

Dust Grains In Attenuation and Emission

from cosmic noon to the early Universe

Irene Shivaei

Centro de Astrobiología (CAB), Madrid, Spain

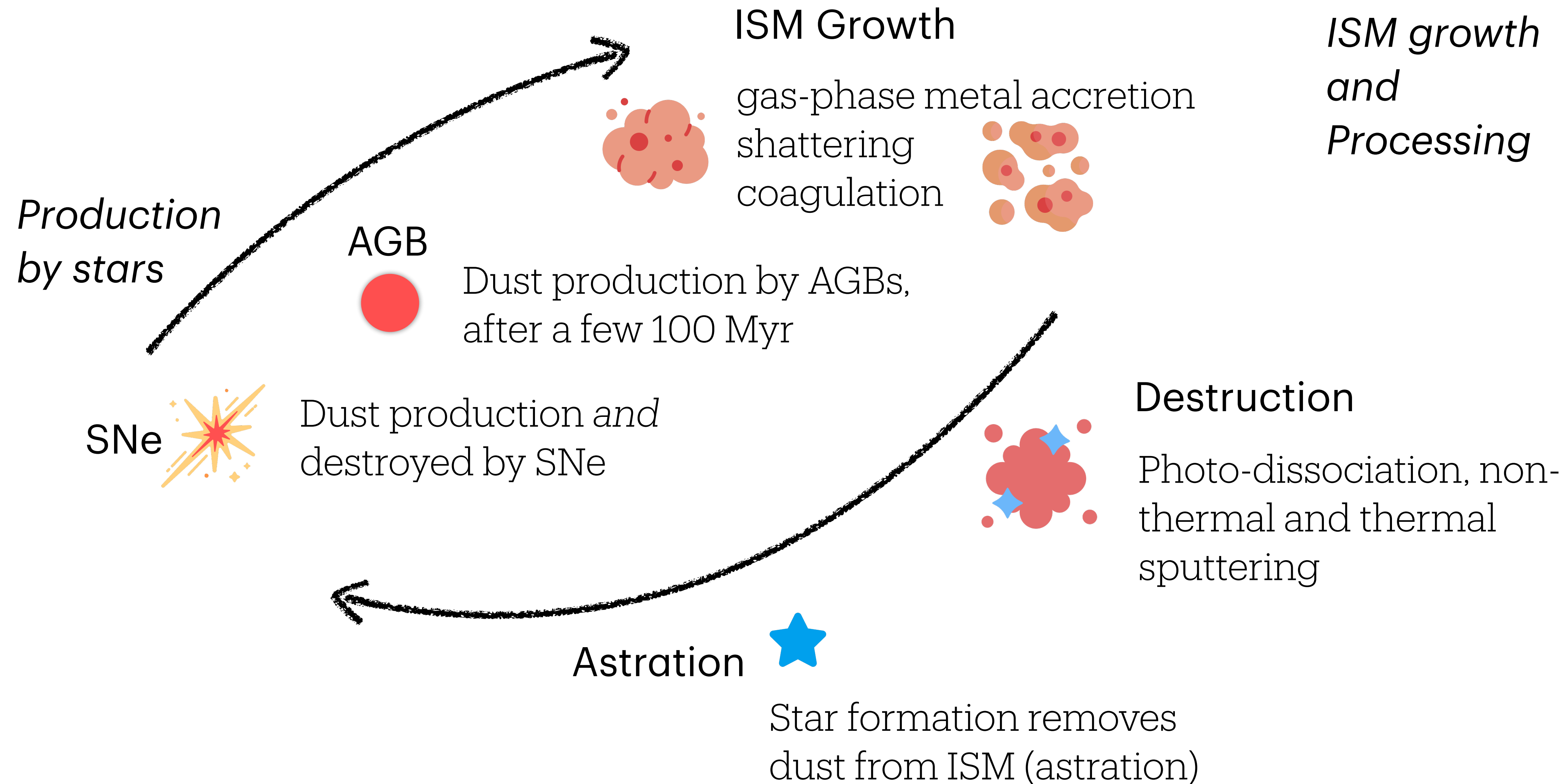


CSIC
CONSEJO SUPERIOR DE INVESTIGACIONES CIENTÍFICAS

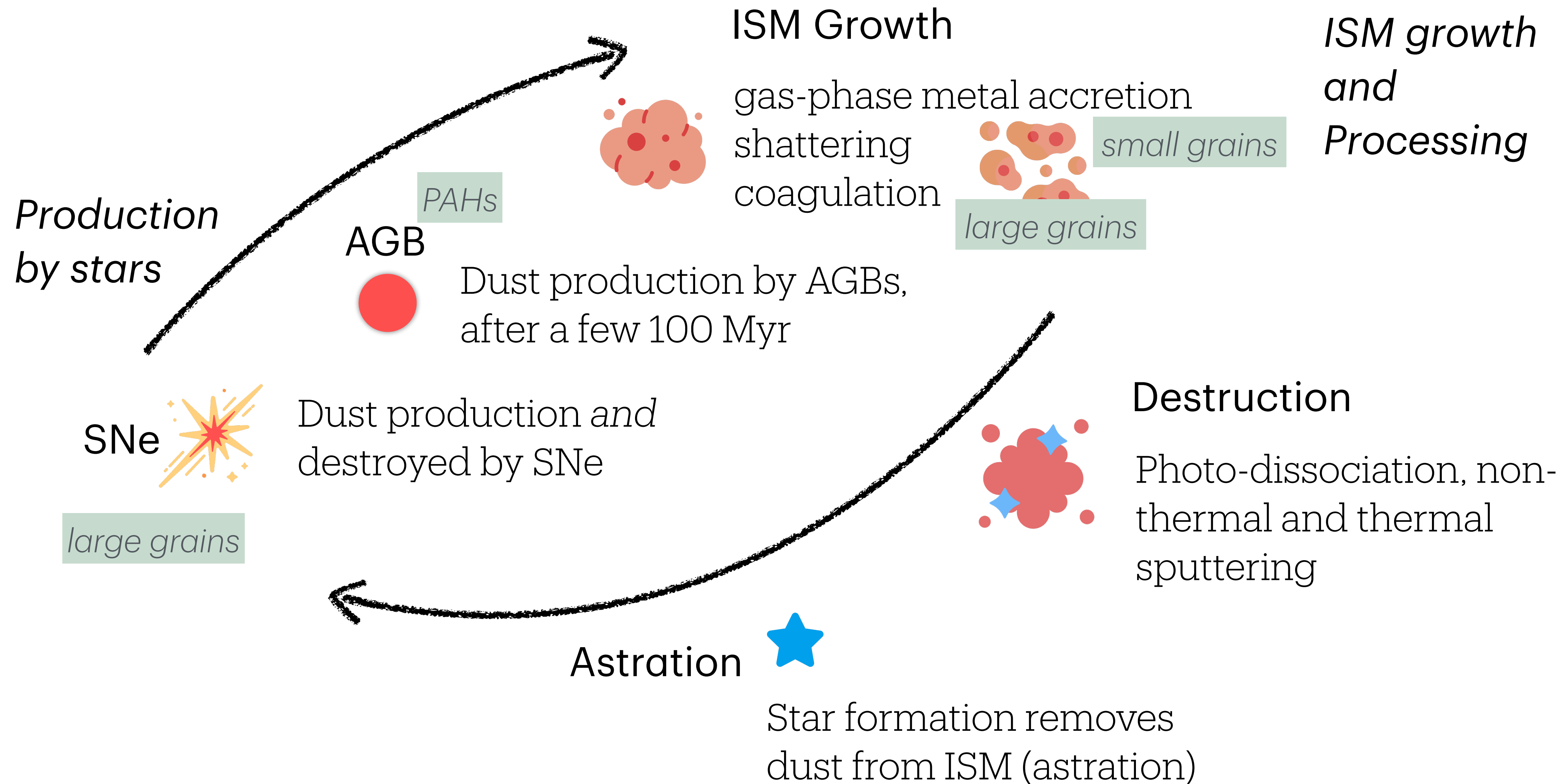


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Lifecycle of dust



Lifecycle of dust

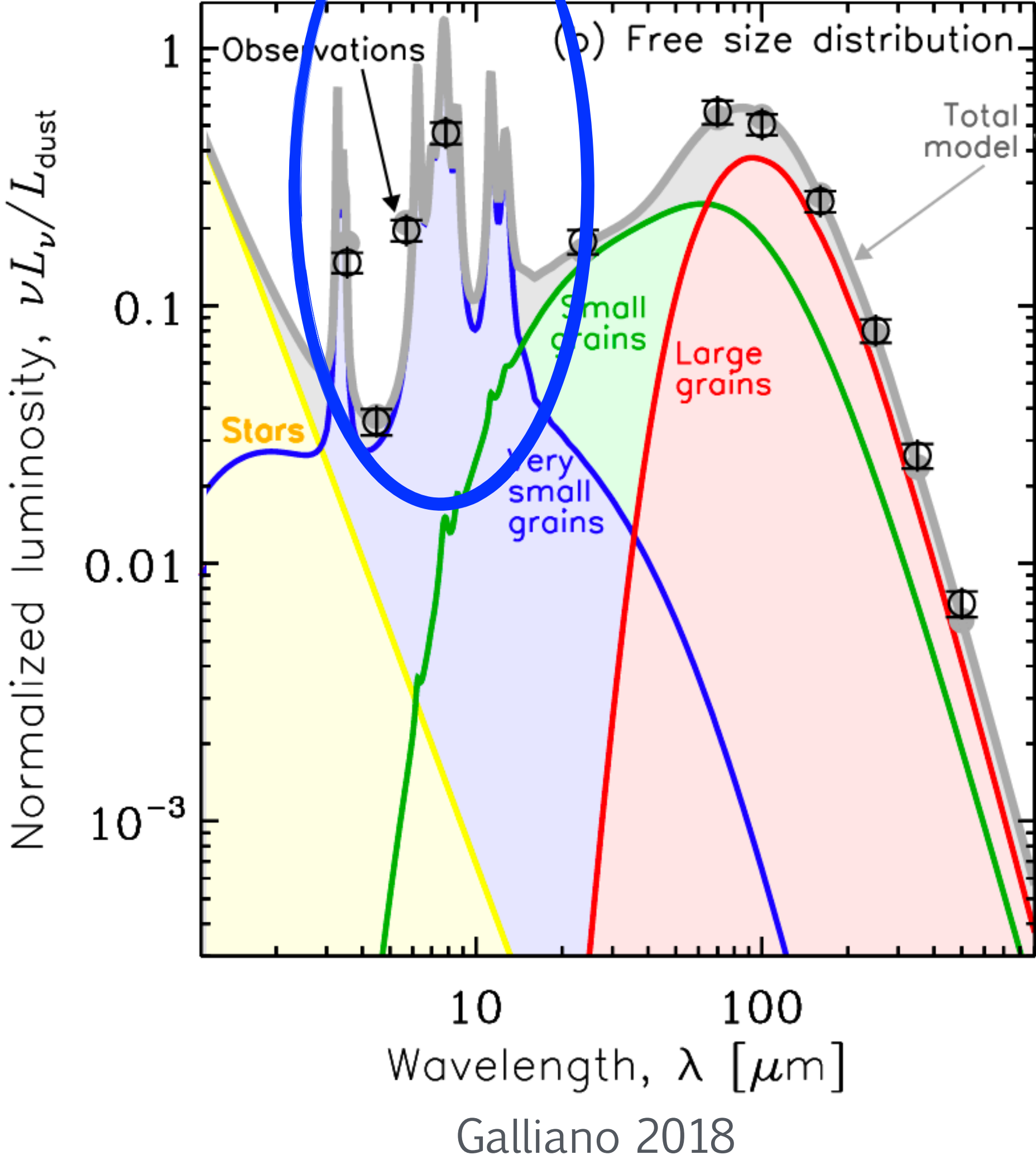
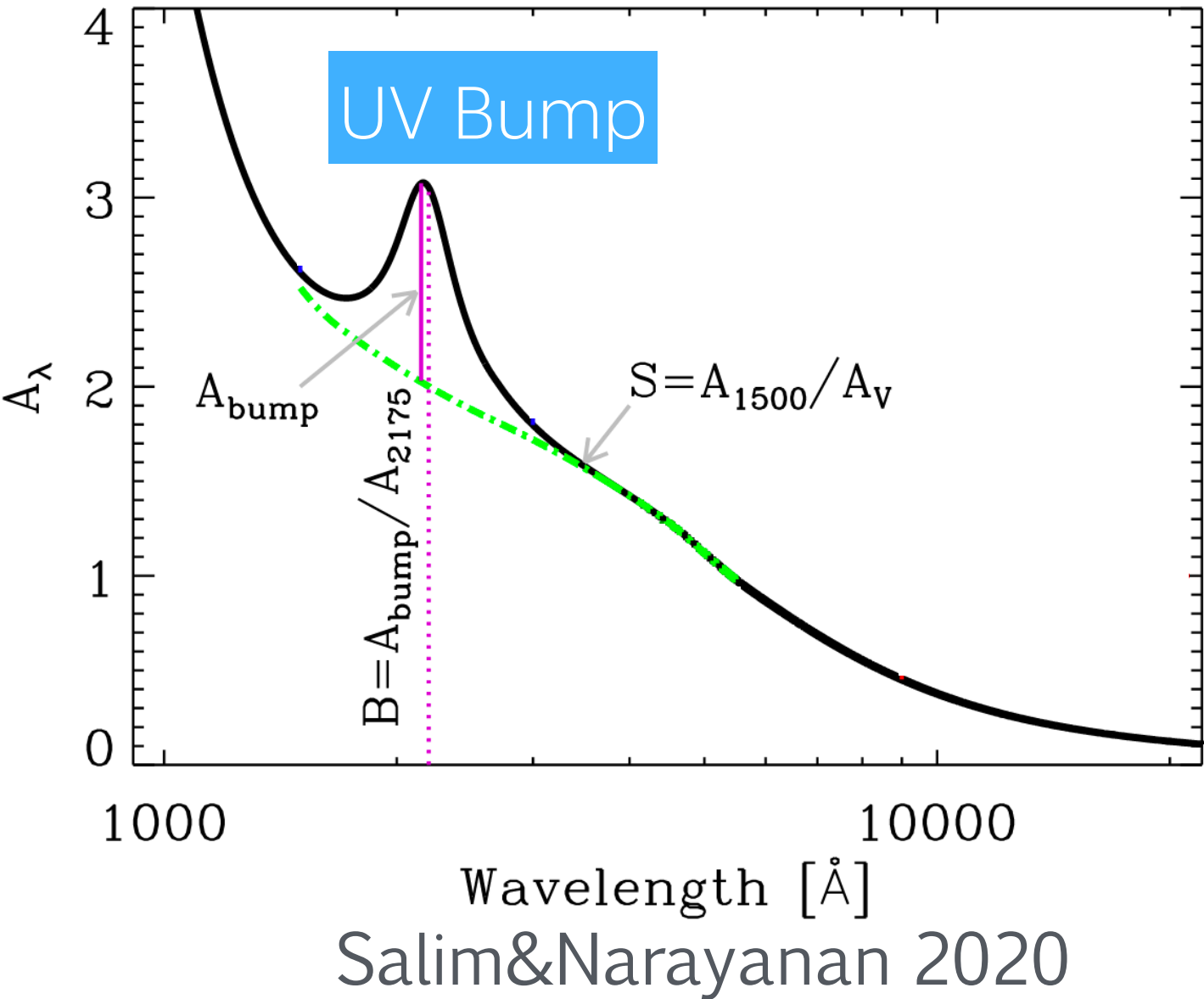


Grains with different sizes

Talk by
Karin Sandstorm

Very small grains (PAHs): florescent emission

- UV 2175A bump
- mid-IR bands



Grains with different sizes

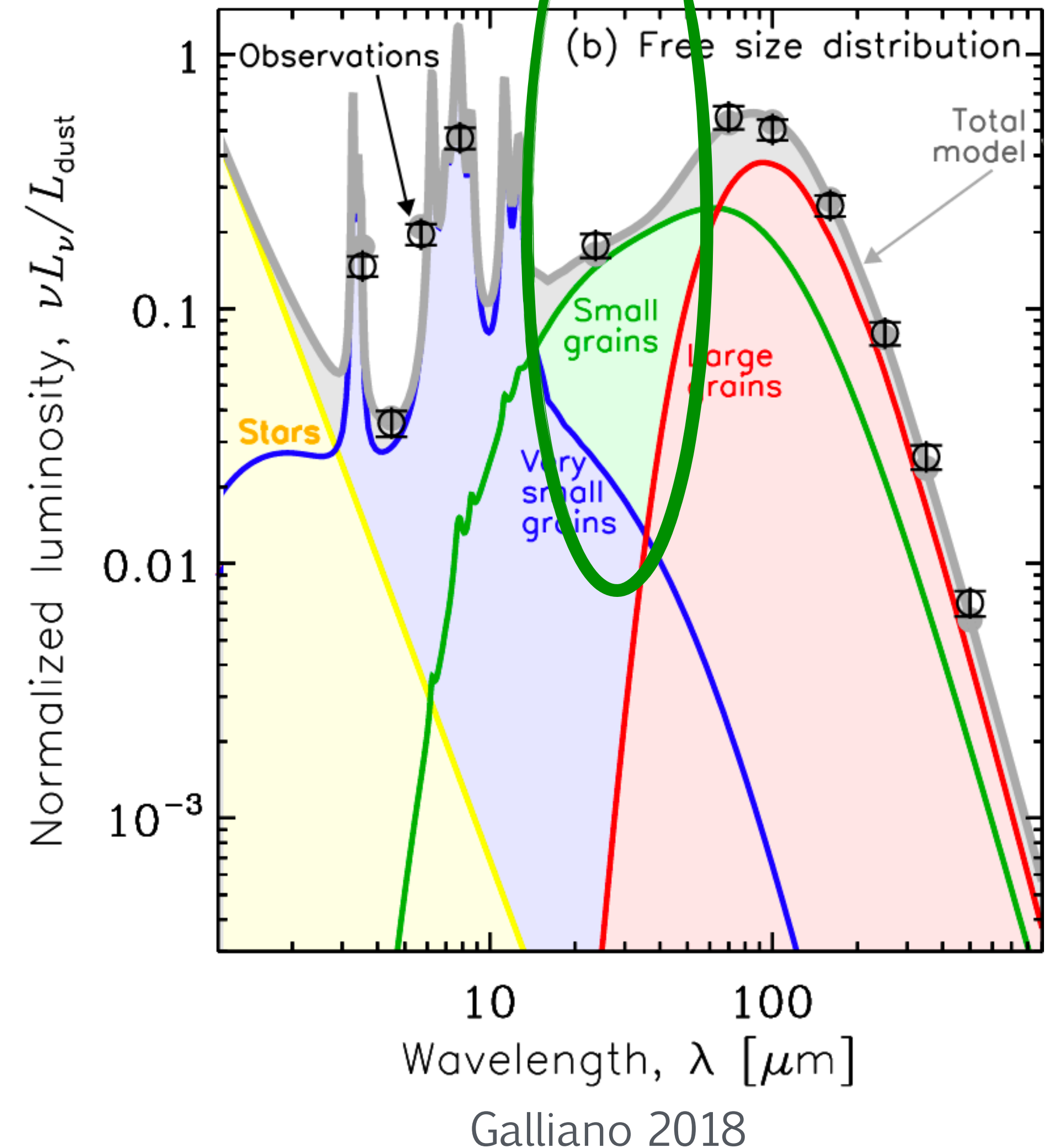
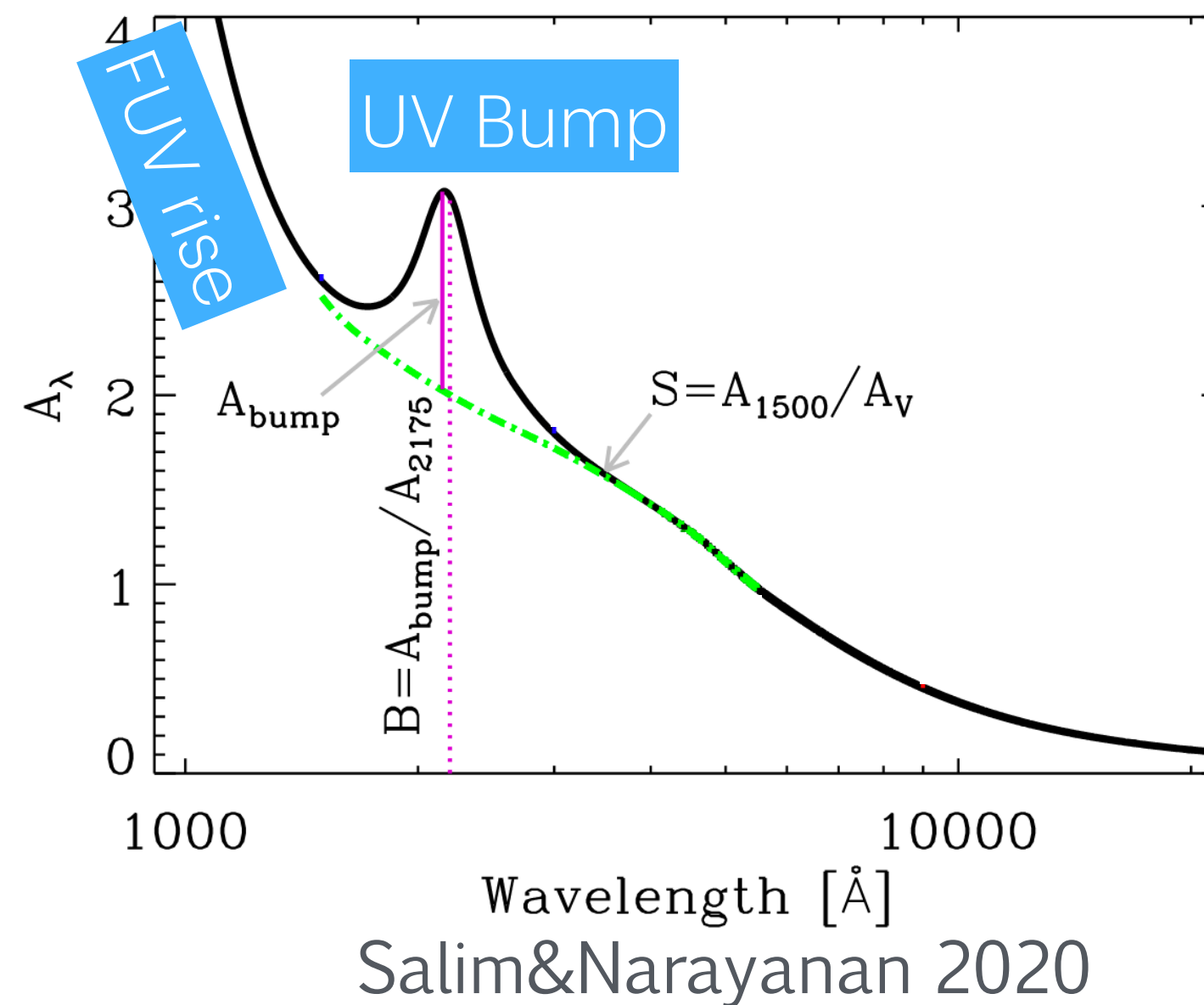
Talk by
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Very small grains (PAHs): florescent emission

- UV 2175Å bump
- mid-IR bands

Small grains: efficient UV absorber, hotter, emit at mid to far-IR

- far-UV attenuation
- ~10-70micron emission



Grains with different sizes

Very small grains (PAHs): florescent emission

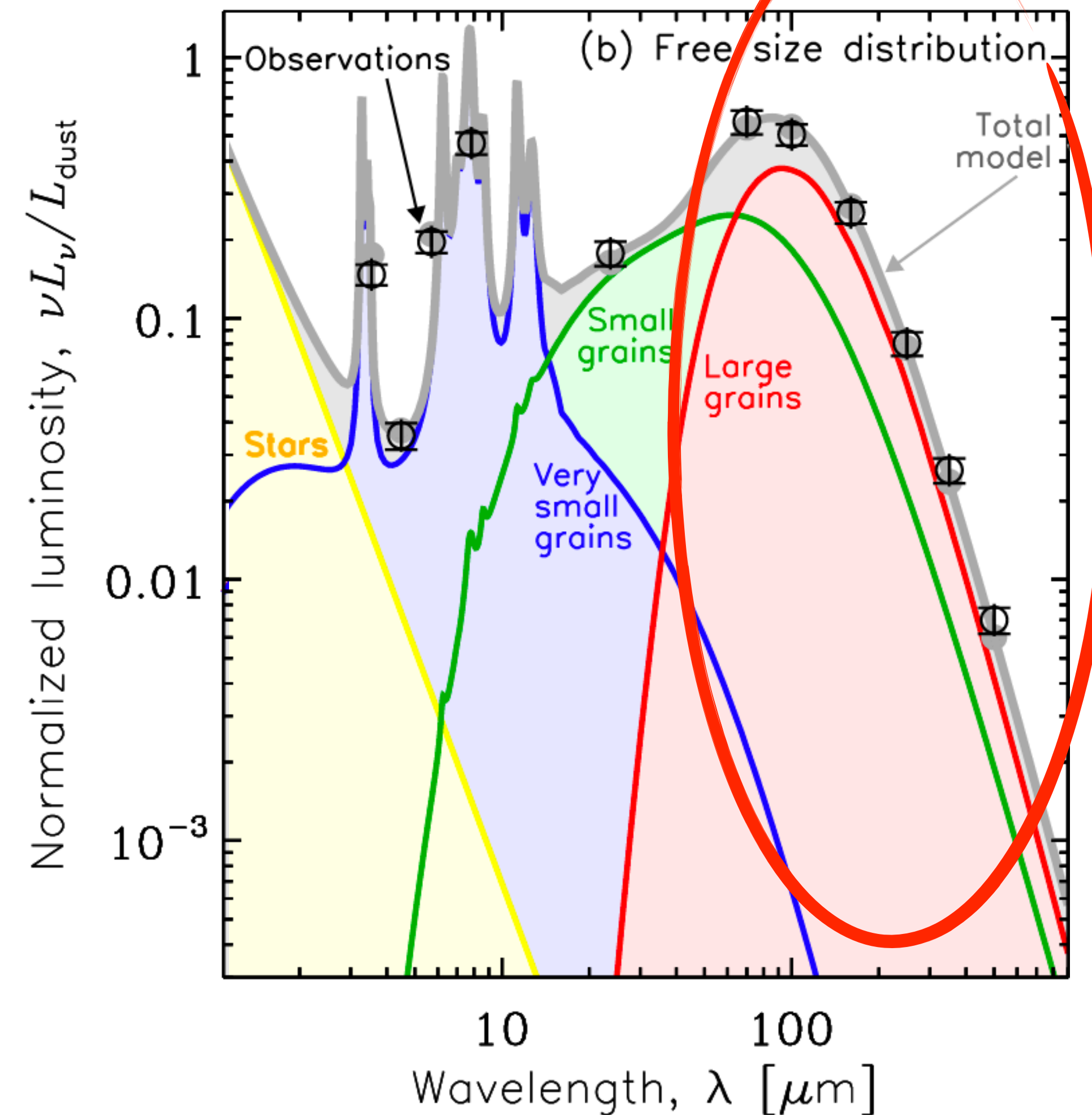
- UV 2175Å bump
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Small grains: efficient UV absorber, hotter, emit at mid to far-IR

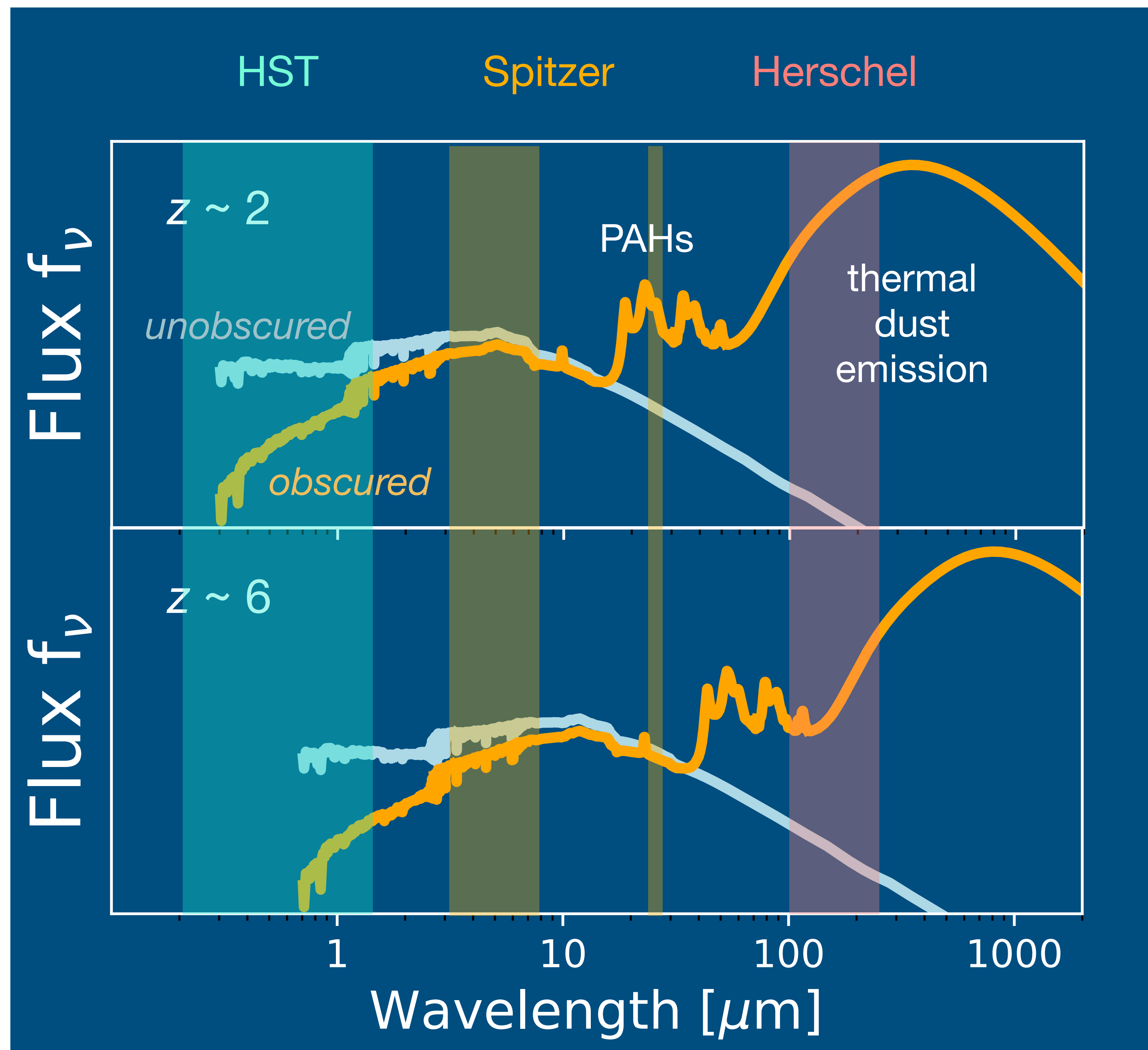
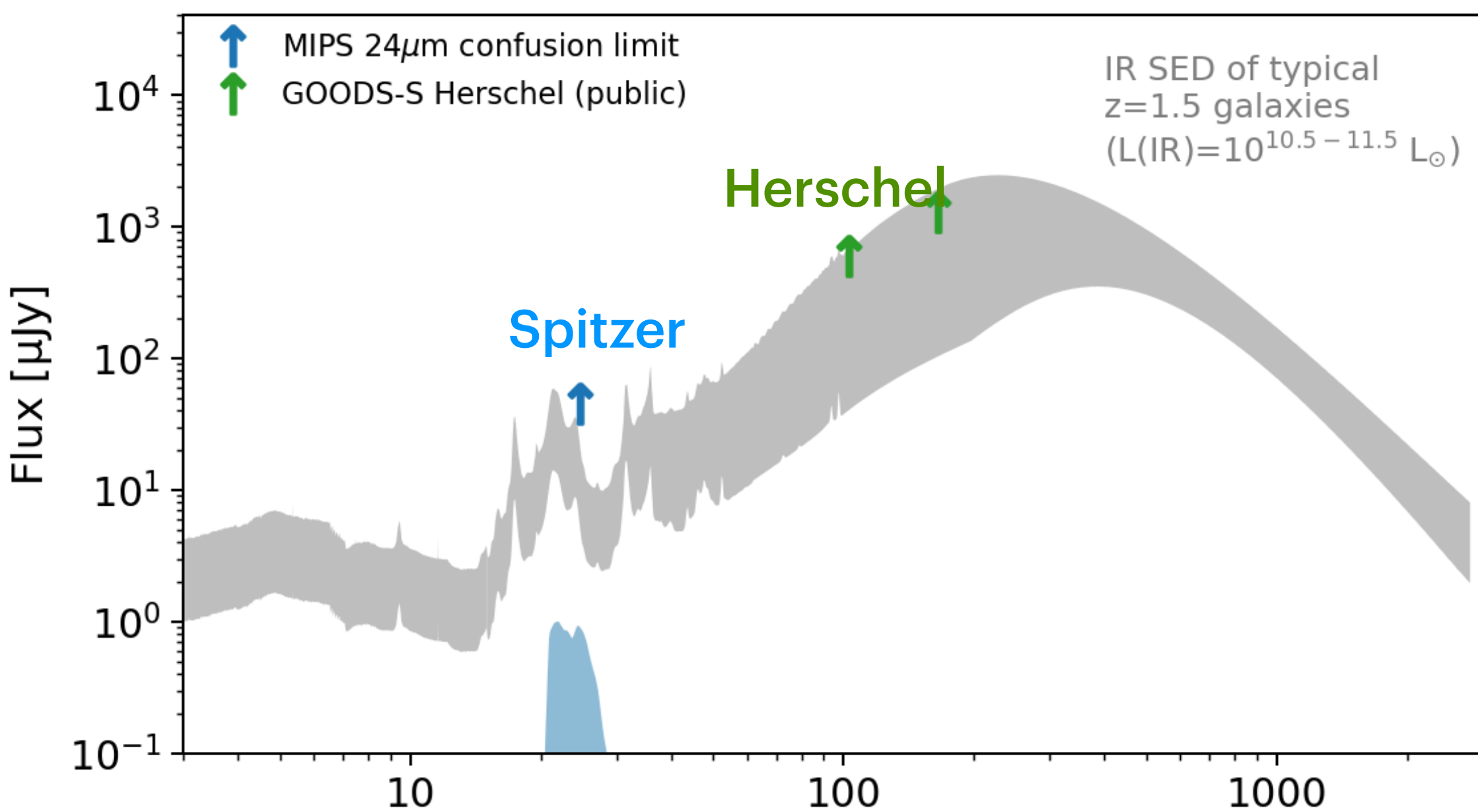
- far-UV attenuation
- ~10-70micron emission

