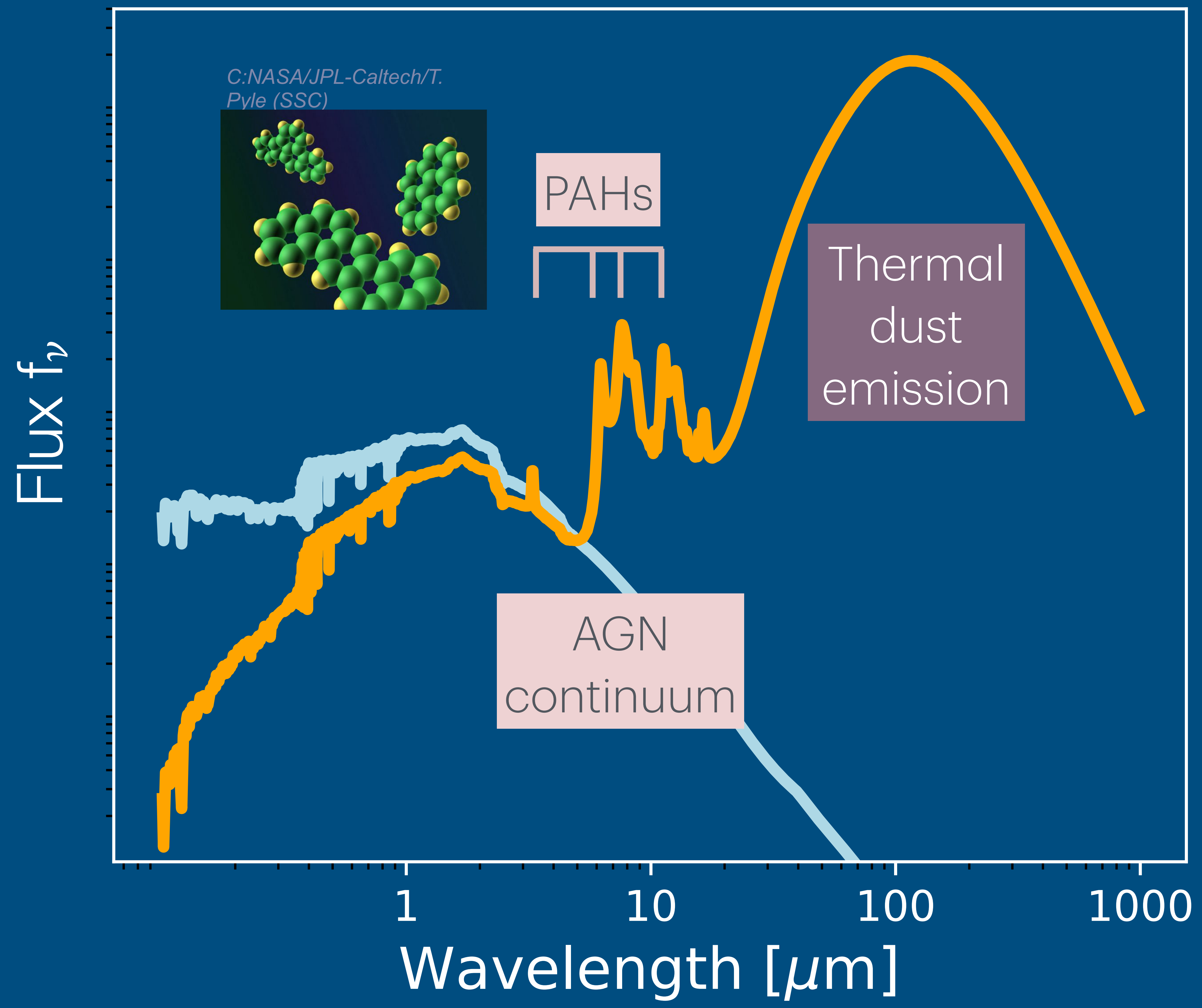
How to observe dust? - attenuation



Stellar attenuation (**UV slope, stellar dust curve, UV bump**)

Nebular attenuation (**Balmer line ratios**)

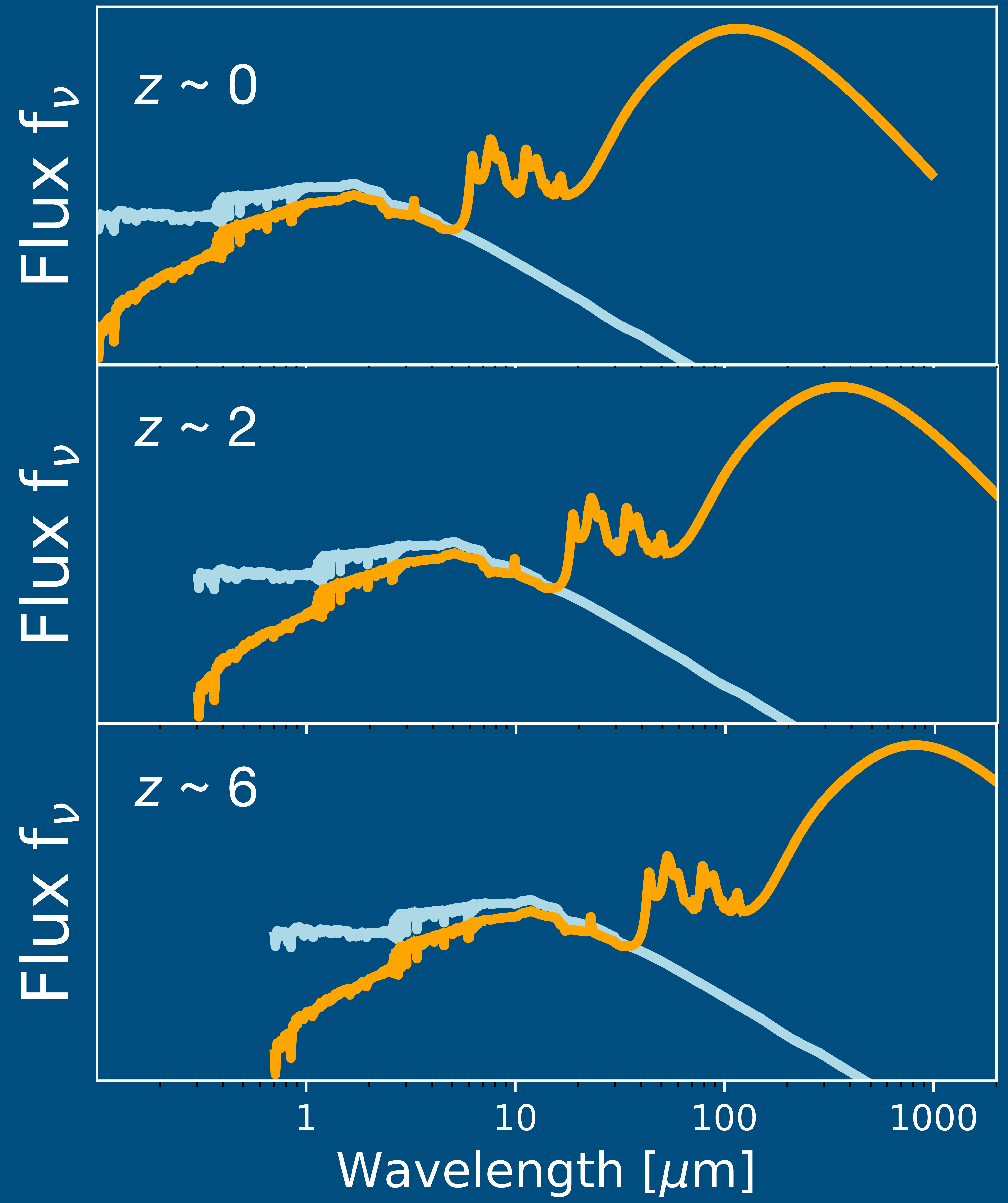
How to observe dust? - emission



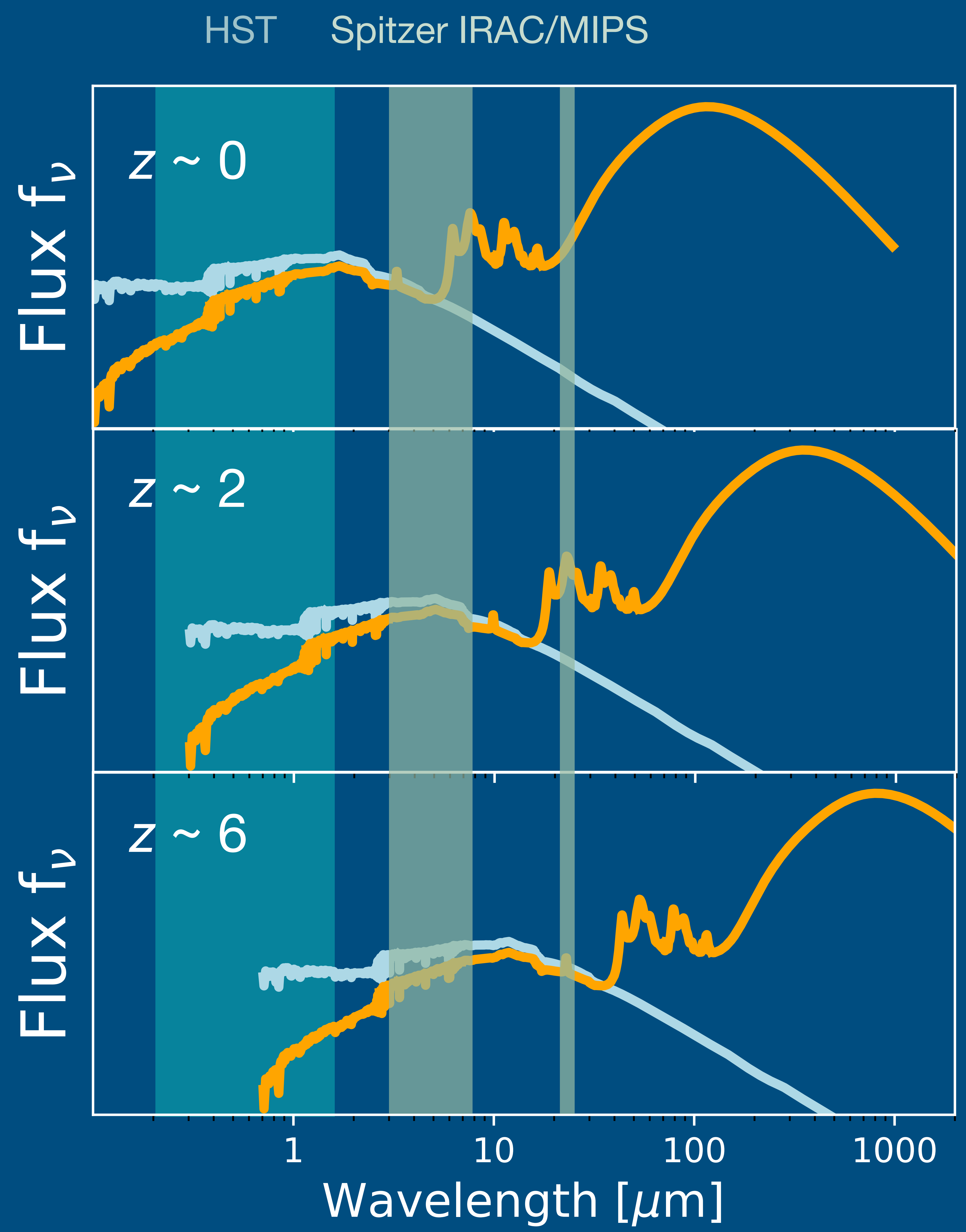
Warm dust: **mid-IR**
AGN emission, PAH grains (PAH fraction, PAH ratios, silicate absorption)

Cold dust: **larger grain, most of the dust mass (dust mass, temperature, emissivity slope)**

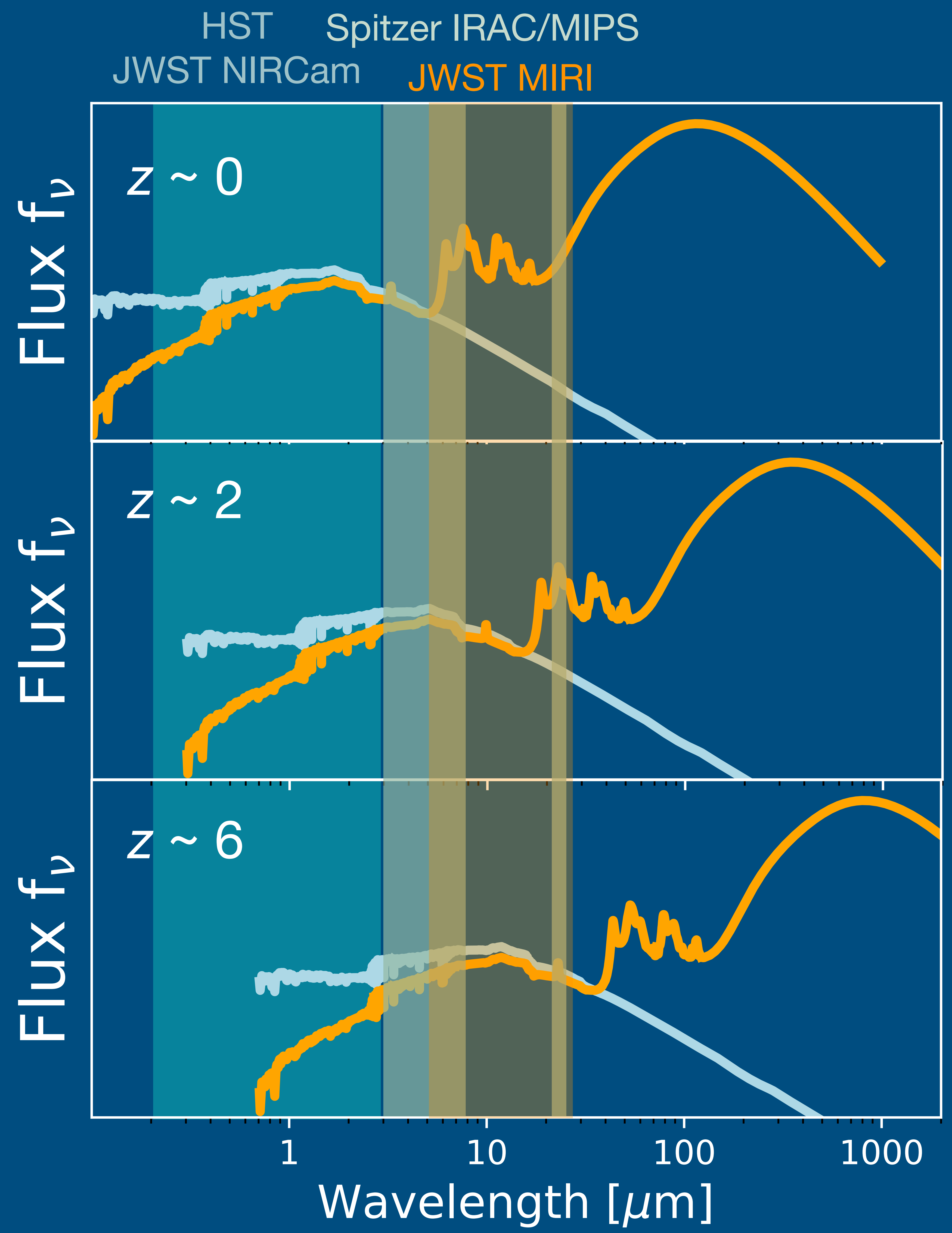
From local to high-z



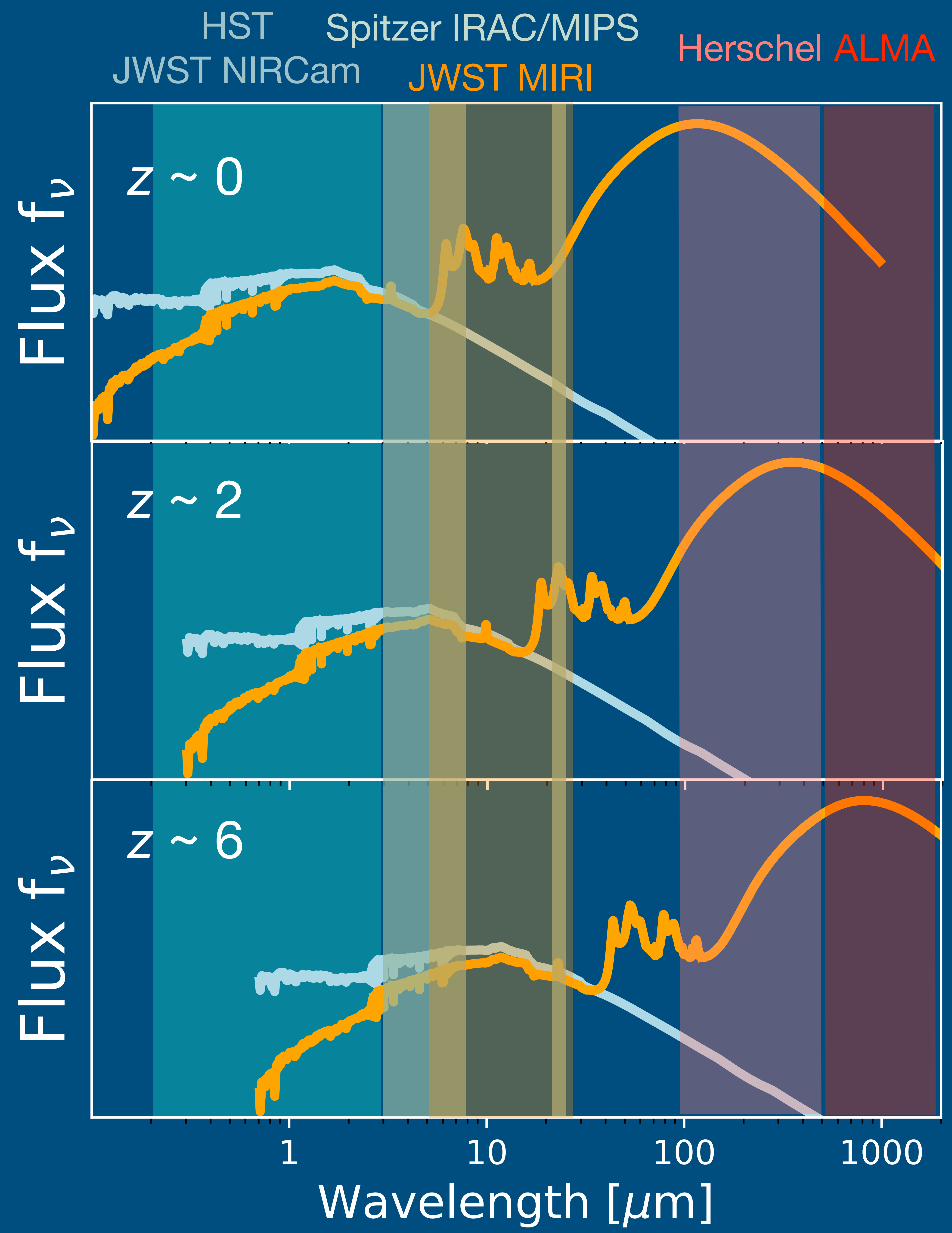
From local to high-z Facilities: Hubble and Spitzer precursors of JWST



