



DUST EMISSION

IN GALAXIES

Karin Sandstrom - UC San Diego

Tucson - 11/13/25

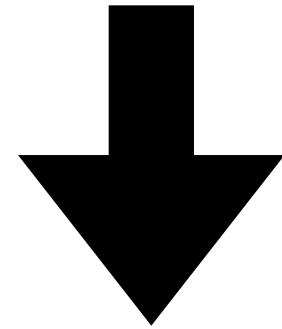
Basics of Dust Emission

Composition and size of dust
grain.

Radiation field intensity and
spectrum

Basics of Dust Emission

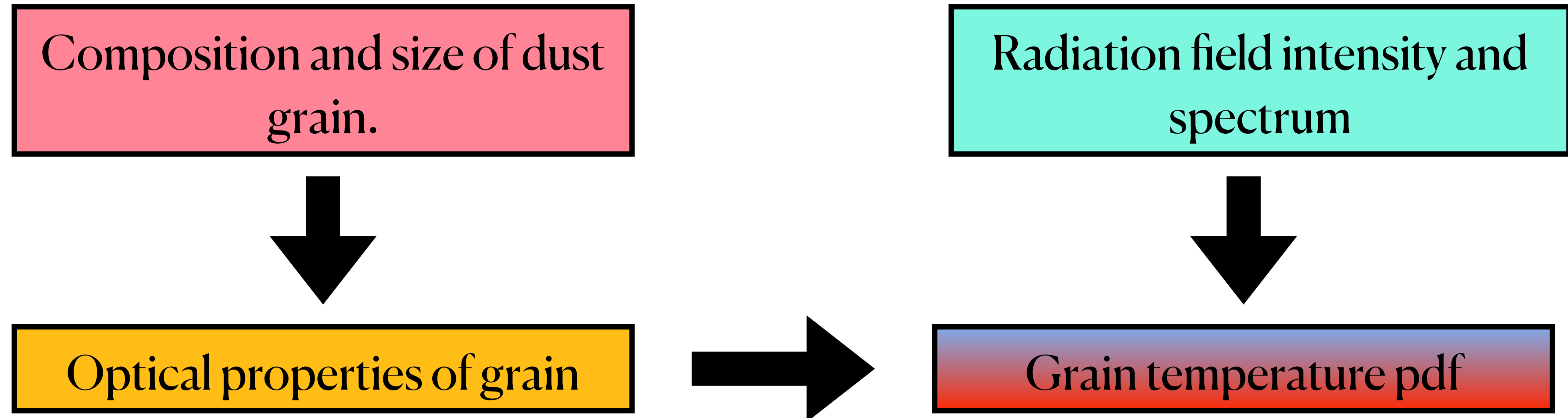
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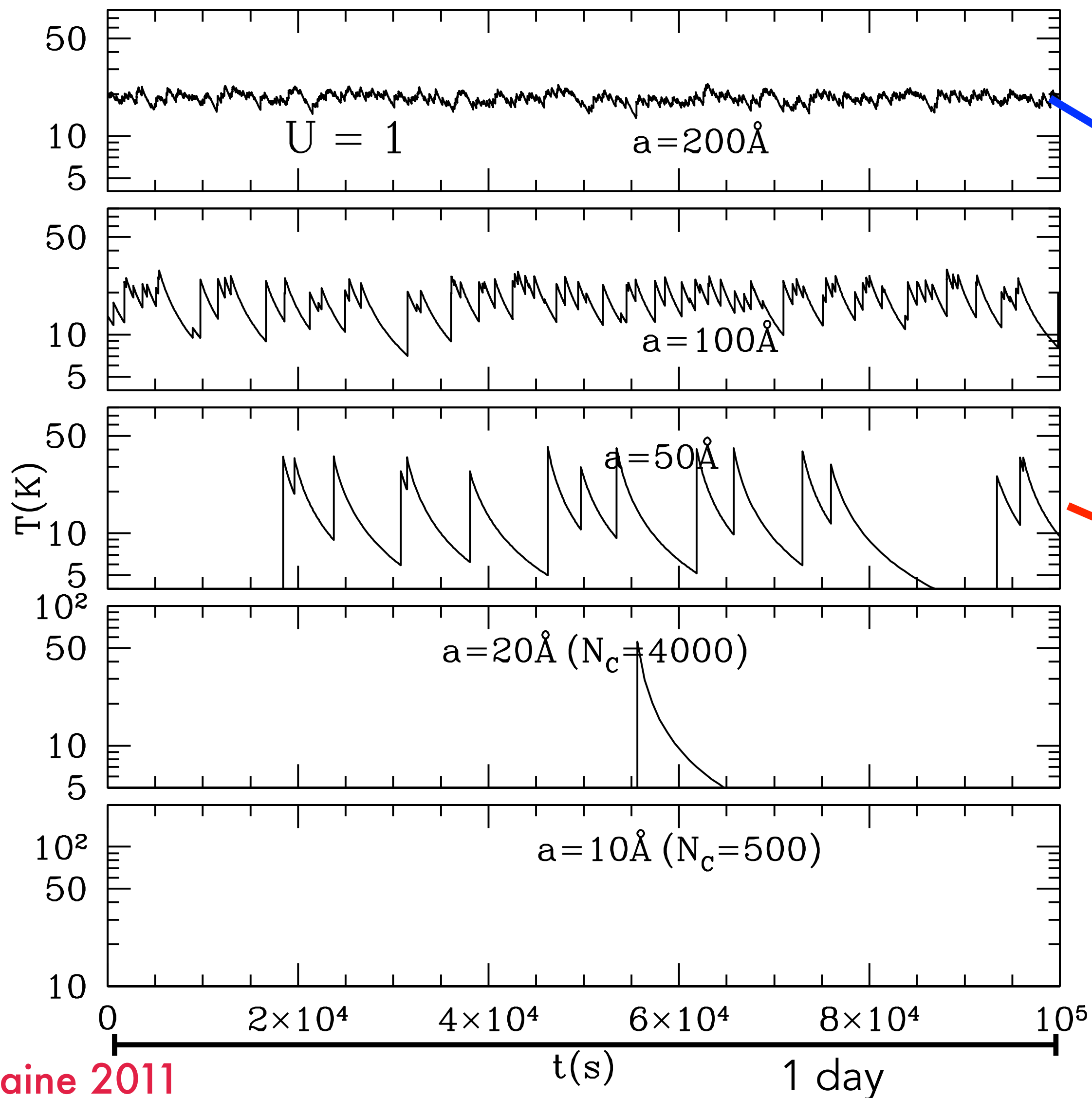
Optical properties of grain

Radiation field intensity and
spectrum

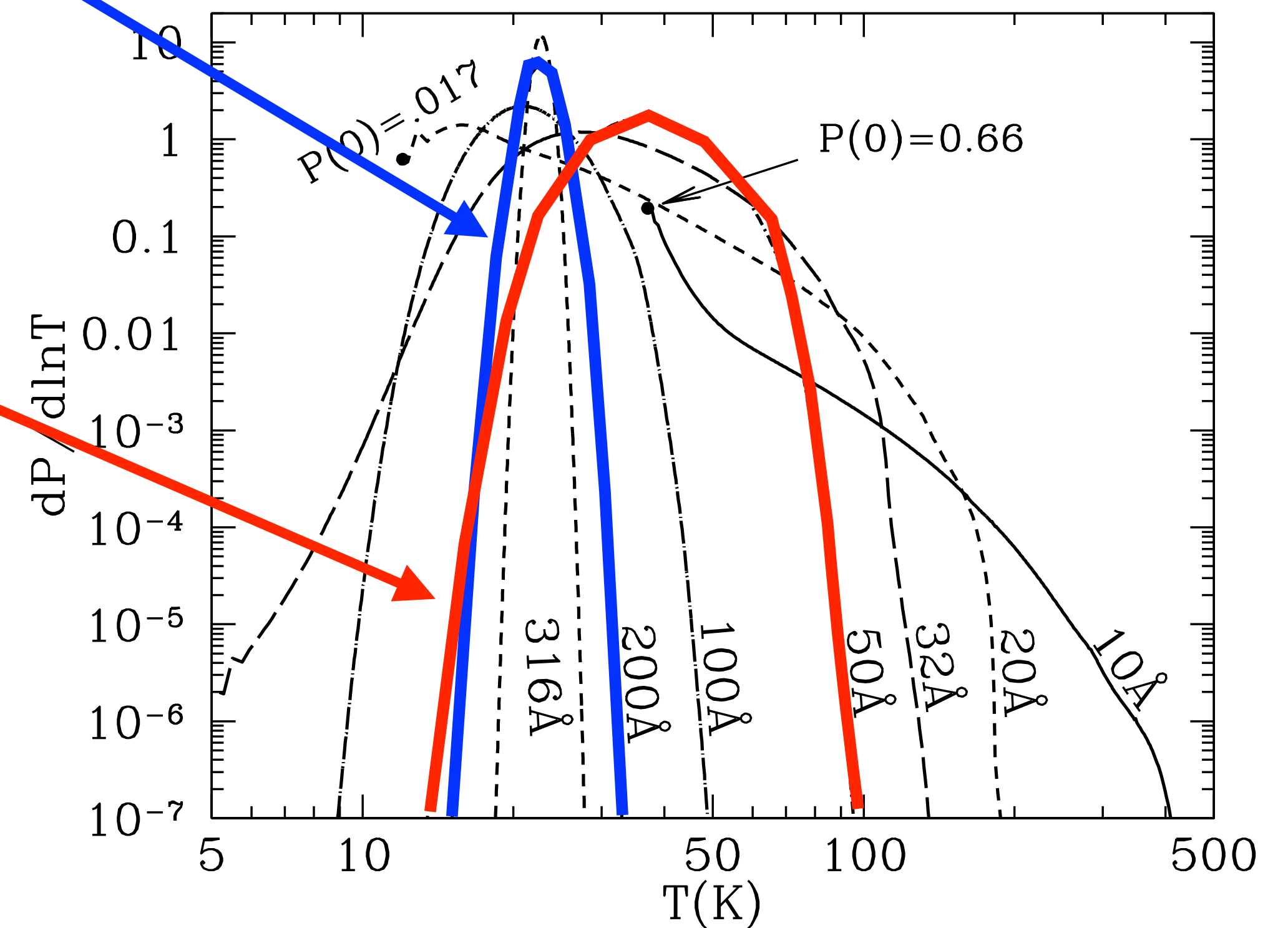
Basics of Dust Emission



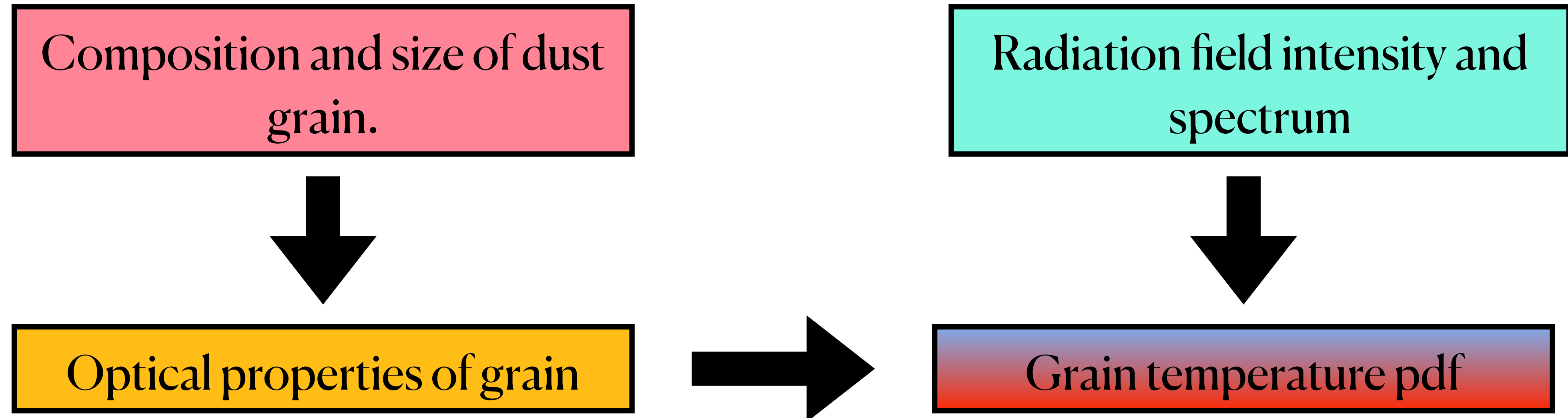
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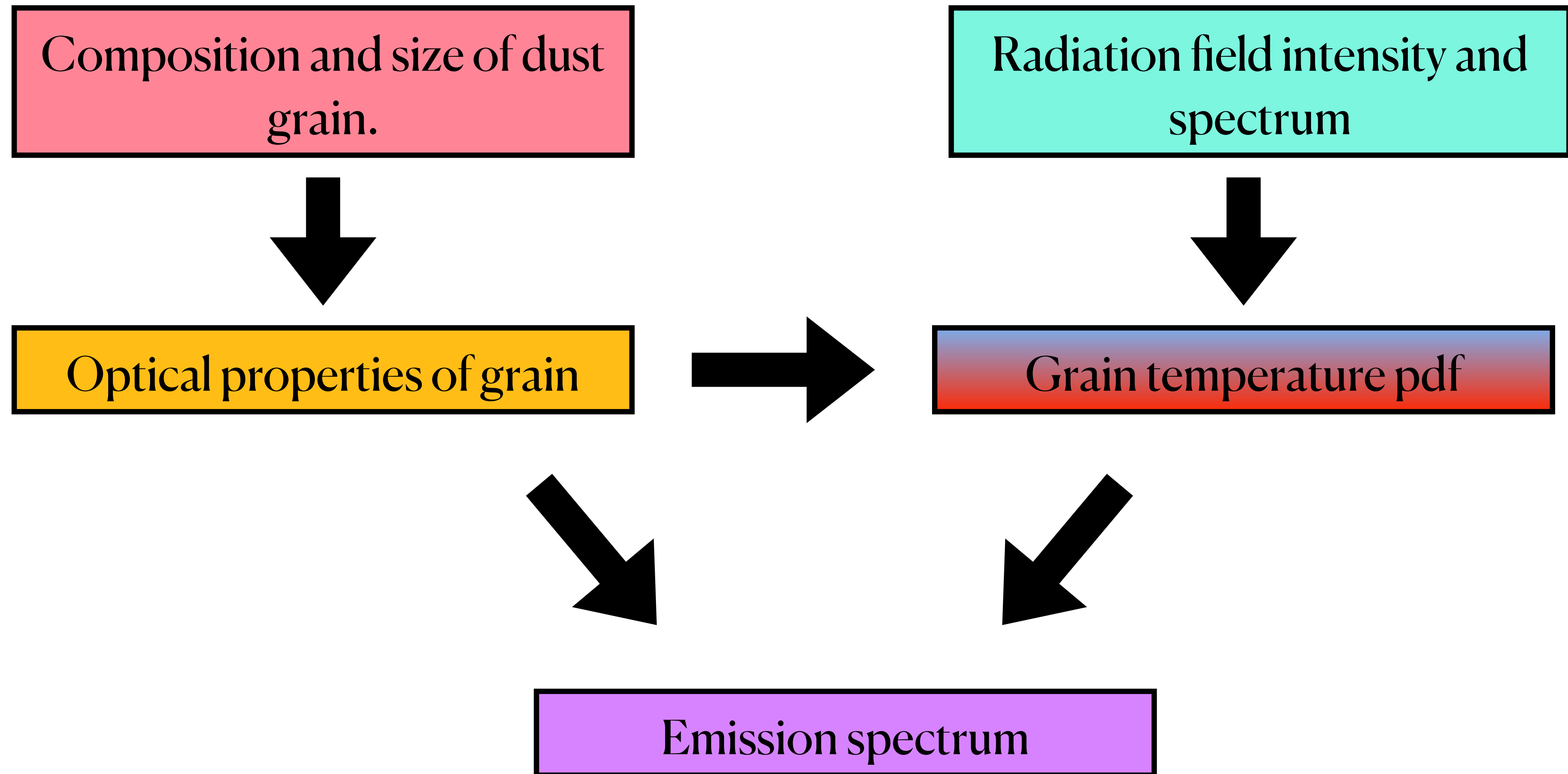
For a given radiation field intensity, larger grains can be in equilibrium, but small grains may not be.



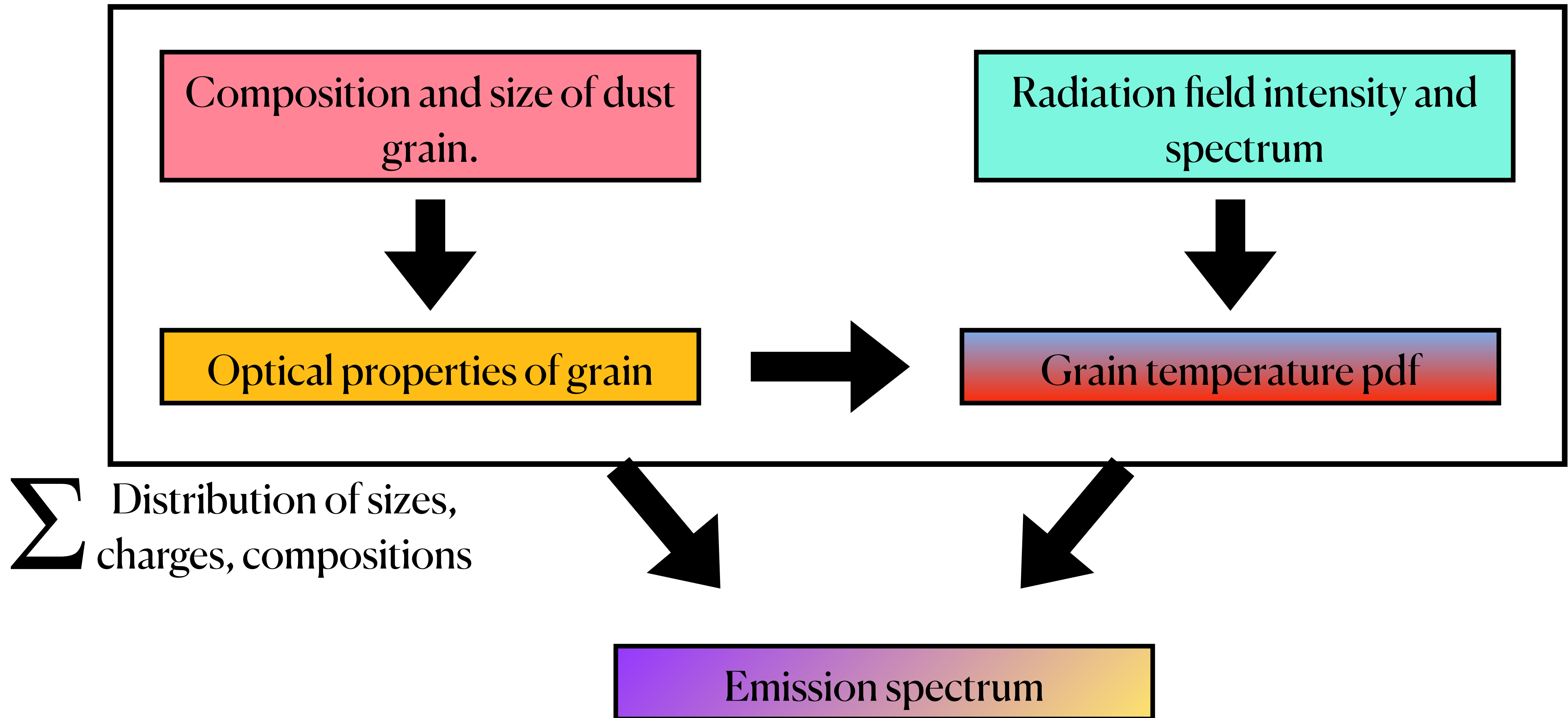
Basics of Dust Emission



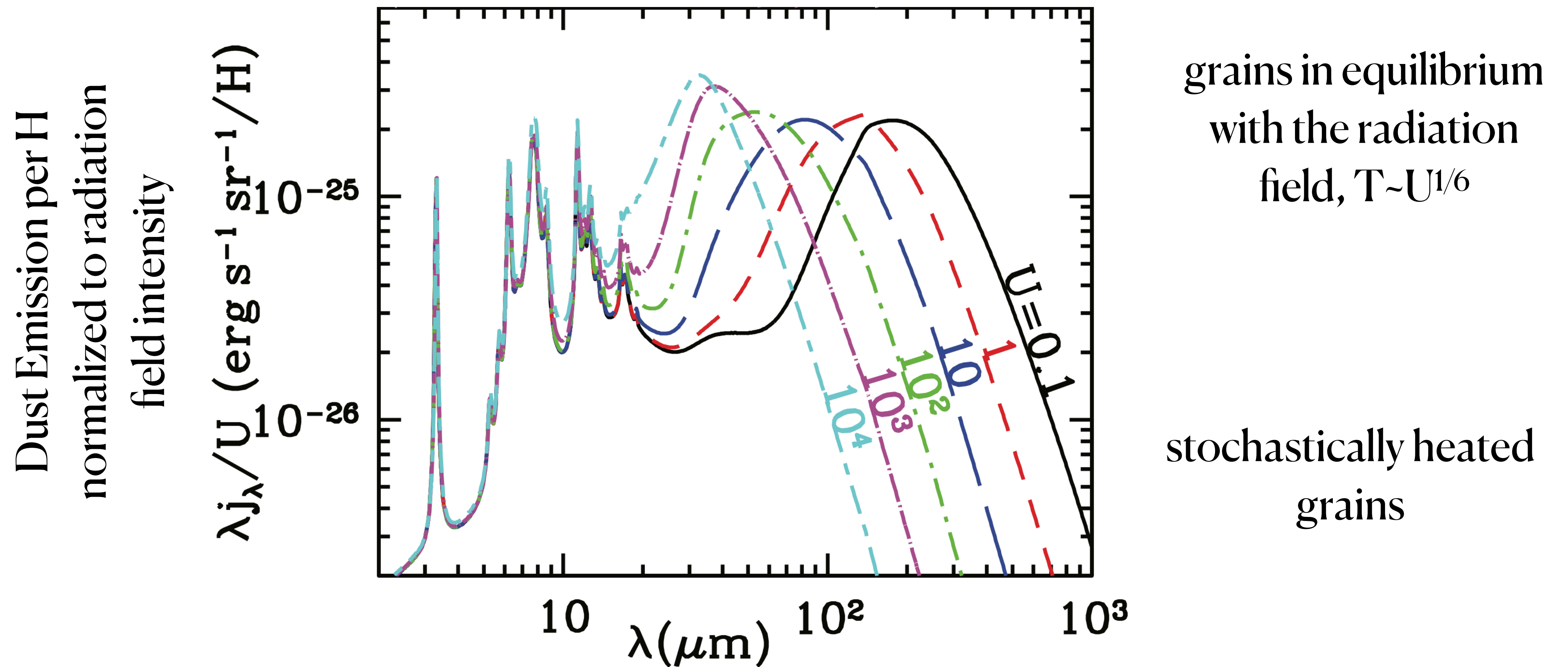
Basics of Dust Emission



Basics of Dust Emission

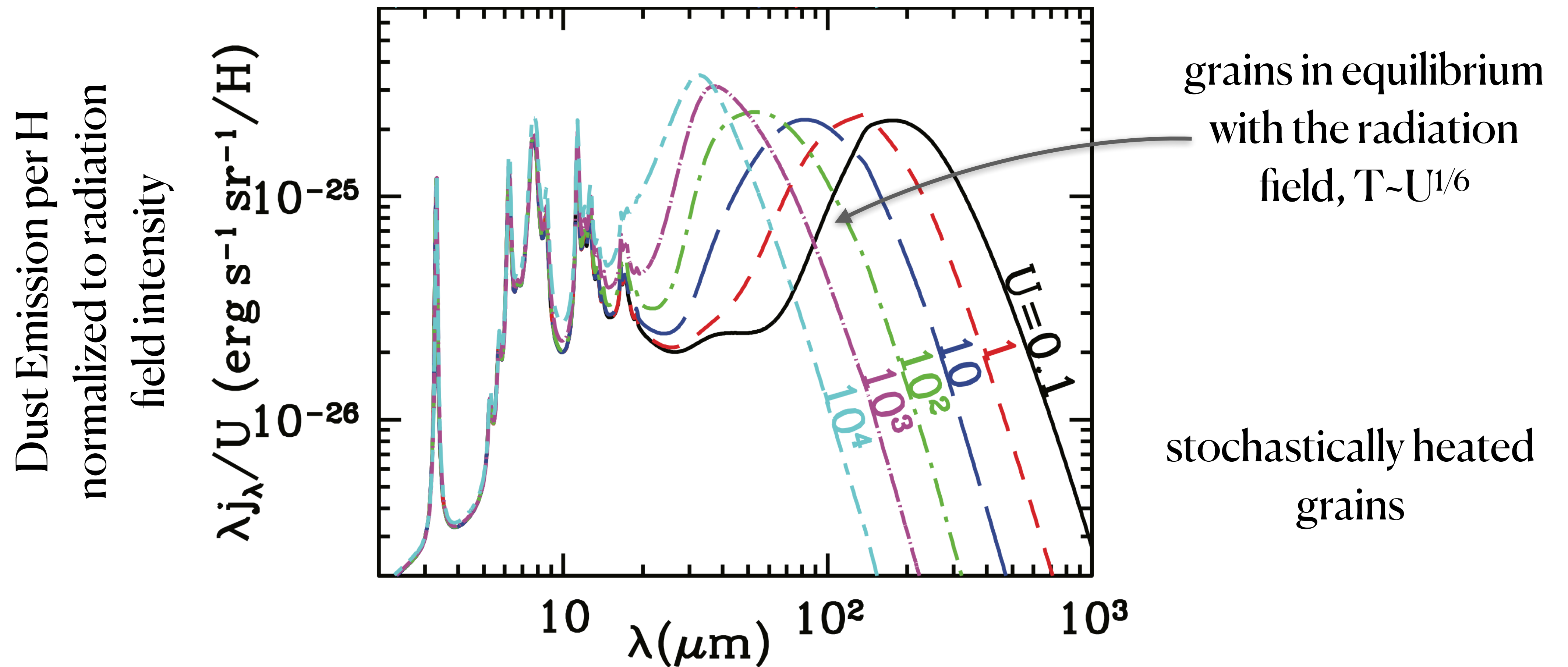


Emission from a Population of Grains Exposed to Single Radiation Field



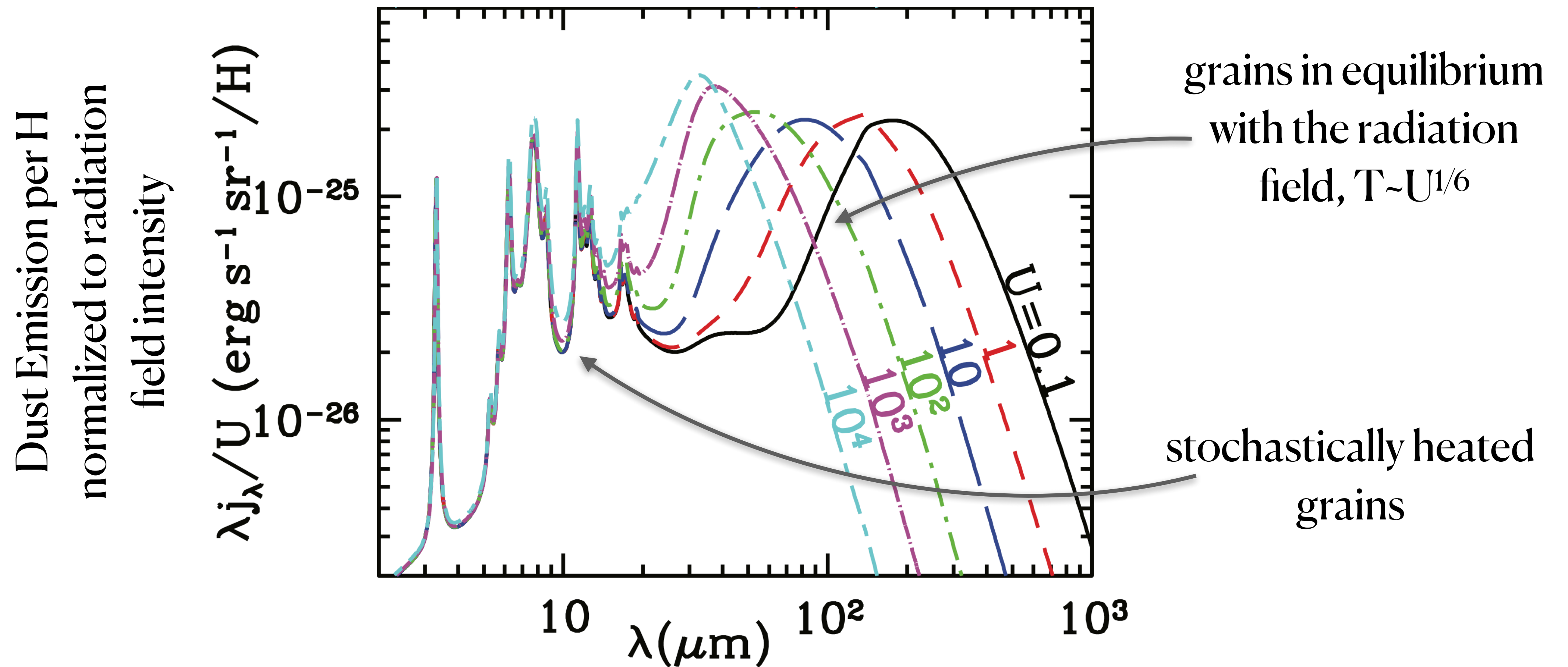
Draine & Li 2007

Emission from a Population of Grains Exposed to Single Radiation Field



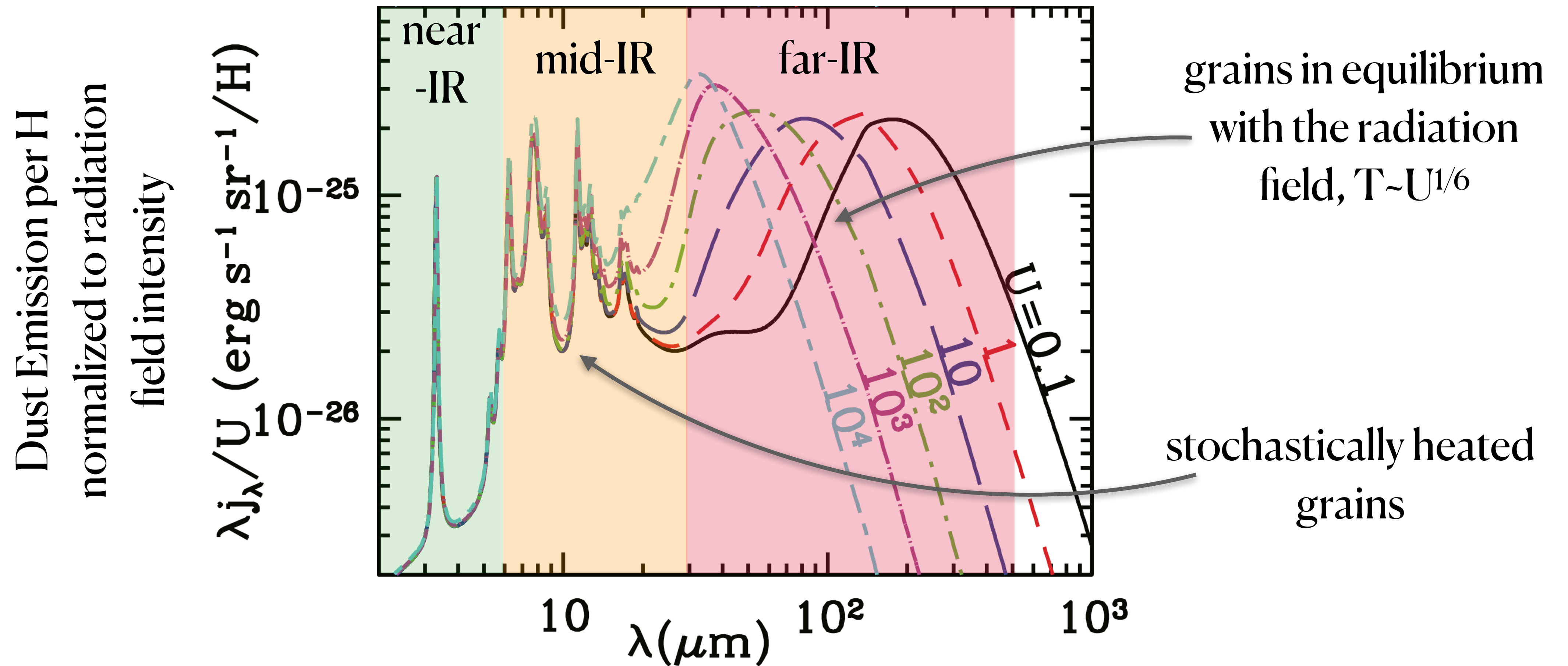
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Emission from a Population of Grains Exposed to Single Radiation Field



Draine & Li 2007

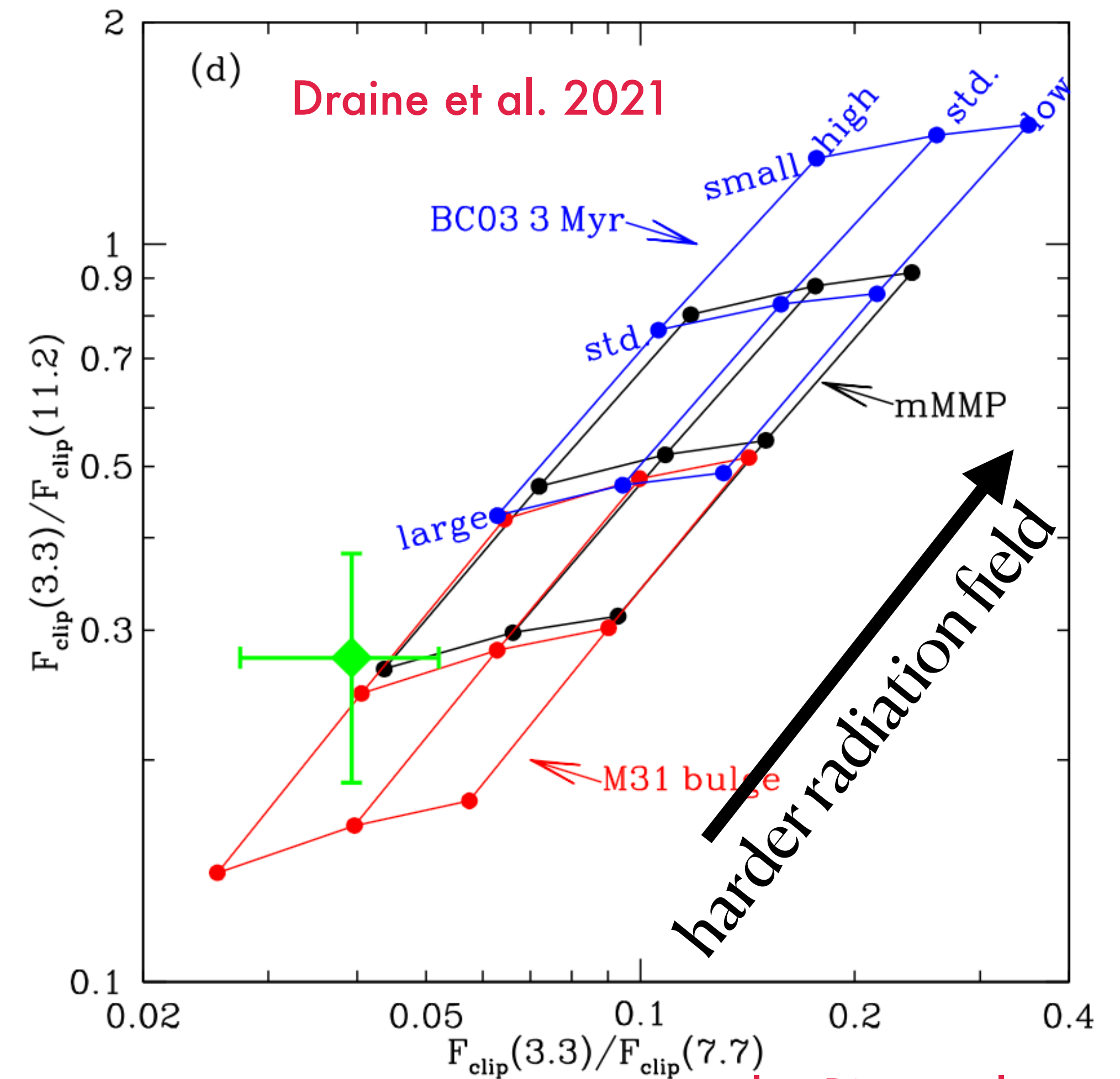
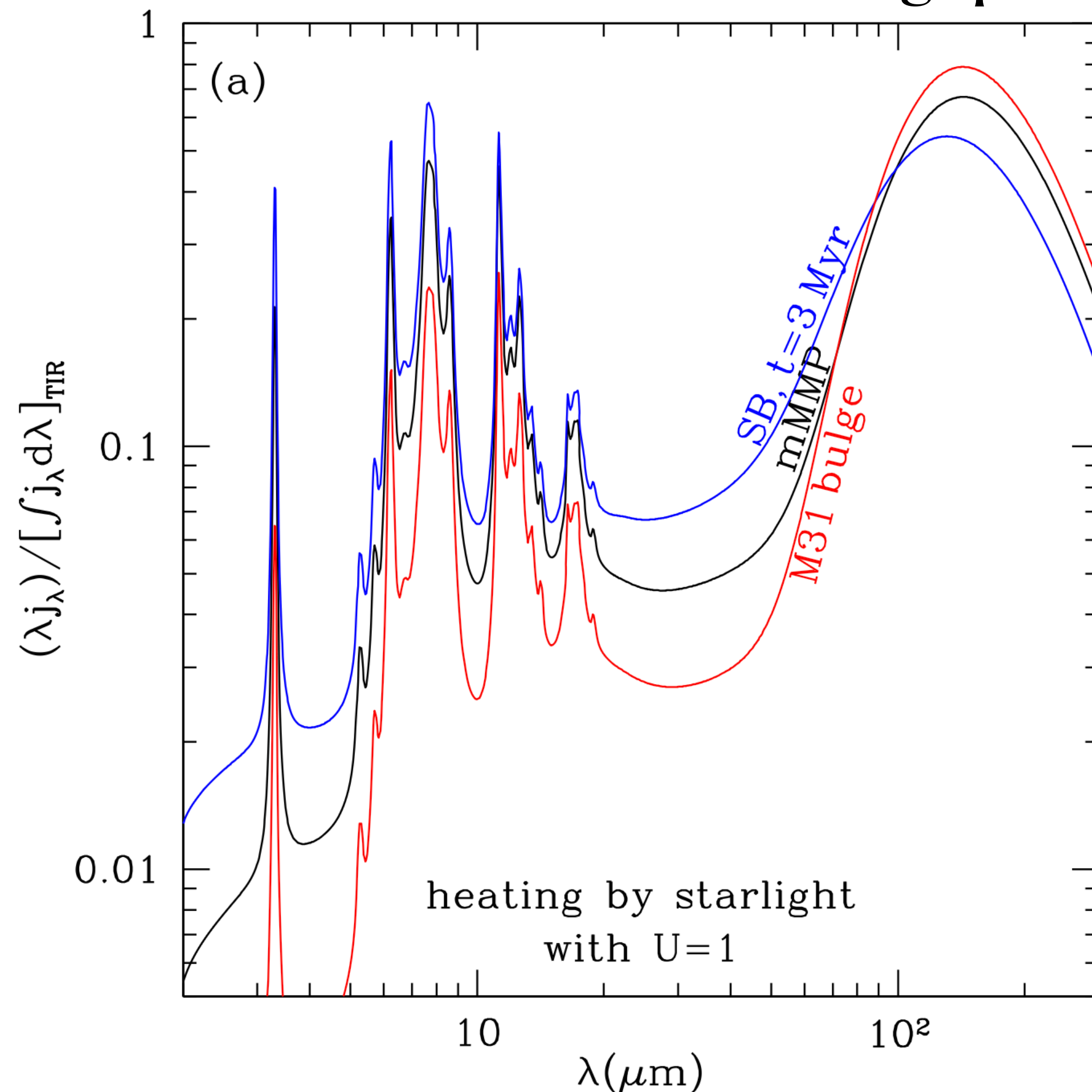
Emission from a Population of Grains Exposed to Single Radiation Field



Draine & Li 2007

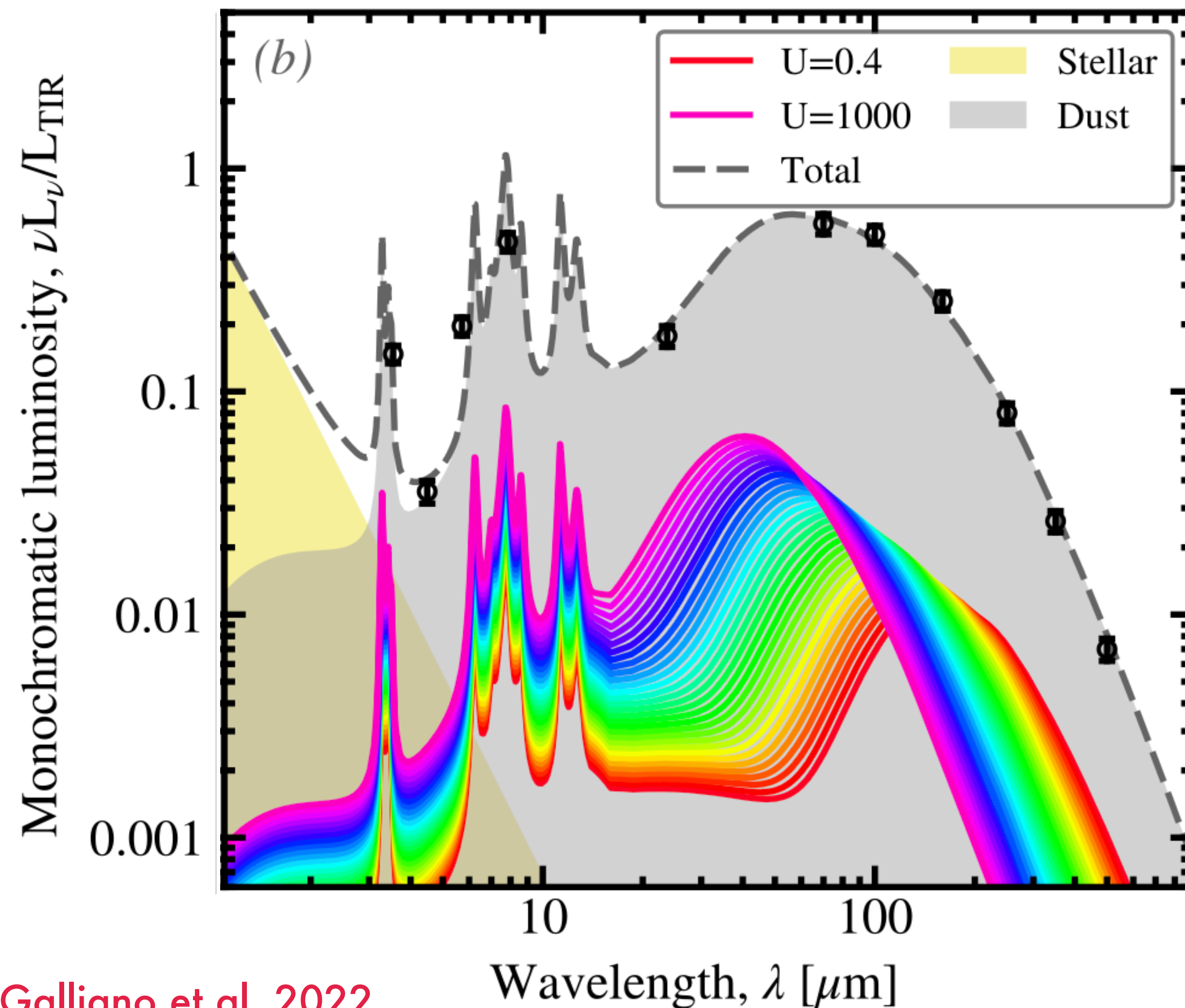
What happens if you change the radiation field spectrum?

Matters mostly for small stochastically heated grains, where the average photon energy determines peak T.



see also Rigopoulou et al. 2021

What happens with a distribution of radiation field intensities?