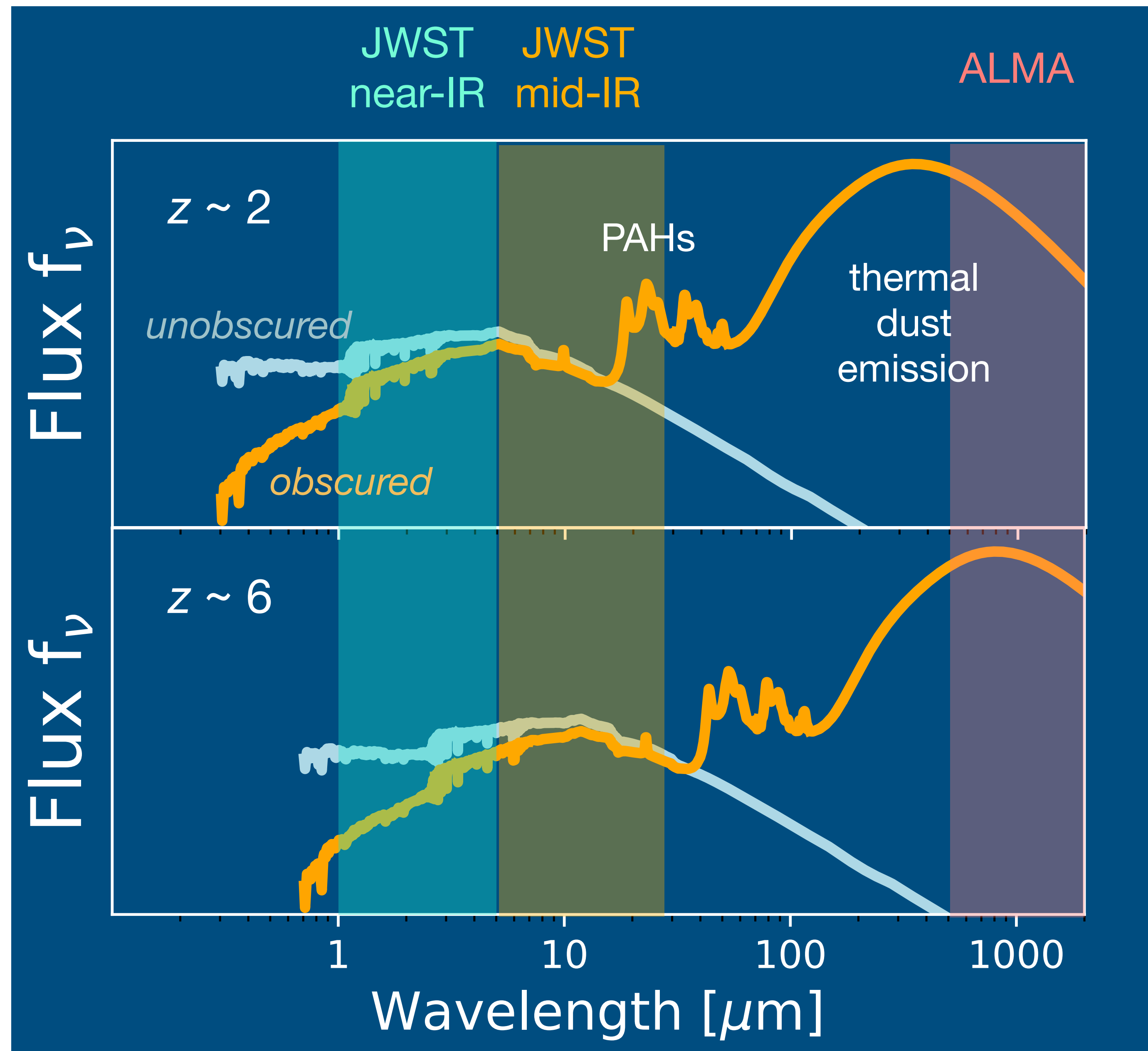
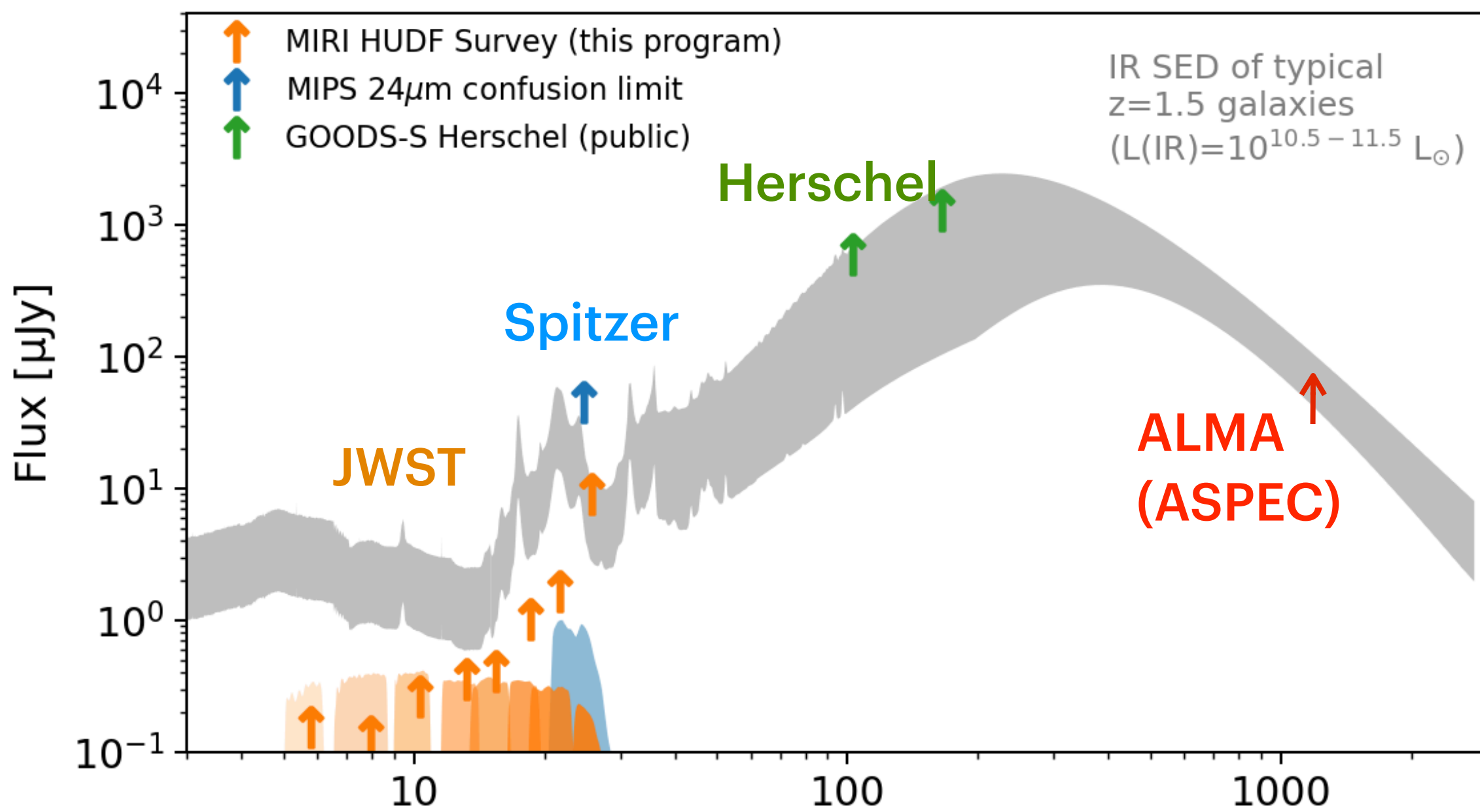
Large grains: in thermal equilibrium, colder, bulk of dust mass

- UV-optical attenuation
- far-IR emission



Galliano 2018





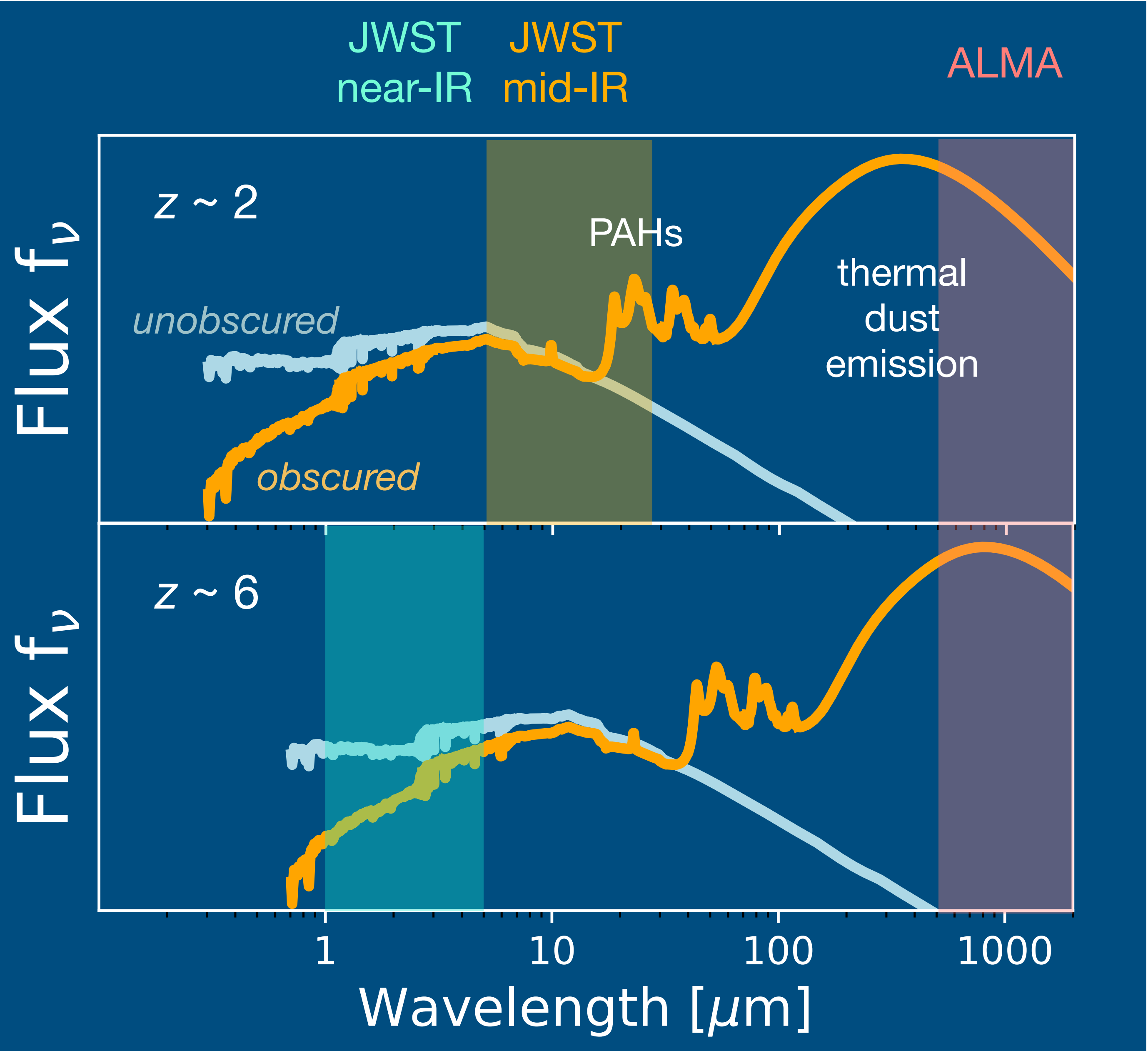
Power of JWST and ALMA

Cosmic Noon

- Small grains: PAHs
- Large grains: cold dust

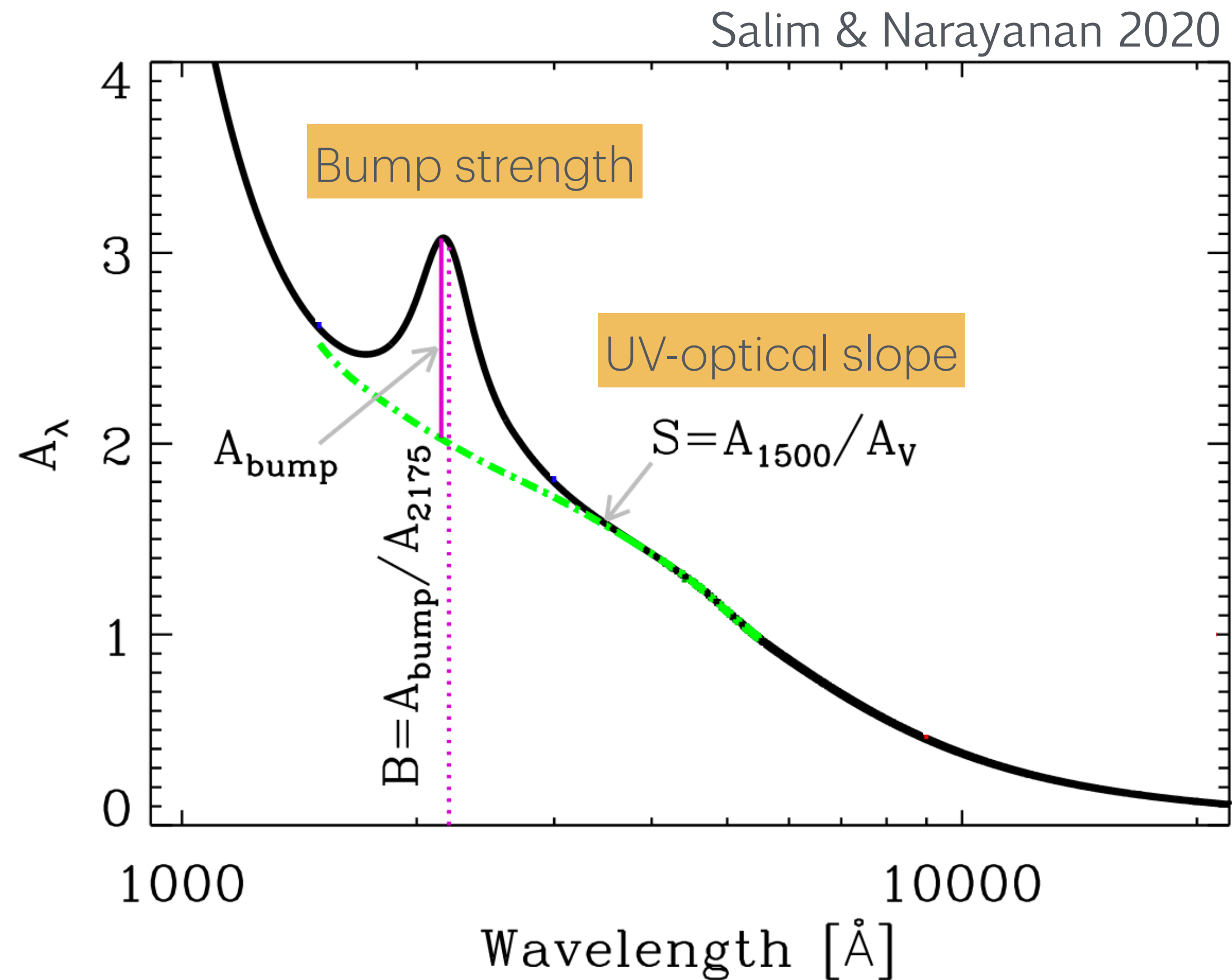
Early Universe

- Small grains: UV bump + stellar attenuation curve
- Large grains: cold dust

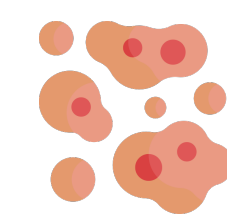


Attenuation curve

Talk by
Samir Salim



What changes the UV-optical curve slope?



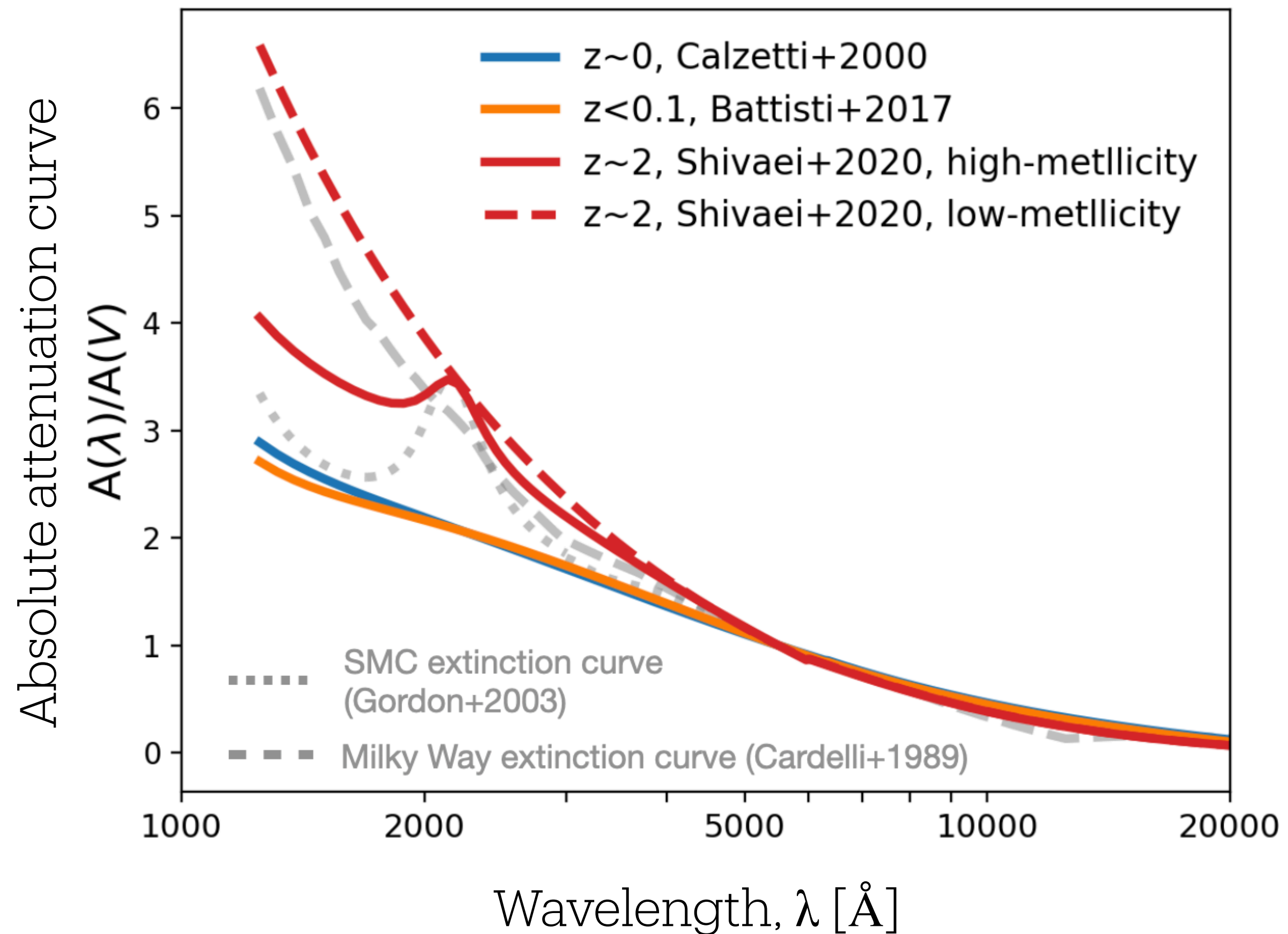
Grain properties (underlying extinction curve)



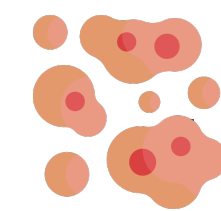
Dust-star geometry

Stellar attenuation curve

Large variations in UV-optical slope and UV bump from $z \sim 0$ to 3



What changes the UV-optical curve slope?



Grain properties

- Significant change with metallicity

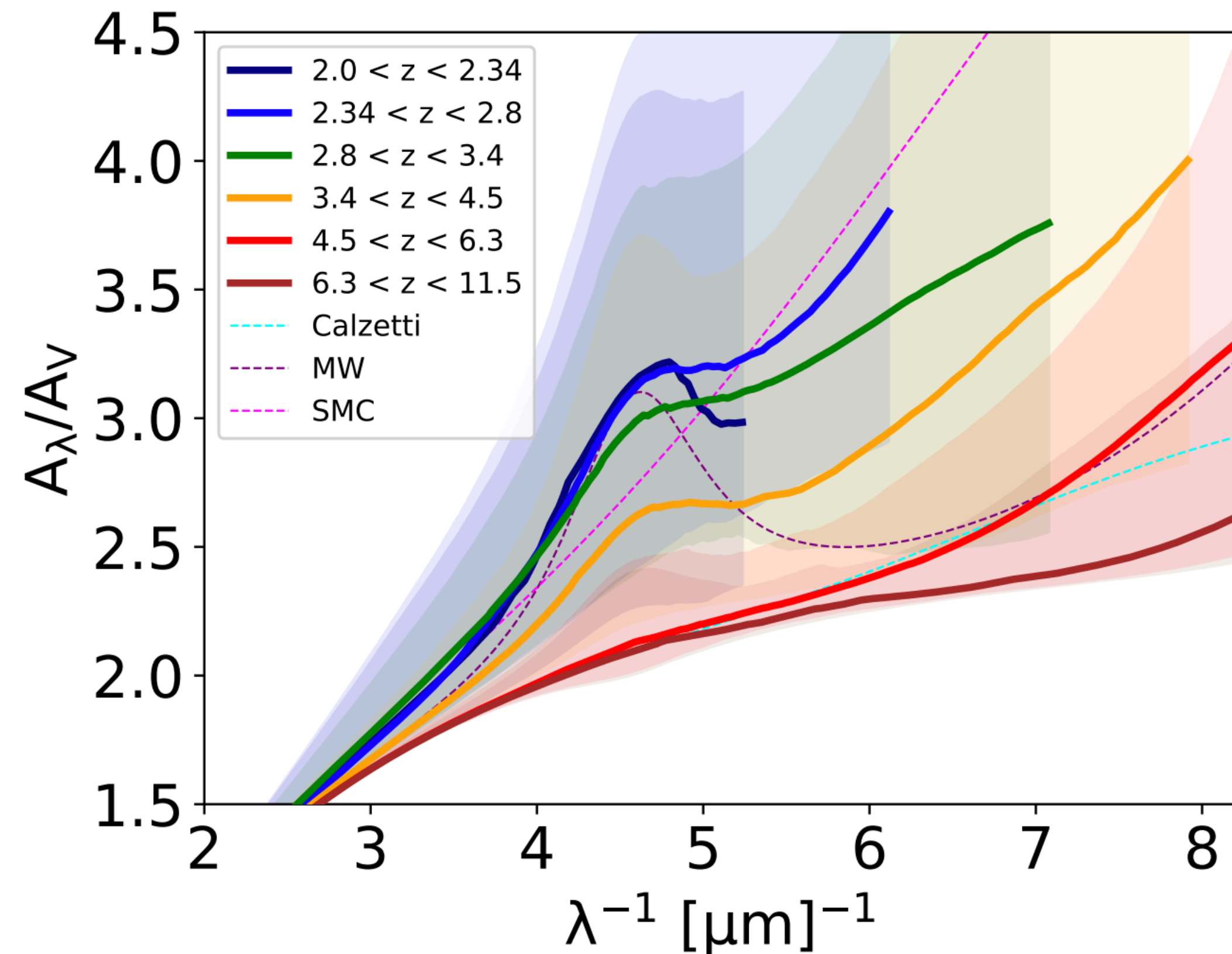


Dust-star geometry

See e.g., Calzetti et al. 1994, 2000; Wild et al. 2011; Kriek & Conroy 2013; Reddy et al. 2015; Scoville et al. 2015; Battisti et al. 2016, 2017a,b; Salmon et al. 2016; Salim et al. 2018; Buat et al. 2018; Battisti et al. 2020; Shivaiei et al. 2020a,b; Calzetti et al. 2021; Nagaraj et al. 2022; Maheson et al. 2025

Redshift evolution of attenuation curve?

At high- z : evidence for shallow curves, but not always

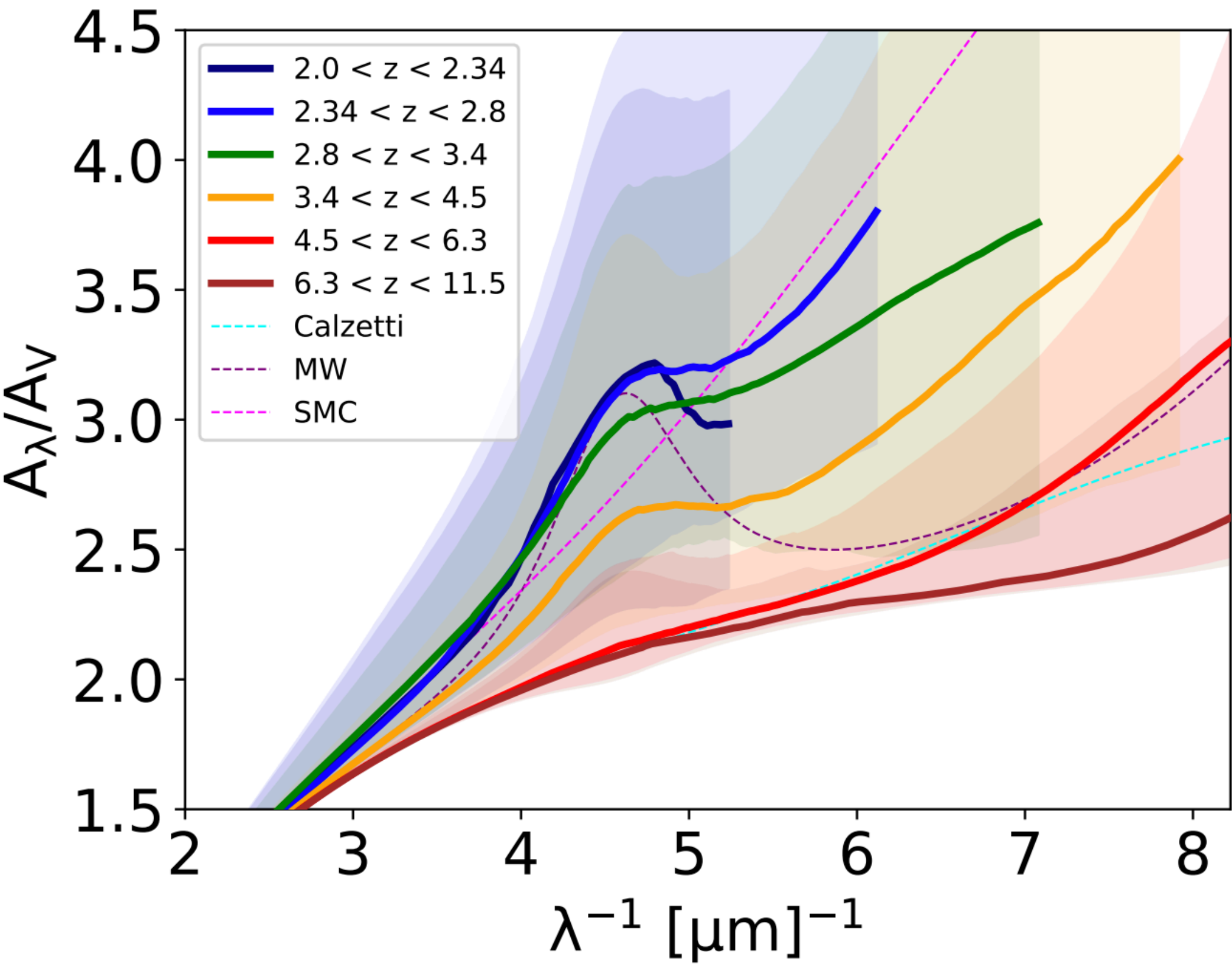


Markov+2024

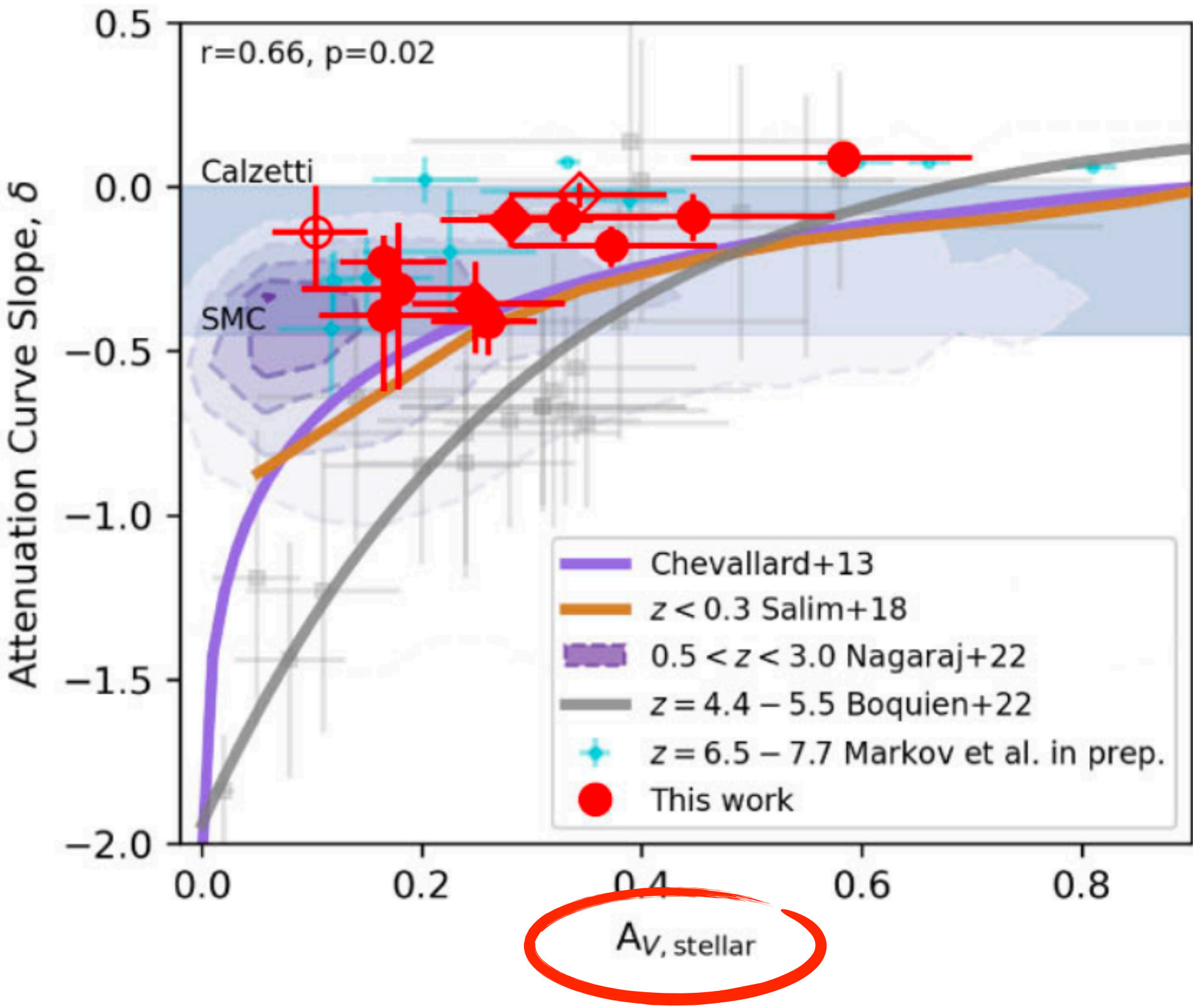
(also Markov+2025, McKinney+2025)