From local to high-z
Facilities: JWST

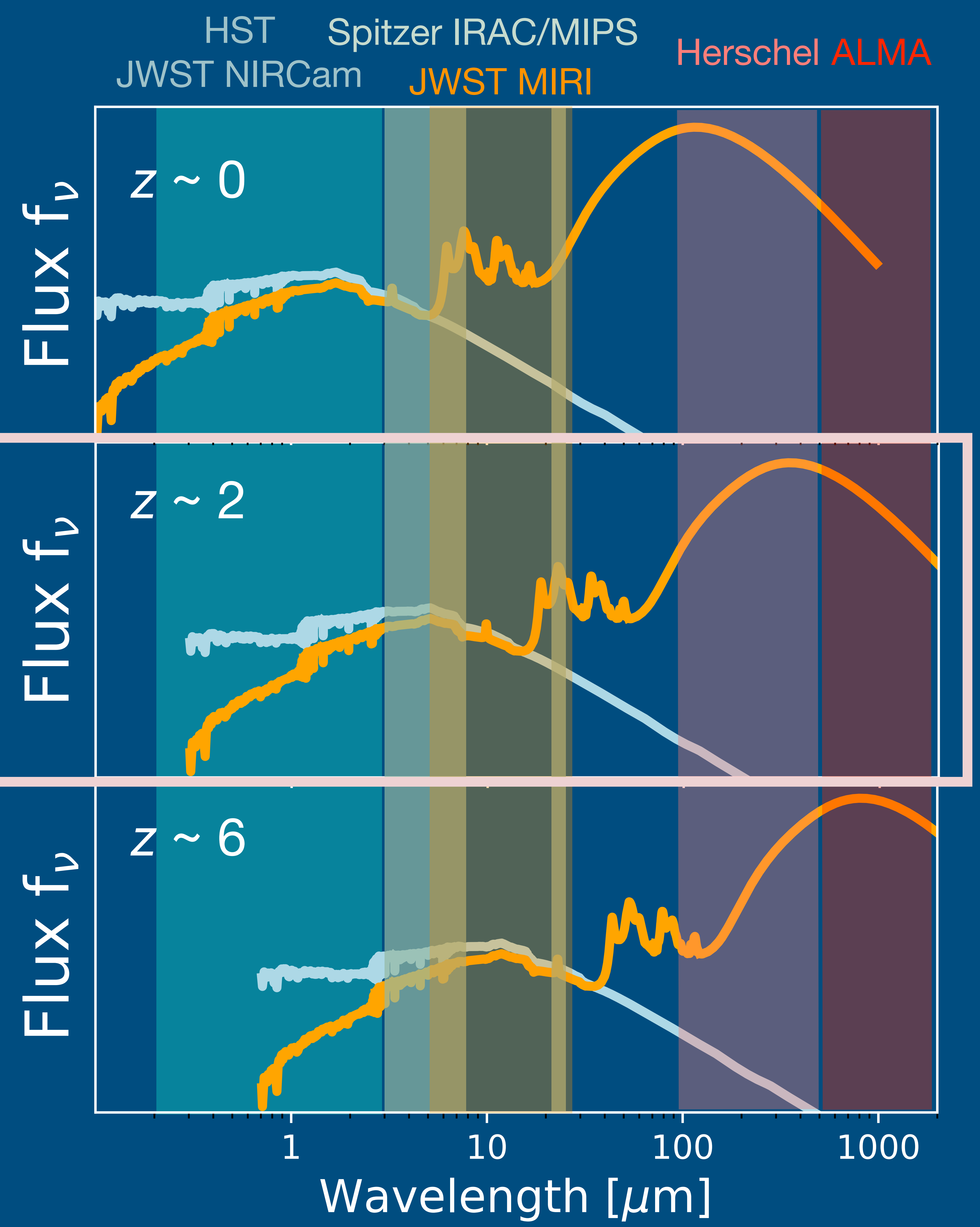


From local to high-z
Facilities: Herschel and ALMA



Cosmic Noon

New redshift frontier for infrared studies and dust physics



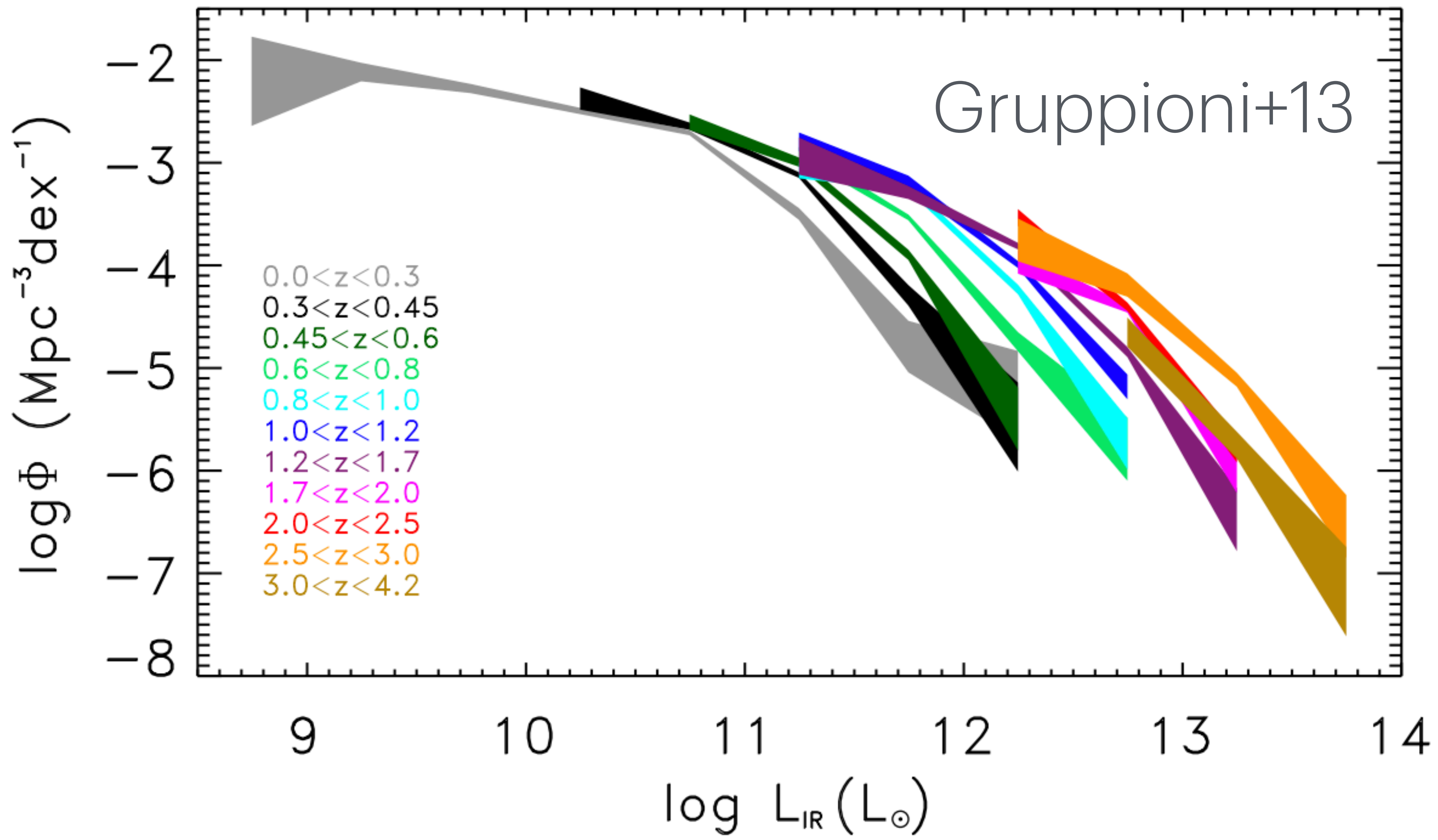
Goals of the meeting:

- a reflection on the **infrared science**,
- but also on the **infrared facilities that we have used in the past decades**,
- and even more importantly that we will use in the next decade, including of course **PRIMA**.

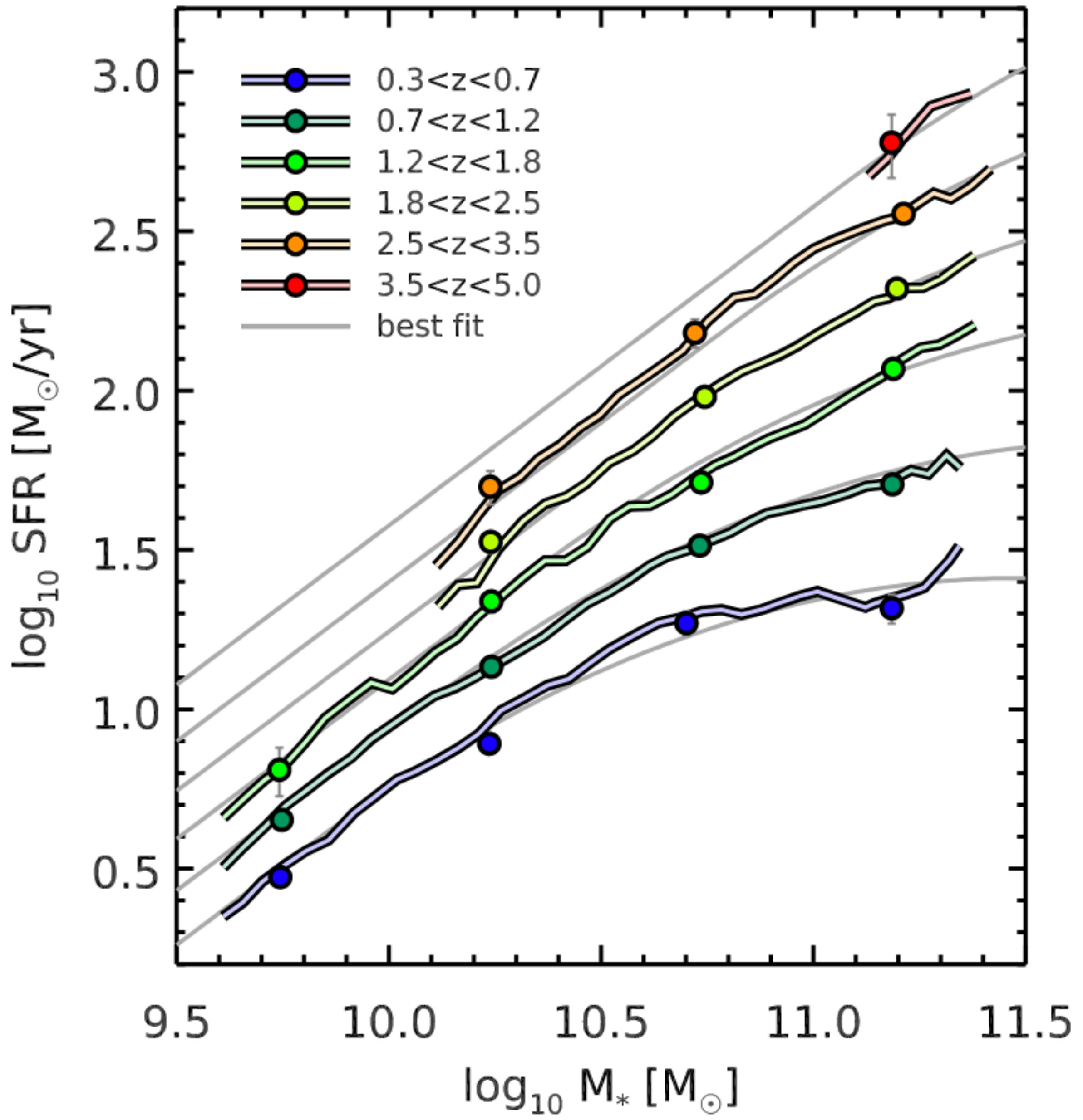
Era of Spitzer and Herschel

Revealing the highly-obscured Universe

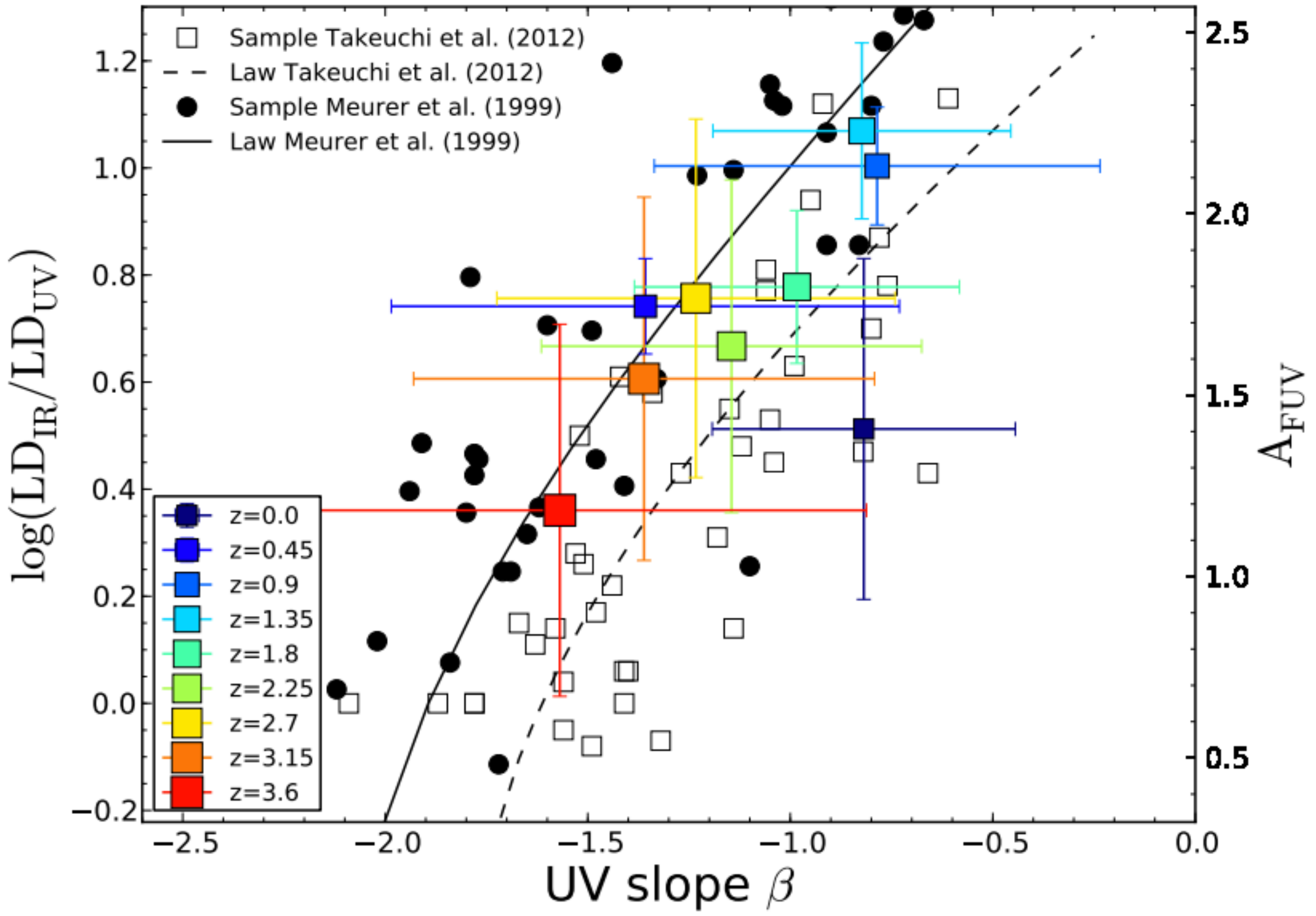
- Obscured star formation and IR emission