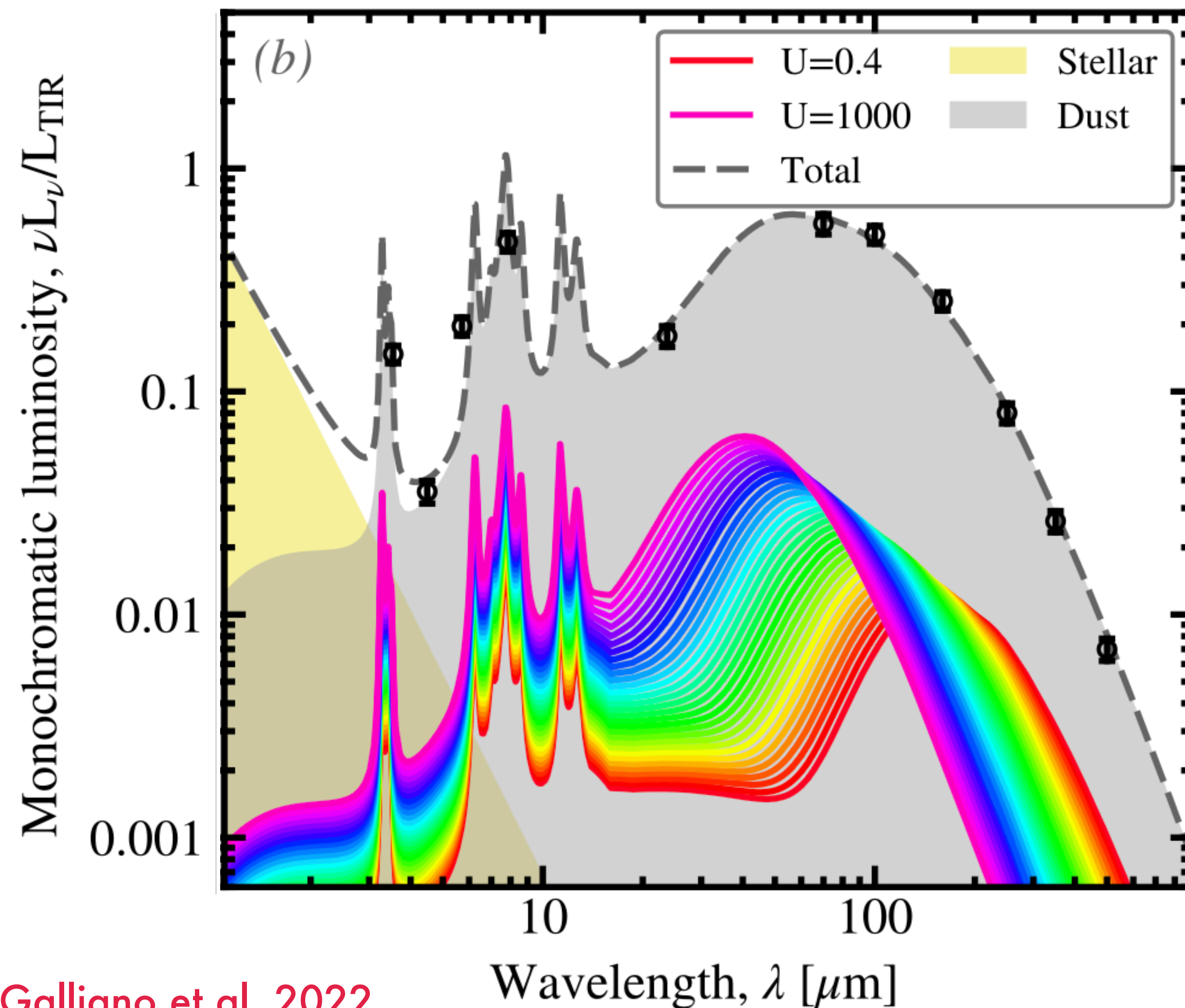


Galliano et al. 2022

Distribution of U (equivalent to distribution of T):

- broadens far-IR peak
- changes long wavelength slope
- increases mid-IR for similar MBB peak

What happens with a distribution of radiation field intensities?



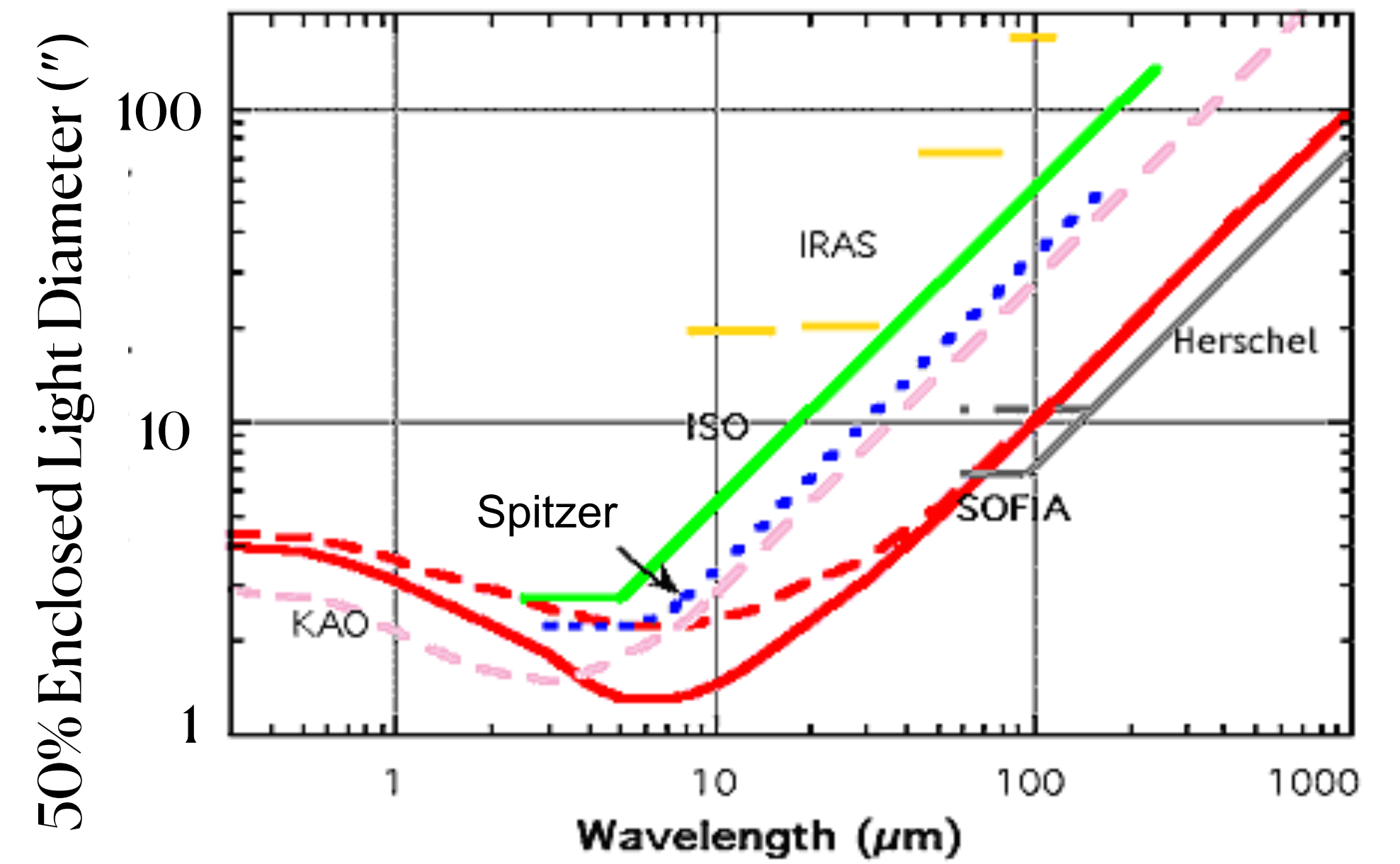
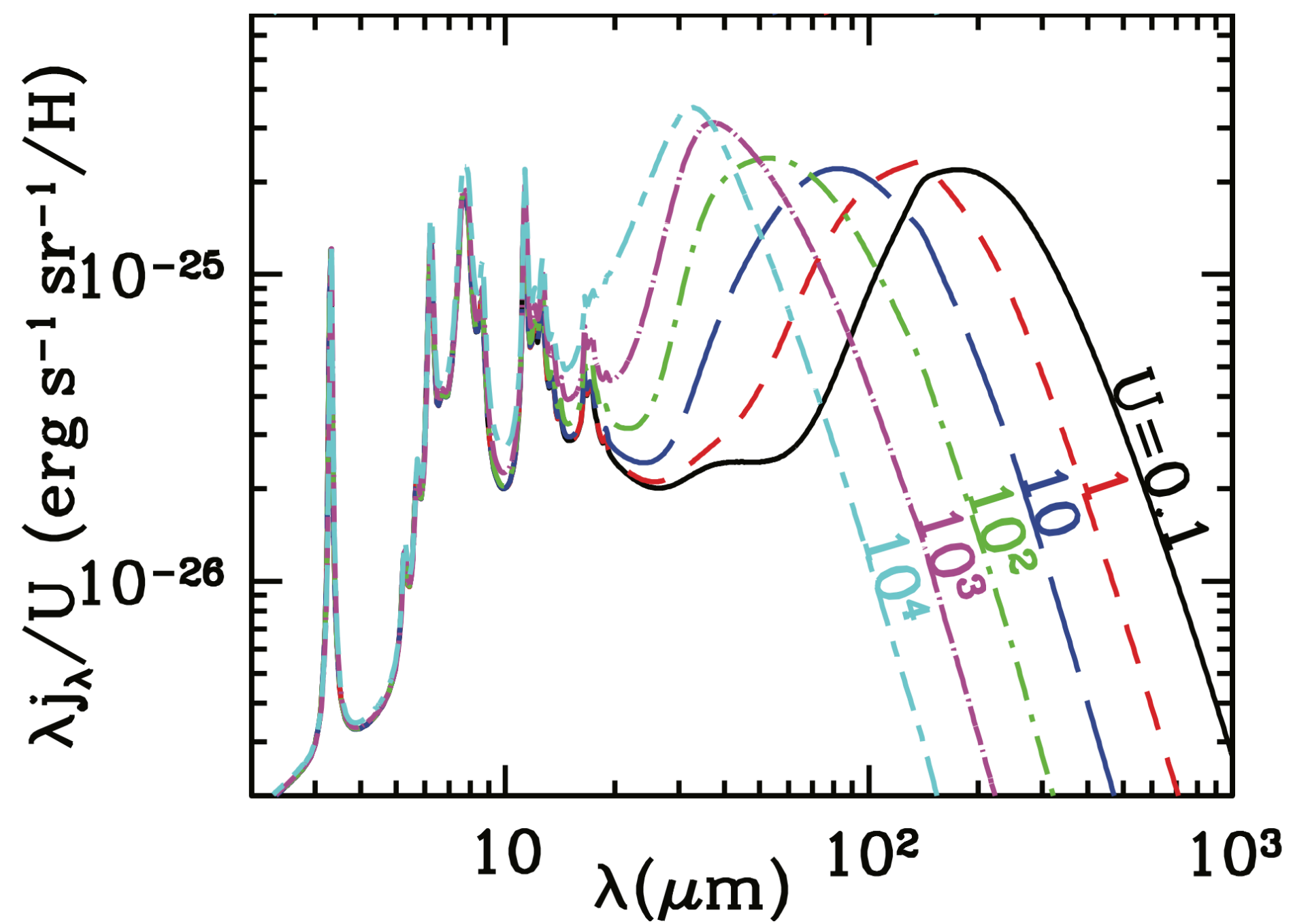
Distribution of U (equivalent to distribution of T):

- broadens far-IR peak
- changes long wavelength slope
- increases mid-IR for similar MBB peak

Common practice: power-law distribution for dM/dU with delta function at U_{min}

(Dale+2001,
Draine & Li 2007, Aniano+2020)

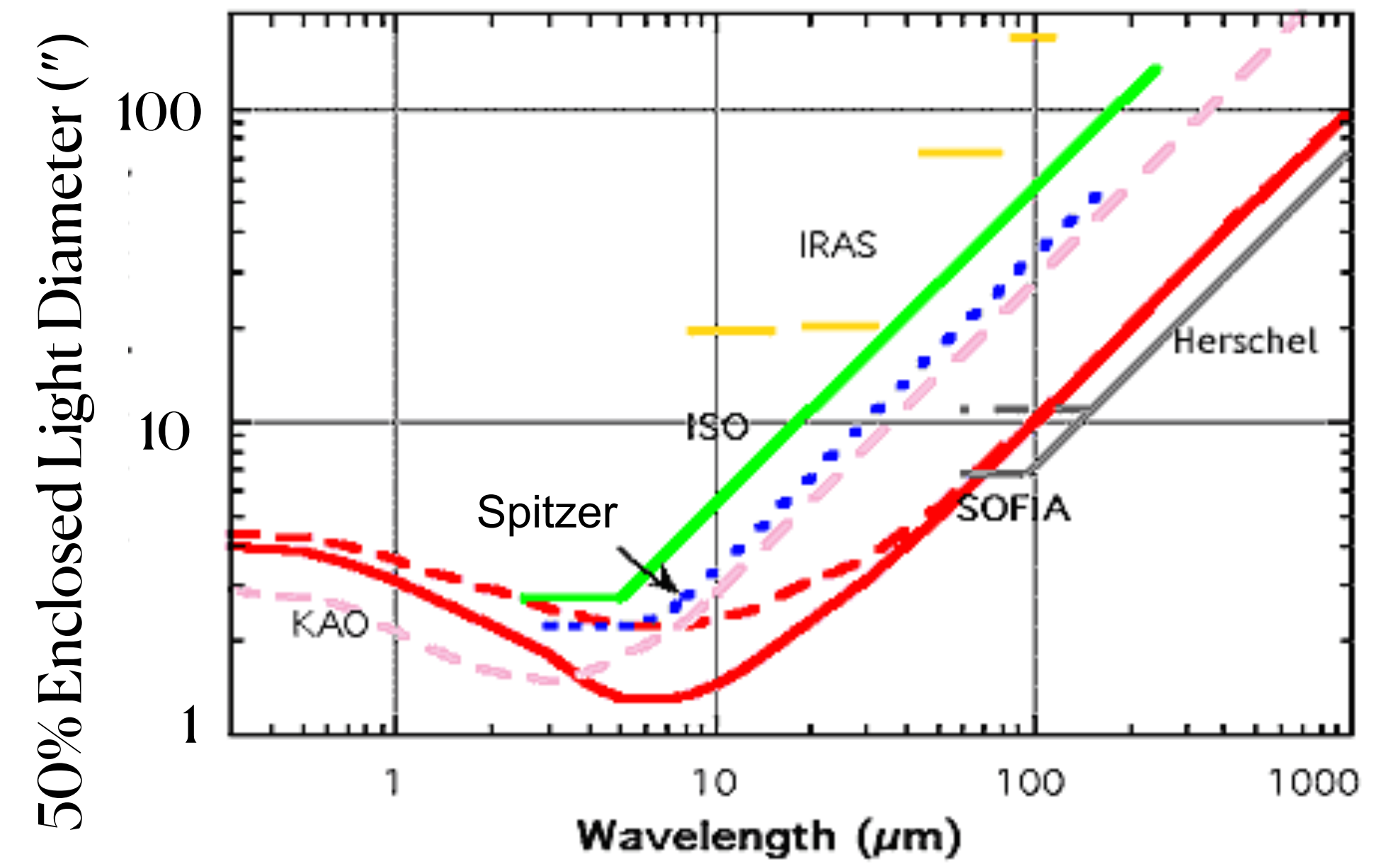
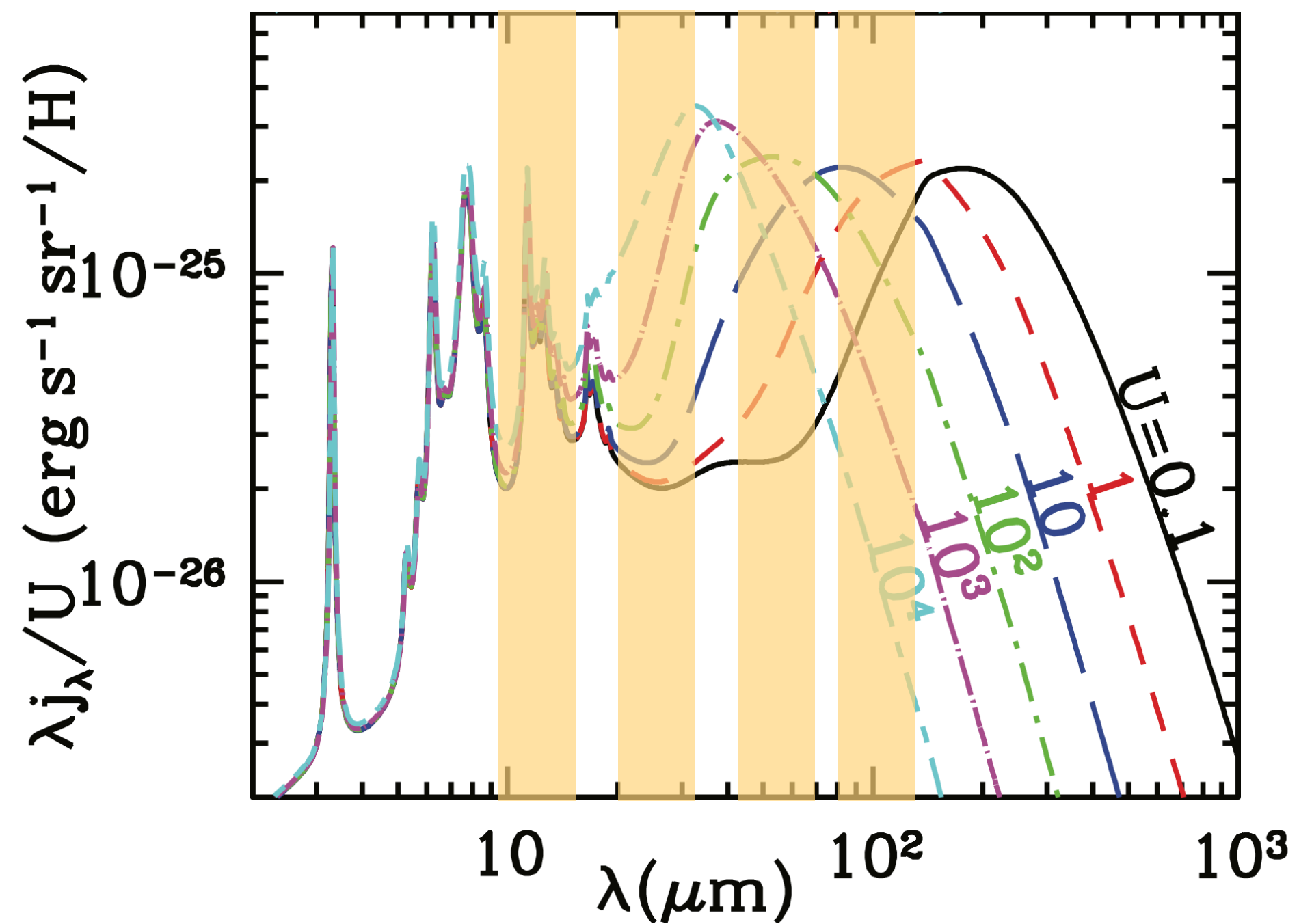
Our Observational Tools



Our Observational Tools



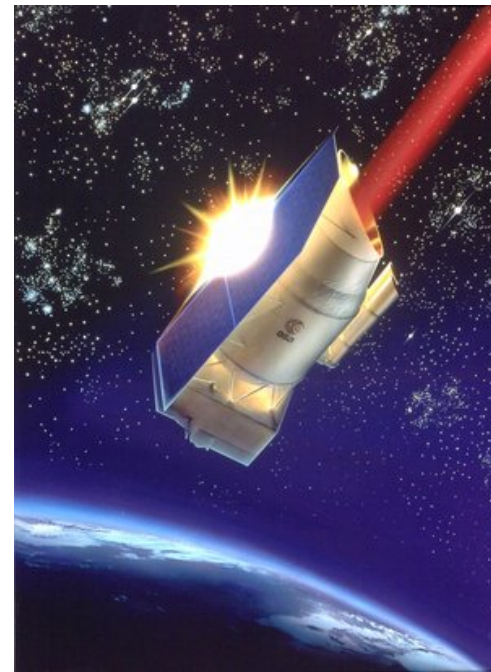
IRAS - 0.57 m



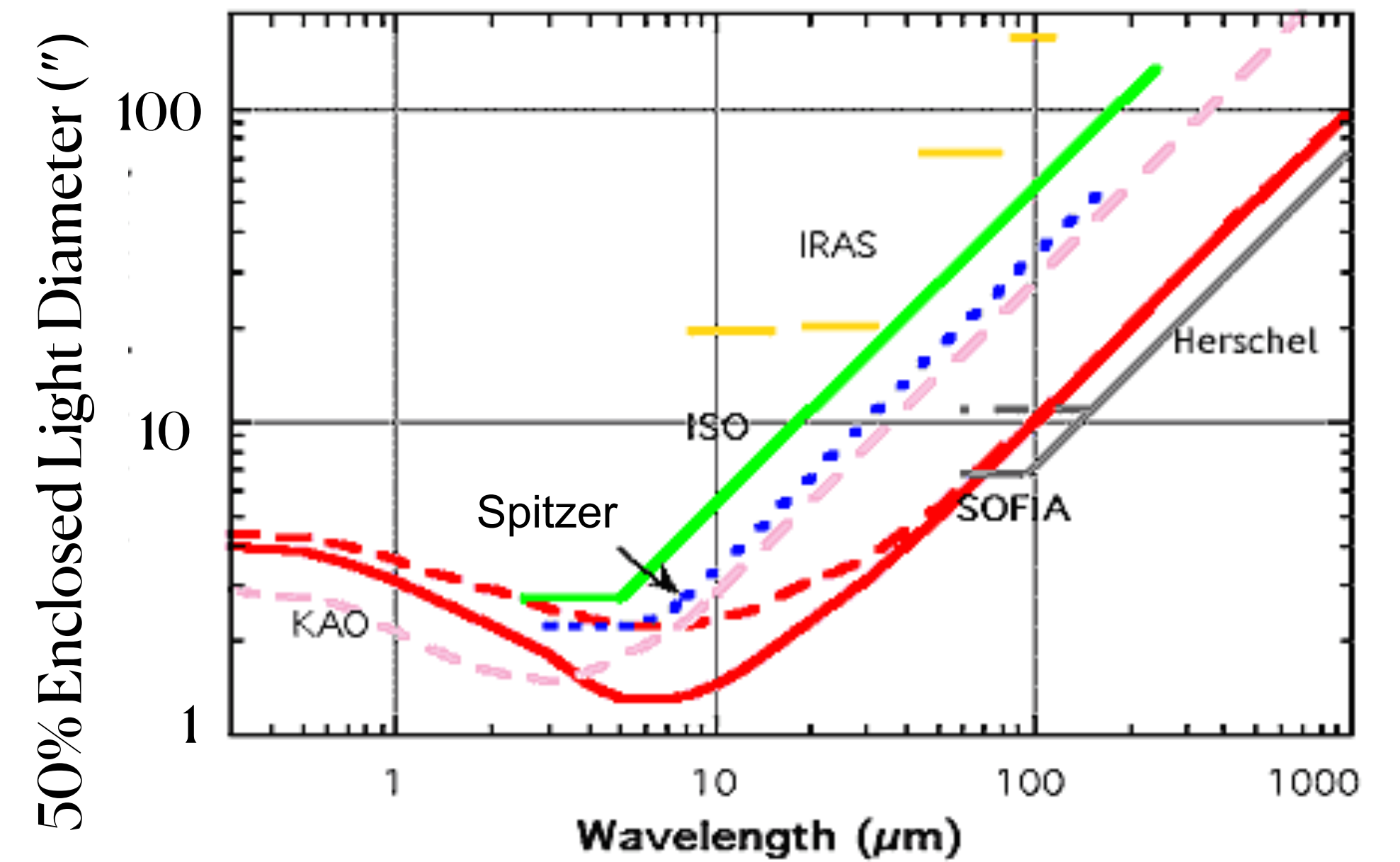
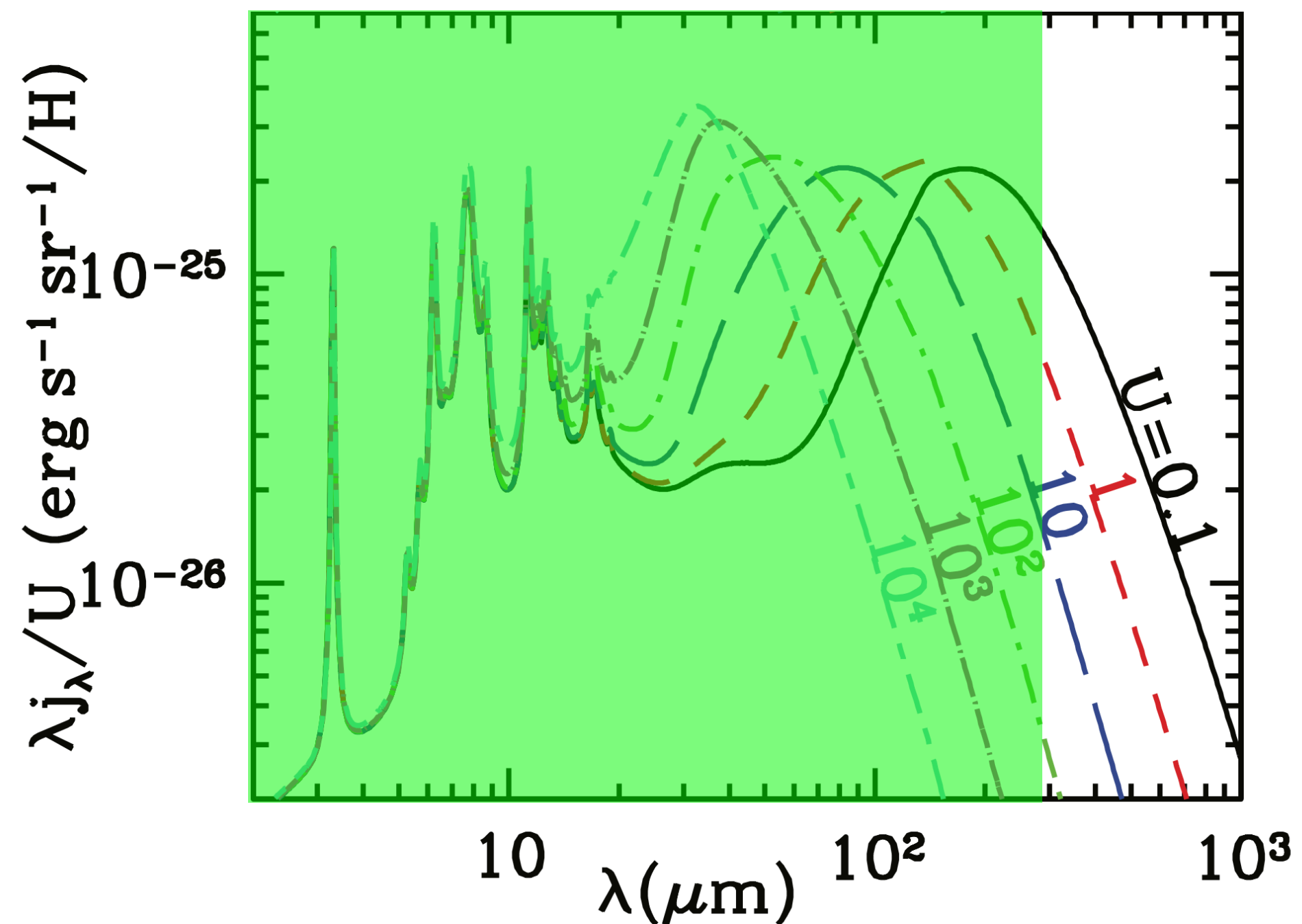
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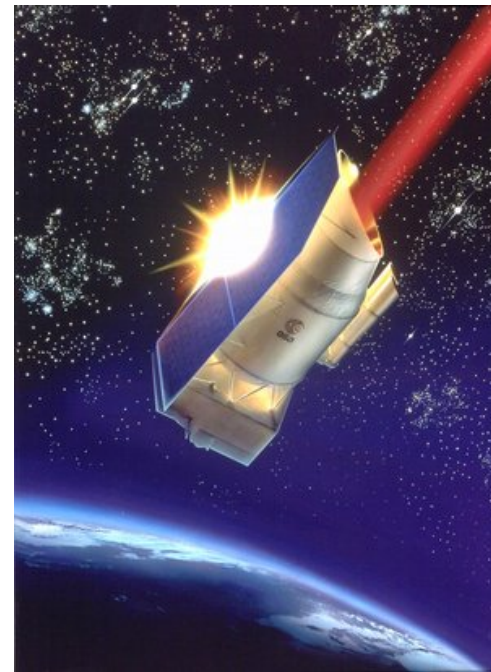
ISO - 0.6 m



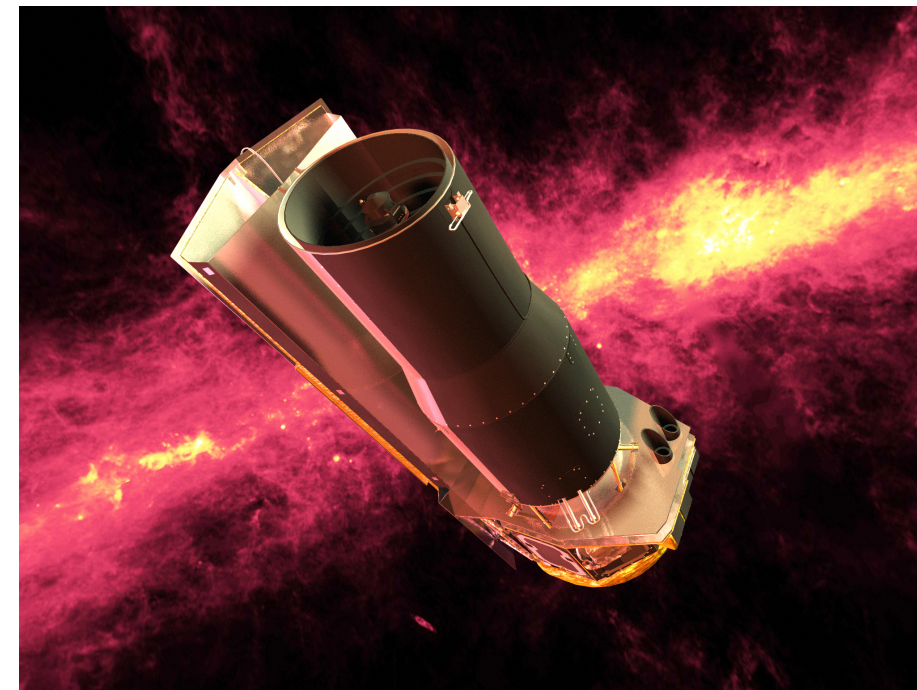
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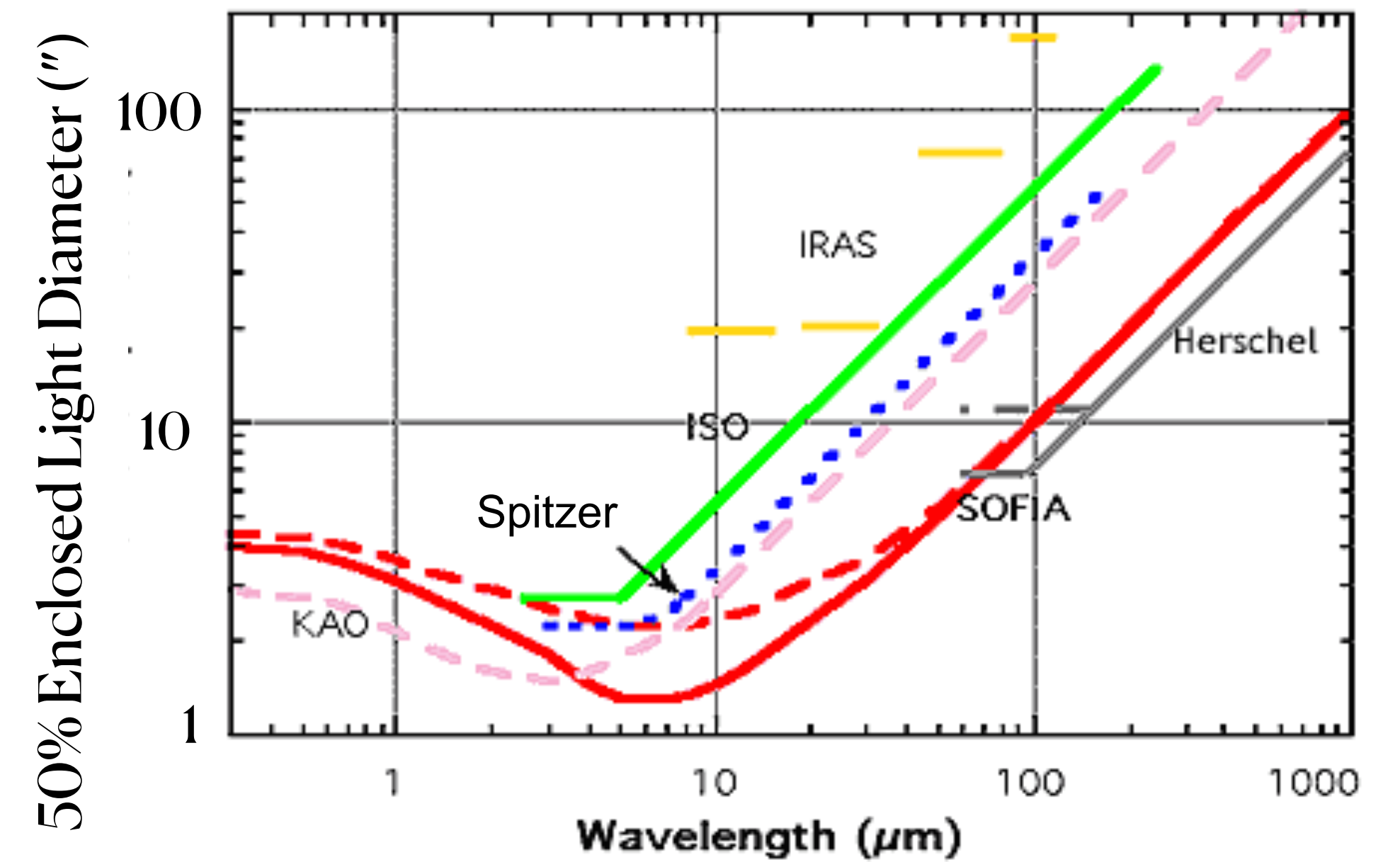
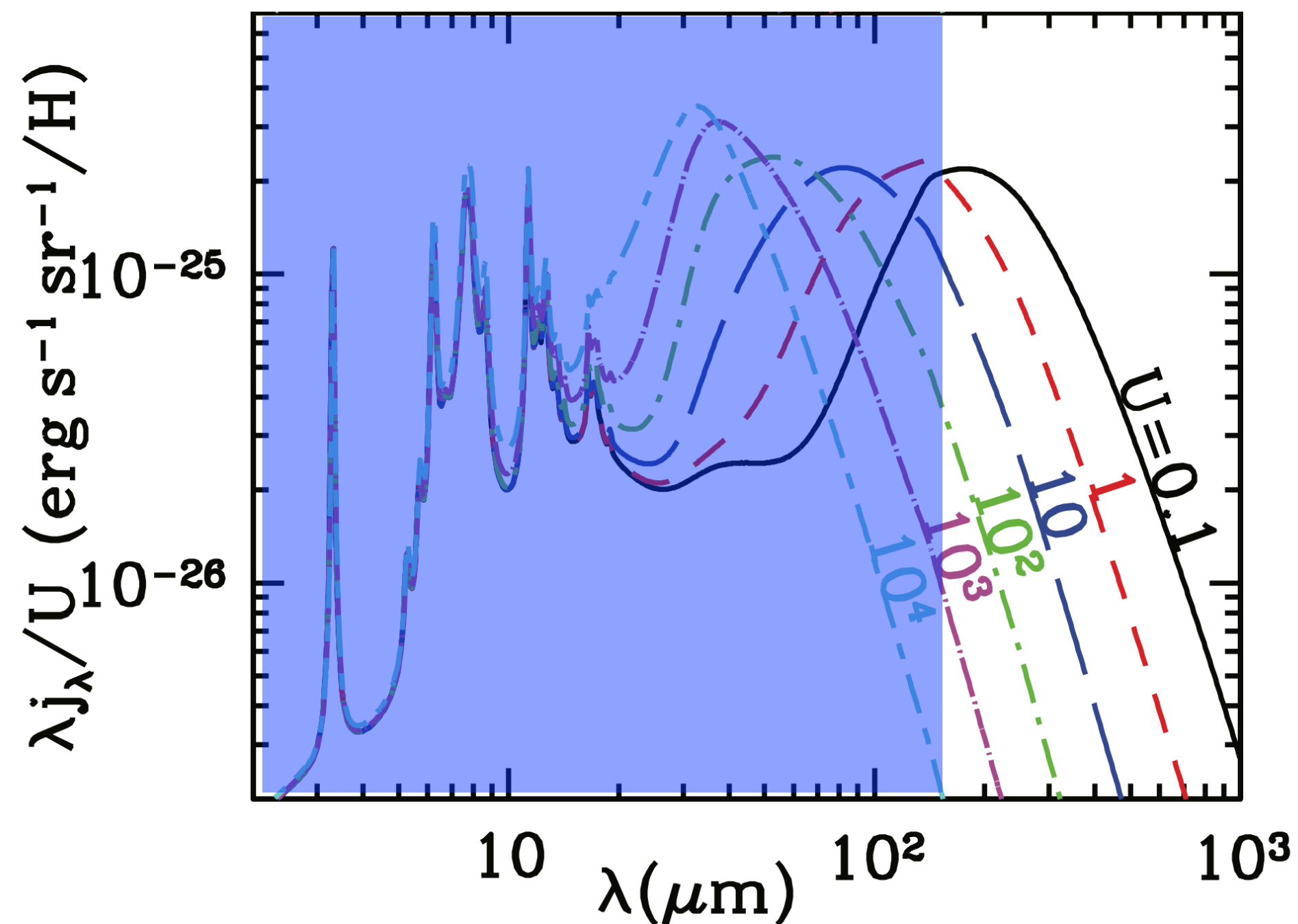
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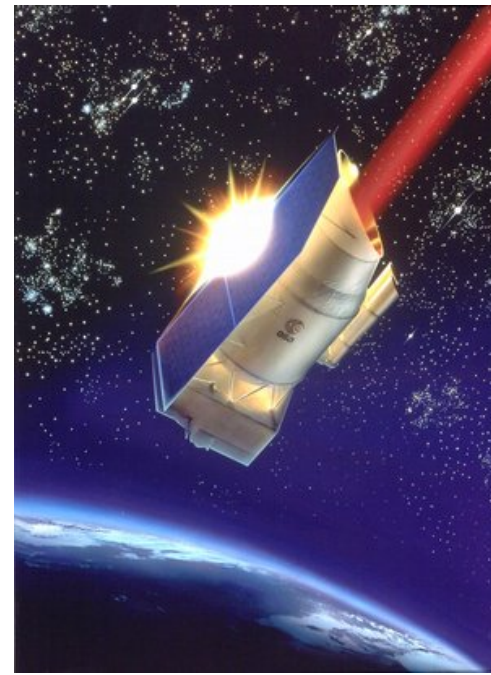
Spitzer - 0.85 m



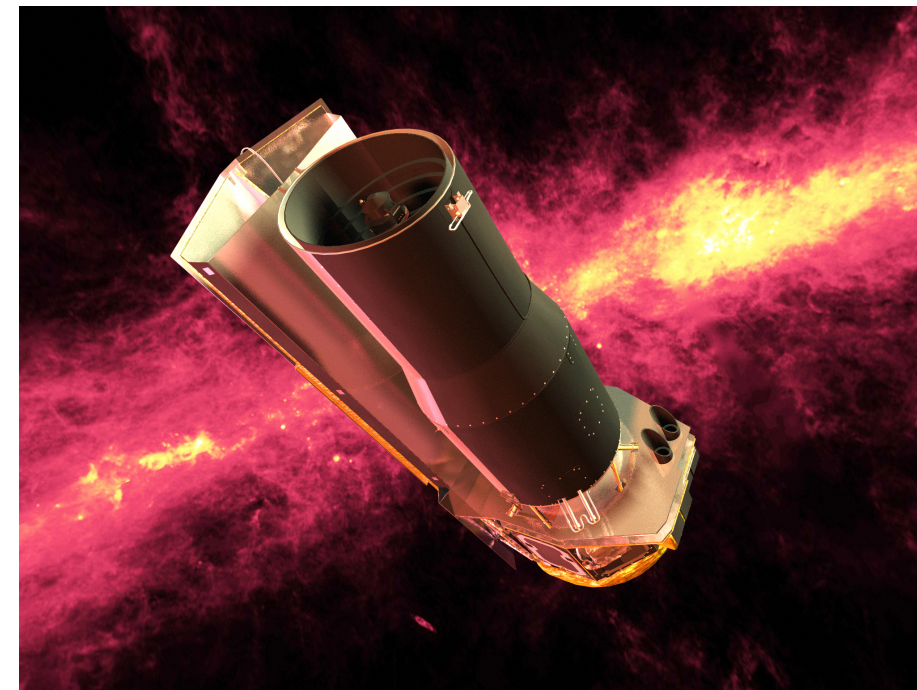
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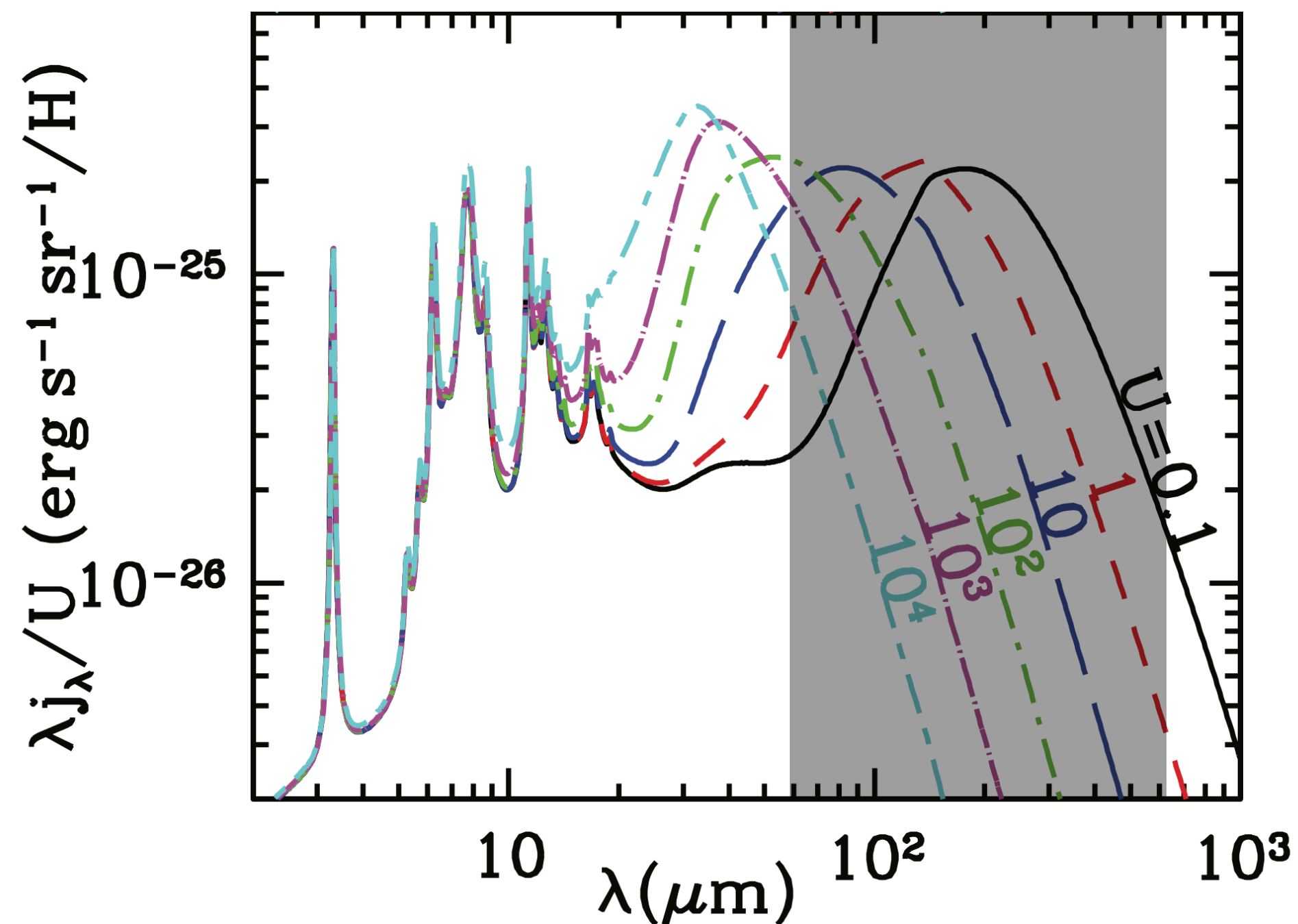
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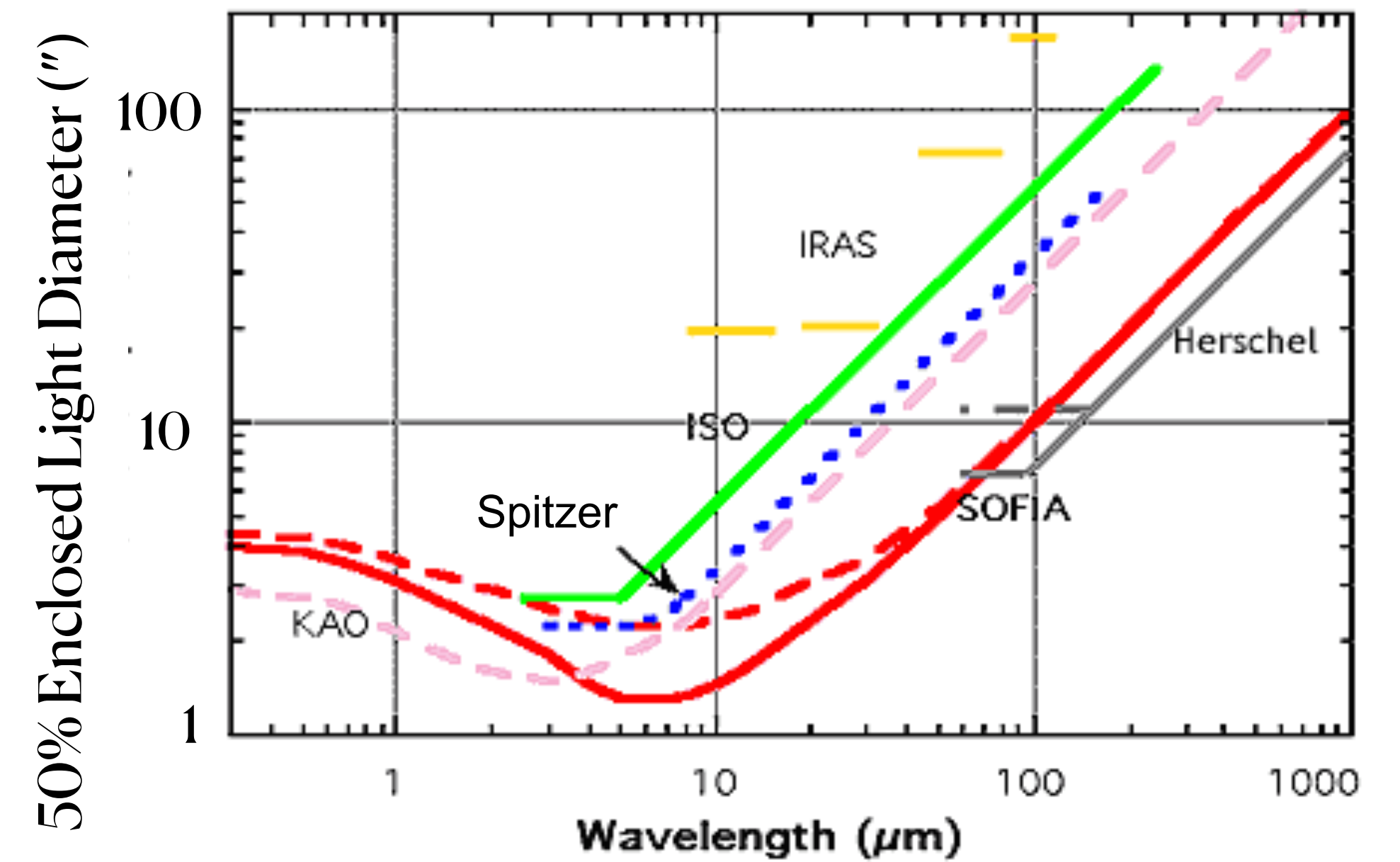
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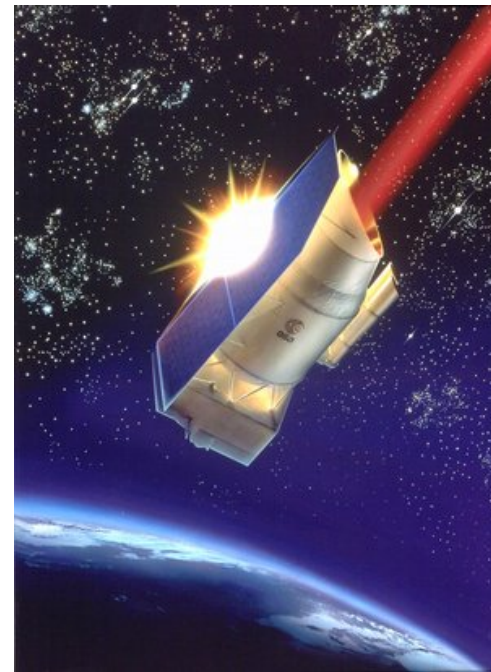
Herschel - 3.5m



