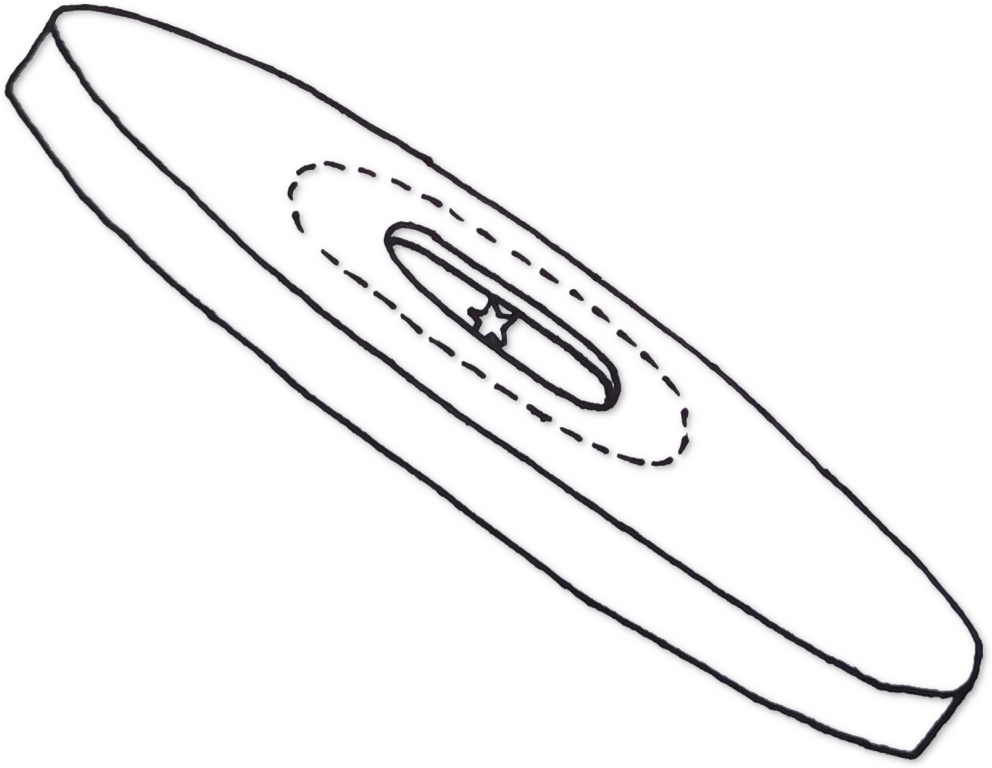
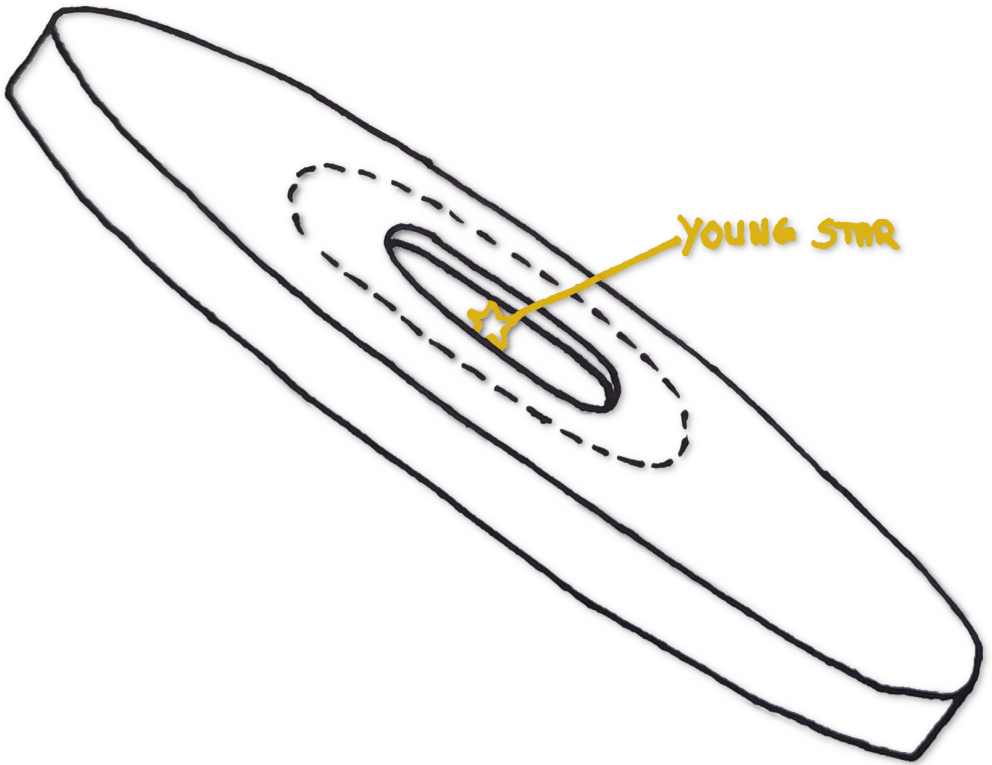
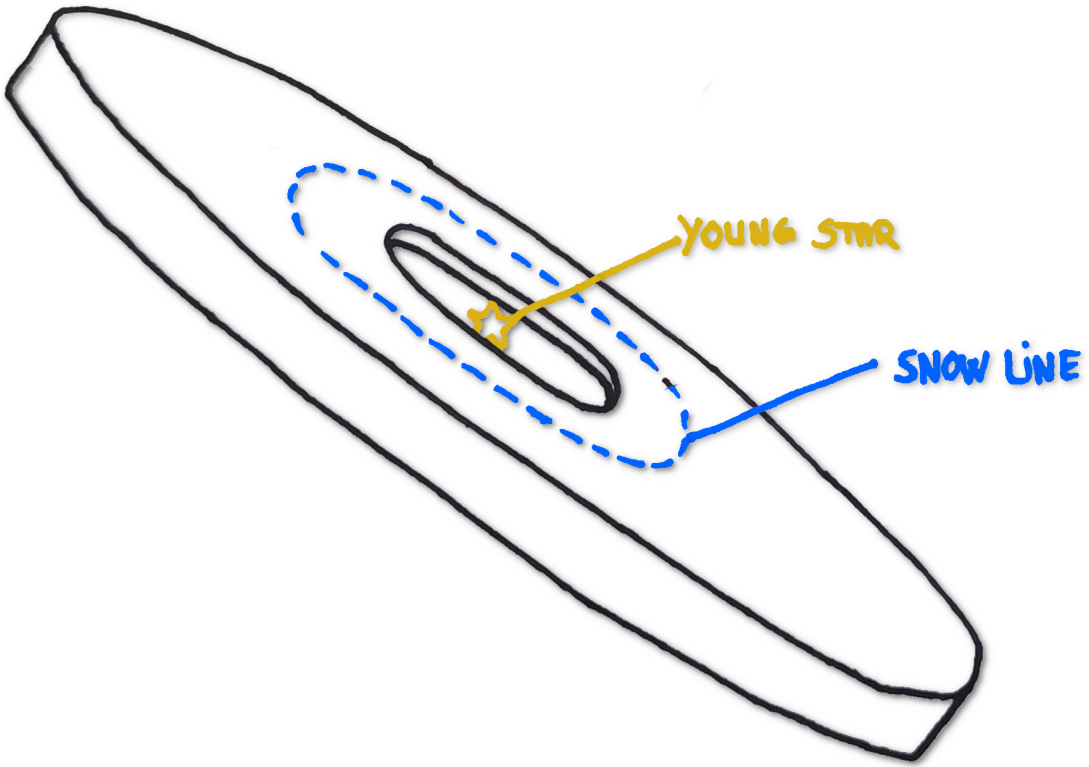
The role of external UV on protoplanetary disks with JWST

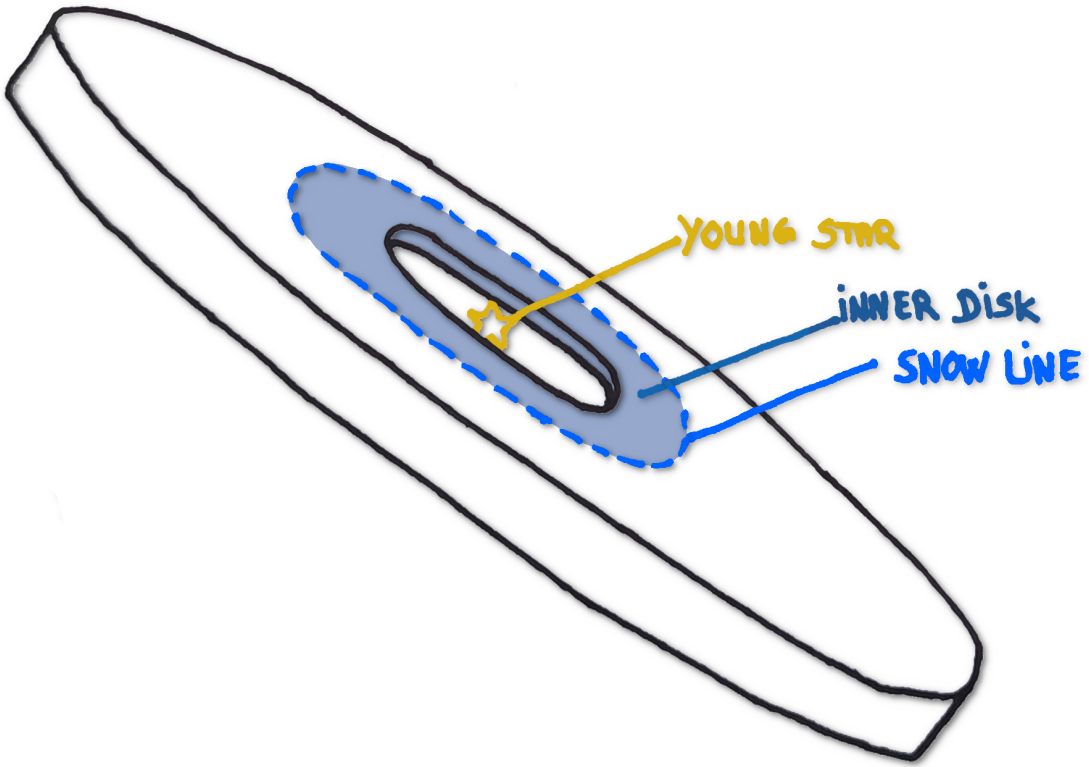
Ilane Schroetter
Chercheur contractuel à l'IRAP (Toulouse)