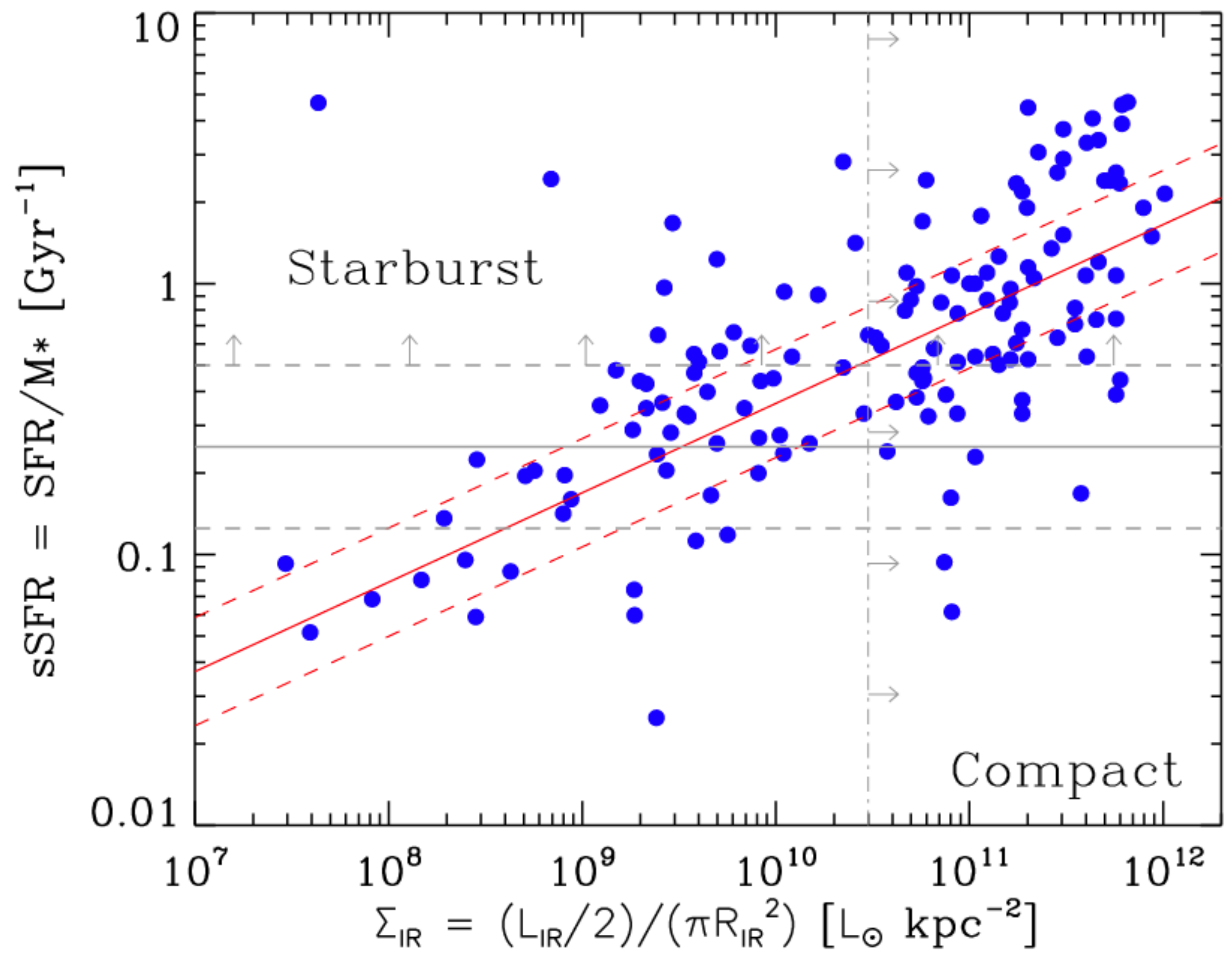
Schreiber+14



Burgarella+13



Elbaz+11

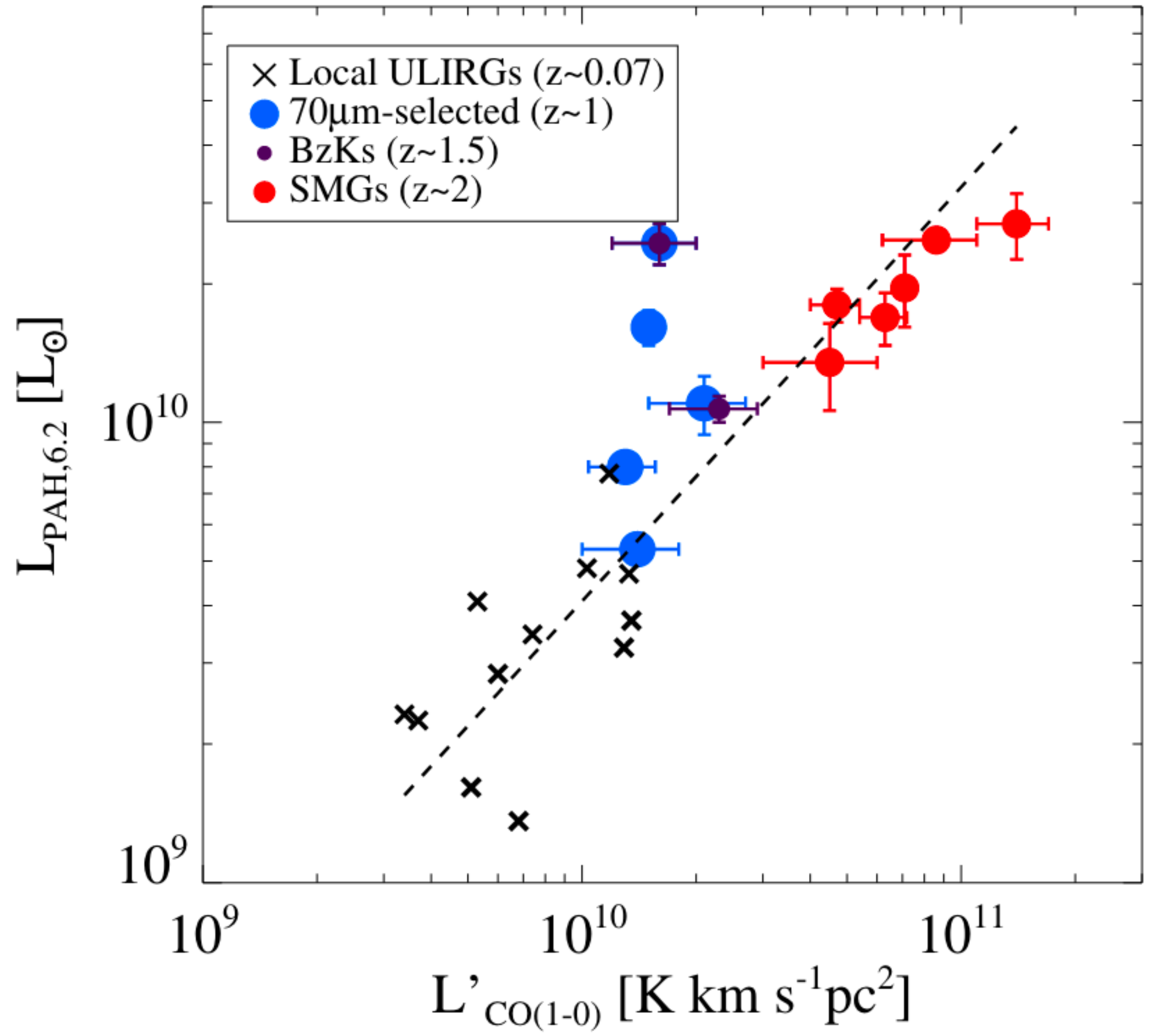


Era of Spitzer and Herschel

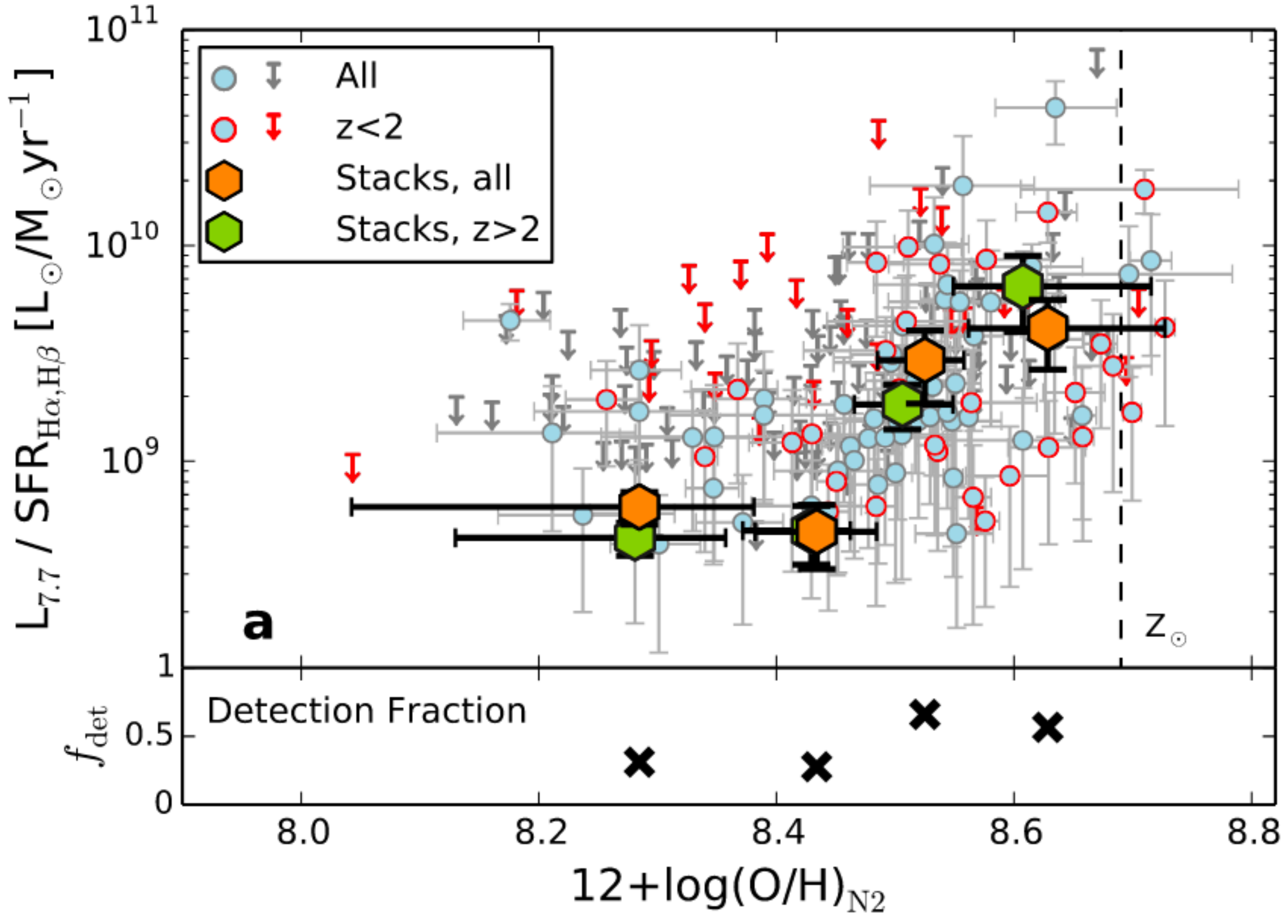
Revealing the highly-obscured Universe

- mid-IR emission (PAHs) with imaging and spectroscopy

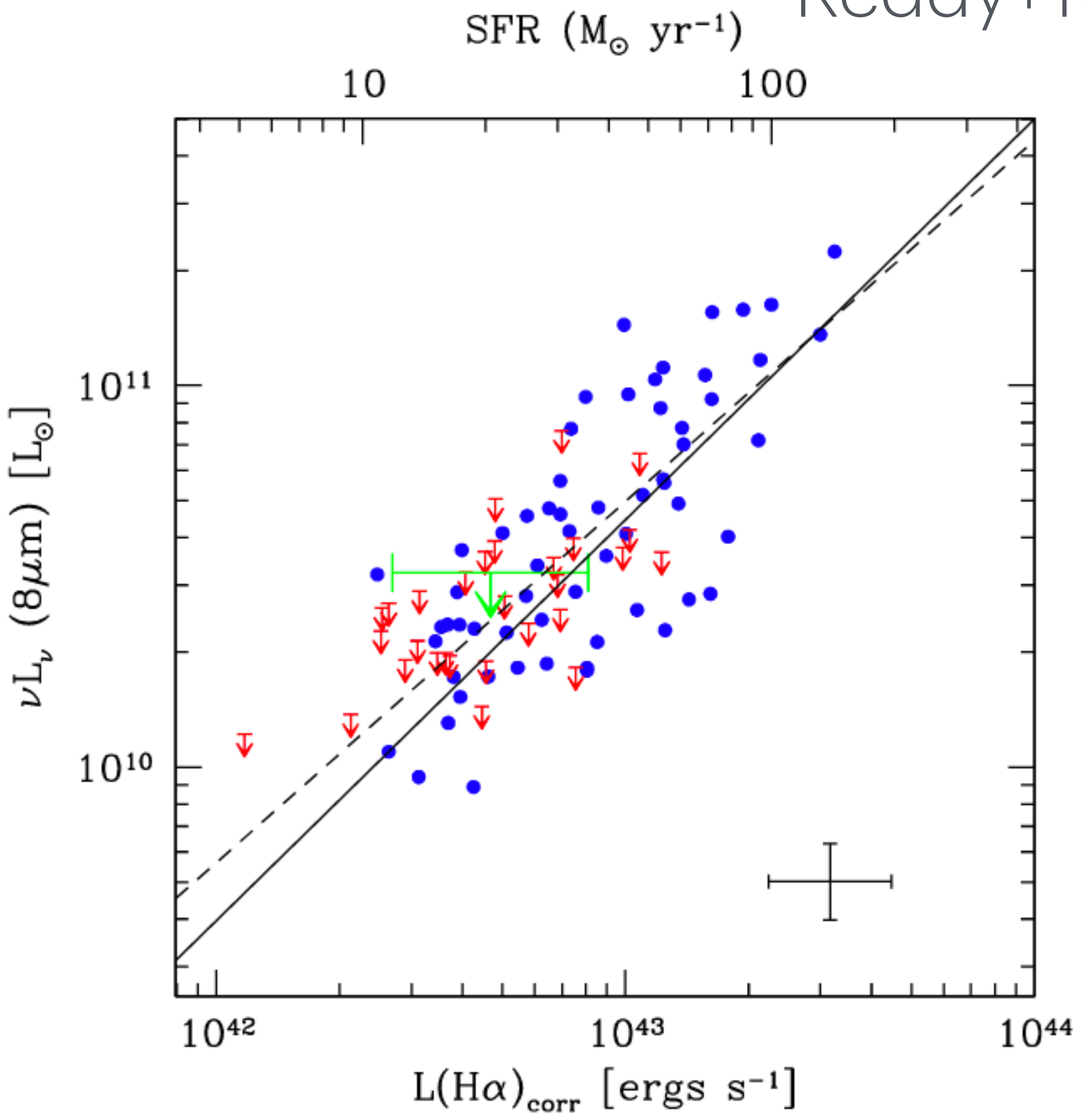
Pope+13

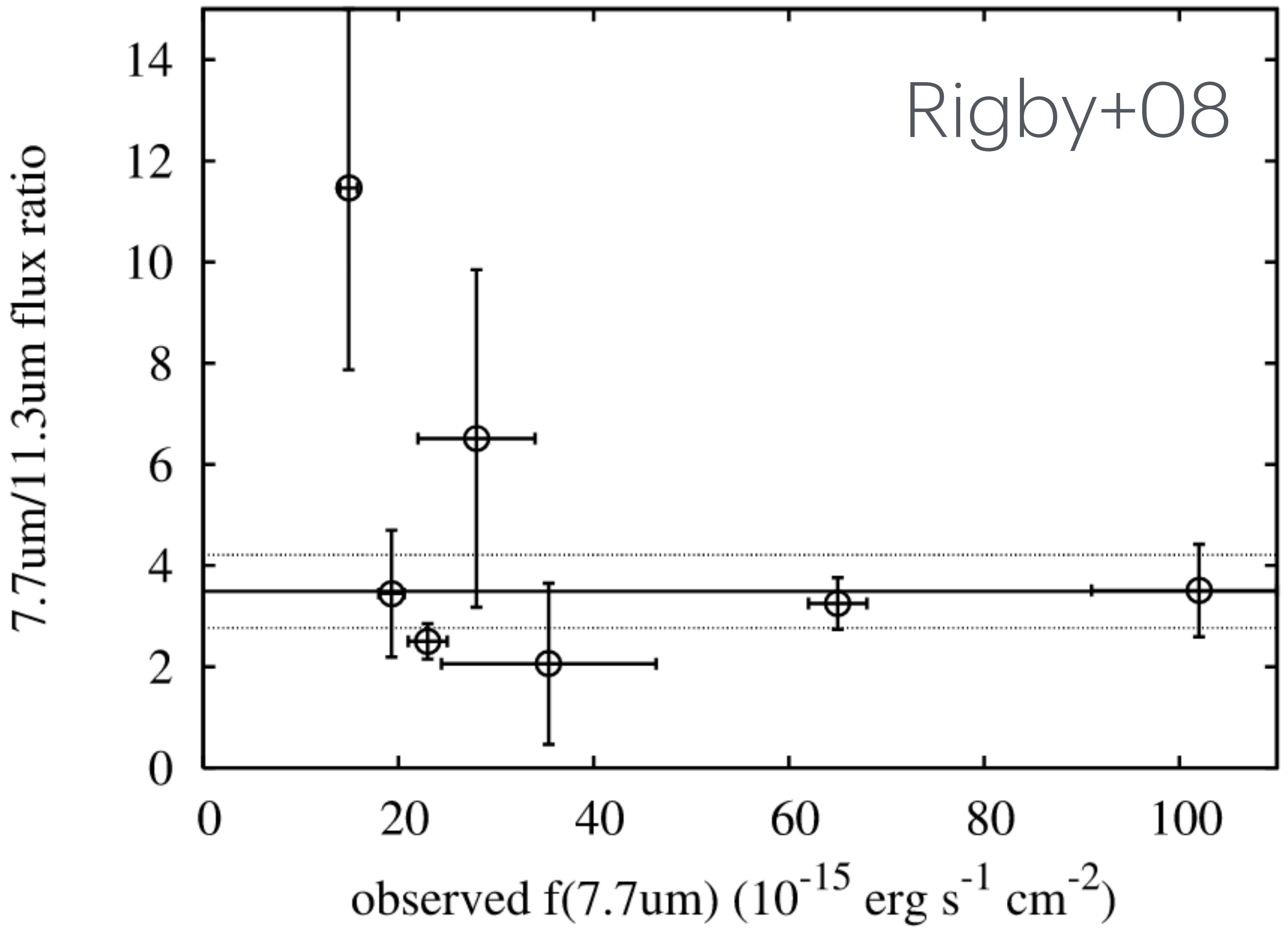


Shivaei+17

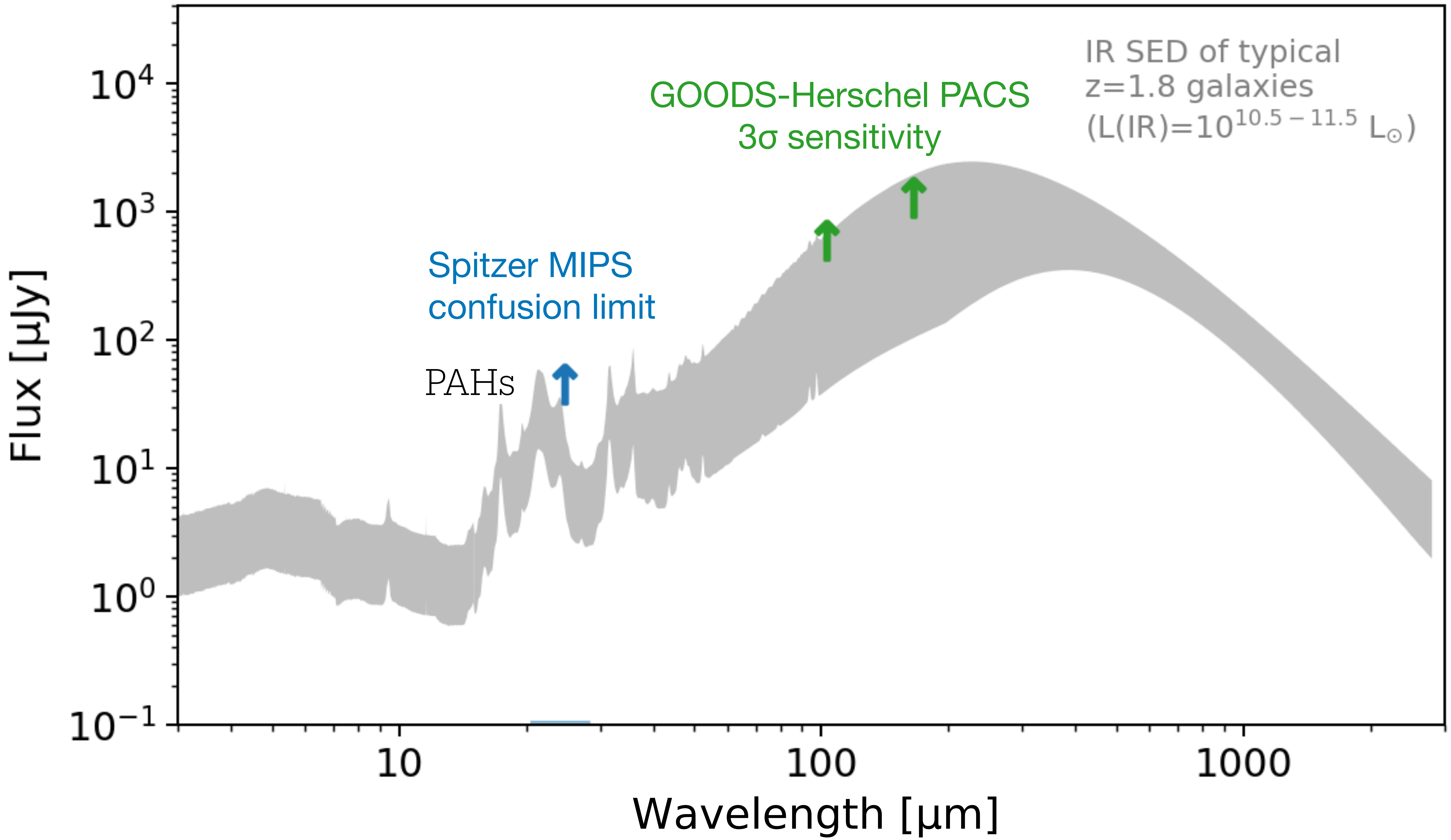


Reddy+10





What were we missing?



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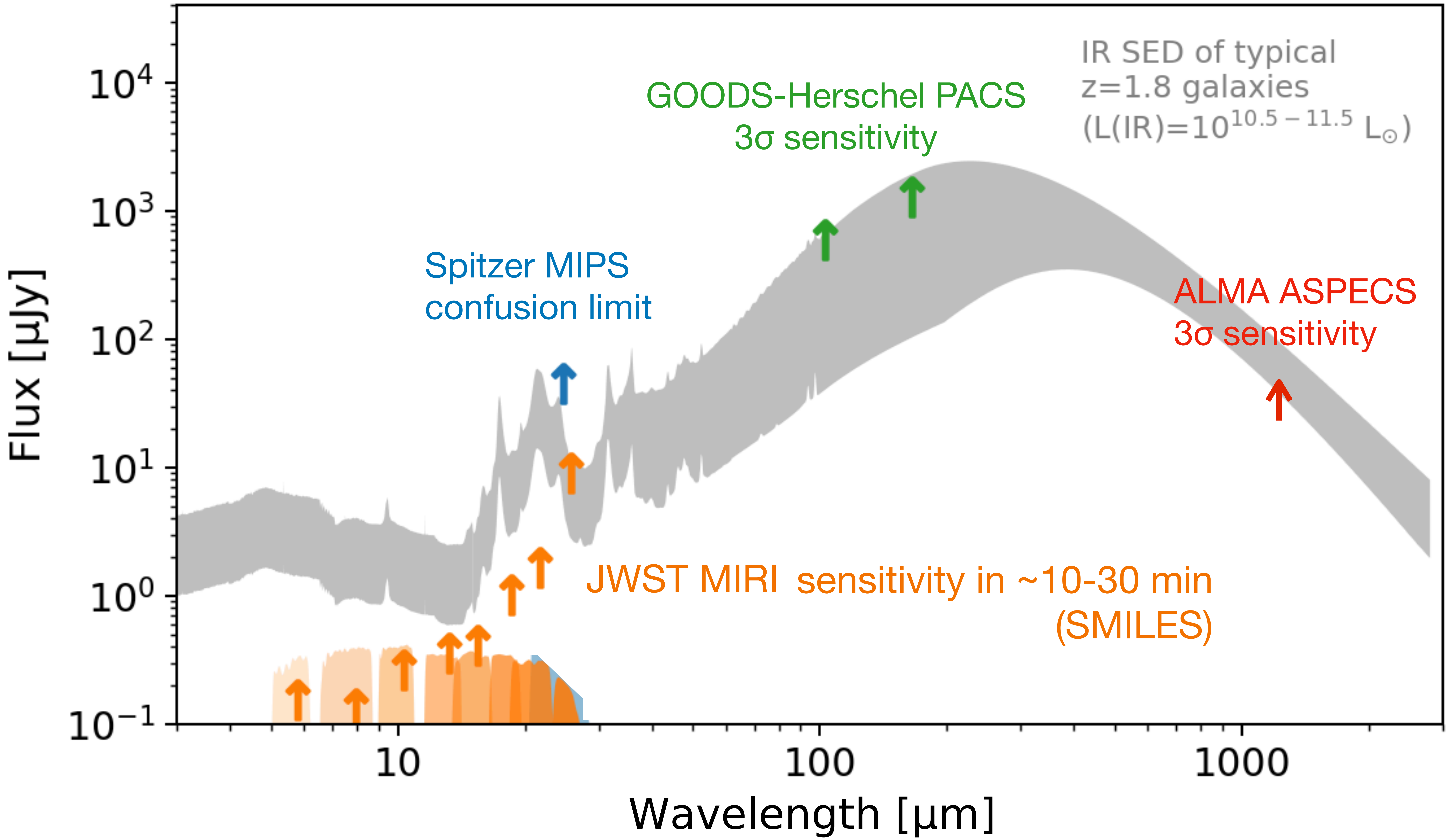
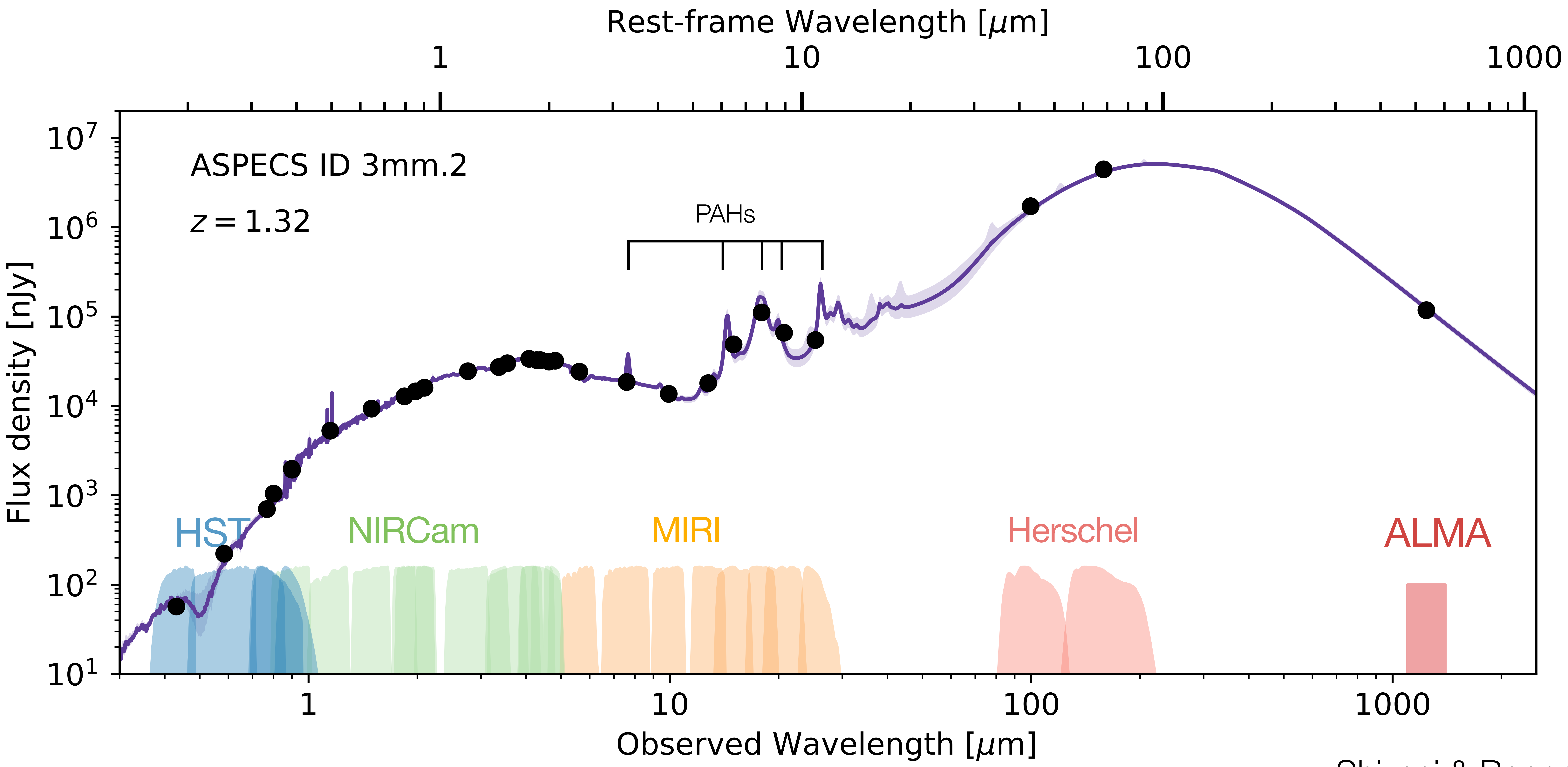