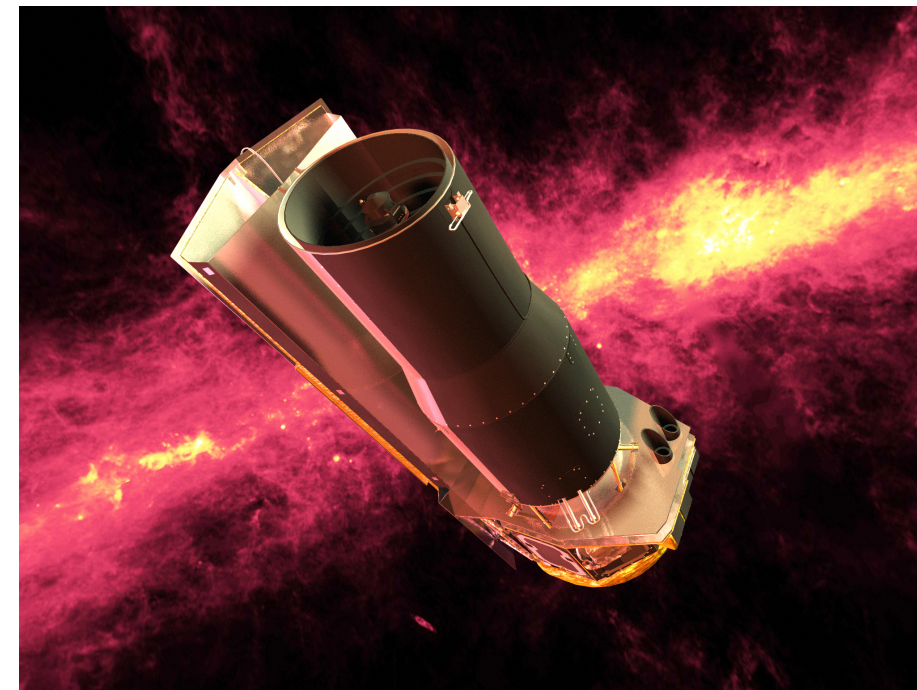
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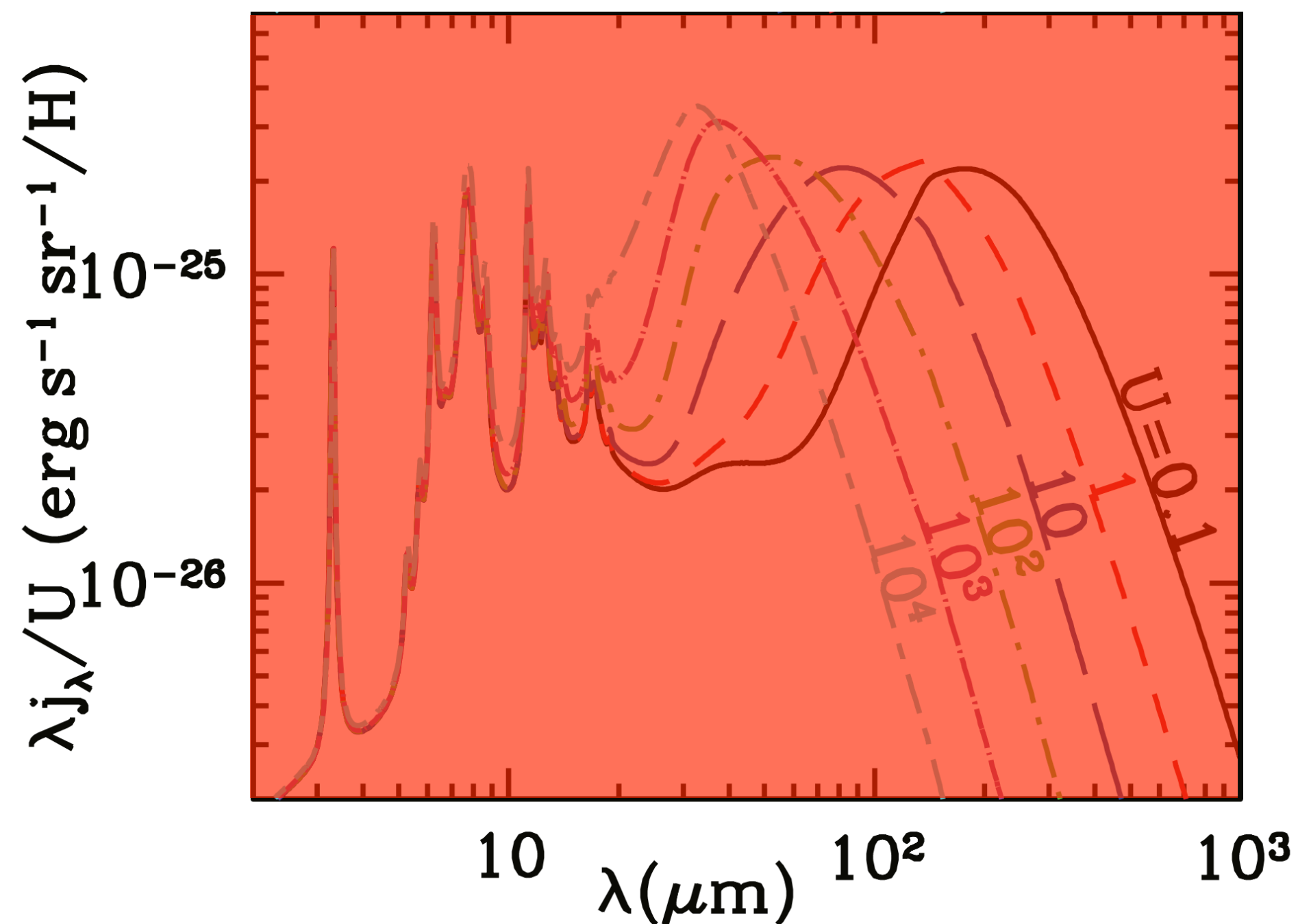
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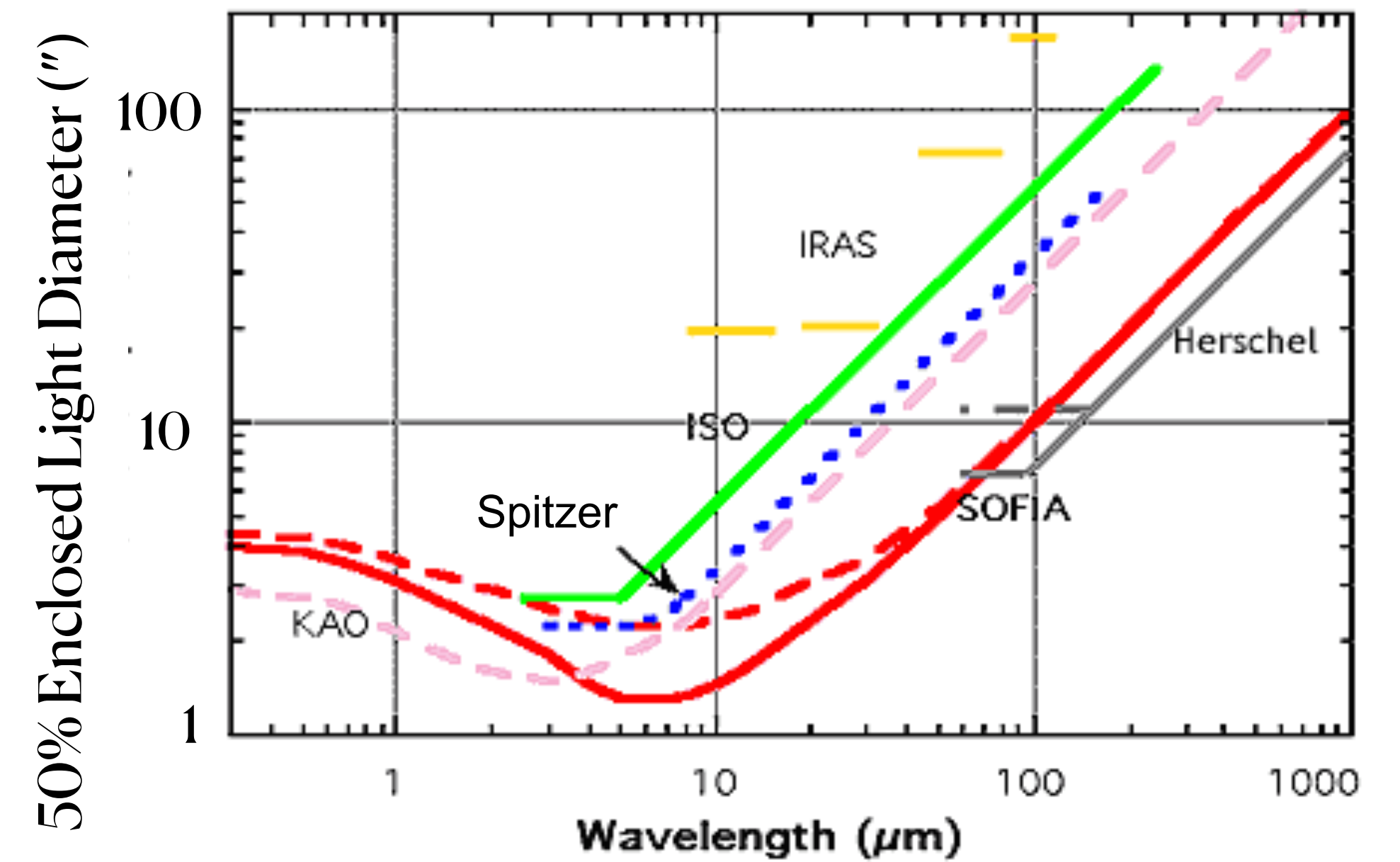
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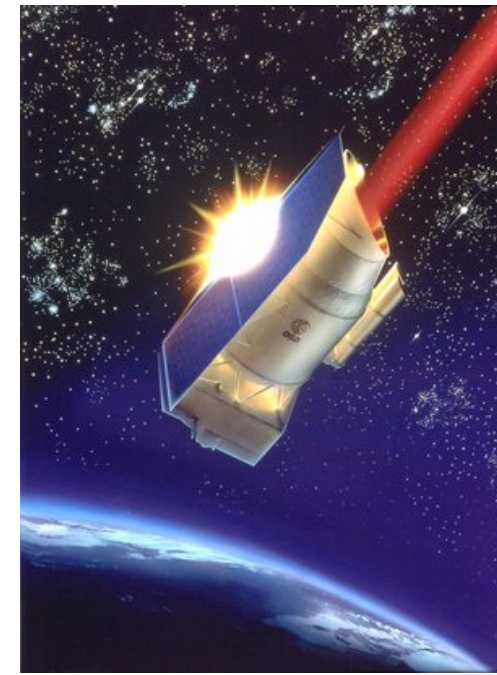


SOFIA - 2.5m

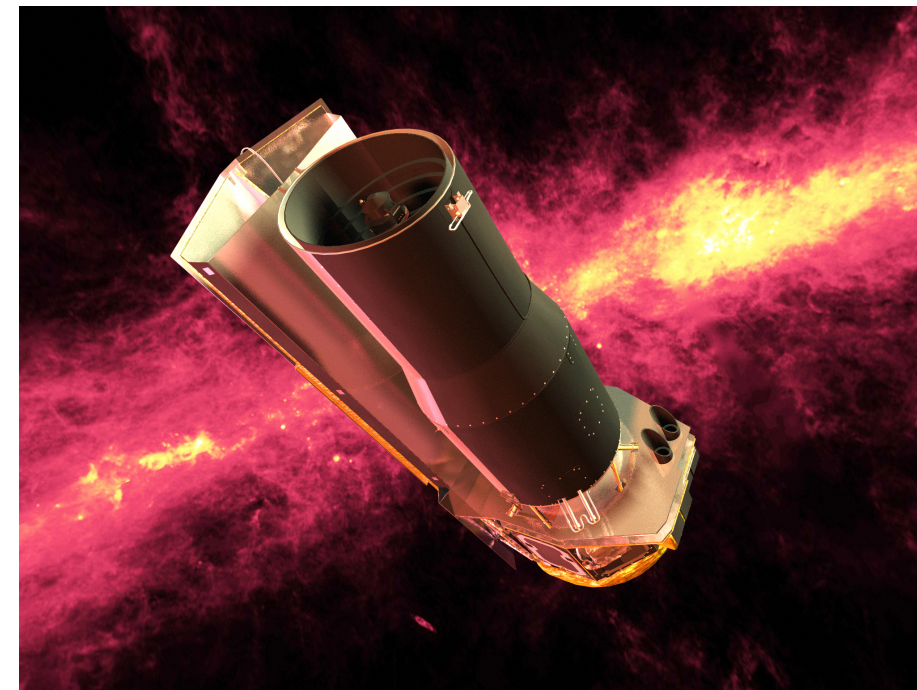
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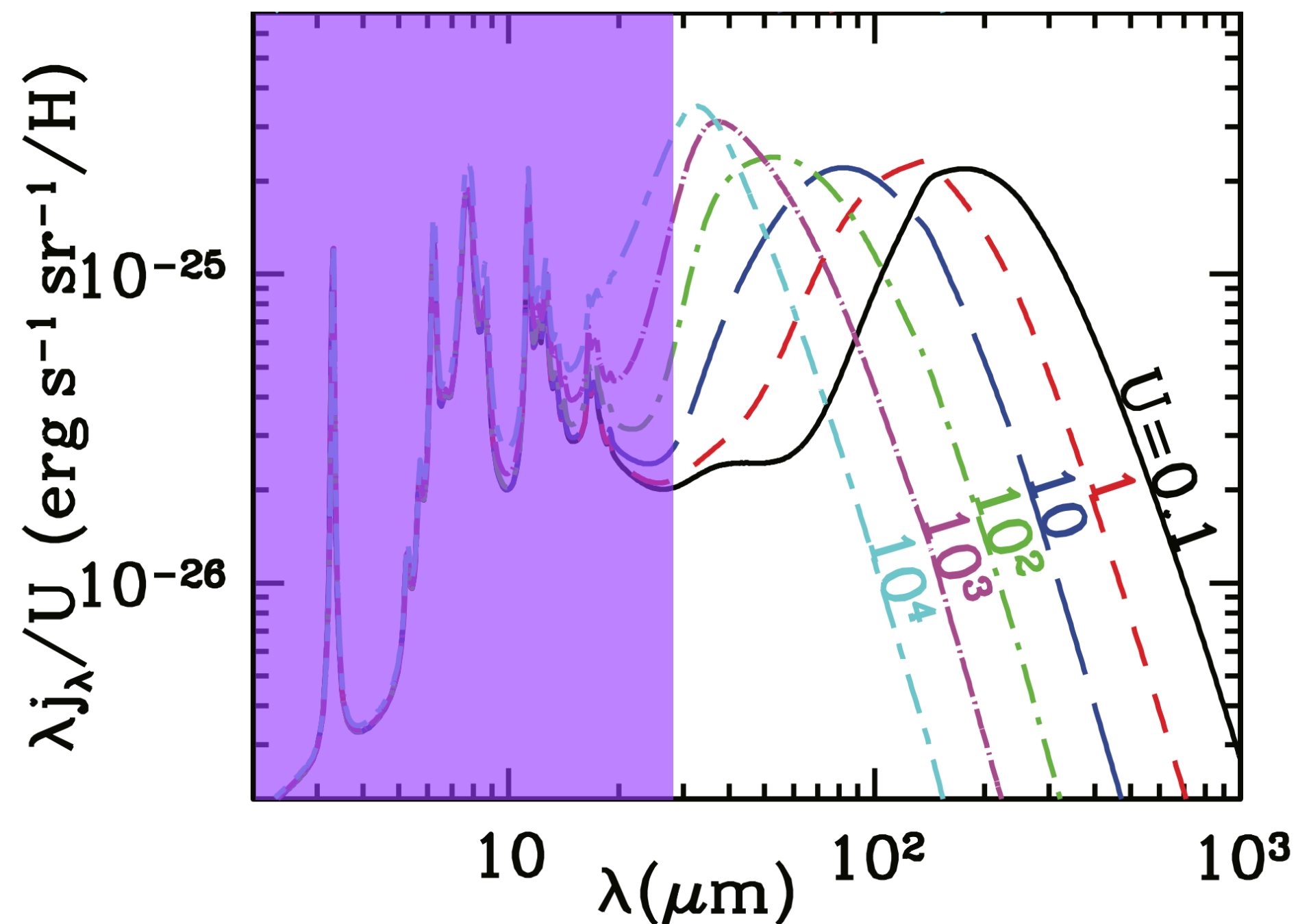
IRAS - 0.57 m



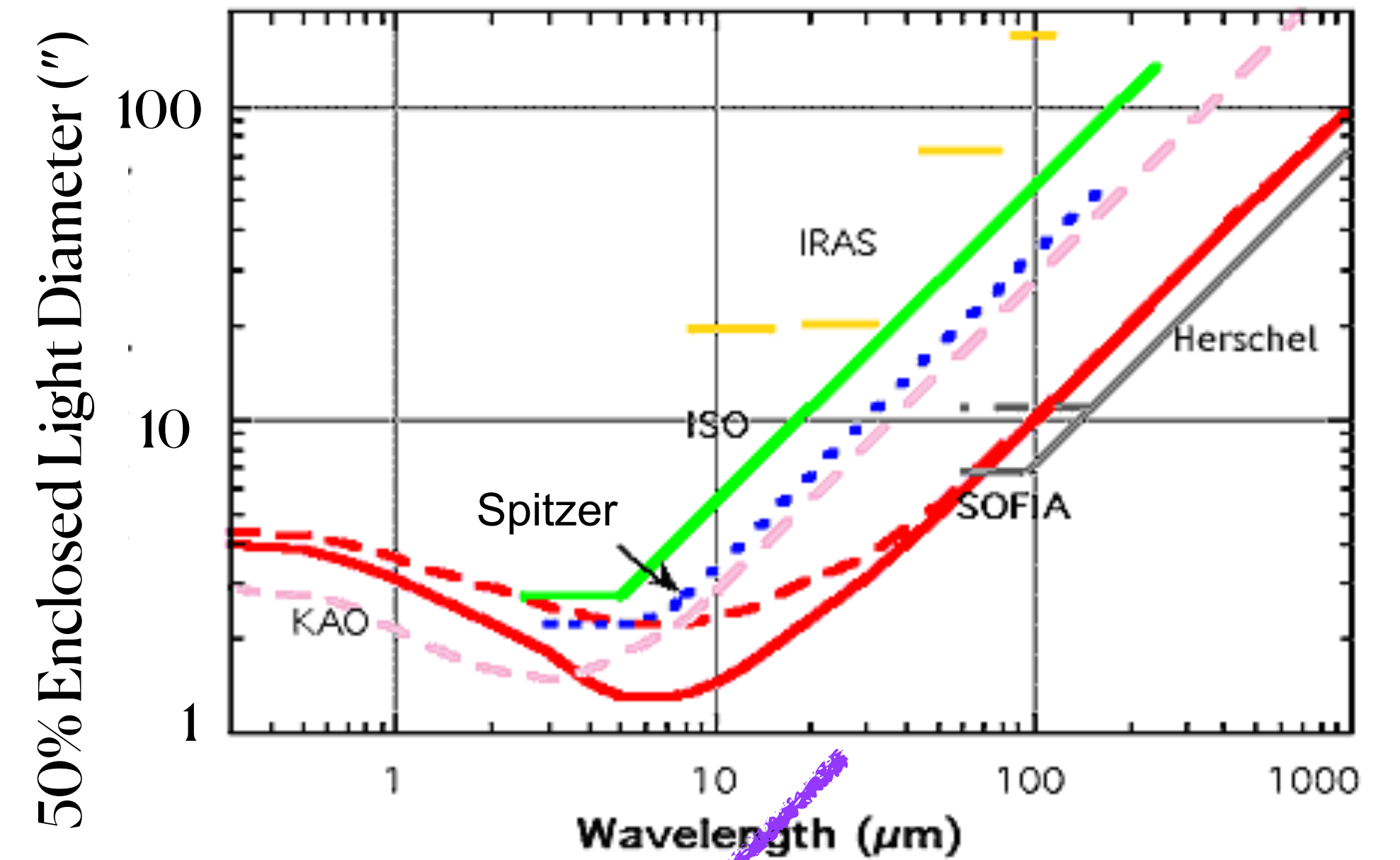
ISO - 0.6 m



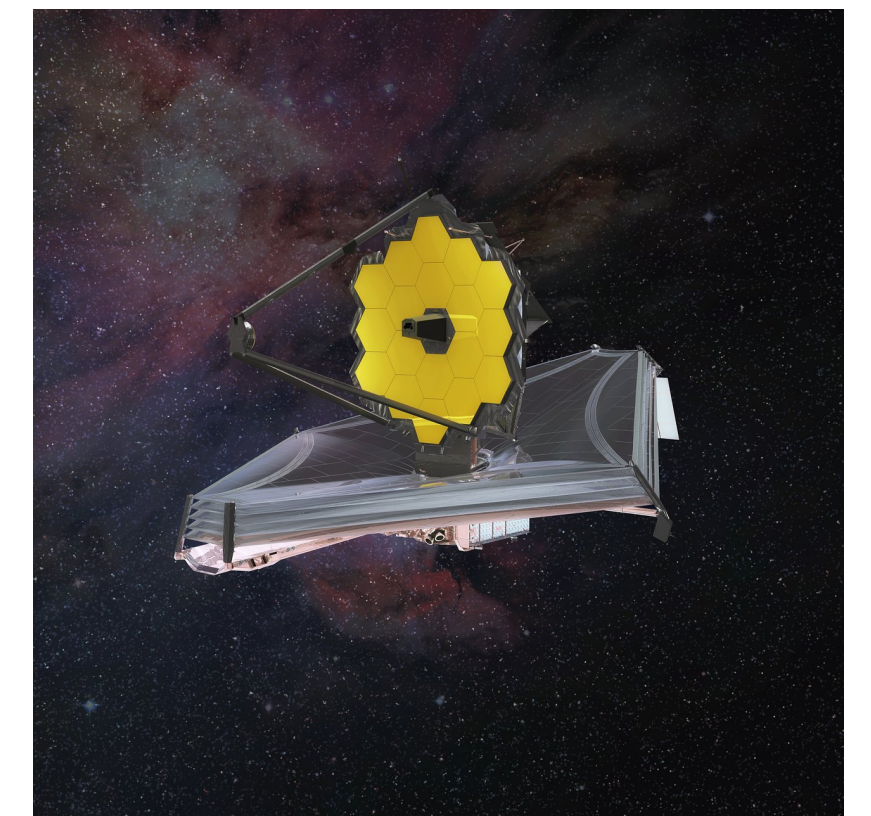
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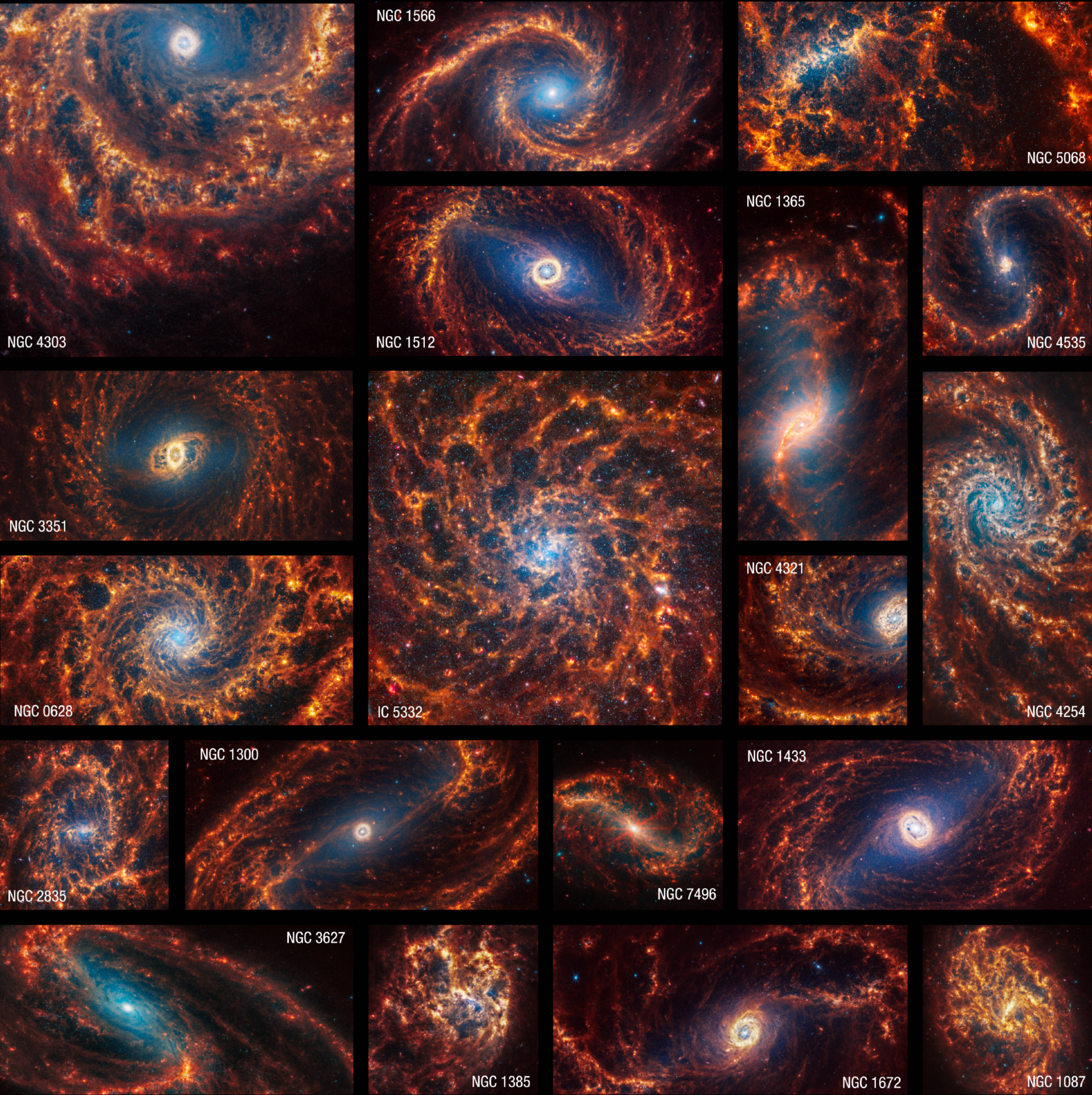
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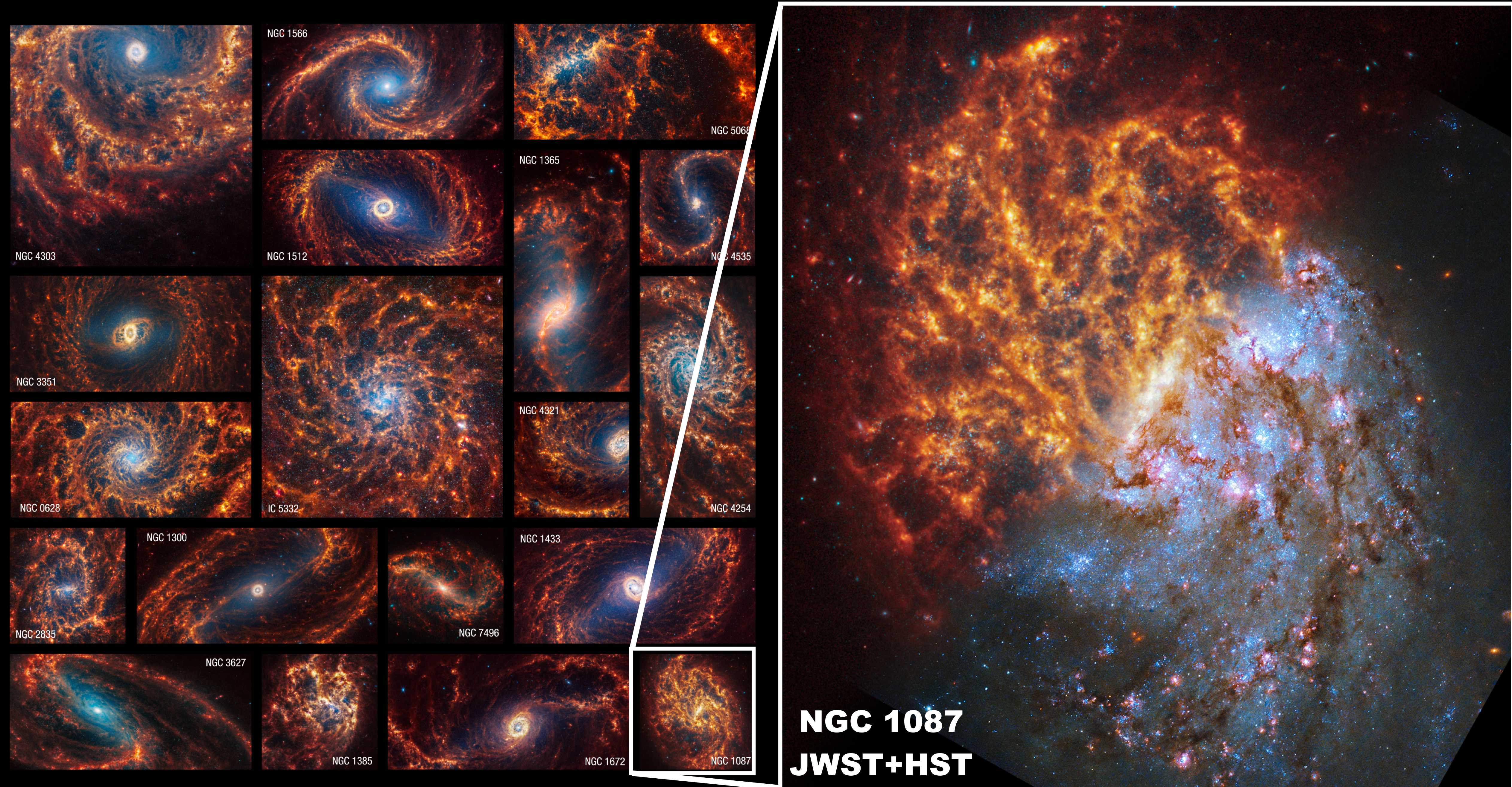


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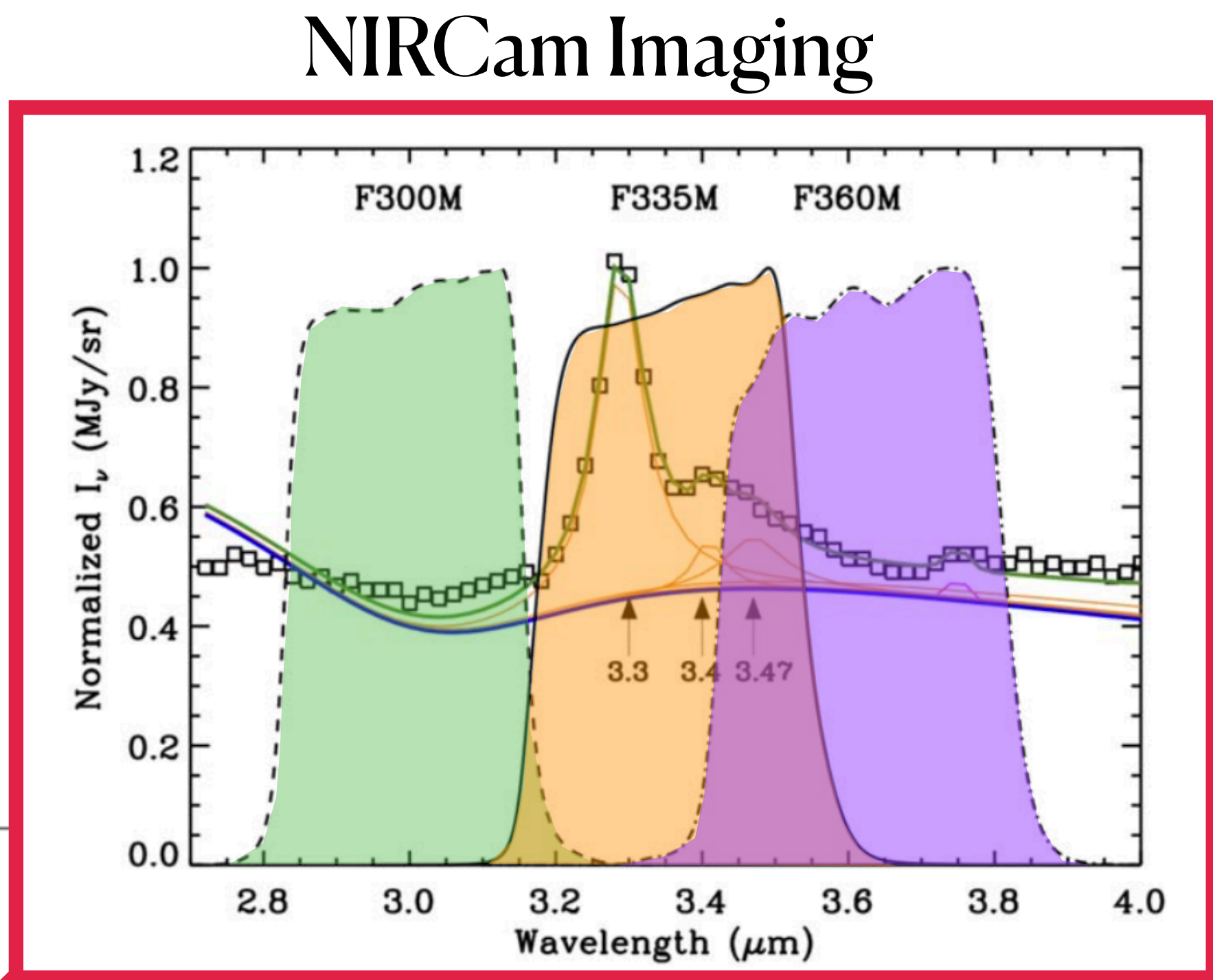
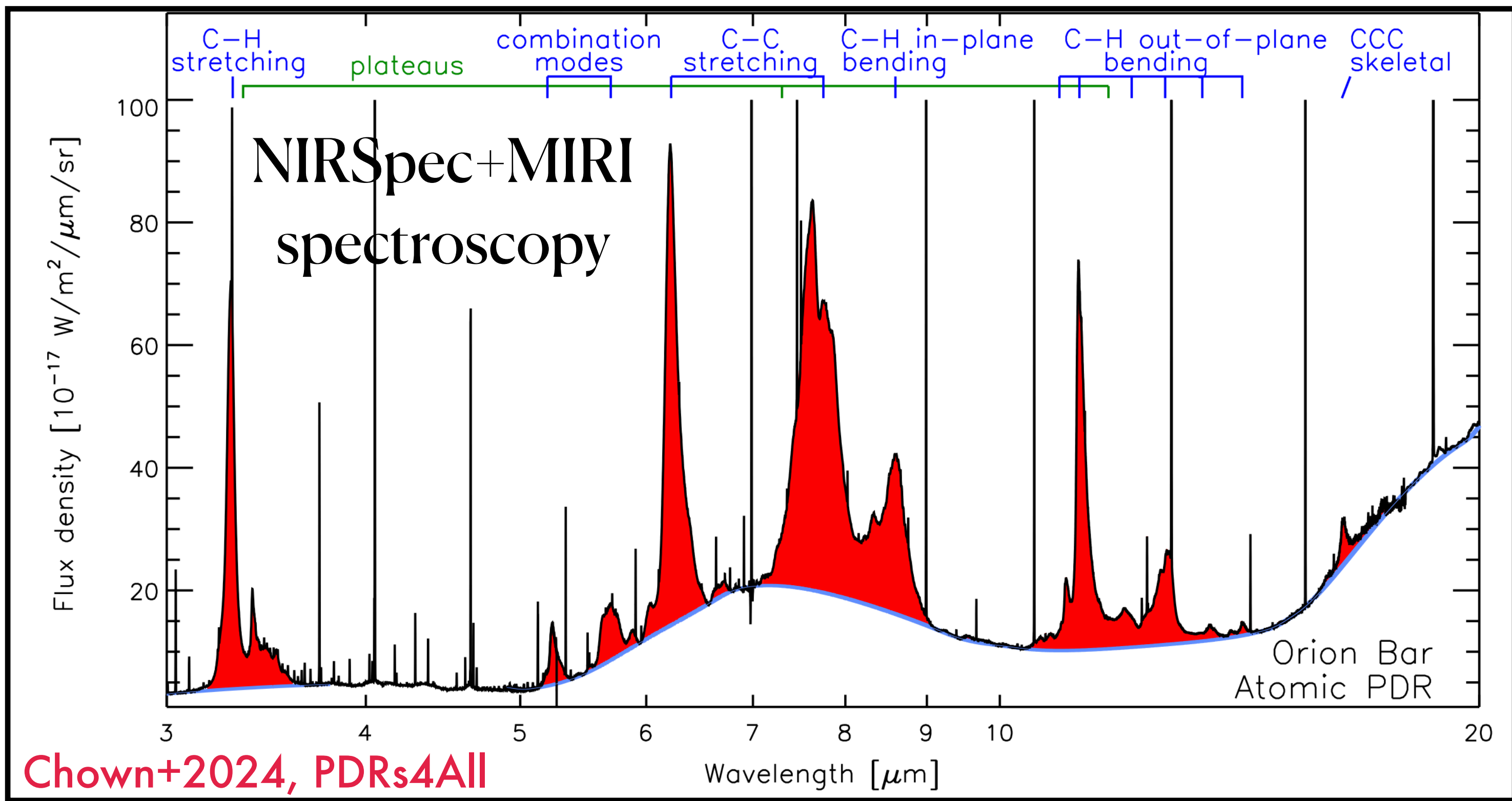


JWST - 6.5m

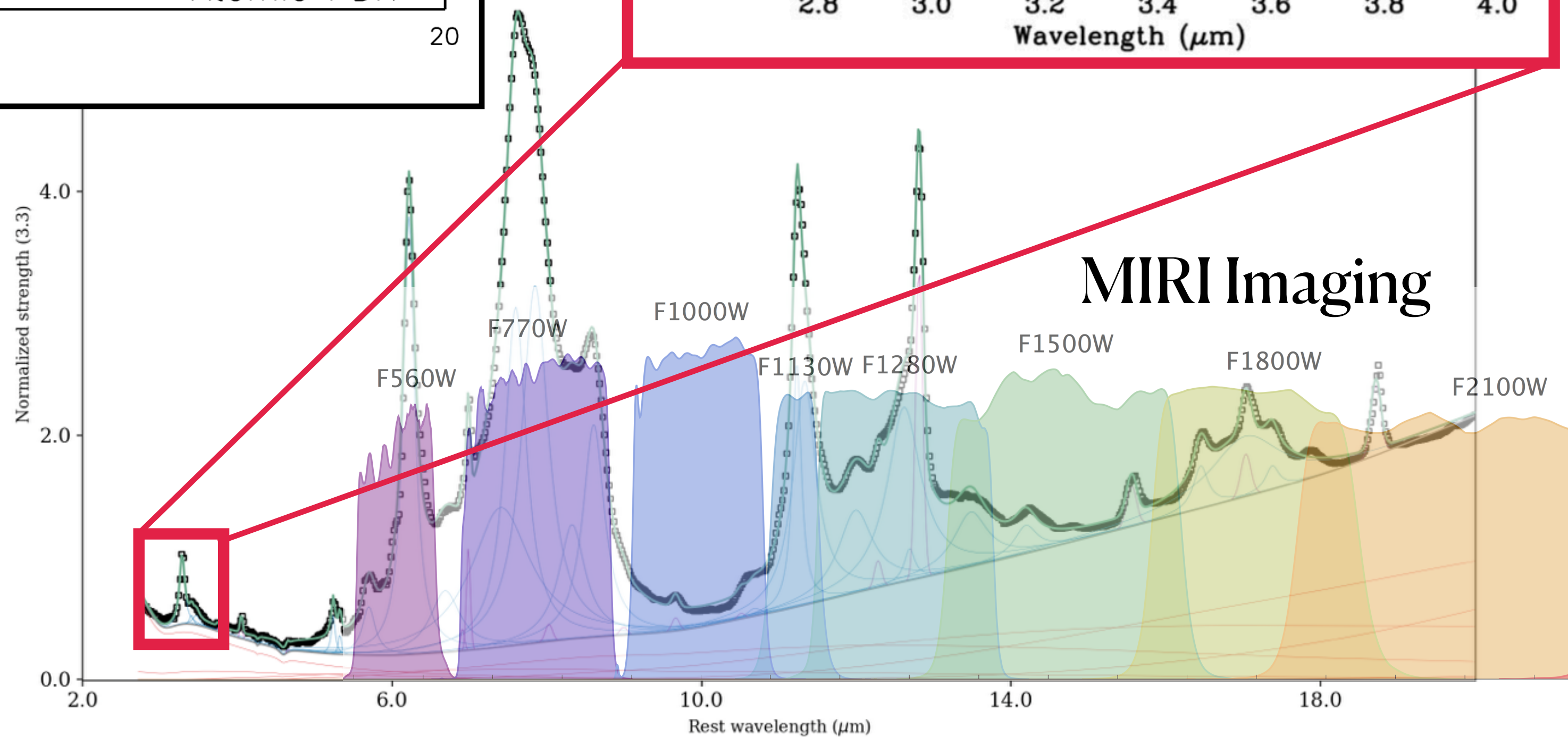




NGC 1087
JWST+HST



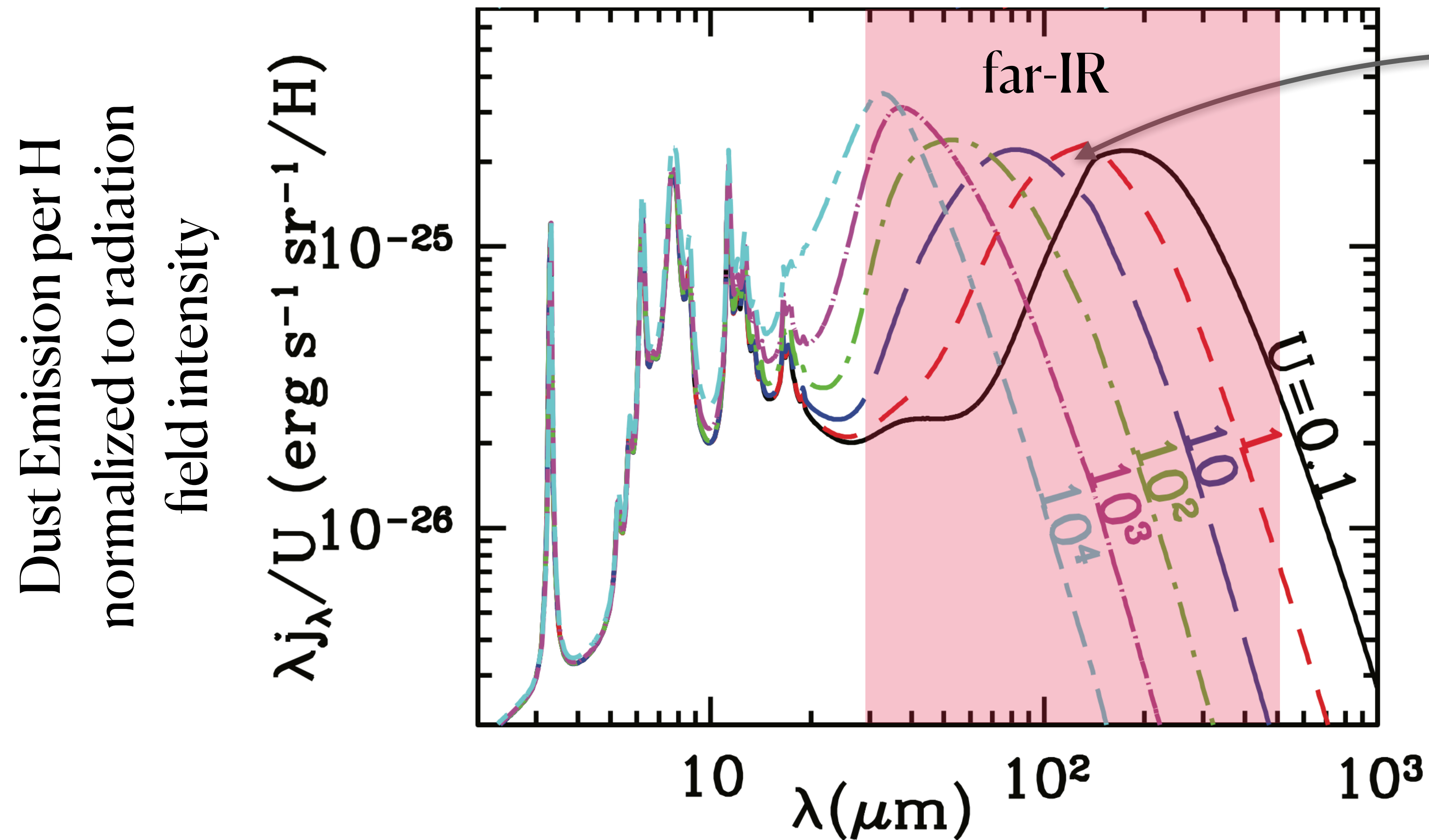
JWST is *outstanding* for observing PAHs



Things we would like to learn from dust emission:

- How does dust mass vary within and between galaxies?
- What controls the small carbonaceous grain (PAH) fraction?
- Do the properties of PAHs vary throughout the ISM?
- Can we use dust emission as a tracer of star formation and/or gas?