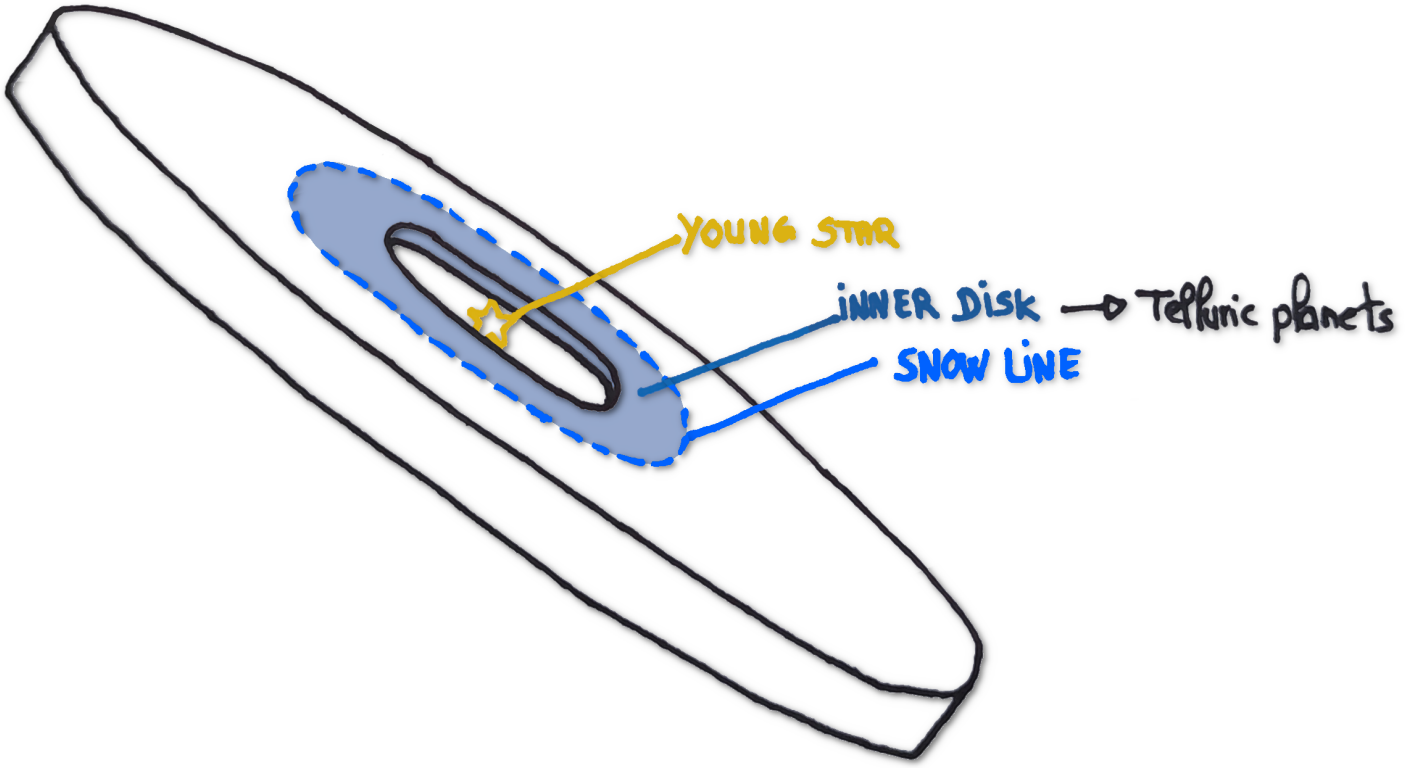
PCMI2024-Bordeaux - october 28th

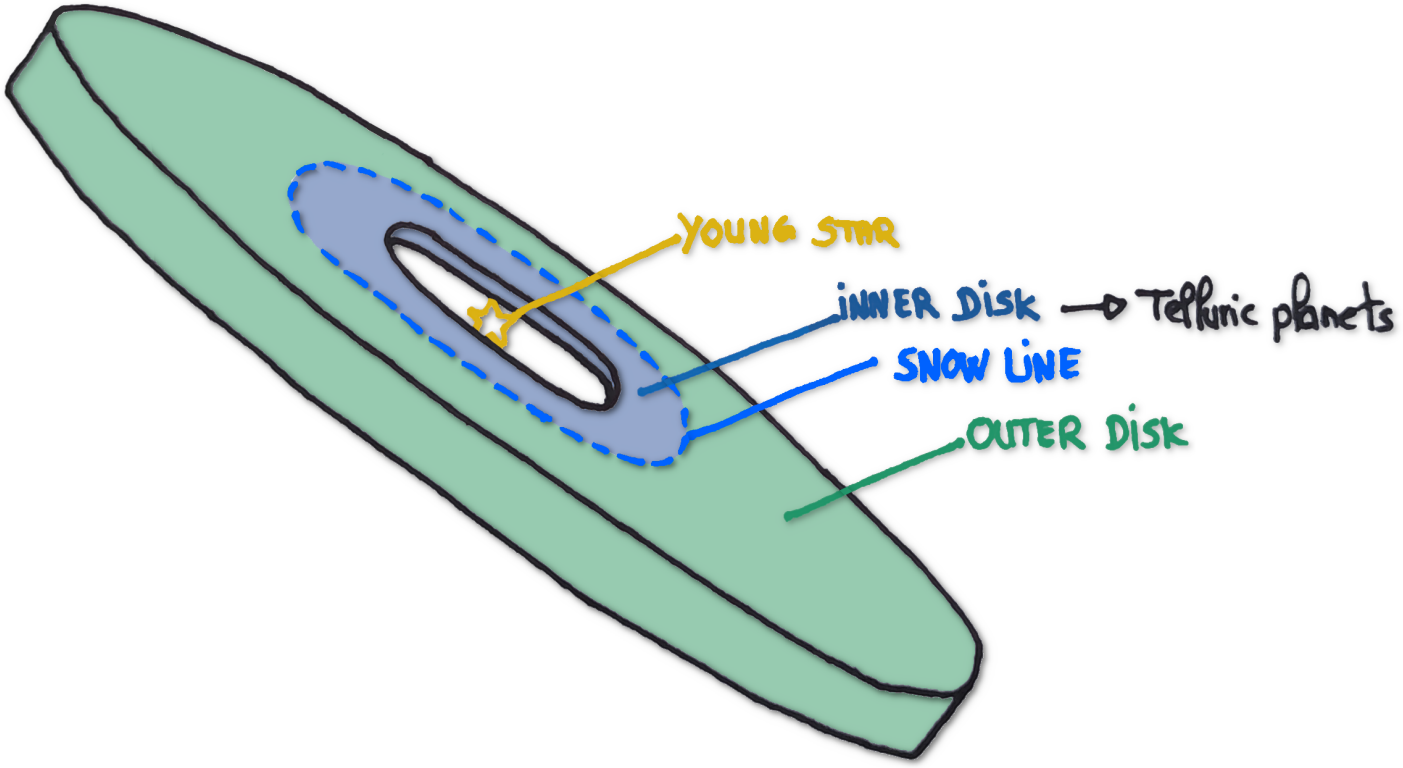


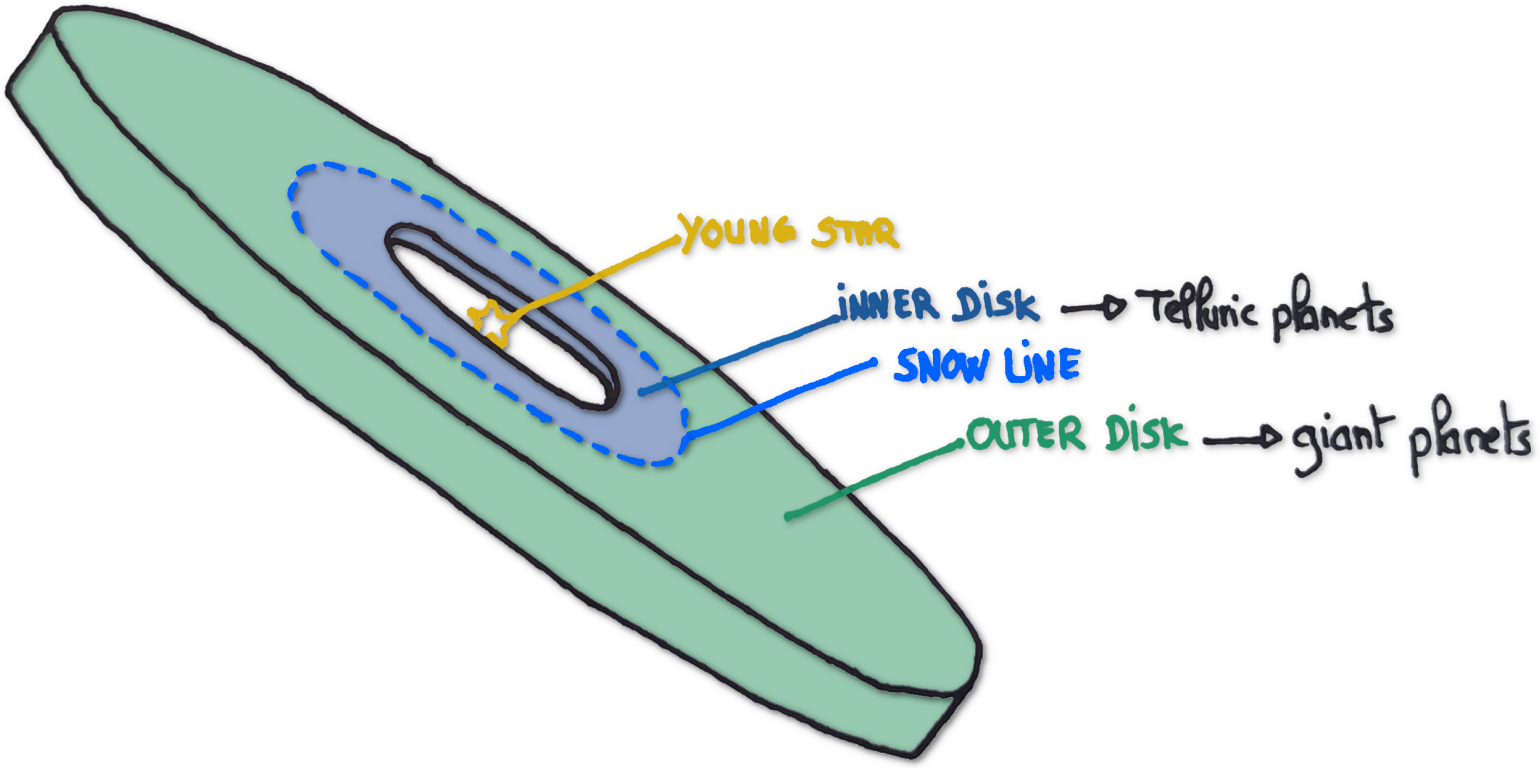

YOUNG STAR

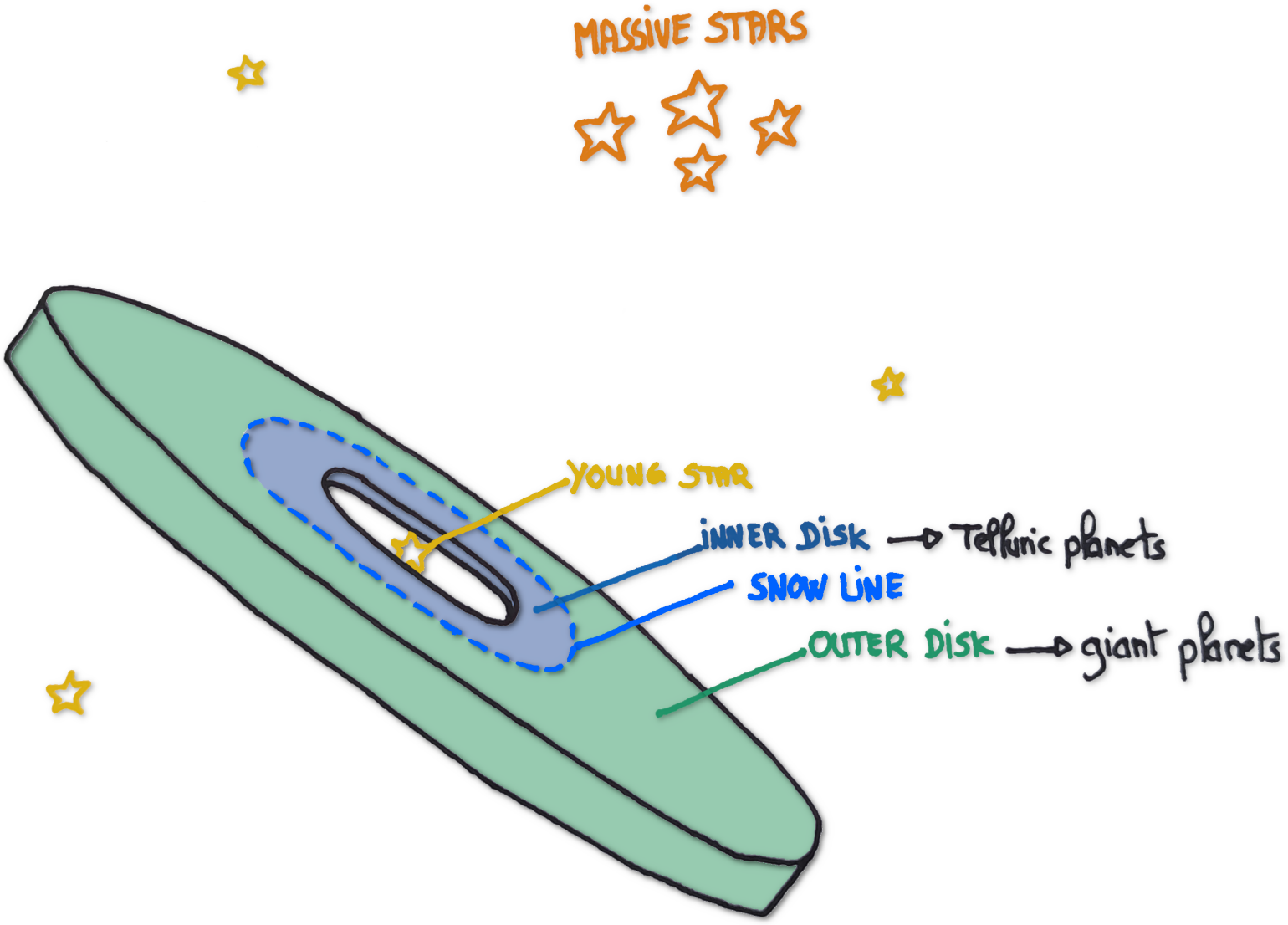

YOUNG STAR
SNOW LINE

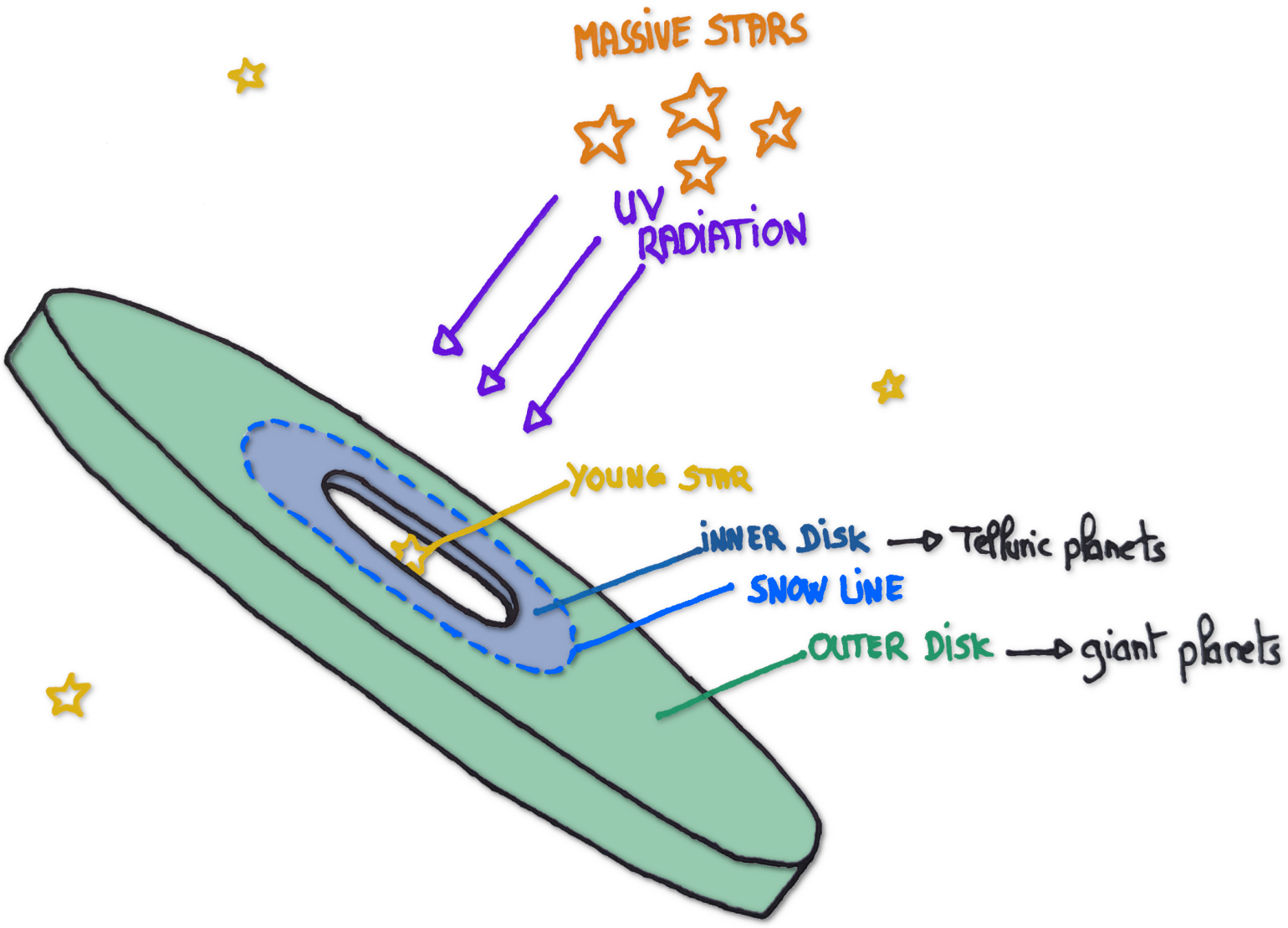

YOUNG STAR
INNER DISK
SNOW LINE

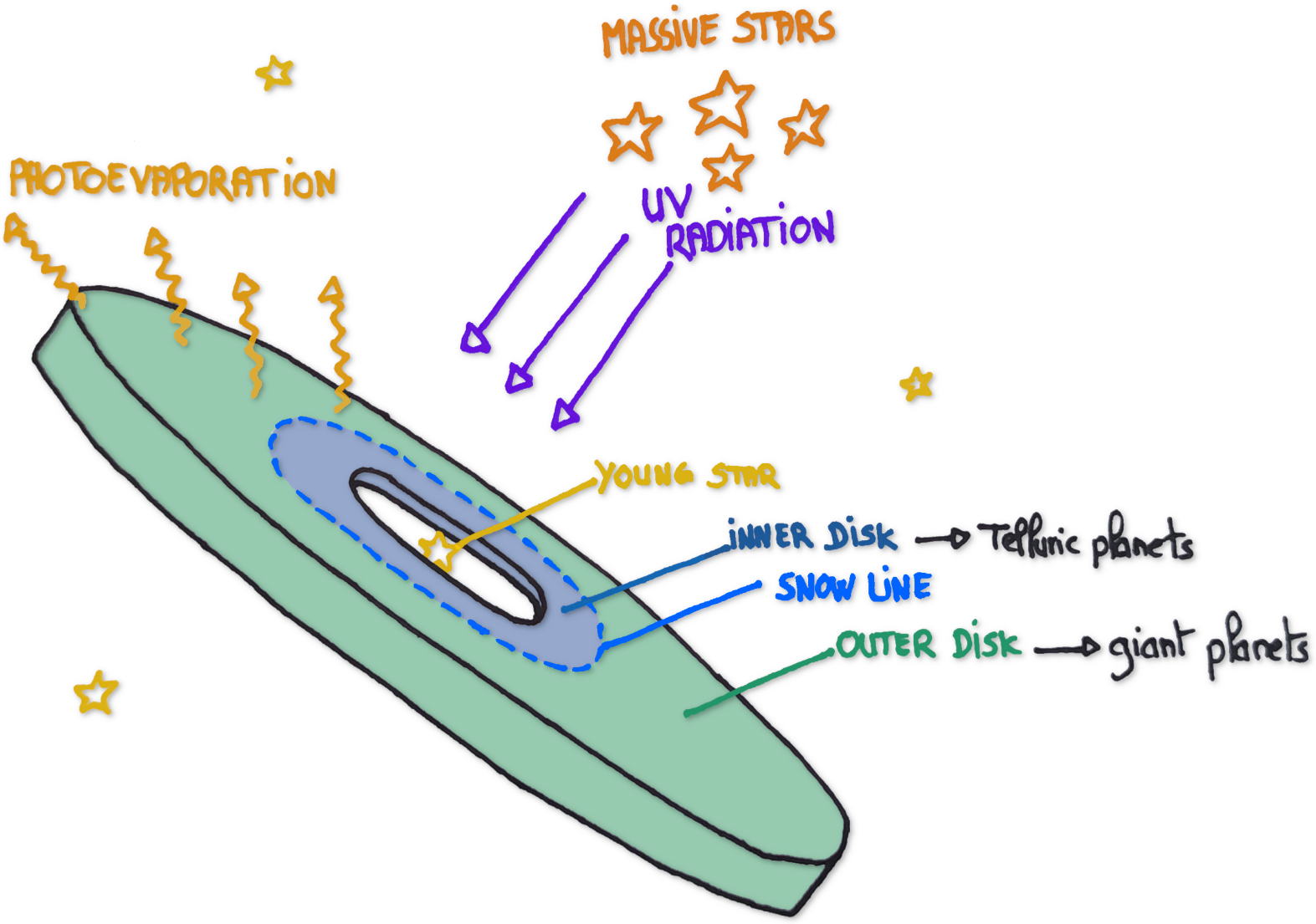

YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE

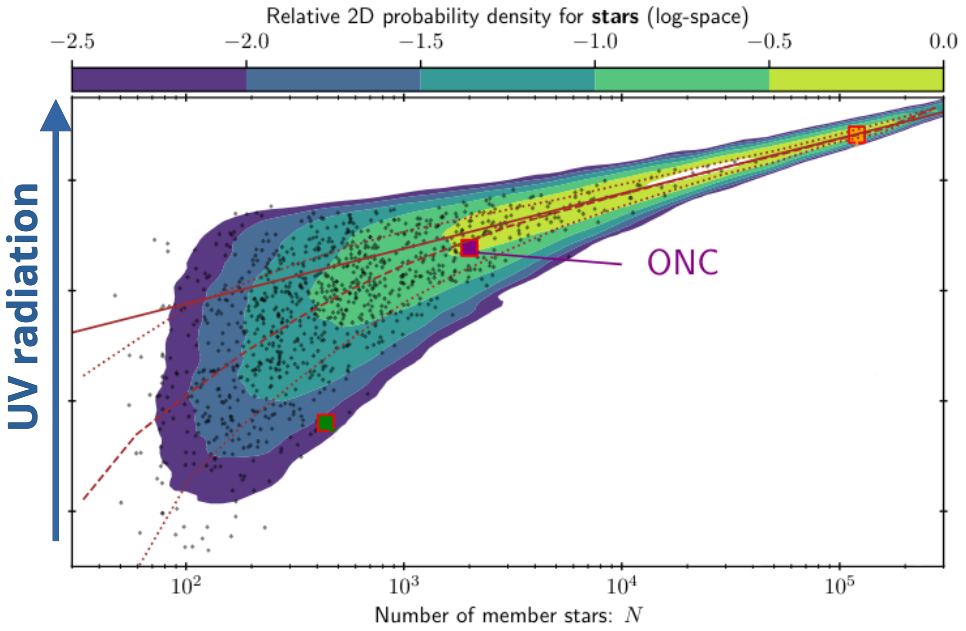

YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE
OUTER DISK


YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE
OUTER DISK → giant planets

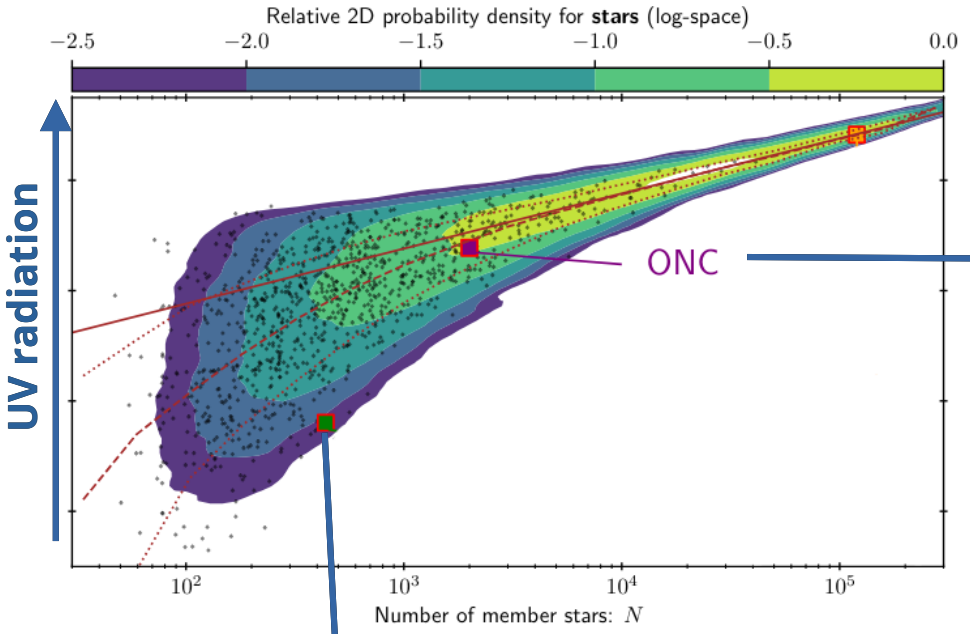

MASSIVE STARS
YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE
OUTER DISK → giant planets


MASSIVE STARS
UV RADIATION
YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE
OUTER DISK → giant planets


MASSIVE STARS
PHOTOEVAPORATION
UV RADIATION
YOUNG STAR
INNER DISK → Telluric planets
SNOW LINE
OUTER DISK → giant planets



[Winter & Haworth 2022]



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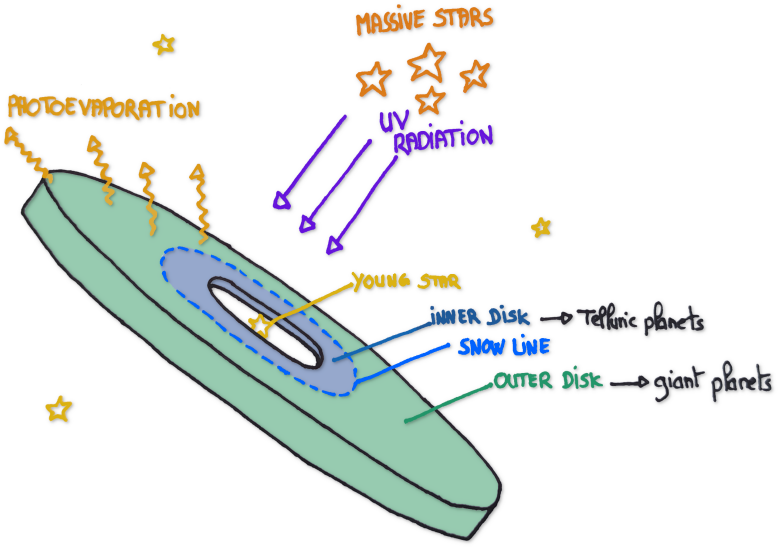
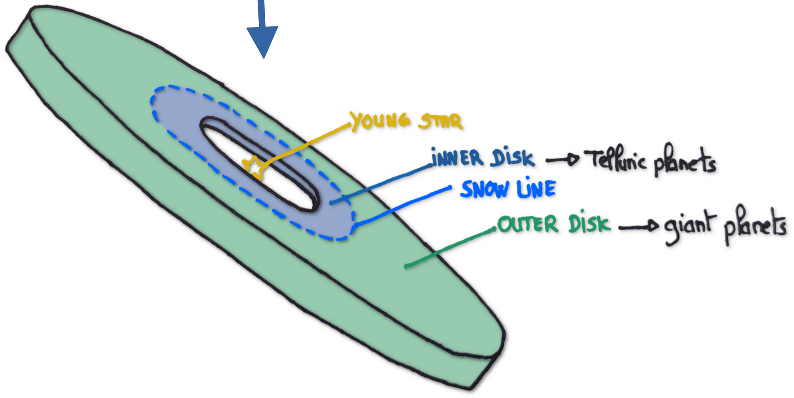
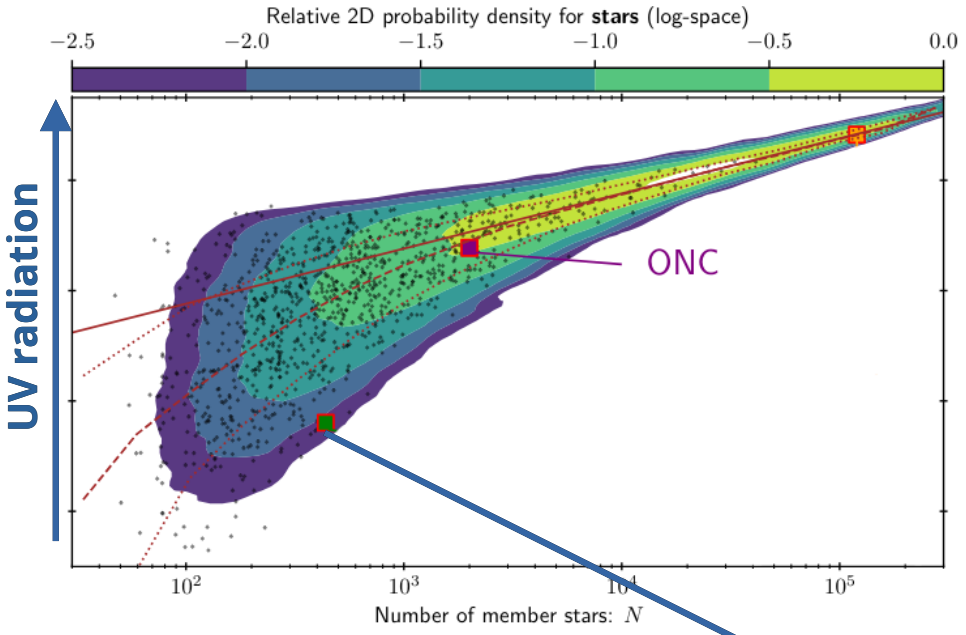






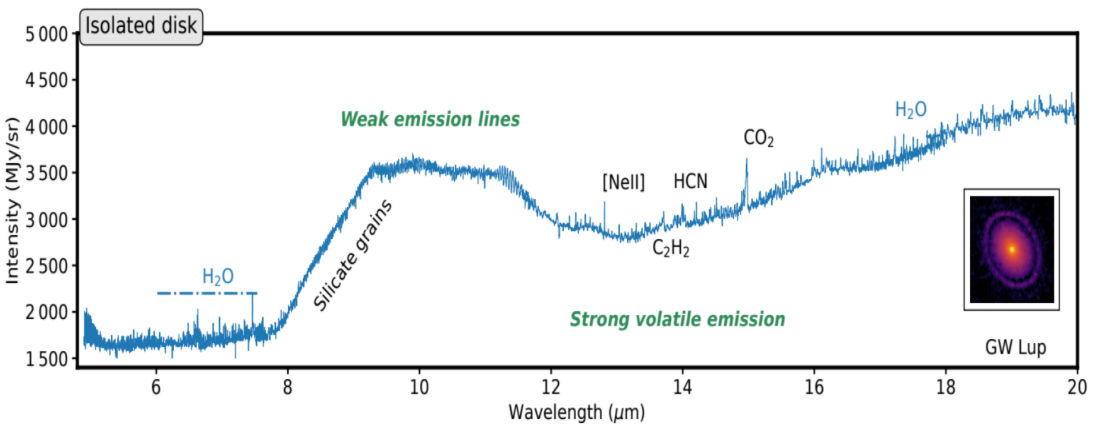
[Winter & Haworth 2022]

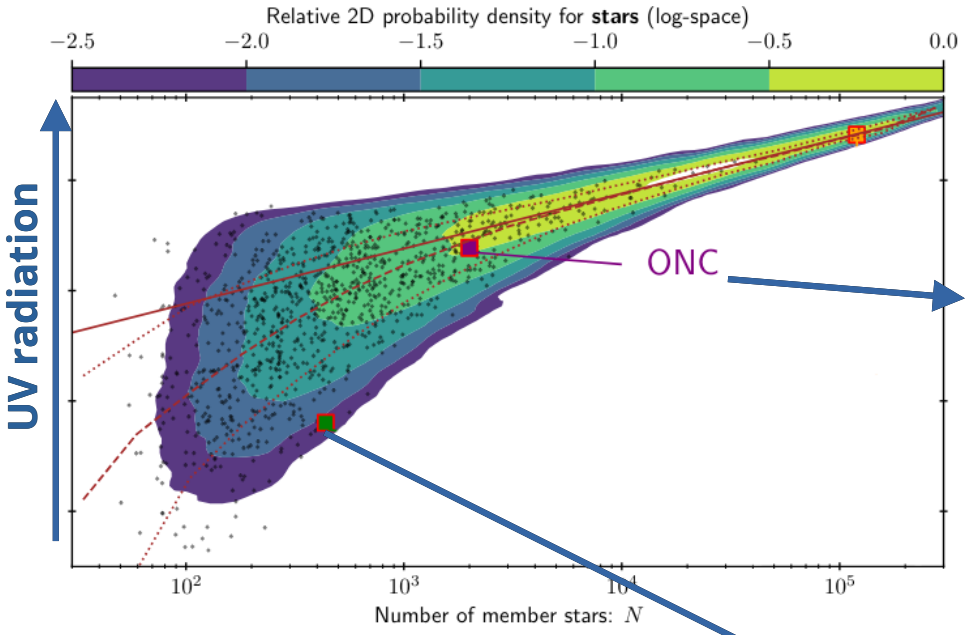
Isolated disk:

→ weak emission lines

→ neutral species

JWST MIRI MRS





[Winter & Haworth 2022]

Isolated disk:

→ weak emission lines

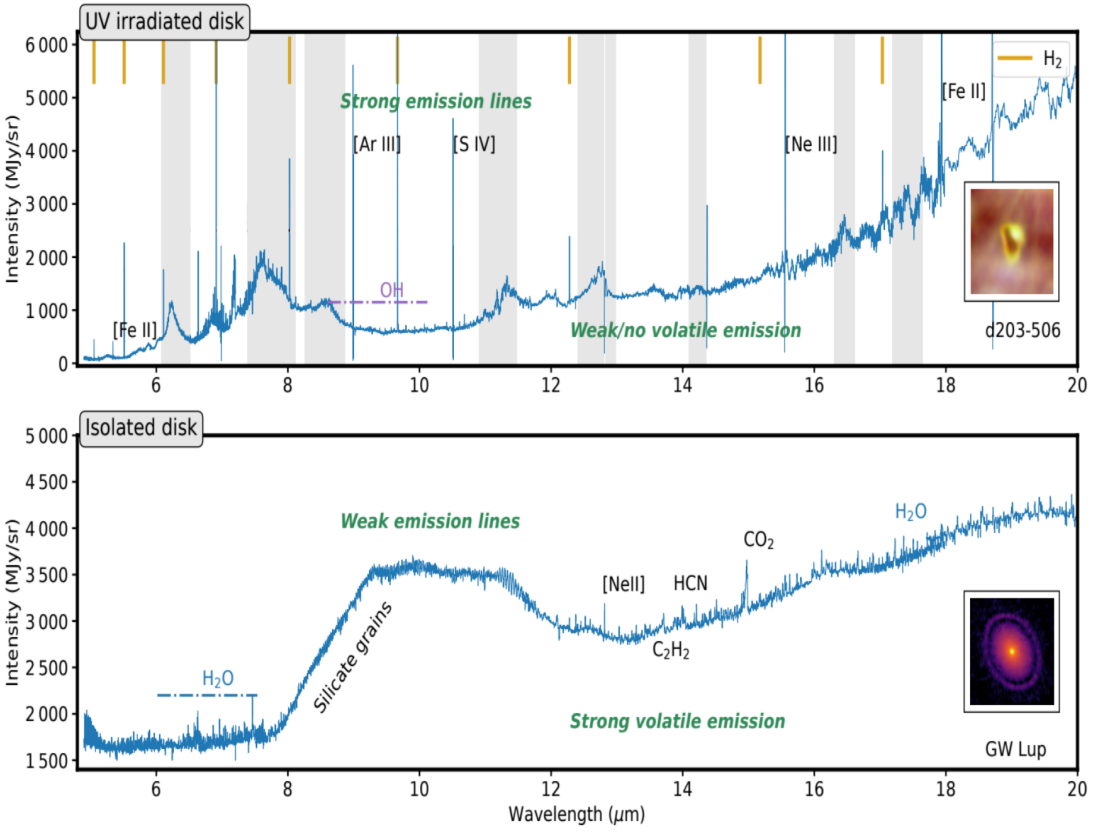
→ neutral species

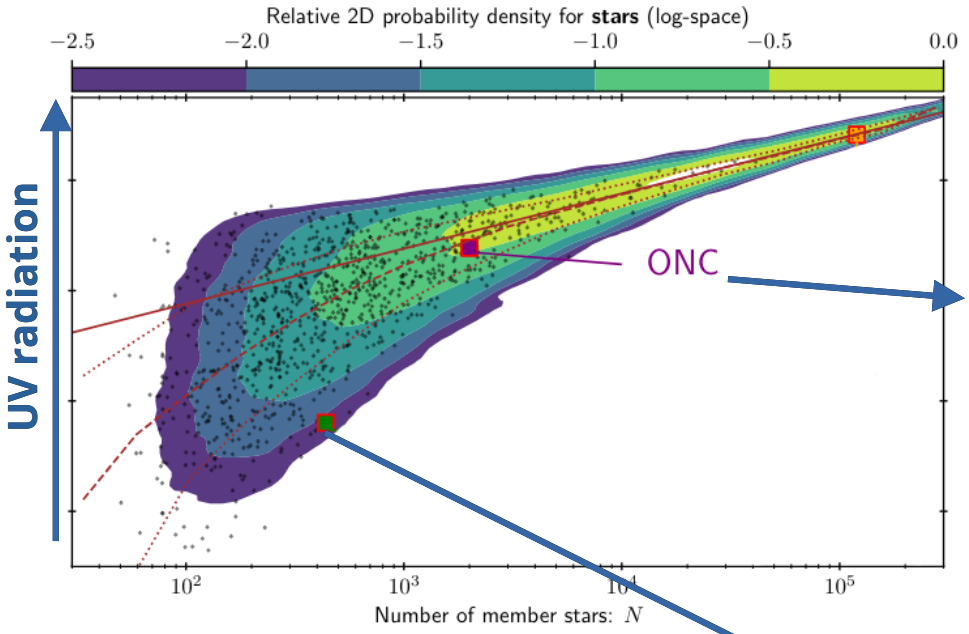
UV-irradiated disk:

→ strong emission lines

→ ions & radicals

JWST MIRI MRS





[Winter & Haworth 2022]

Isolated disk:

→ weak emission lines

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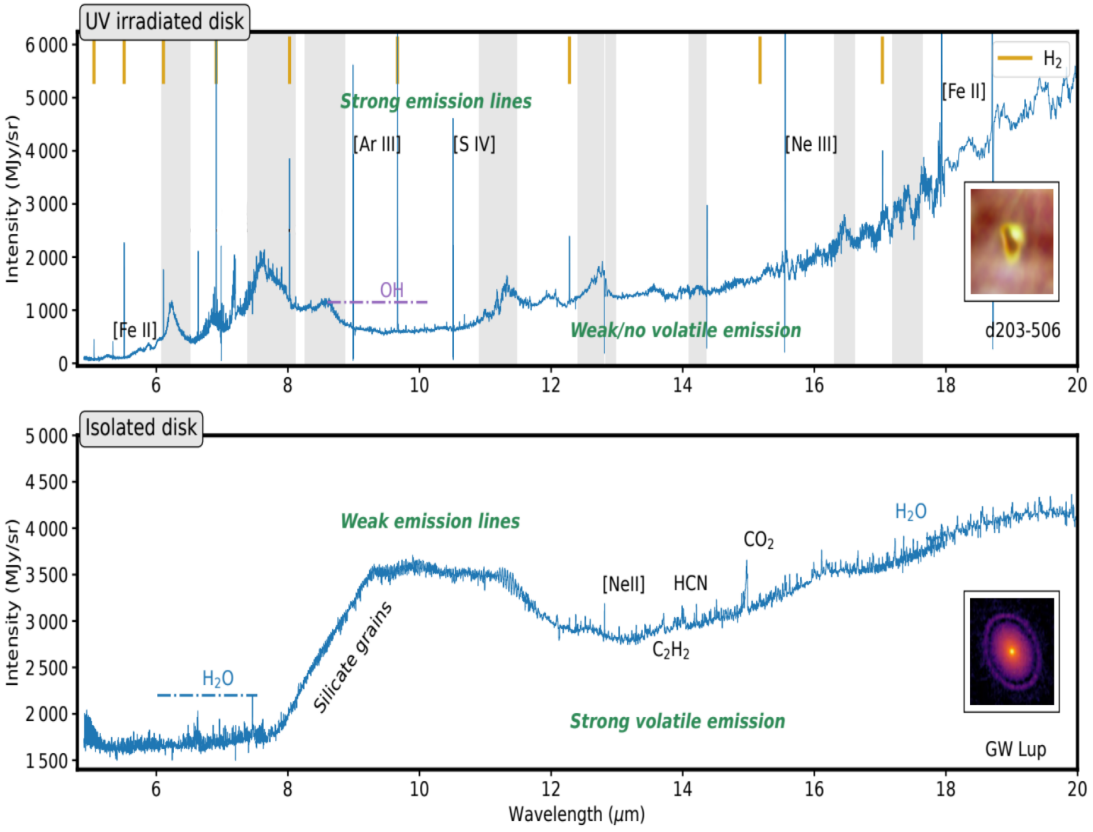
UV-irradiated disk:

→ strong emission lines

→ ions & radicals

JWST MIRI MRS



Solar System formed in high UV radiation environment
[Adams 2010, Desh & Miret-Roig 2024]

PDRs4All

ERS program:
PIs: Berné, Habart, Peeters

100+ collaborators from 18 countries

~ 40h JWST observations

NIRCam + **NIRSpec** + **MIRI**

More details in pdrs4all.org

Publications:

Goicoechea et al. 2024, A&A, 689, L4

Fuente et al. 2024, A&A, 687, A87

Van De Putte et al. 2024, A&A, 687, A86

Berné et al. 2024 Science, 383, 6686, p988

Zannese et al. 2024, Nature Astronomy

Schroetter et al. 2024, A&A, 685, A78

Pasquini et al. 2024, A&A, 685, A77

Elyajouri et al. 2024, A&A, 685, A76

Chown et al. 2024, A&A, 685, A75

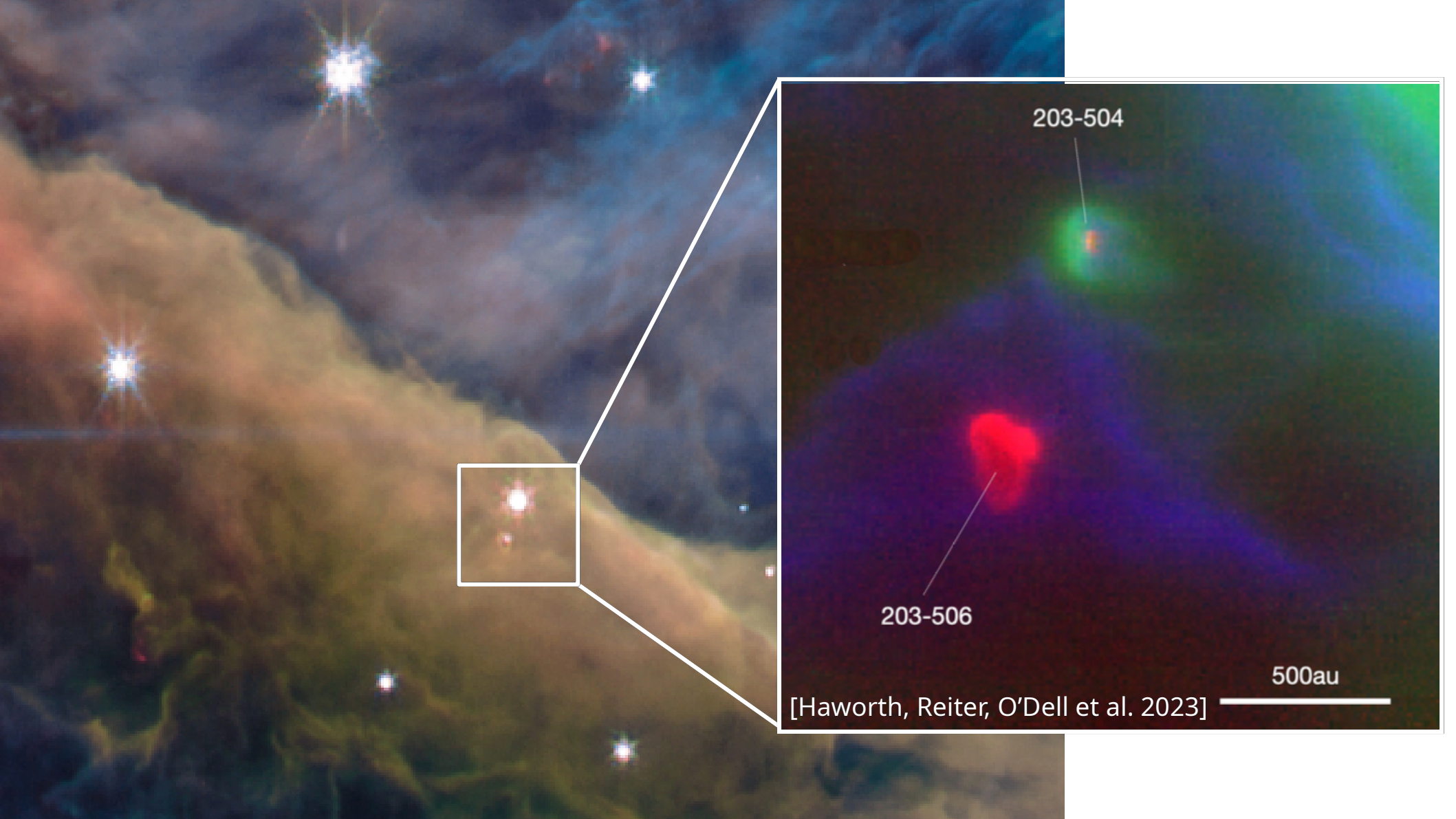
Peeters et al. 2024, A&A, 685, A74

Habart et al. 2024, A&A, 685, A73

Berné et al. 2023, Nature, 621, 56

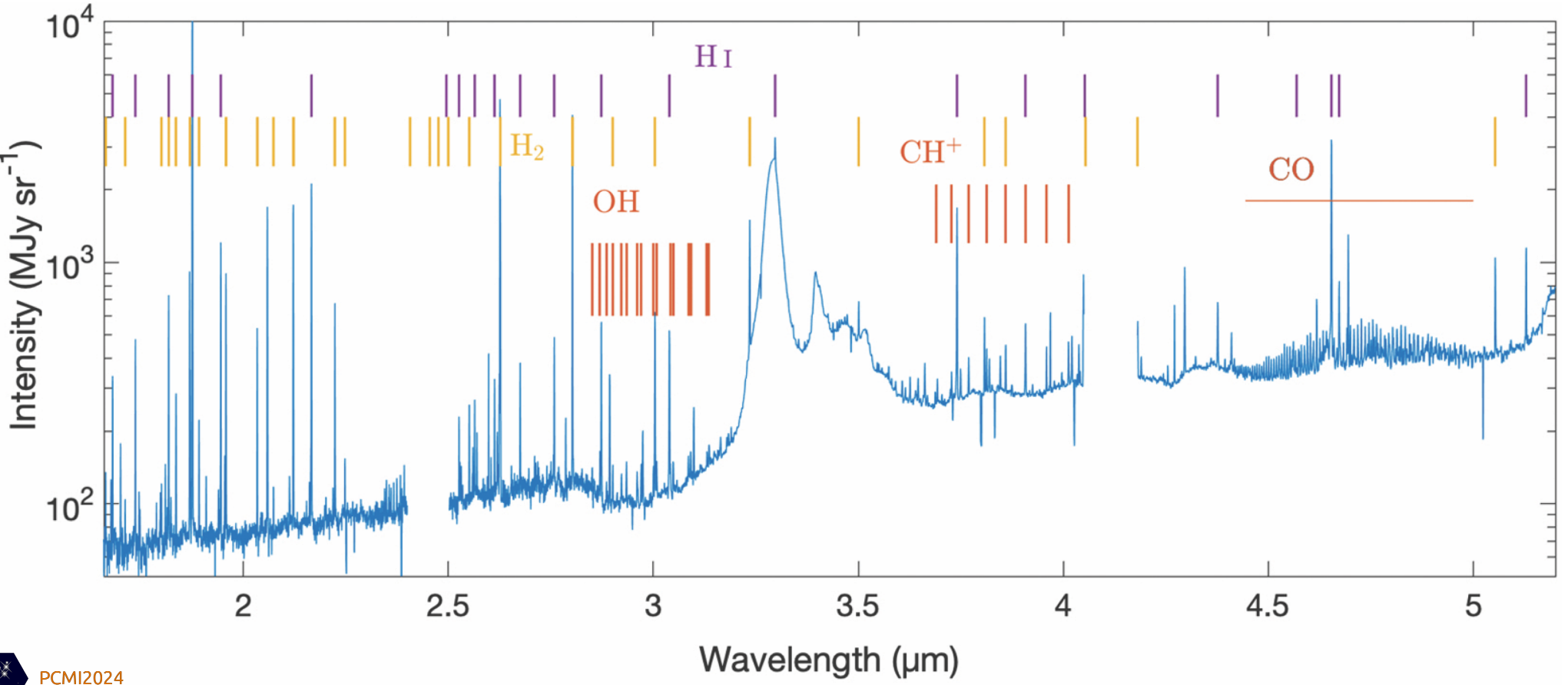
What we do in Toulouse

JWST Team in Toulouse


203-504
203-506
500au
[Haworth, Reiter, O'Dell et al. 2023]

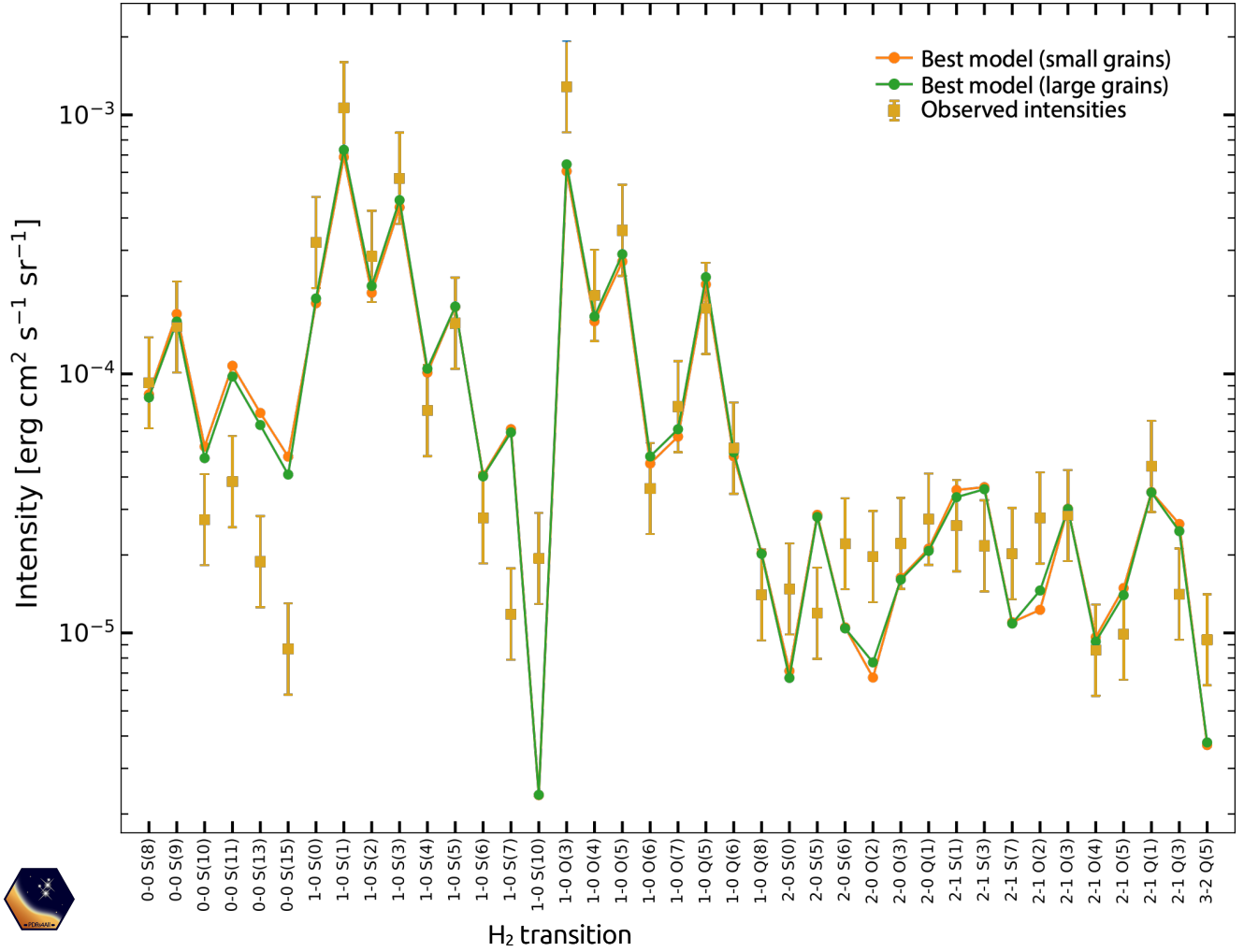
NIRSpec spectrum of the d203-506 protoplanetary disk