Stellar attenuation curve

At high- z : evidence for shallow curves, but not always



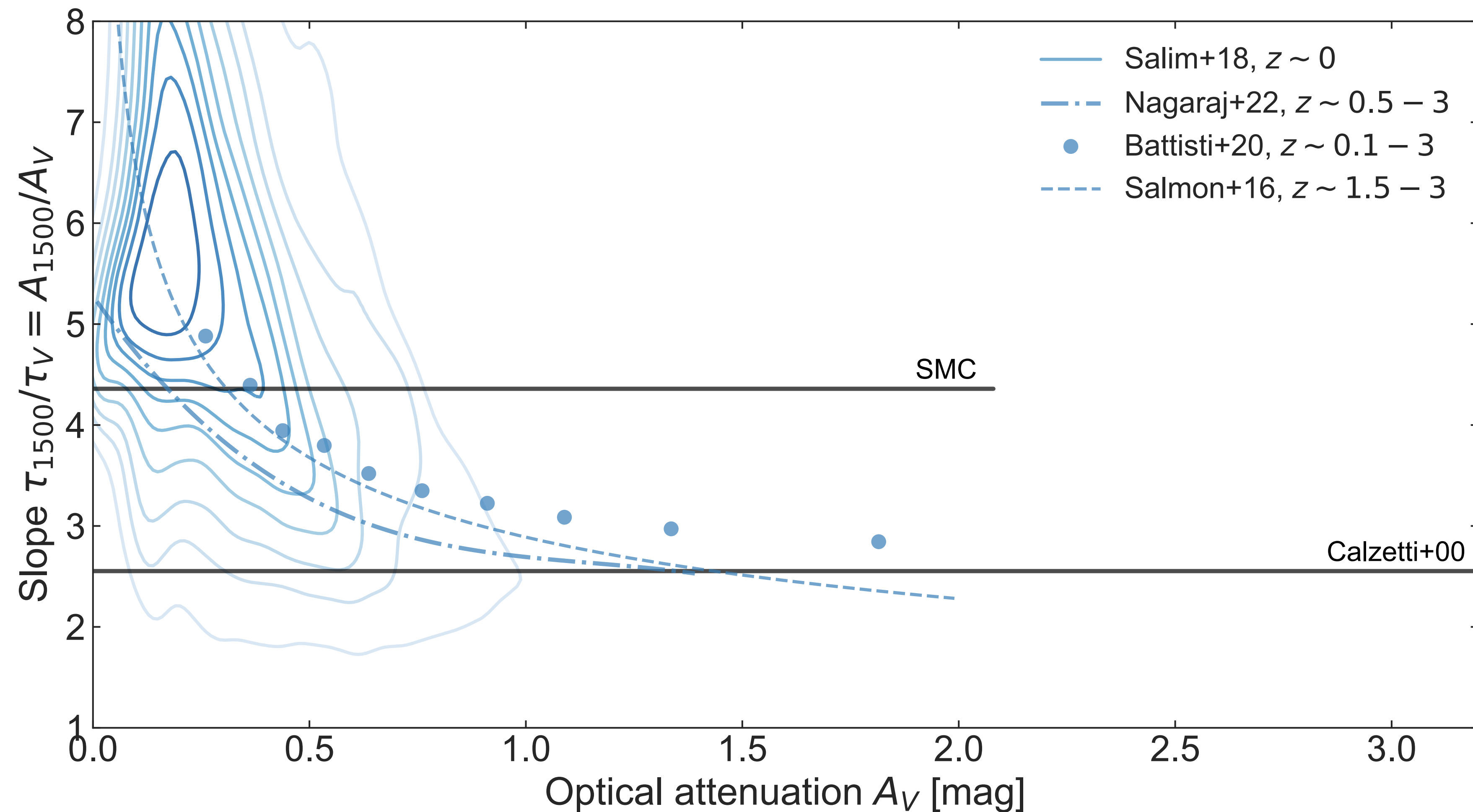
Markov+2024
(also McKinney+2025)



Fisher+2025
(also Markov+2025, Shivaiei+2025)

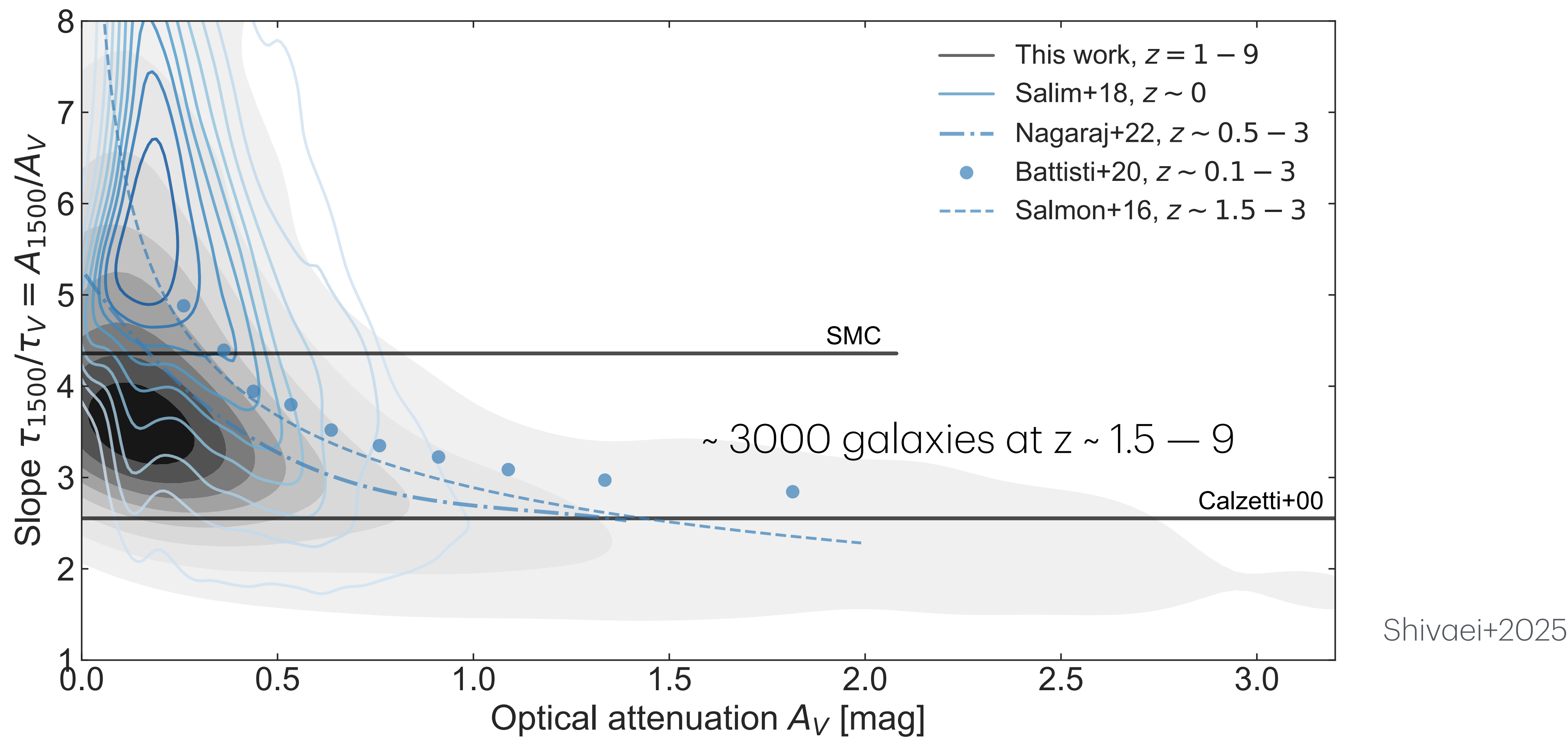
Curve slope- A_V relation

Effects of scattering, dust-star geometry, and ISM chemical evolution



Curve slope- A_V relation

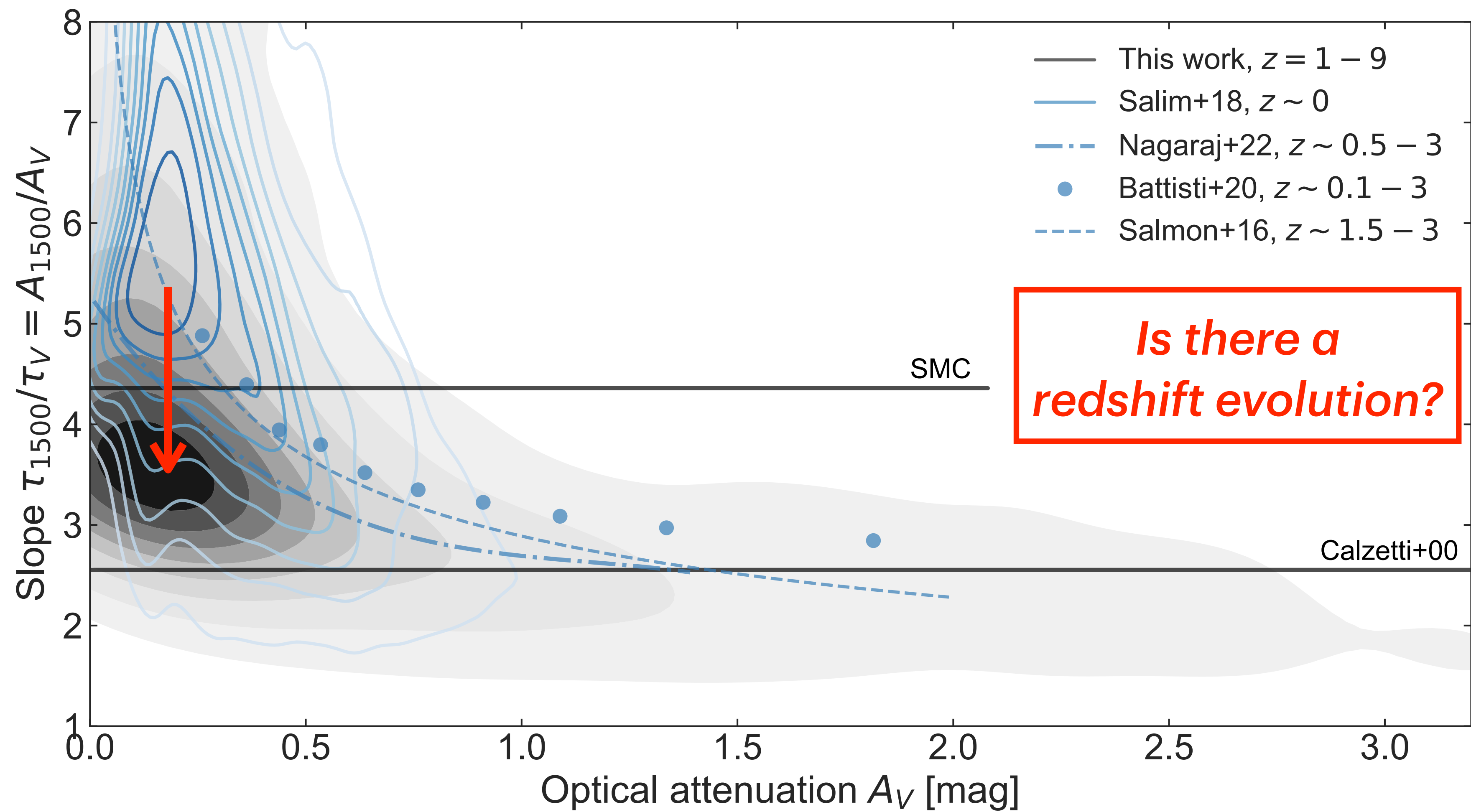
Effects of scattering, dust-star geometry, and ISM chemical evolution



See for theoretical work, Chevallard et al. 2013; Narayanan et al. 2018; Trayford et al. 2020; Markov et al. 2025; Matsumoto et al. 2025

Curve slope- A_V relation

Effects of scattering, dust-star geometry, and ISM chemical evolution

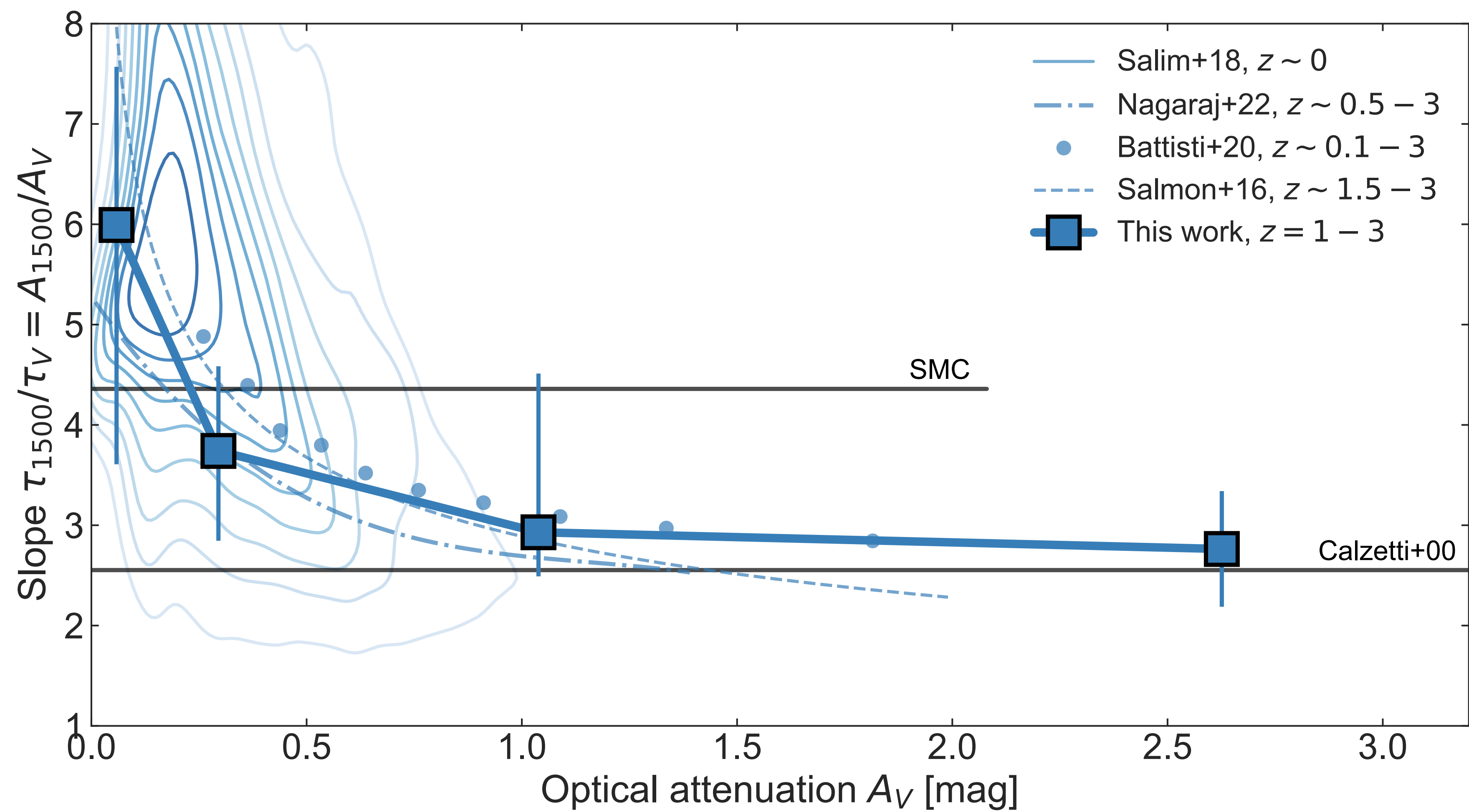


Shivaei+2025

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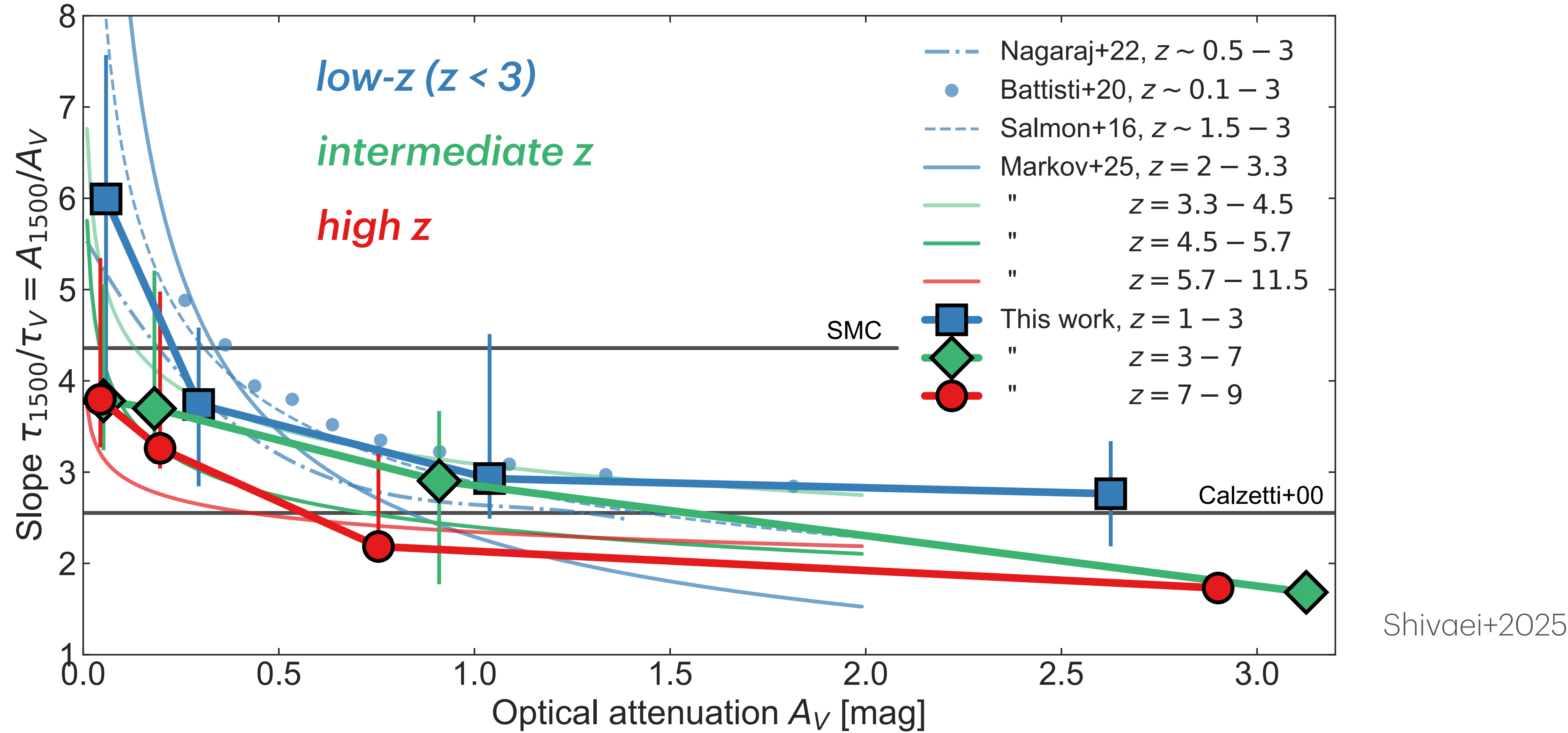
Curve slope- A_V relation

Is there a redshift evolution?



Shivaei+2025

Shallower curves at high- z



[Different methodologies]

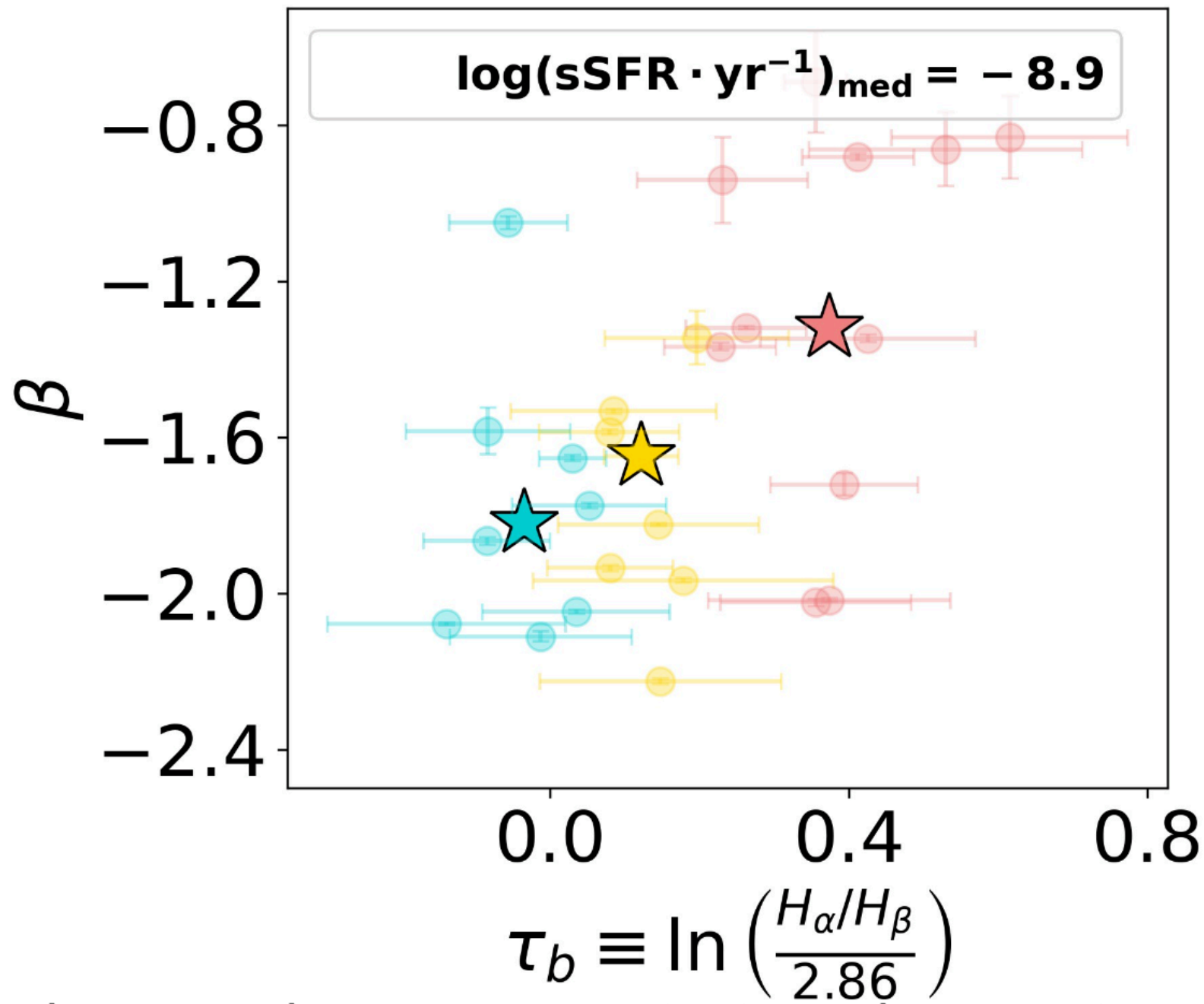


Poster 108



Ana Varo O'Ferral
PhD student at CAB (Madrid)

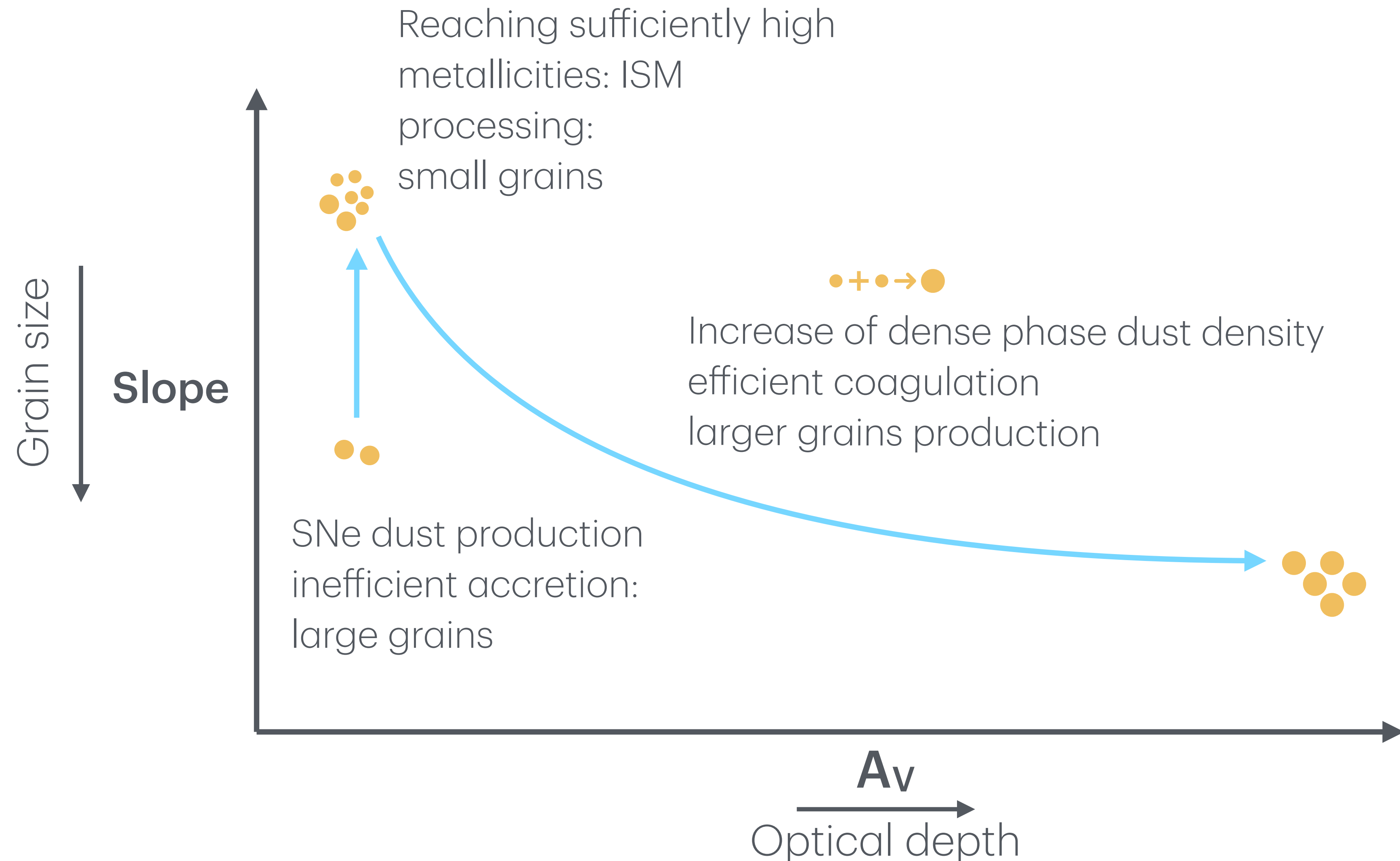
Talk by
Giulia Rodighiero



Balmer decrement-method (Calzetti+00):
empirical, no SED fitting

converging on finding shallow curves at
high- z ?

A theory: dust grain evolution



A theory: dust grain evolution

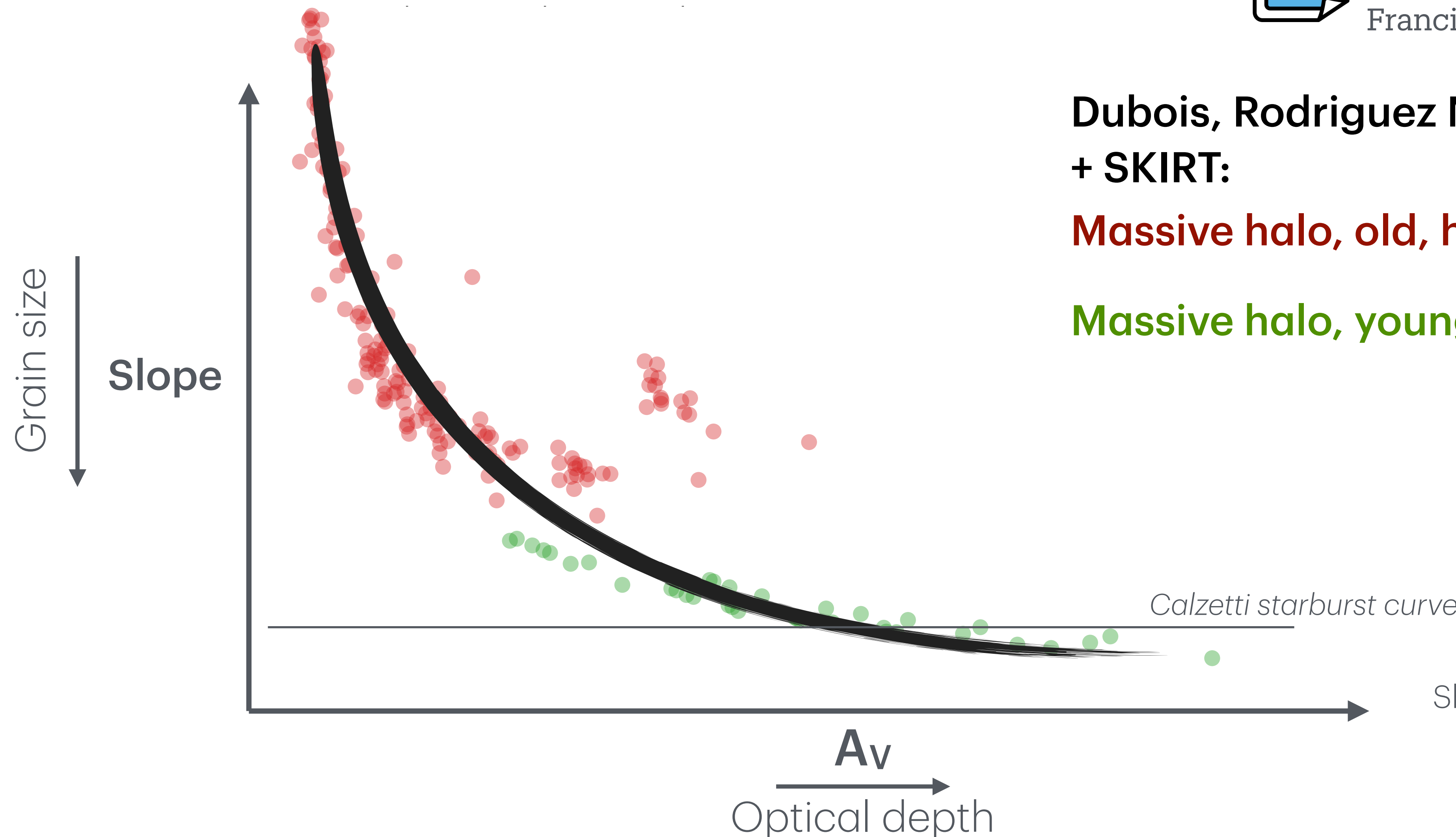
Models:



Poster 54



Francisco (Curro) Rodriguez Montero



**Dubois, Rodriguez Montero+24 models
+ SKIRT:**

Massive halo, old, high-Z, low f_{gas}

Massive halo, young, high-Z, high f_{gas}

Shivaei+2025

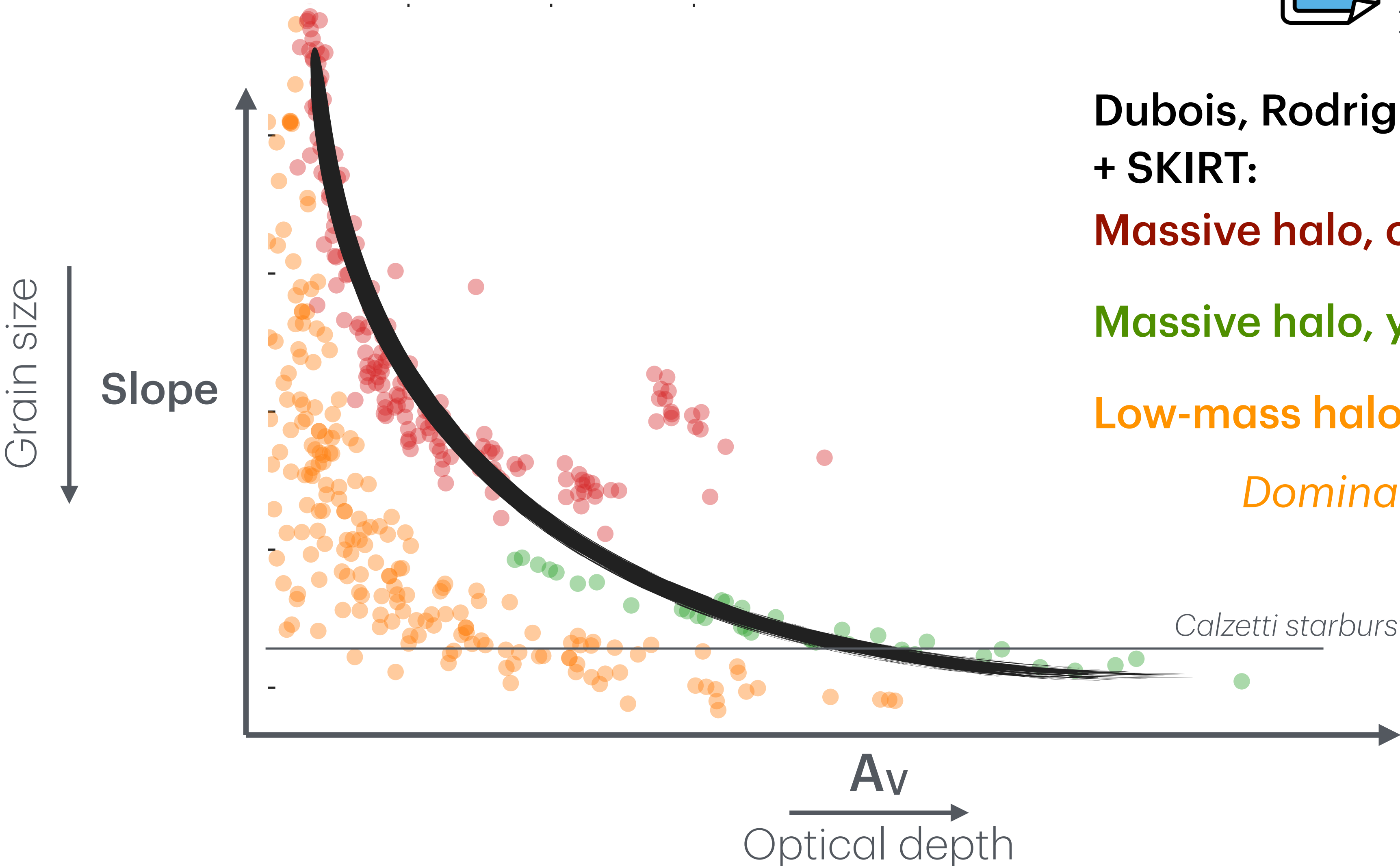
A theory: dust grain evolution



Poster 54

Francisco (Curro) Rodriguez Montero

Models:



Dubois, Rodriguez-Montero+24 models
+ SKIRT:

Massive halo, old, high-Z, low f_{gas}

Massive halo, young, high-Z, high f_{gas}

Low-mass halo, young, low-Z, high f_{gas}

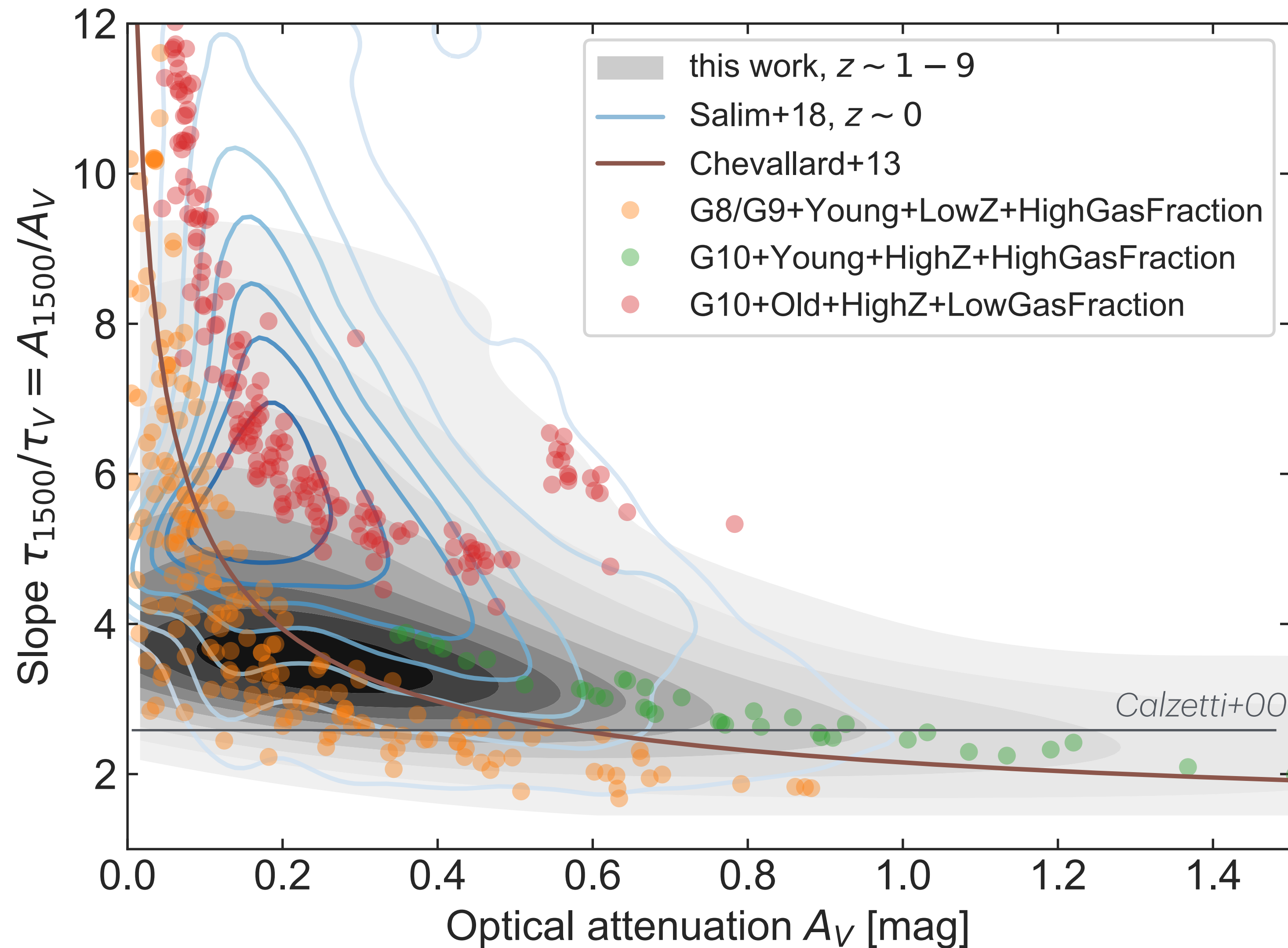
Dominant SNe dust

Calzetti starburst curve

Shivaei+2025

A theory: large dust grains at high-z

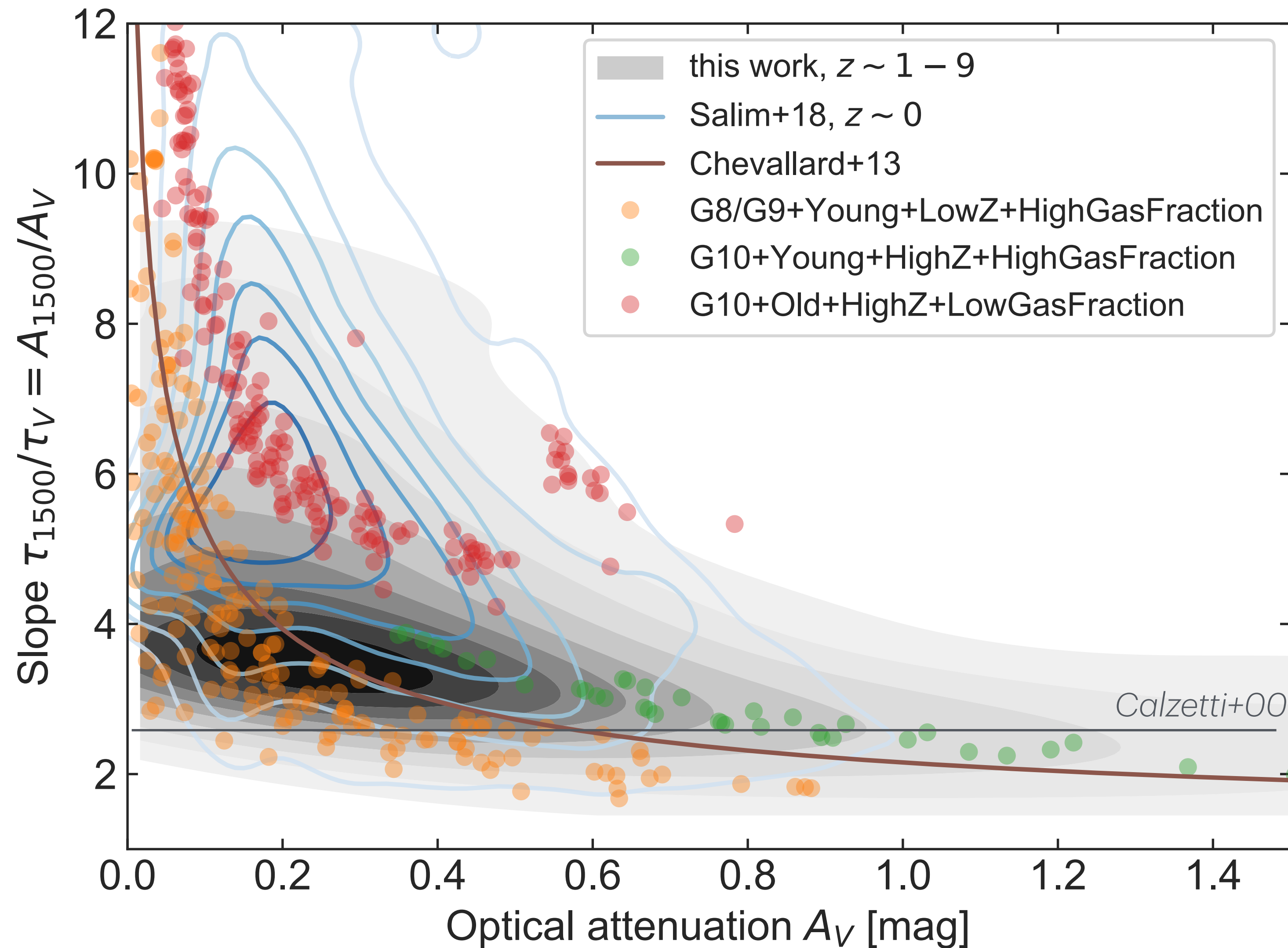
Talk by
Jed McKinney



Dust in high-z galaxies is increasingly dominated by large grains produced in supernova ejecta with limited ISM processing at early times

Shivaei+2025

A theory: large dust grains at high-z

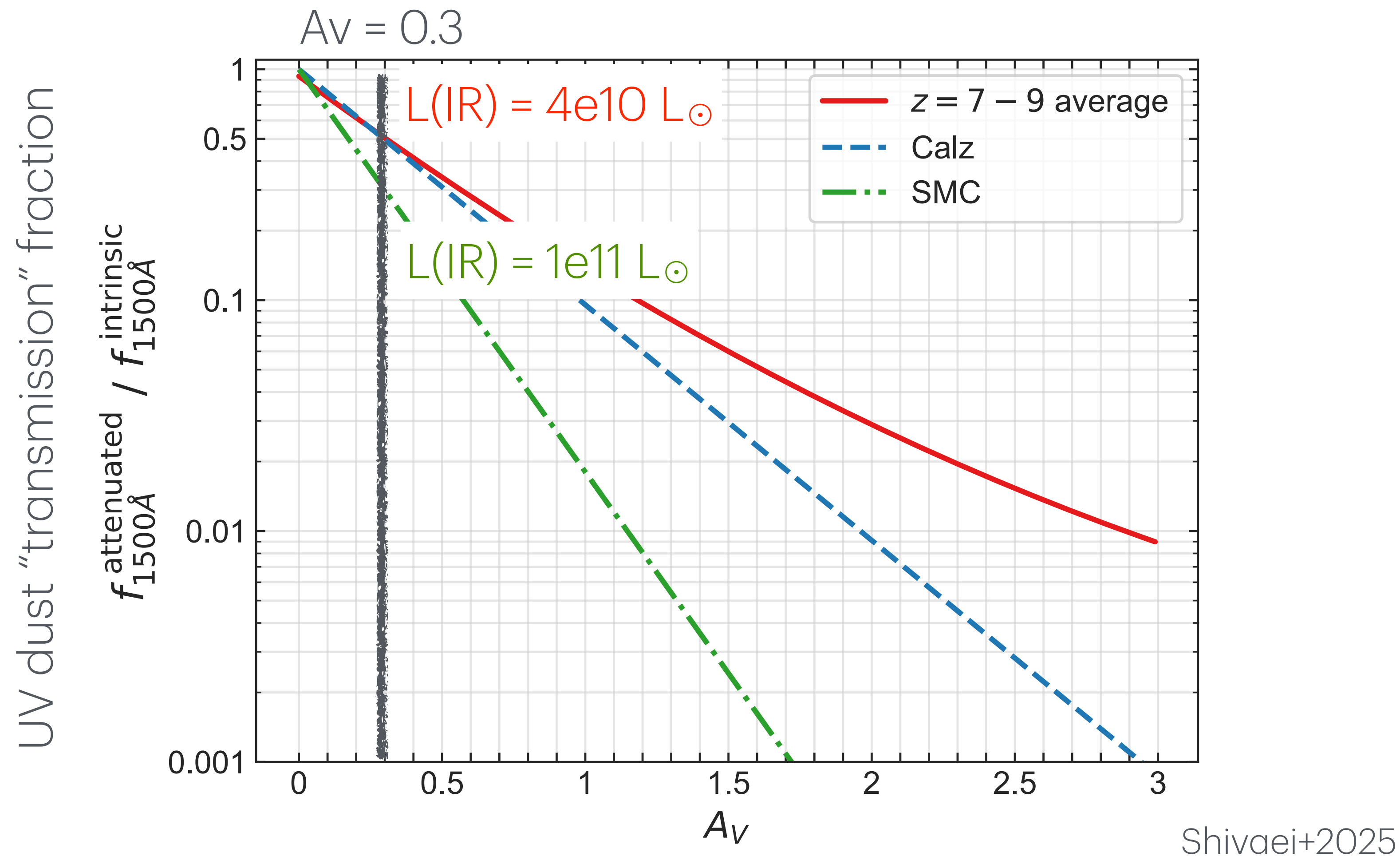


shallow curve at high-z:
less efficient in UV attenuation
and IR emission

Shivaei+2025

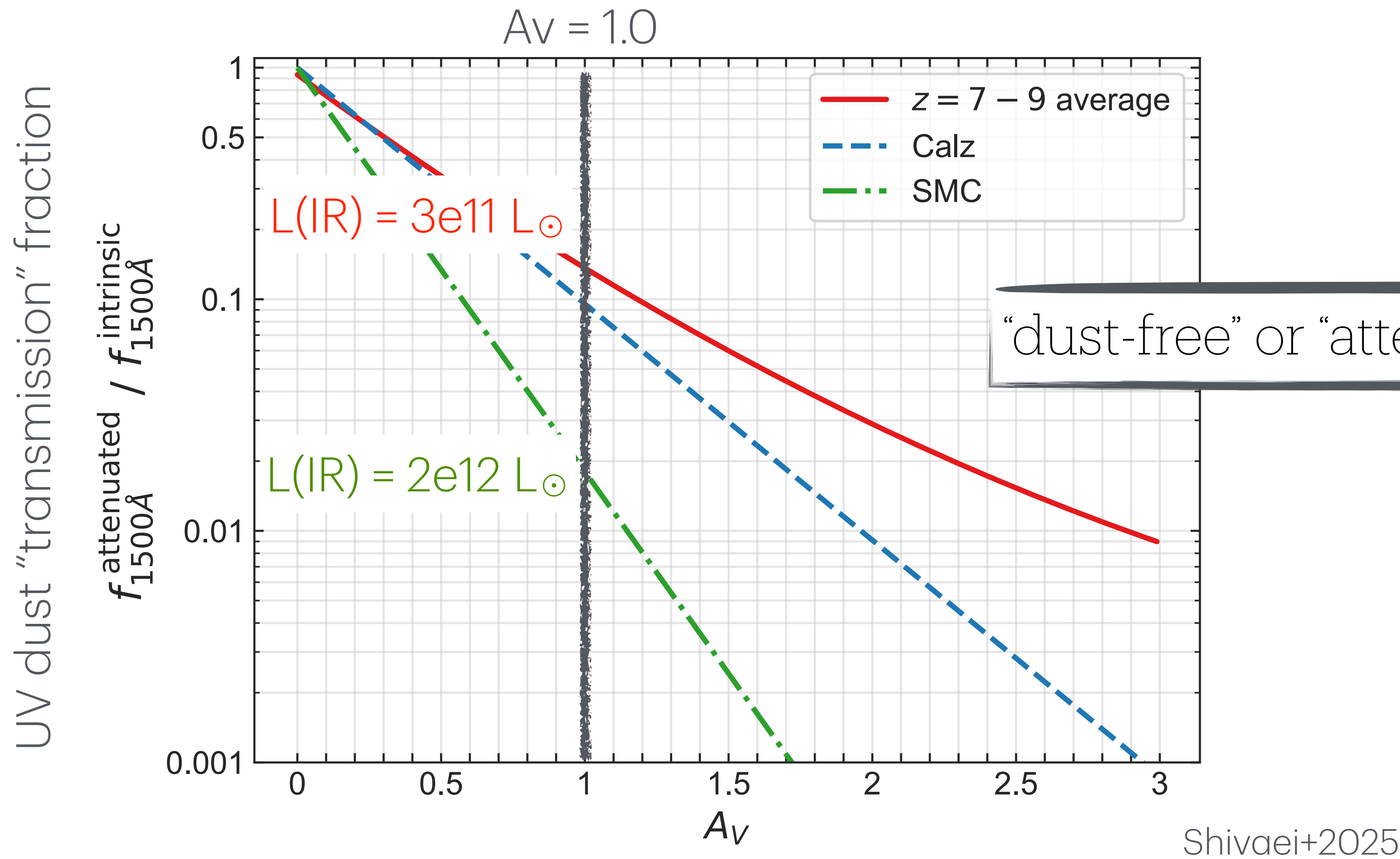
Much less UV attenuation at $z > 7$ than previously expected?

shallow curve: less efficient in UV attenuation and IR emission



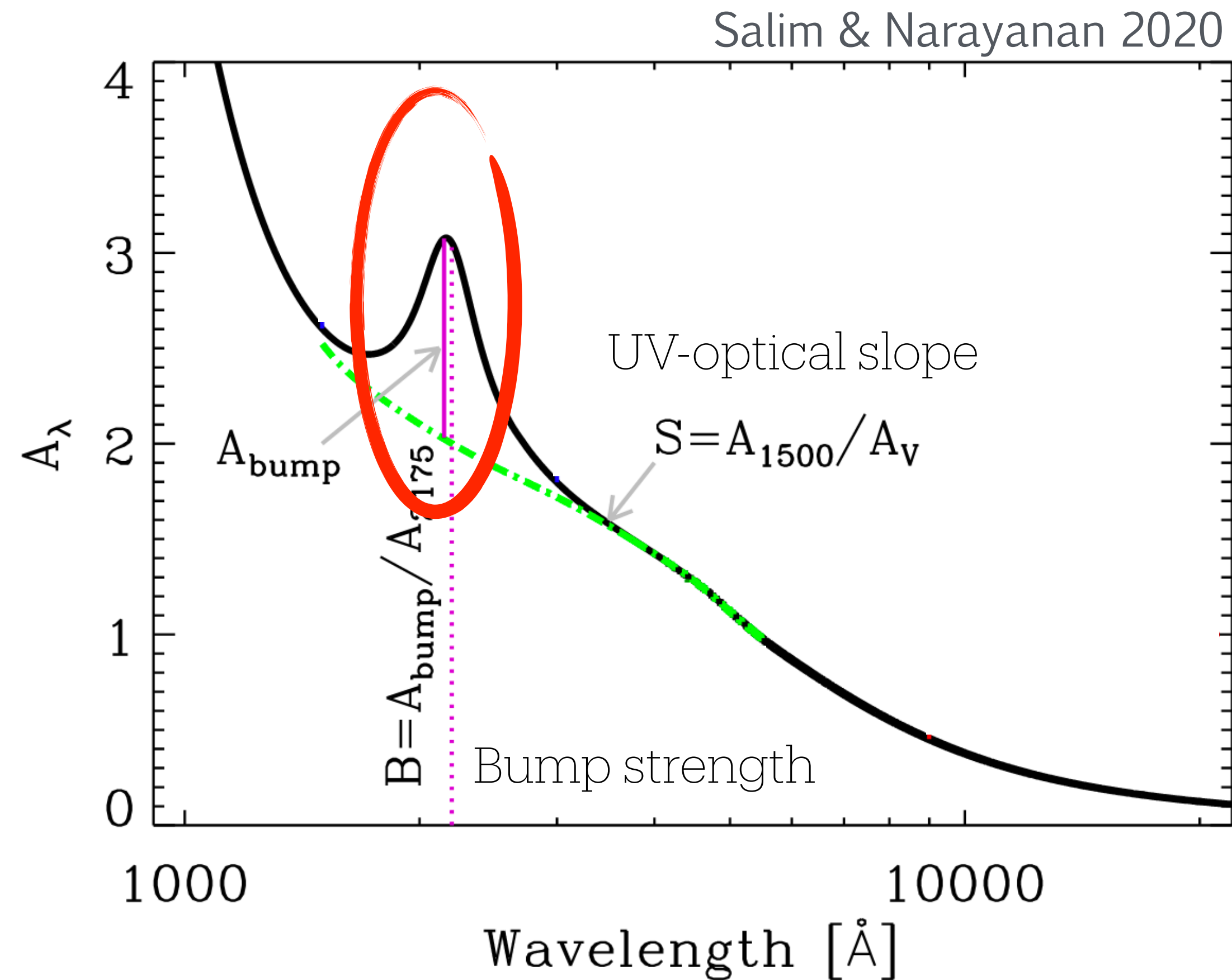
Much less UV attenuation at $z > 7$ than previously expected?

shallow curve: less efficient in UV attenuation and IR emission



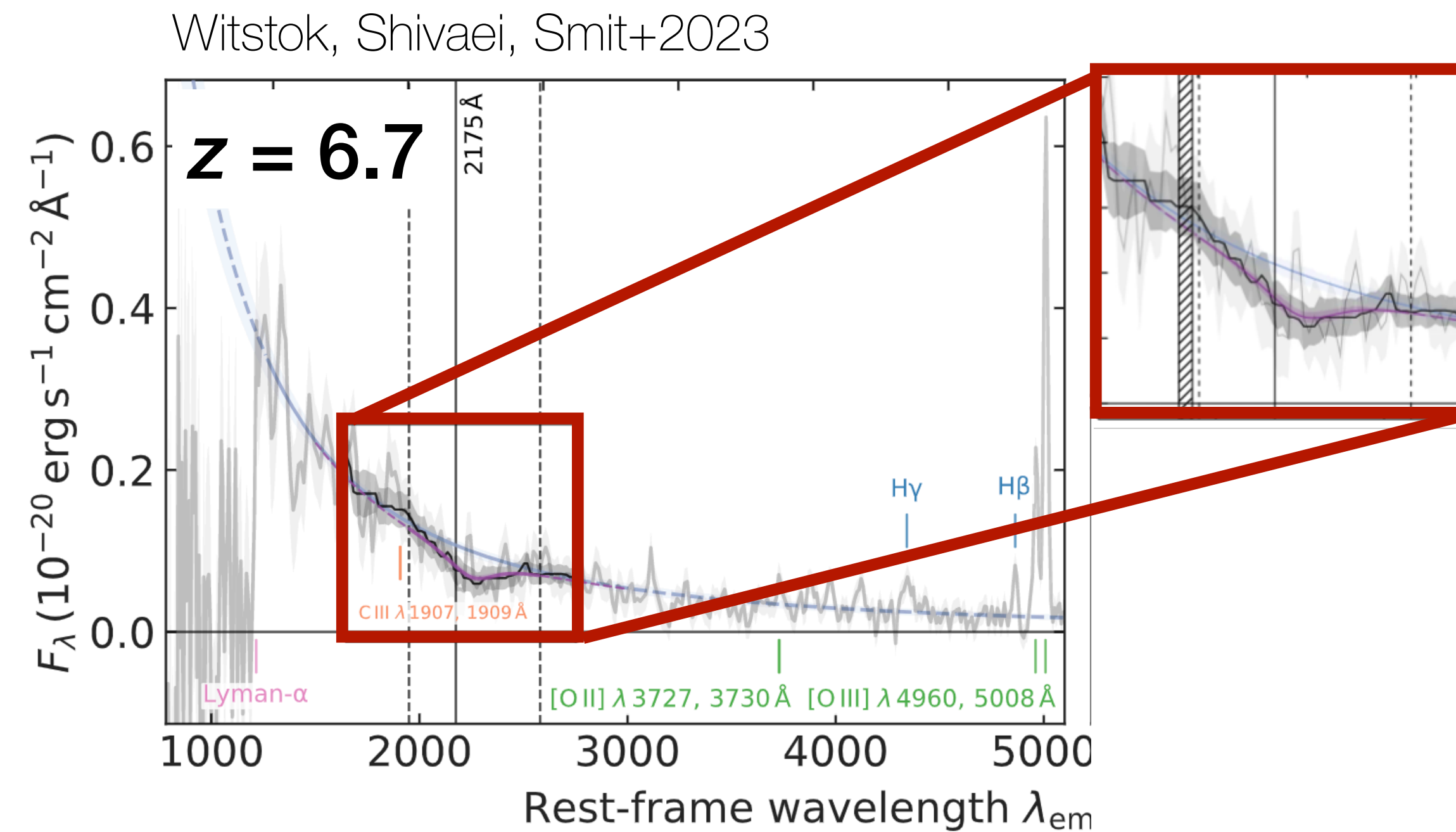
Talk by
Desika Narayanan

Very Small Grains: UV bump at high- z ?



What about the UV attenuation bump?

Very Small Grains: Bump at high-z

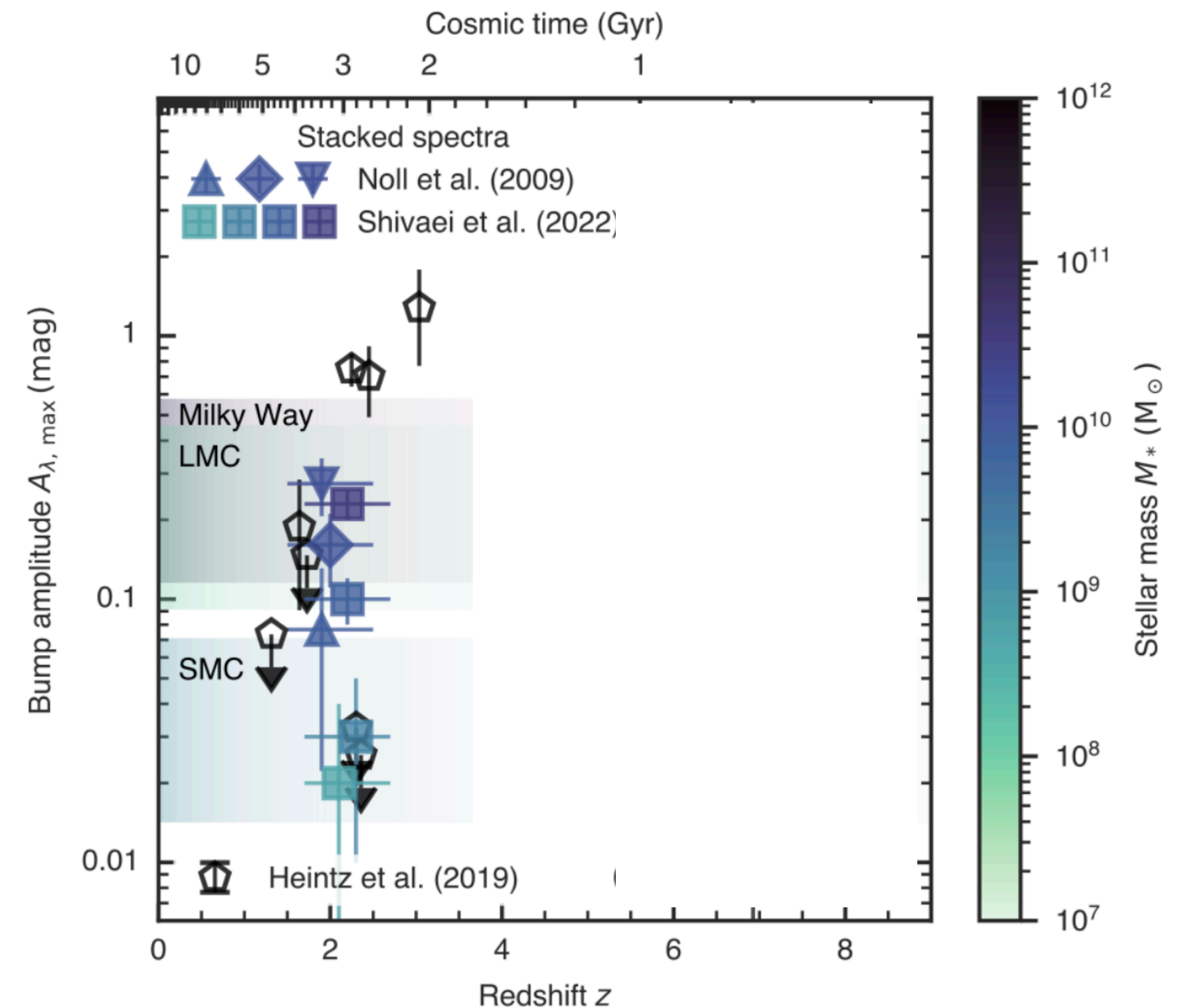
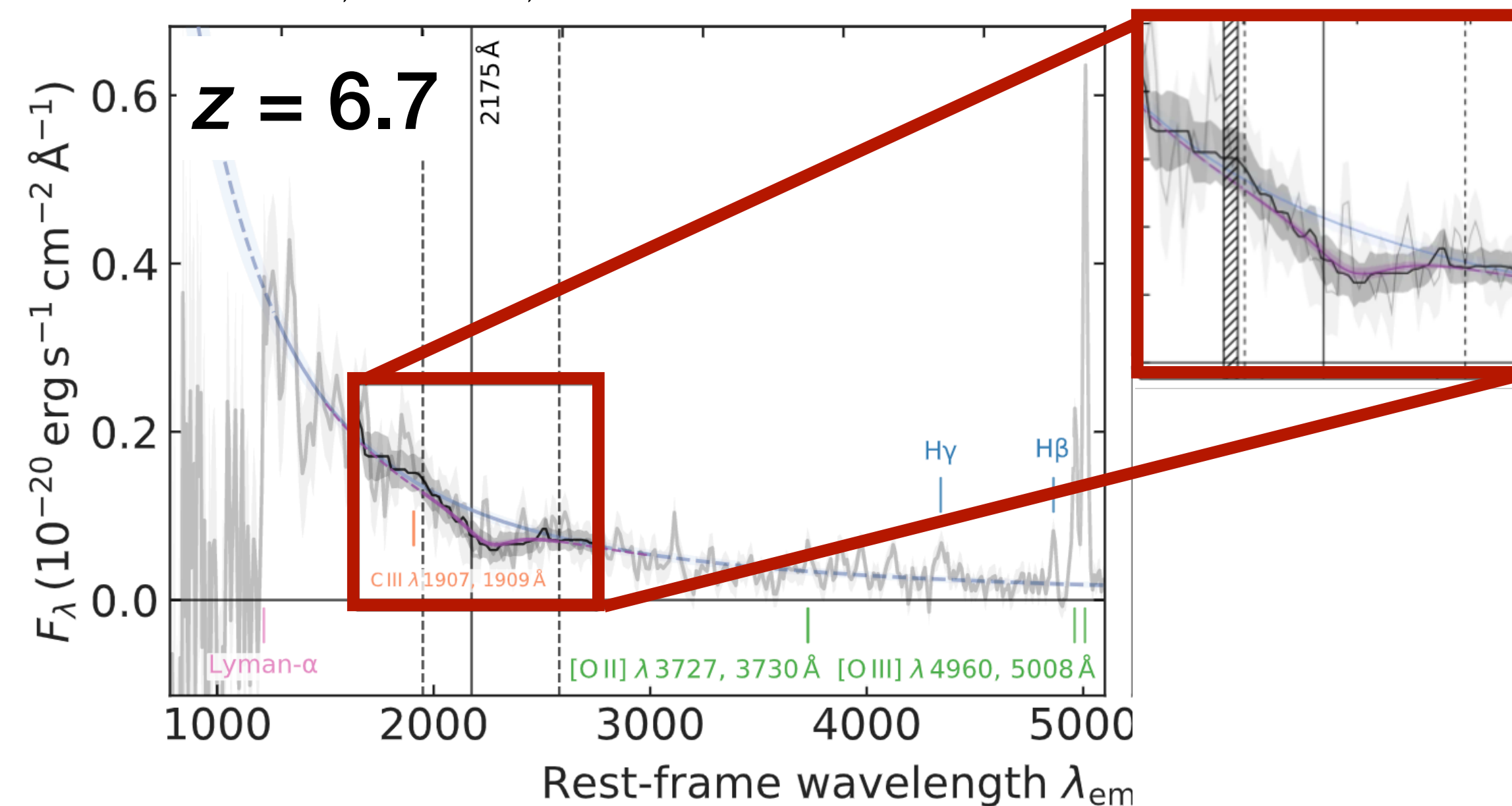


Also: Markov+24,25, Lin, Q+2025, Fisher+2025, Ormerod+2025, Nanni+2025

Very Small Grains: Bump at high-z

PAHs? AGB stars?