How does dust mass vary within & between galaxies?



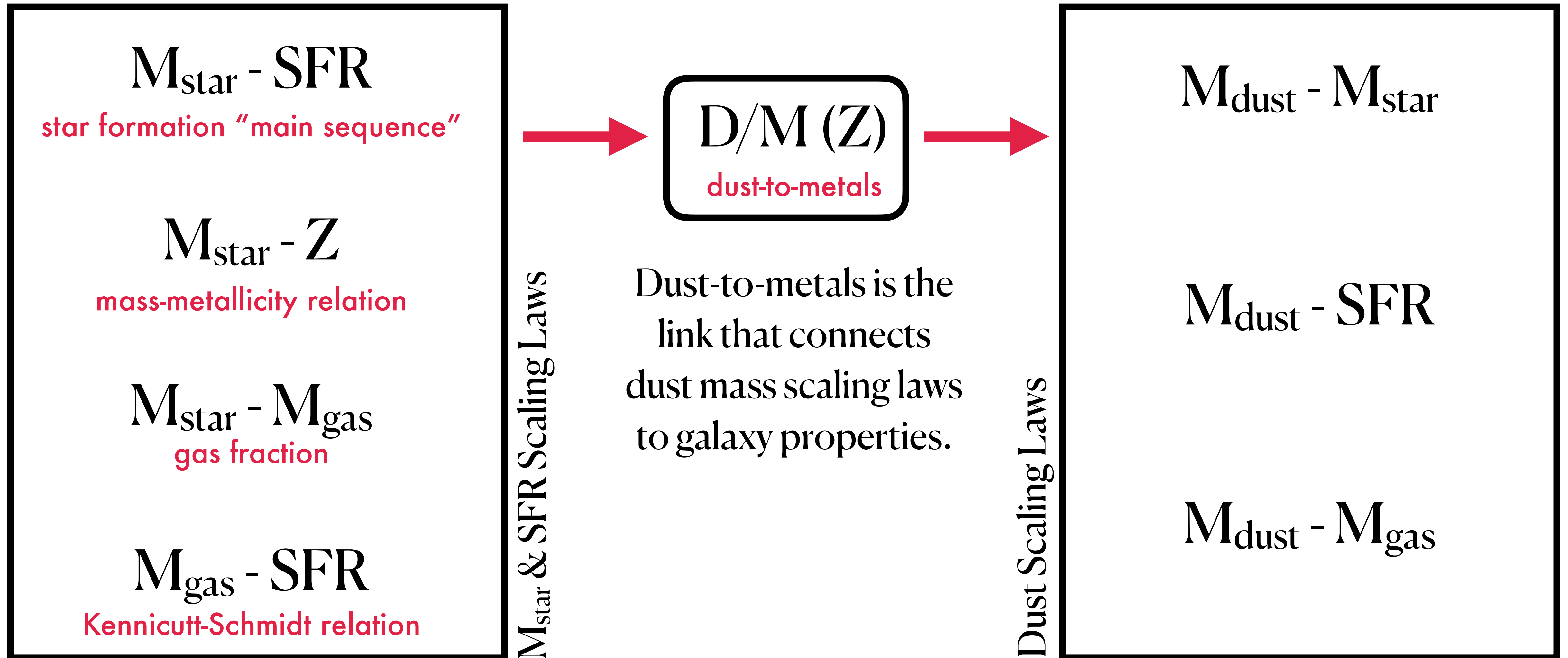
Draine & Li 2007

From peak of
modified blackbody,
learn U (or T).

Scale up/down to get
dust mass or dust
mass surface density
(M_{dust} or Σ_{dust}).

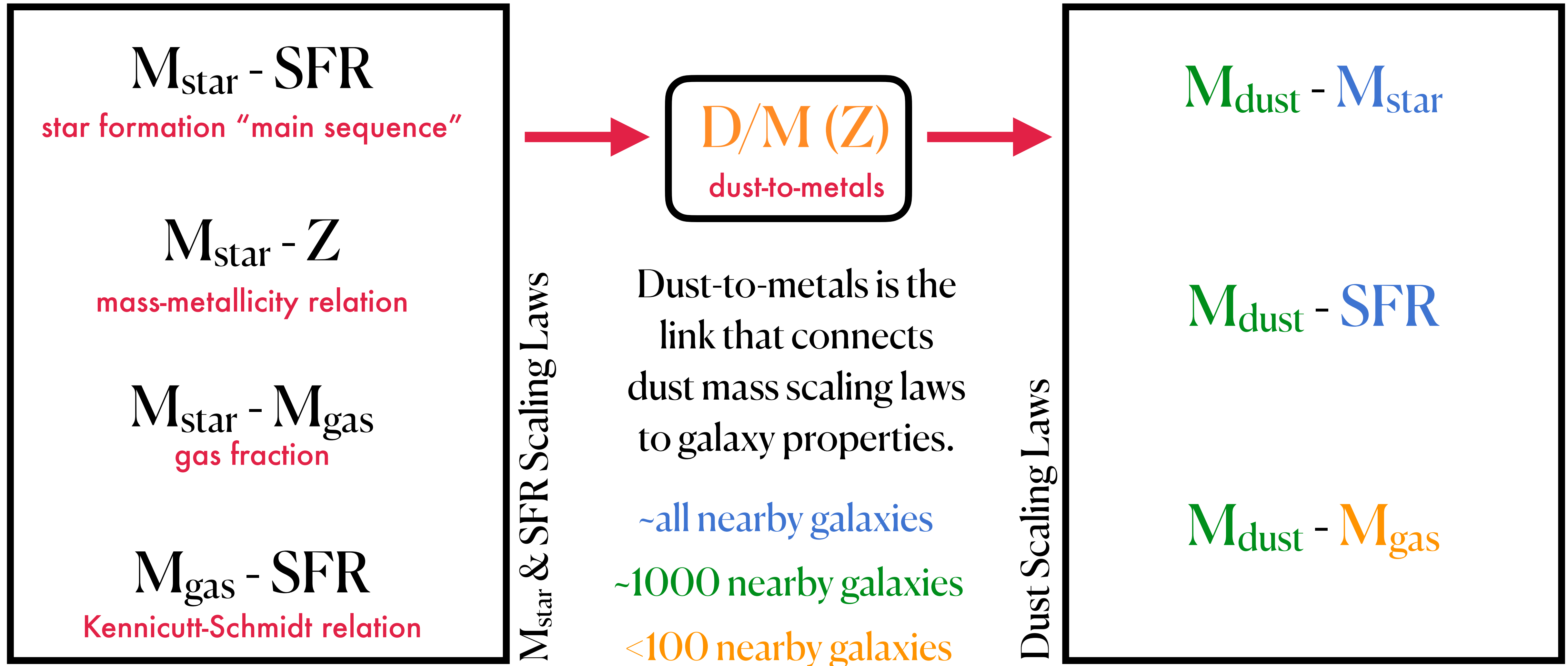
How does dust mass vary within & between galaxies?

Dust Mass Scaling Relations



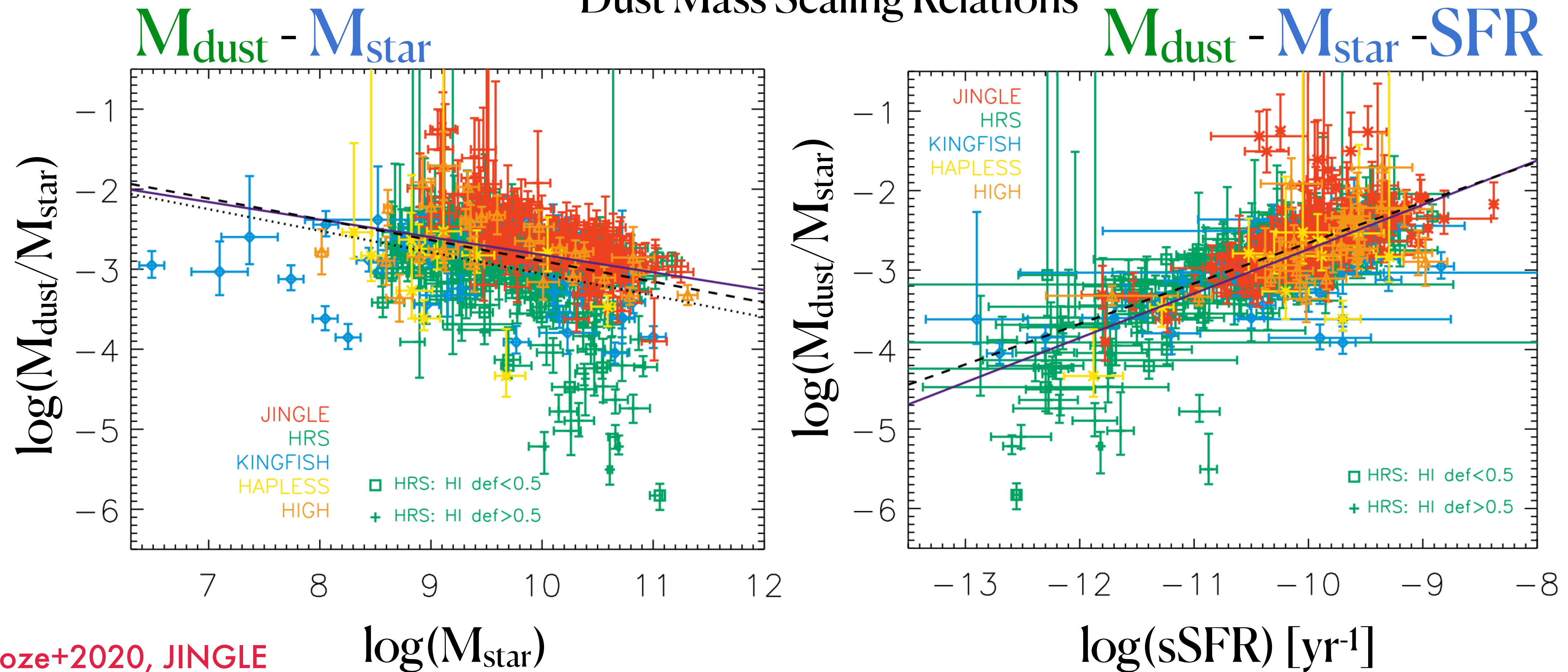
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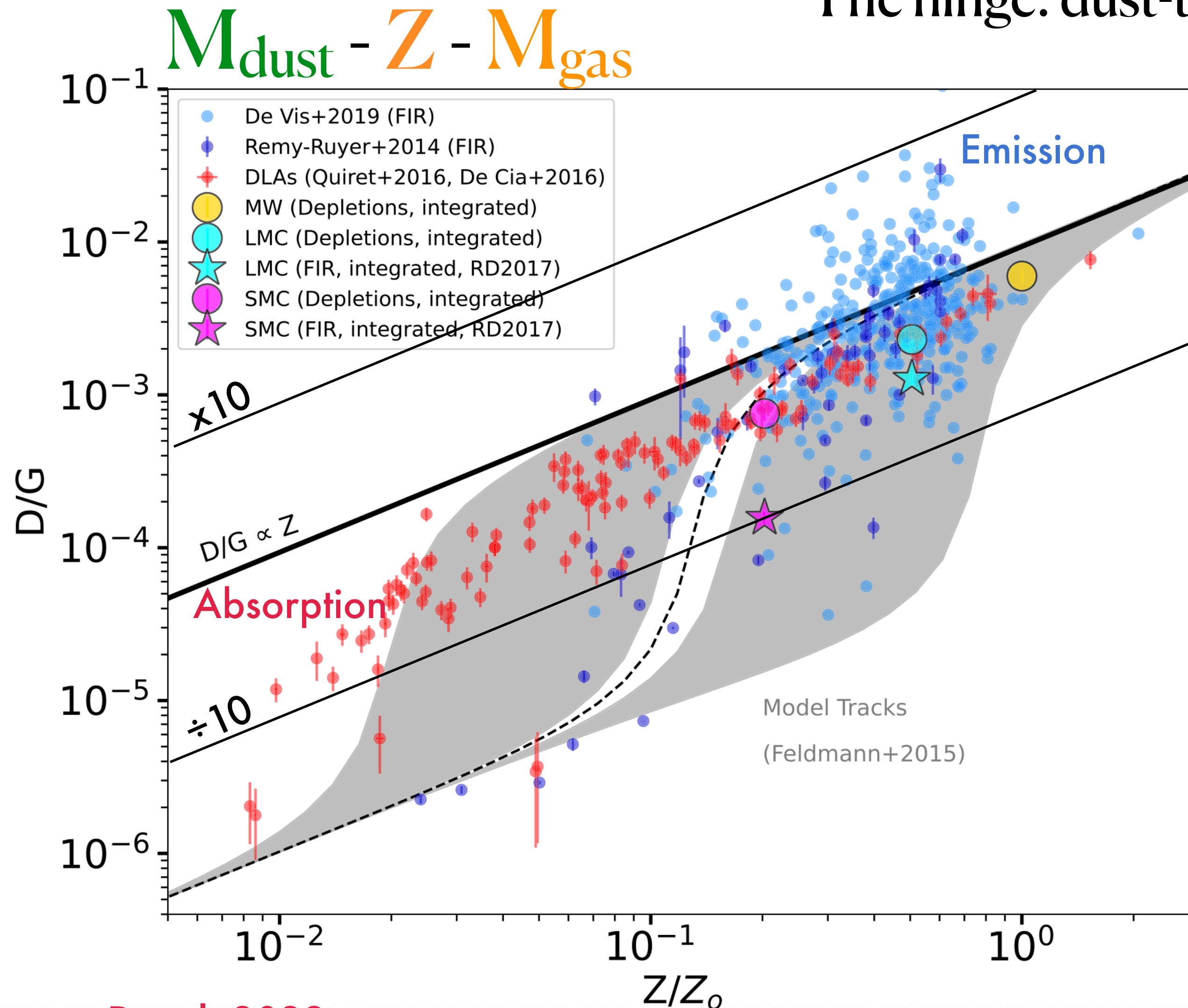


$M_{\text{dust}}/M_{\text{star}}$ trend with sSFR reflects combination of gas fraction, Z, and D/M.

see also Cortese+2012, de Vis+2017, Cassasola+2020, Galliano+2021, Chasteney+2025

How does dust mass vary within & between galaxies?

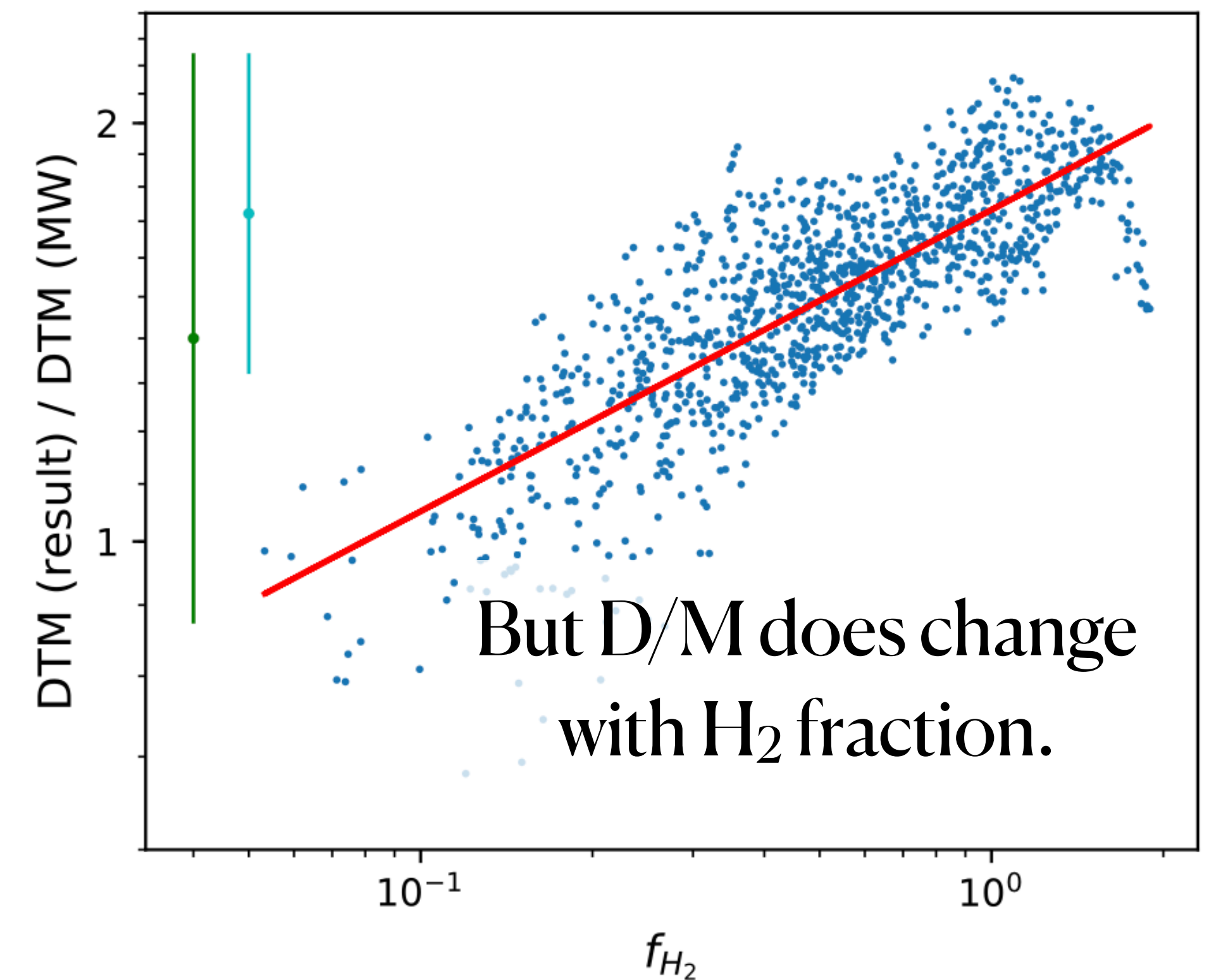
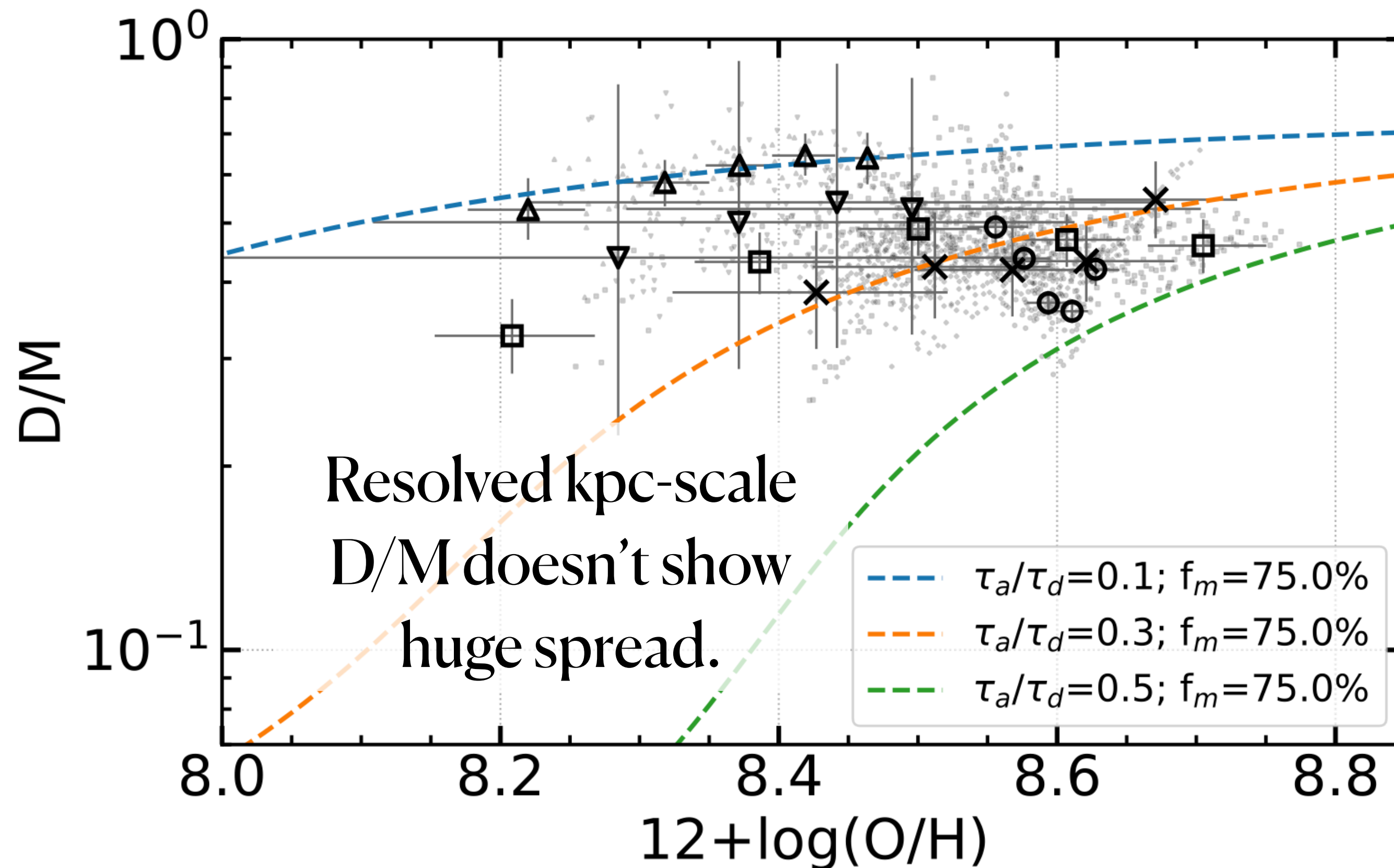
The hinge: dust-to-metals ratio



- Difference between absorption (depletion) and emission based D/M behavior.
 - *Big* scatter in galaxy-integrated emission values at fixed Z.
 - Sharp drop in emission values at low Z.
- Is this assumed far-IR emissivity issues?
- Is this because of smearing out metallicity & DGR gradients in galaxies vs lines-of-sight?

How does dust mass vary within & between galaxies?

Resolved Dust-to-Metals Ratio



Emission-based D/M highly tied to assumed dust opacity, X_{CO} .

We have all of the far-IR we're going to get for a while.

There are ~1000 resolved galaxies with far-IR observations from Herschel.

https://irsa.ipac.caltech.edu/data/Herschel/z0MGS_Dust/overview.html

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 z0MGS_Dust Overview

 z0MGS_Dust Primary Data Access

 z0MGS_Dust Catalogs

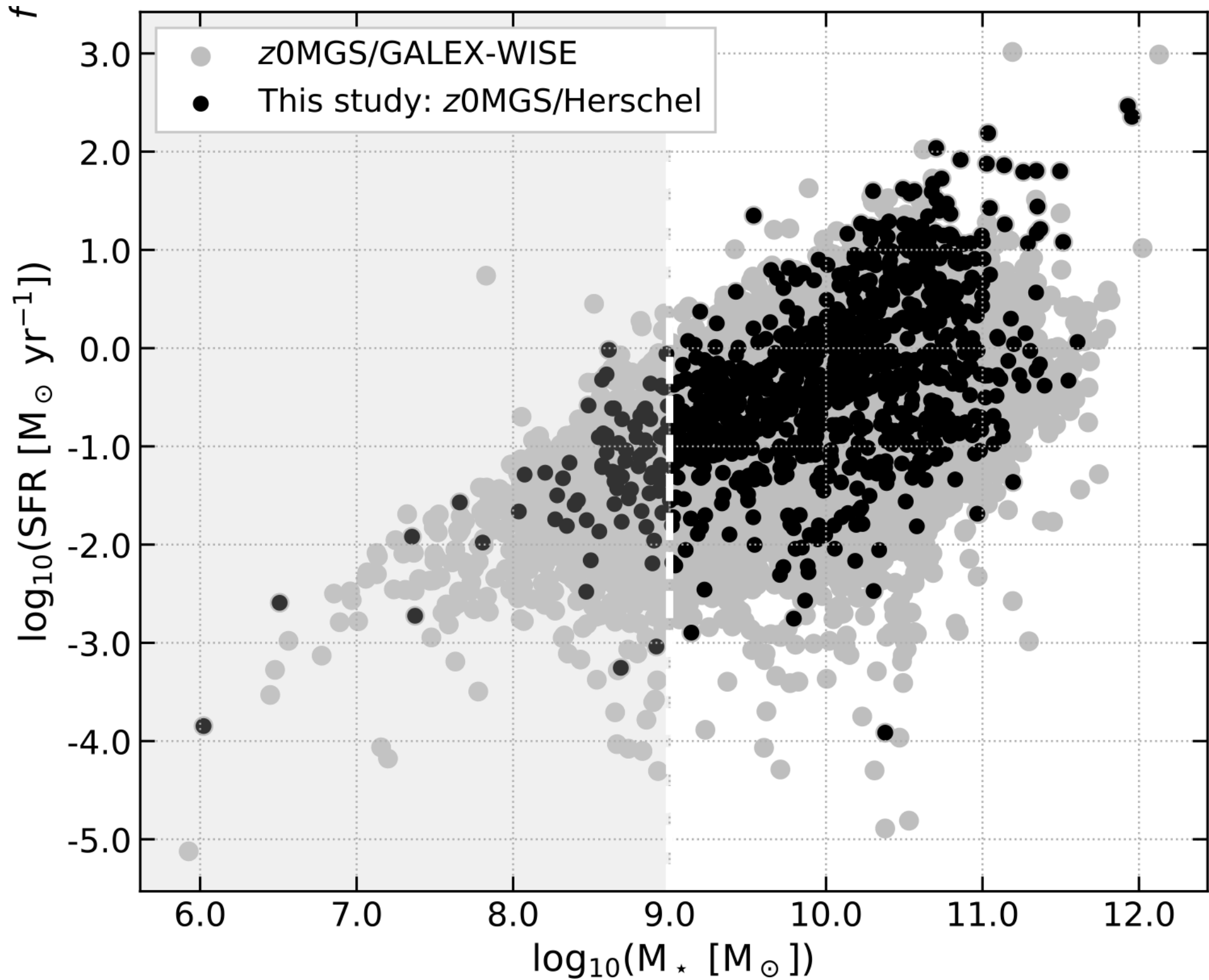
Overview

The z0MGS_Dust project consists of Herschel images from PACS and SPIRE available for 1578 galaxies, dust emission parameters for 819 galaxies, and integrated photometry and dust parameters for 877 galaxies. The final catalog used in this study uses [WISE](#) and Herschel data to derive interstellar dust parameters and scaling relations with other galactic information such as stellar mass, star formation rate, and related values.

If you use z0MGS_Dust data, please cite both the journal article [Chasten et al. \(2024\)](#) and the dataset Digital Object Identifier (DOI): [10.26131/IRSA581](#).

Data Set Characteristics

Data Product	Description	Data Access
Images	Herschel/PACS 70, 100, 160 micron Herschel/SPIRE 250, 350, 500 micron Dust parameter maps	Data Collection Explorer Browseable Directories
Catalog	z0MGS_Dust Catalog	Catalog Search Tool Browseable Directory Program Interface

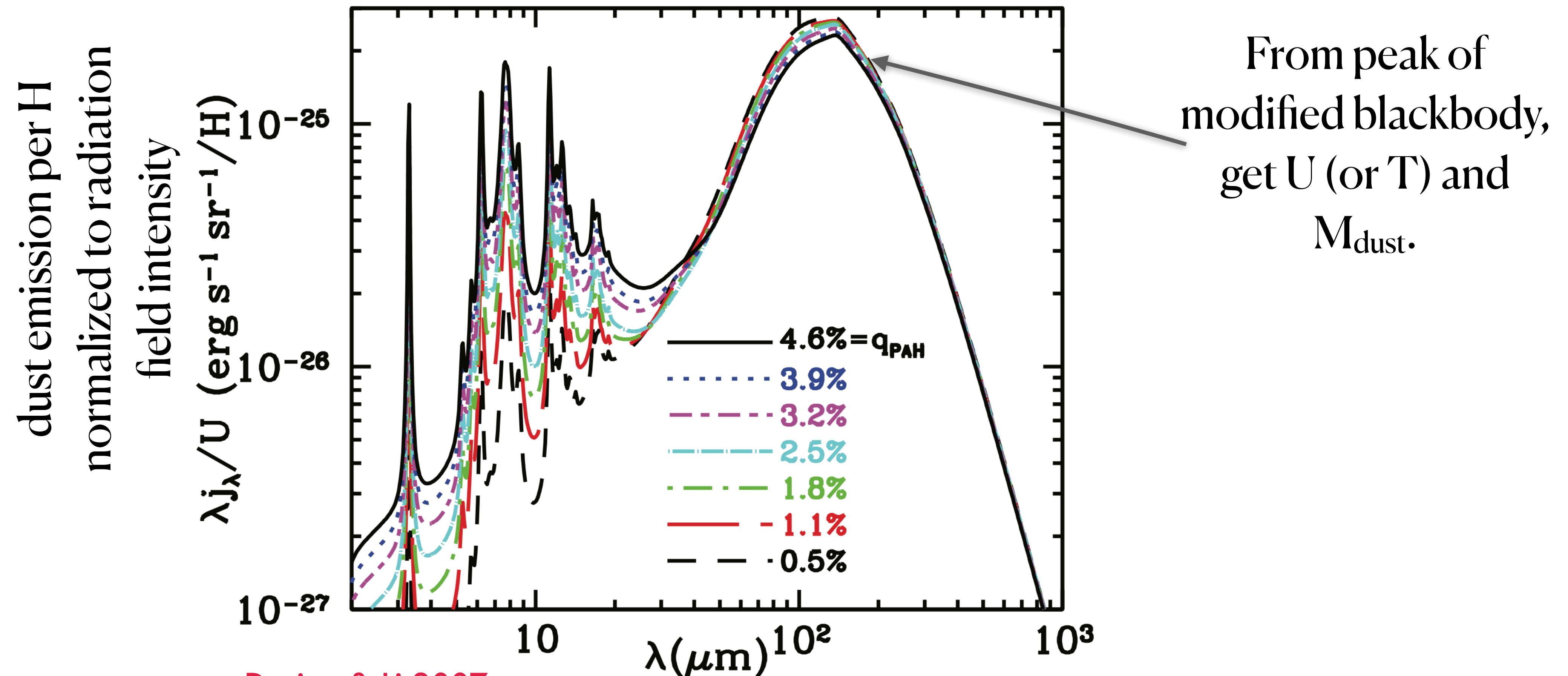


All Herschel maps and dust SED fit results available at IRSA (Chasten et al. 2025)

See also DustPedia database (Davies+2017,2019; Clark+2018,2019)

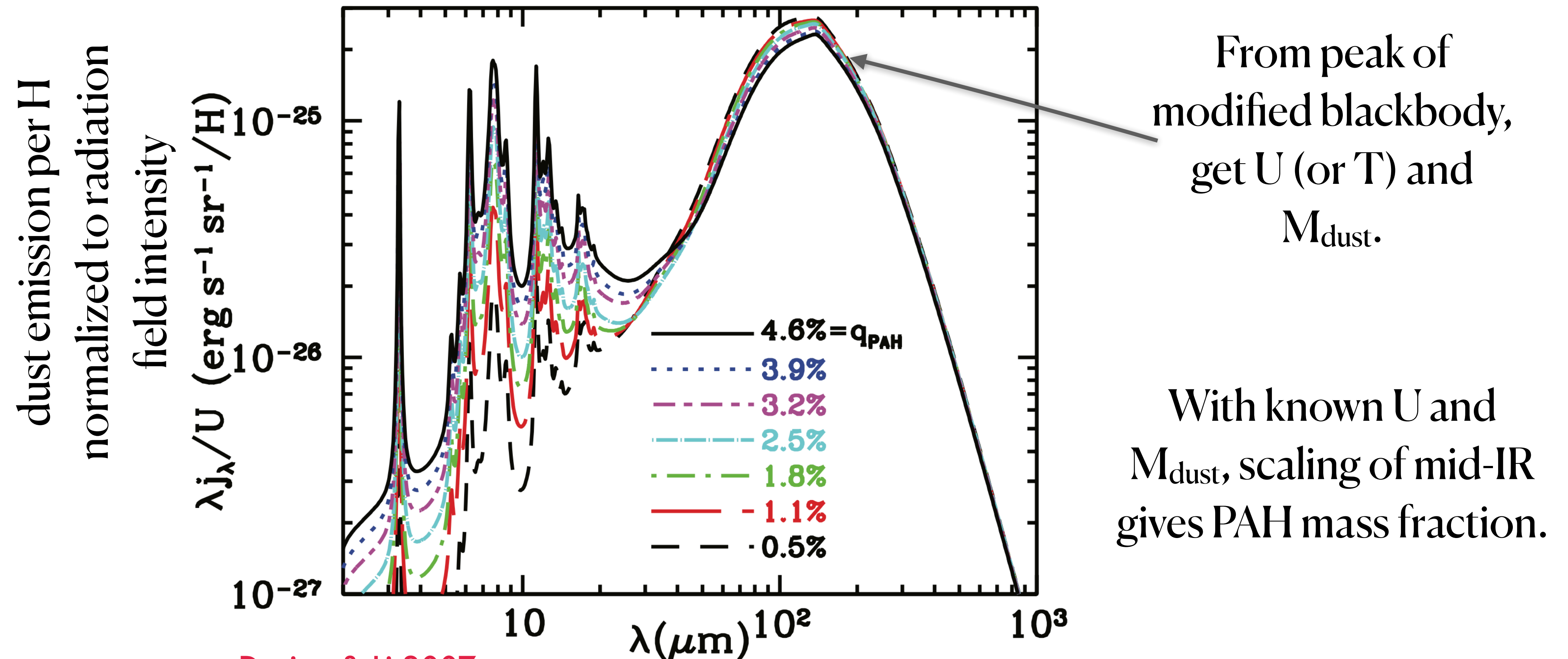
What controls the PAH fraction?

PAH Fraction = fraction of dust mass in the form of carbonaceous grains with $<10^3$ C atoms.



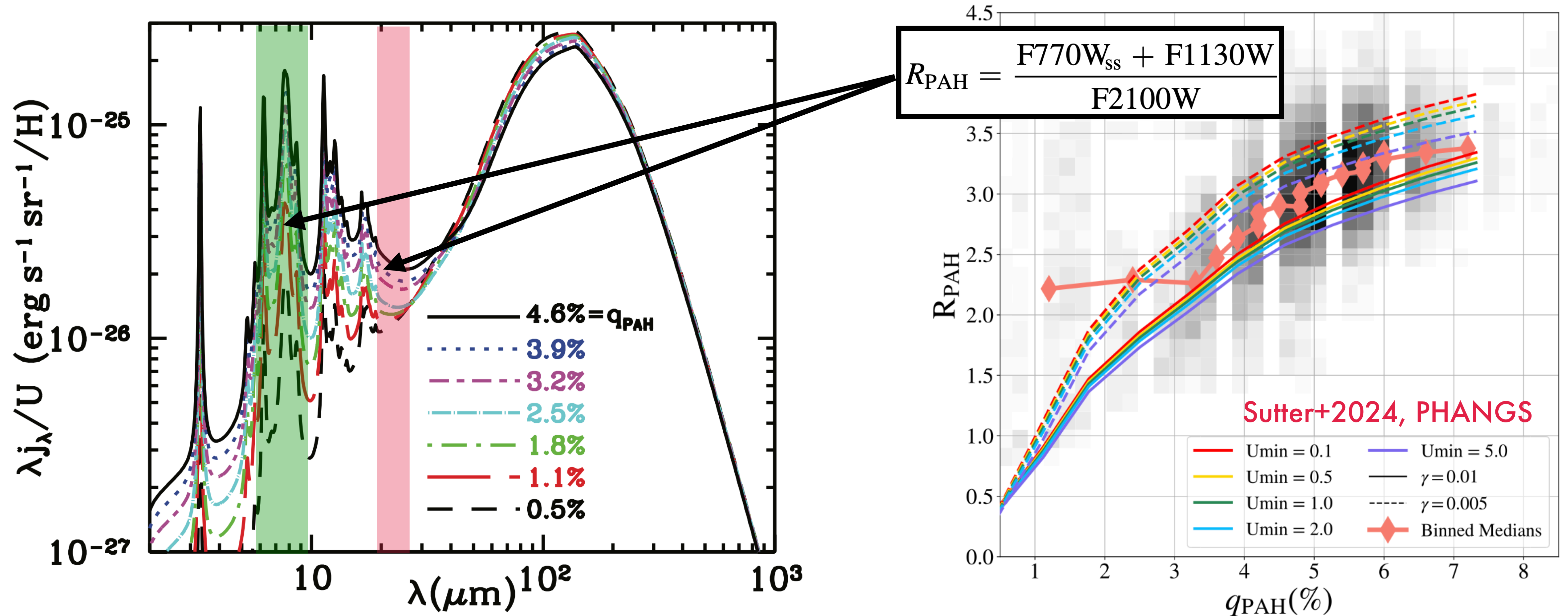
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What controls the PAH fraction?

Mid-IR JWST-based tracer R_{PAH} tracks q_{PAH} at far higher angular resolution.



Based on mid-IR tracers of PAH fraction with Spitzer: Engelbracht+2005, 2008, Marble+2010

What controls the PAH fraction?

Two main behaviors:

1) Destruction of PAHs in ionized gas.

2) Deficit of PAHs at low metallicity.