[Berné, Habart, Peeters et al. Science, 2024]



H_2: a probe of photoevaporation mass loss

[Berné, Habart, Peeters et al. Science, 2024]



Meudon PDR code (Le Petit et al. 2006) model
(fit to 29 H_2 lines observed with NIRSpec)

gas density

gas temperature

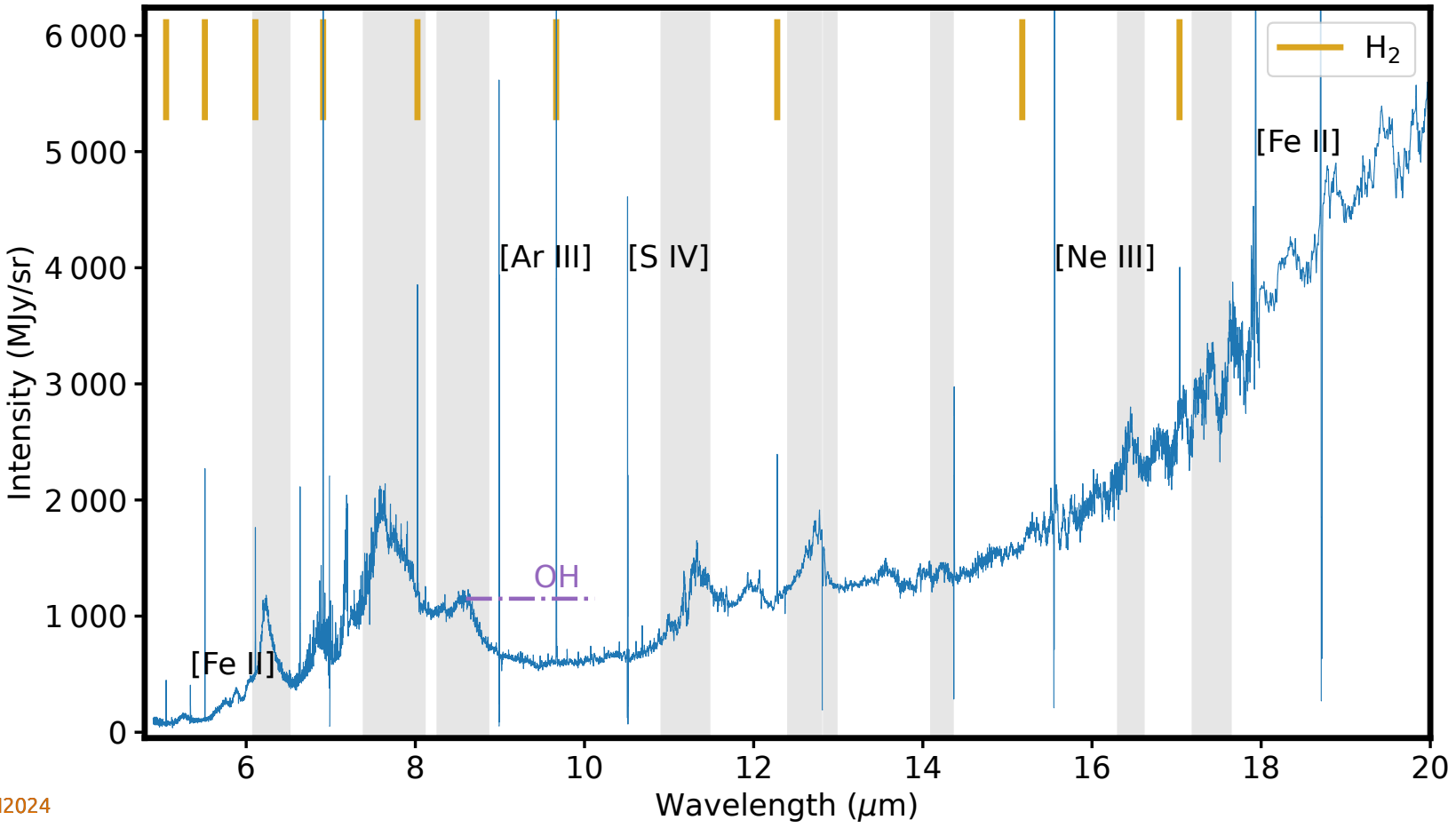
→ **mass loss rate**, due to Far UV photoevaporation:

$$\dot{M} = [0.14 - 4.4]\text{x}10^{-6}\ \mathrm{M}_\odot/\mathrm{year}$$

Up to an Earth mass / year: mass loss rates of this magnitude can suppress giant planet formation.

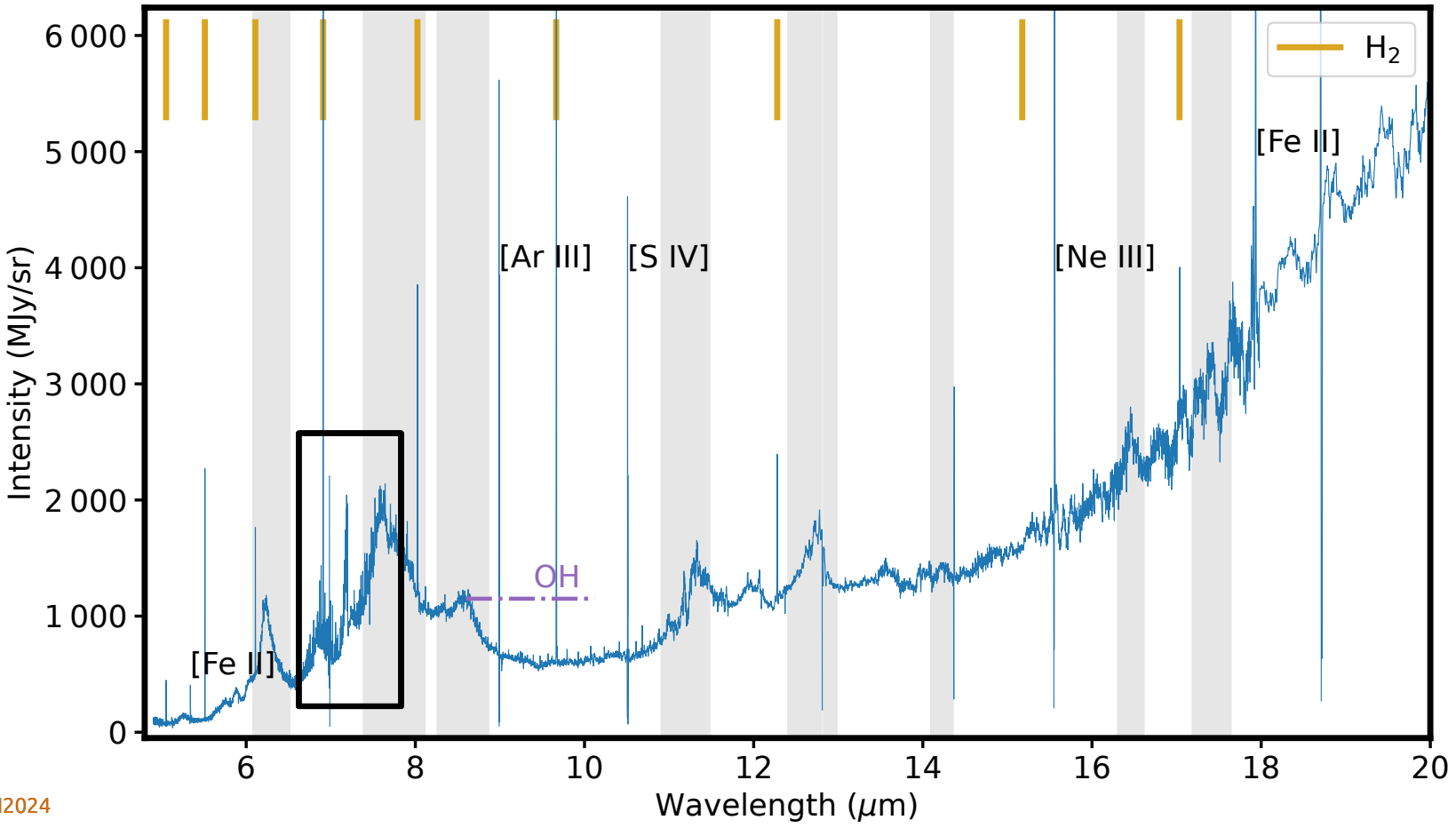
MIRI spectrum

[Berné, Martin-Drumel, Schroetter et al. Nature, 2023]



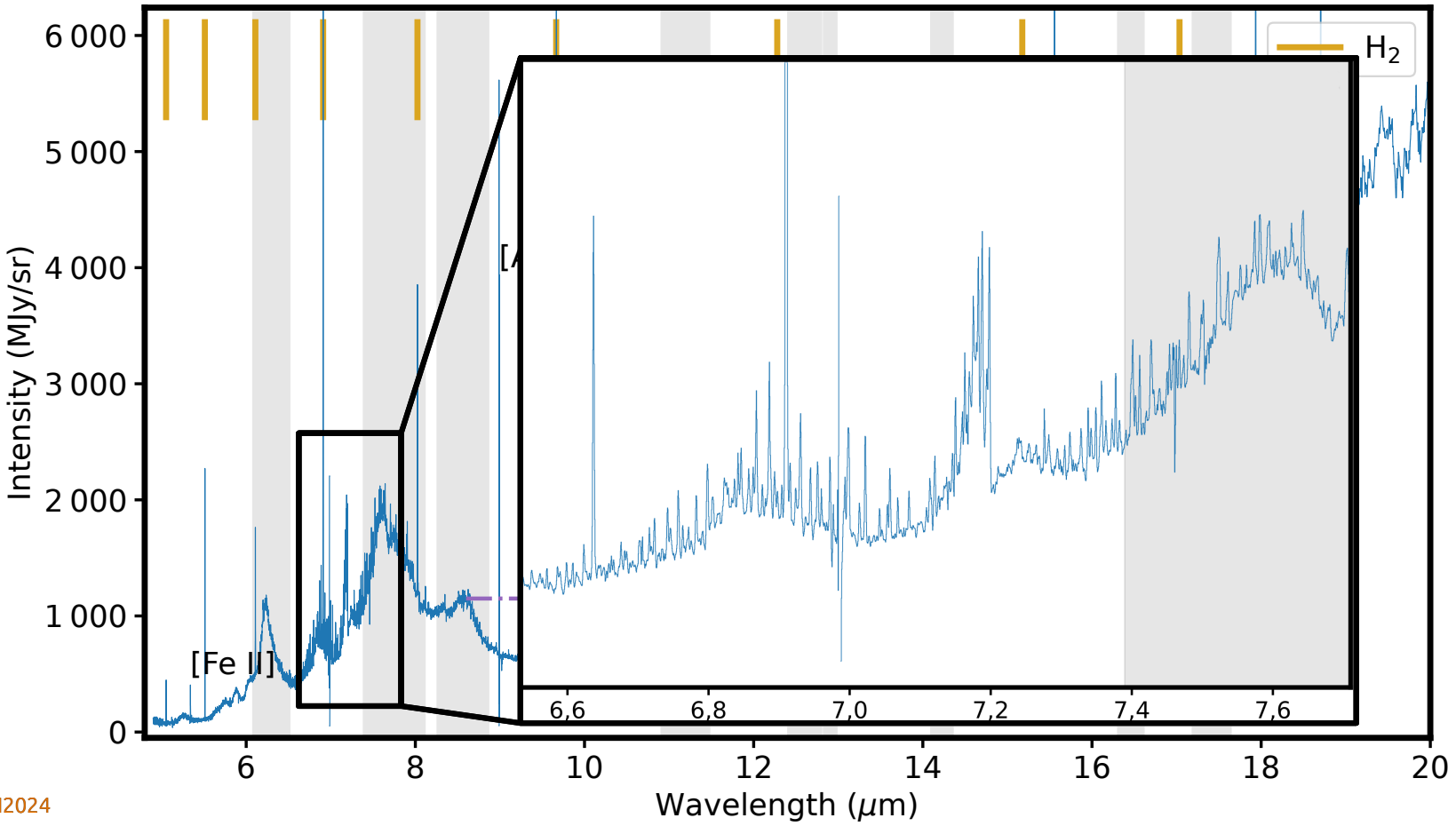
MIRI spectrum

[Berné, Martin-Drumel, Schroetter et al. Nature, 2023]



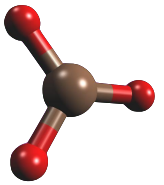
MIRI spectrum

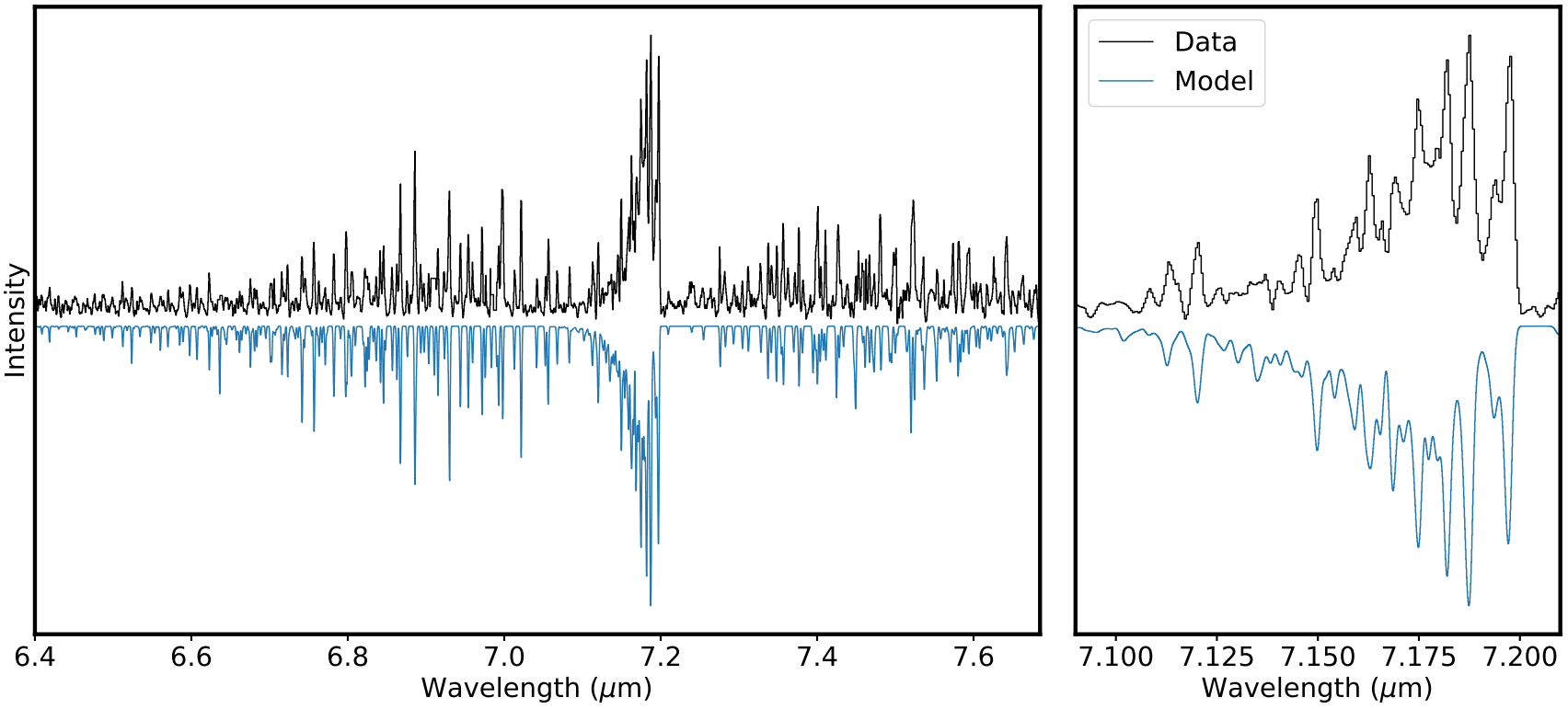
[Berné, Martin-Drumel, Schroetter et al. Nature, 2023]