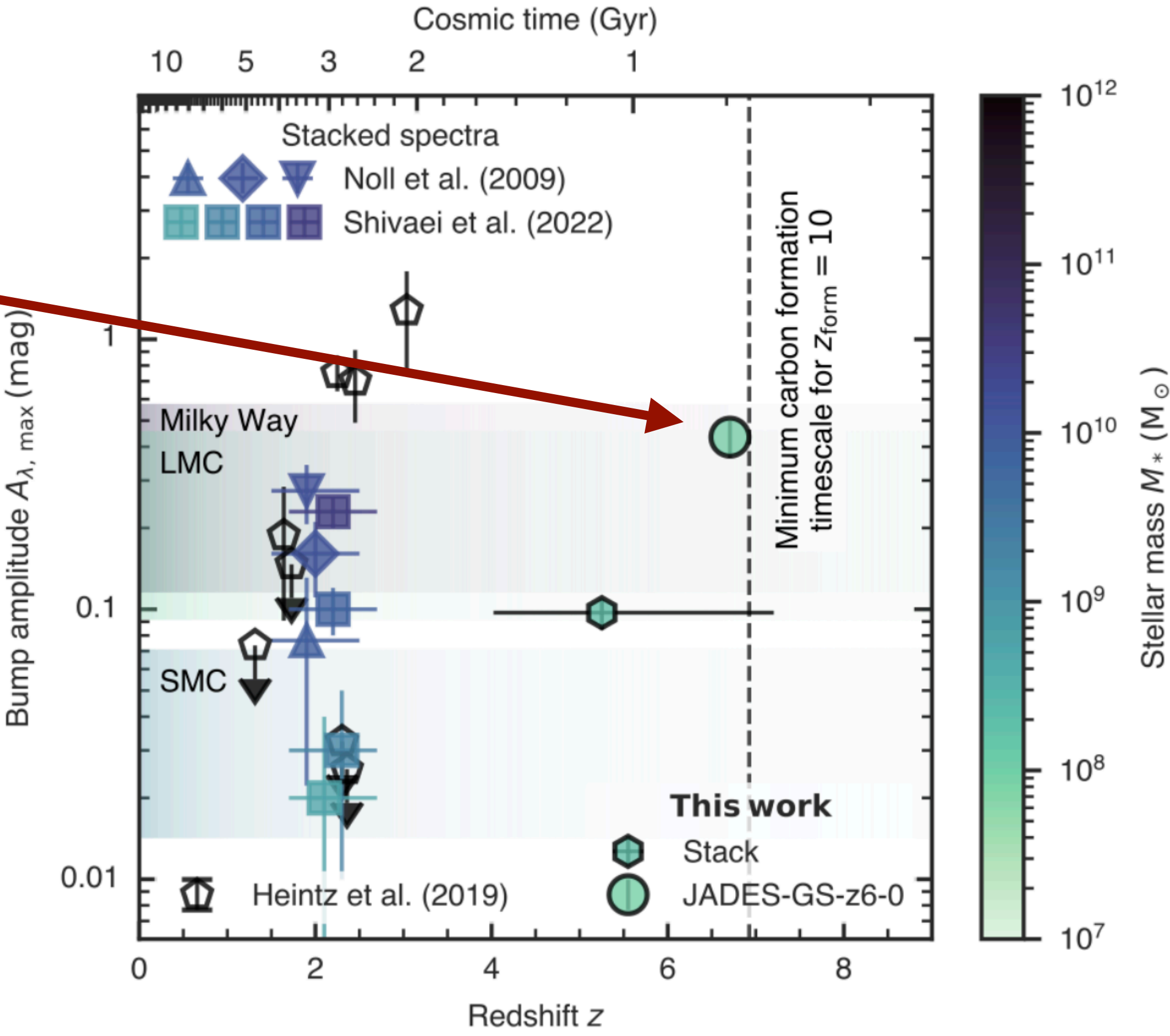
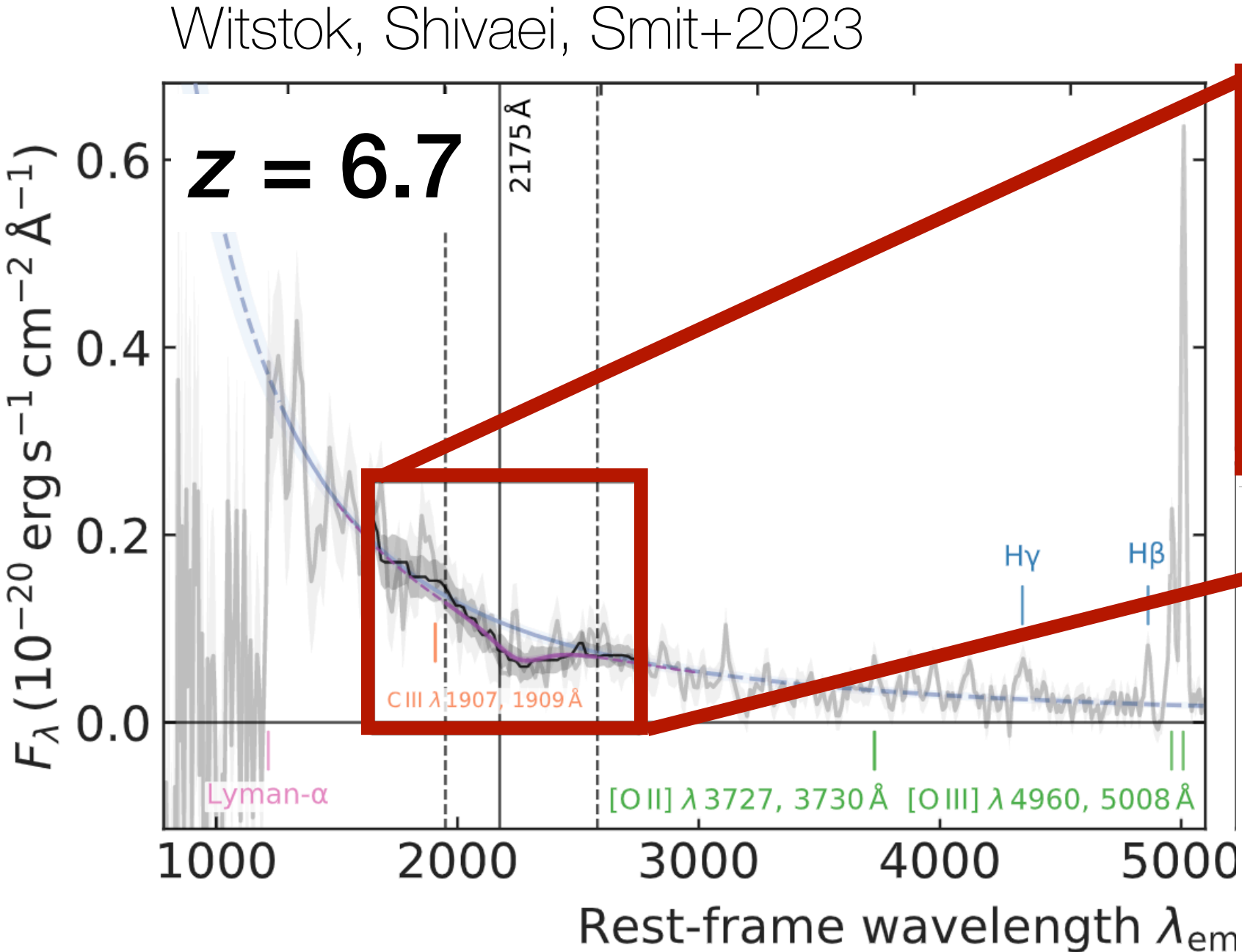
Witstok, Shivaiei, Smit+2023



Also: Markov+2024,25, Lin, Q+2025, Fisher+2025, Ormerod+2025, Nanni+2025

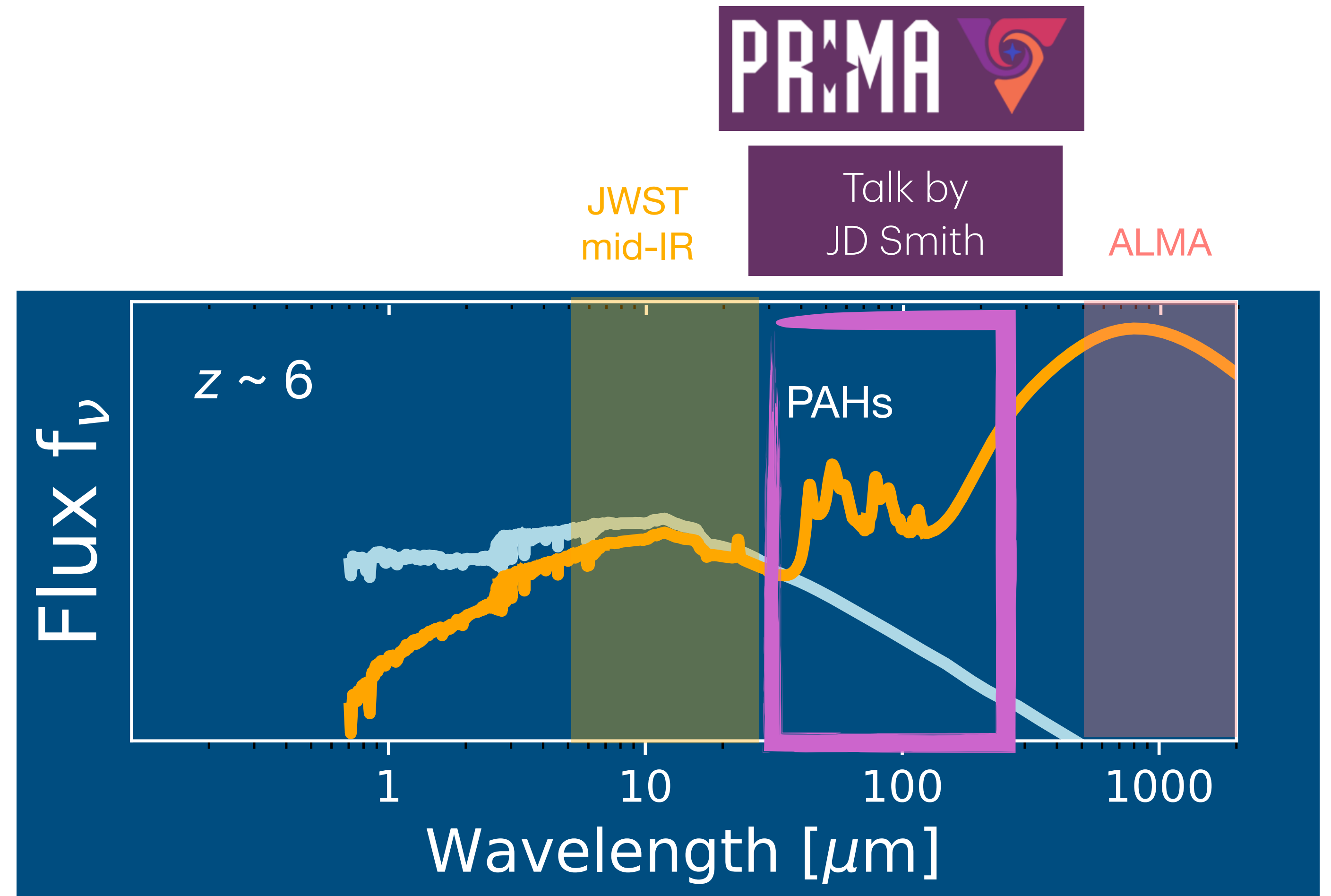
Very Small Grains: Bump at high-z

PAHs? AGB stars?

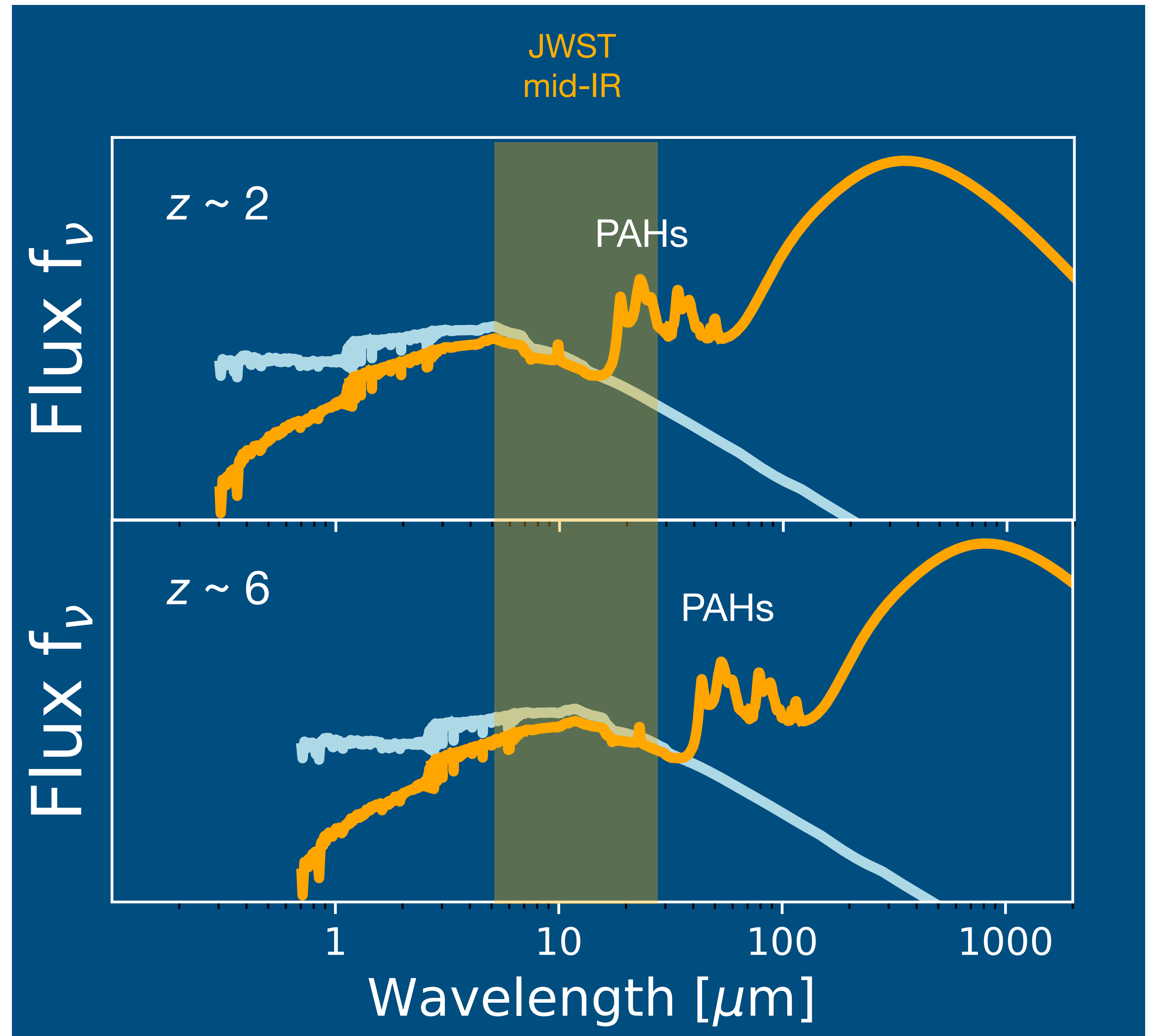


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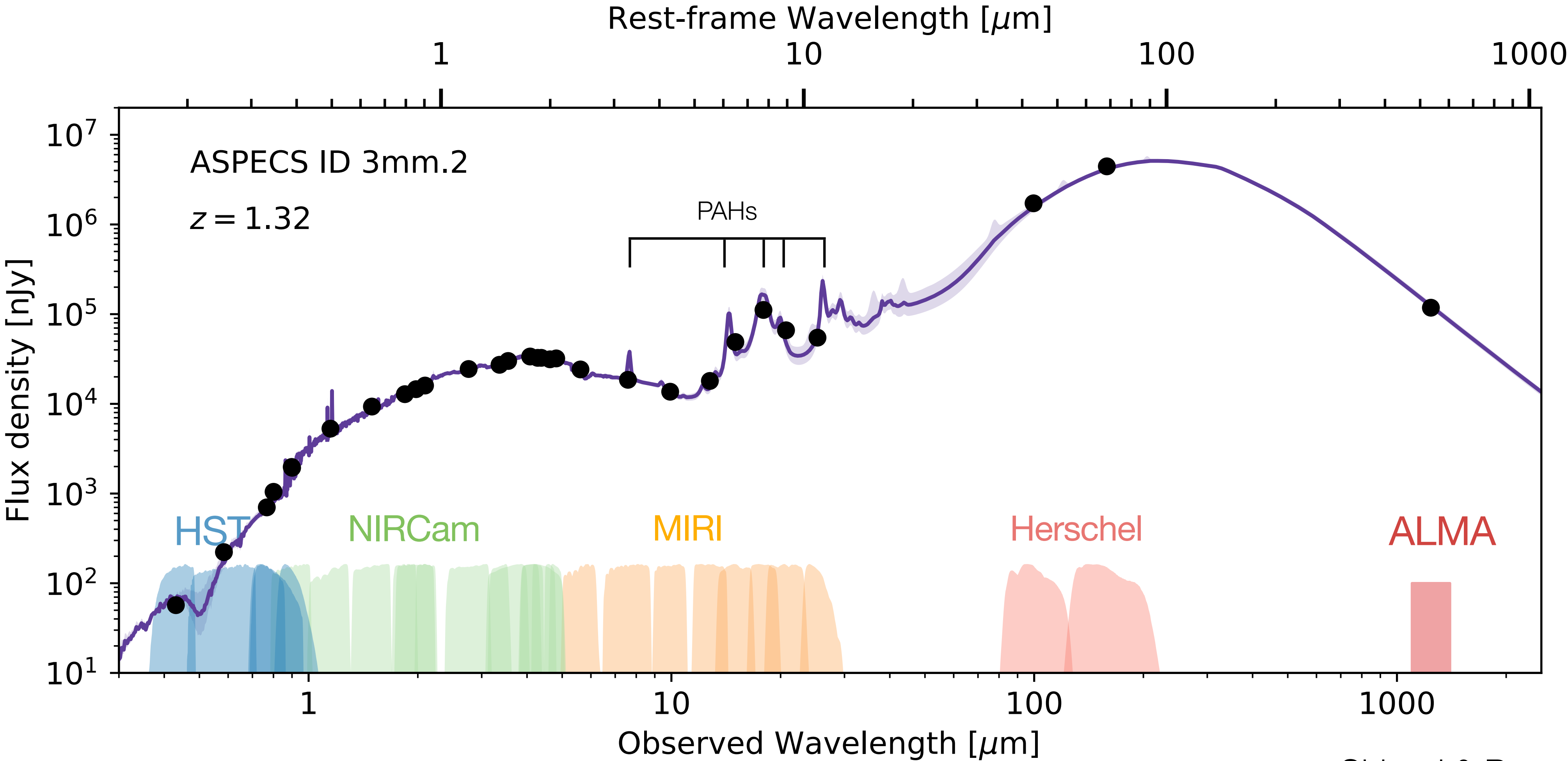
PAHs at high-redshifts



PAHs at high-redshifts



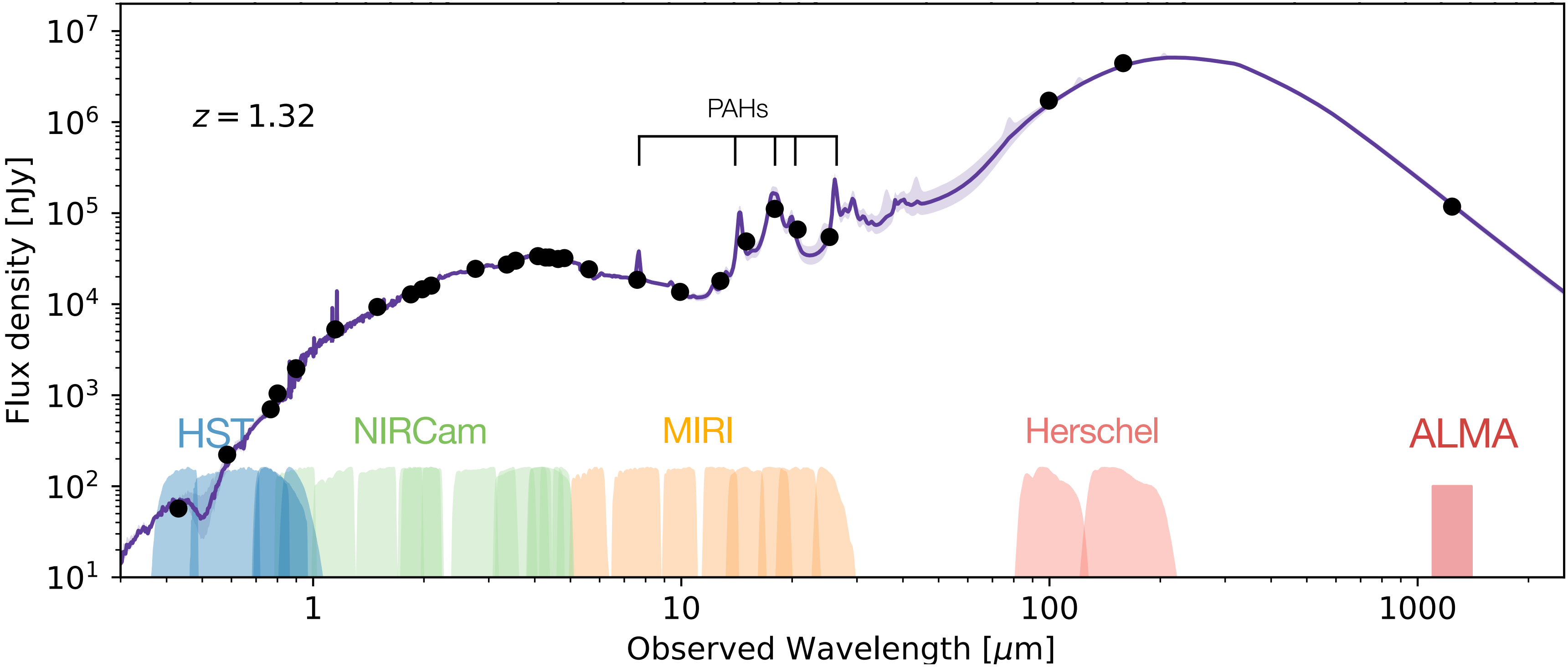
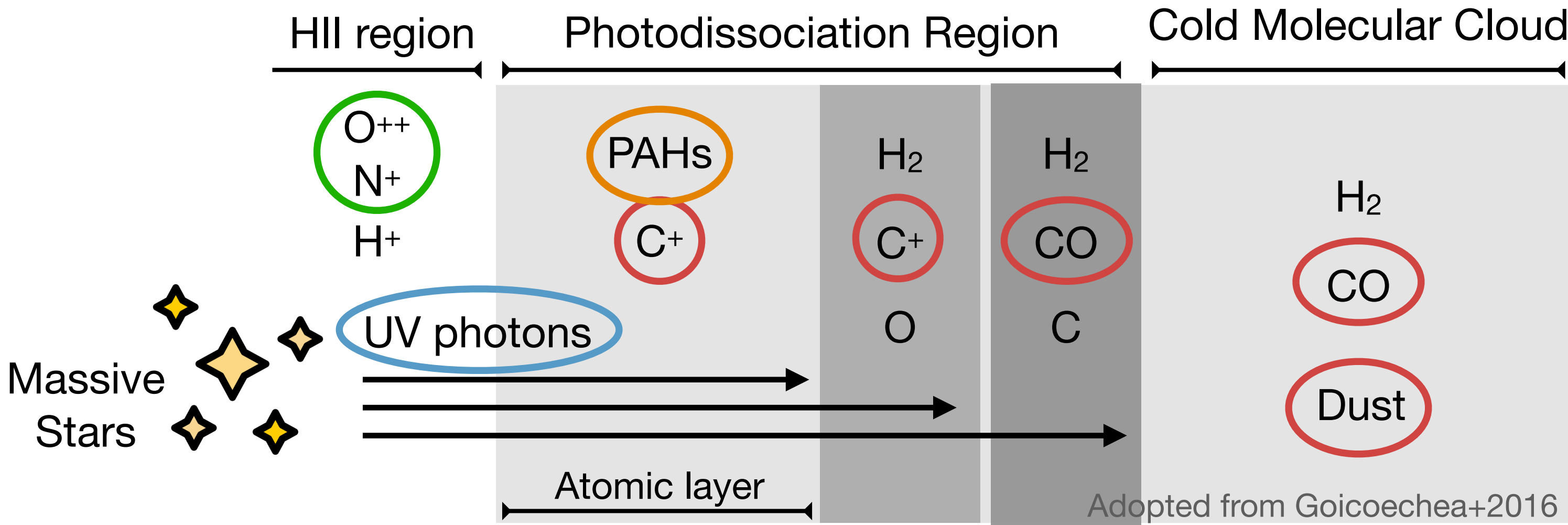
A new era in cosmic noon studies:



Shivaei & Boogaard (2024)

UV-irradiated molecular cloud edge

- ◆ **Stellar light** (UV)
- ◆ **Metals** (near-IR spectra)
- ◆ **PAHs** (mid-IR spectra)
- ◆ **Cold gas** (sub-mm lines, CO)
- ◆ **Cold dust** (far-IR emission)

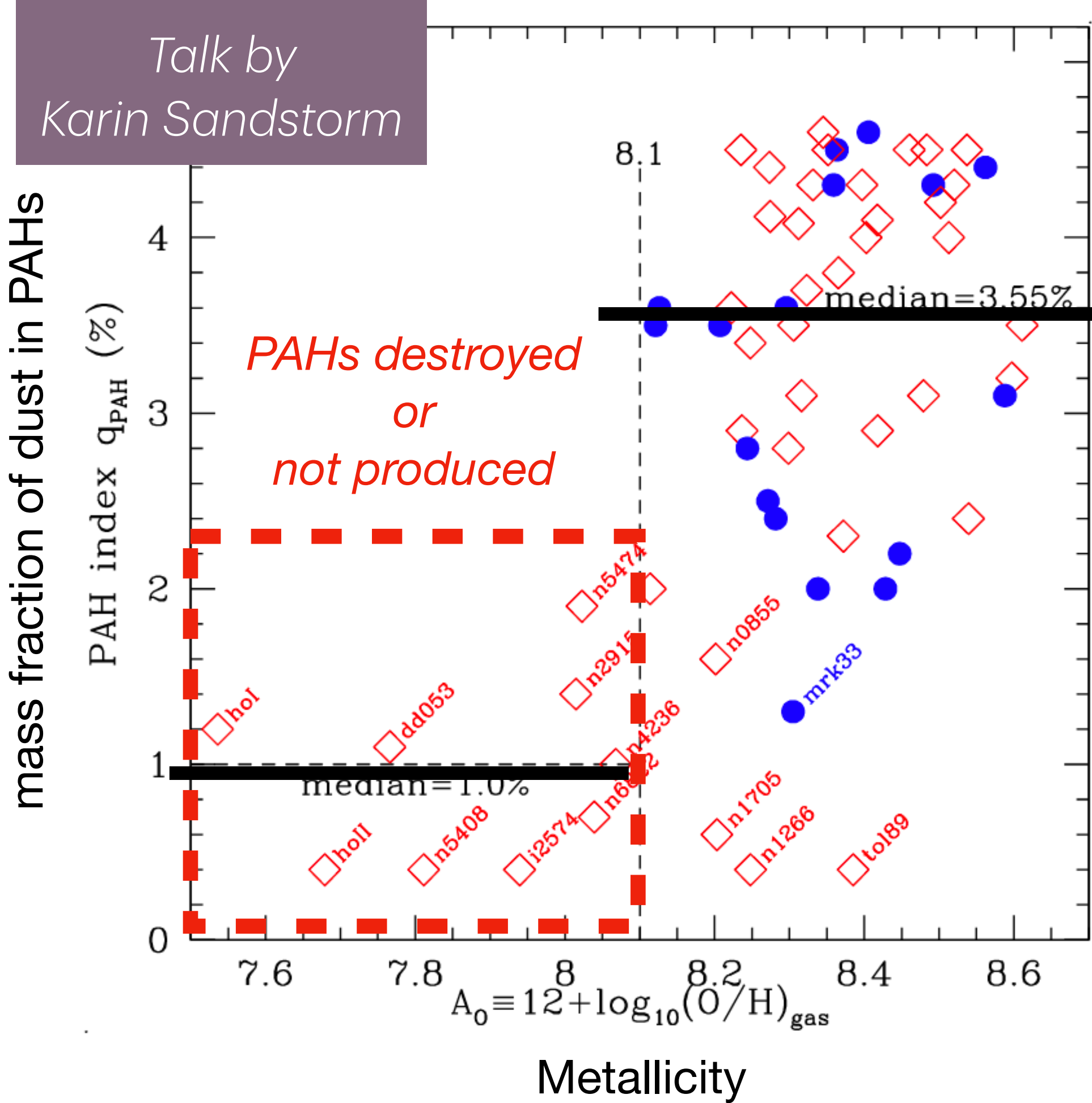


Shivaei & Boogaard (2024)

PAH production/survival in the ISM

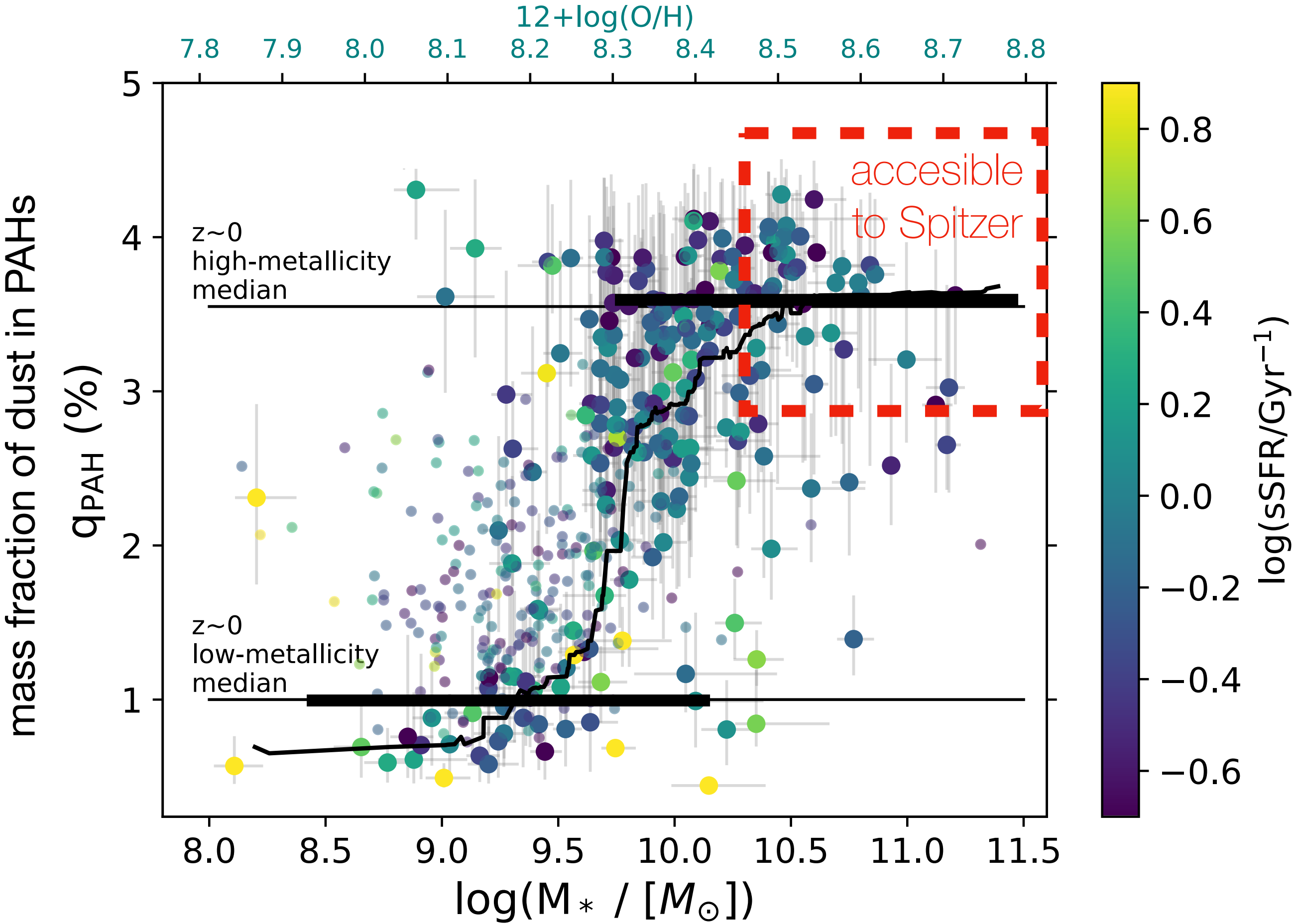
z ~ 0 view:

Draine+2007



z ~ 1-2 view:

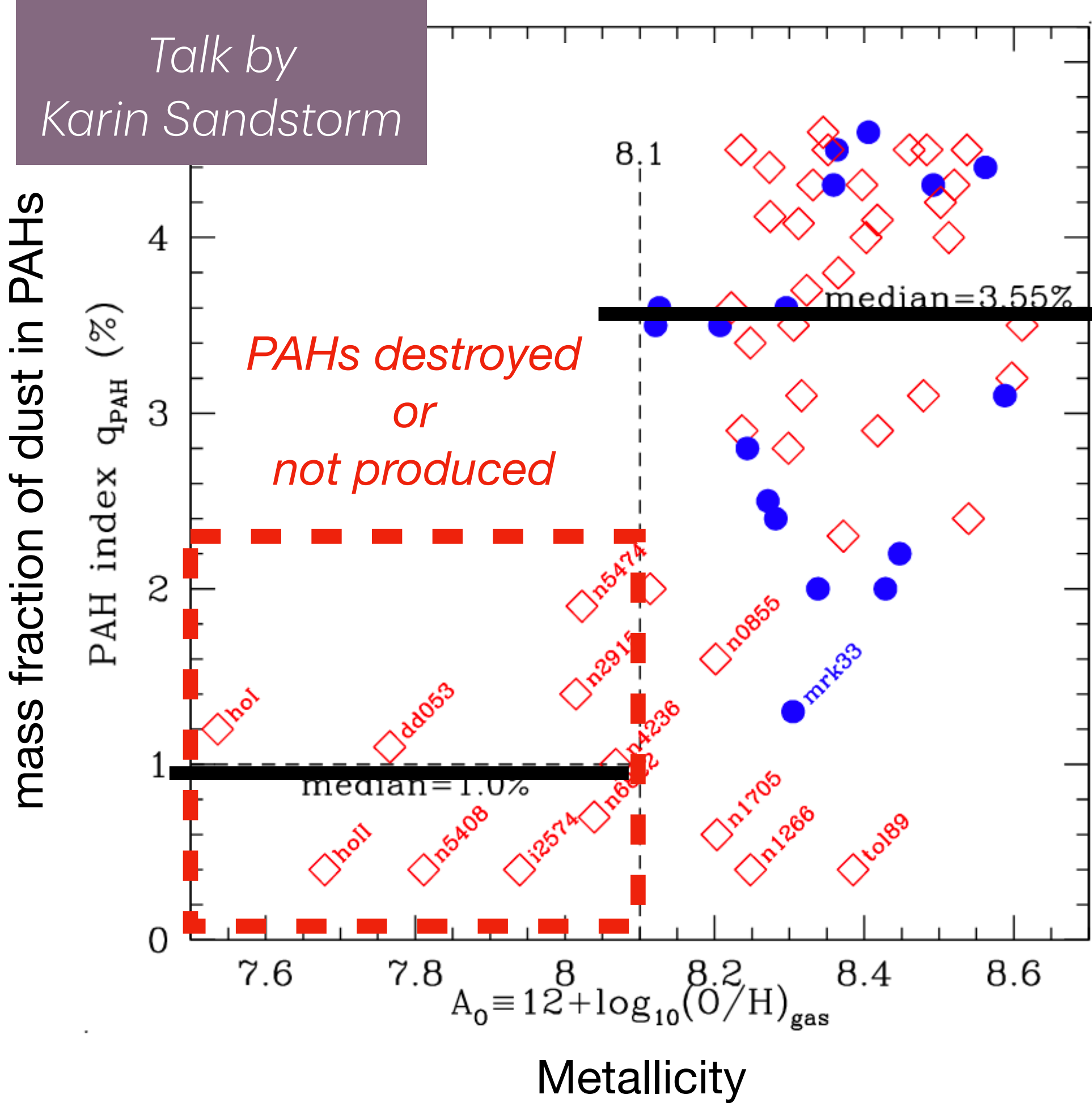
Shivaei+2024



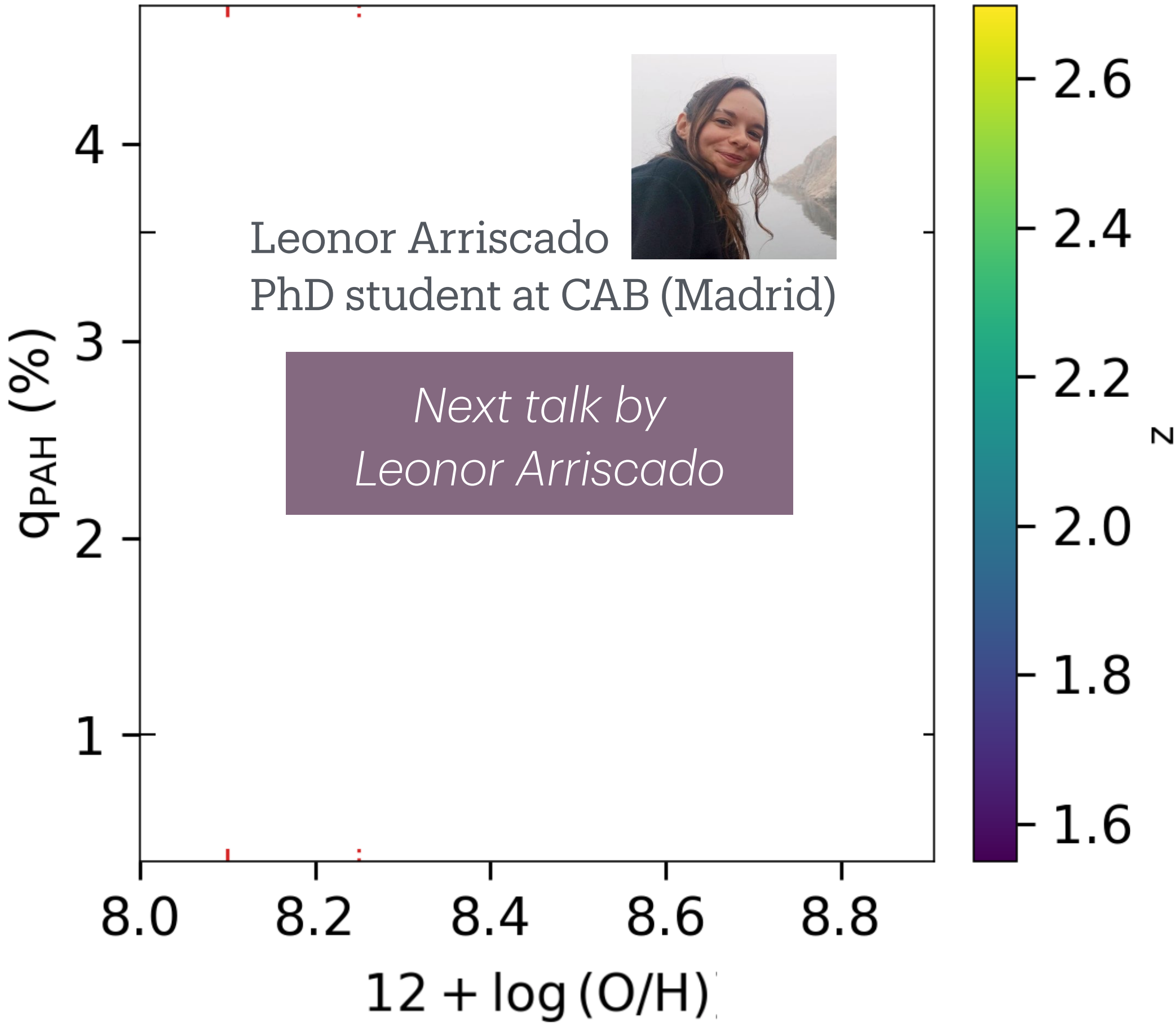
PAH production/survival in the ISM

z ~ 0 view:

Draine+2007



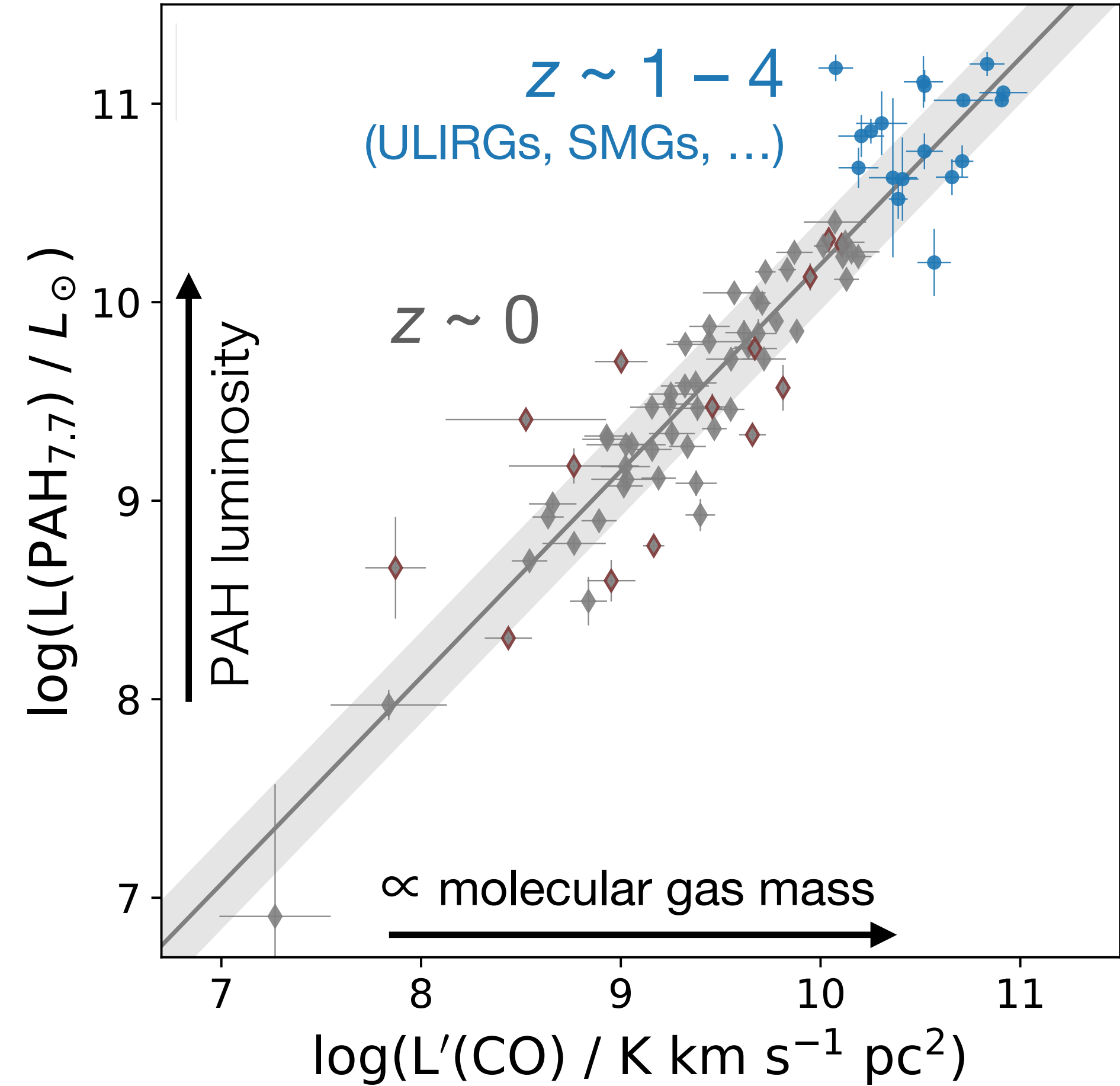
z ~ 1-3 view:



Tight correlation between PAH and CO emission across redshifts and galaxy populations

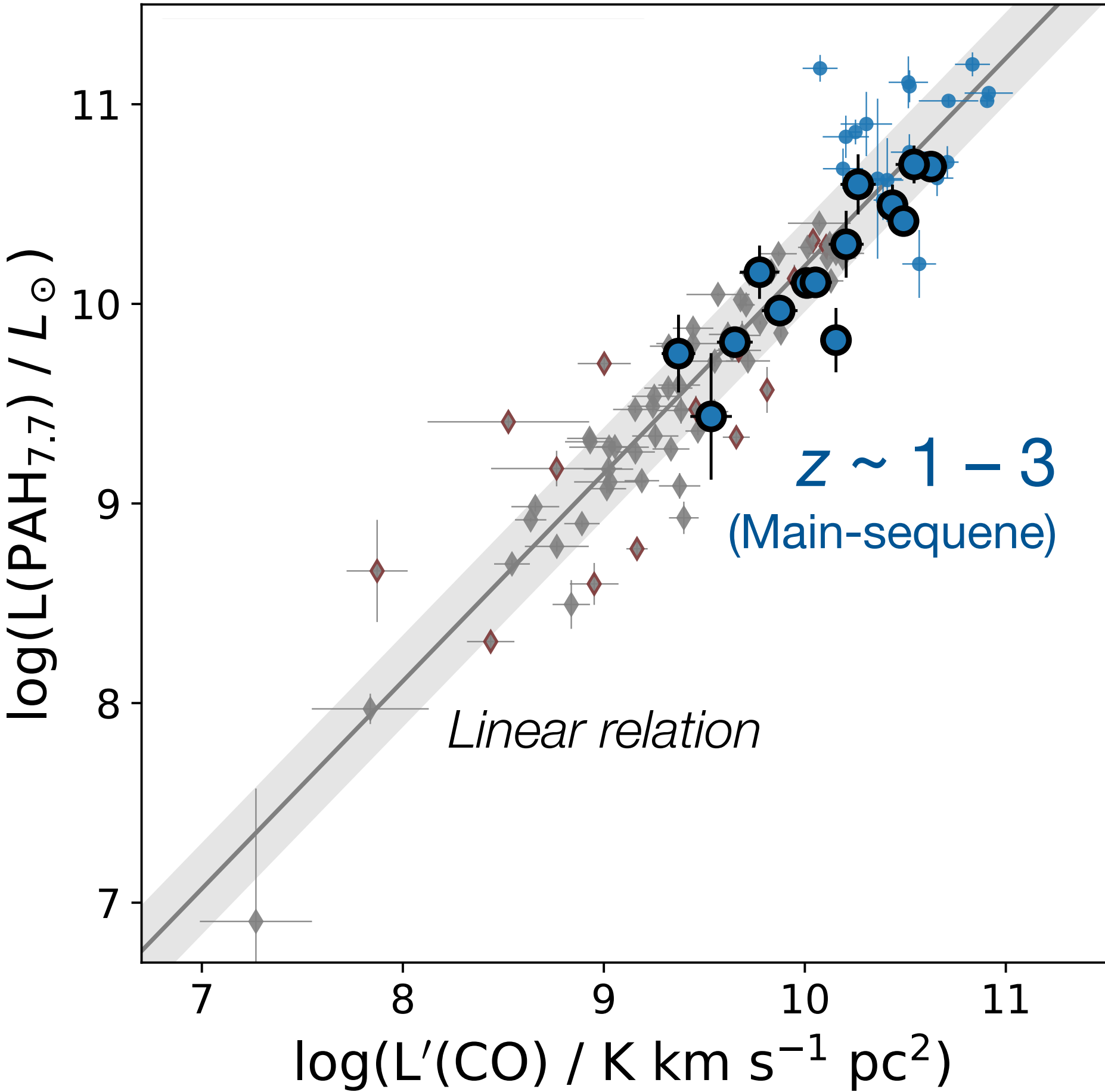
Pre-JWST view:

Cortzen+2019



Now with MIRI:

Shivaei & Boogaard (2024)



Tight correlation between PAH and CO emission across redshifts and galaxy populations

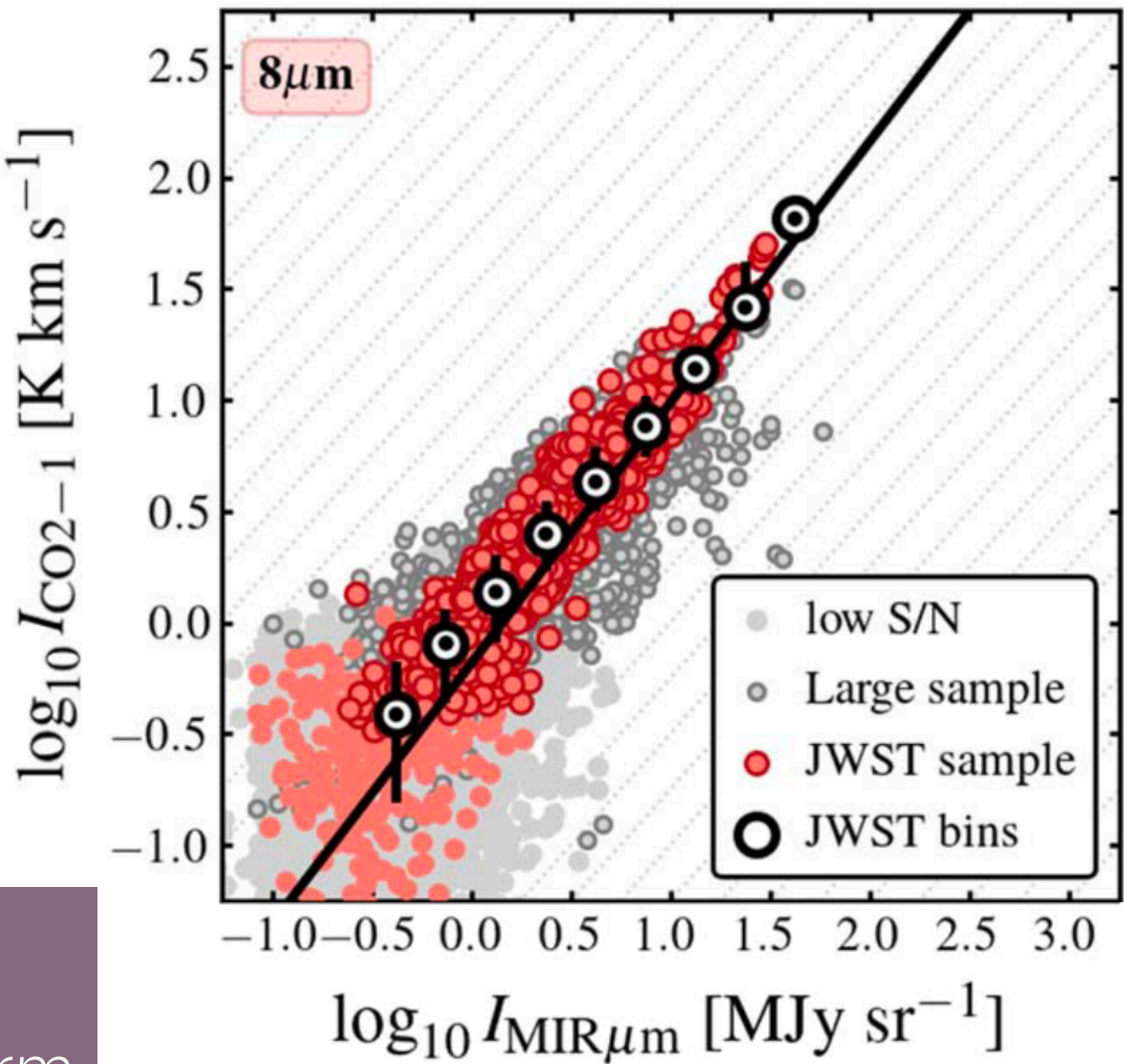


Poster 71

Ryan Chown

Talk by
Karin Sandstorm

resolved $z \sim 0$



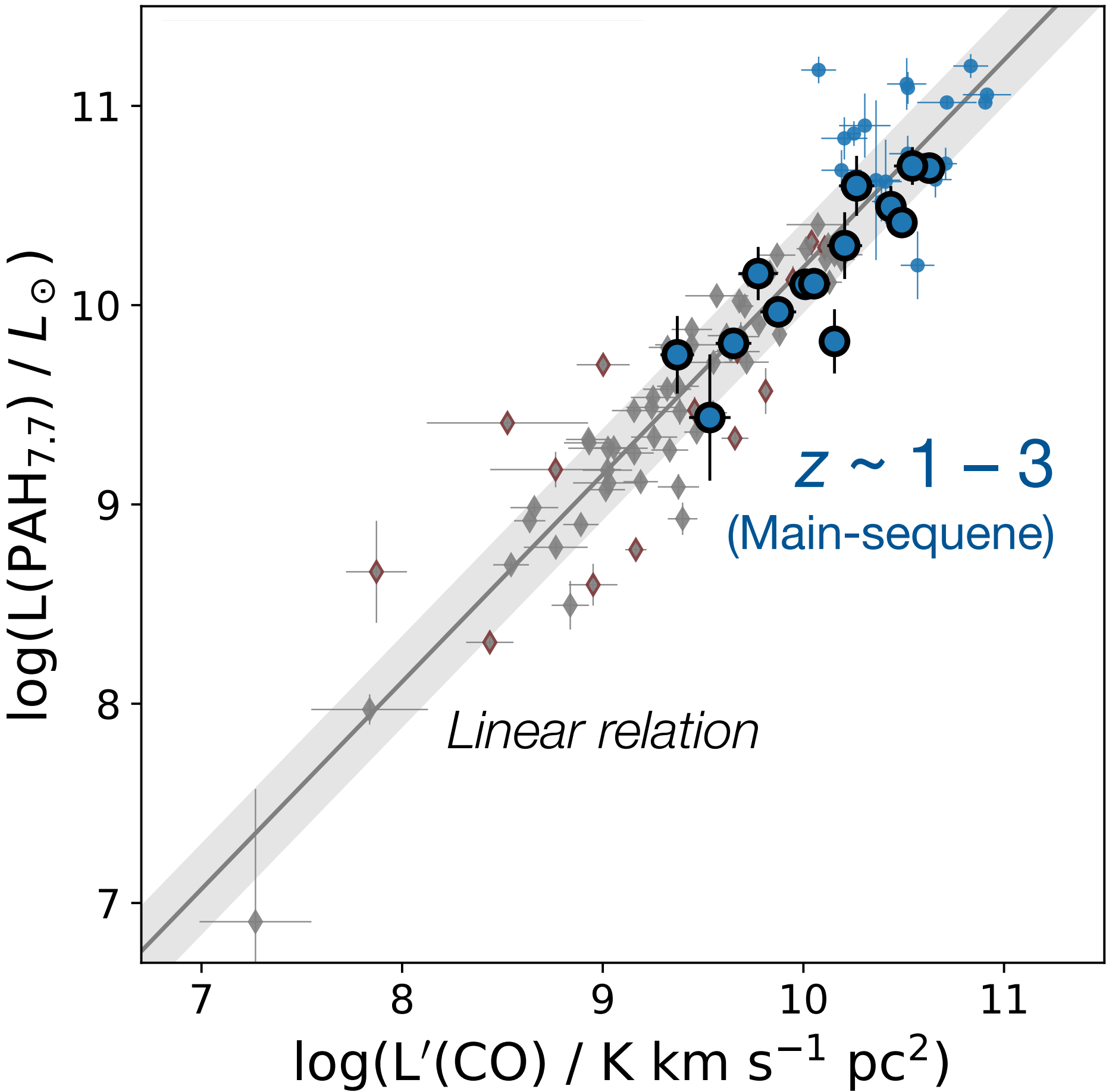
Leroy+2023

$$I_{\text{PAH}} \propto \text{DGR} \times q_{\text{PAH}} \times N_{\text{H}_2} \times U$$
$$\propto (\text{DGR} \times q_{\text{PAH}} \times X_{\text{CO}} \times U) I_{\text{CO}}$$

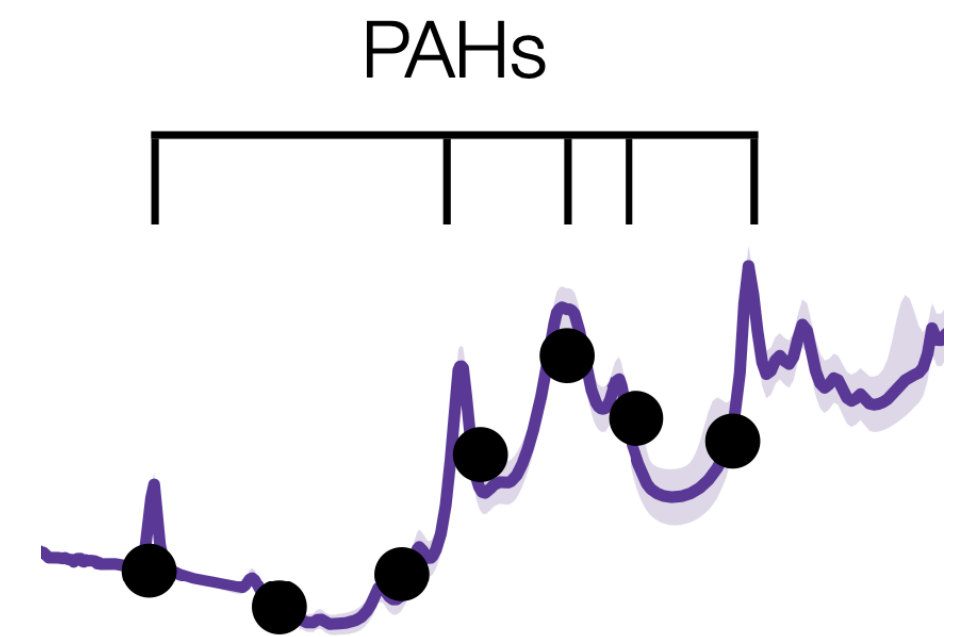
also Chown+2025, Gao+2025, Villanueva+2025, Leroy+2025

Integrated $z \sim 0 - 3$

Shivaei & Boogaard (2024)

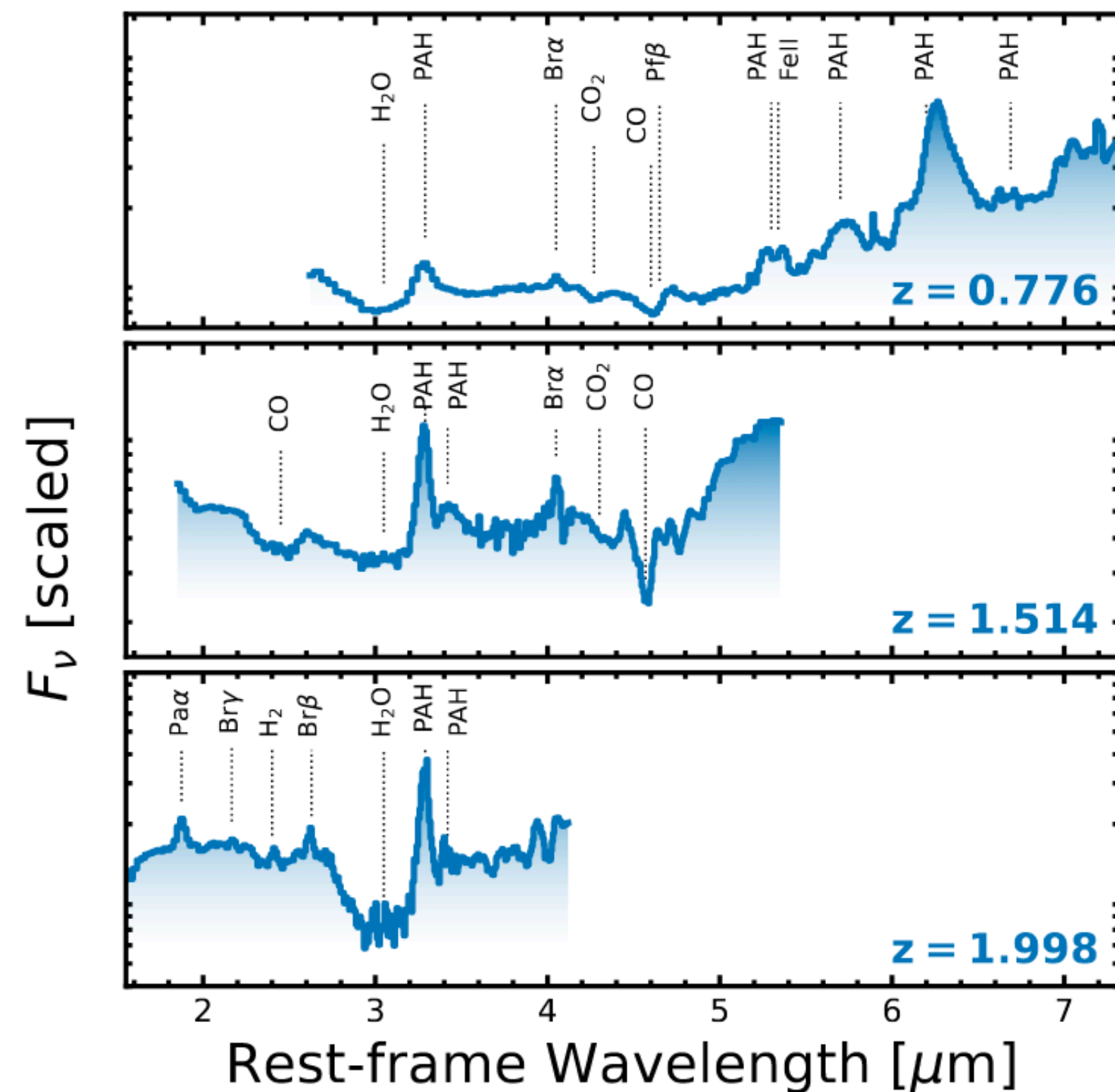


Peering into PAHs: spectroscopy



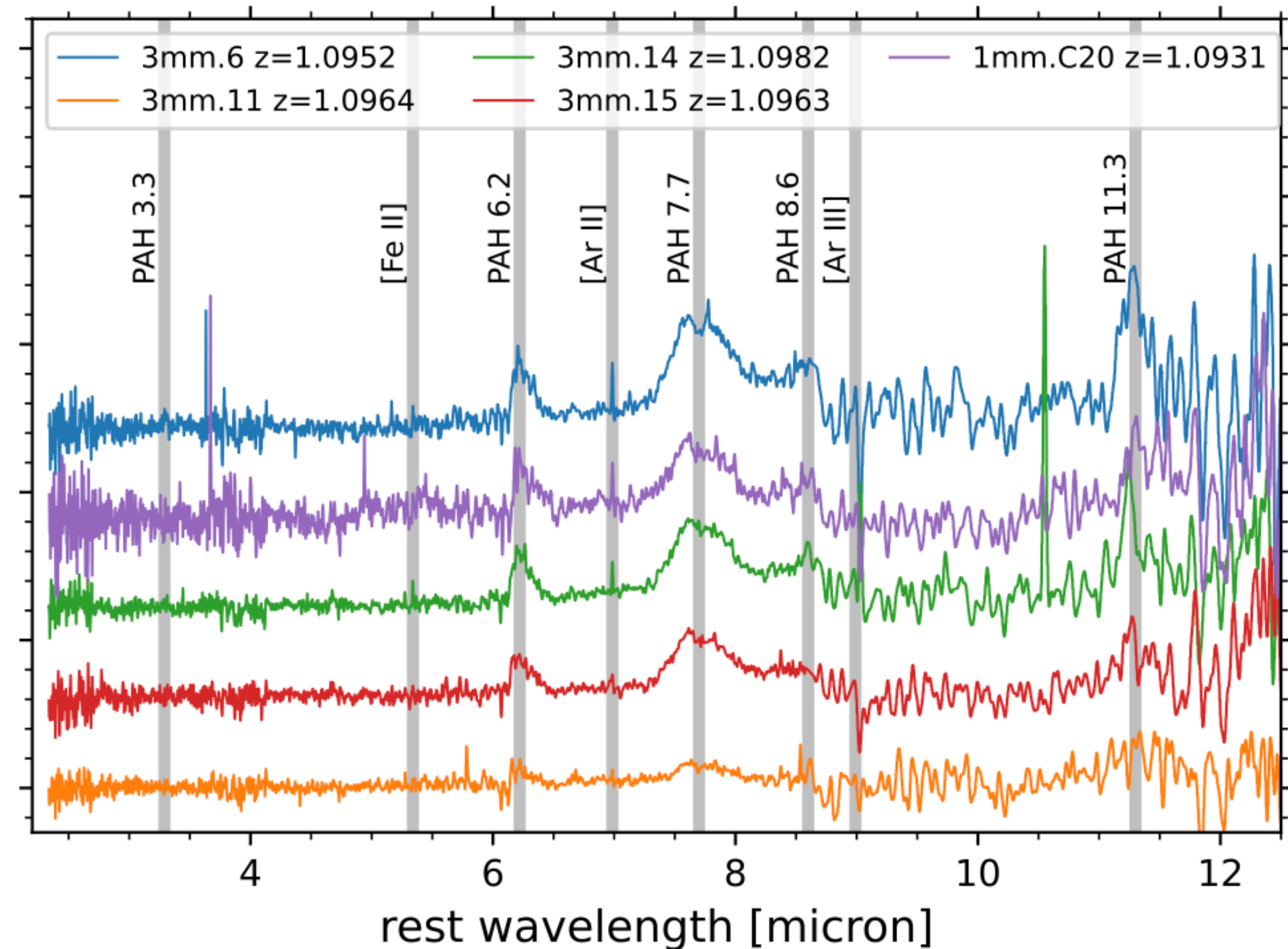
Peering into PAHs: spectroscopy

MIRI LRS spectra: PAH3.3 in massive IR-bright galaxies at $z = 0.7 - 2.5$



McKinney+2025

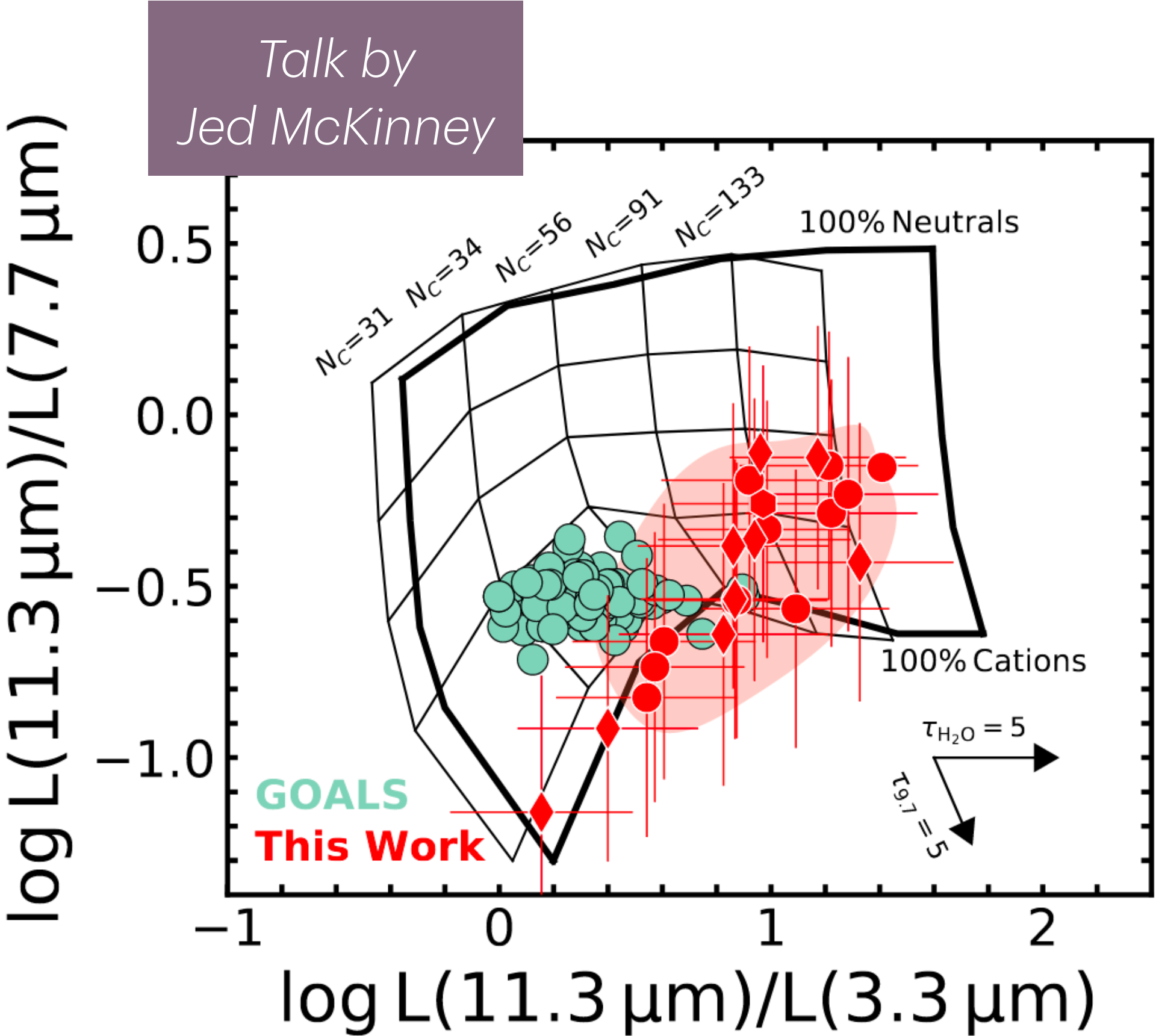
MIRI MRS spectra: PAH3.3 to 11.3 in main-sequence galaxies at $z = 1.1$