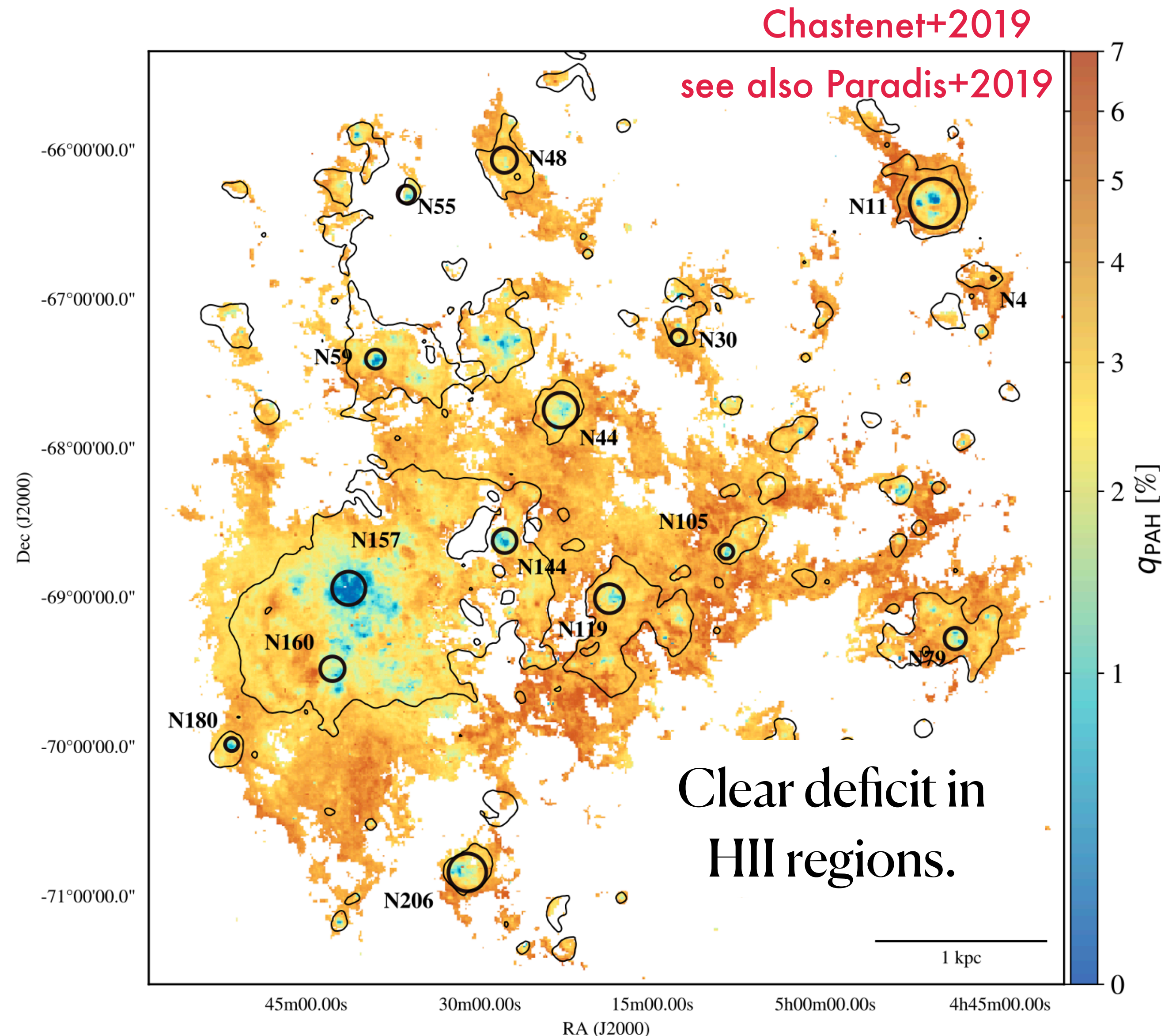
Destruction of PAHs in Ionized Gas

The lack of PAHs in regions of ionized gas has been clear for many years with observations from IRAS, ISO, and Spitzer in Milky Way HII regions.

Cesarsky+1996, Kassis+2006, Povich+2007

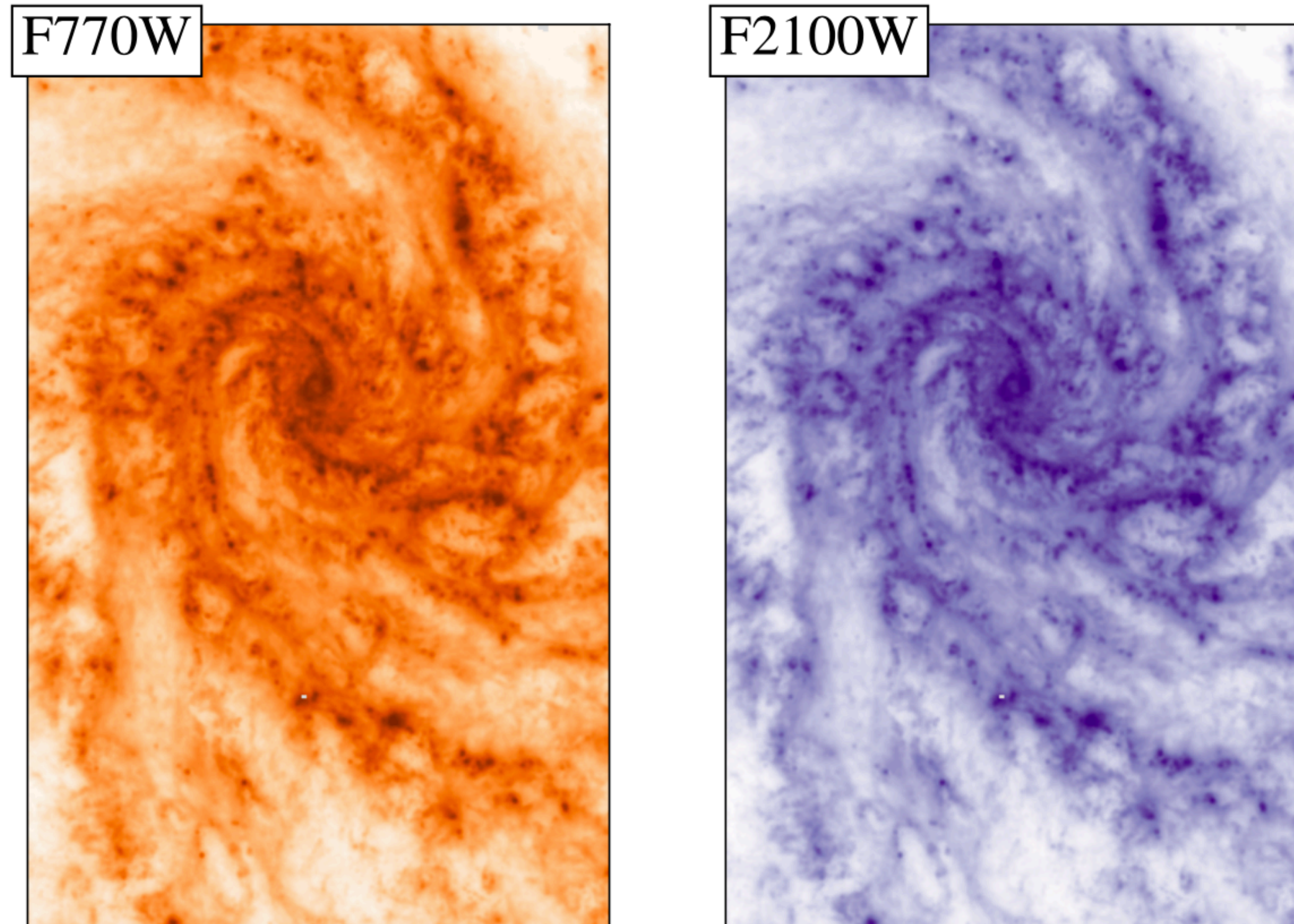
With sufficient angular resolution, can see this in other galaxies.

3-500 μm dust fitting $\rightarrow$ 10 pc map of q_{PAH} in Magellanic Clouds.



Destruction of PAHs in Ionized Gas

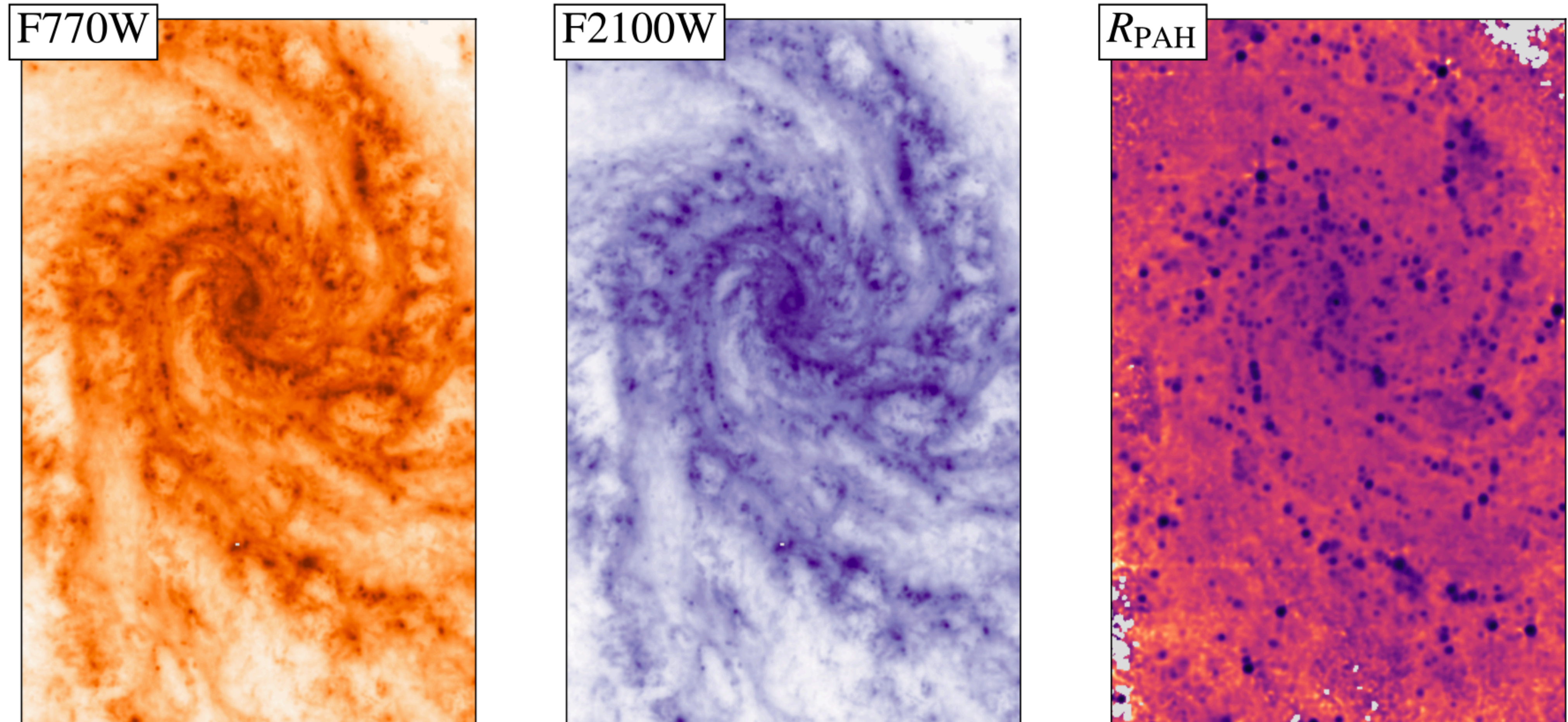
~5-10 pc resolution now possible in galaxies out to ~10 Mpc with JWST MIRI



Chasten et al. 2023a, Sutter et al. 2024

Destruction of PAHs in Ionized Gas

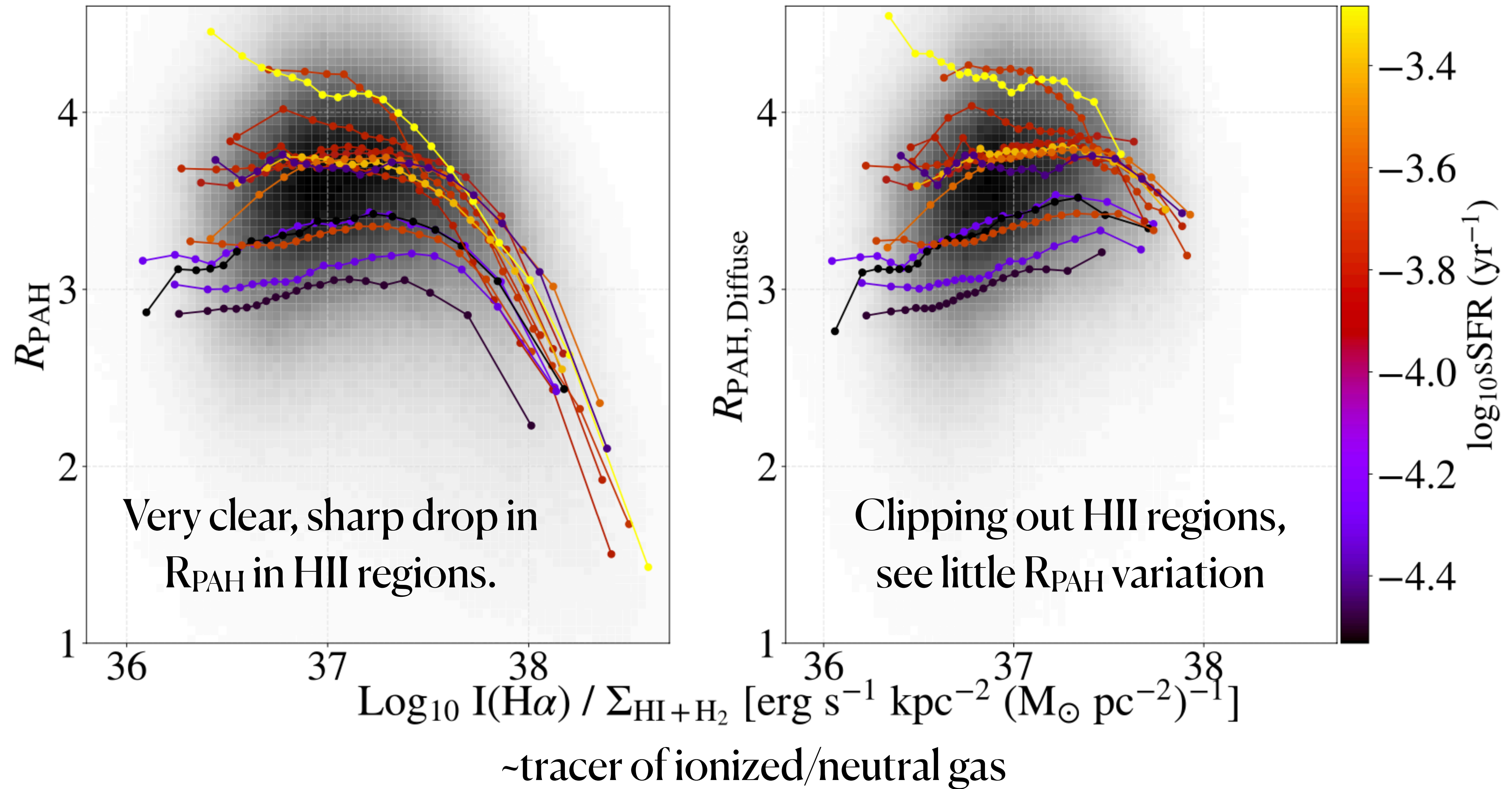
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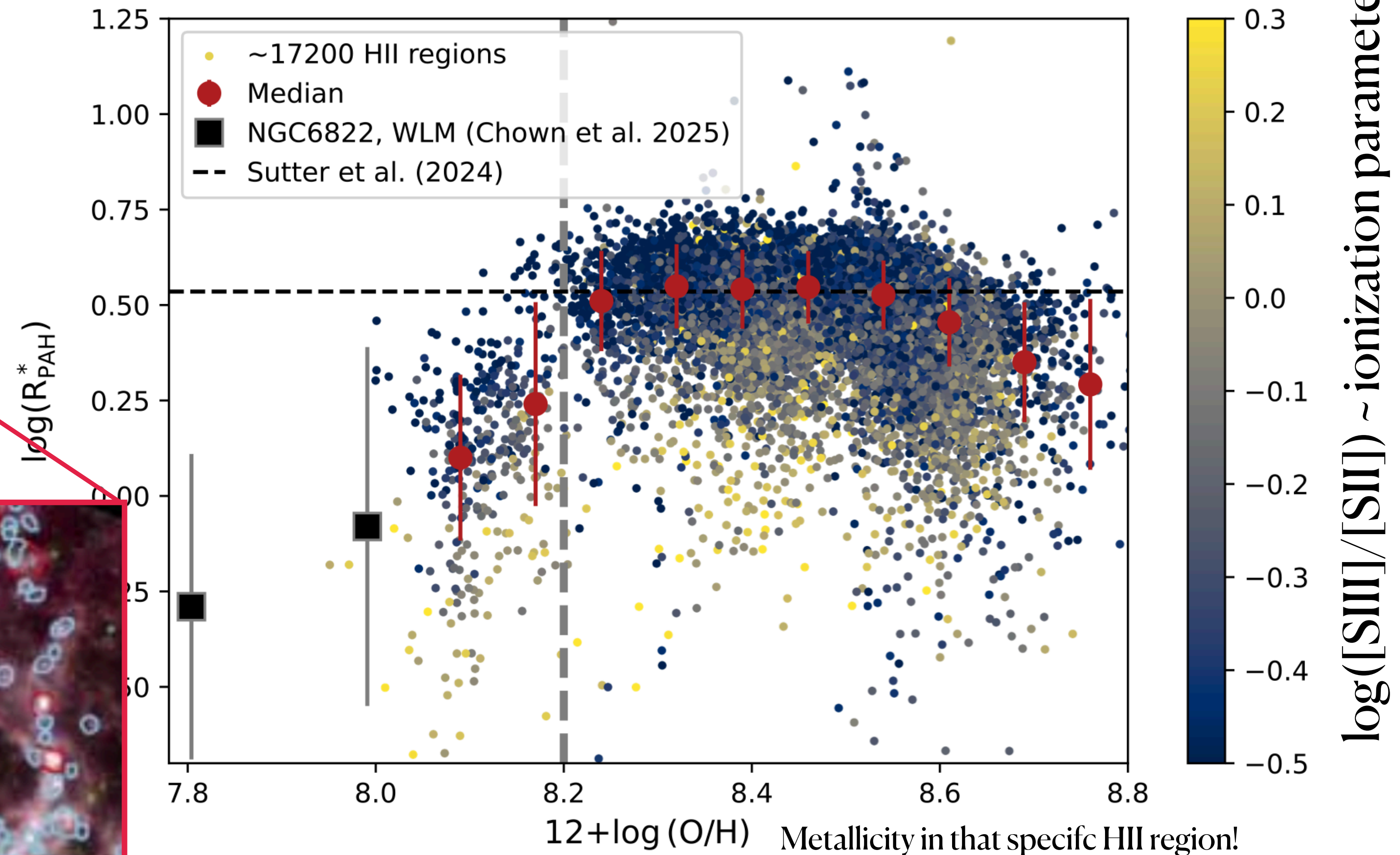
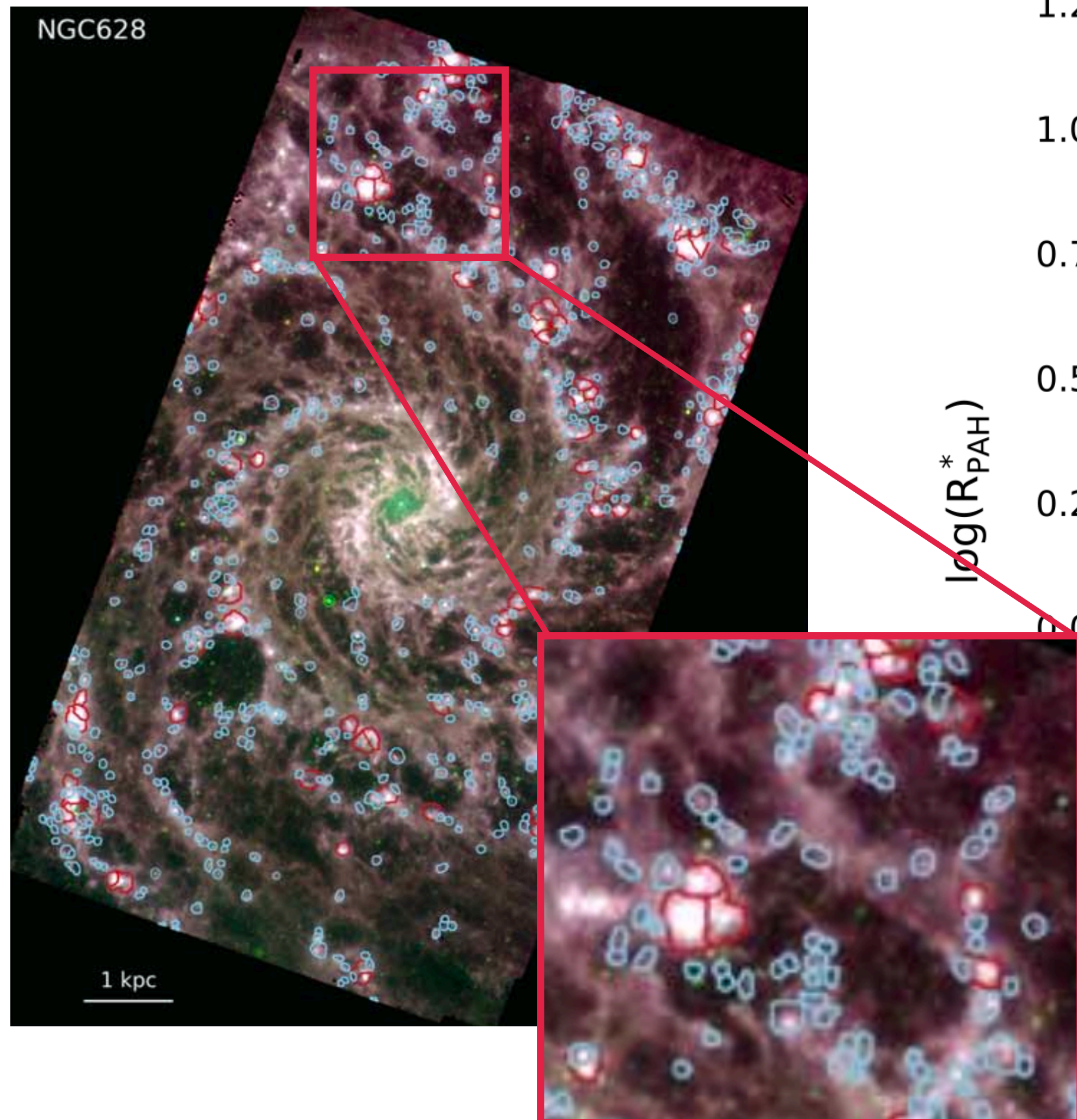
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Destruction of PAHs in Ionized Gas

Sutter et al. 2024



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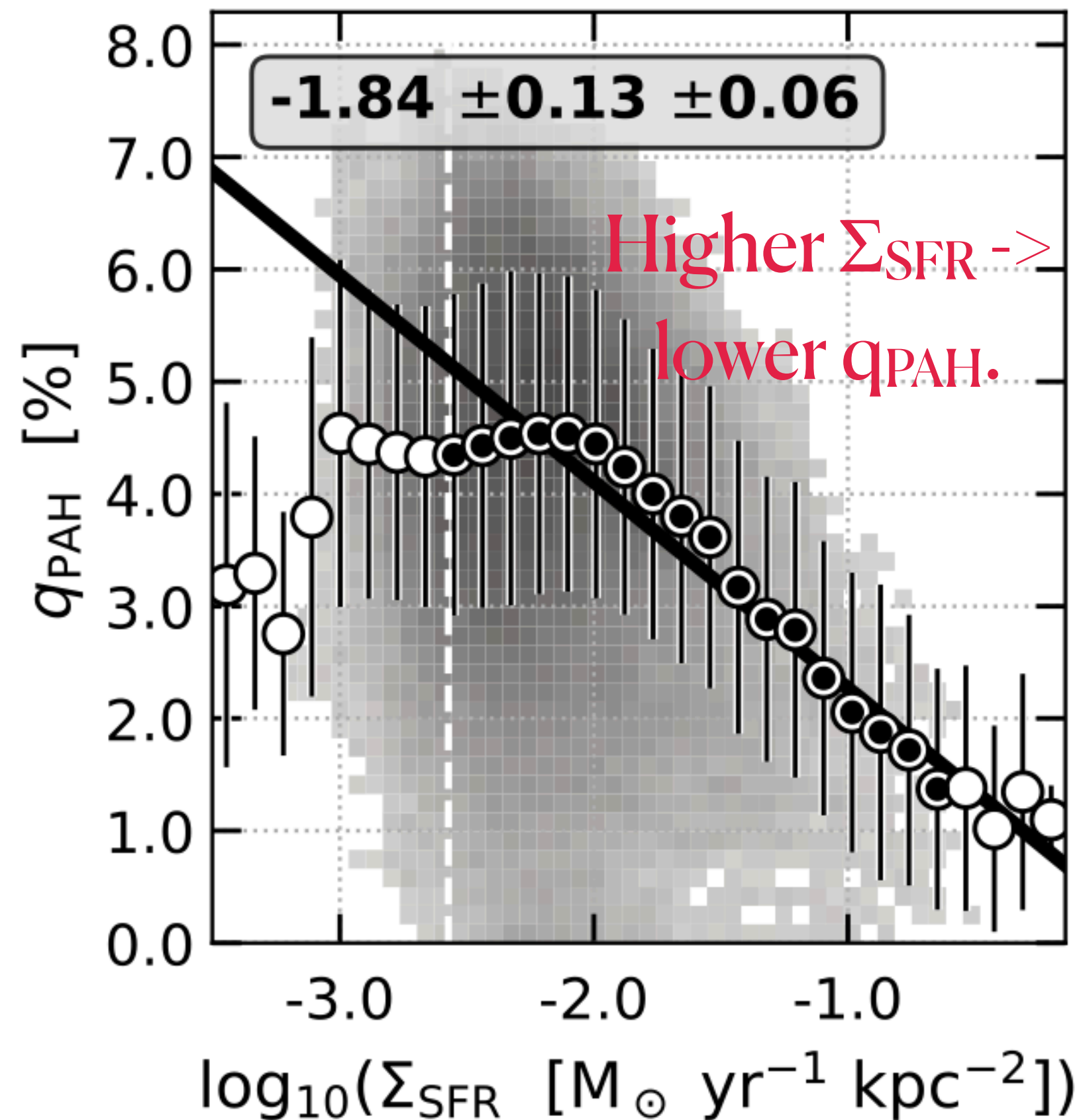


Egorov+2023, 2025, PHANGS

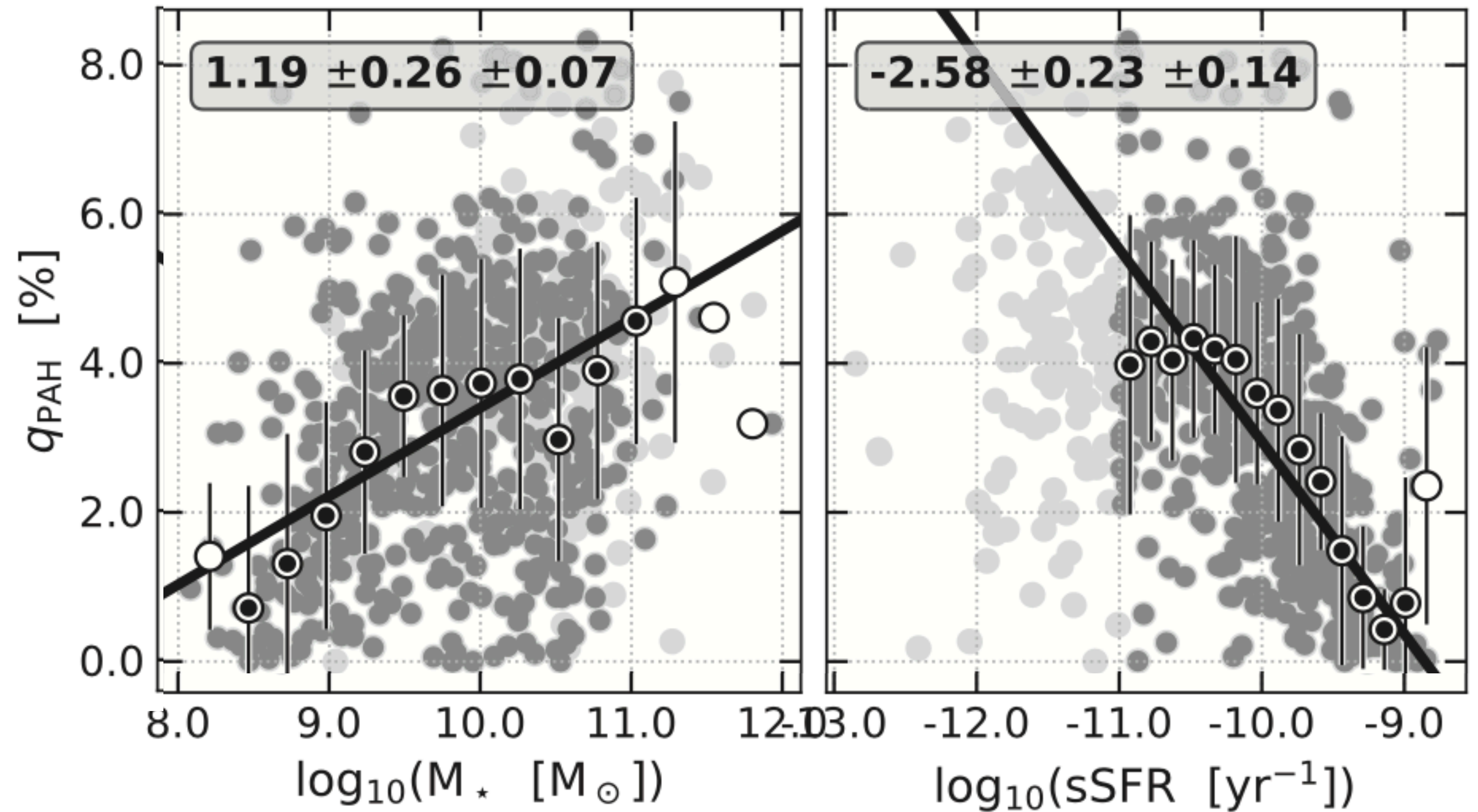
Destruction of PAHs in Ionized Gas

PAH destruction in HII regions matters on the scale of entire galaxies!

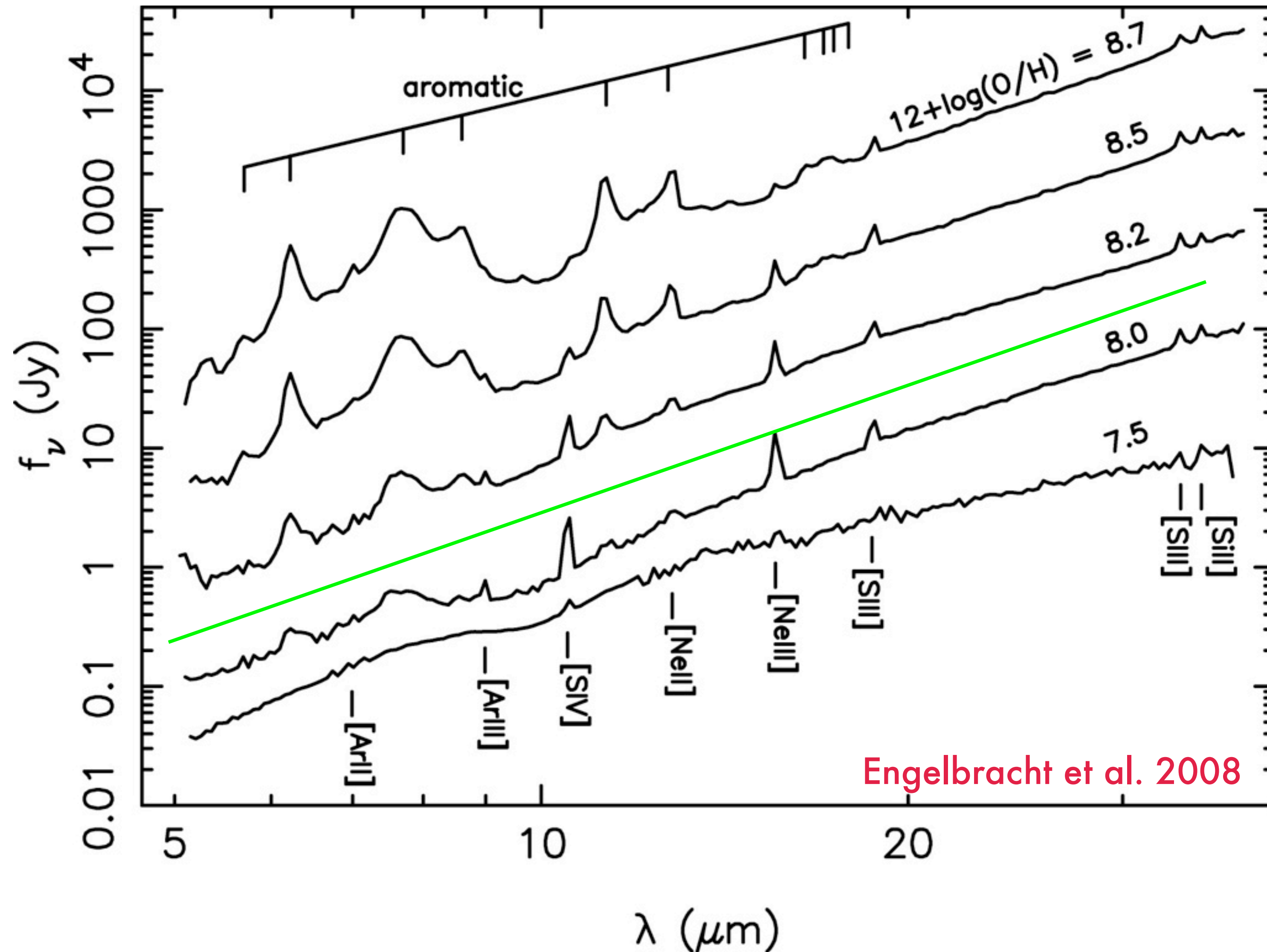
~kpc resolution



Galaxy integrated



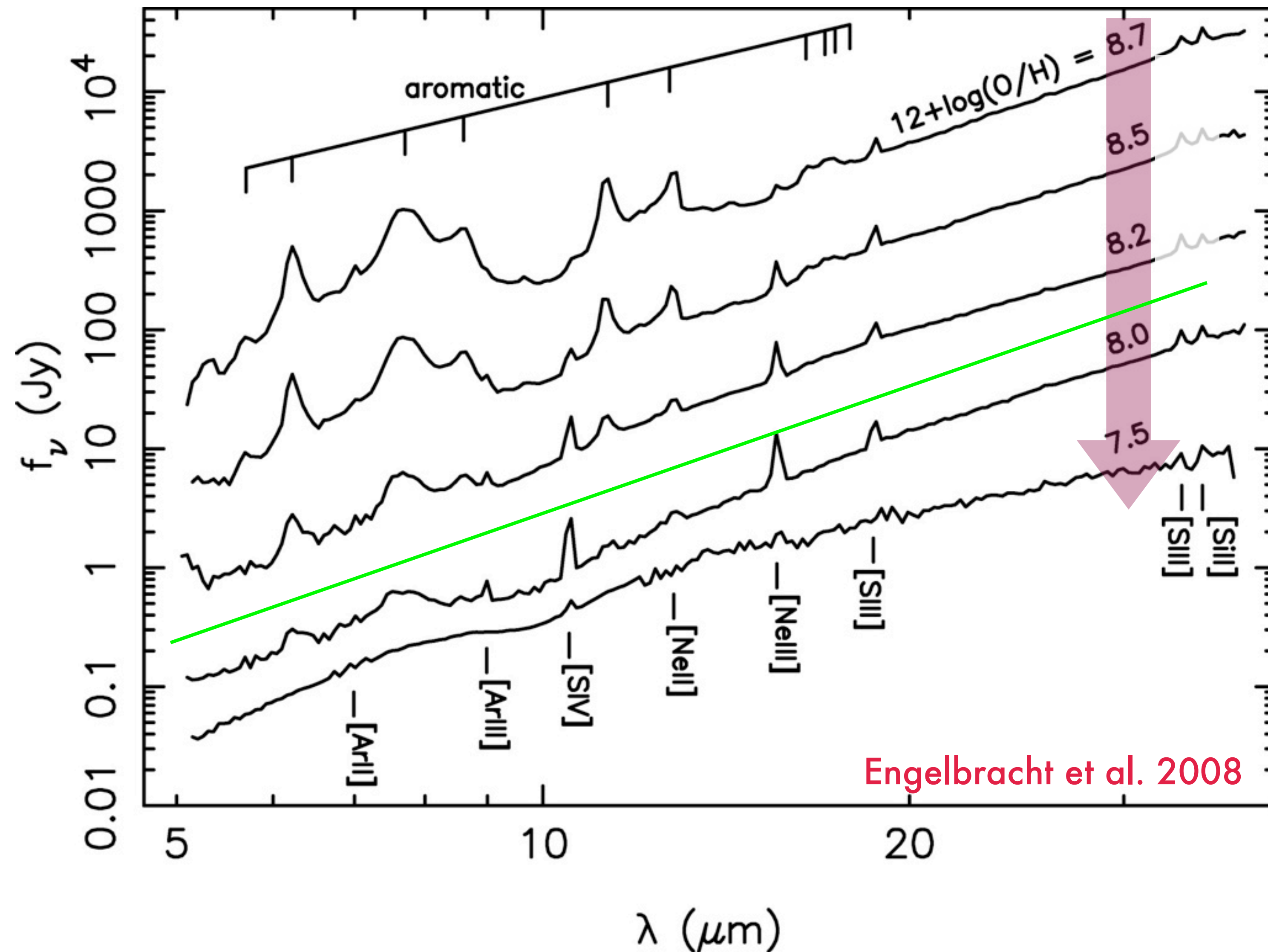
Deficit of PAHs at Low Metallicity



Observations with ISO and Spitzer have shown a deficit of PAH emission from low-metallicity galaxies.

Lots of evidence for PAH-Z deficiency:
Madden et al. 2000
Galliano et al. 2003, 2005
Engelbracht et al. 2005
Madden et al. 2006
Wu et al. 2006
Draine et al. 2007
Remy-Ruyer et al. 2015
etc., etc.