MIRI: first detection of the Methyl-Cation: CH_3^+

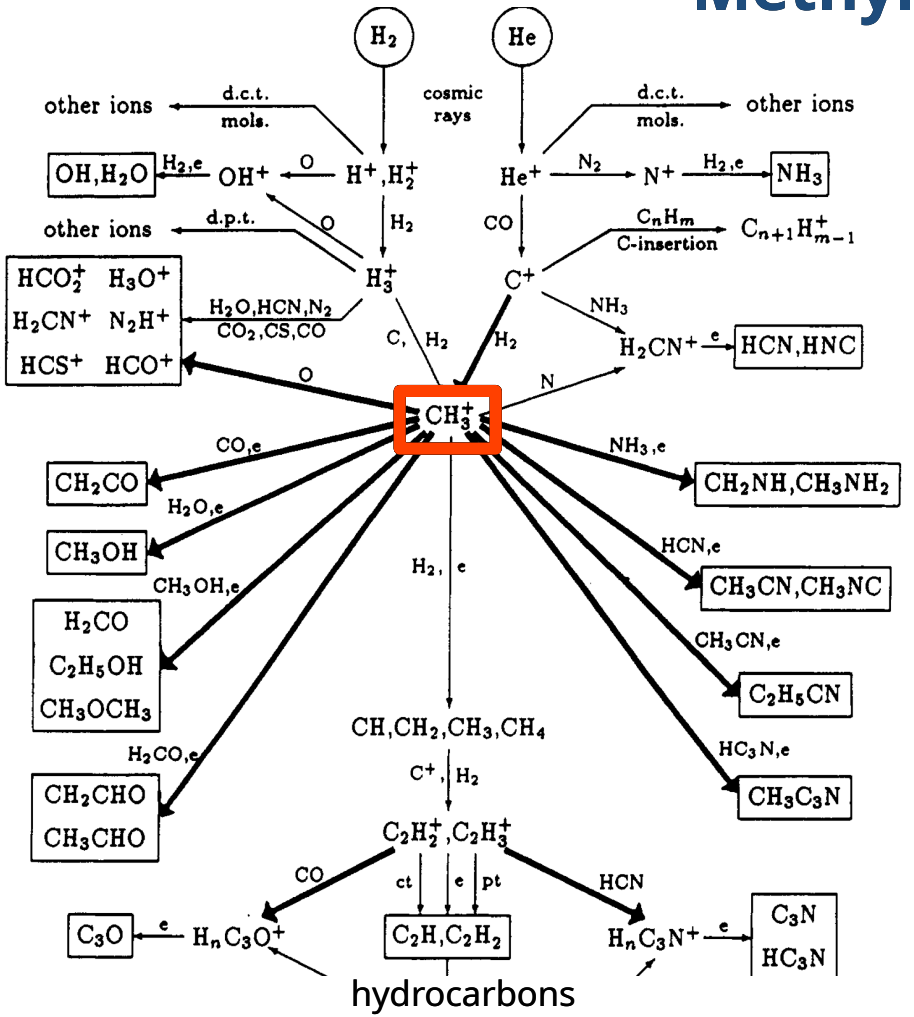
[Berné, Martin-Drumel, Schroetter et al. Nature, 2023] [Changala et al. A&A 2023]

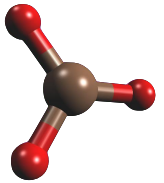




Collaboration with spectroscopists : P. Bryan Changala, Ning L. Chen, Hai L. Le, Bérenger Gans, Kim Steenbakkers, Thomas Salomon, Luis Bonah, Marie-Aline Martin-Drumel, Ugo Jacovella, Séverine Boyé-Péronne, Christian Alcaraz, Oskar Asvany, Sandra Brünken, Sven Thorwirth, Stephan Schlemmer

Methyl-Cation : CH_3^+





- Is a product of UV driven chemistry in the outer disk

- In d203-506, it is the **3rd most abundant** species after H_2 and CO

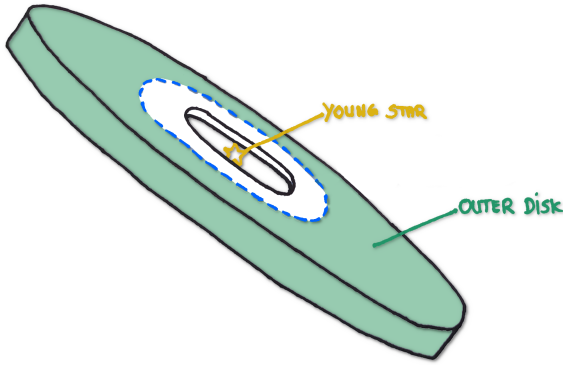
→ The organic chemistry is probably strongly linked to CH_3^+, as predicted decades ago

→ Future survey with ALMA/NOEMA will search for the products of CH_3^+ in UV driven chemistry (collaboration with J. Goicoechea)

[I. Smith, *Chem. Rev,* 1992]

More details on outer disk

[Schroetter, Berné et al. in Prep.]



More details on outer disk

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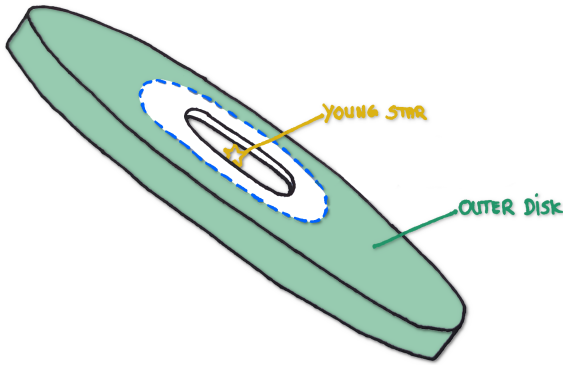

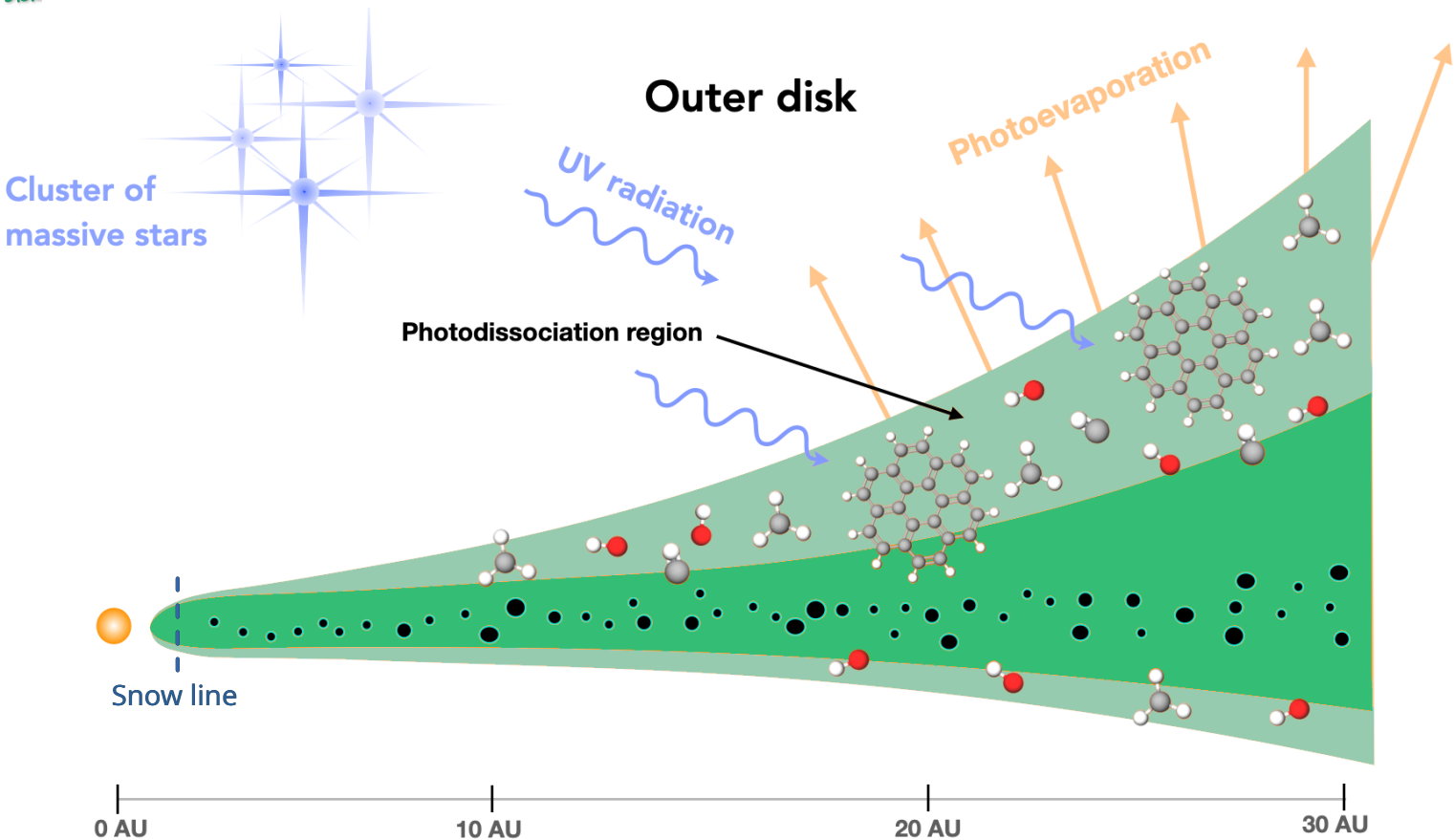

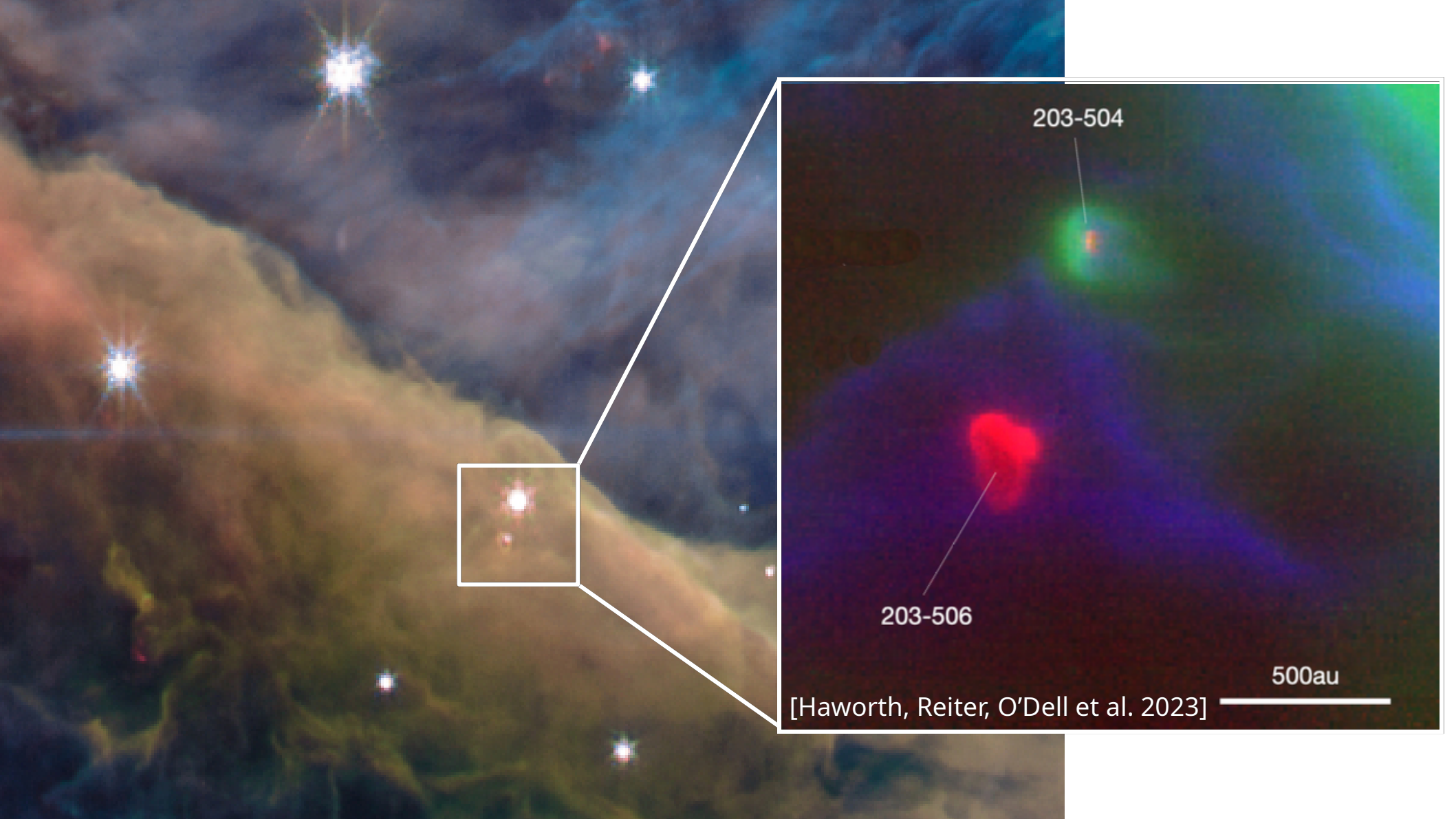
203-504
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[Haworth, Reiter, O'Dell et al. 2023]

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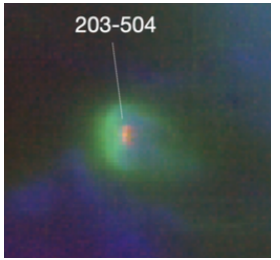