A new era in cosmic noon studies:



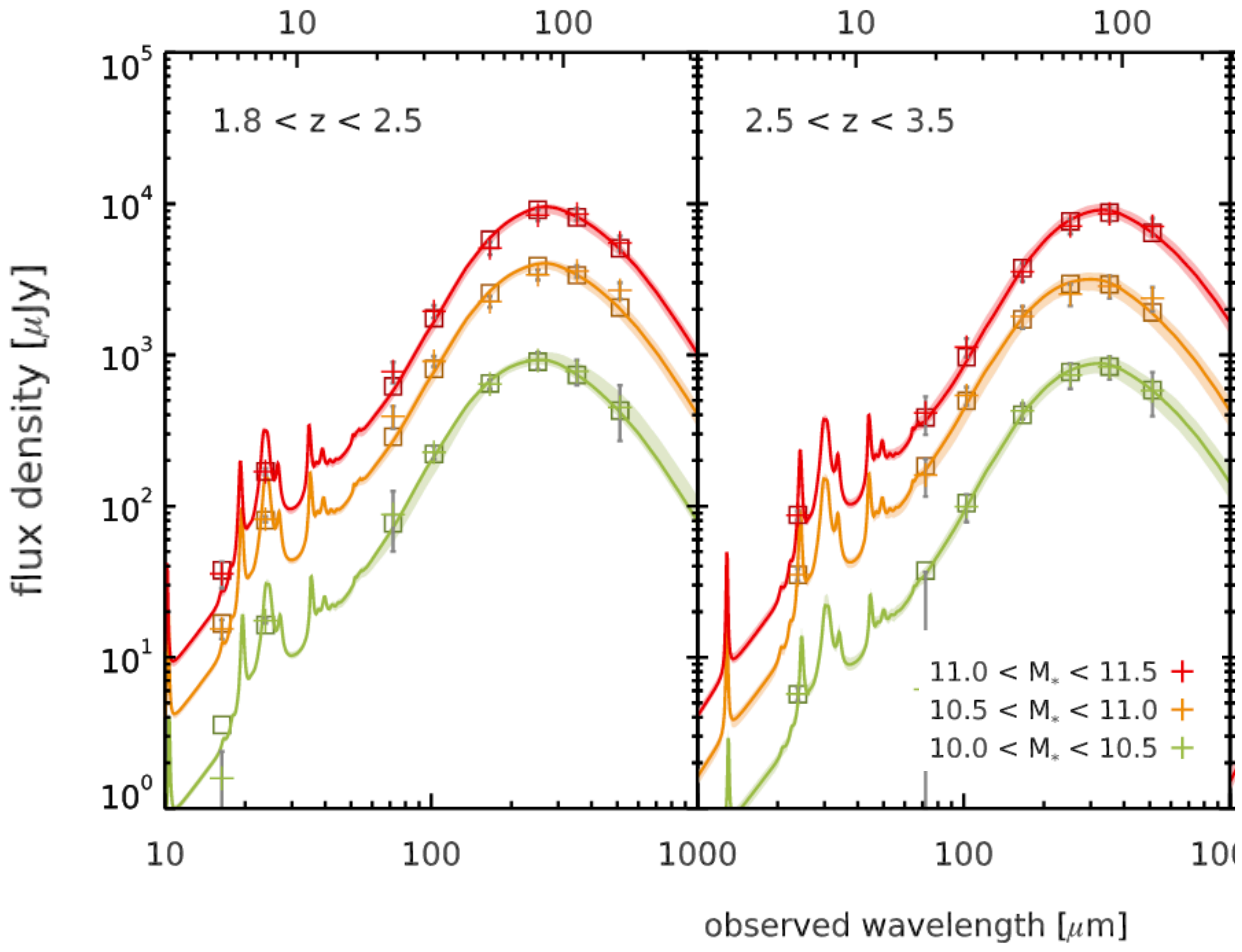
Shivaei & Boogaard (2024)

Dust FIR SED

Shape of IR SED and dust effective temperature

Herschel

Schreiber+2017



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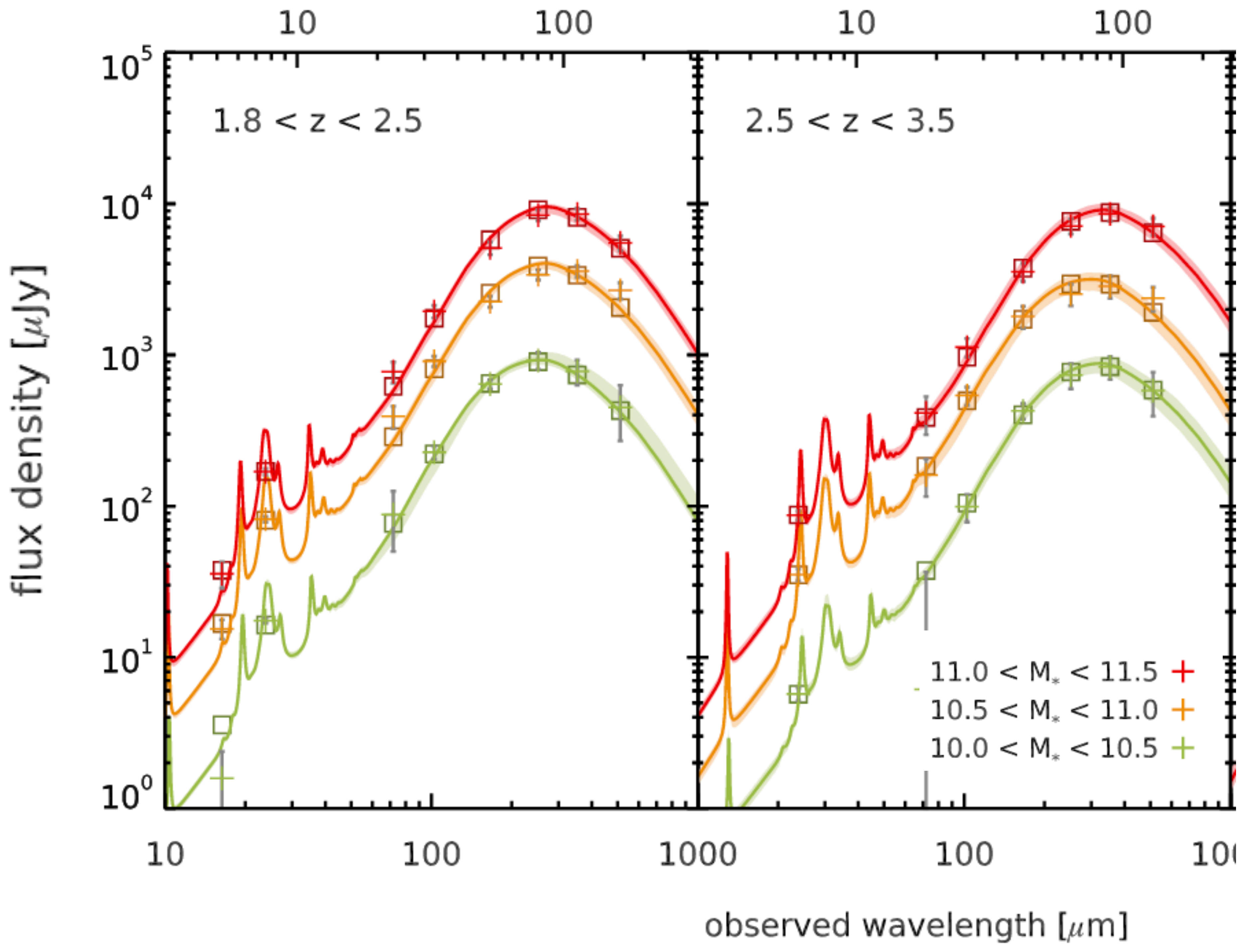
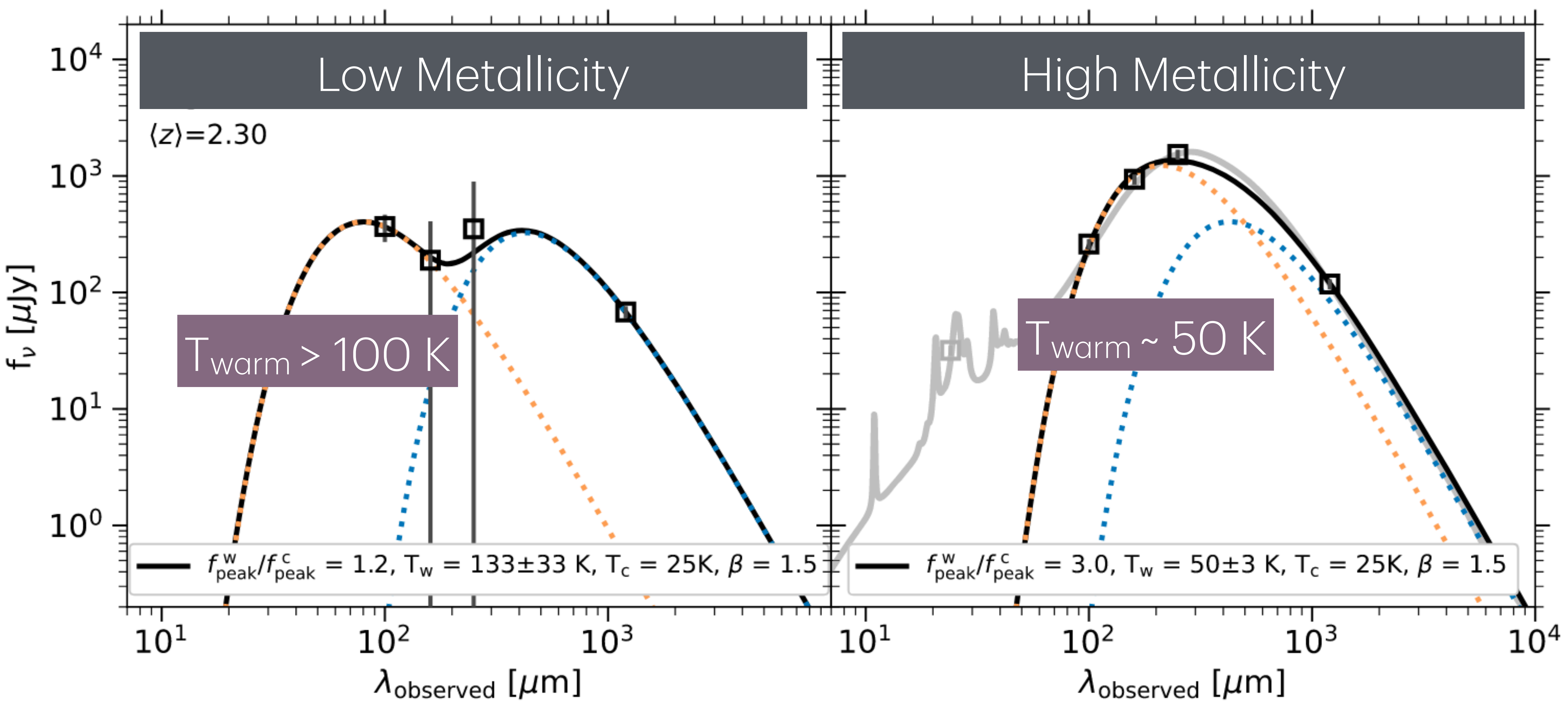