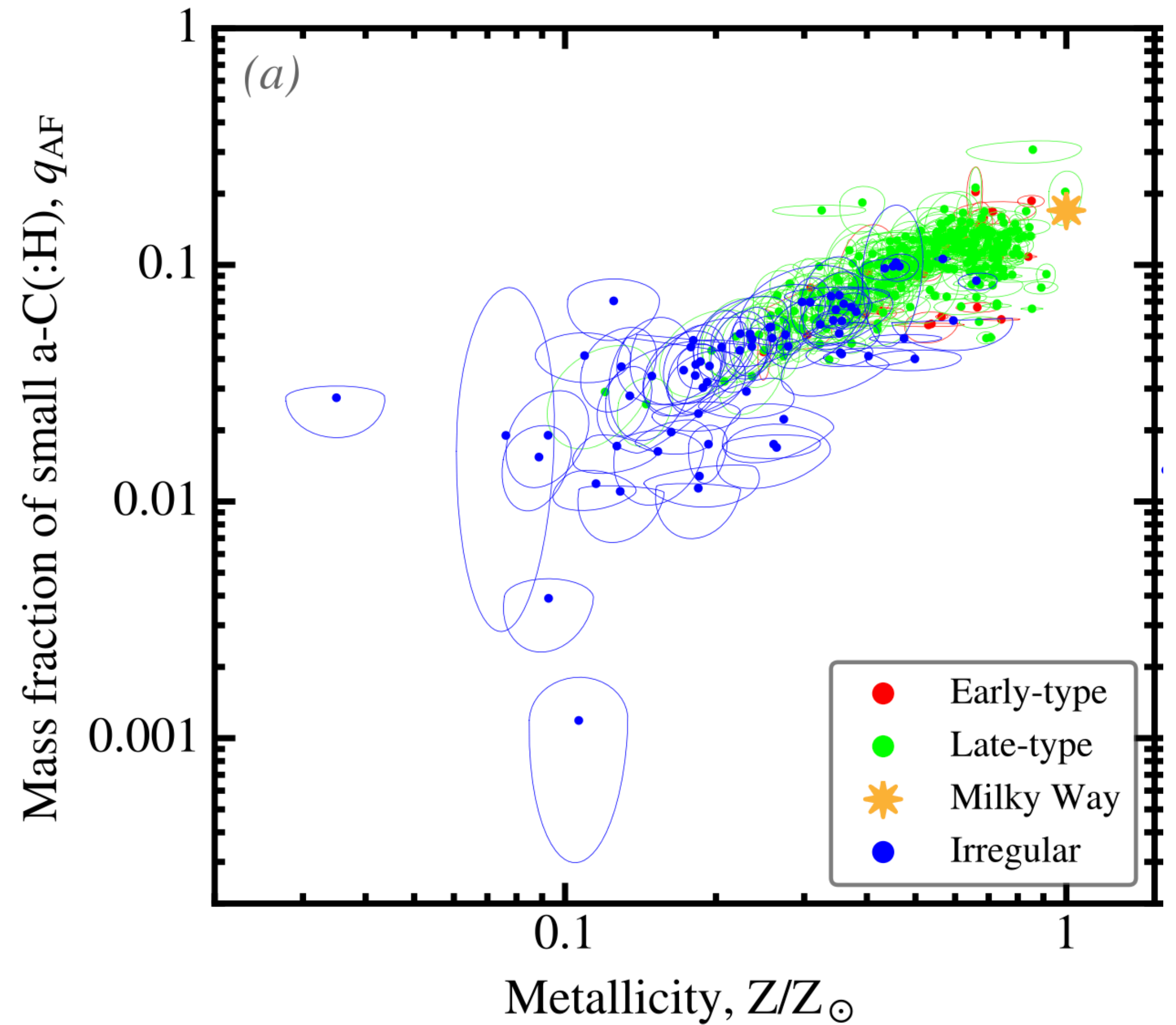
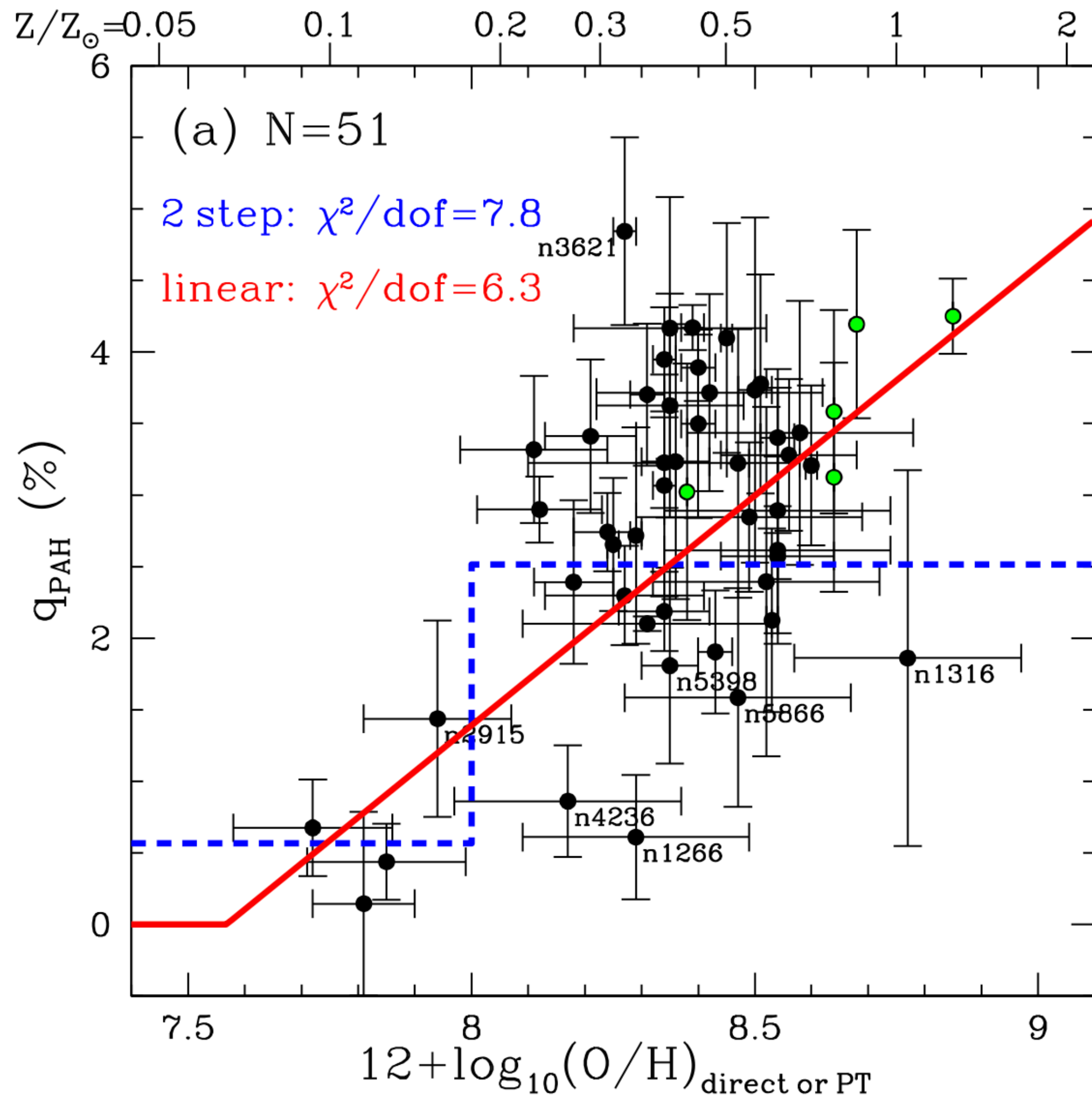
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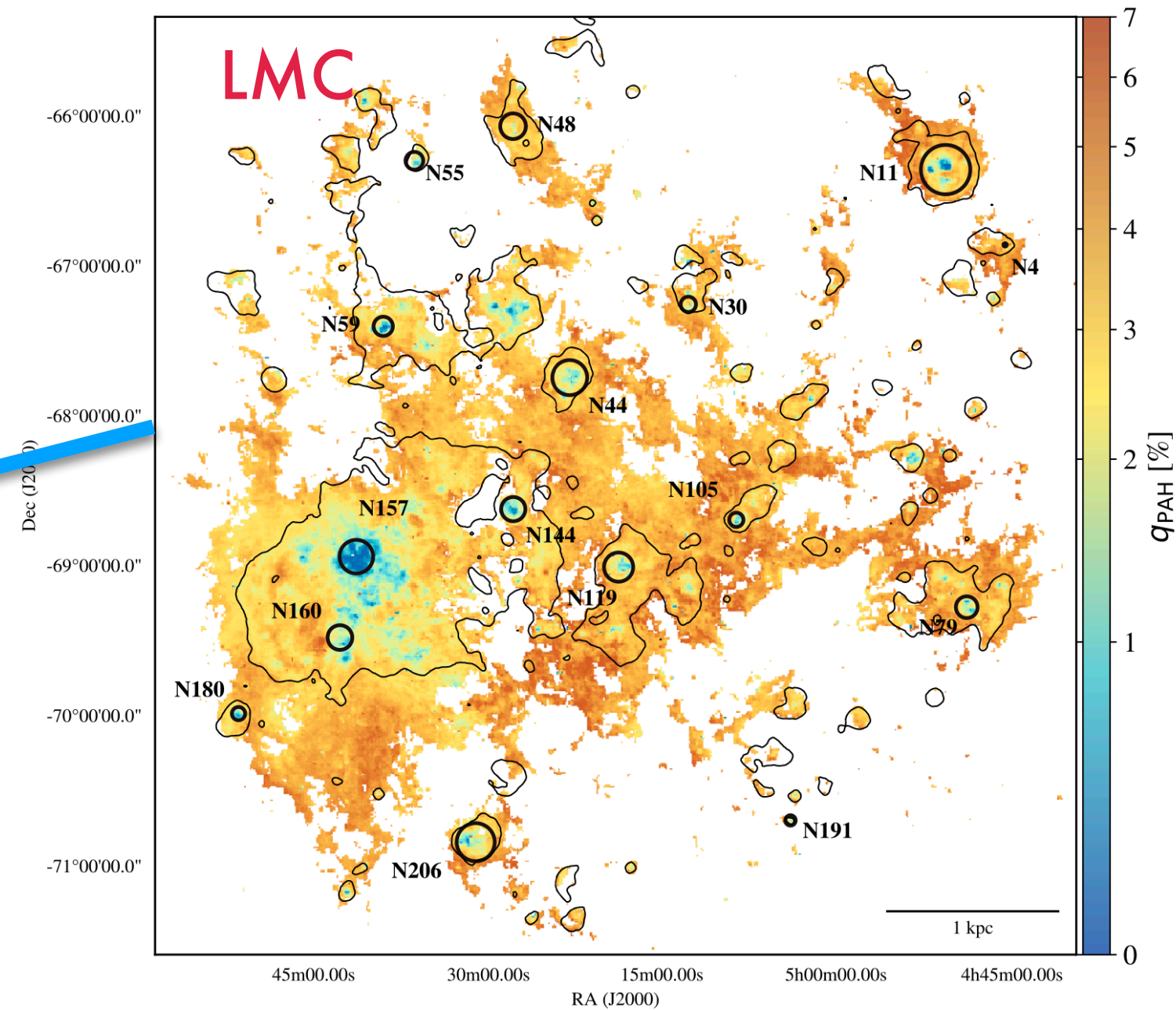
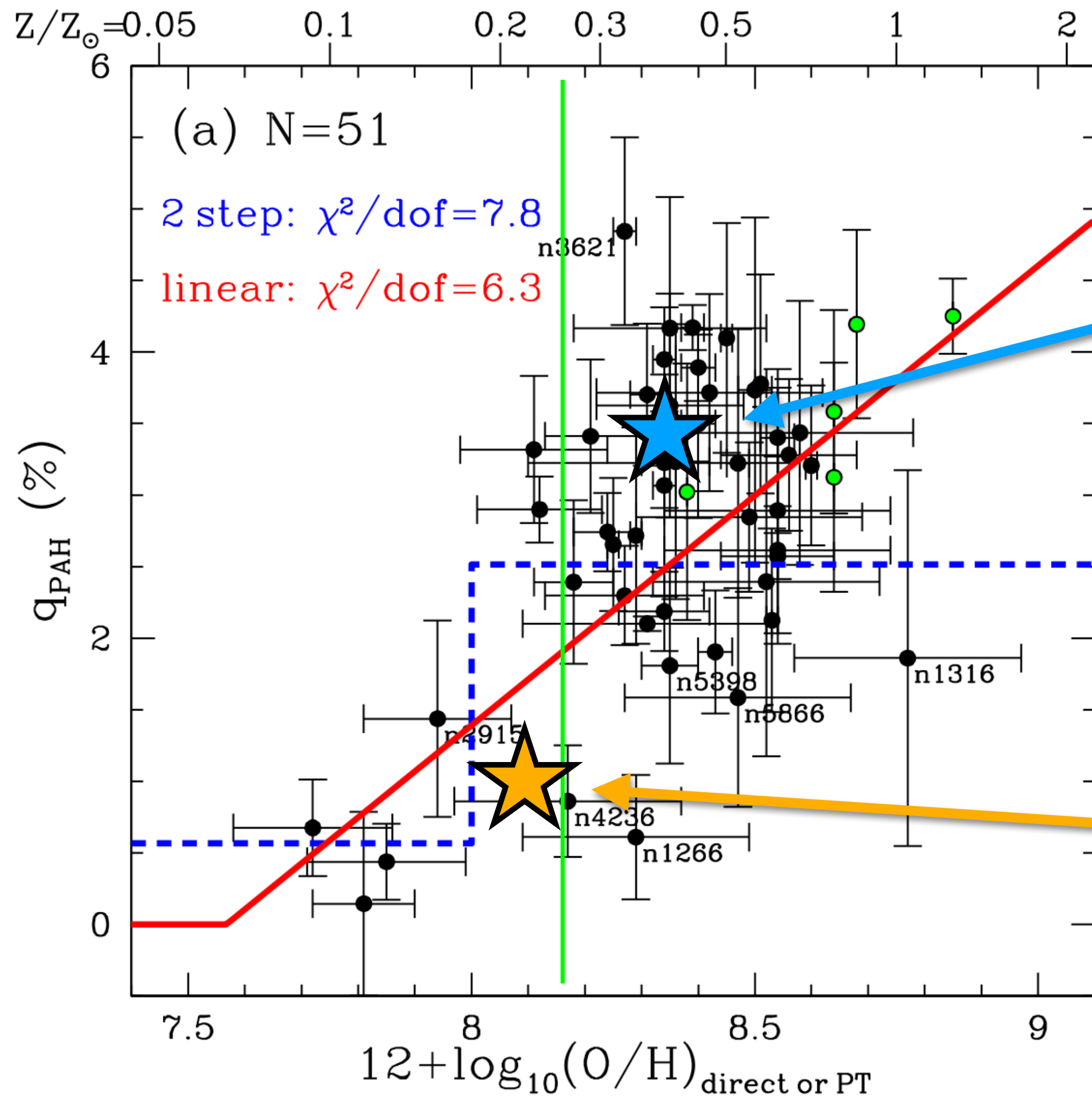
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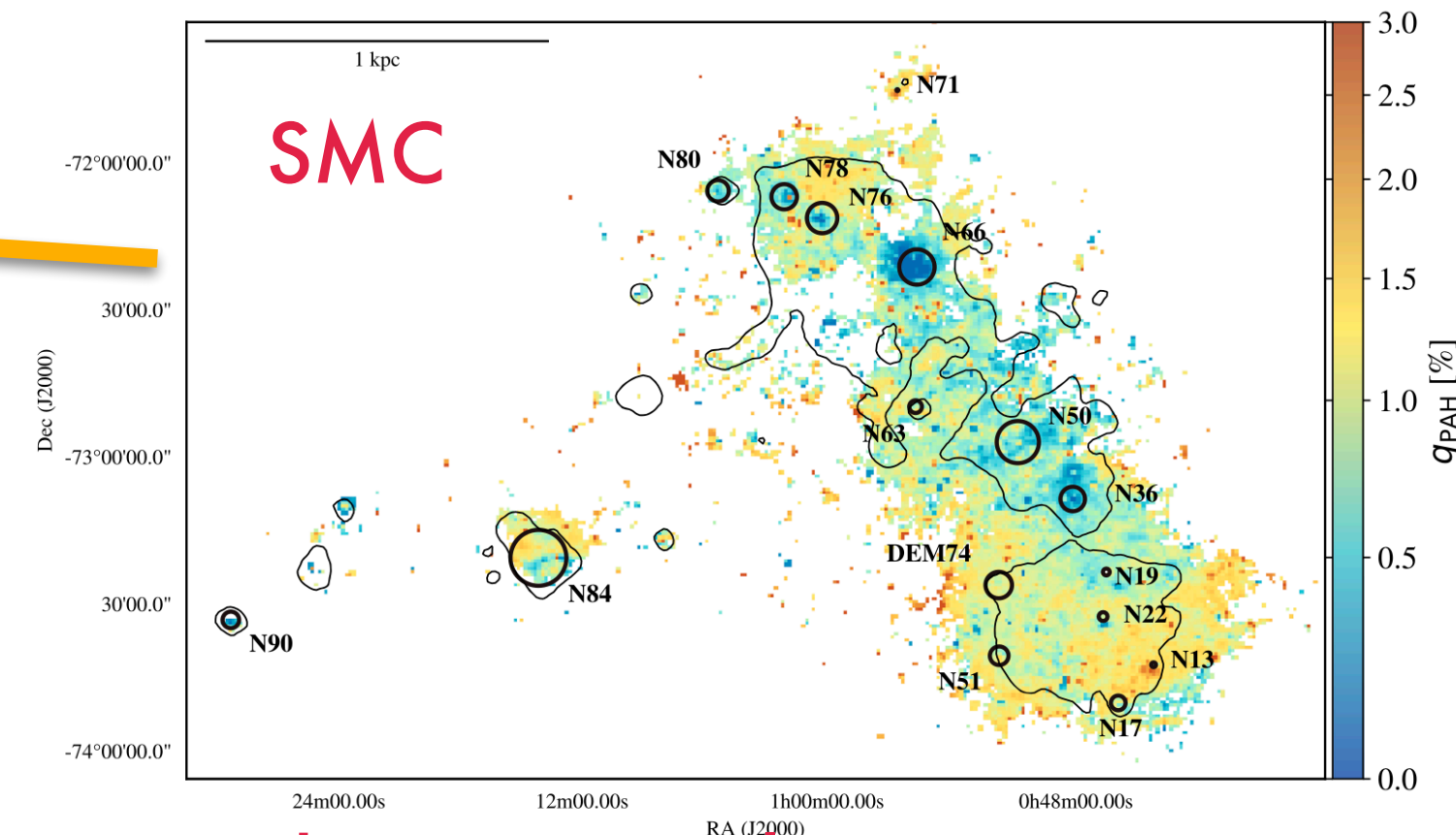
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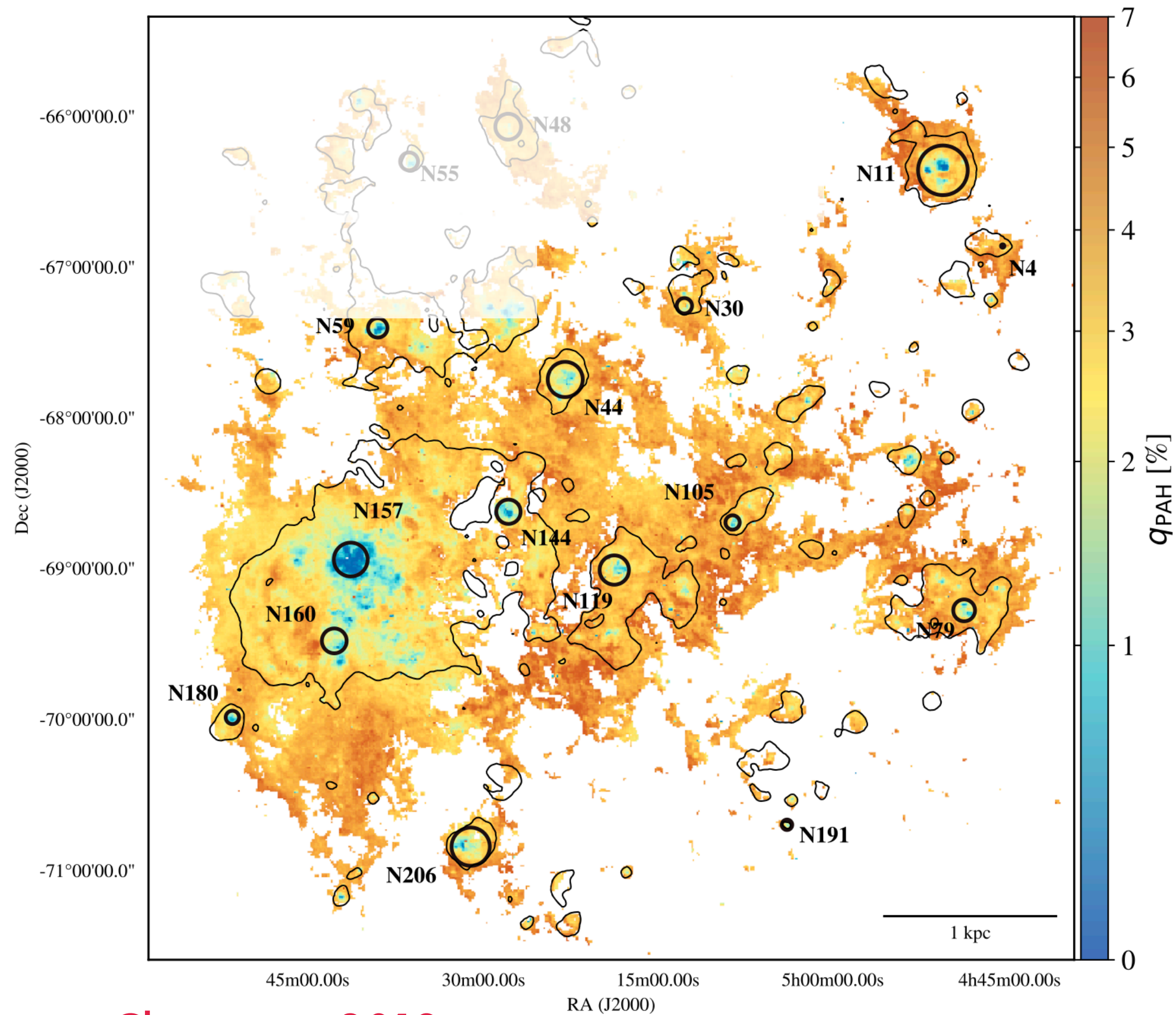
Somewhere between the SMC & LMC's metallicity there is a dramatic change in PAH abundance.



WHY?

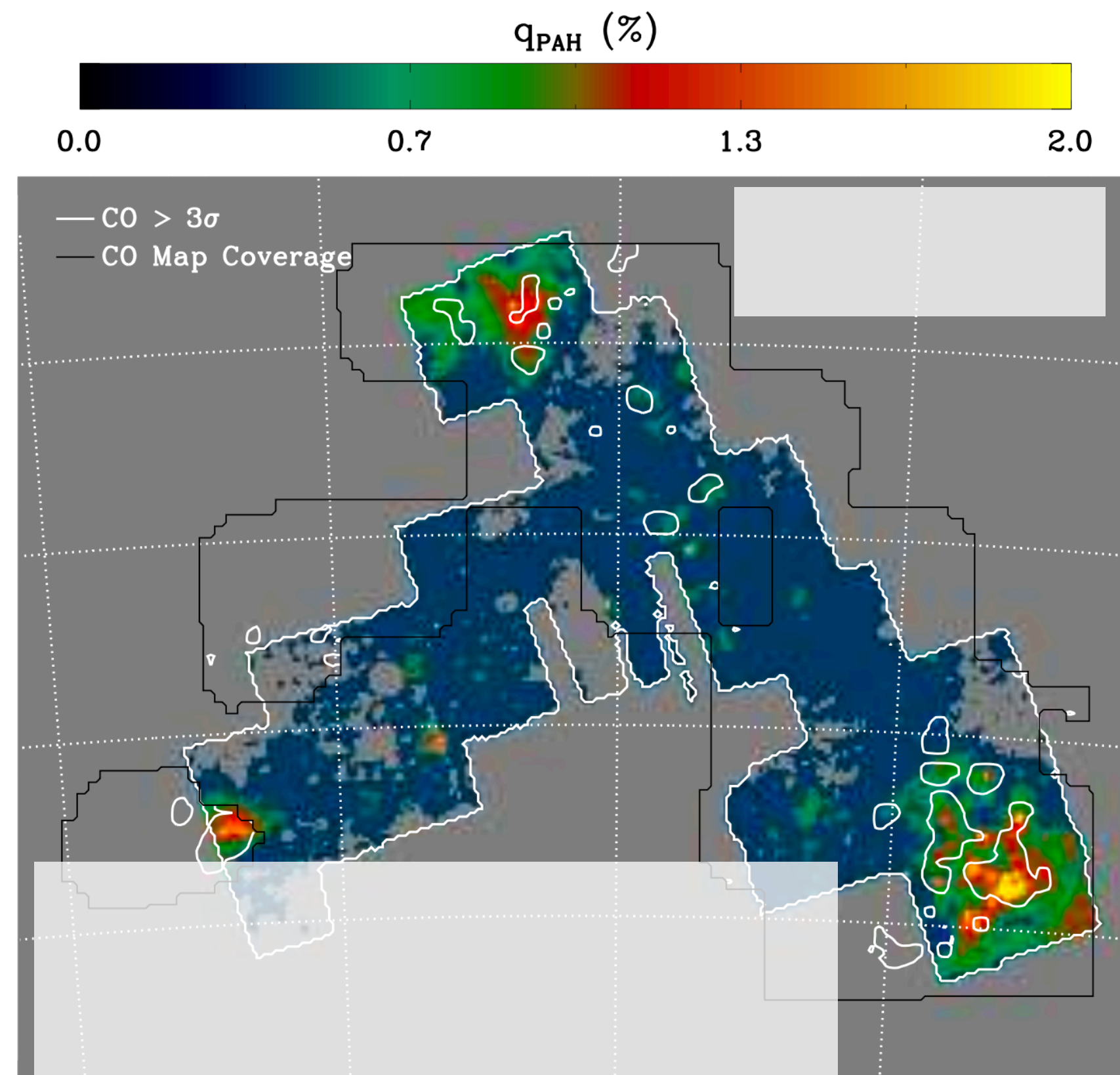
Deficit of PAHs at Low Metallicity

Part of the story may be a low filling factor of regions with high q_{PAH} .



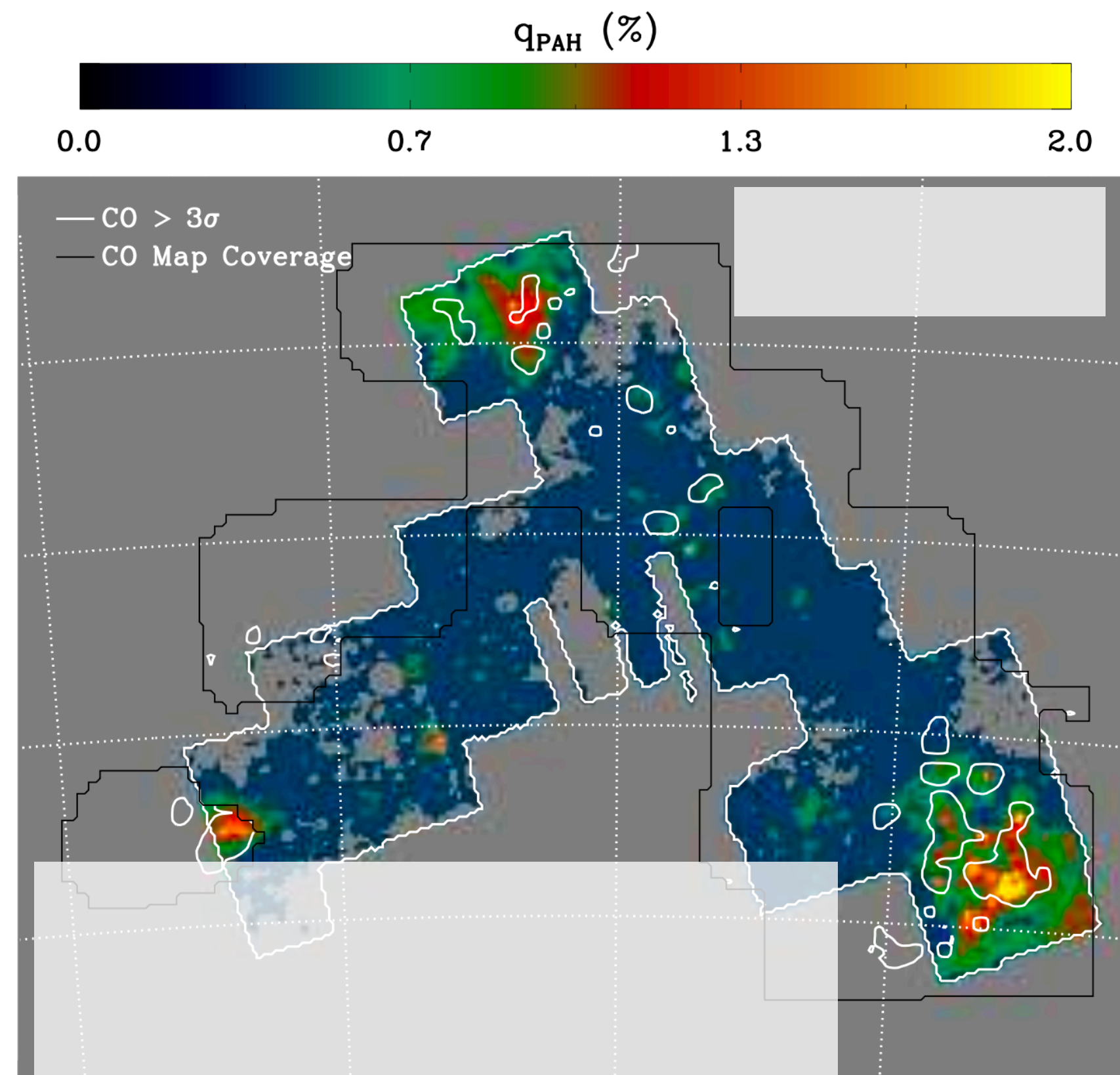
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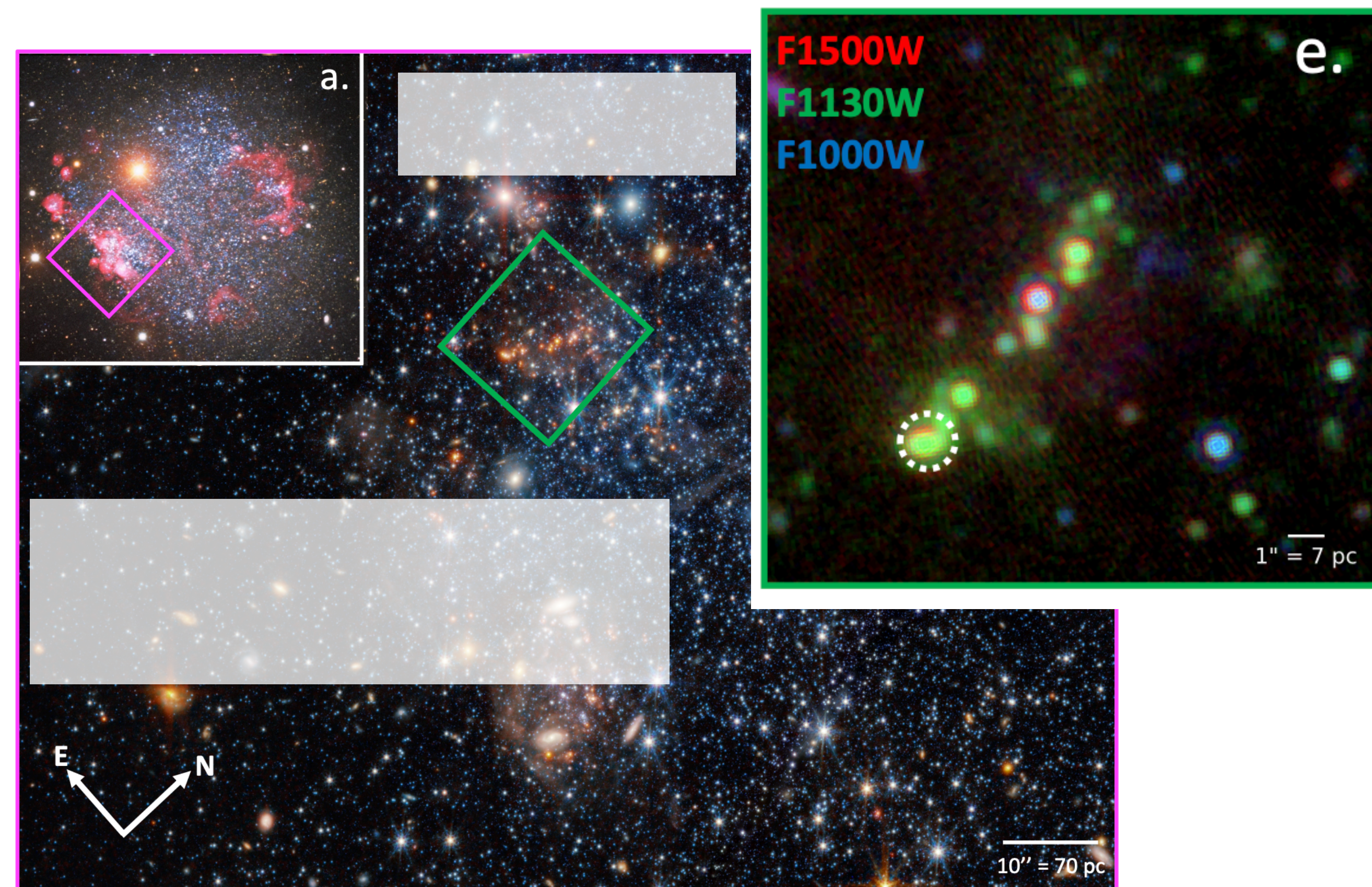


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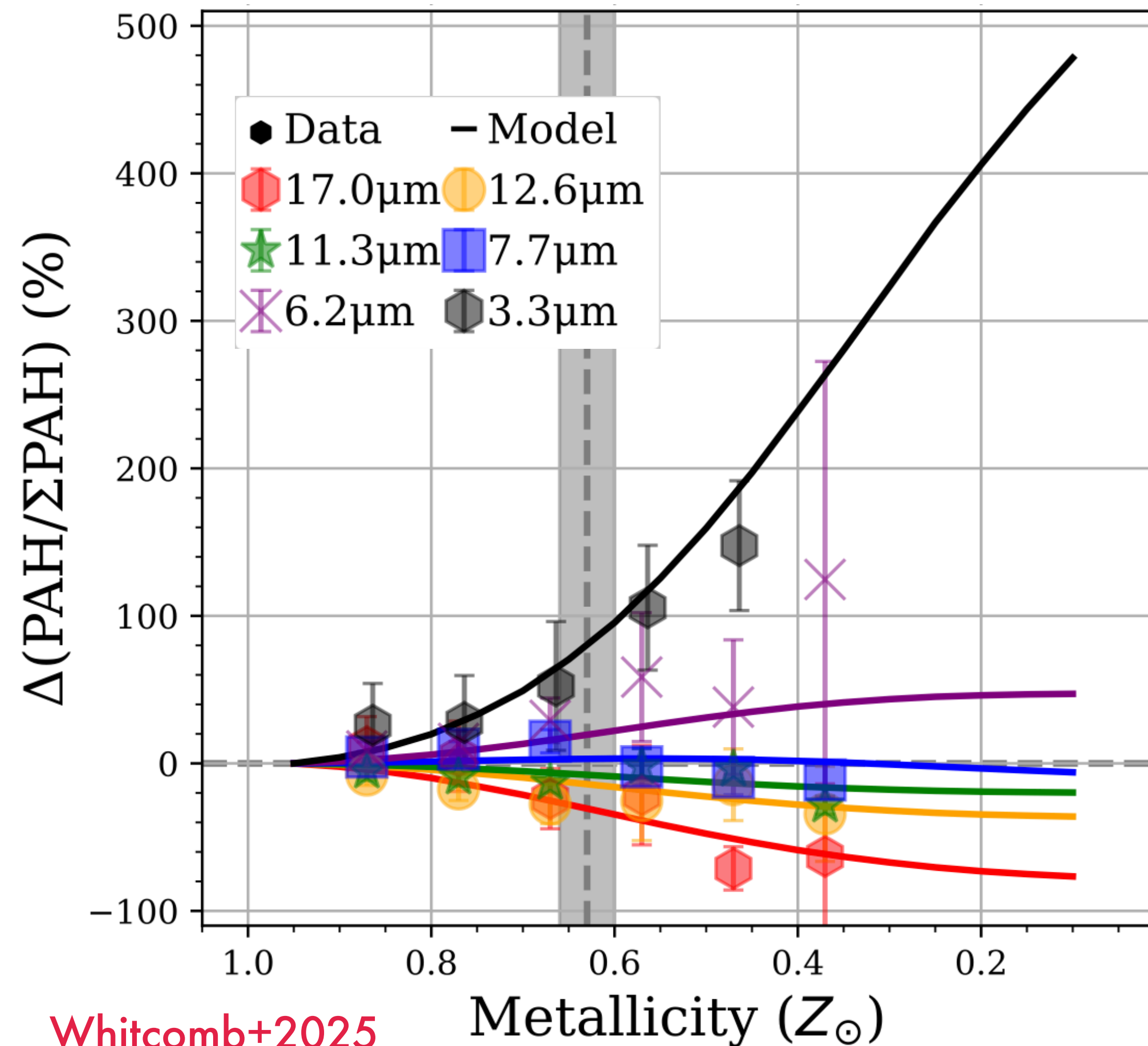
Sandstrom+2010



Tarantino+2026 (in prep)

Deficit of PAHs at Low Metallicity

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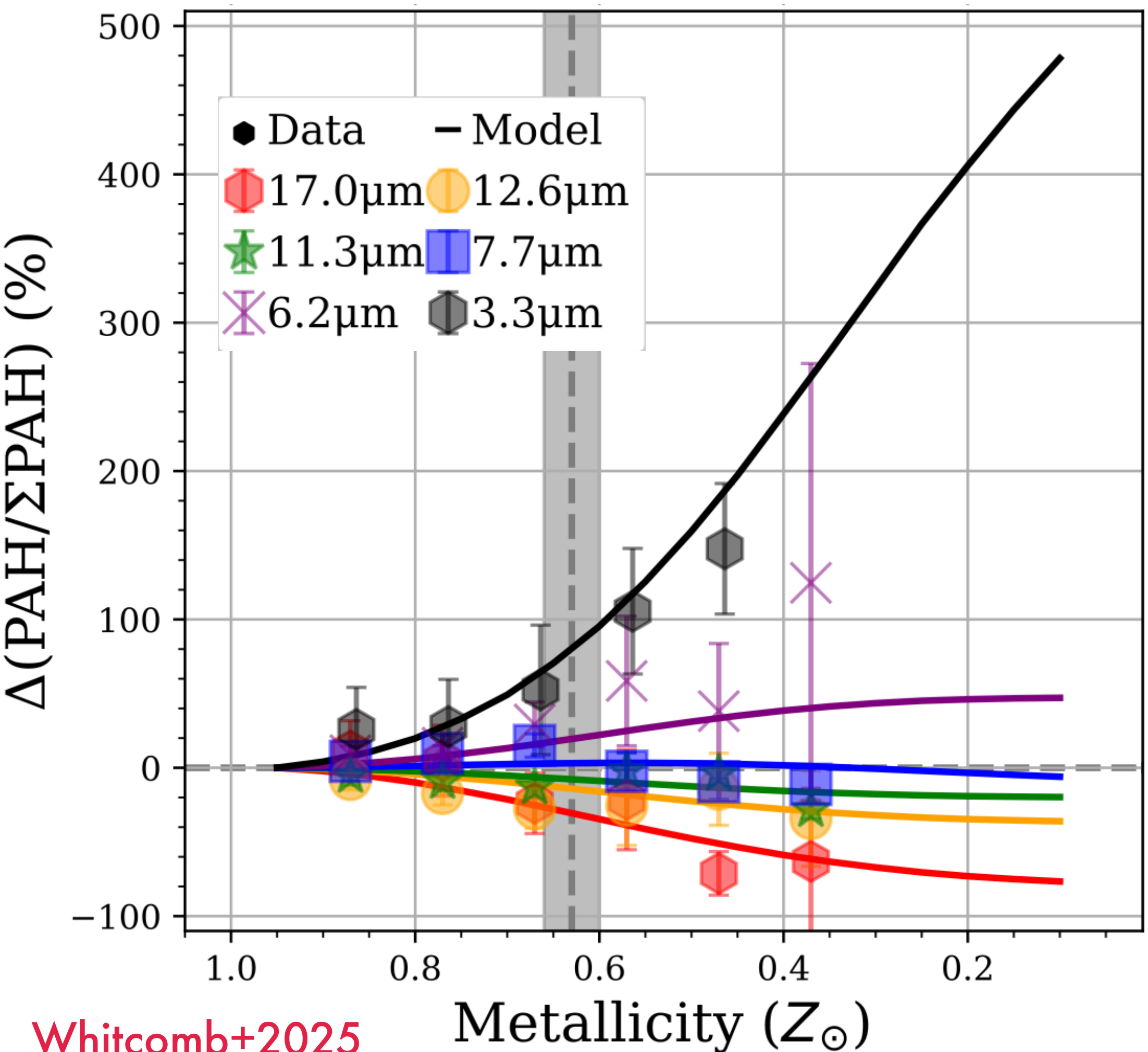
Whitcomb+2025

Short λ features increase in importance at low Z , suggests smaller PAHs. Destruction generally leads to larger PAHs $\rightarrow$ “inhibited growth” explanation.

Sandstrom+2012, Whitcomb+2024, 2025, Tarantino+2026 (in prep)

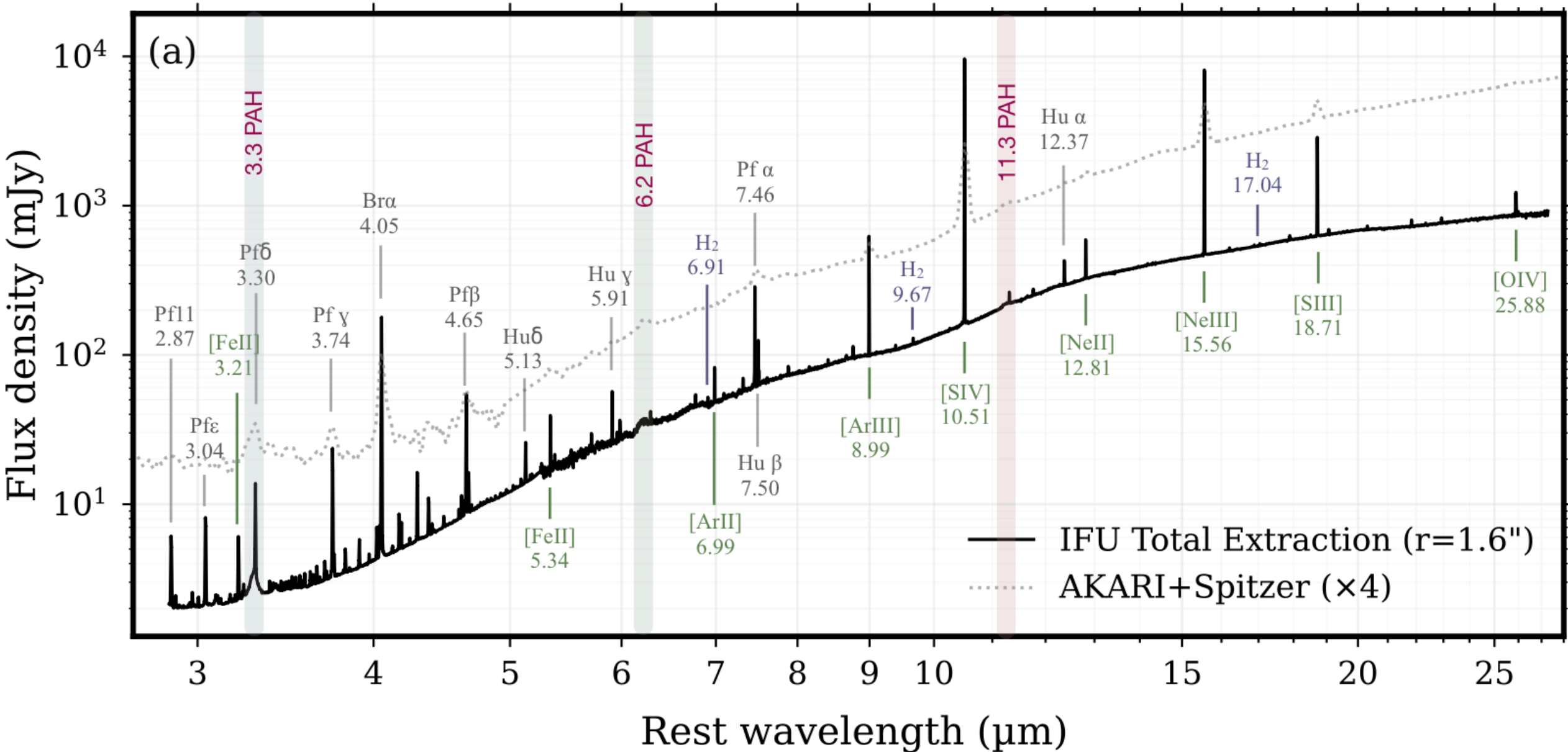
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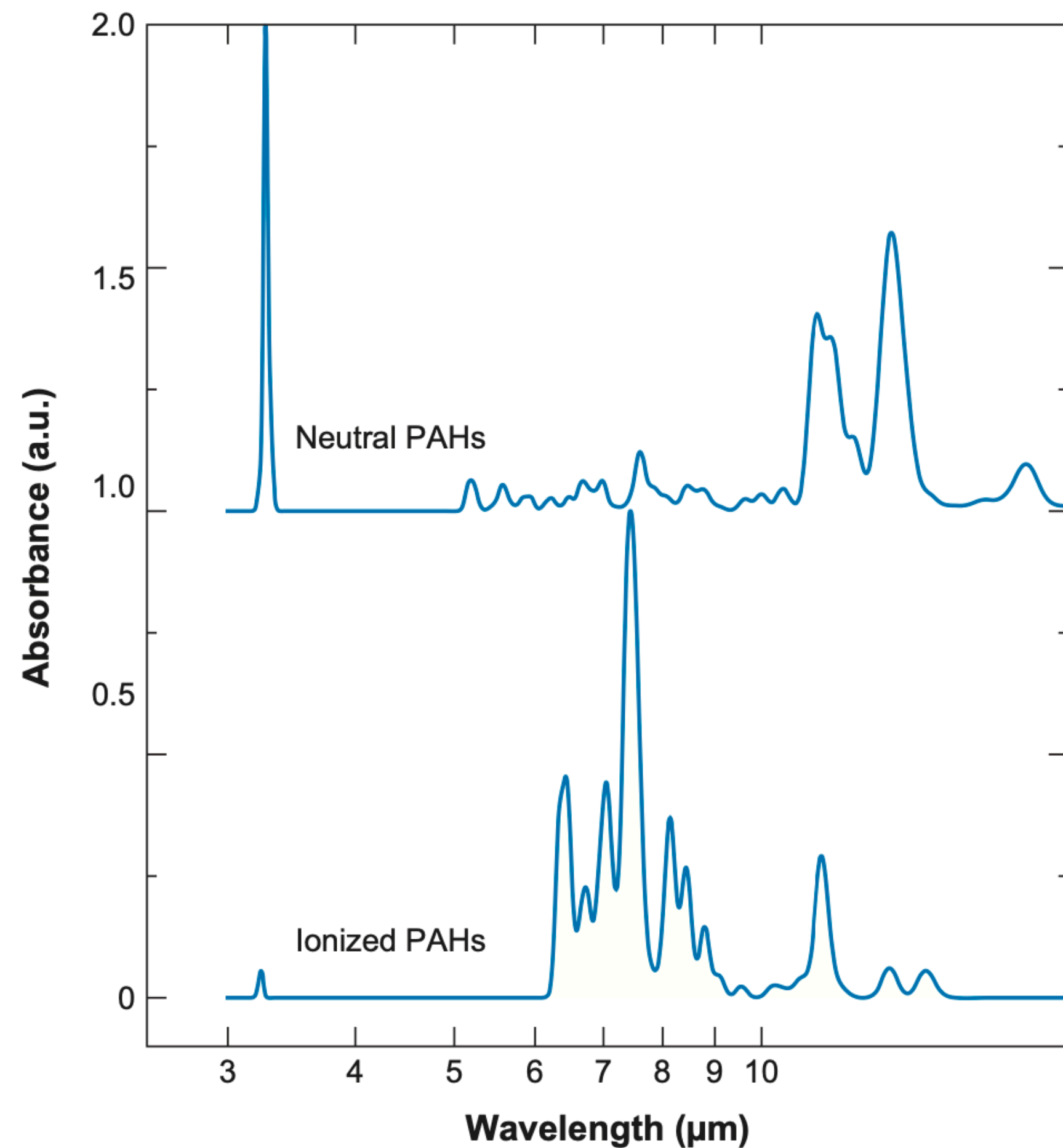
Sandstrom+2012, Whitcomb+2024, 2025, Tarantino+2026 (in prep)



particularly dramatic - Lai+2025 II Zw 40

Do properties of PAHs vary throughout the ISM?