PAHSPECS Program (Shivaei+in prep)

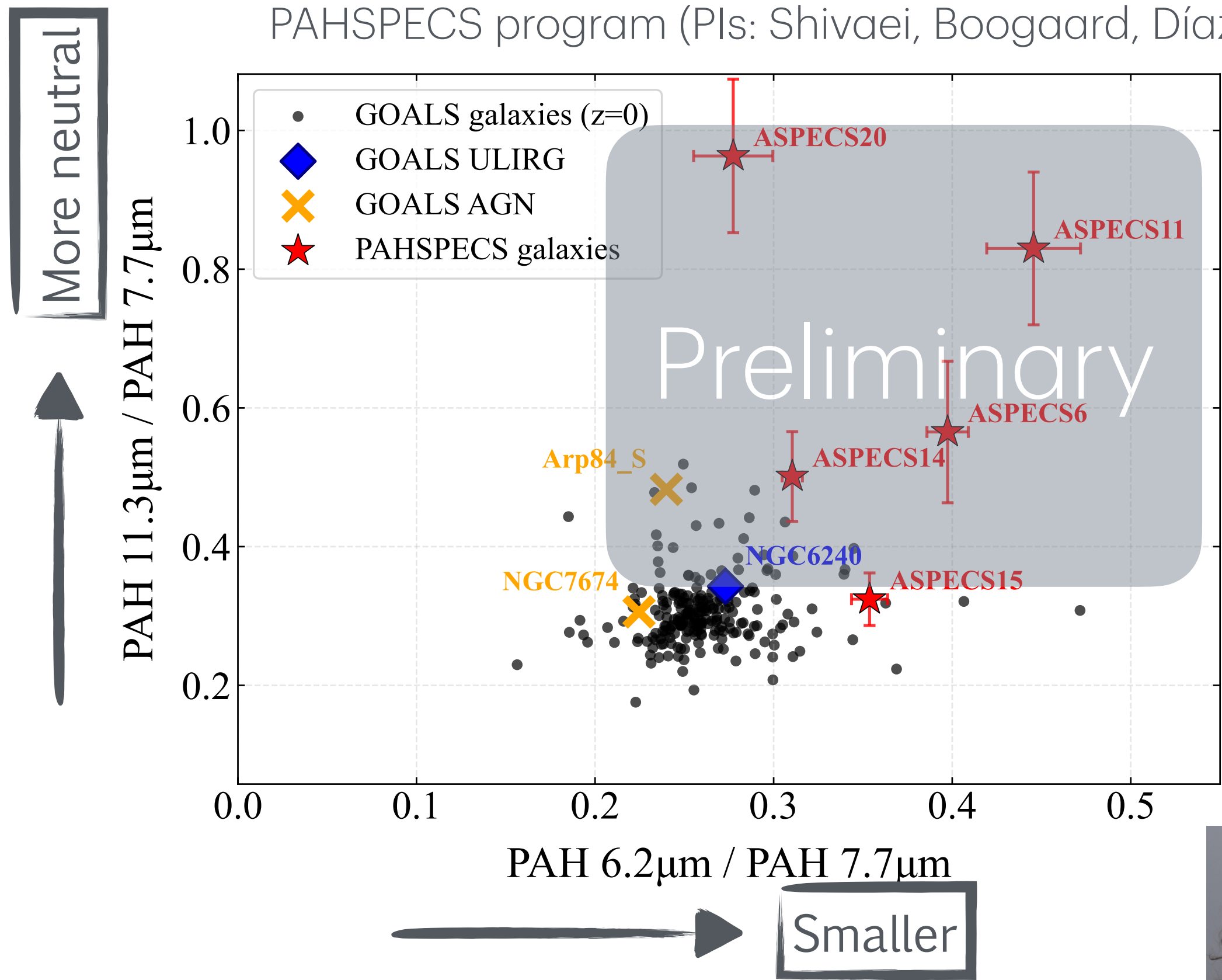
PAH grain size and charge at cosmic noon

massive IR-bright galaxies at $z = 0.7 - 2.5$



Main-sequence galaxies at $z = 1.1$

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



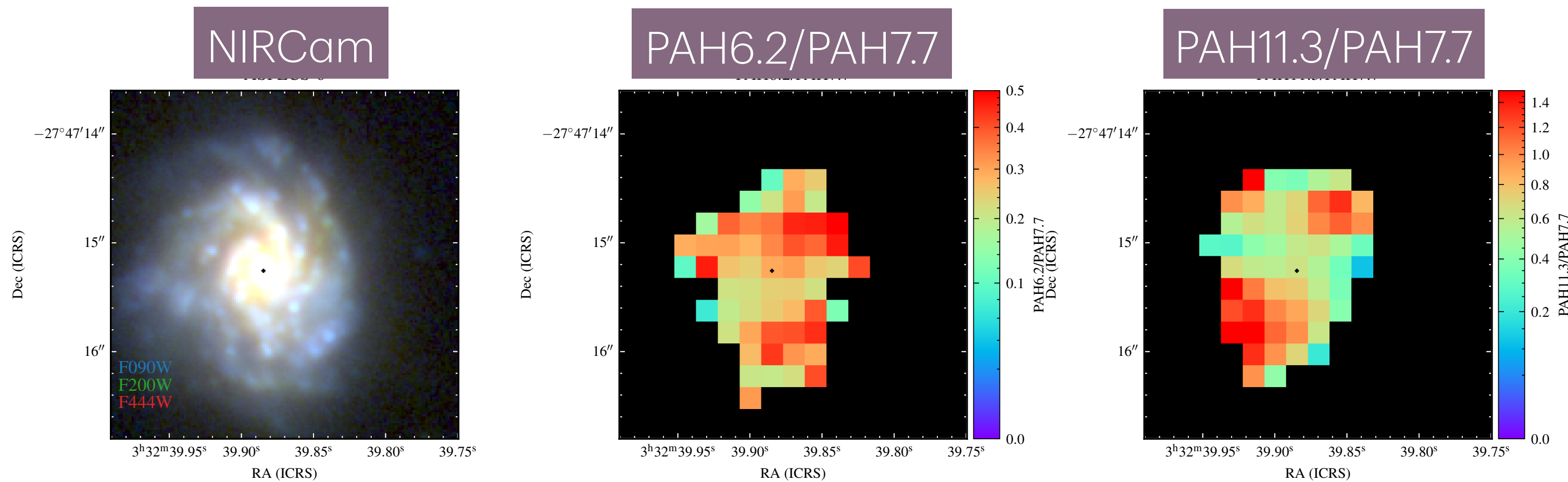
Lofaro+in prep

Cristina Lofaro
PhD student at IA-FORTH



Resolved PAH diagnostics at cosmic noon

Donnan+in prep

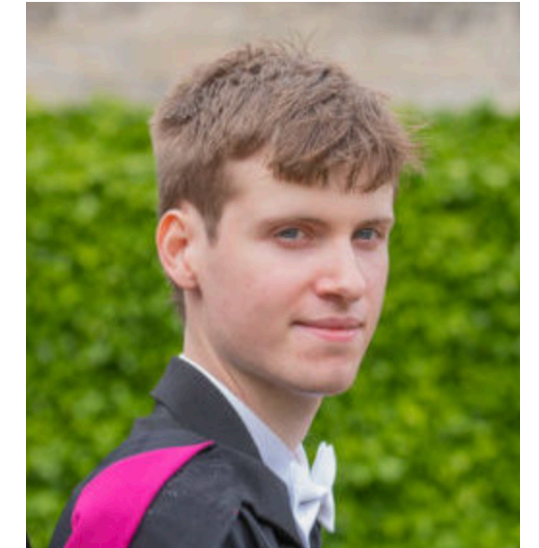


PAHSPECS program (PIs: Shivaei, Boogaard, Díaz-Santos)

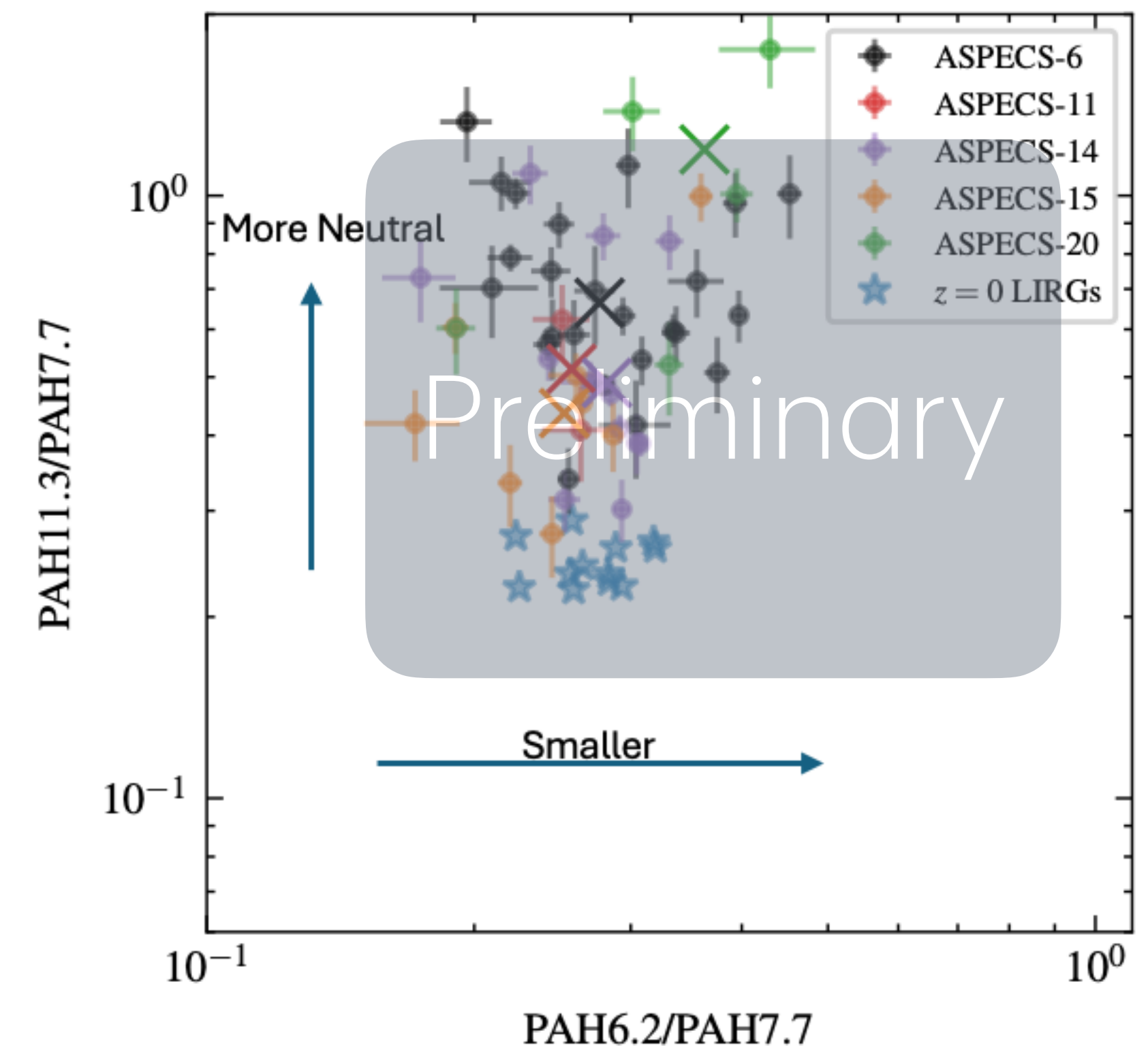
PAHs appear more neutral than locally with clear variation on spatially resolved scales



Poster 101

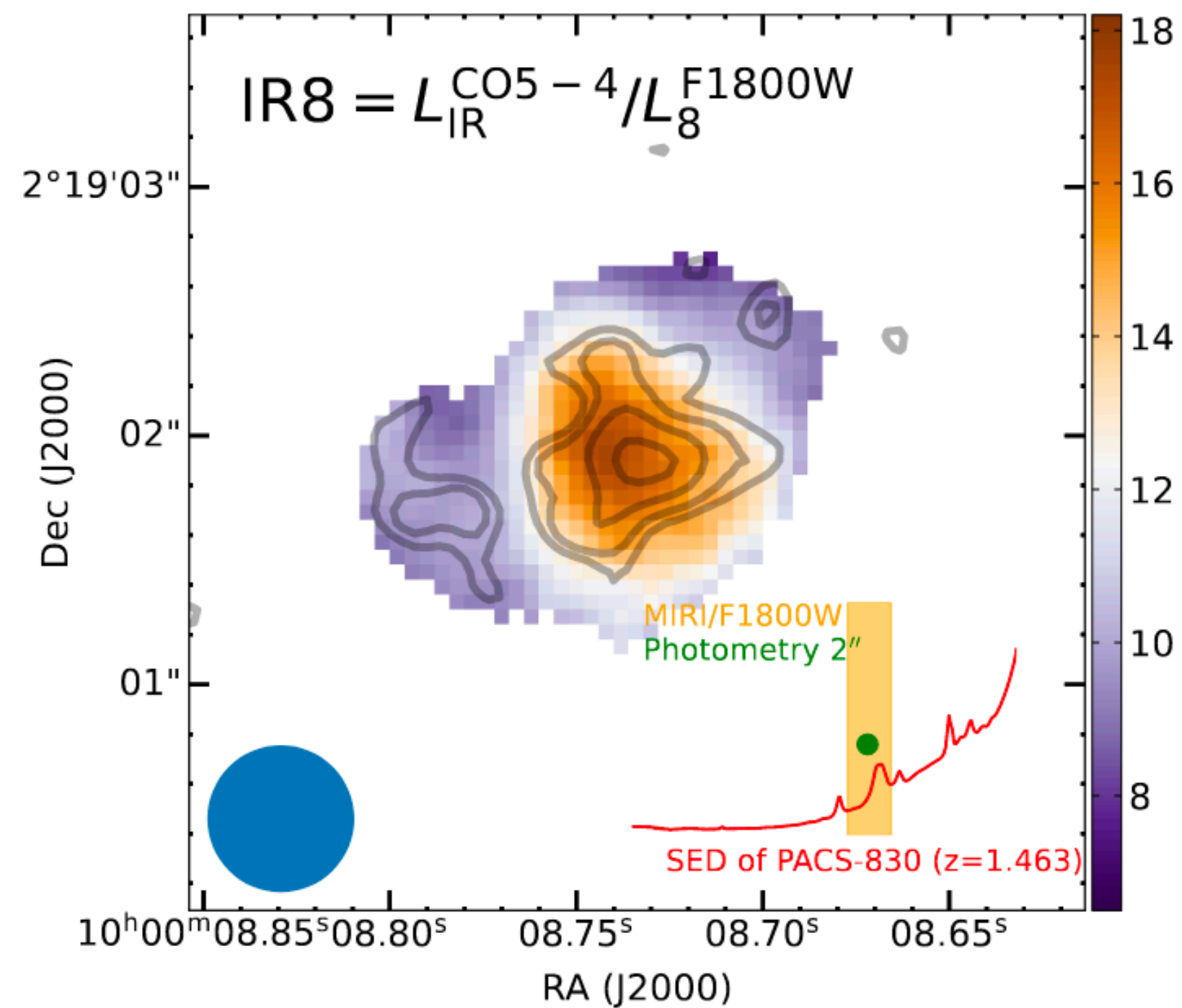


Fergus Donnan
Postdoc at UC San Diego



Resolved PAH emission at cosmic noon

PAH deficit in the core of a
starburst galaxy at $z=1.5$



Liu+2025

Destruction of PAHs by the intense
ionizing radiation field

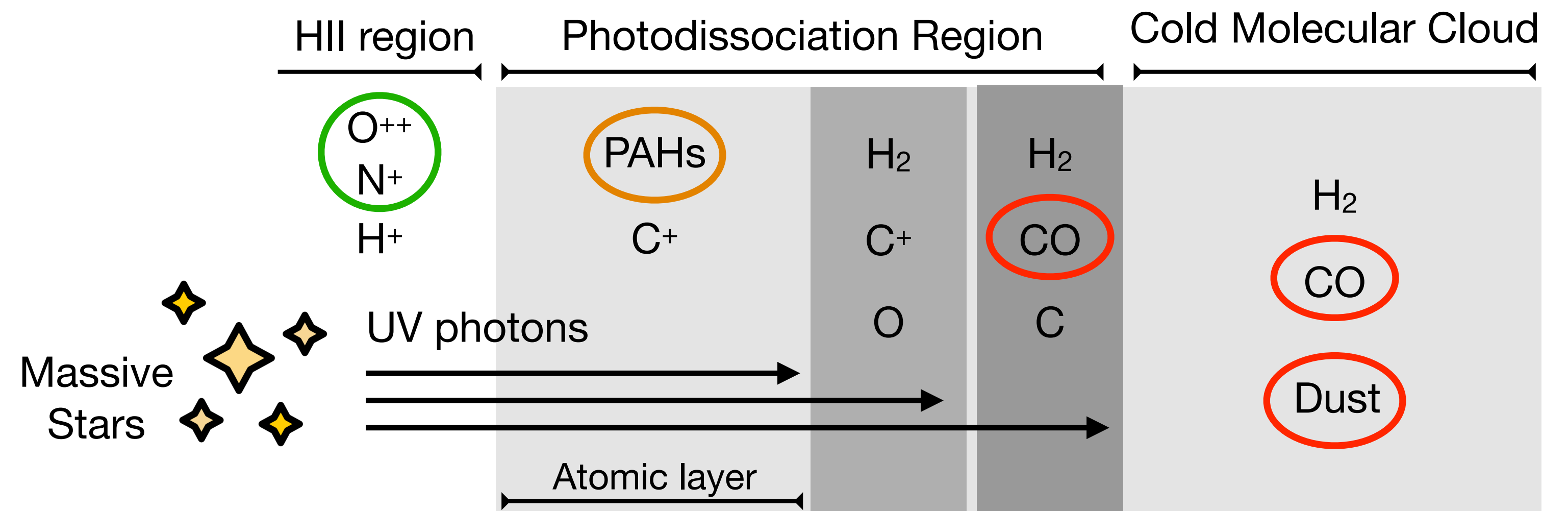
or

Decreased emission in the
photodissociation region

Baryon Cycle: gas, metals, dust

UV-irradiated molecular cloud edge

- ◆ PAHs (mid-IR spectra)
- ◆ Metals (near-IR spectra)
- ◆ Cold gas (sub-mm lines, CO)
- ◆ Cold dust (far-IR emission)

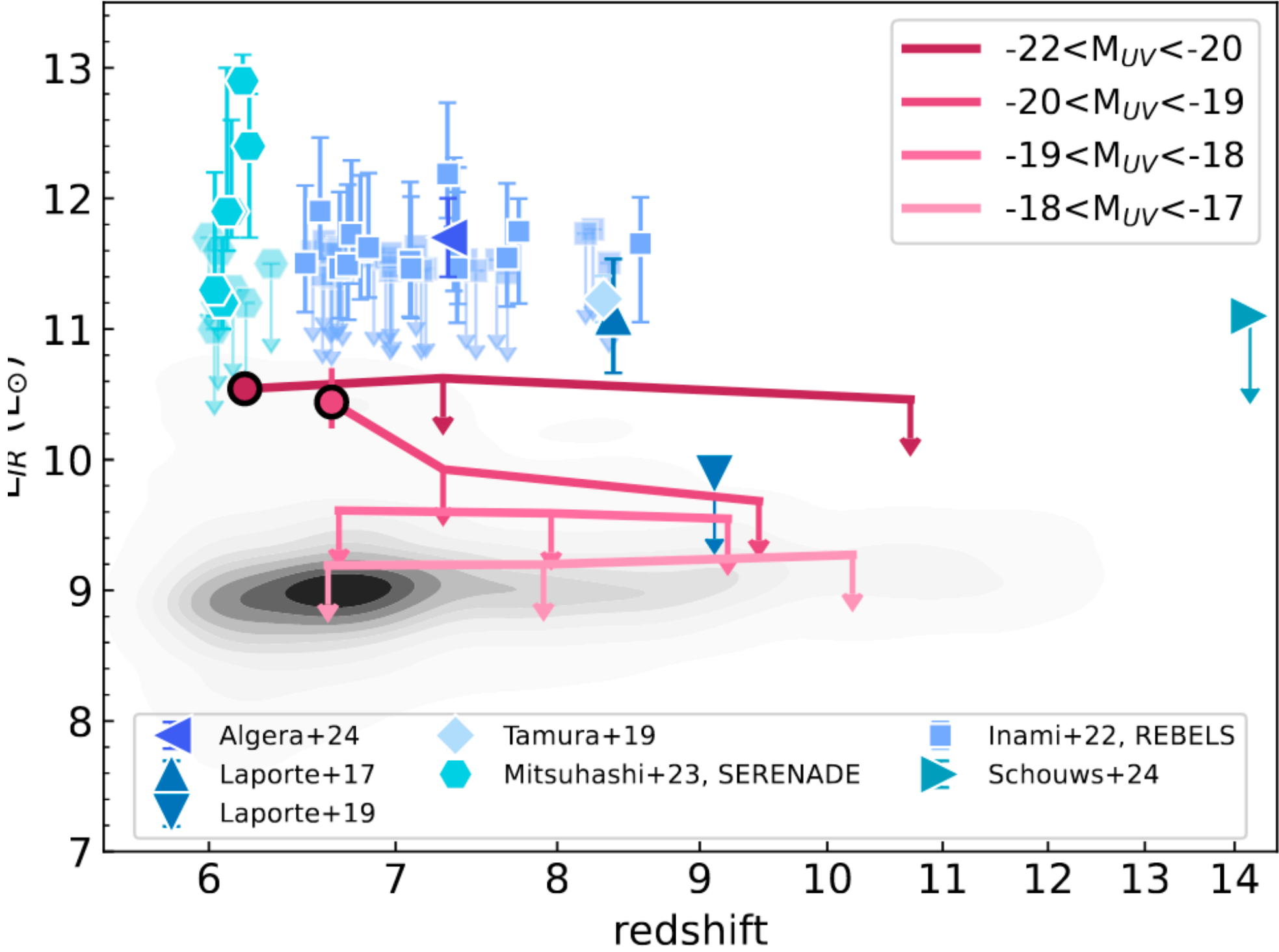
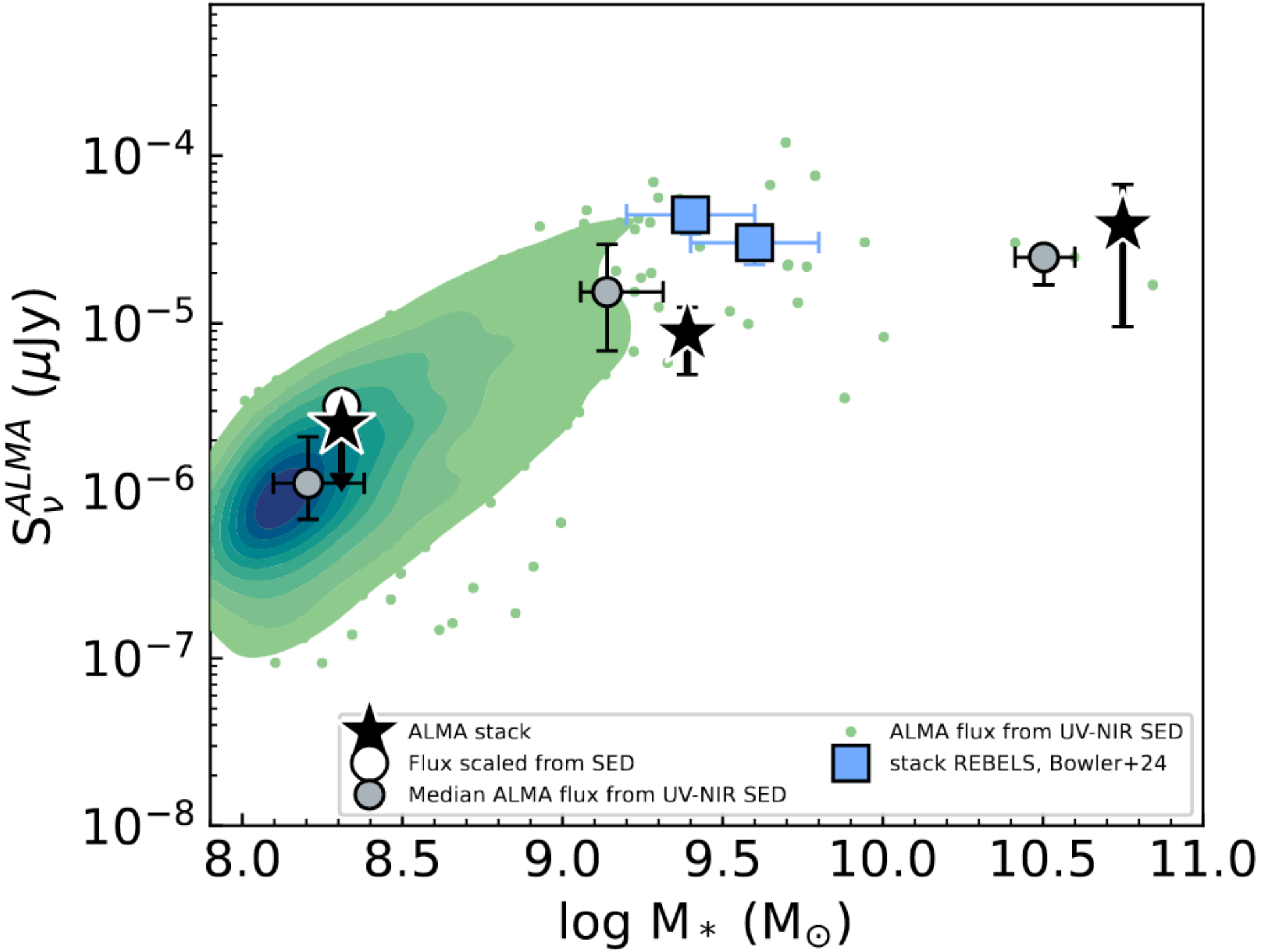


Adopted from Goicoechea+2016

ALMA for typical galaxies at high-z

- Stacks of a few thousands JADES (GS) galaxies at $z \sim 6-10$
- Still not detected for fainter UV and lower mass bins