Herschel + ALMA

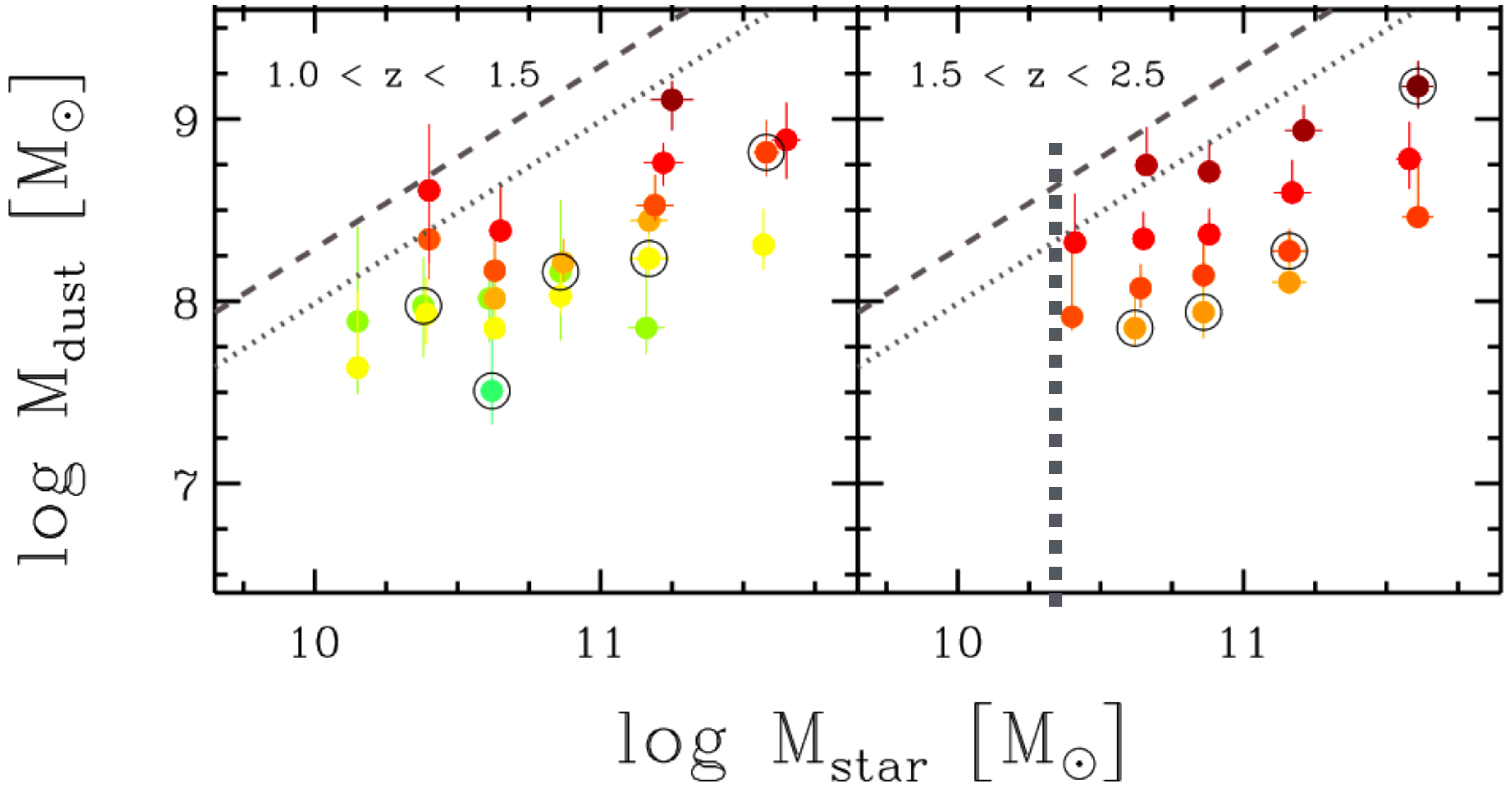
Shivaei+2022a



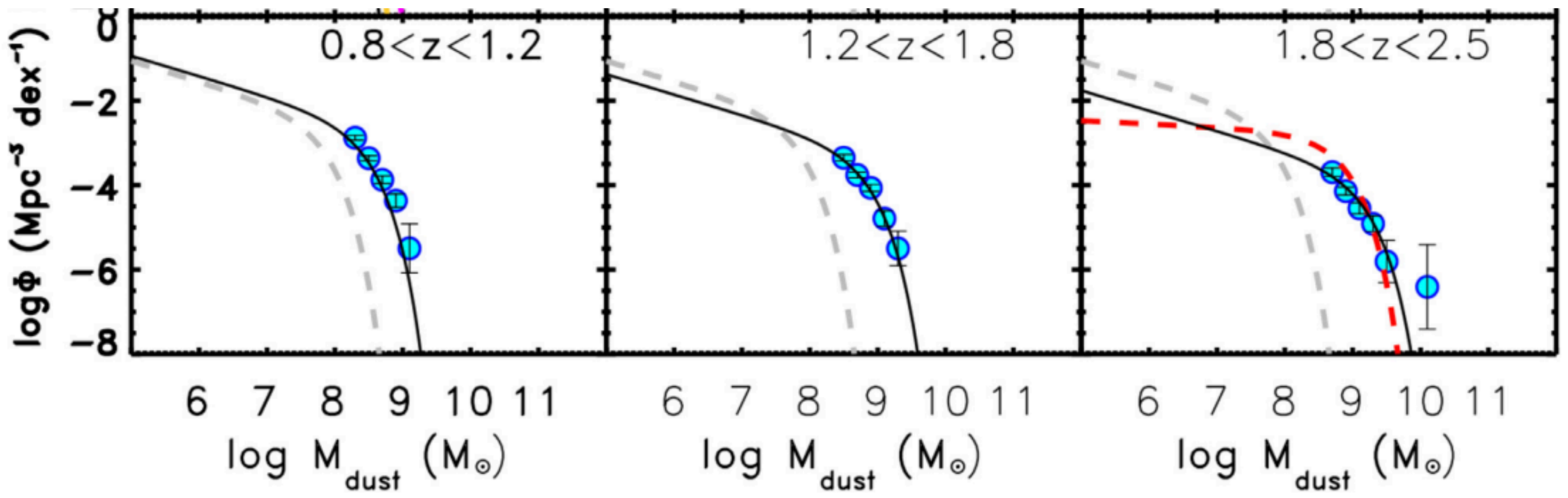
Dust masses

Herschel

Santini+2014



Pozzi+2020



Dust masses

Herschel

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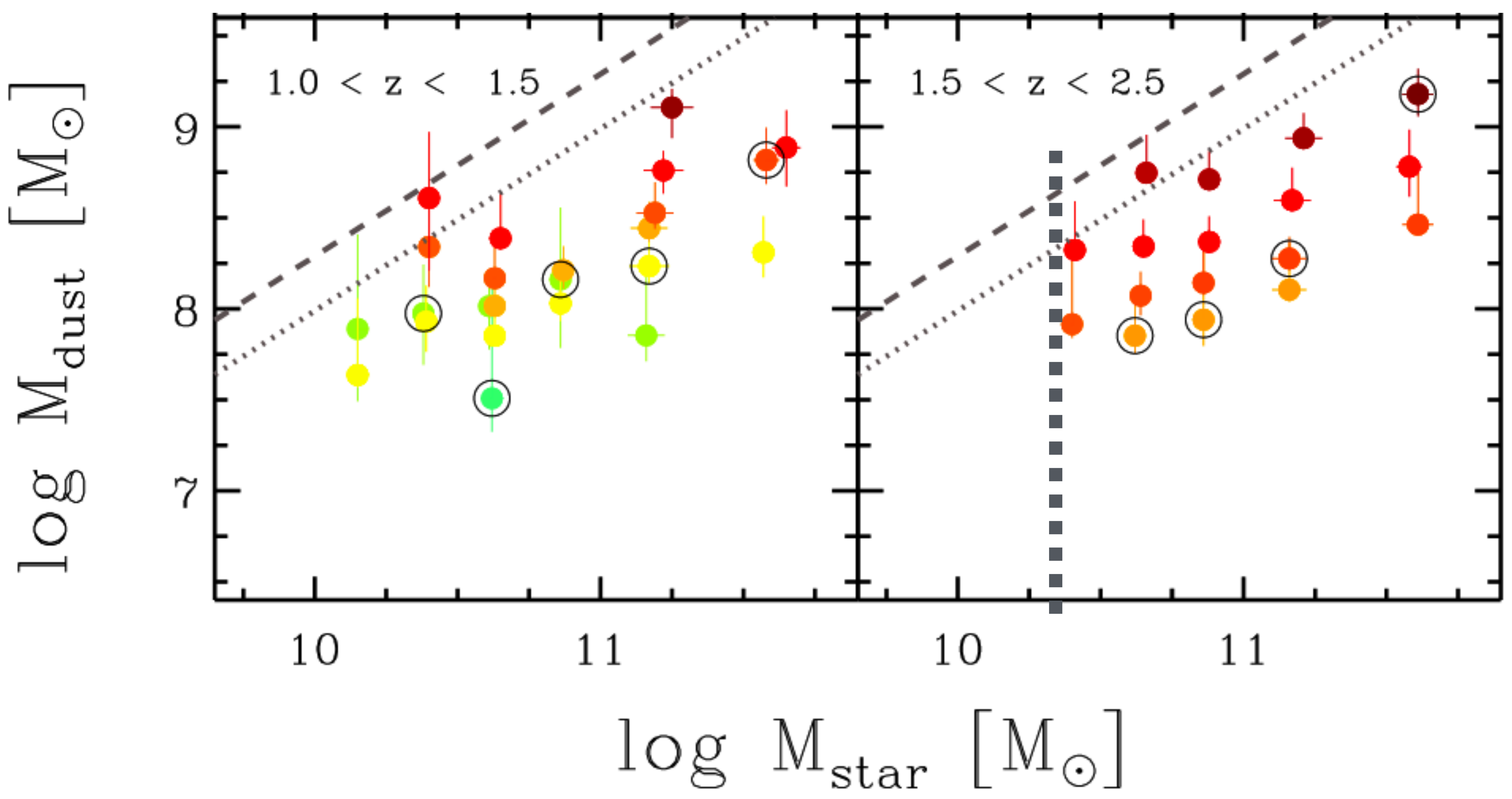
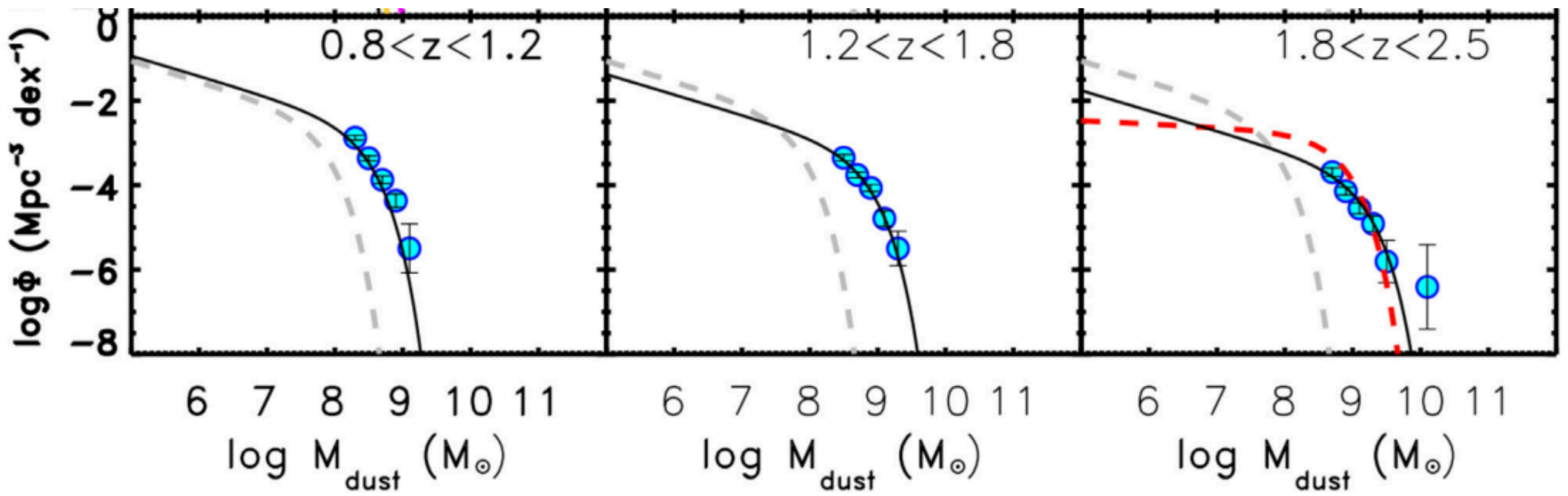
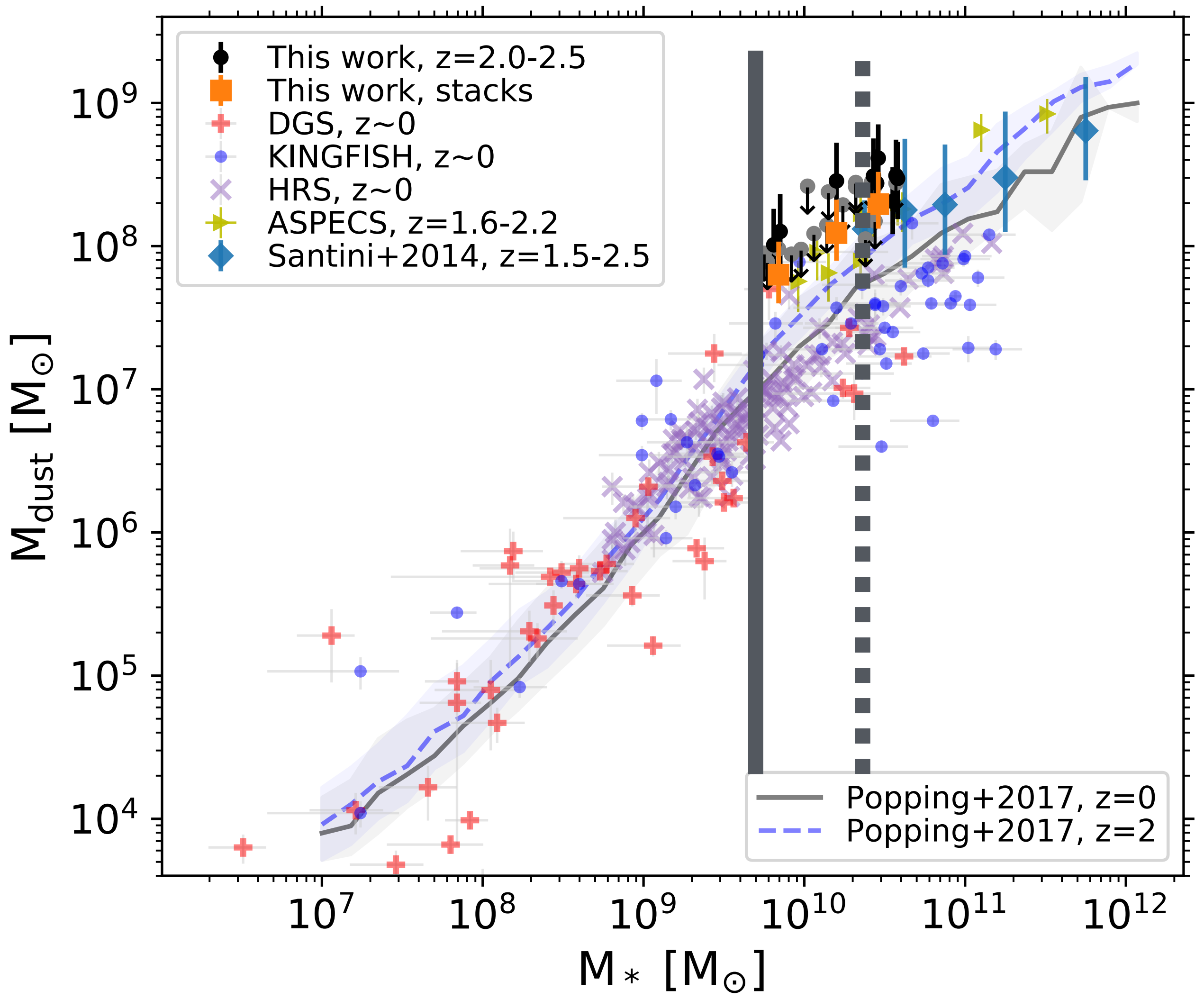


Pozzi+2020

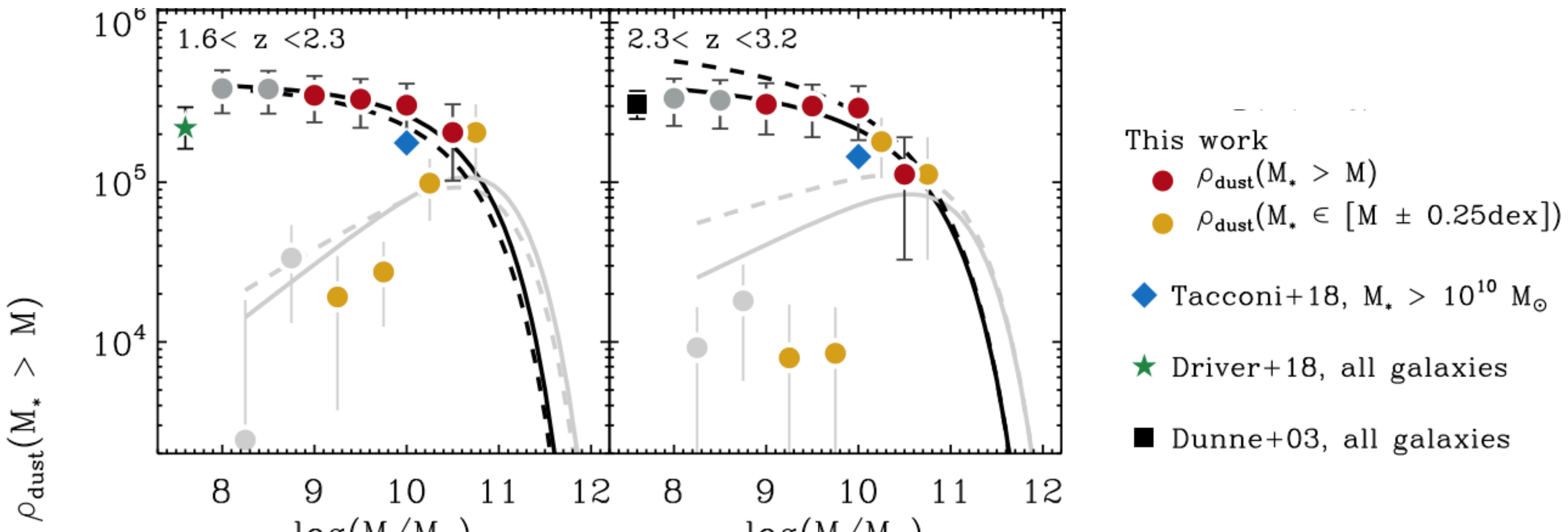


Herschel + ALMA



Shivaei+2022a

Magnelli+2020 (ASPECS)



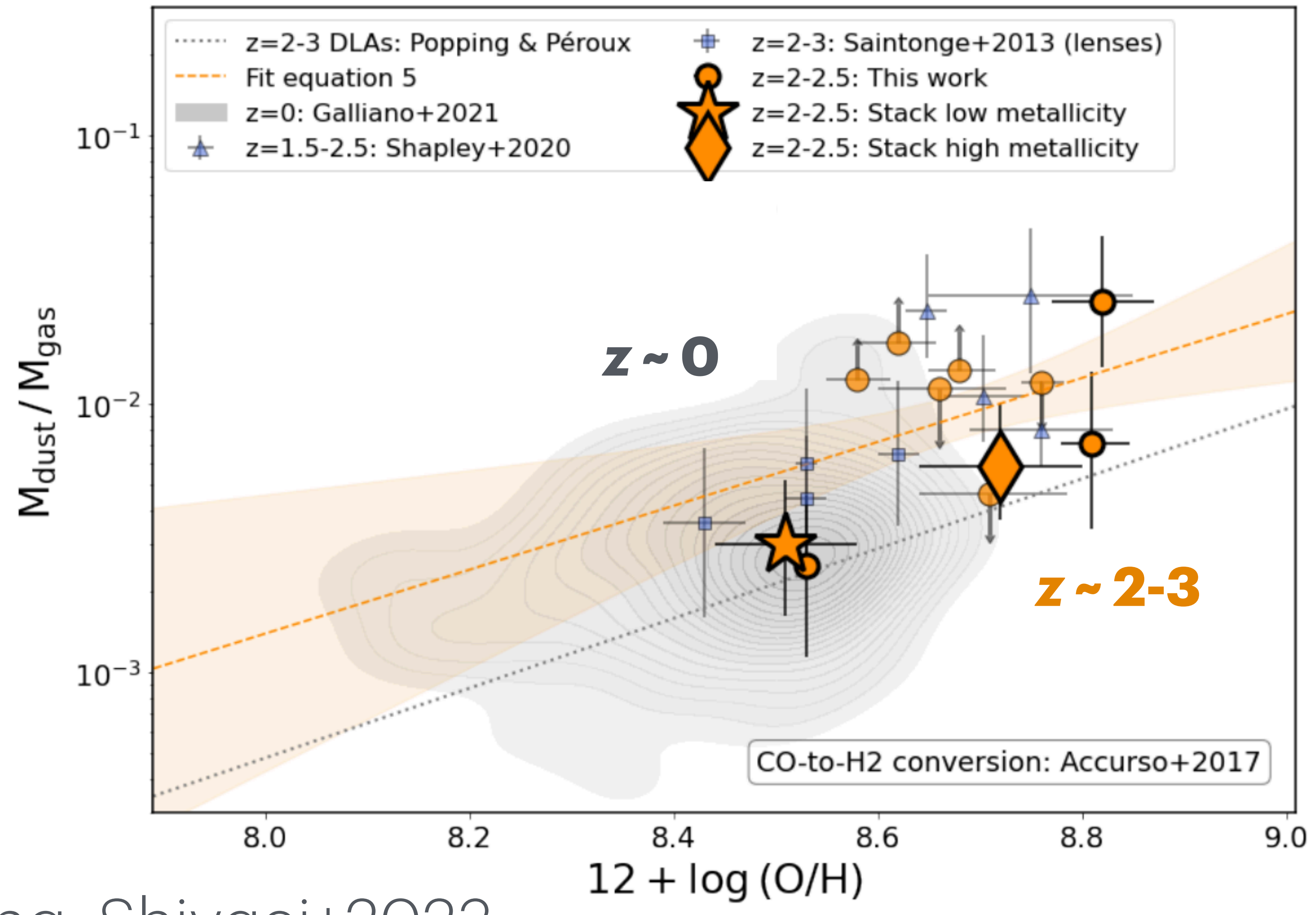
Bryon cycle and star formation

Benchmark Cosmic Noon ALMA large programs in Cycle 11

ALMA Chemical Evolution (ACE)

PIs: **Shivaei**, Popping
co-Is present in this meeting: **Boogaard, Pope**

CO and dust continuum of 25 galaxies at z~2 with metallicity measurements down to 35% solar



Popping, Shivaei+2023

Cosmic Noon Disks with Observed Rotation (CONDOR)

PIs: Rizzo, Kaasinen, Aravena

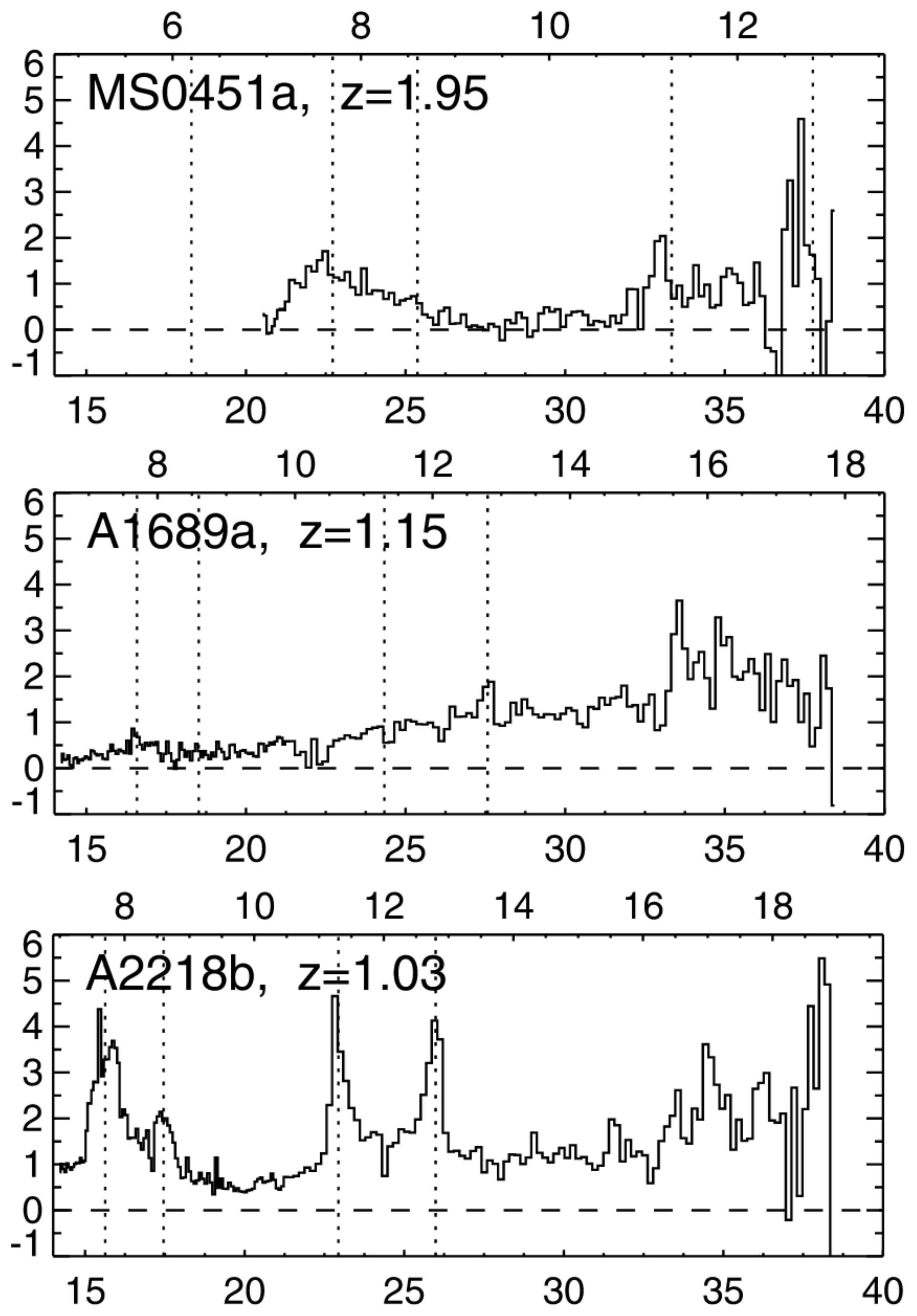
resolving the CO emission of 10 massive main-sequence disk galaxies at Cosmic Noon

PAHs

Physics of PAH molecules

Spitzer IRS spectra of lensed galaxies

Rigby+2008



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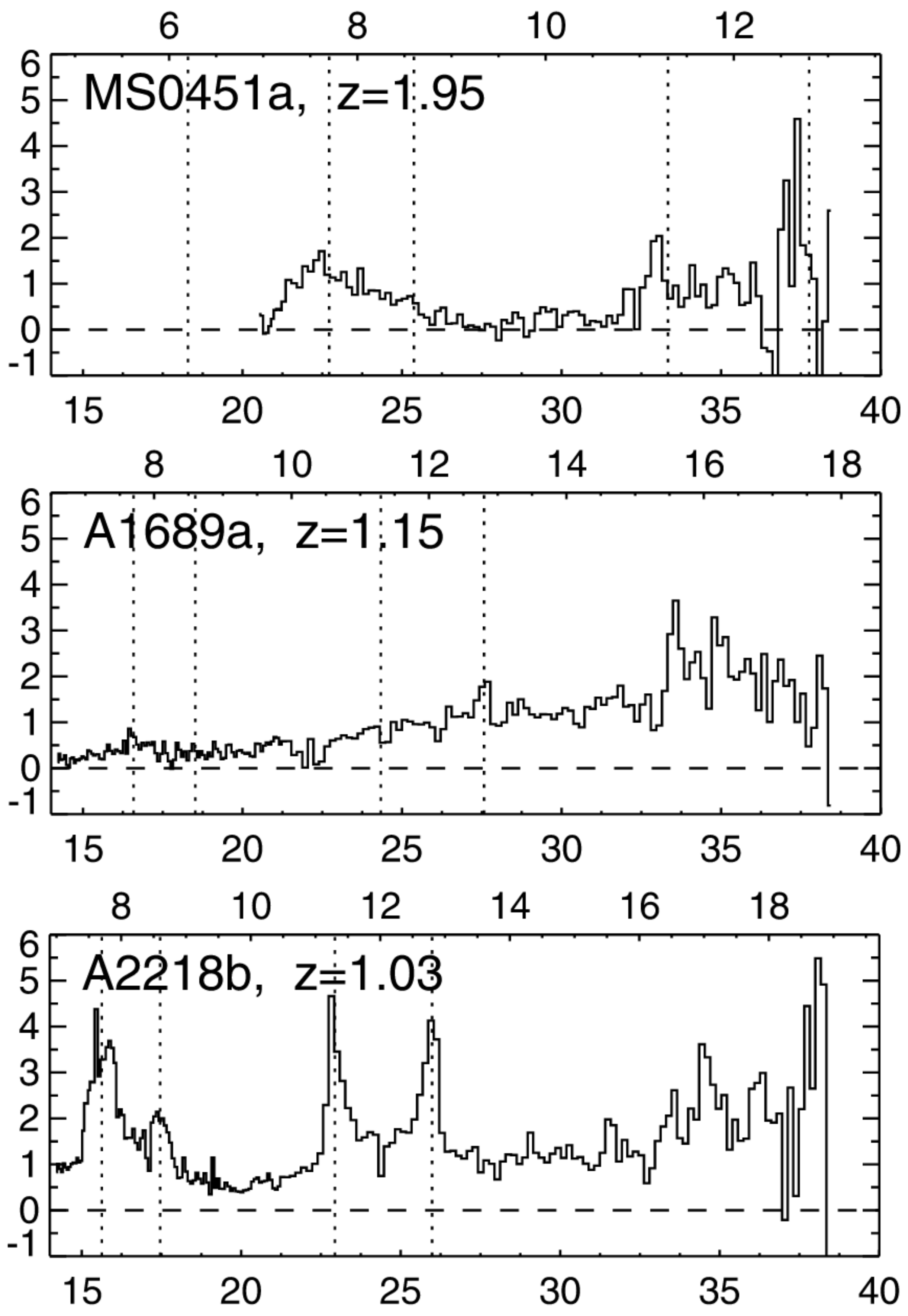
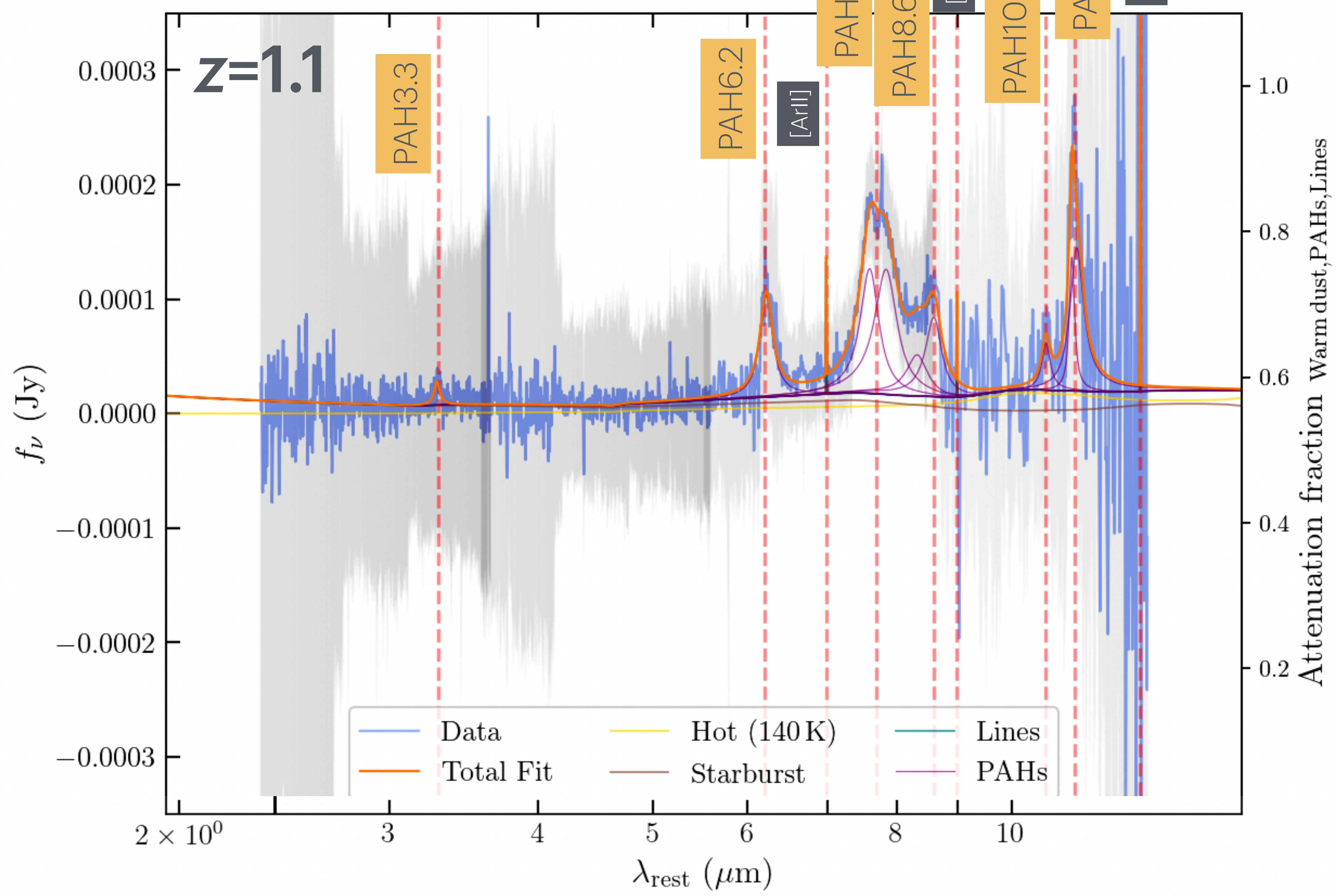