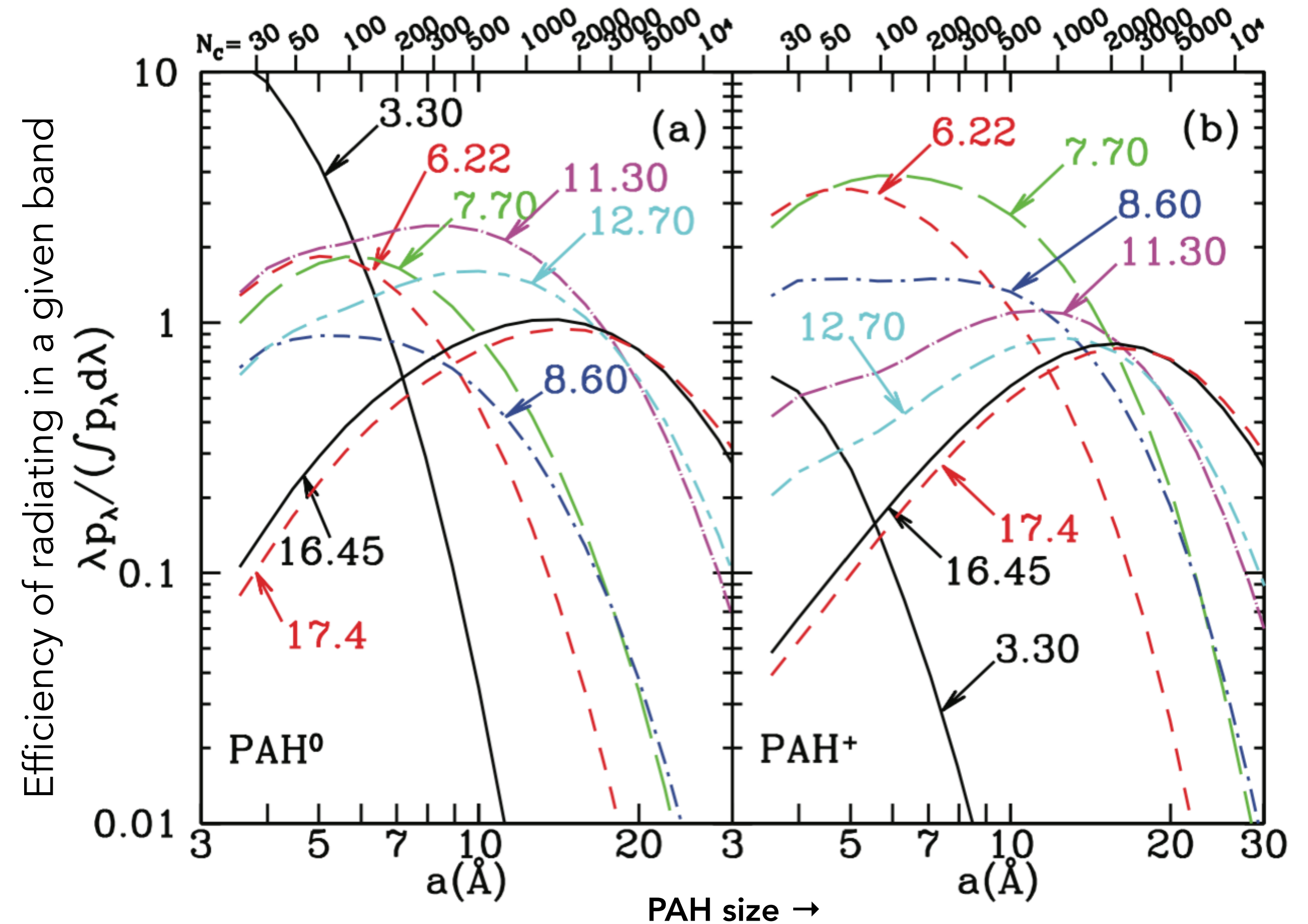
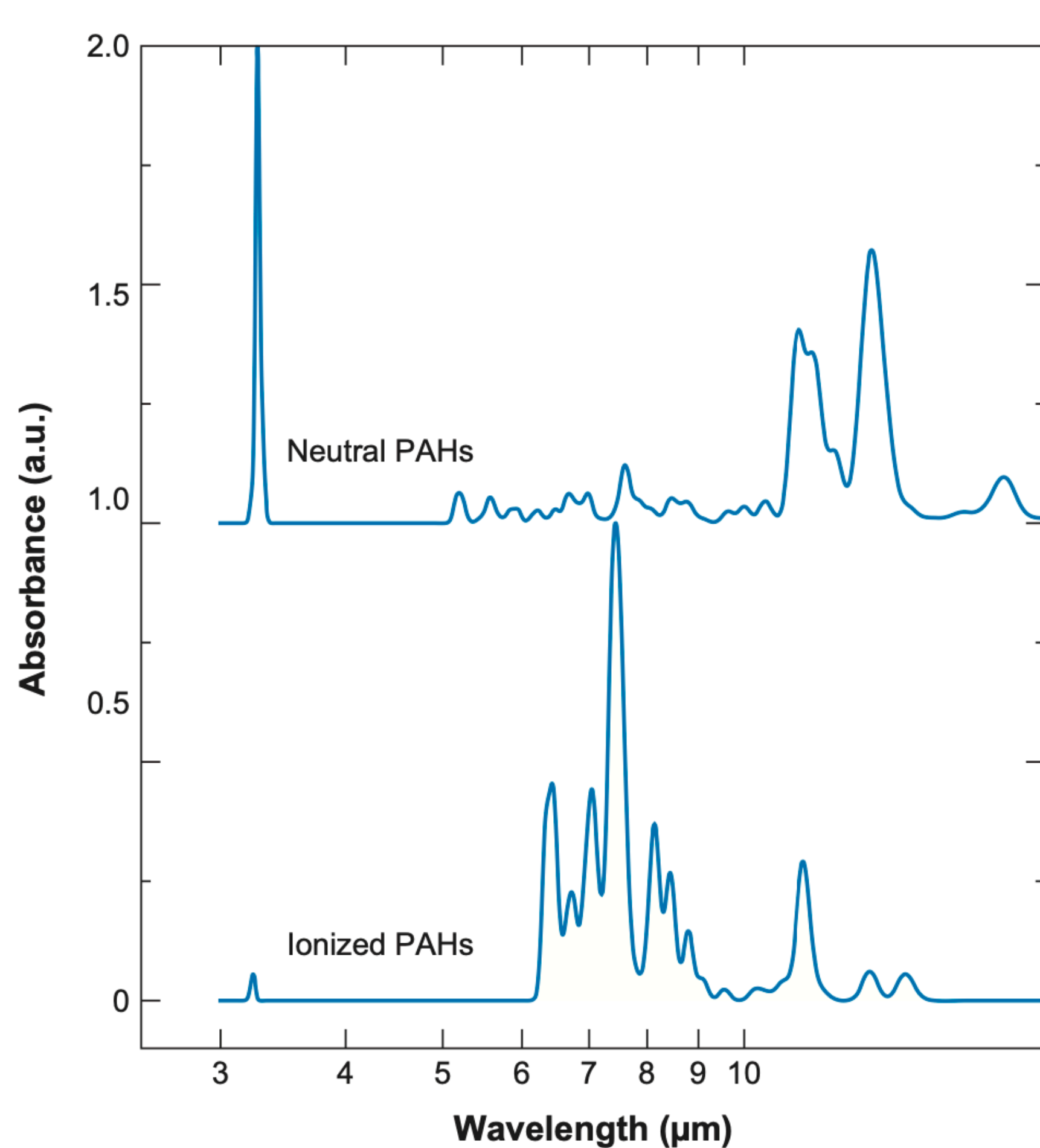
Ratios of major mid-IR features trace size, charge, *and* radiation field hardness.



Allamandola et al. 1999 (reproduced in Tielens 2008)

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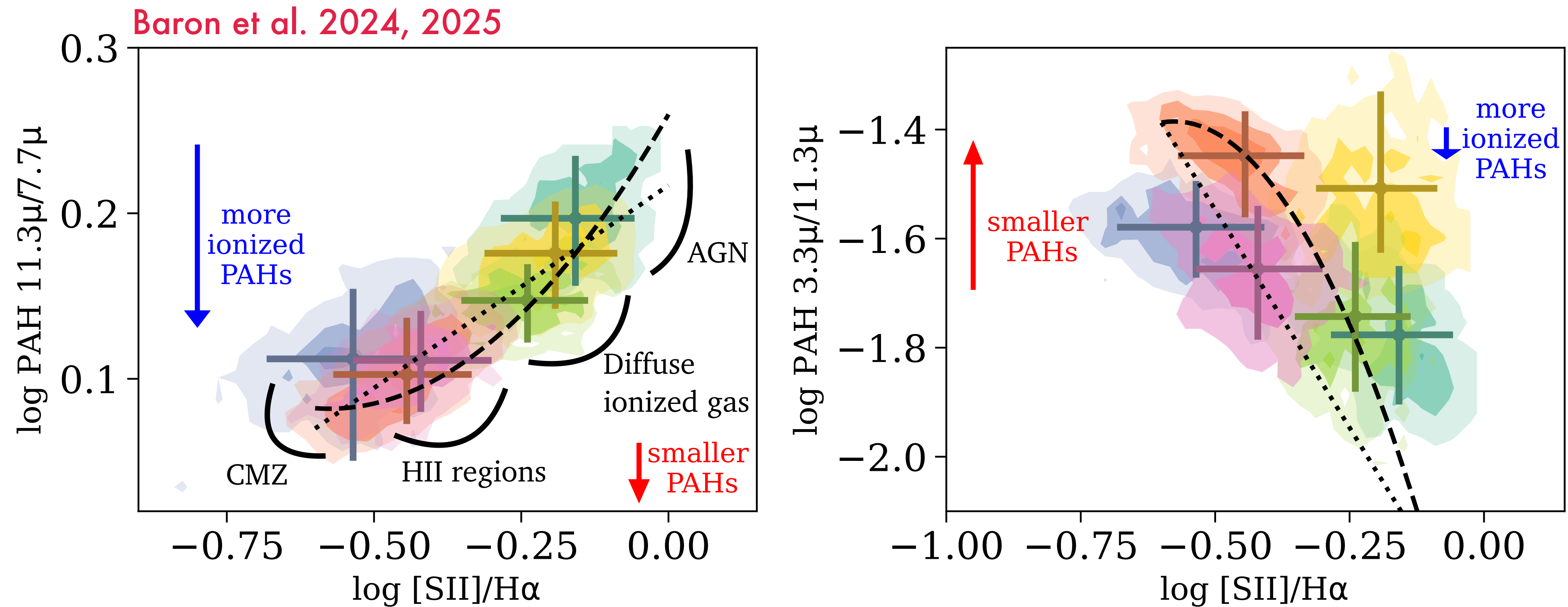
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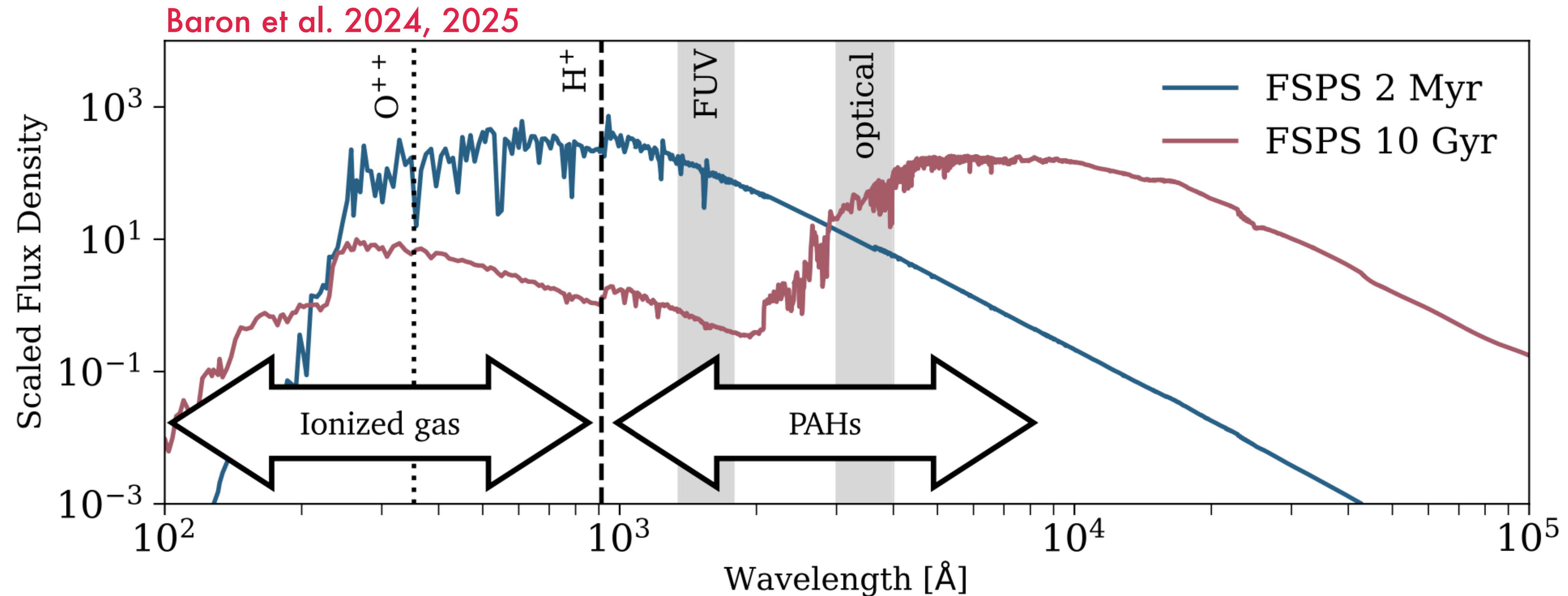
Draine & Li 2007, Draine et al. 2021

How important is the radiation field spectrum?



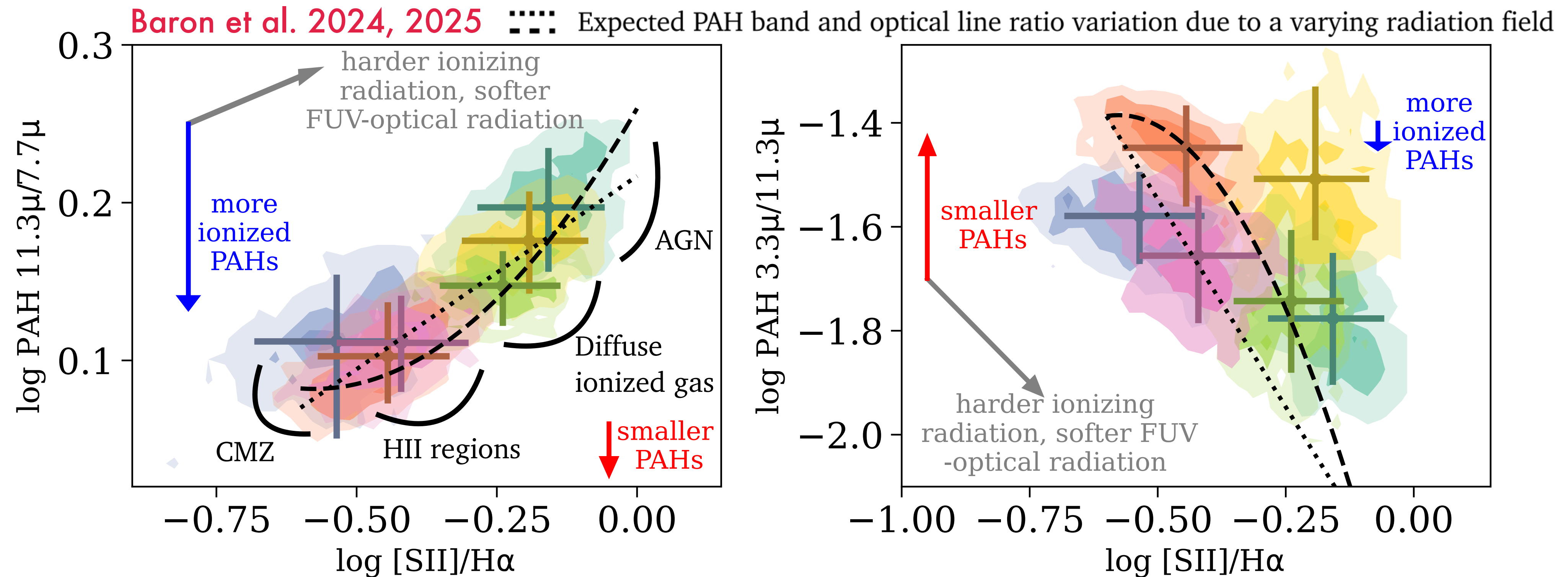
One of the strongest trends is between optical line ratios and PAH band ratios.

How important is the radiation field spectrum?



Ionized gas & PAHs see different parts of the radiation field.

How important is the radiation field spectrum?



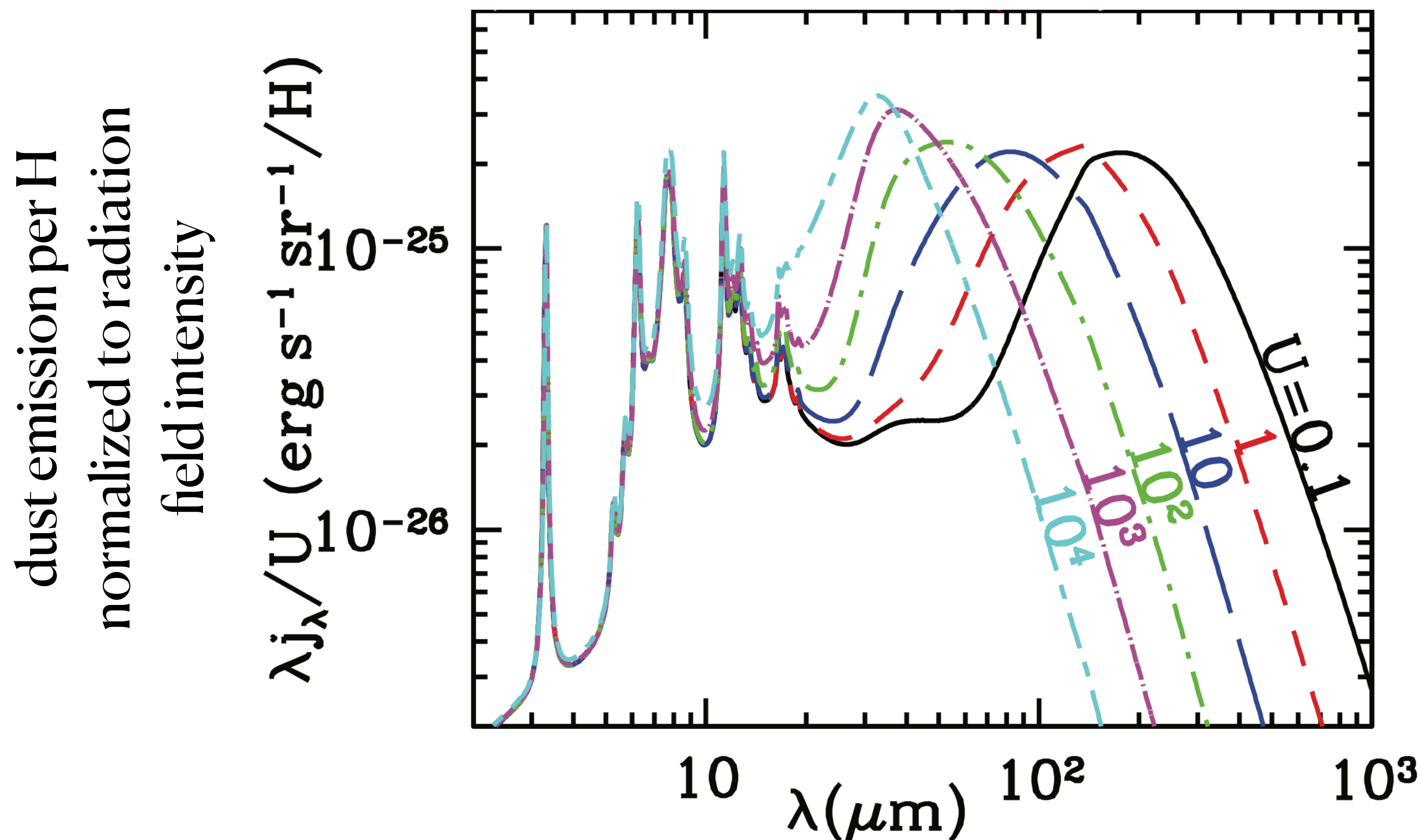
Observed trends are consistent with ~constant size & charge
and varying radiation field spectrum!

See also poster by Deb Pathak!

Can we use dust emission as a tracer of star formation and/or gas?

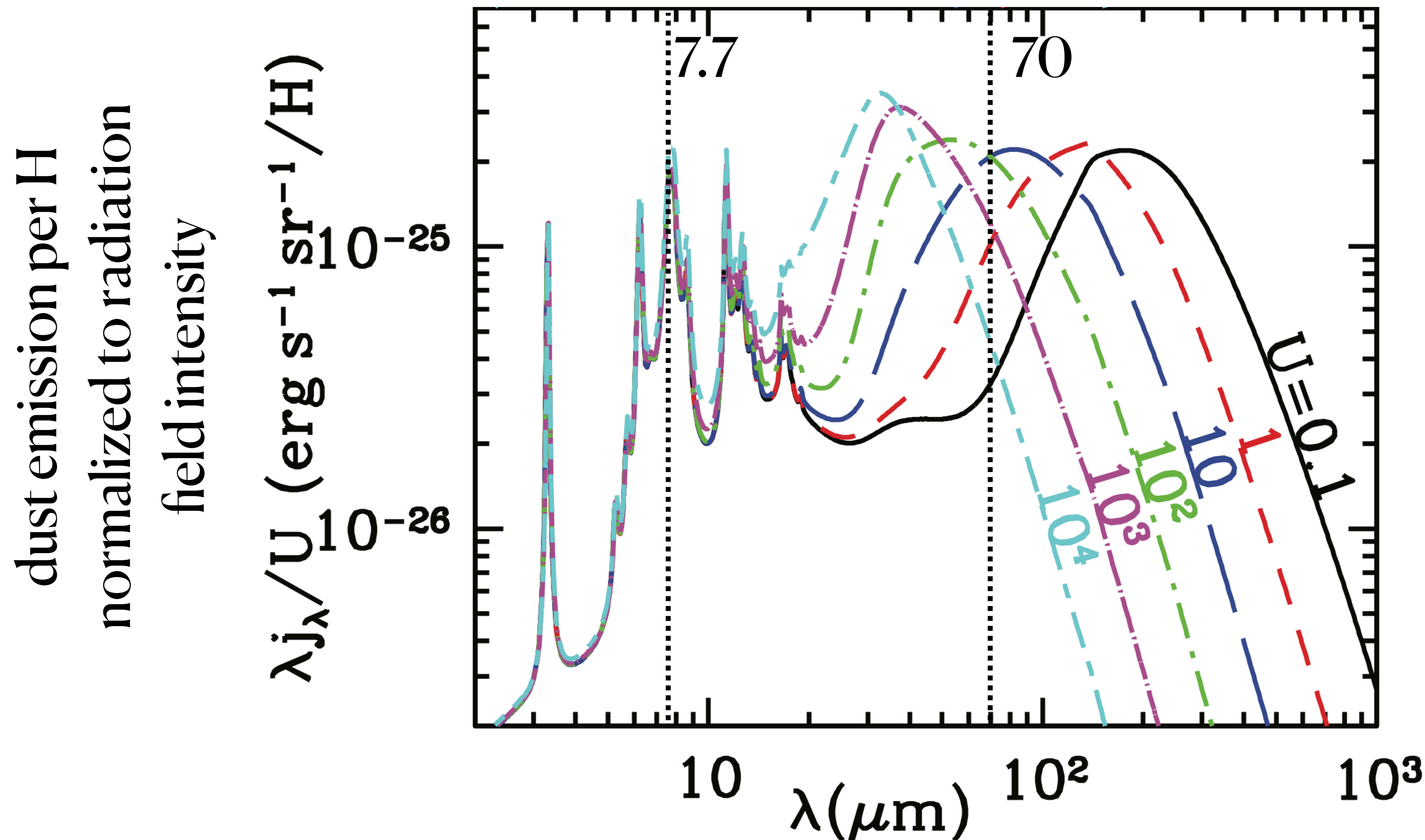
Yes, but it is always a bit of both!

1) Dust is well-mixed with gas to first order.



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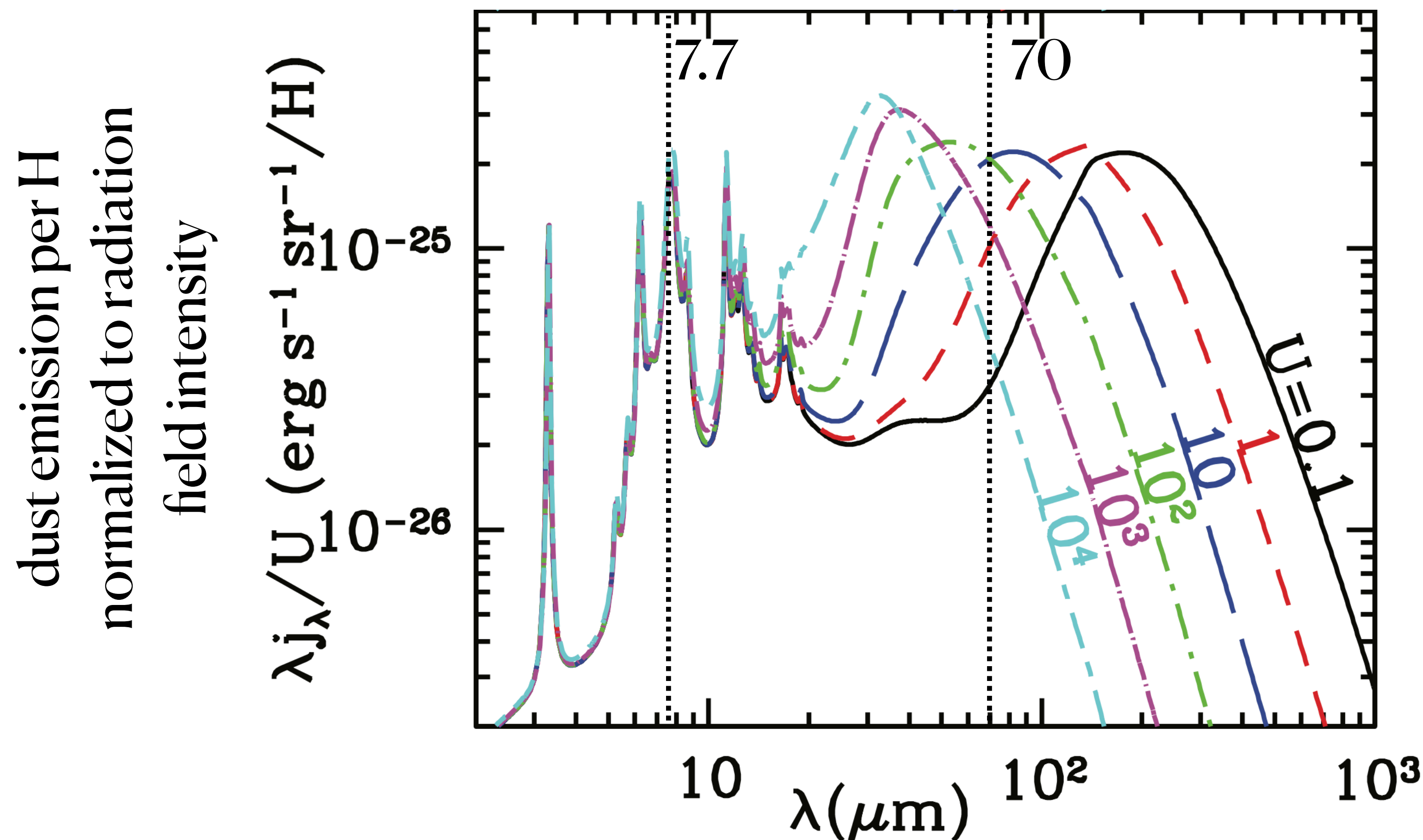
Draine & Li 2007

1) Dust is well-mixed with gas
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2) Depending on λ , emission
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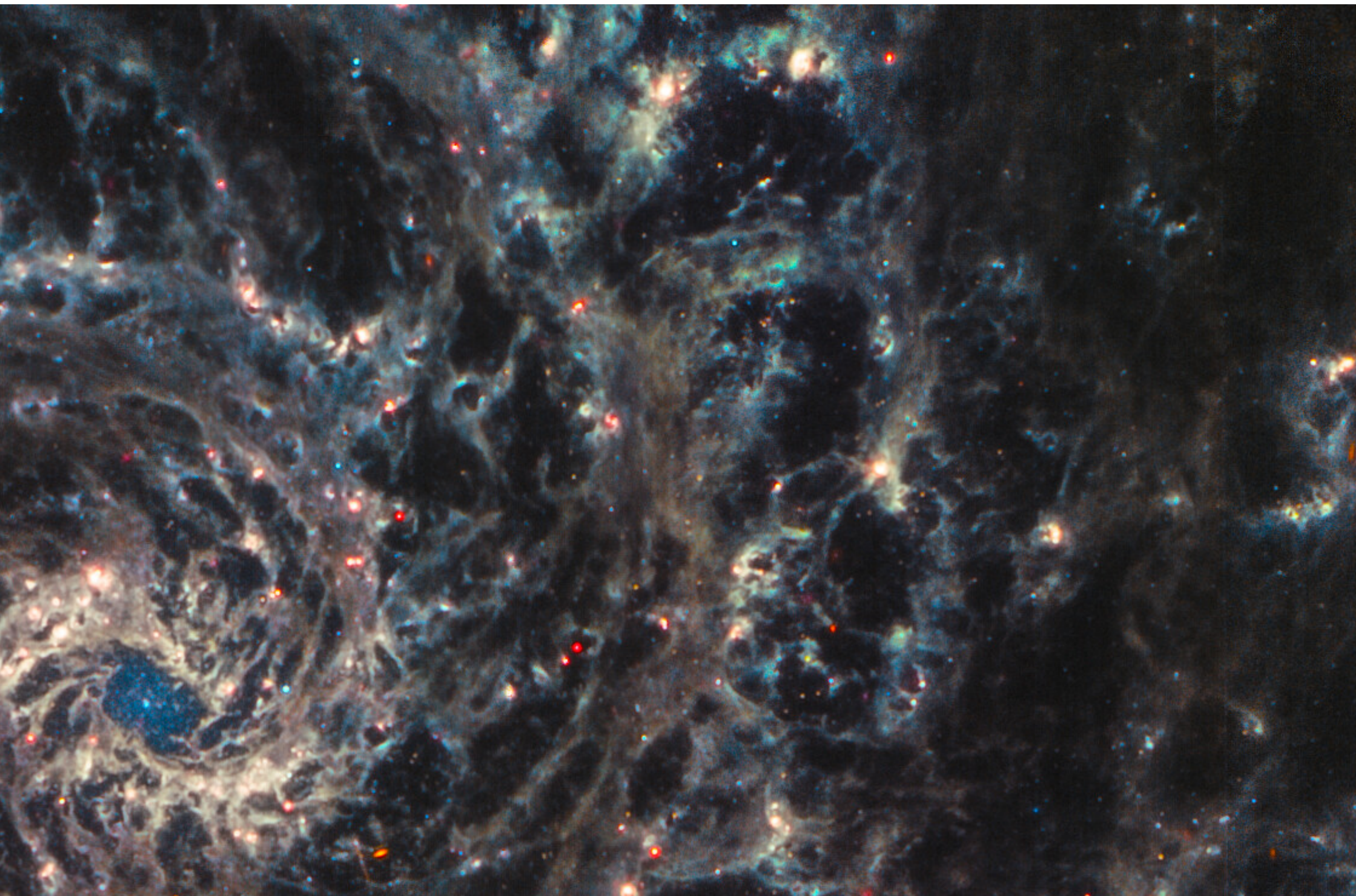
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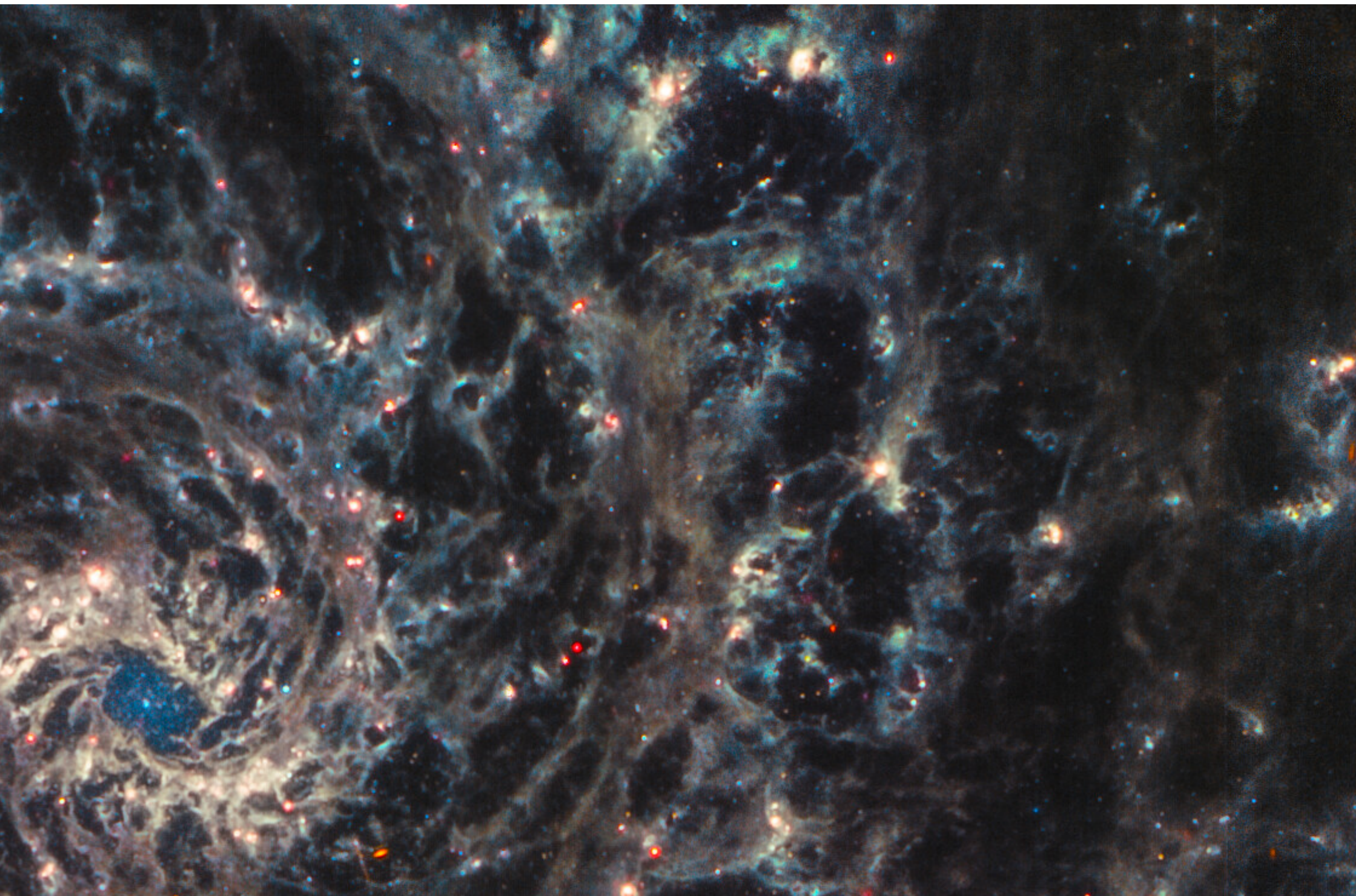
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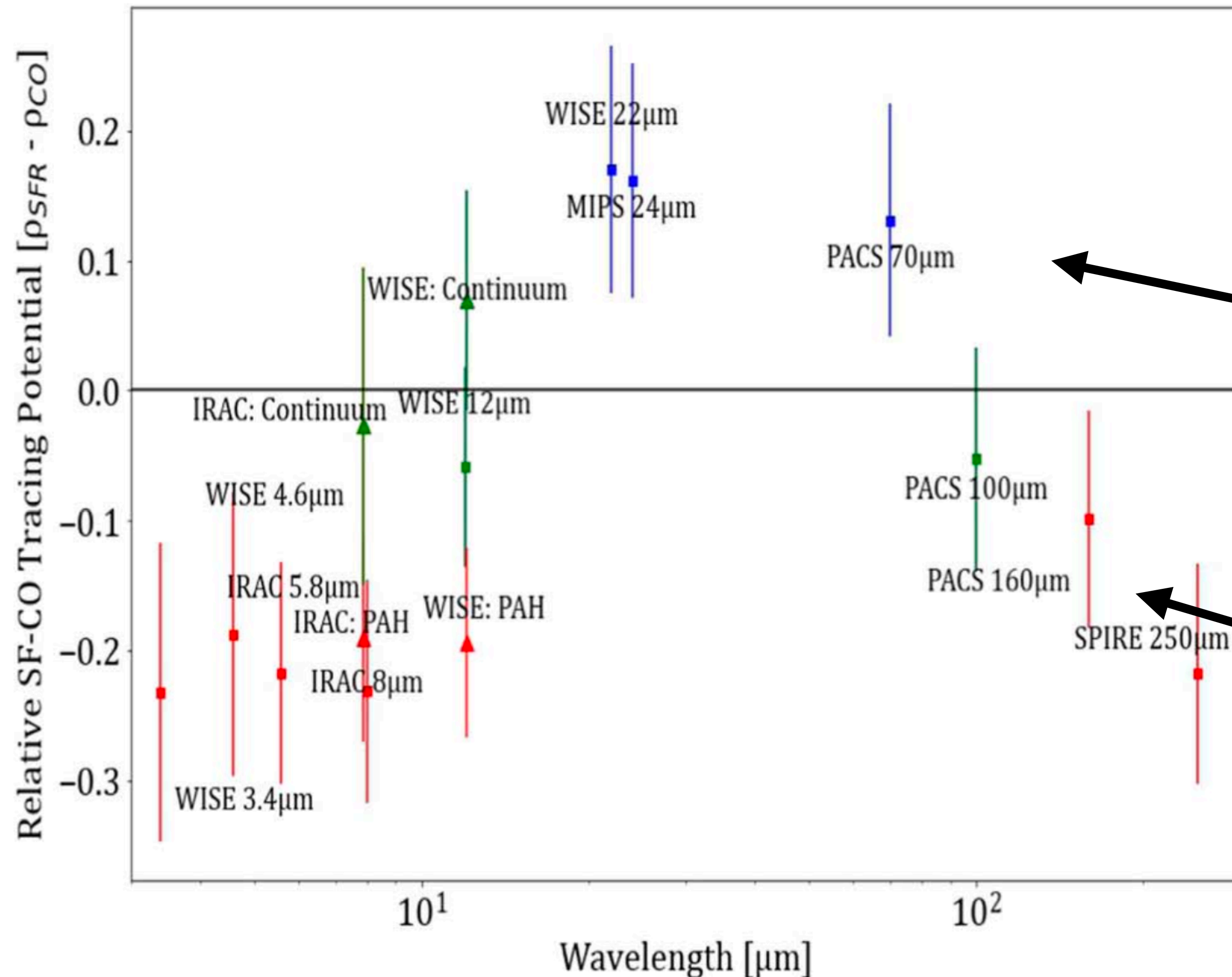
3) U increases rapidly near massive star forming regions.

4) U includes contributions from older stellar pops.

Can we use dust emission as a tracer of star formation and/or gas?

Yes, but it is always a bit of both!

Whitcomb+2023



Correlation of $\sim$ kpc SFR and CO with mid- to far-IR dust emission in SINGS.

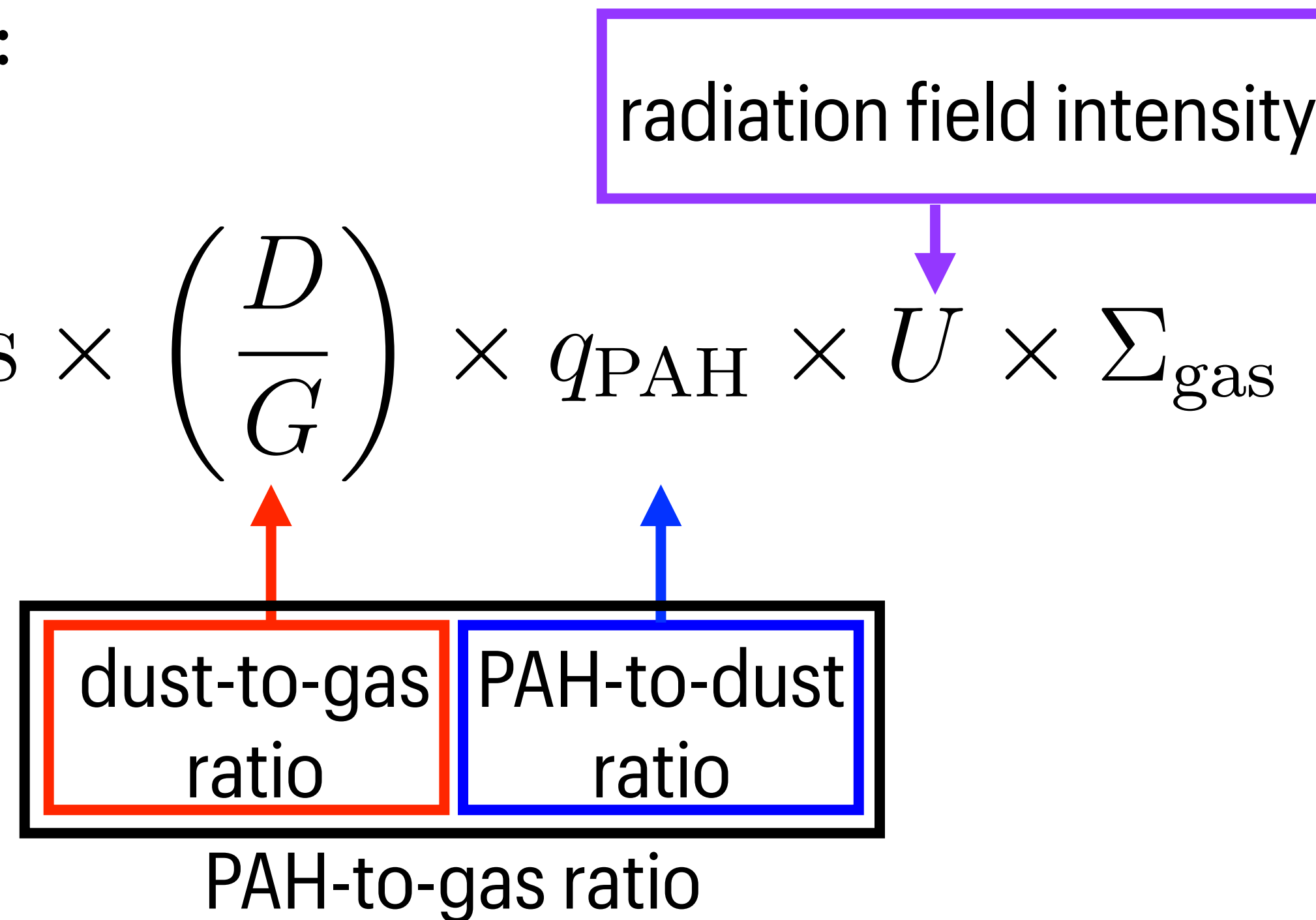
- Contribution from hot dust in equilibrium with high U & non-linear U dependence leads to better correlation with SFR.

- Stochastic emission and cold equilibrium dust emission better correlate with gas.

Can we use dust emission as a tracer of star formation and/or gas?