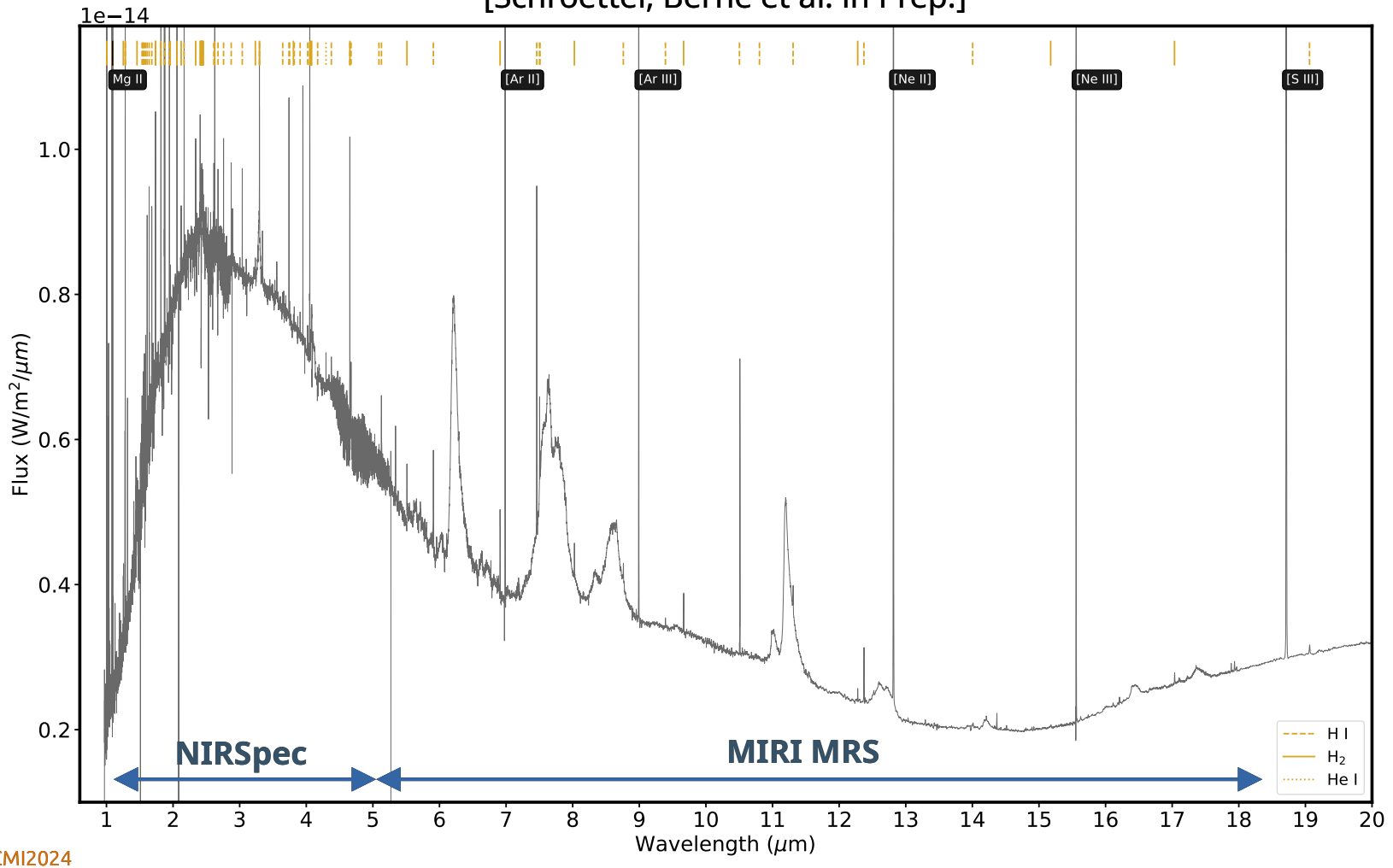

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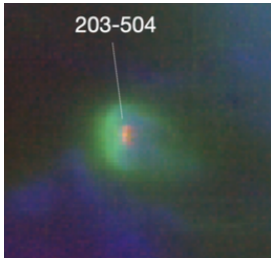

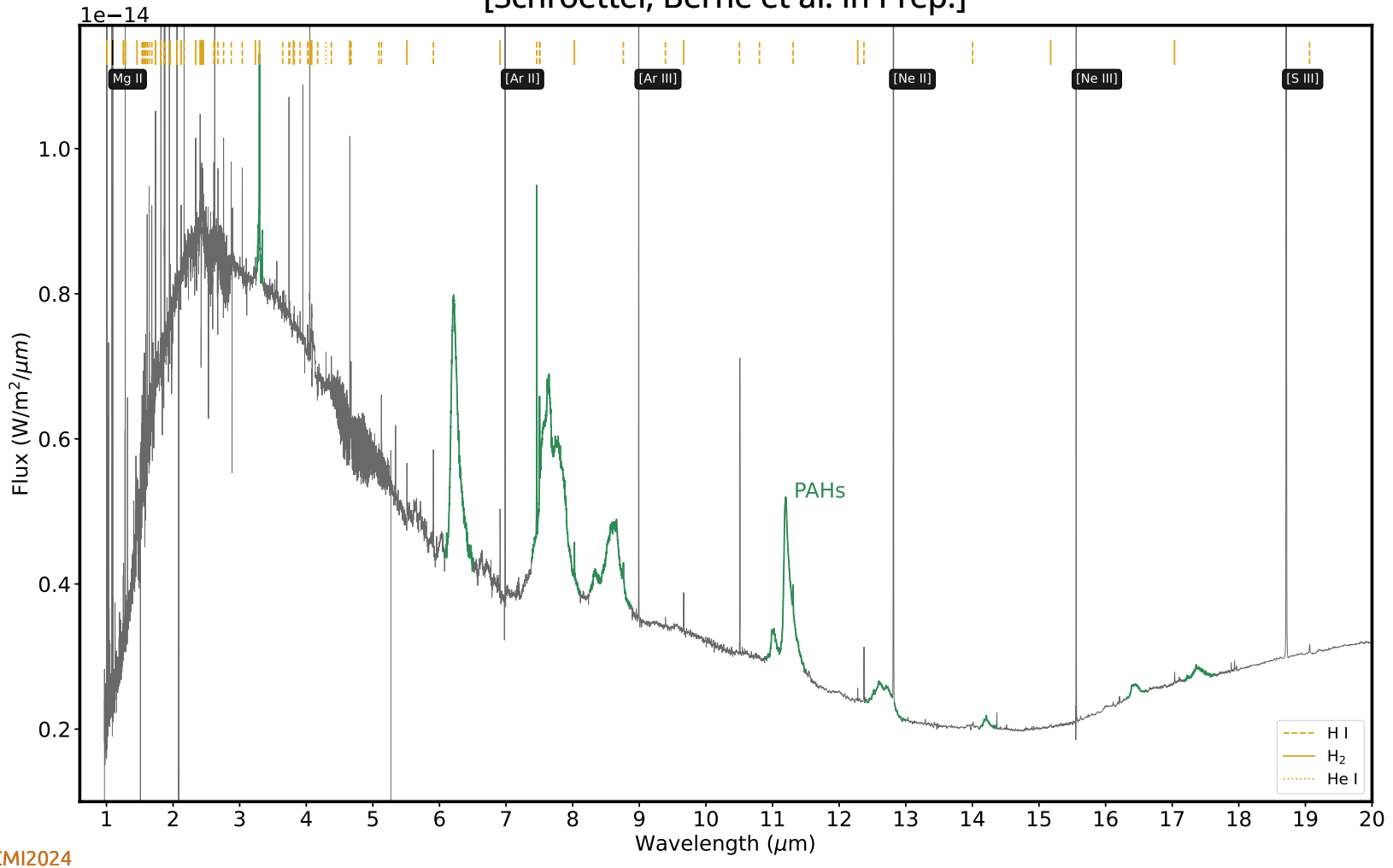

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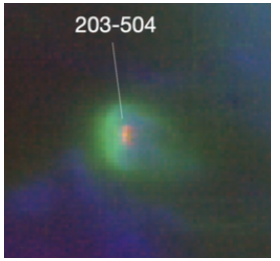

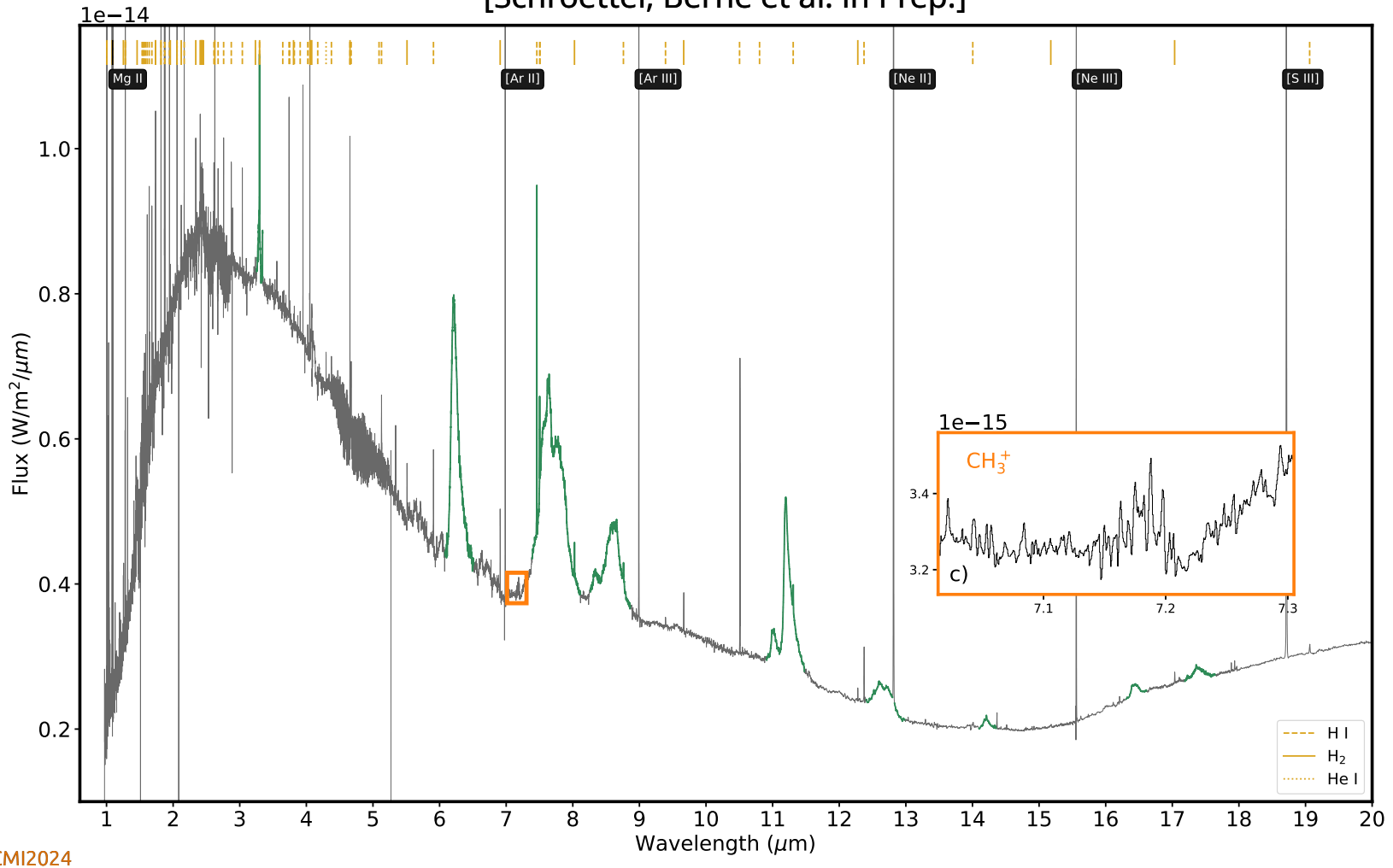

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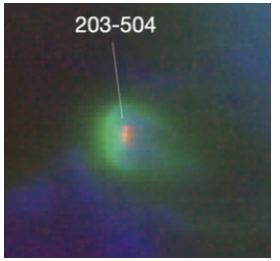
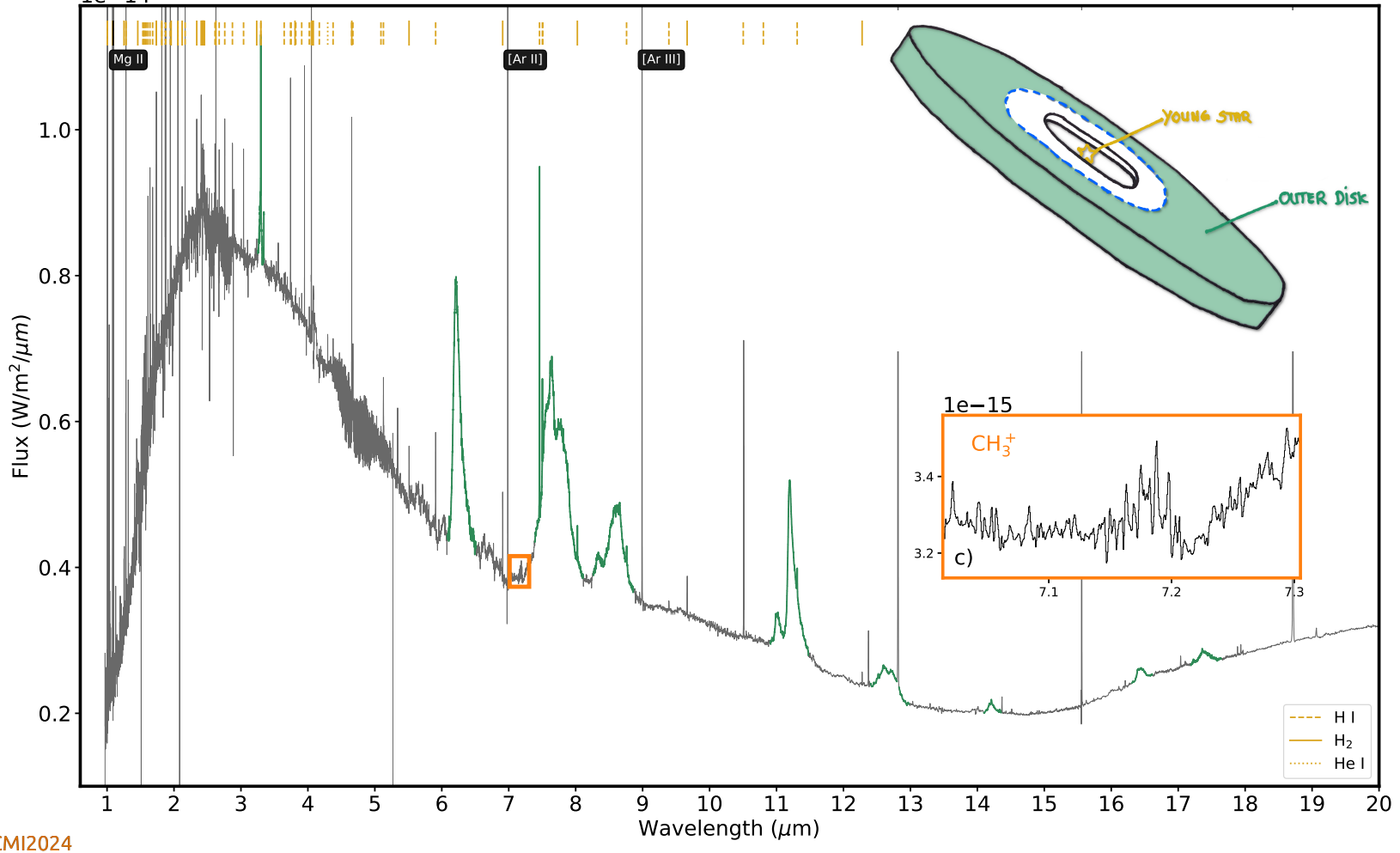
[Schroetter, Berné et al. in Prep.]