JWST MIRI MRS of main-sequence unlensed galaxies

PAHSPECS program (PIs: Shivaei, Díaz-Santos, Boogaard)

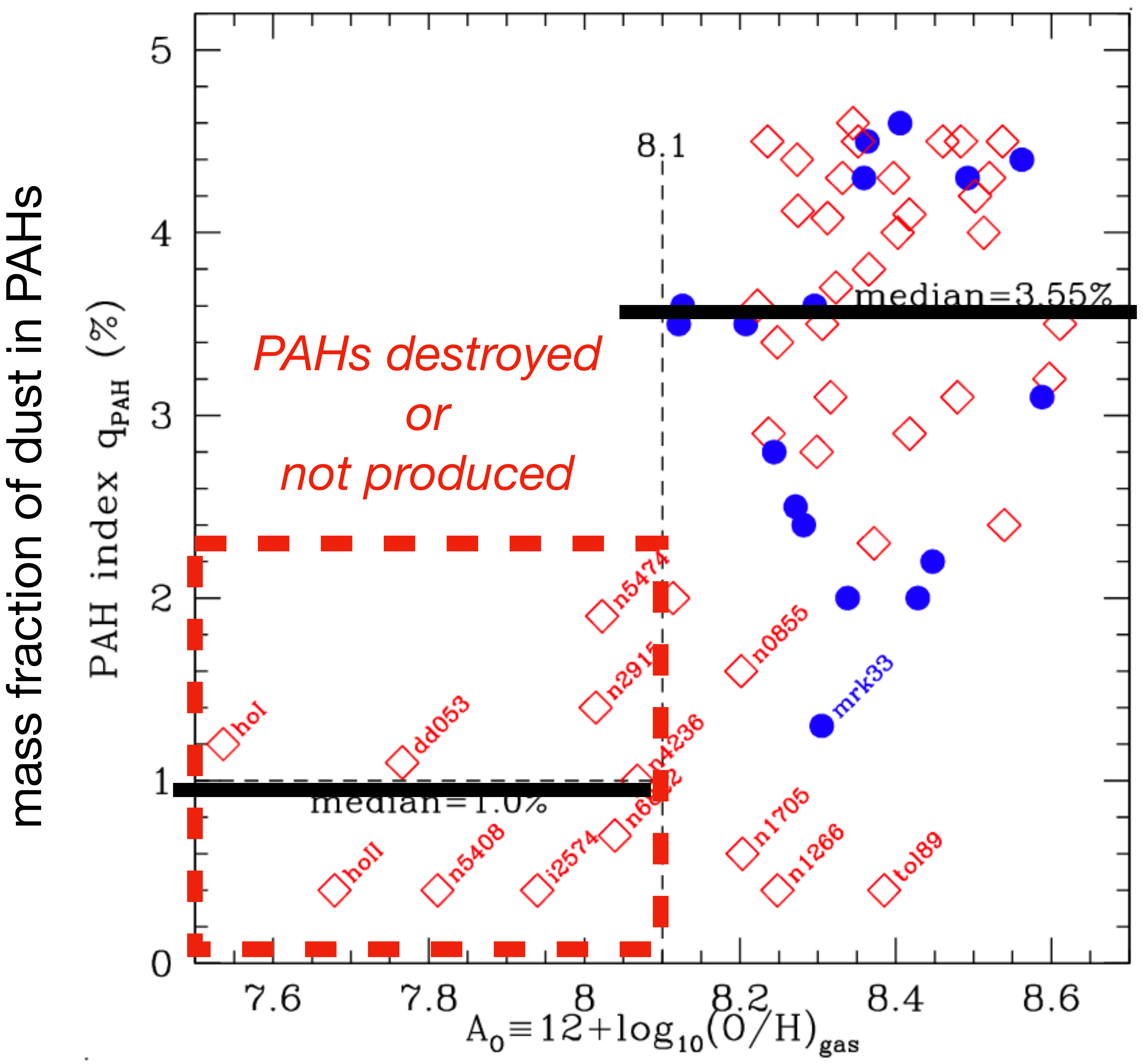
c: Cristina Lofaro



PAHs

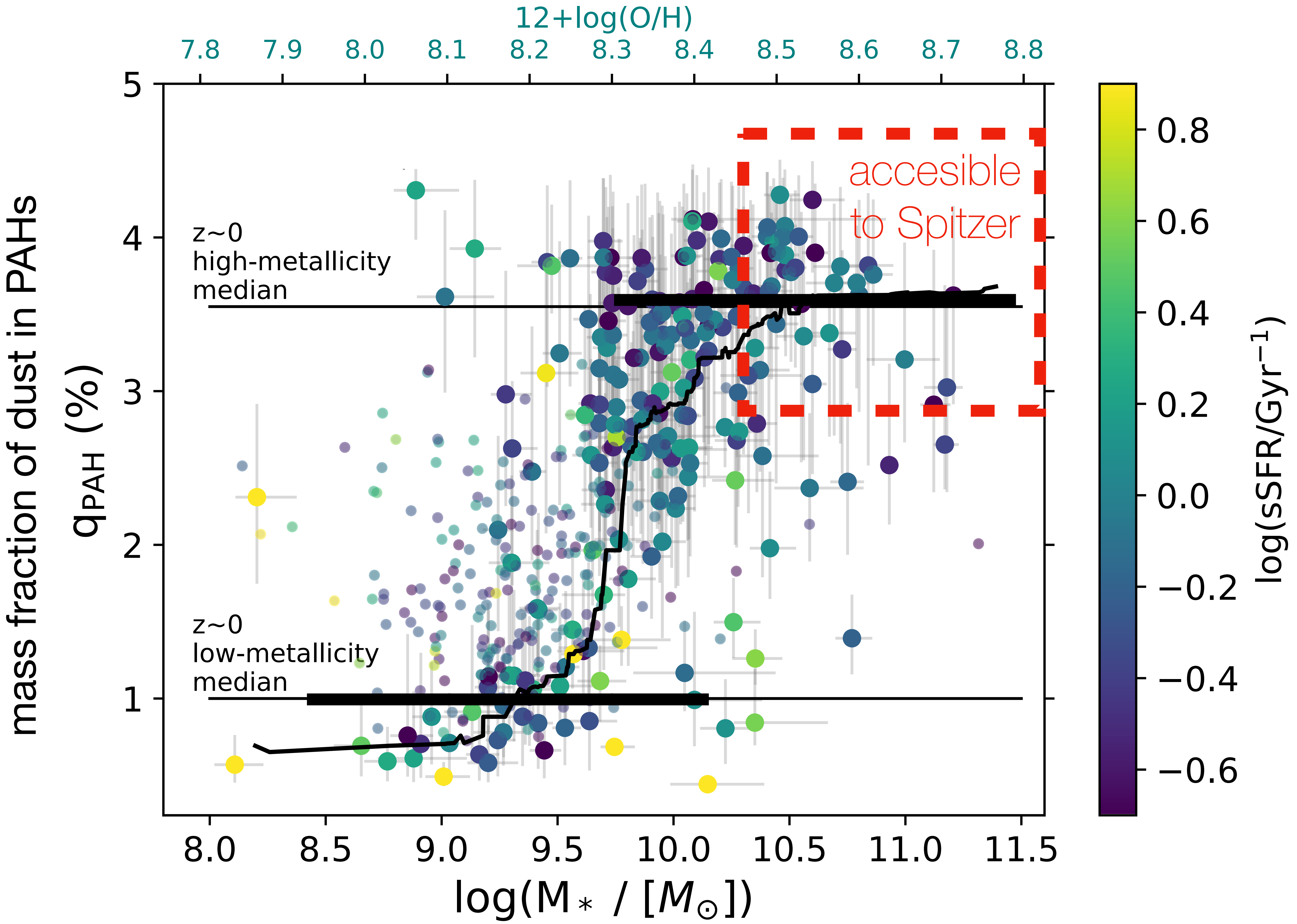
z ~ 0 view:

z ~ 1-2 with JWST:



Metallicity

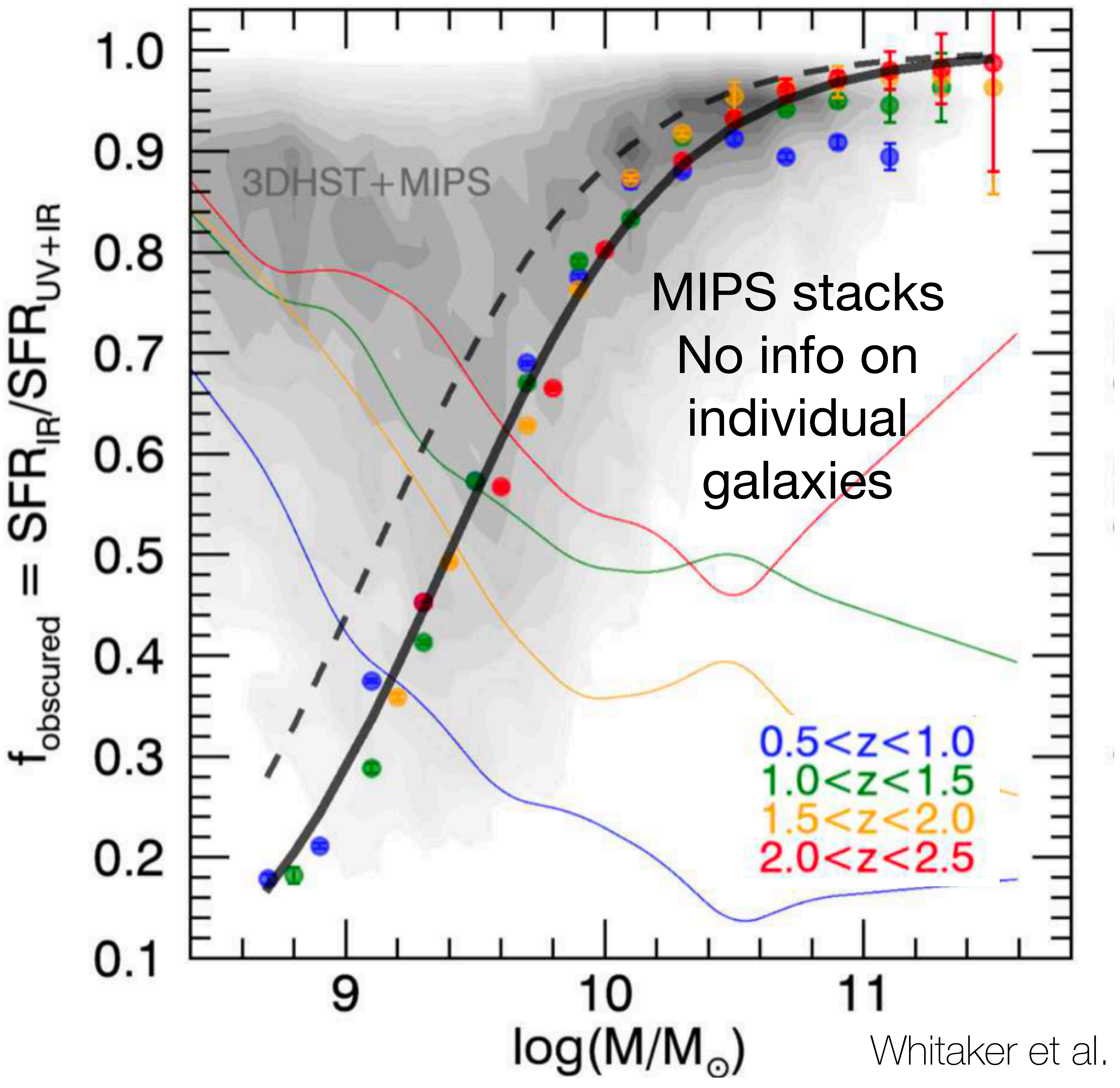
Draine et al. 2007



Shivaei+2024

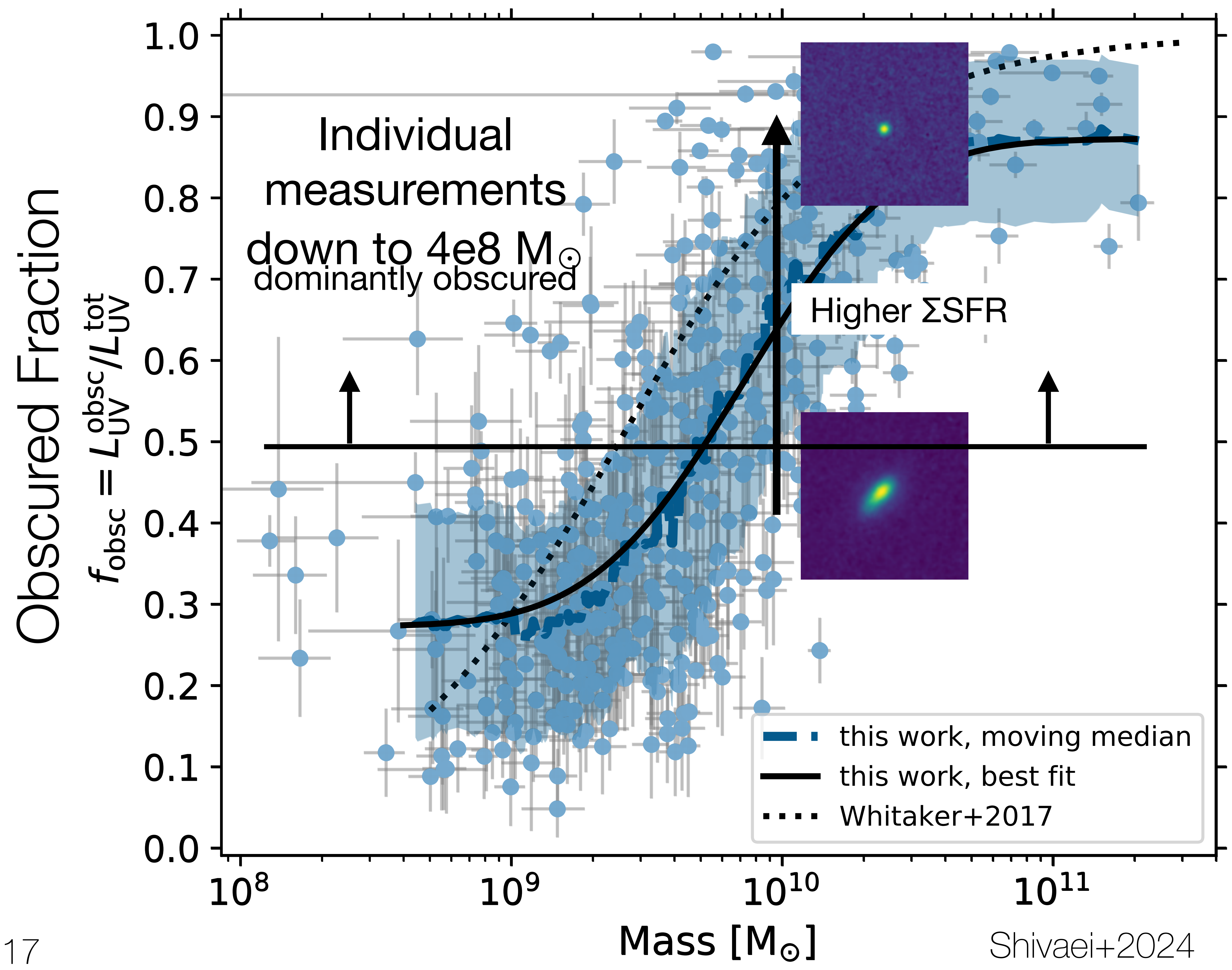
Census of *obscured luminosity* at cosmic noon

Pre-JWST view:



Whitaker et al. 2017

with JWST/MIRI:

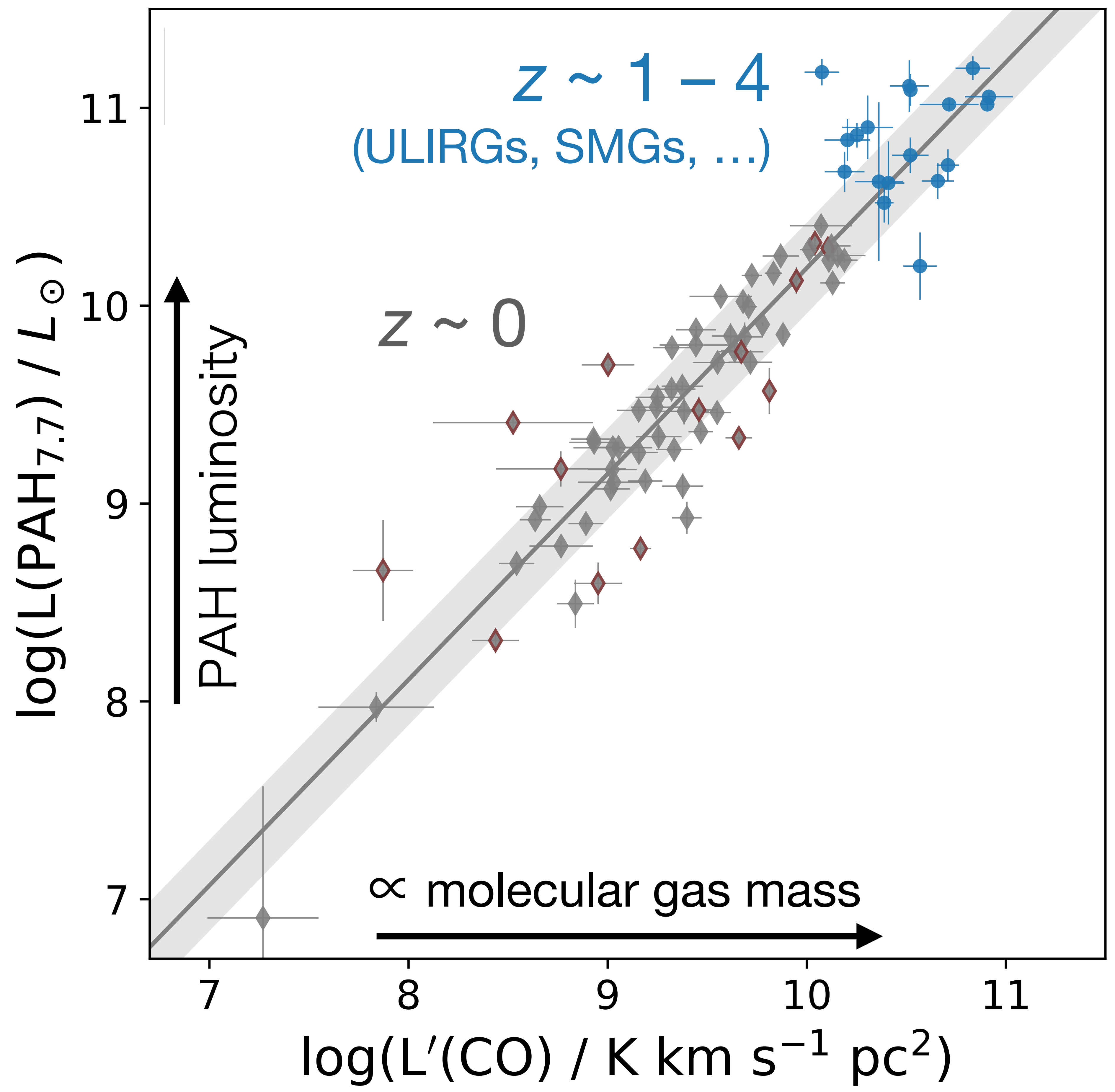


Shivaei+2024

PAHs and cold gas

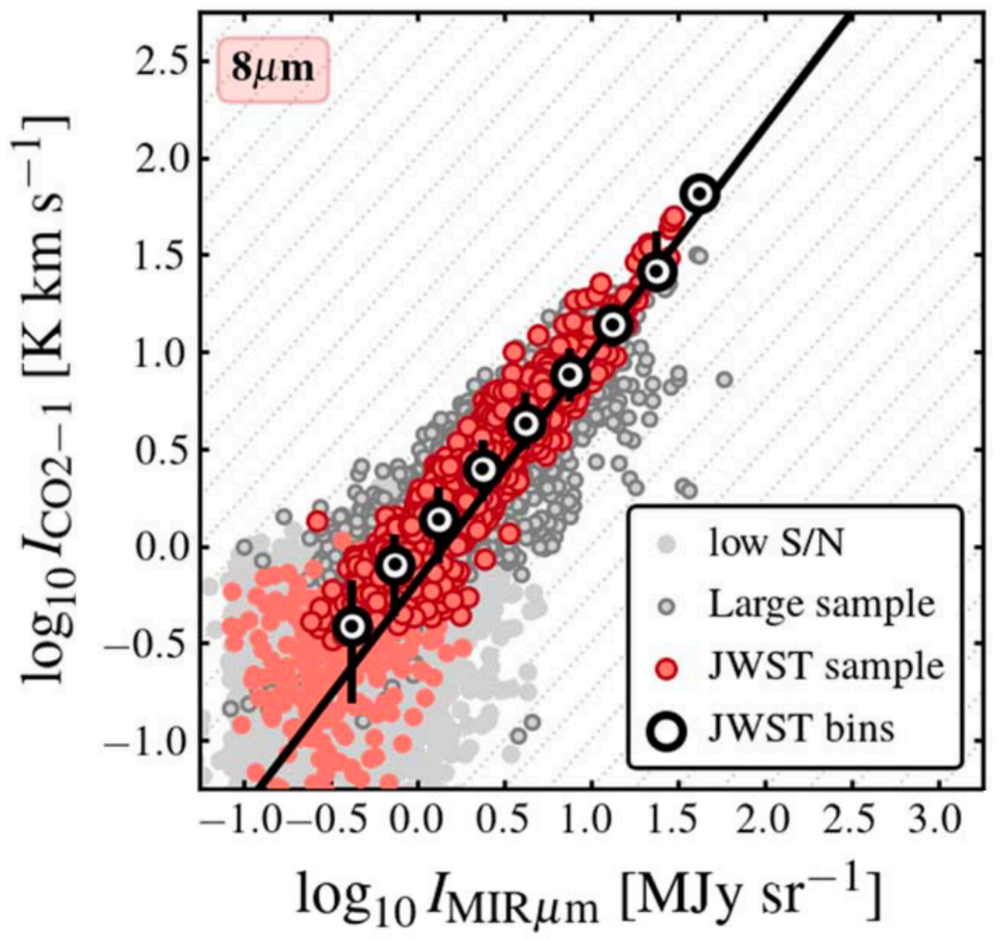
Pre-JWST view:

Cortzen+2019



Leroy+2023, Chown+24

resolved z ~ 0

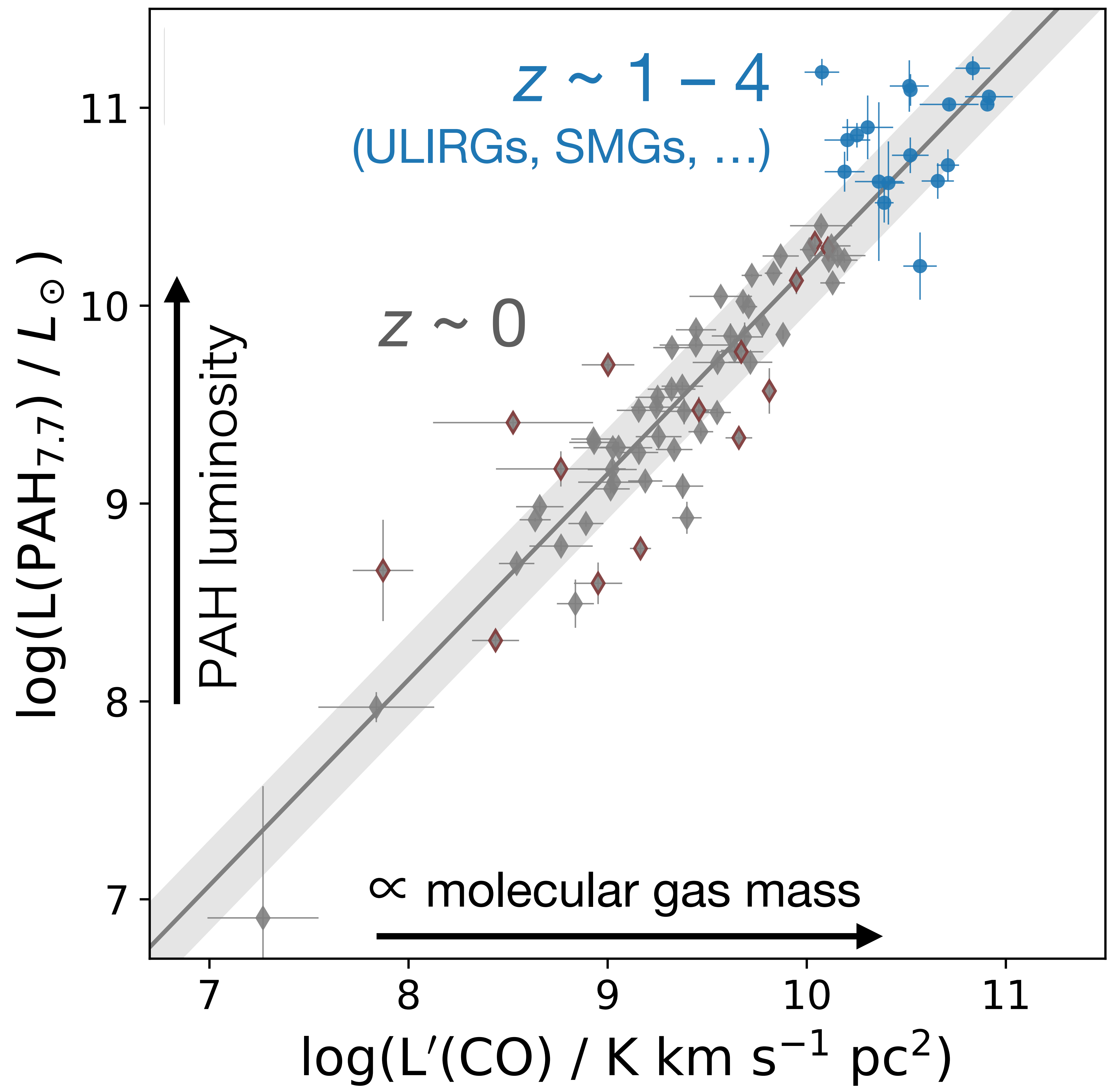


$$I_{PAH} \propto DGR \times q_{PAH} \times N_{H_2} \times U$$
$$\propto (DGR \times q_{PAH} \times X_{CO} \times U)\, I_{CO}$$

PAHs and cold gas

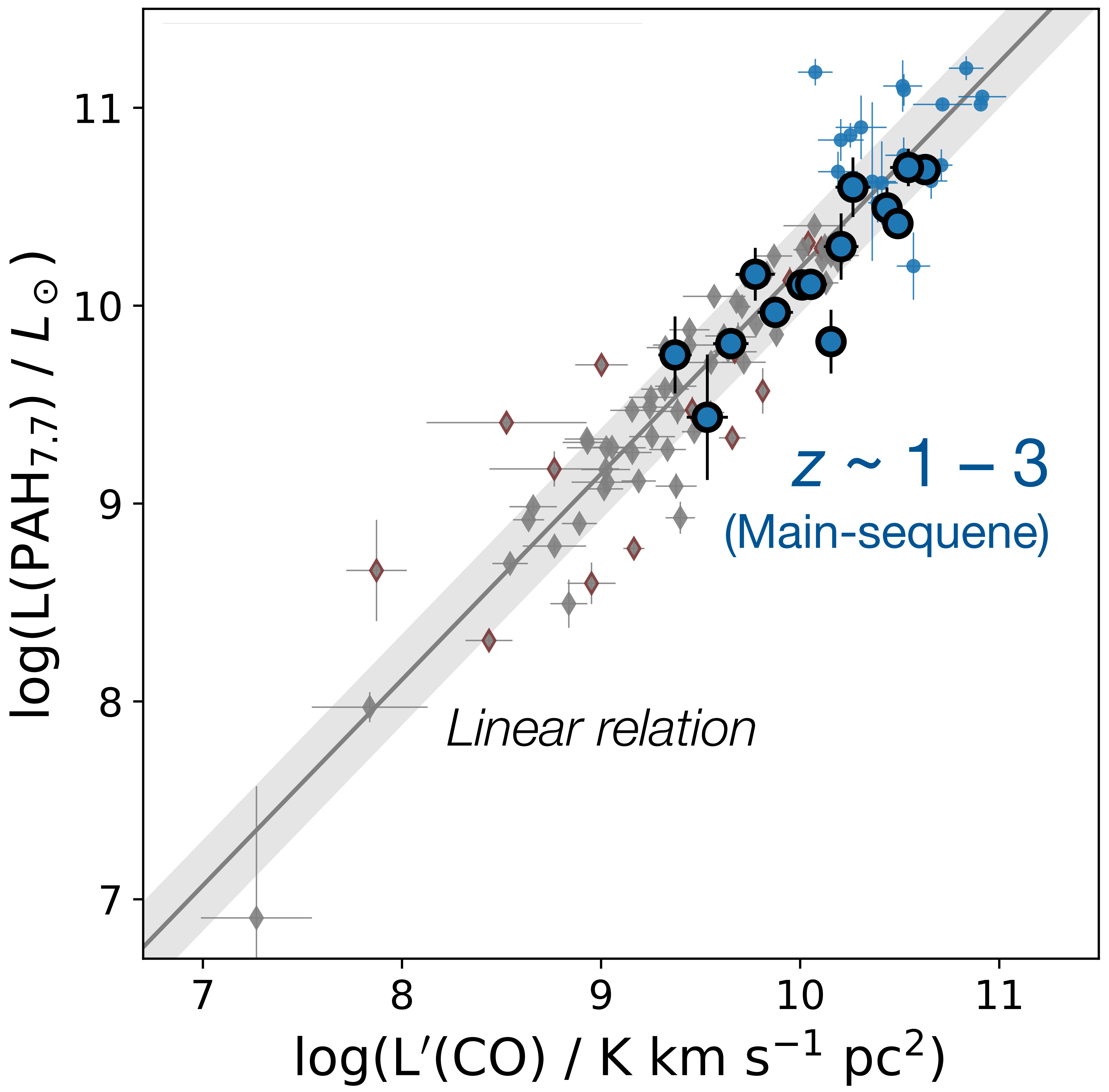
Pre-JWST/ALMA view:

Cortzen+2019

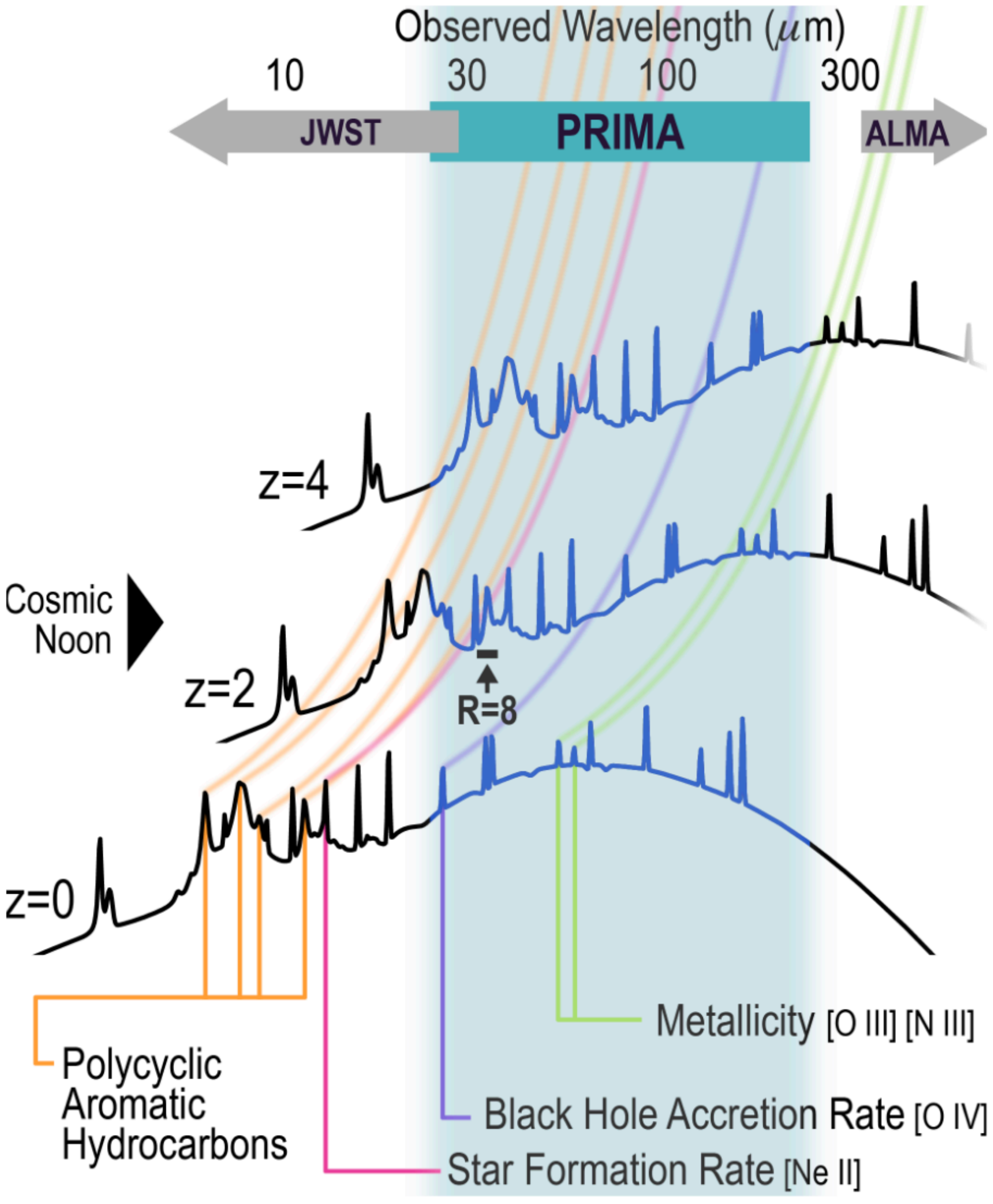


with JWST/MIRI + ALMA:

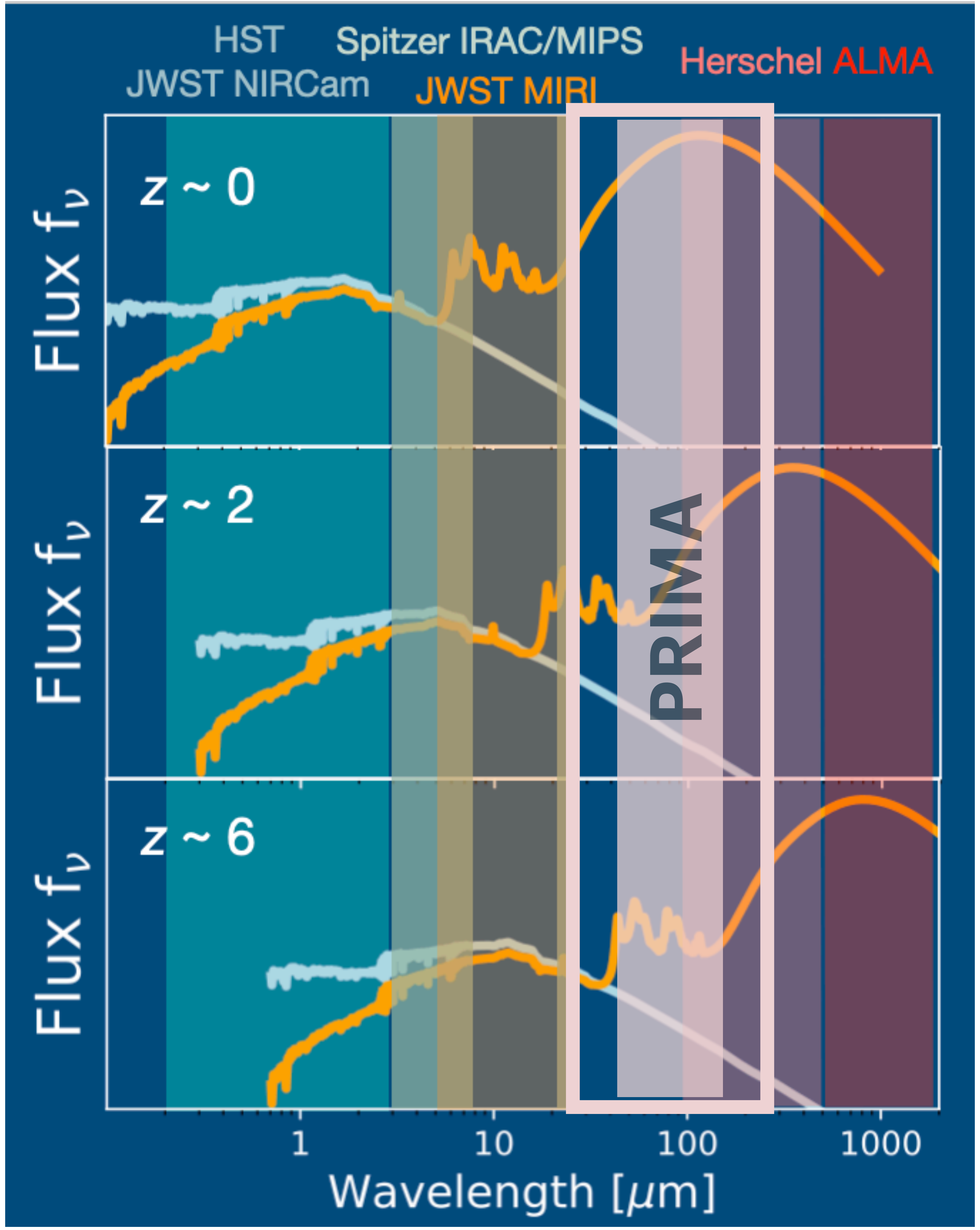
Shivaei & Boogaard (2024)



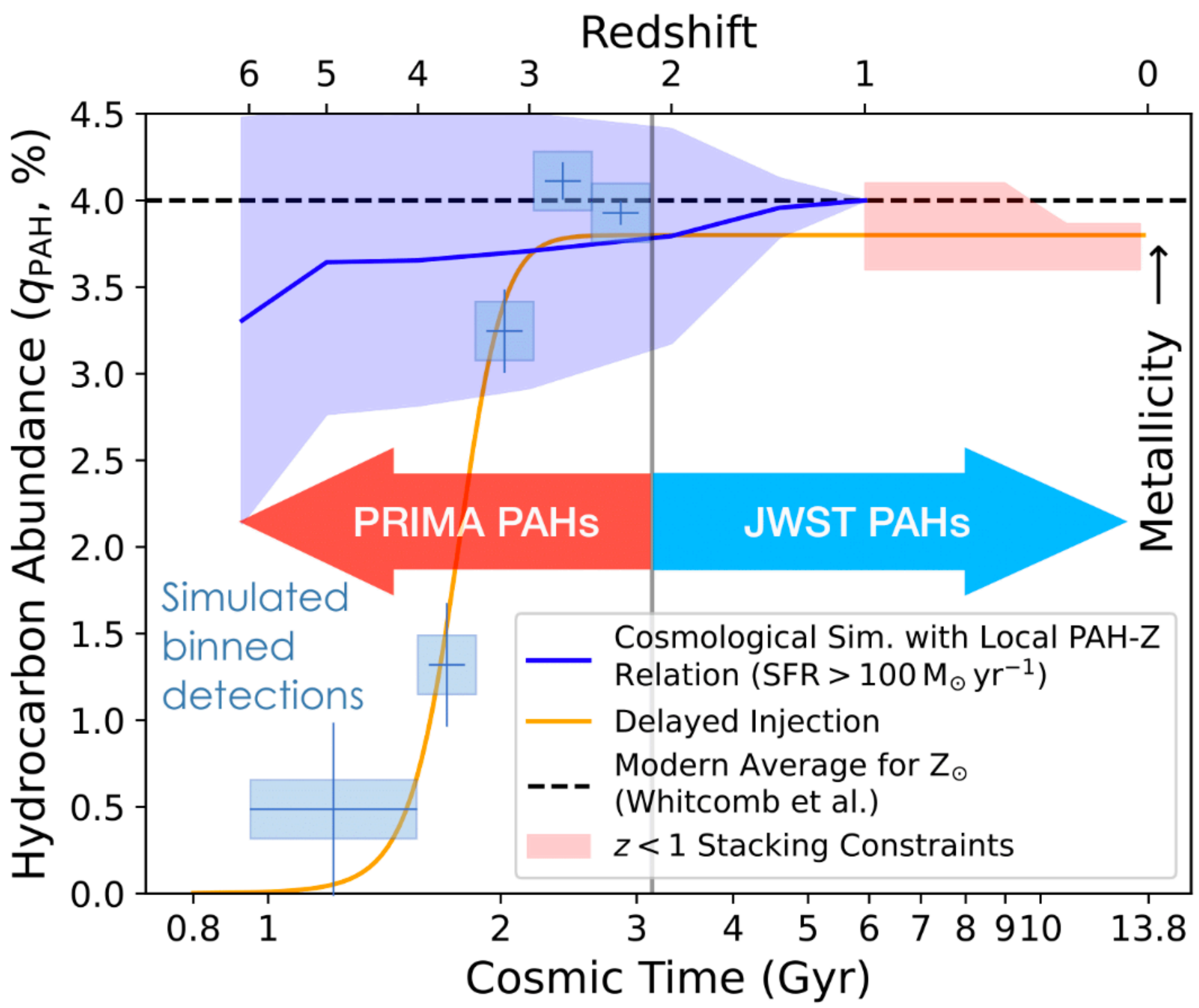
What are we missing?