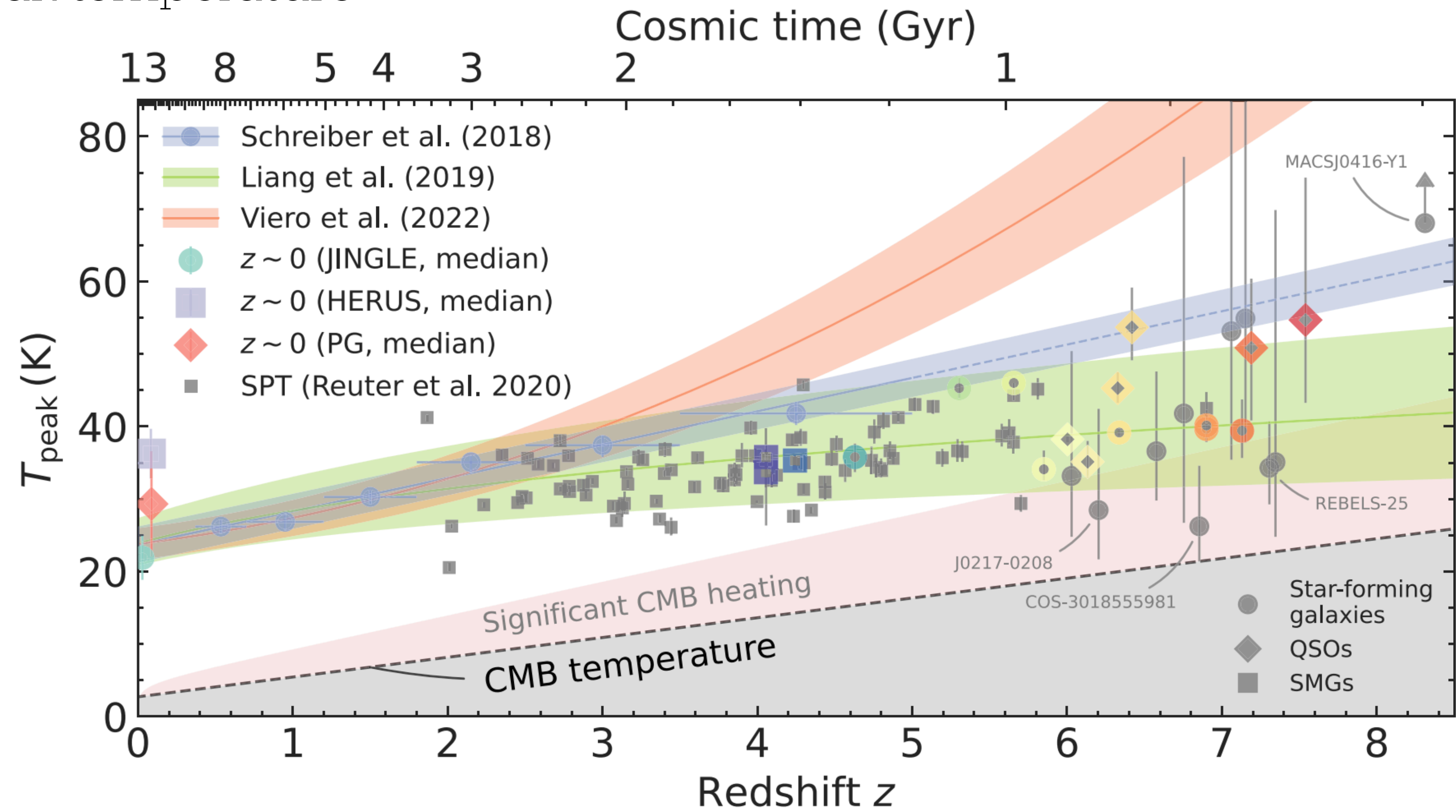
Ciesla+2024



Also: Hill+2024

Linking dust emission to fundamental galaxy properties

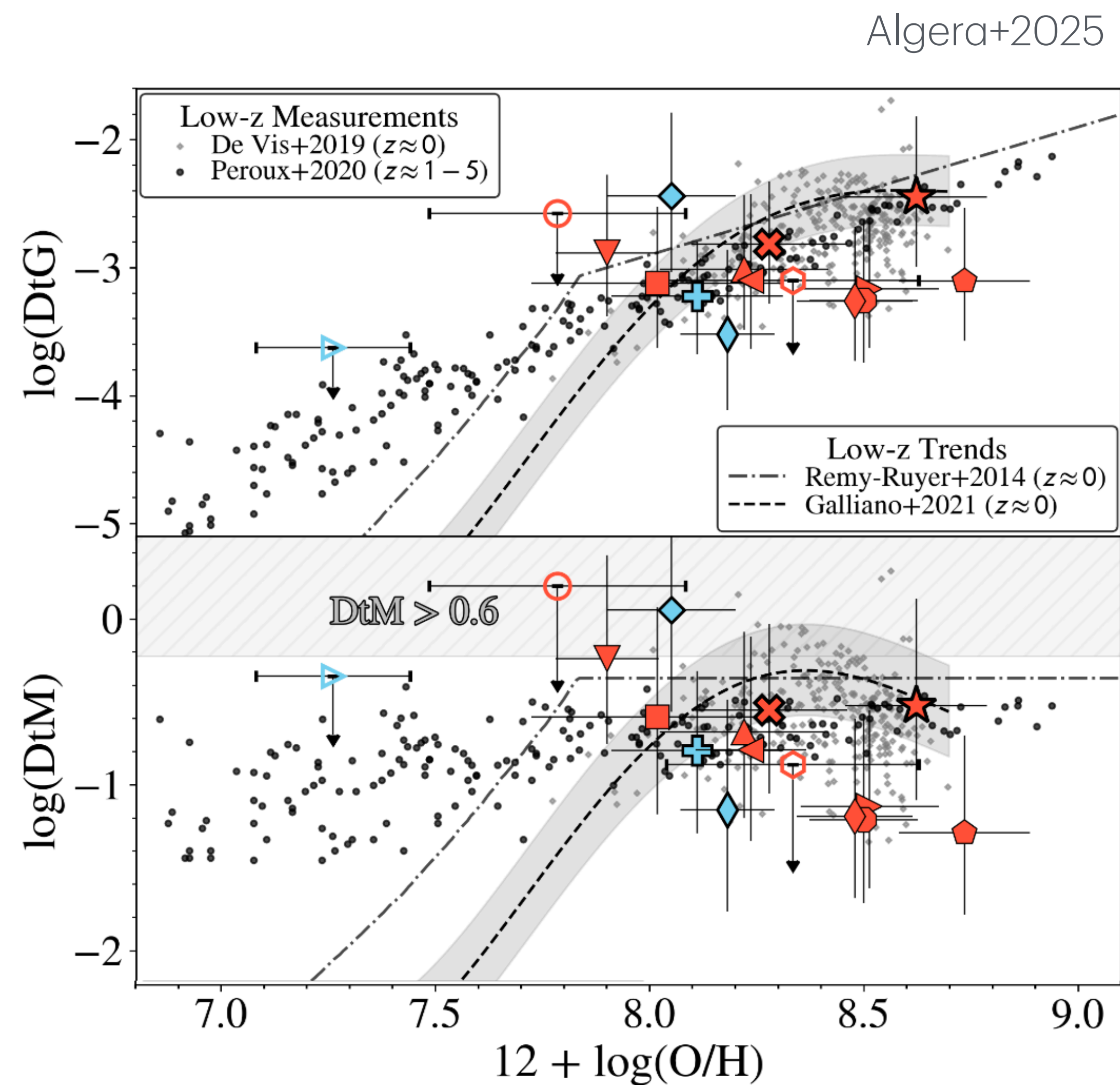
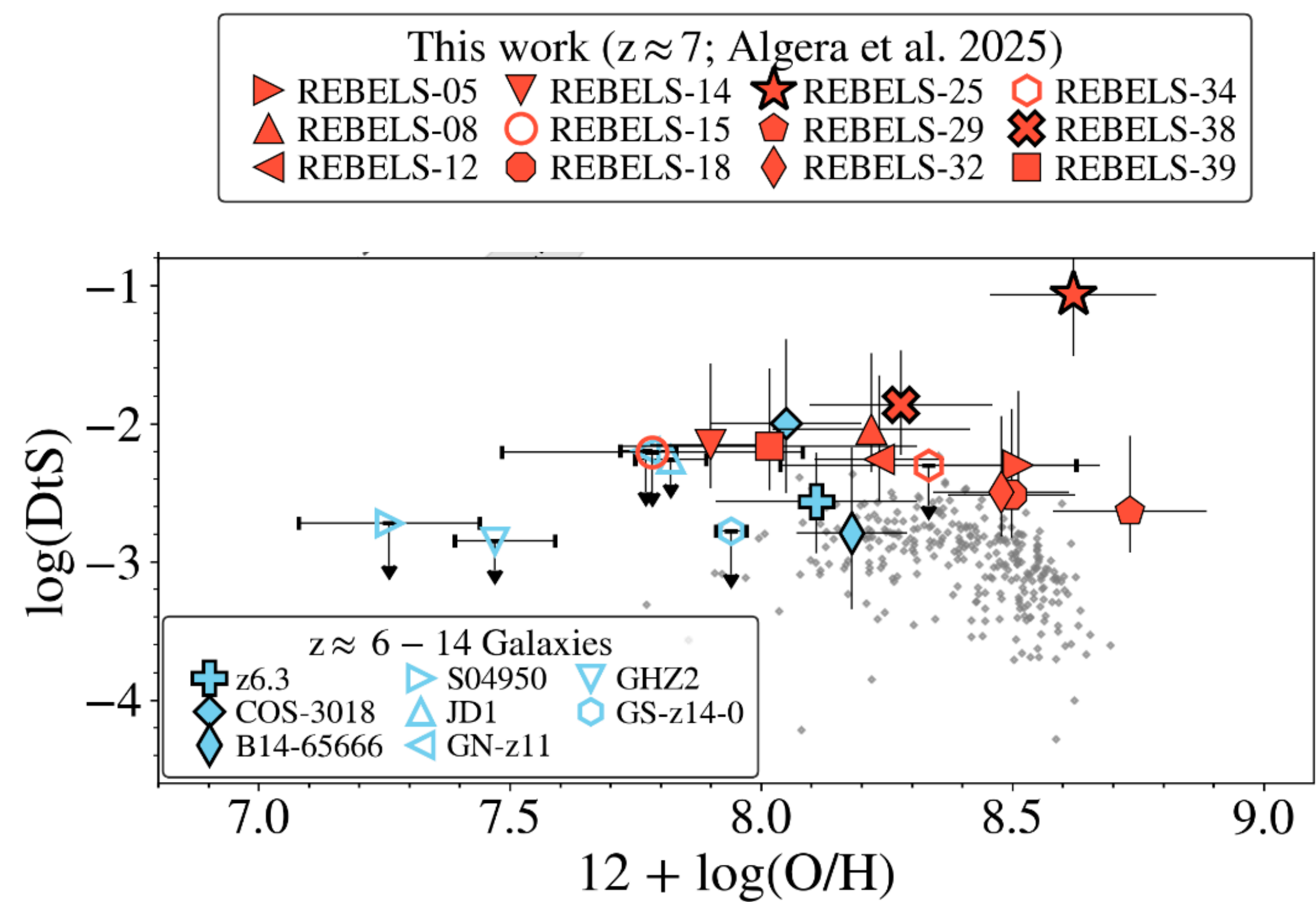
Dust peak temperature



Witstok+2023

Linking dust emission to fundamental galaxy properties

Dust mass

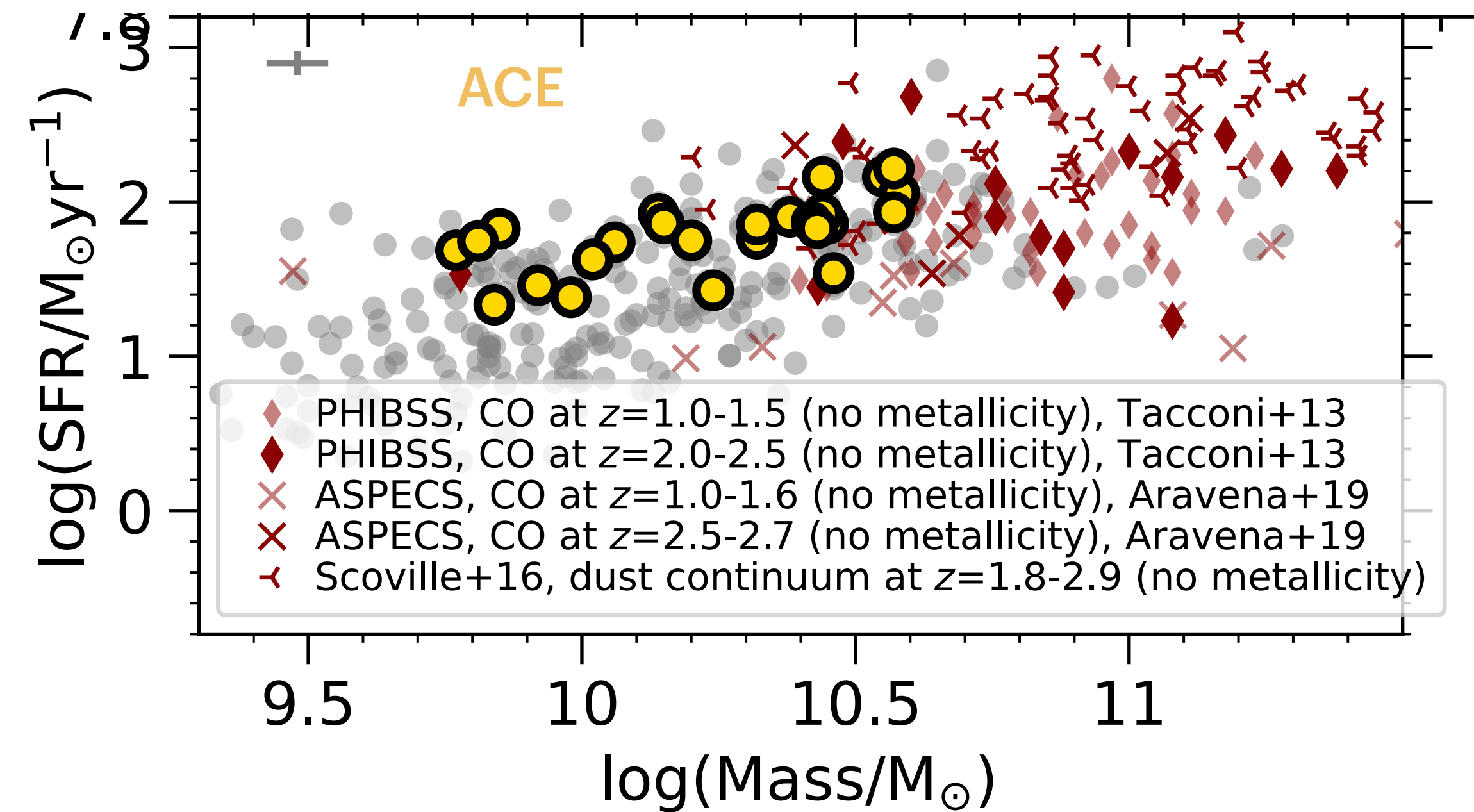
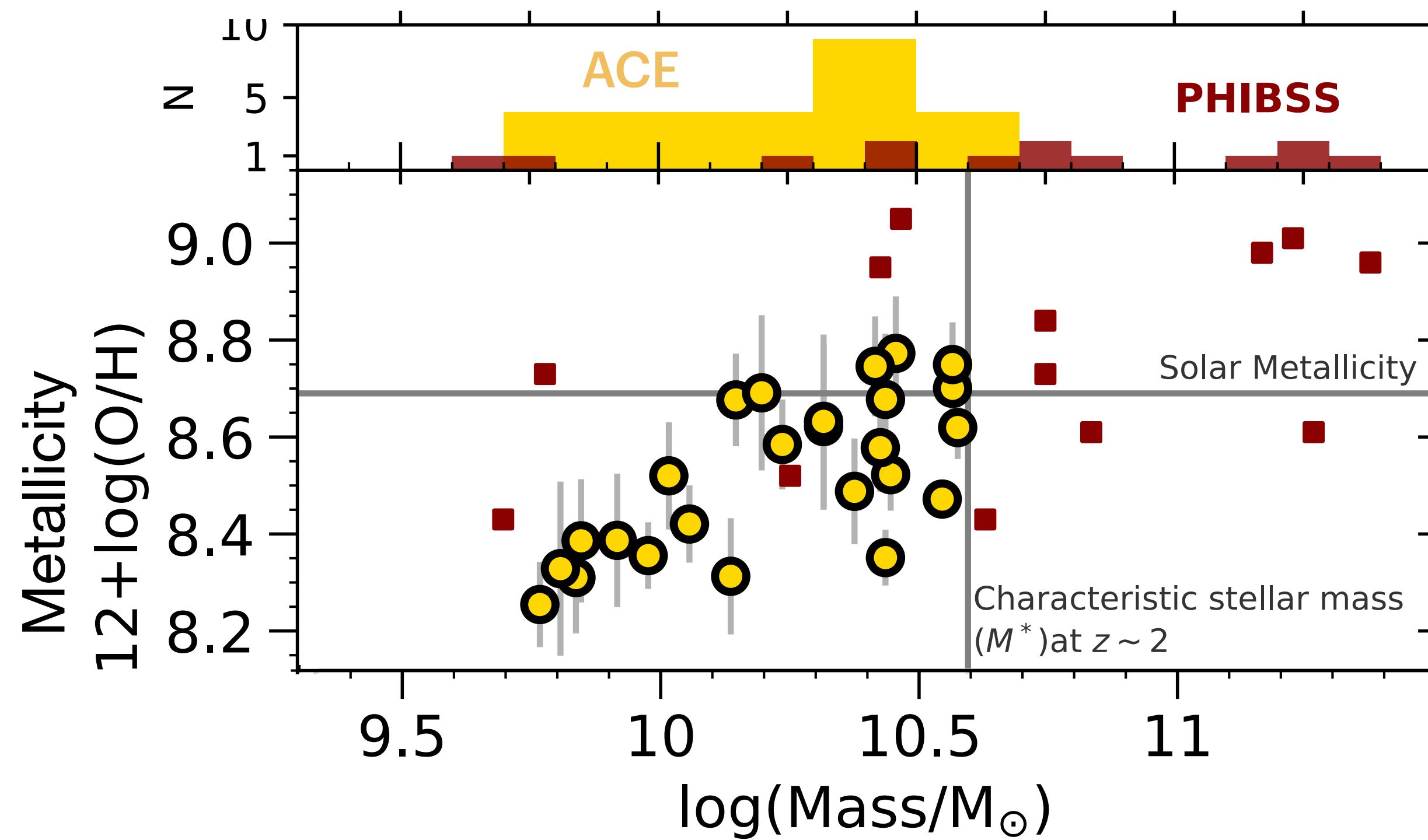


Also: Burgarella+2025



ALMA Chemical Evolution (ACE) Survey

PIs: Irene Shivaei, Gergö Popping



Linking dust emission to fundamental galaxy properties



ALMA Chemical Evolution Survey (PIs: Shivaei, Popping)

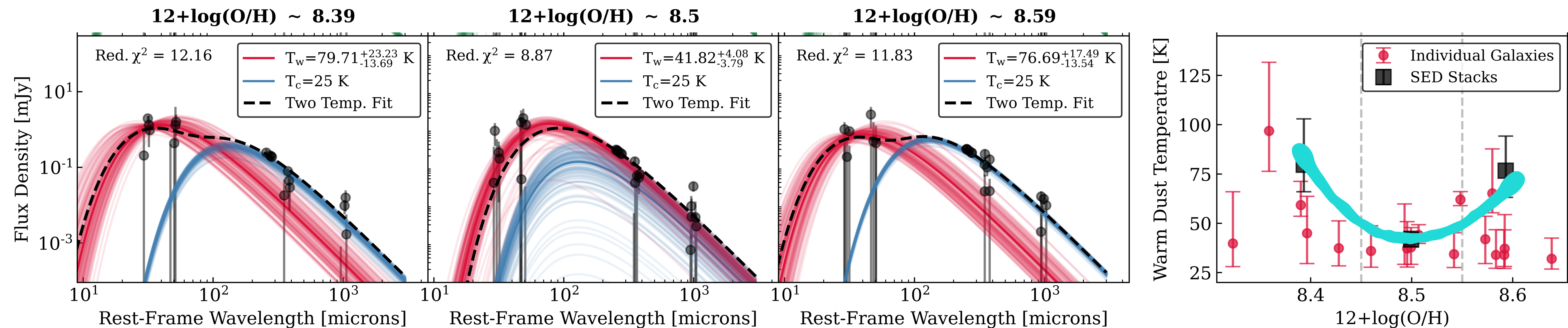
Hotter dust at low metallicities?



Poster 58



Roxana Popescu
PhD student at UMass Amherst



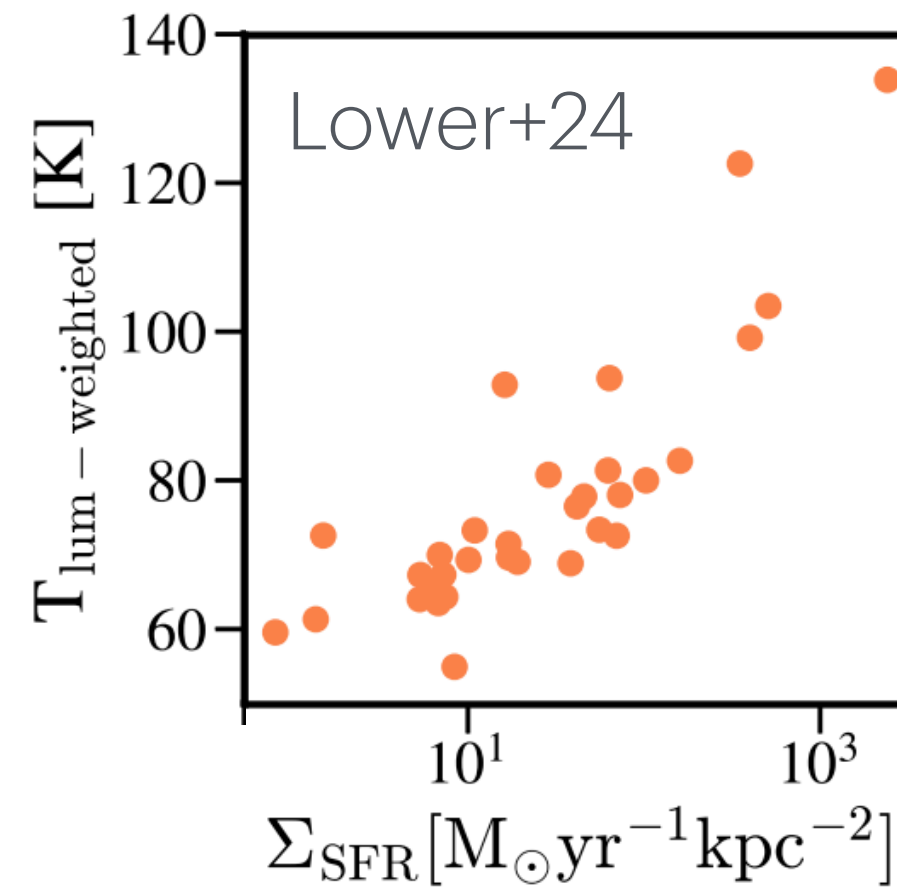
Popescu+in prep

Linking dust emission to fundamental galaxy properties



ALMA Chemical Evolution Survey

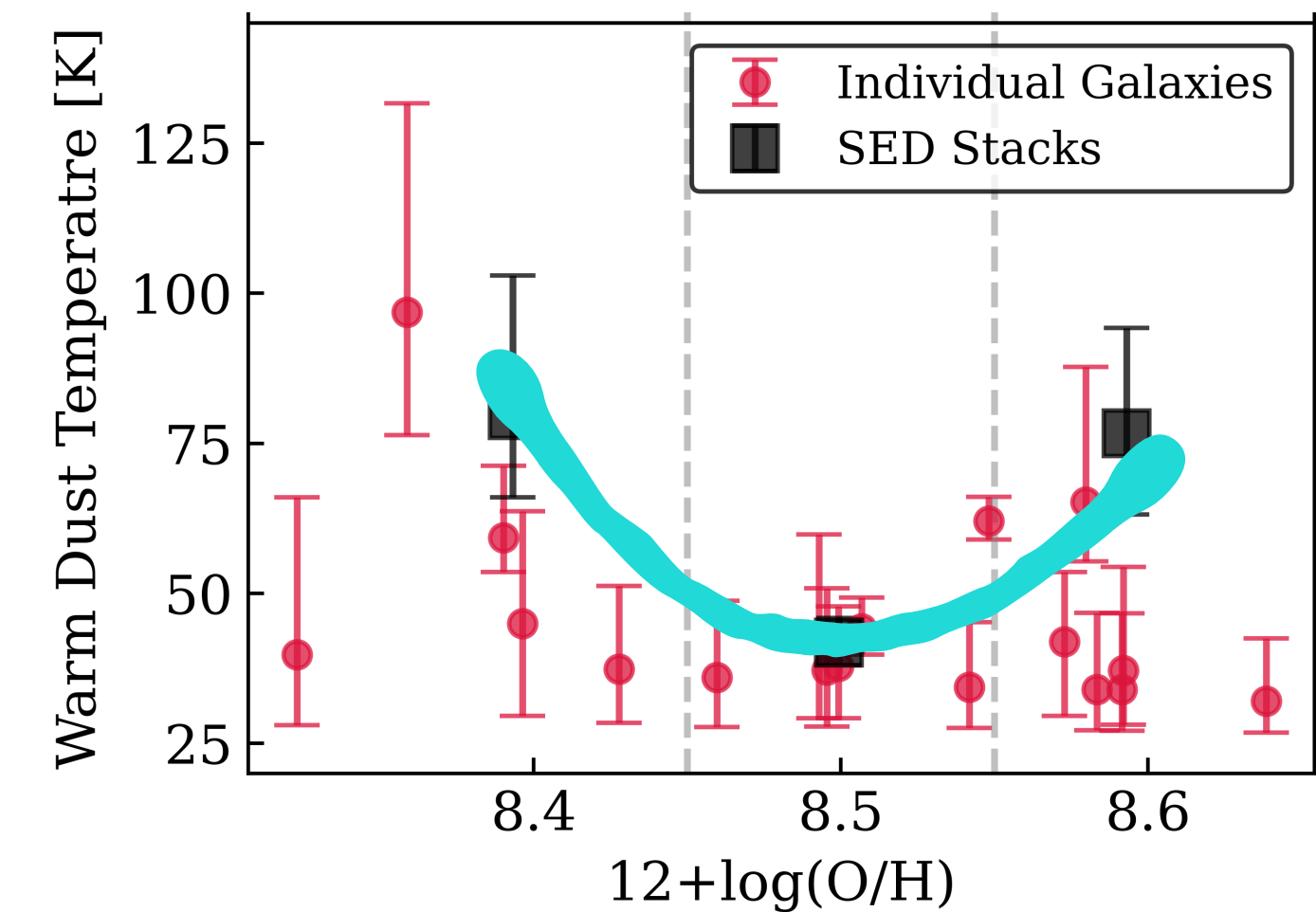
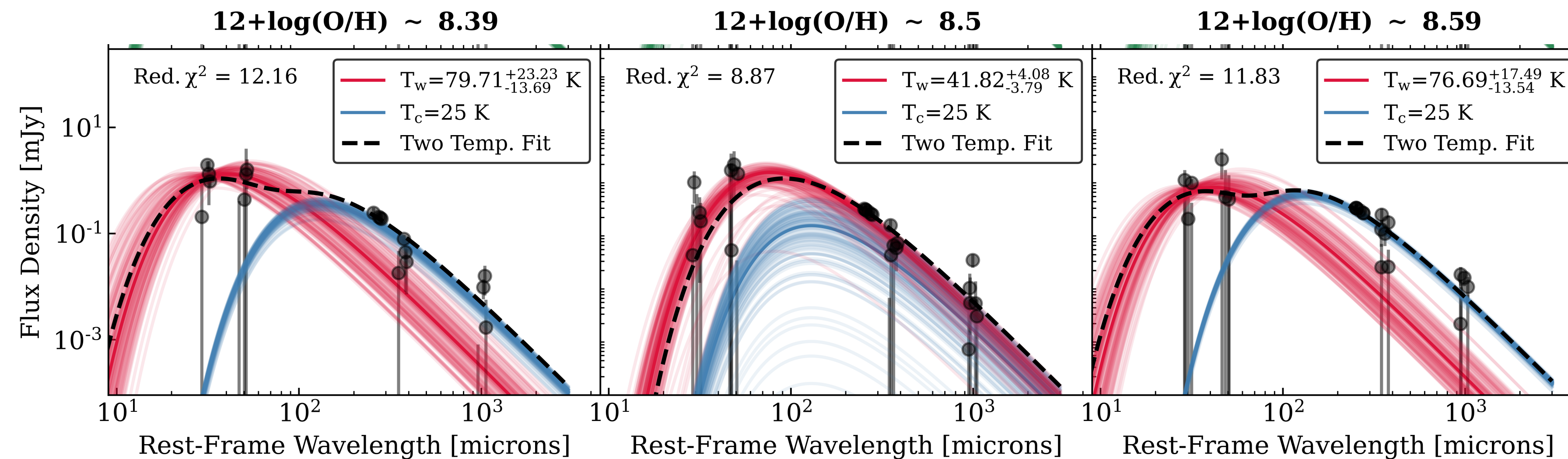
Hotter dust at low metallicities?
Or linked to SFR surface density?



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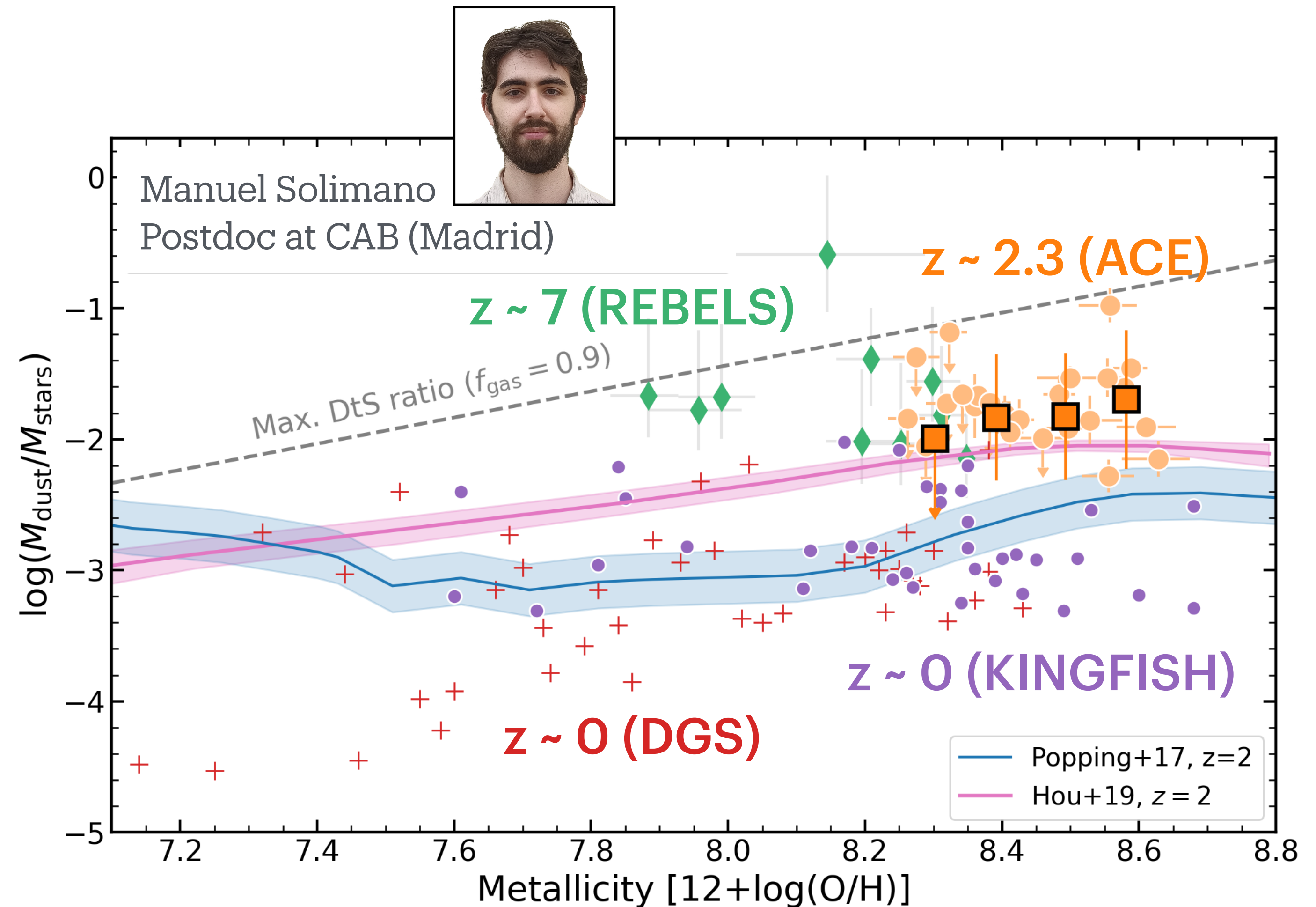
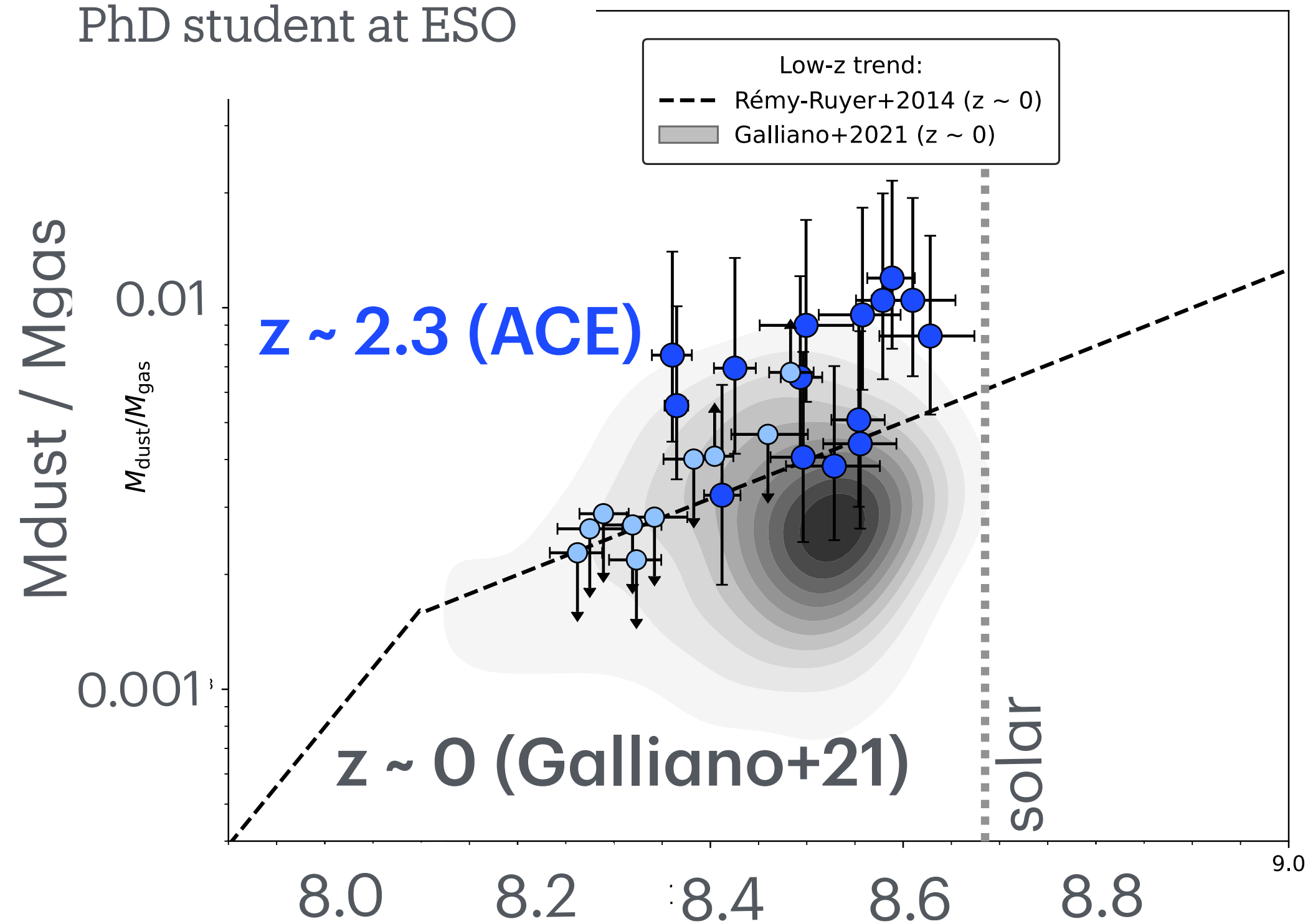
Popescu+in prep

Linking dust emission to fundamental galaxy properties



ALMA Chemical Evolution Survey (PIs: Shivaei, Popping)

Nikki Geesink
PhD student at ESO



Manuel Solimano
Postdoc at CAB (Madrid)



Summary

- ✦ **Stellar dust attenuation curves** have shallower UV-optical slope at high redshifts, at a given A_V : potentially indicating stellar dust dominance. Shallower curves mean lower attenuation, even though there might be dust.
- ✦ **UV attenuation bump** has been observed at very high redshifts, its origin might be related to PAHs. Lower redshift studies connecting UV bump, PAH, metallicity will be informative.
- ✦ The **PAH mass fraction-metallicity** and **PAH-CO luminosity** relationships exist out to $z \sim 2$
- ✦ MIRI spectroscopy is revealing **properties of PAHs** in PAH diagnostic diagrams, showing variations compared to $z \sim 0$
- ✦ Studies both at cosmic noon and higher- z combining **dust emission properties with cold gas and metallicity** are paving the way for understanding dust evolution and origin