For stochastically heated dust emission:

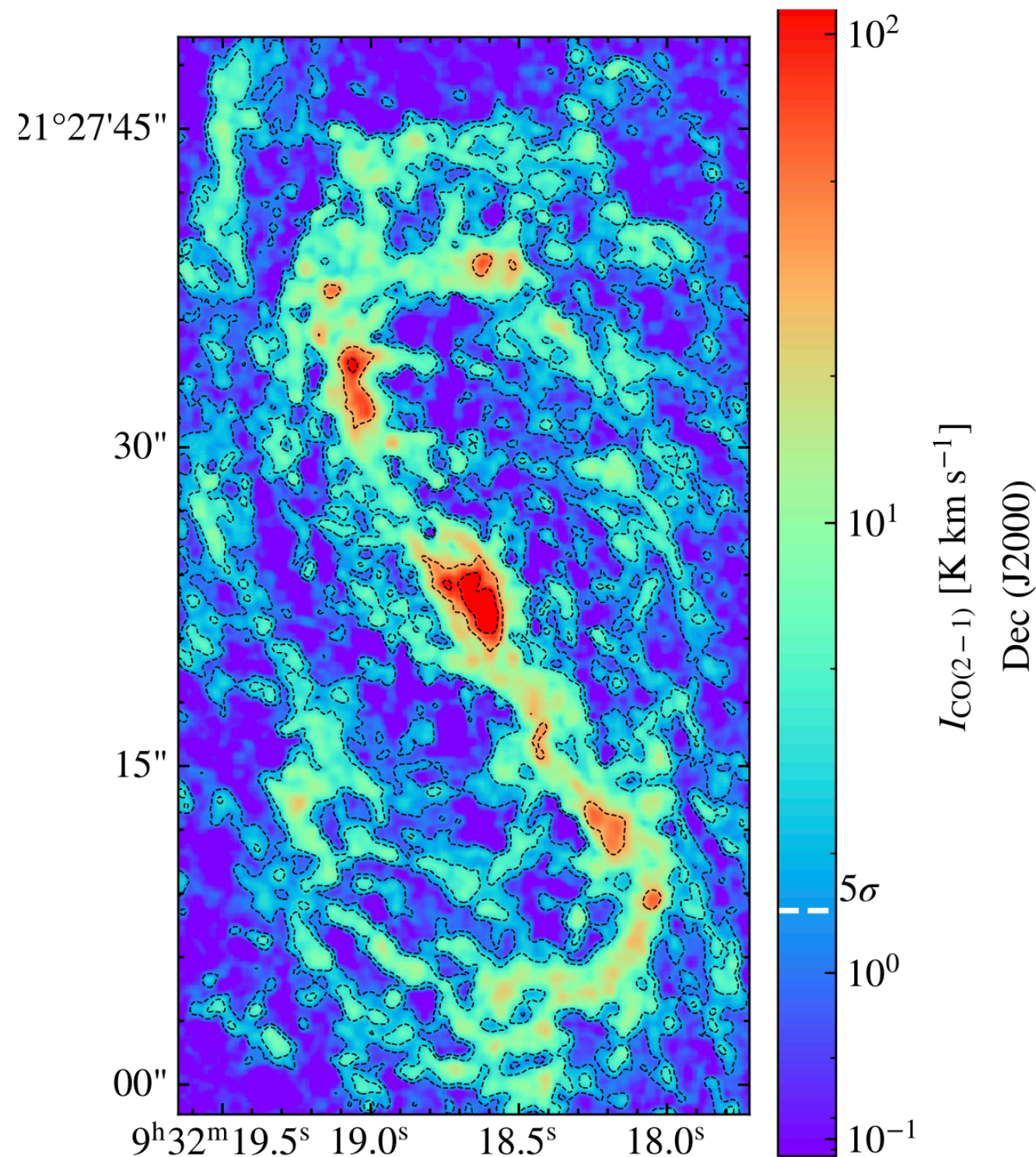
$$I_{\text{mid-IR}} \approx \text{constants} \times \left(\frac{D}{G} \right) \times q_{\text{PAH}} \times U \times \Sigma_{\text{gas}}$$



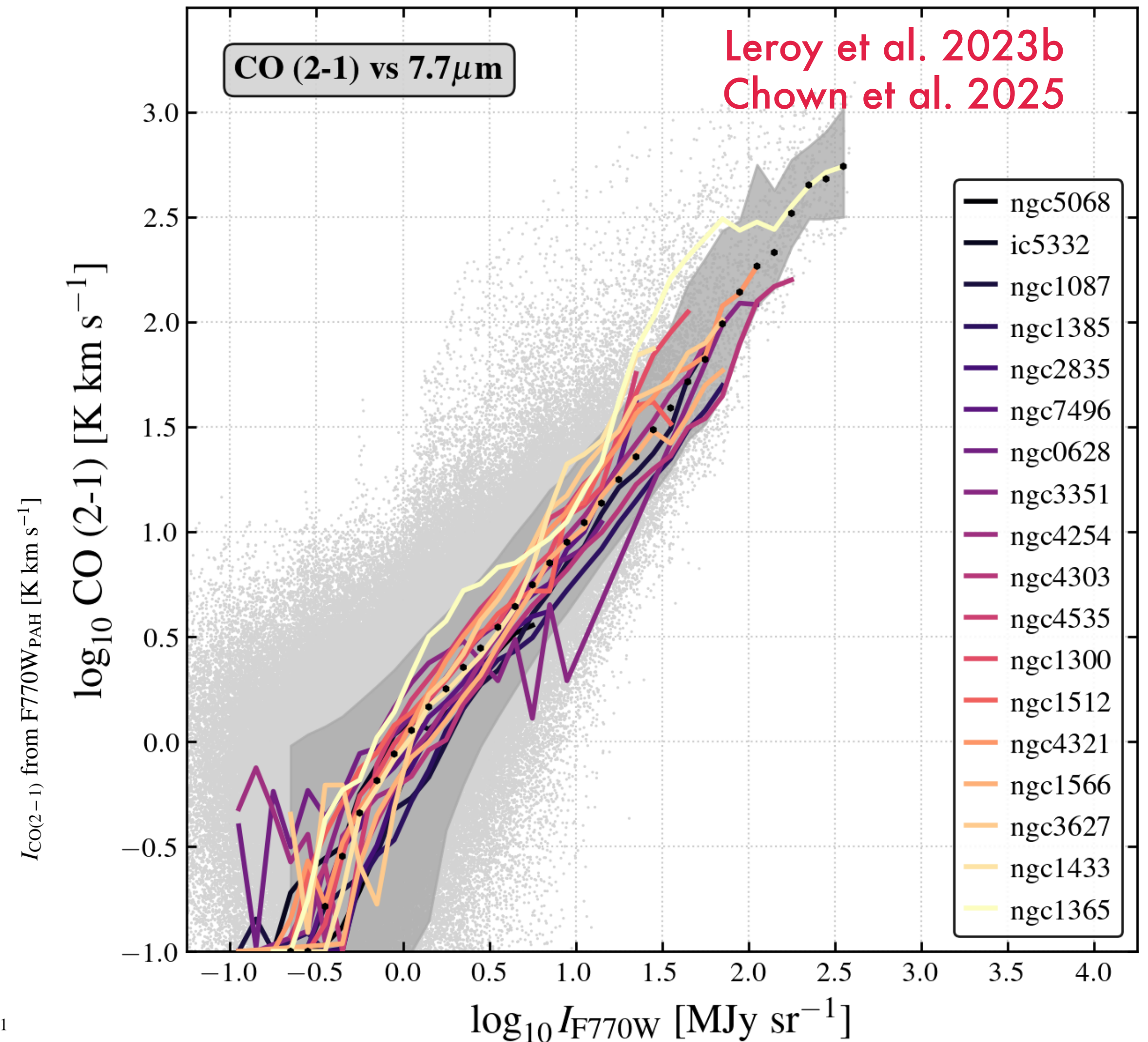
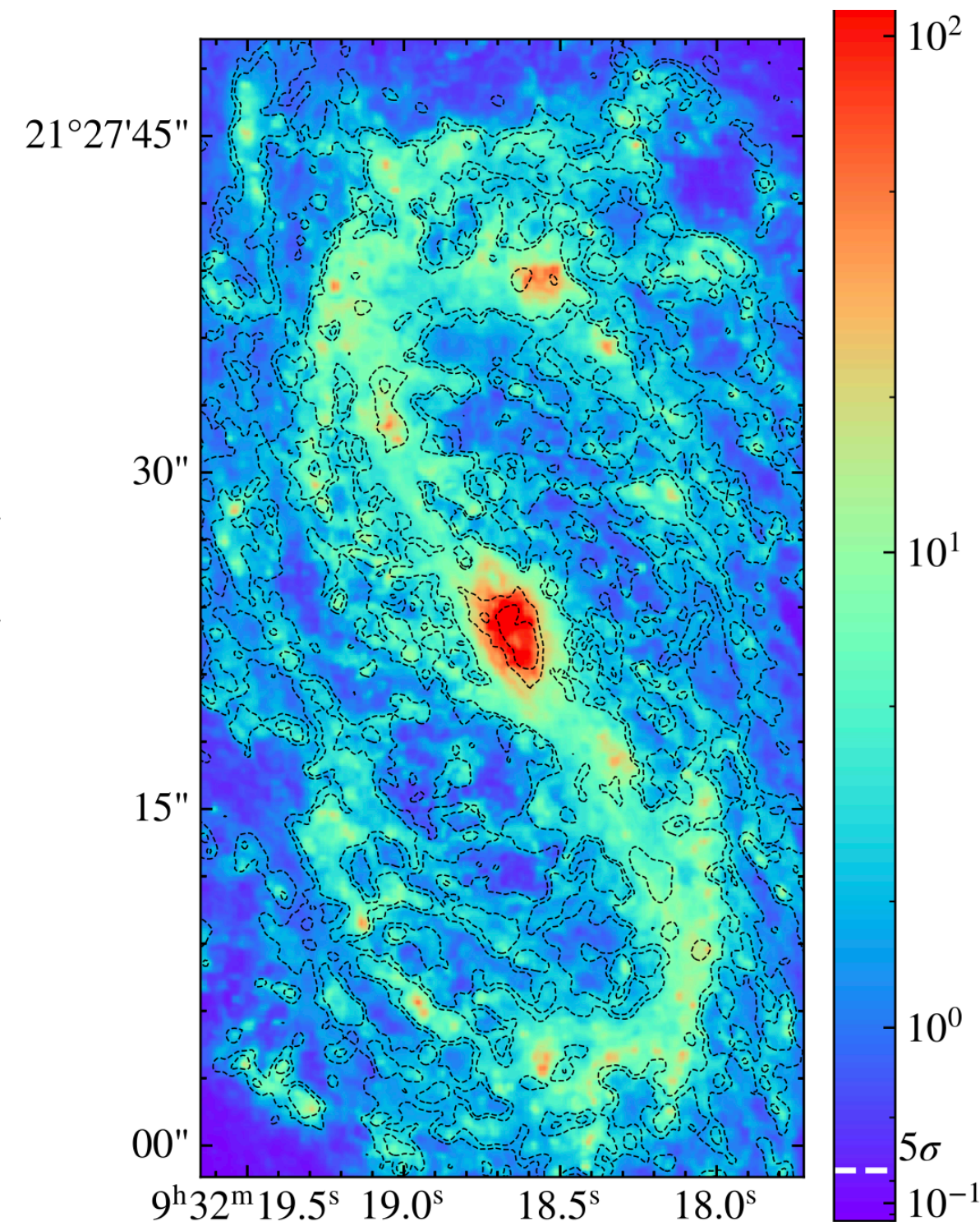
Can we use dust emission as a tracer of star formation and/or gas?

In H_2 dominated regions of galaxies
($\Sigma_{\text{gas}} \sim \Sigma_{\text{H}_2}$), strong, **~linear** correlation
of PAH emission with CO.

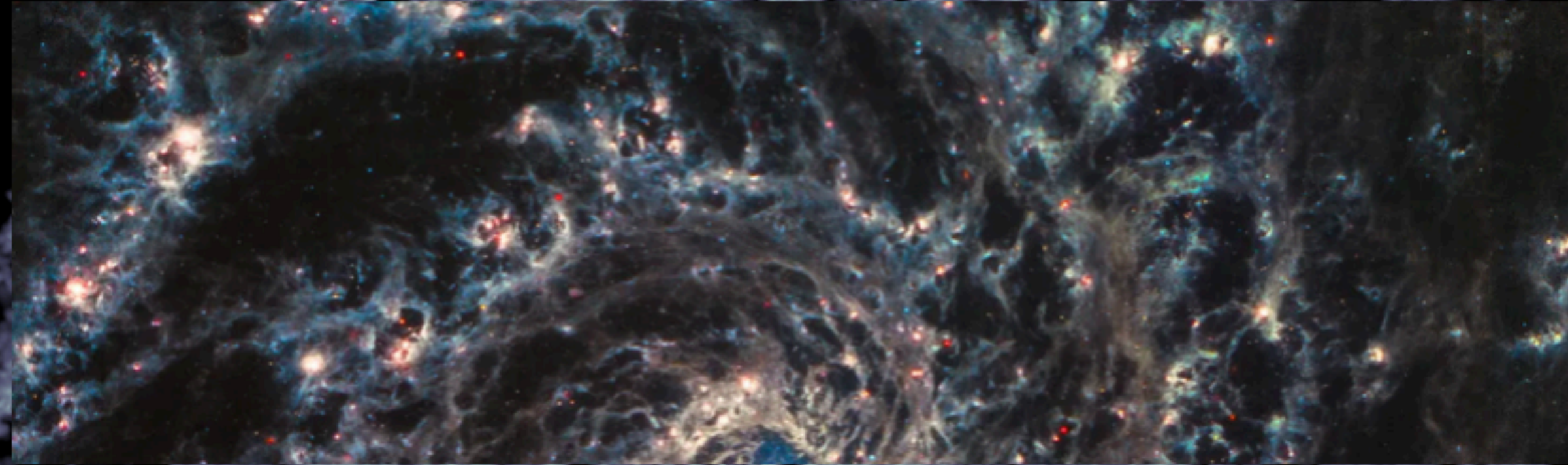
From CO



From PAHs



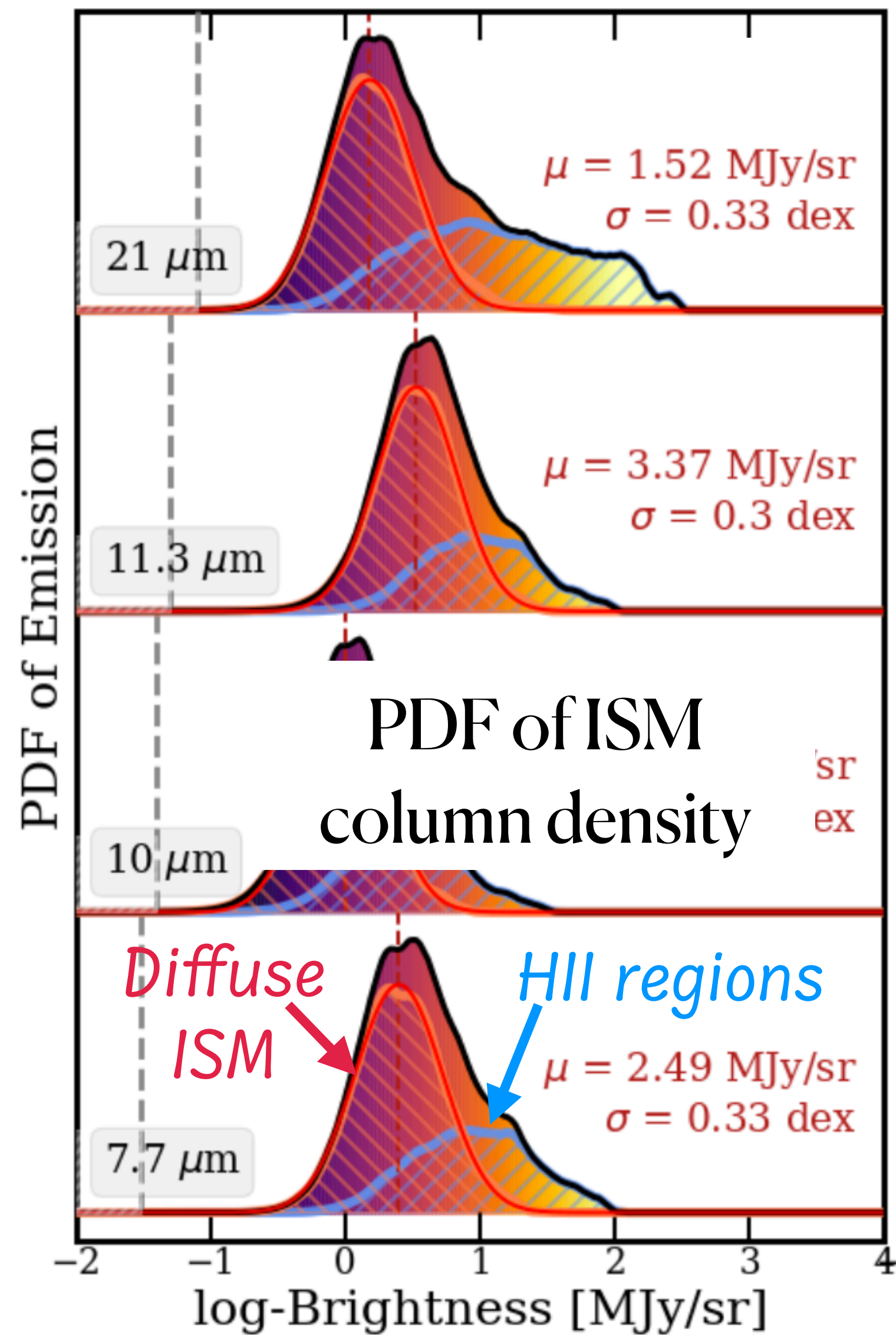
PAH emission with JWST is
the highest available resolution
& sensitivity ISM tracer.



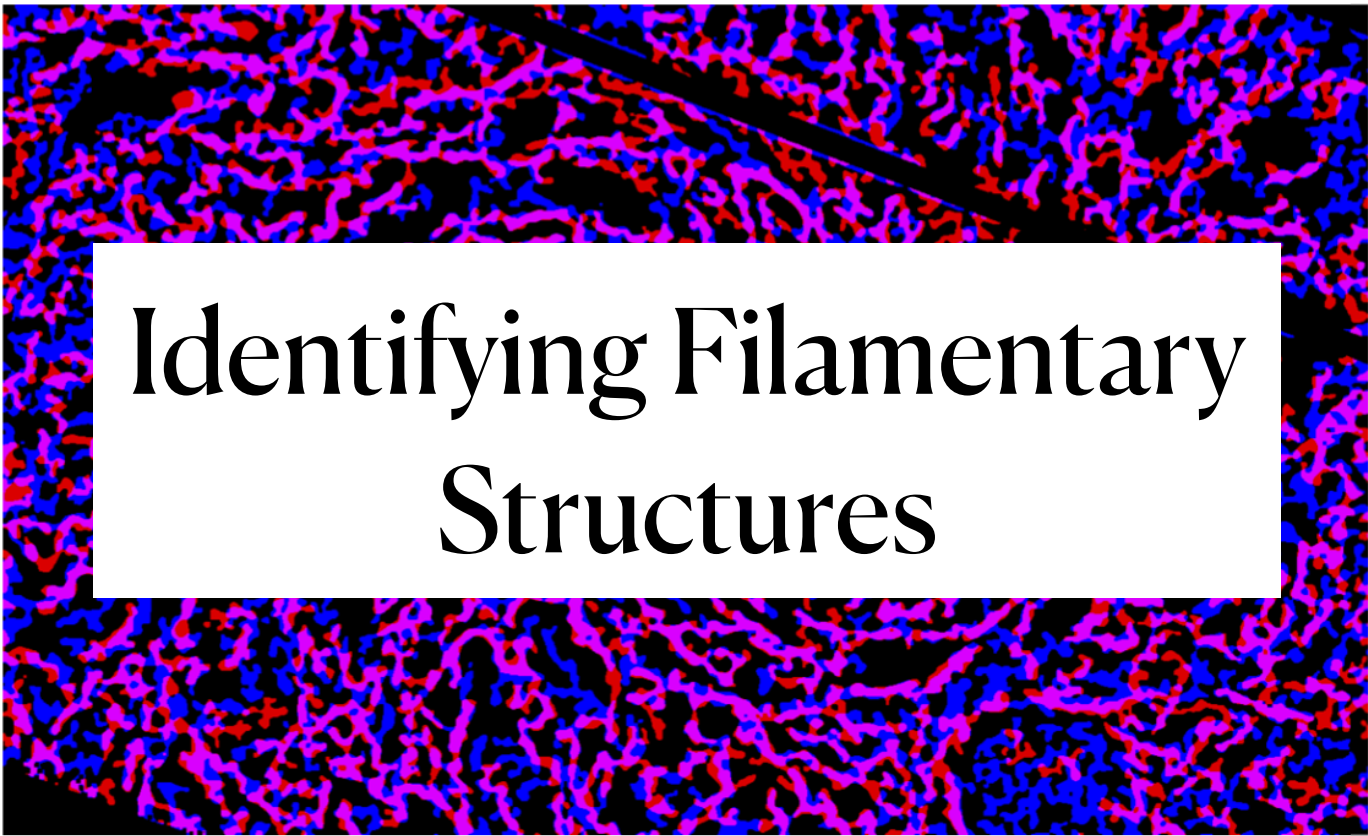
May be very useful as a ~total gas
surface density tracer for
comparison to simulations.

Can we use dust emission as a tracer of star formation and/or gas?

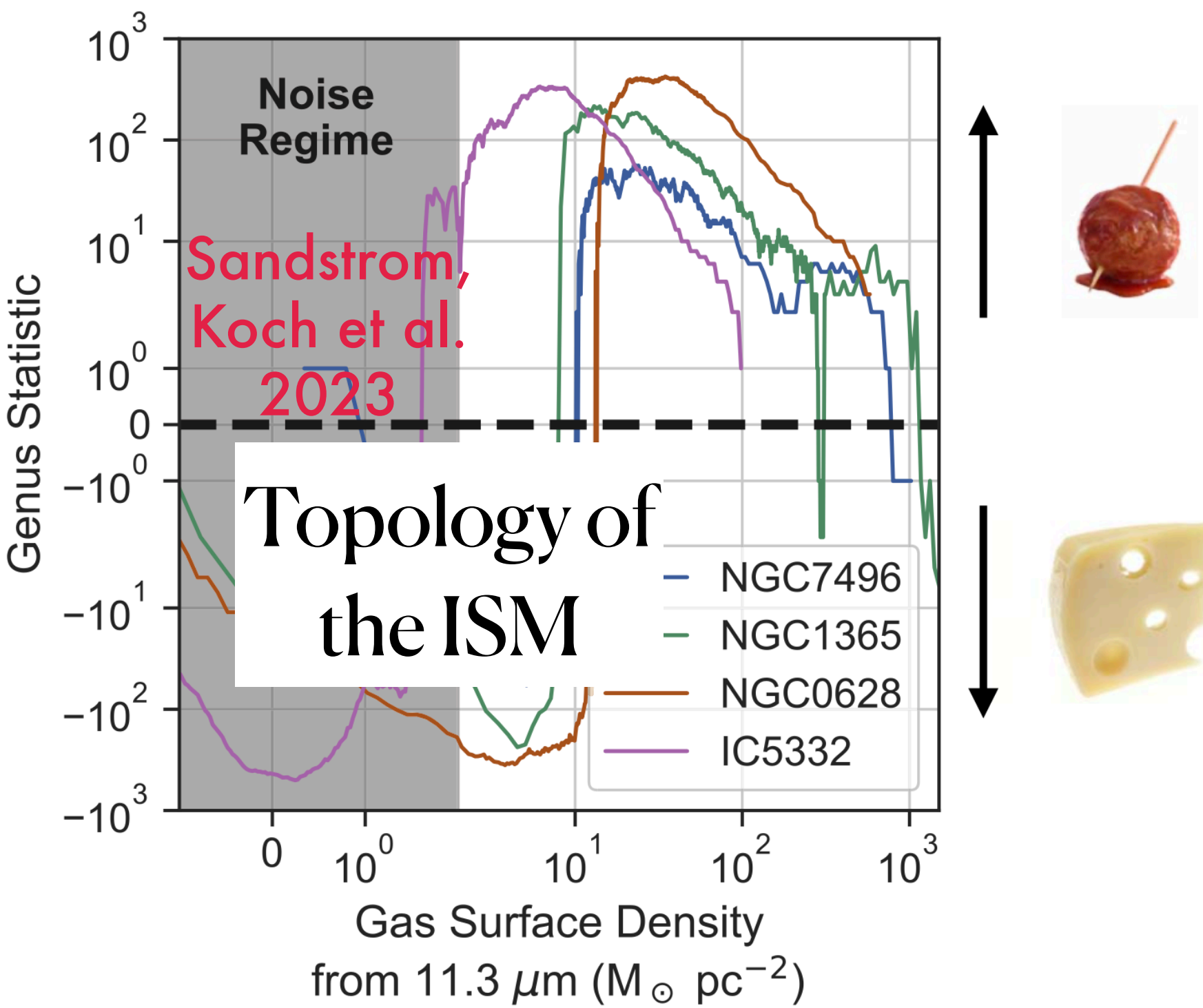
Pathak et al. 2024



Many exciting possibilities for using PAH emission as a gas tracer.

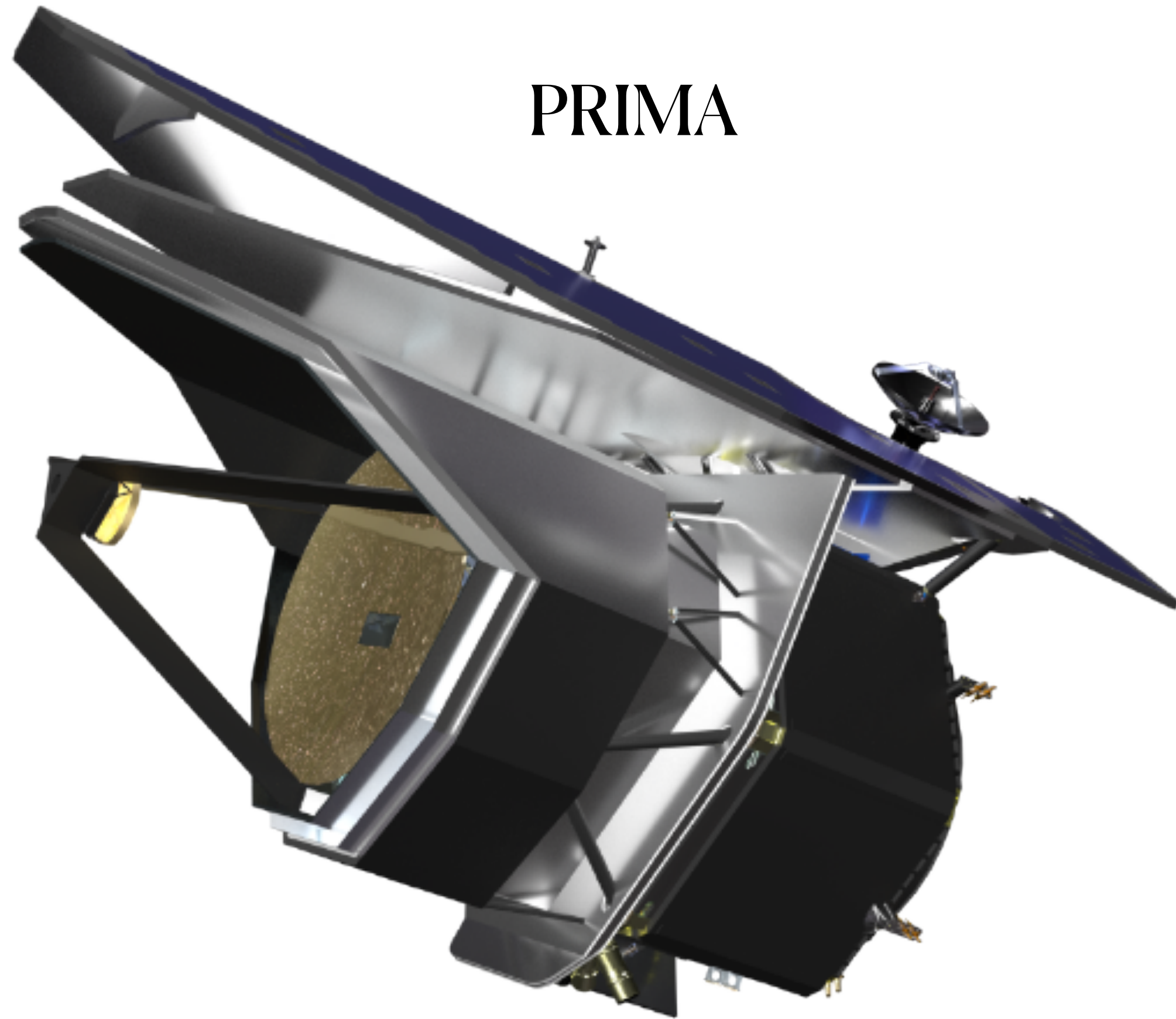


Thilker+2023, Meidt+2023



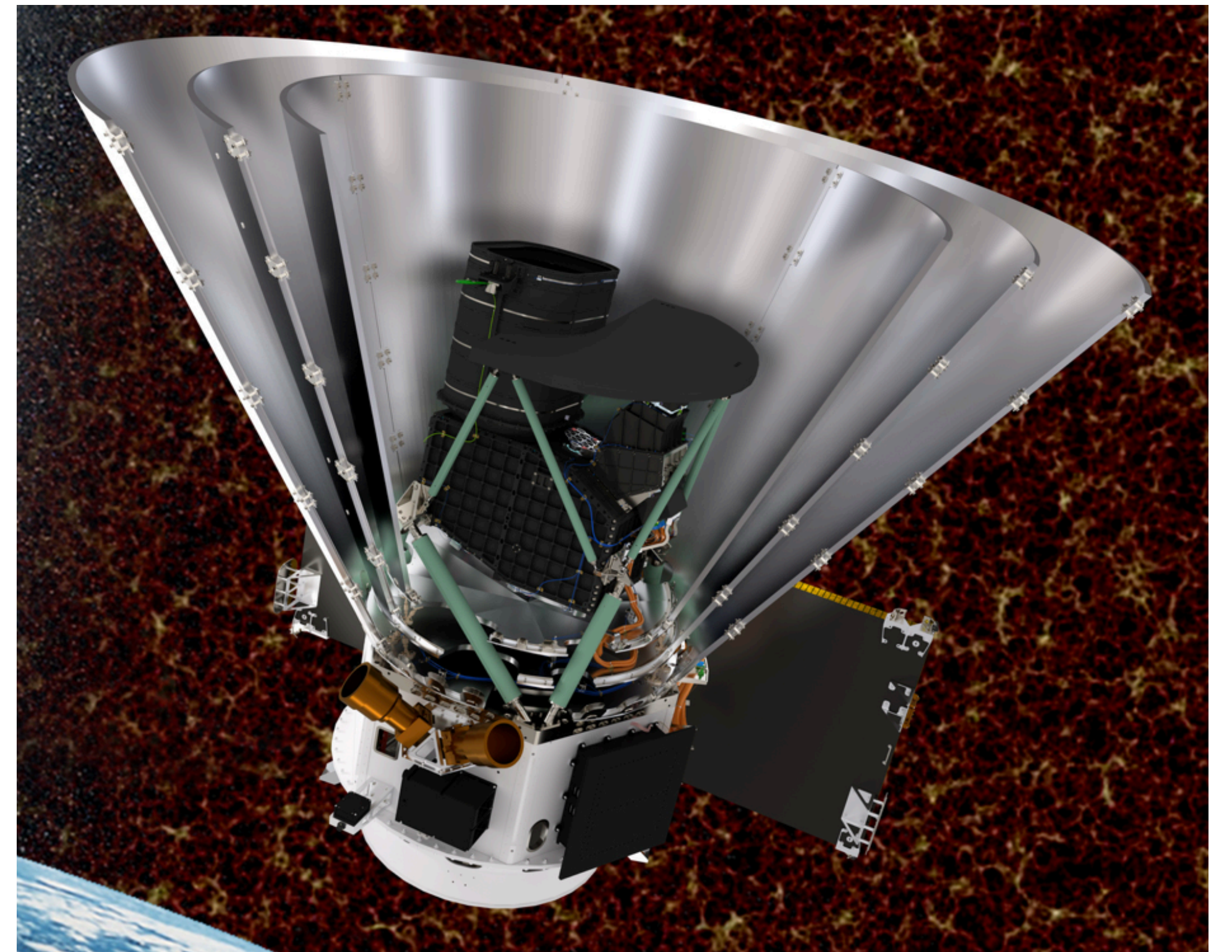
What comes next?

PRIMA



Critical to have access to far-IR.

SPHEREx



6" resolution near-IR spectral map of every nearby galaxy!



What comes next?

We are just scratching the surface of what we will learn from JWST data.
Need more spectroscopy!

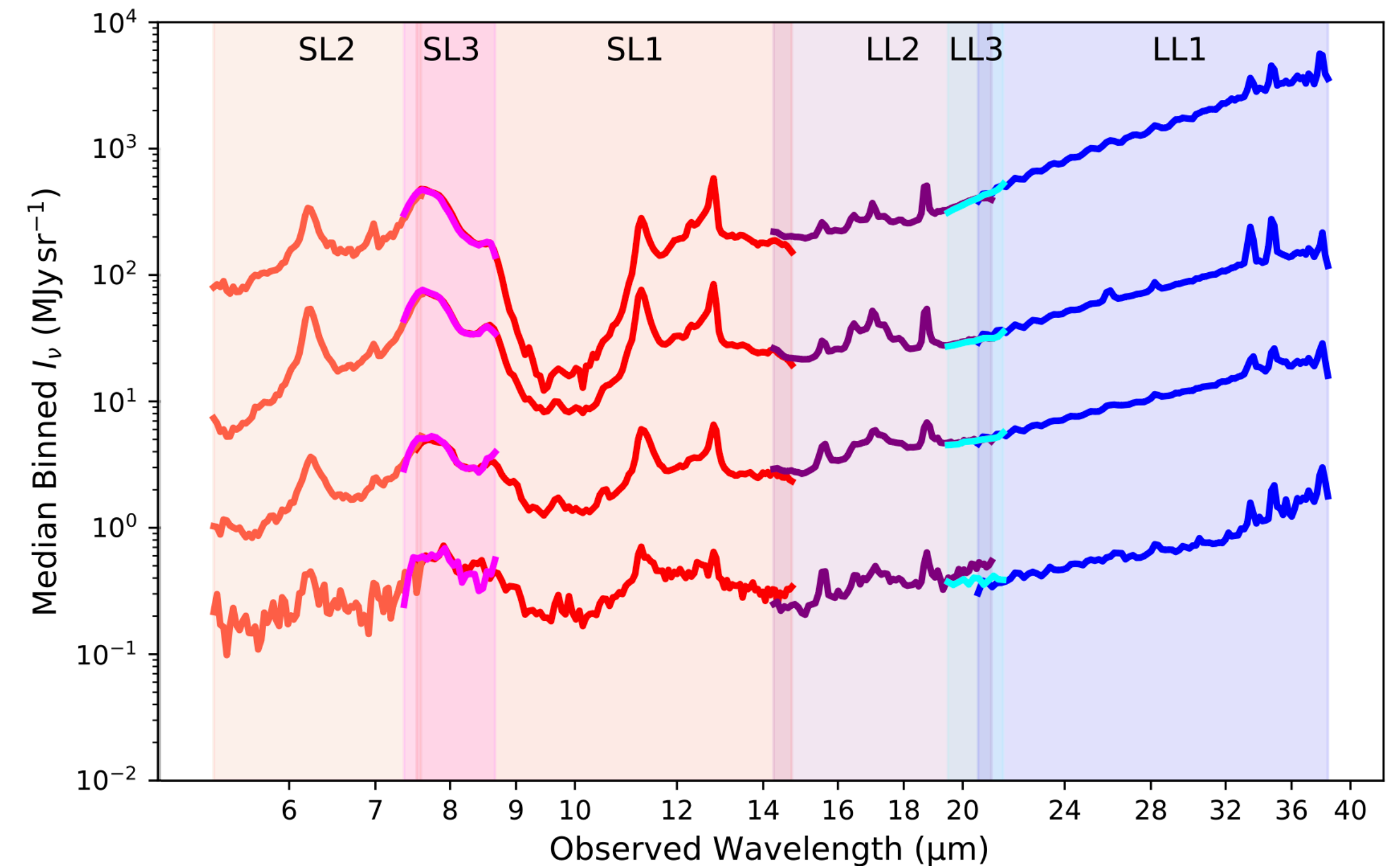
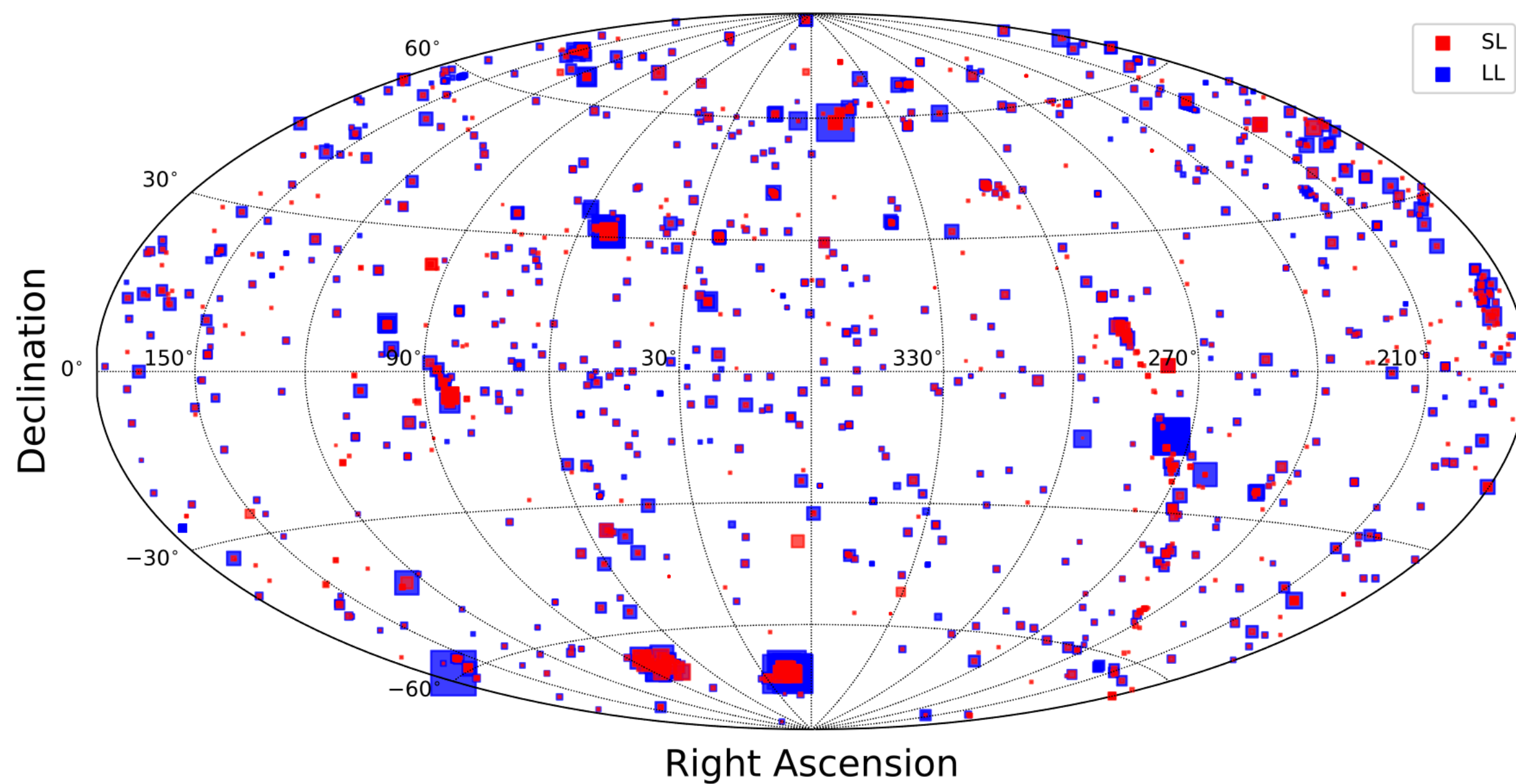
Conclusions

- Dust-to-metals links galaxy scaling relationships to dust. Need to understand the discrepancies between emission and absorption based measurements.
- PAHs are destroyed in ionized gas, and this can impact global PAH fractions in high SFR conditions.
- PAH fraction drops with metallicity - perhaps due to a combination of filling factor and more fragile, easily destroyed PAHs.
- The degree to which PAH band ratios reflect size/charge or radiation field variations is still tbd.
- Dust emission traces both gas and star formation depending on the circumstances.

Spitzer IRS Mapping Legacy Archive

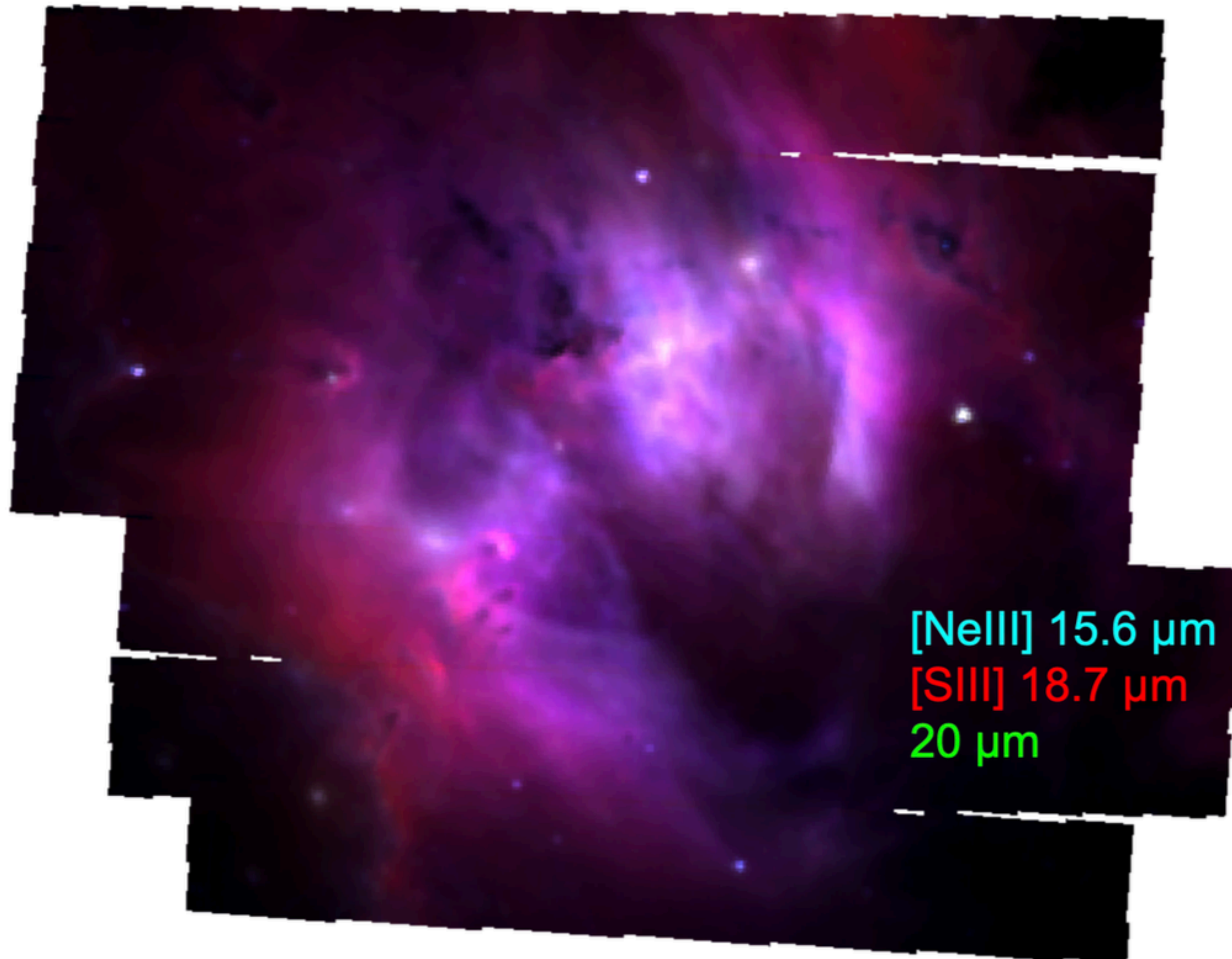
Donnelly et al. 2025 (in prep) - delivery to IRSA later this year

Delivering of all IRS low resolution
spectral mapping cubes.

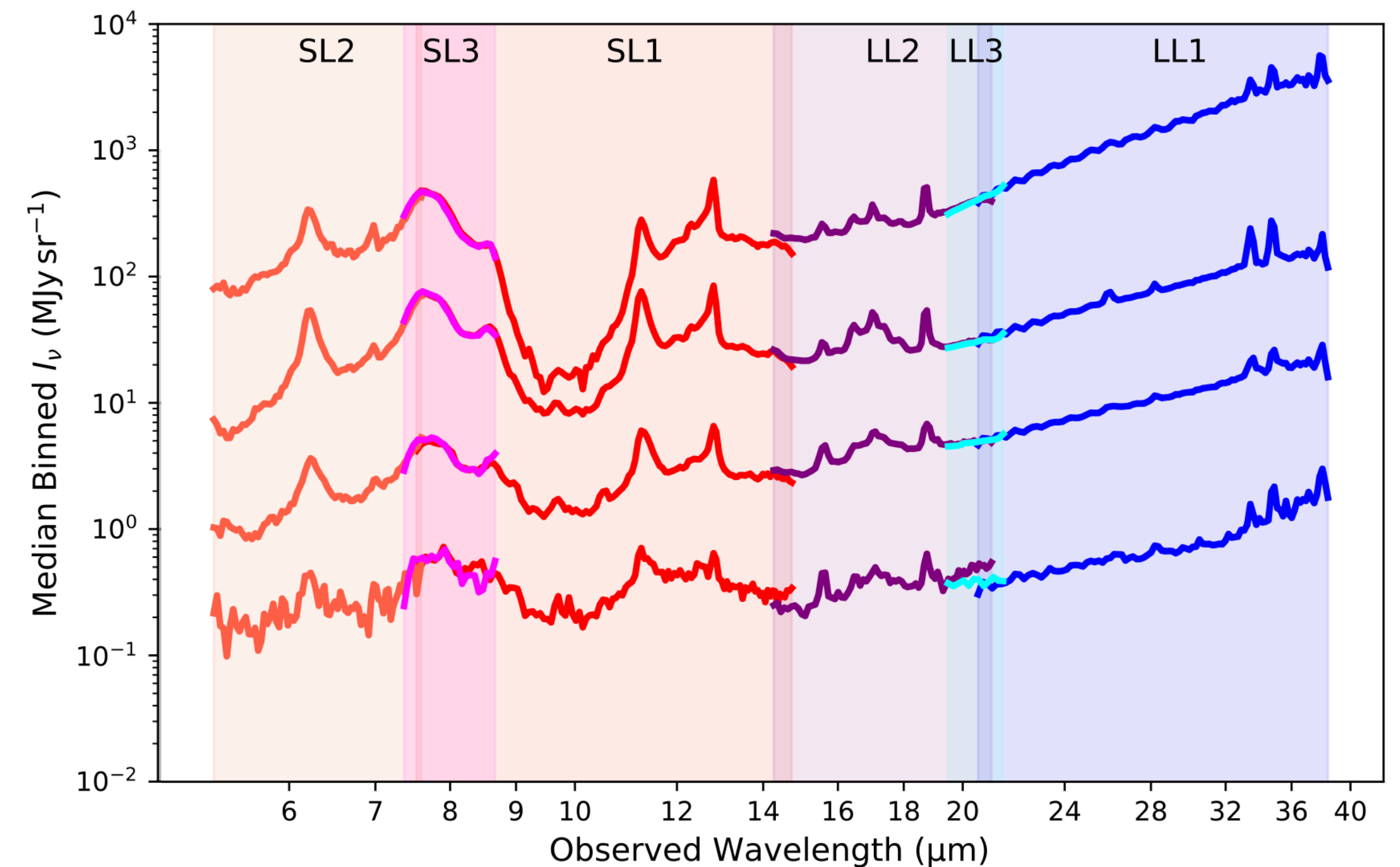


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EXPLORING THE AROMATIC UNIVERSE IN THE JWST ERA

July 6-10 2026
Western University
London, Canada



[**https://www.aromaticuniverse.space/**](https://www.aromaticuniverse.space/)