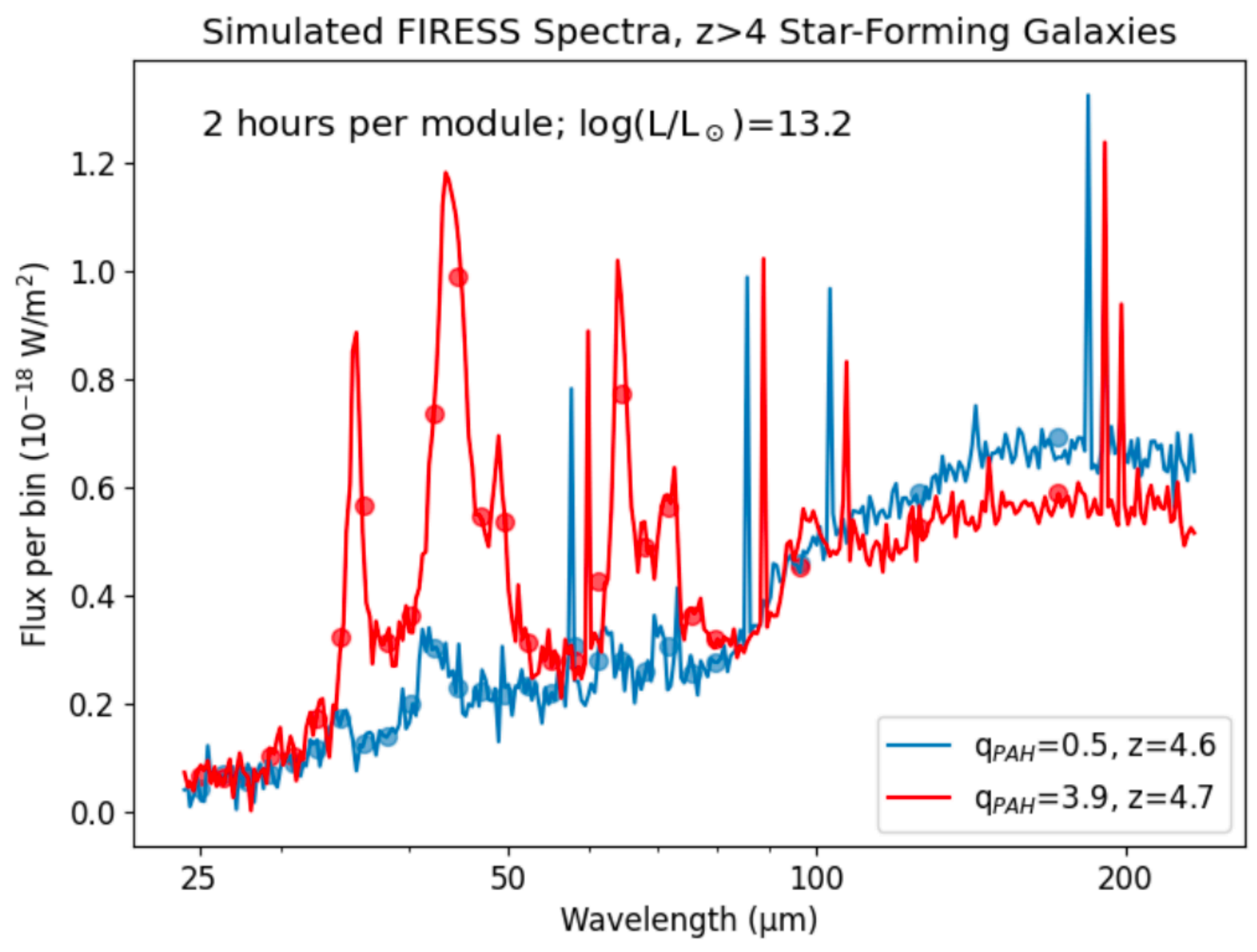


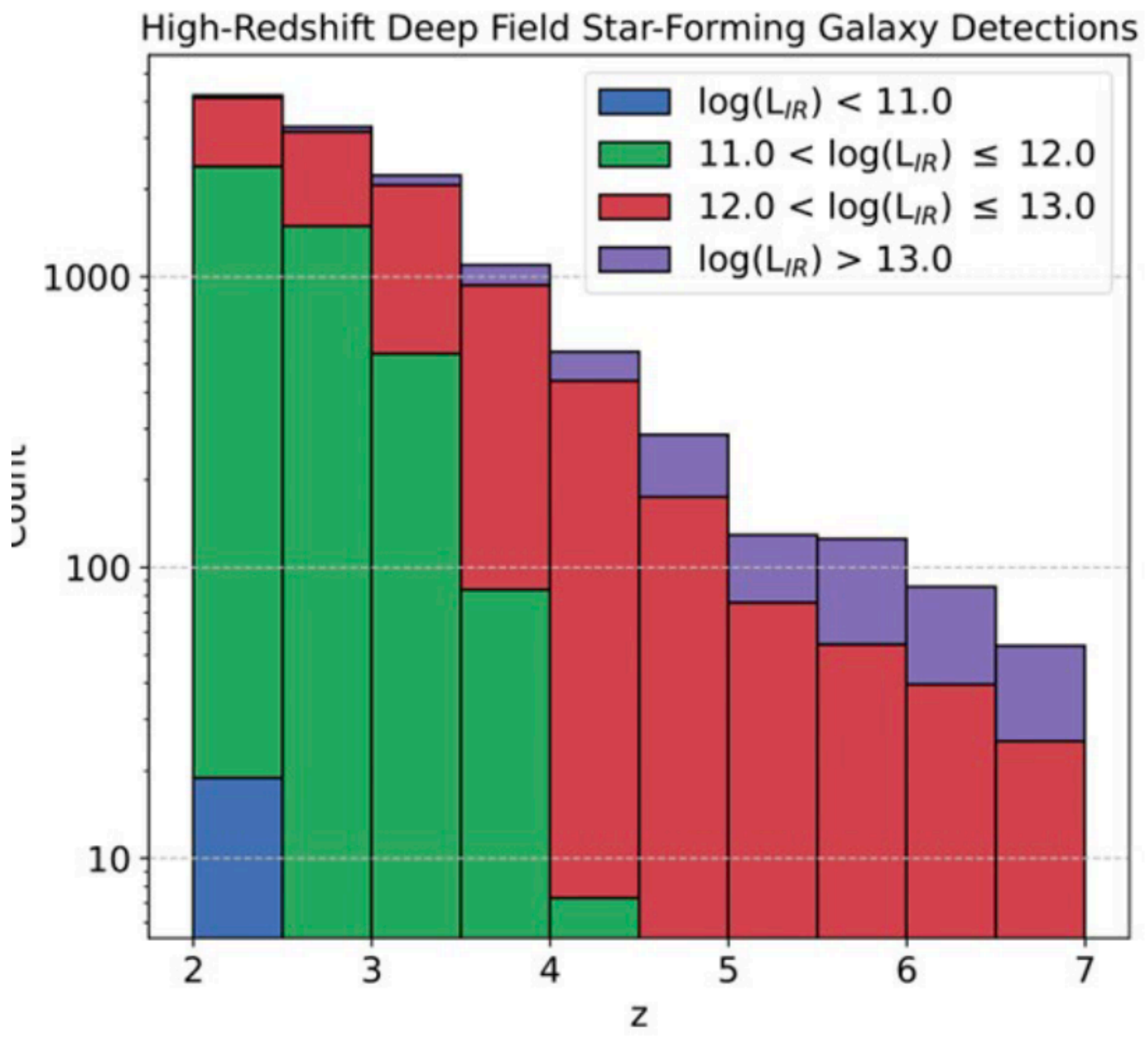
Bisigello+24



PRIMA: PAHs







Donnelly+24 (PRIMA GO SB Vol 1), also: Burgarella+, Blain+

PRIMA: FIR emission

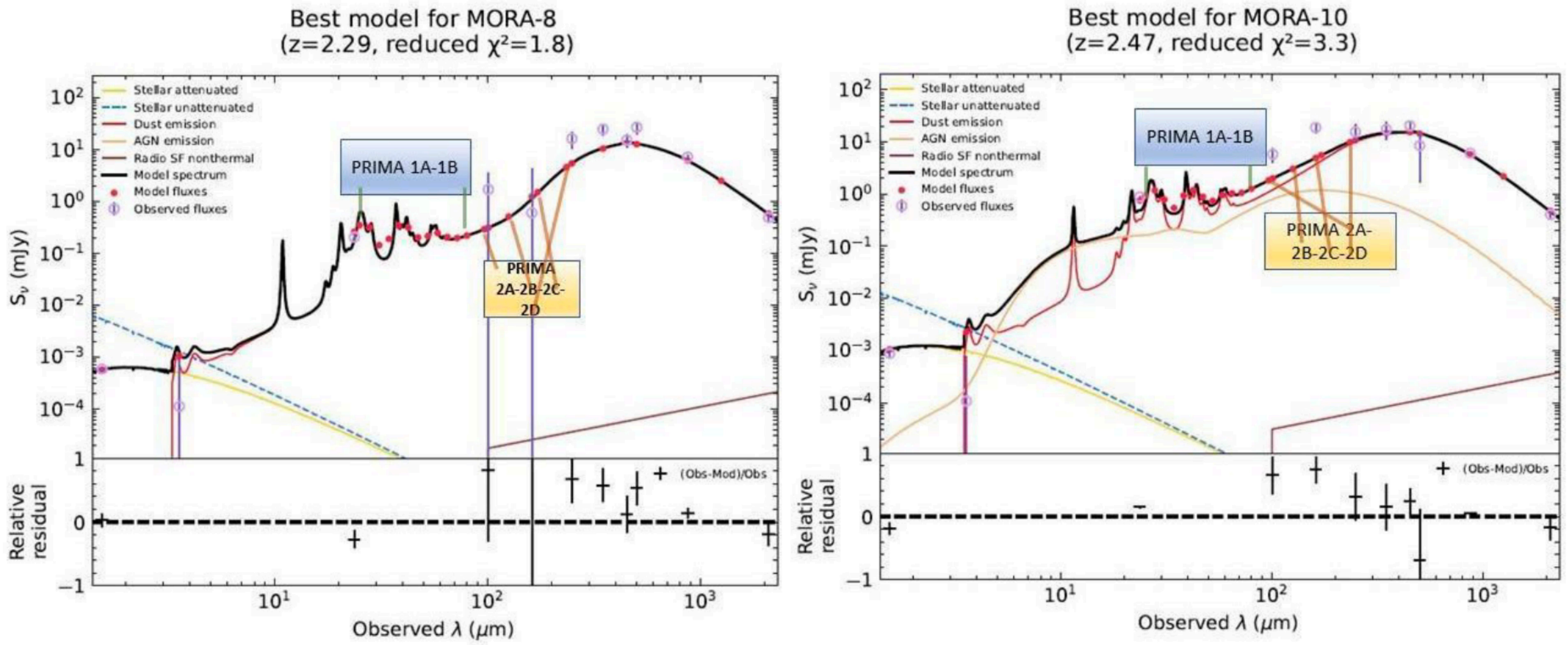


Figure 1: SED analysis of two example galaxies at cosmic noon showing expected PRIMA fluxes from Band1A to Band2D.

Kilerci+24 (PRIMA GO SB Vol 1)

PRIMA: FIR lines

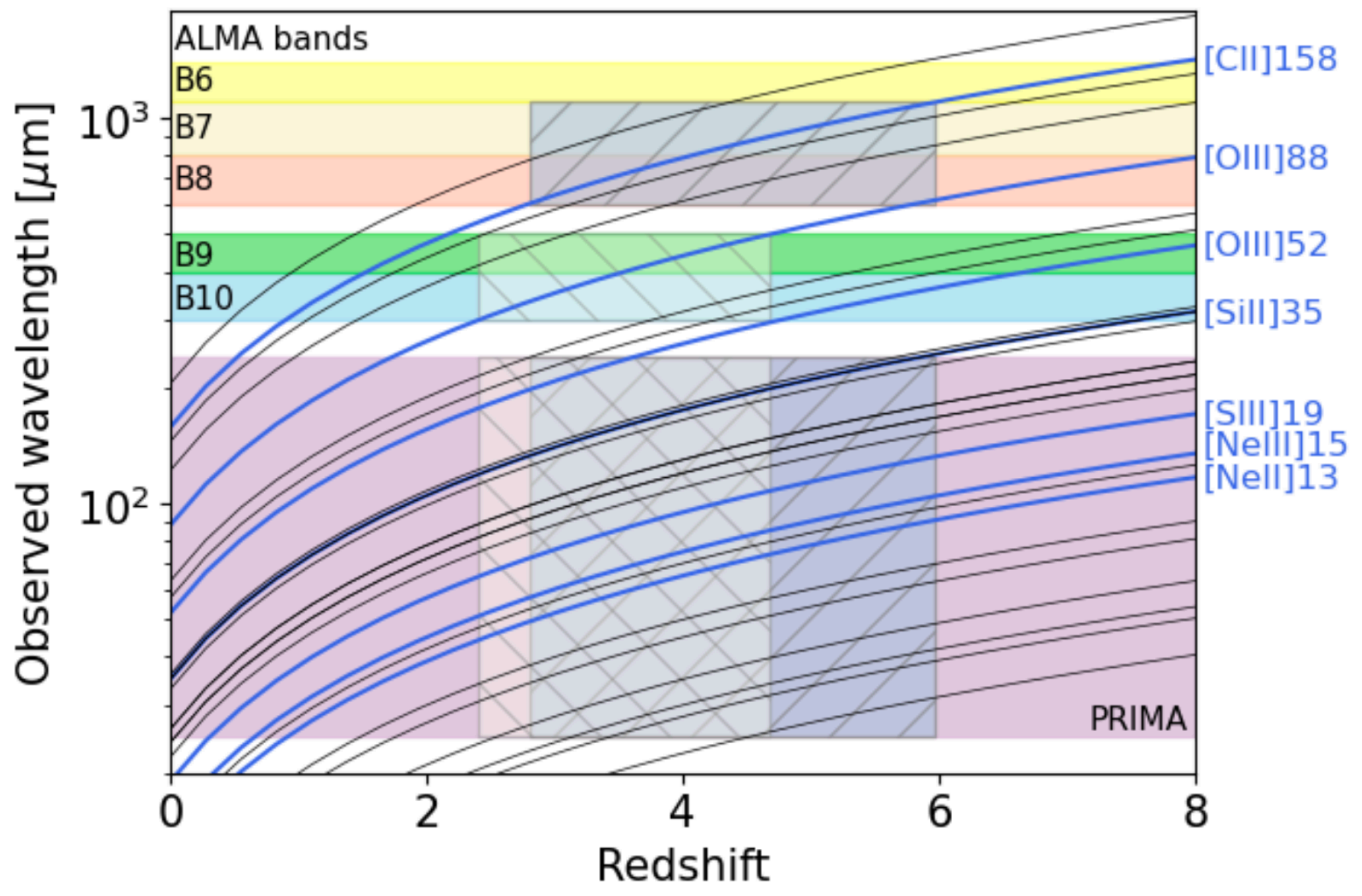
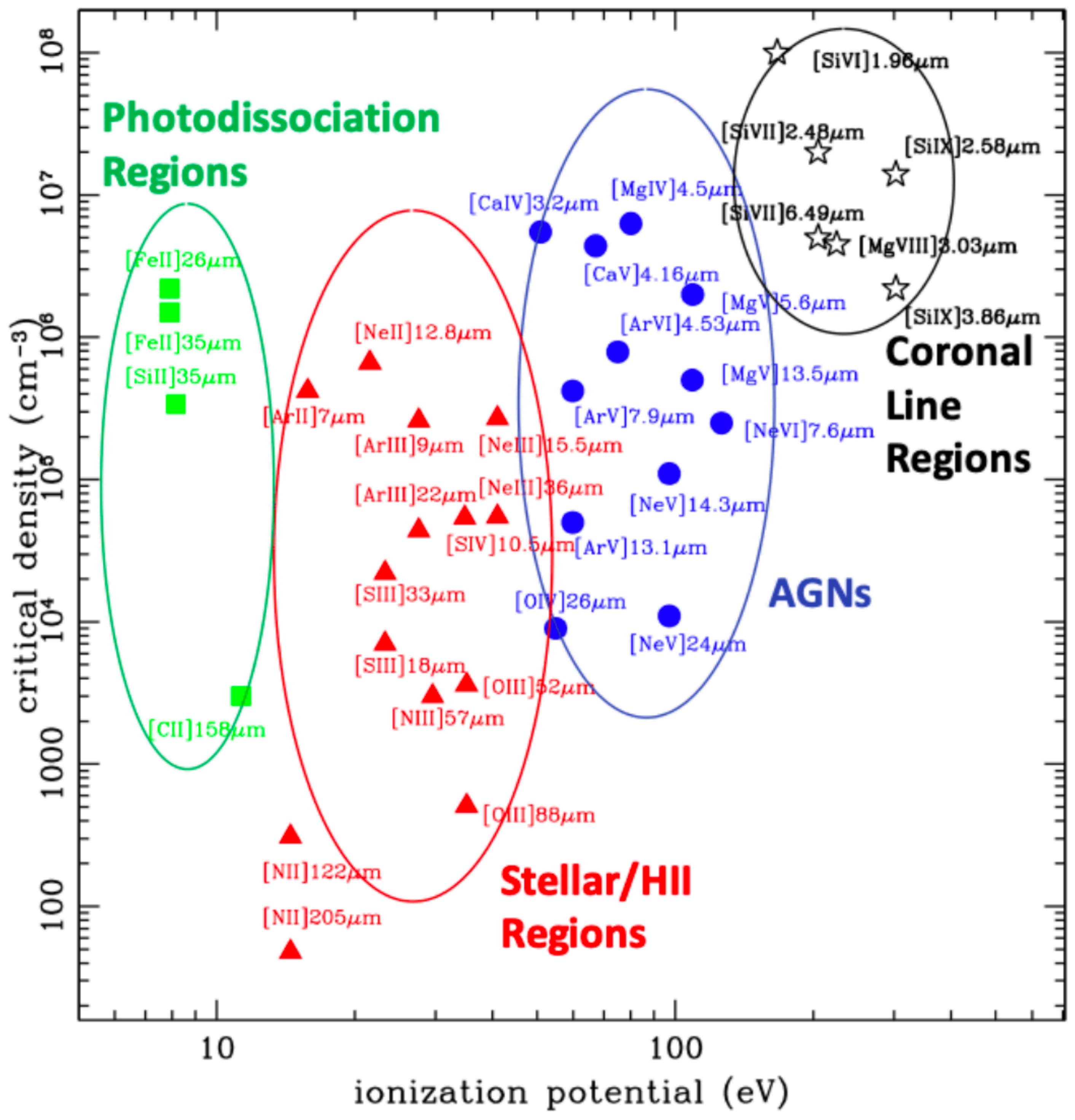


Figure 2: The redshift range that is ideal for PRIMA to follow up ALMA- and JWST-selected samples



Plot from Spinoglio et al. (2019) showing that different lines trace different regions of a galaxy.

Left: Inami+24, Right: Wardlow+ (PRIMA GO SB Vol 1), also Lebouteiller+, Nagao+

PRIMA: Your science!

- Galaxy Evolution Working Group
  - galaxies over the peak epoch of galaxy growth and out to the epoch of reionization: Dust, Metals, ISM, Stellar populations, Star formation
  - Leads: Irene Shivaei, Jed McKinney
  - CoI contacts: Alex Pope, JD Smith
  - ***We are collecting topics for GO Book Volume 2 to form small focused collaborations - time is tight! Join us!***

Summary

- ***Cosmic Noon*** is the new redshift frontier for panchromatic UV-FIR studies of galaxies and dust physics
- ***PRIMA*** is the missing gap to fully sample the UV-FIR SED at Cosmic Noon