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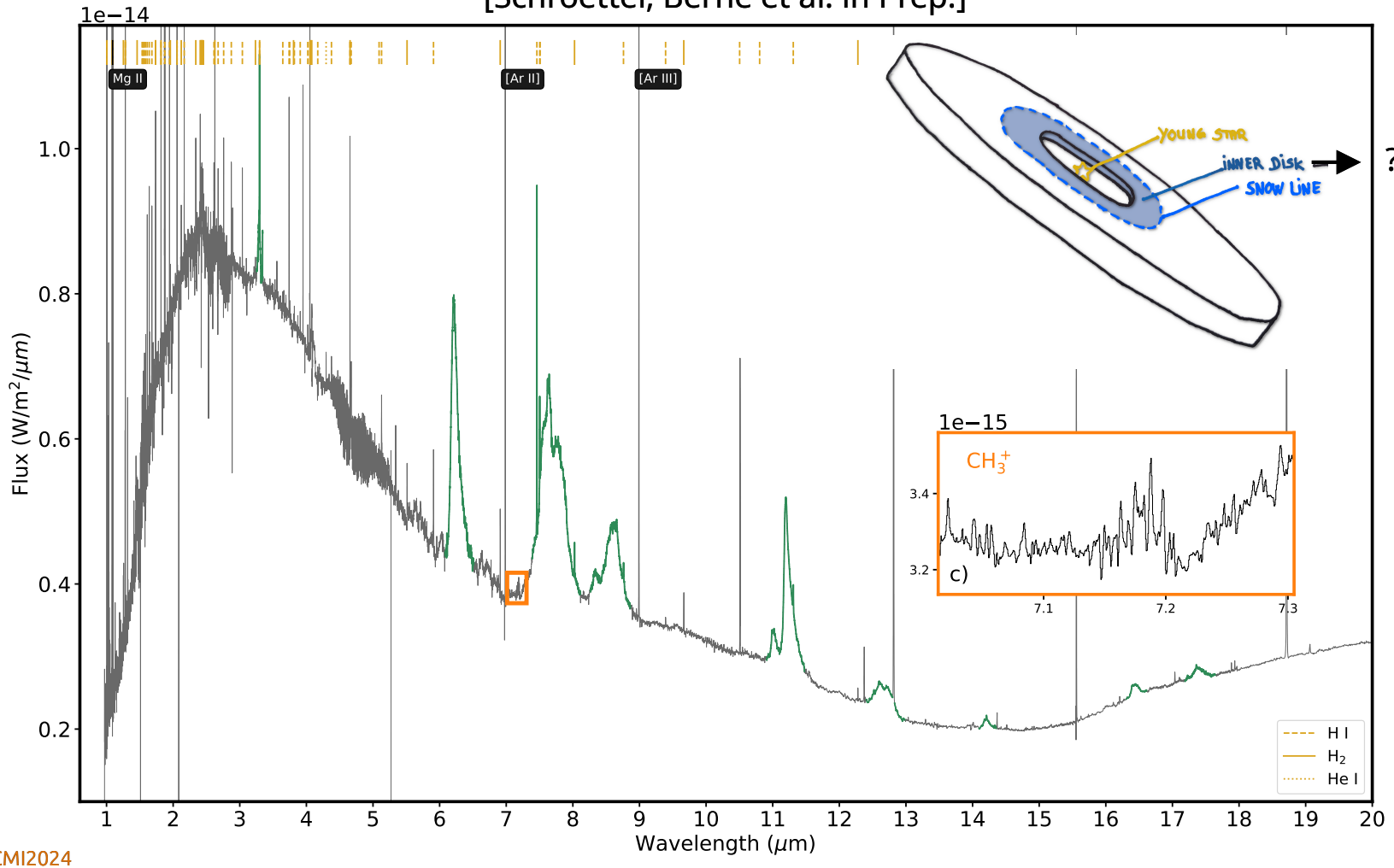

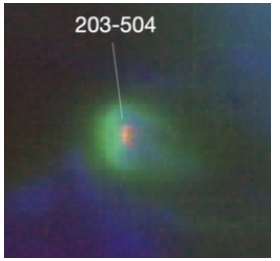

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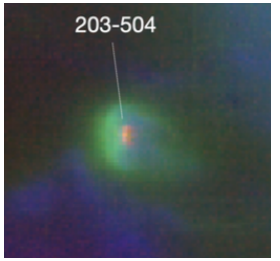

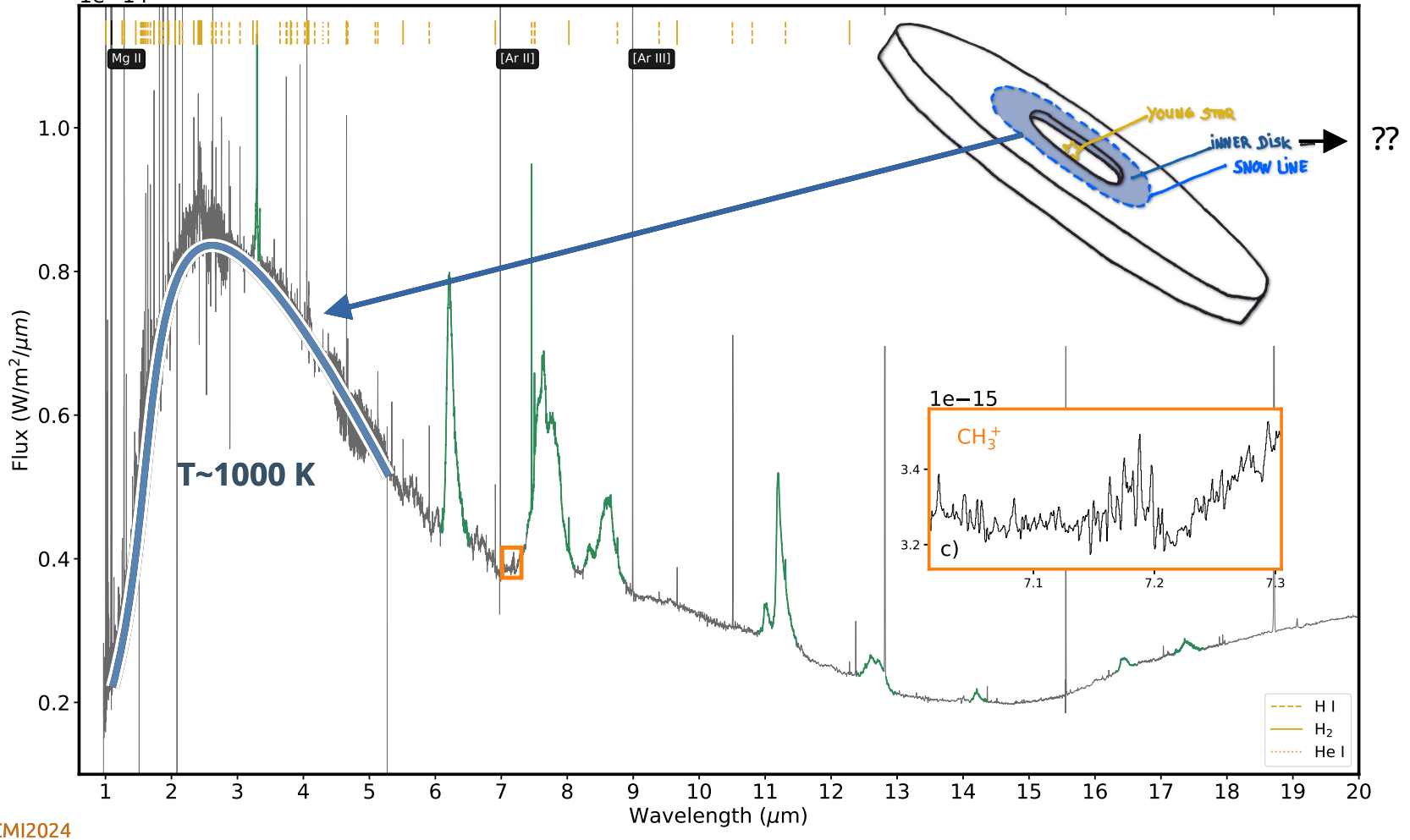

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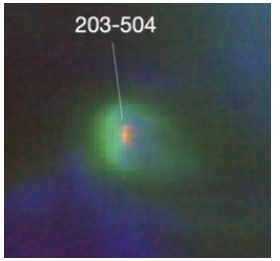
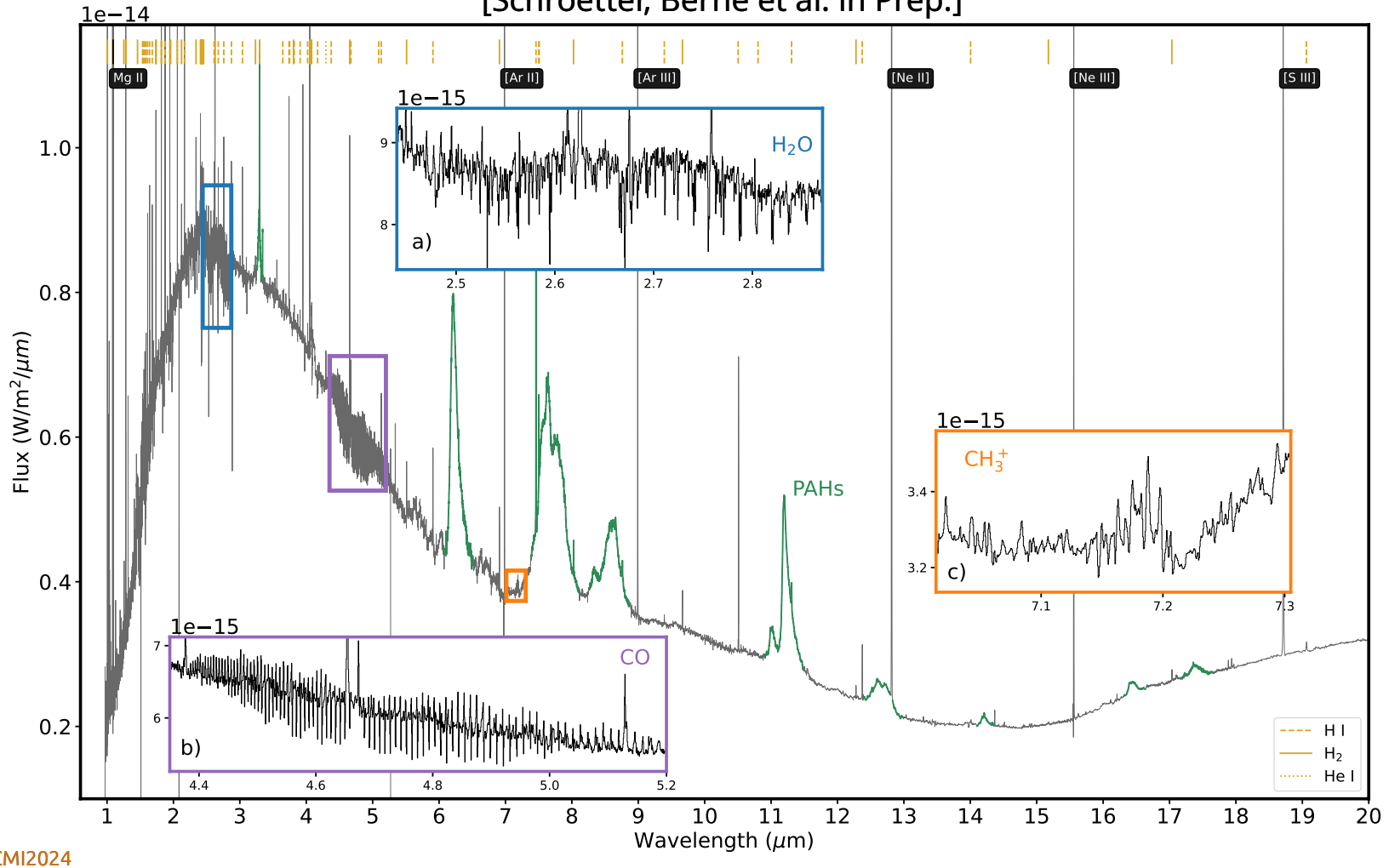
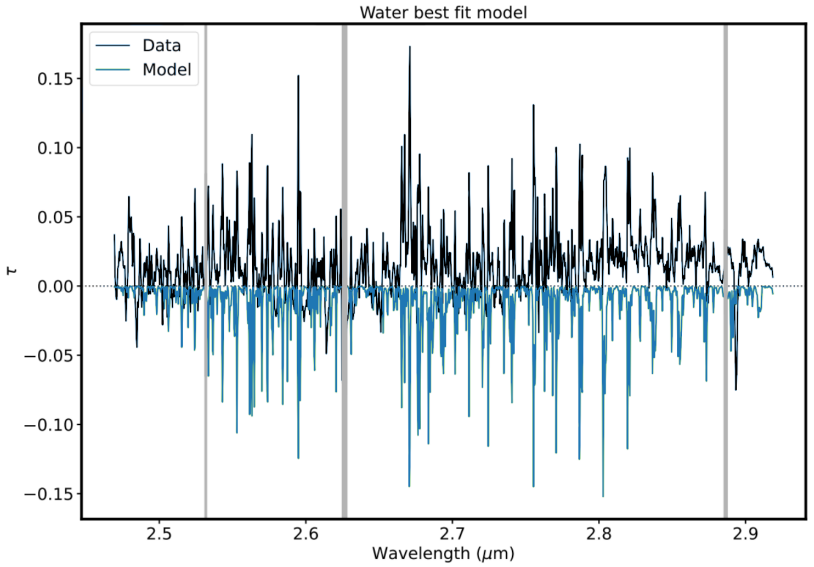
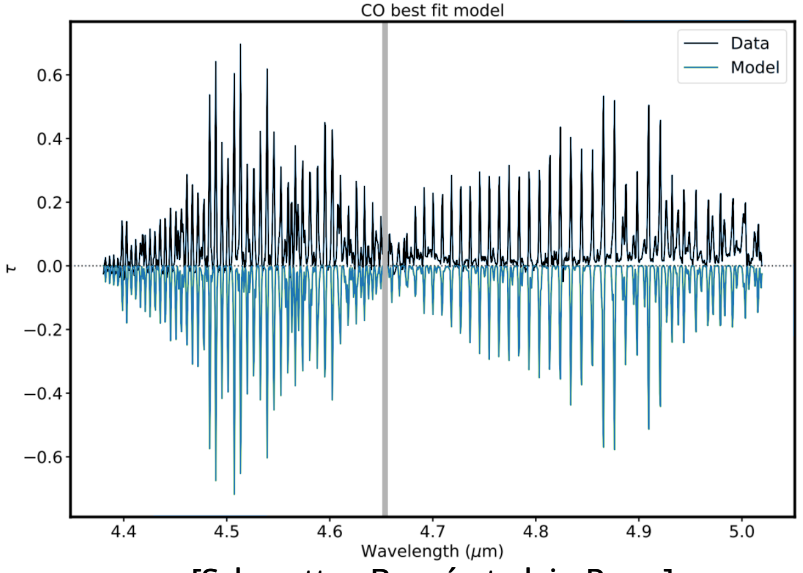


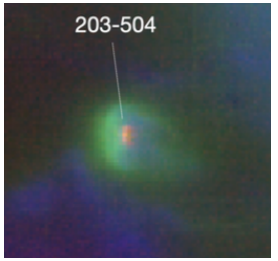






[Schroetter, Berné et al. in Prep.]

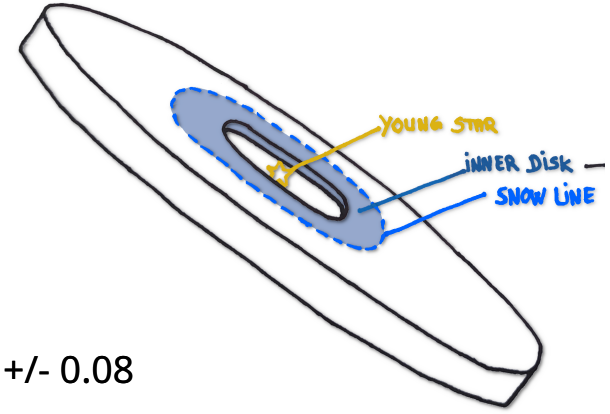
- Water / CO absorption are seen against the viscously heated dust emission



T_{H2O} = 850 +/- 250 K

T_{CO} = 1650 +/- 450 K

- Temperature of molecules implies they are present in the inner 0.05 au



N_{H2O} = 9.1 +/- 1.4 x10^{17} cm^{-2}

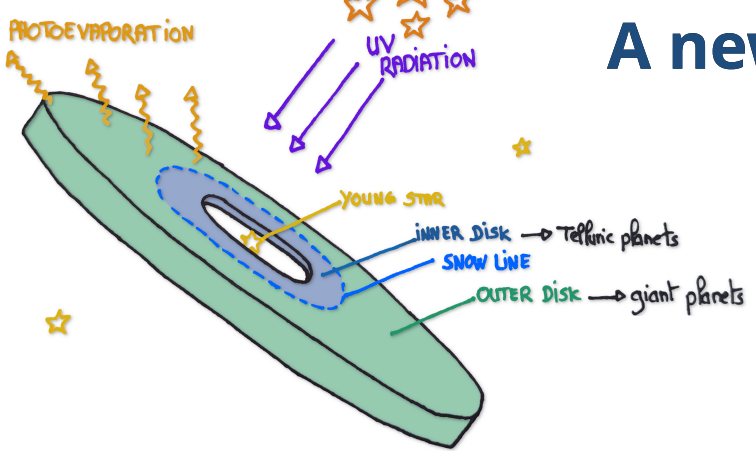
N_{CO} = 1.6 +/- 0.3 x10^{18} cm^{-2}

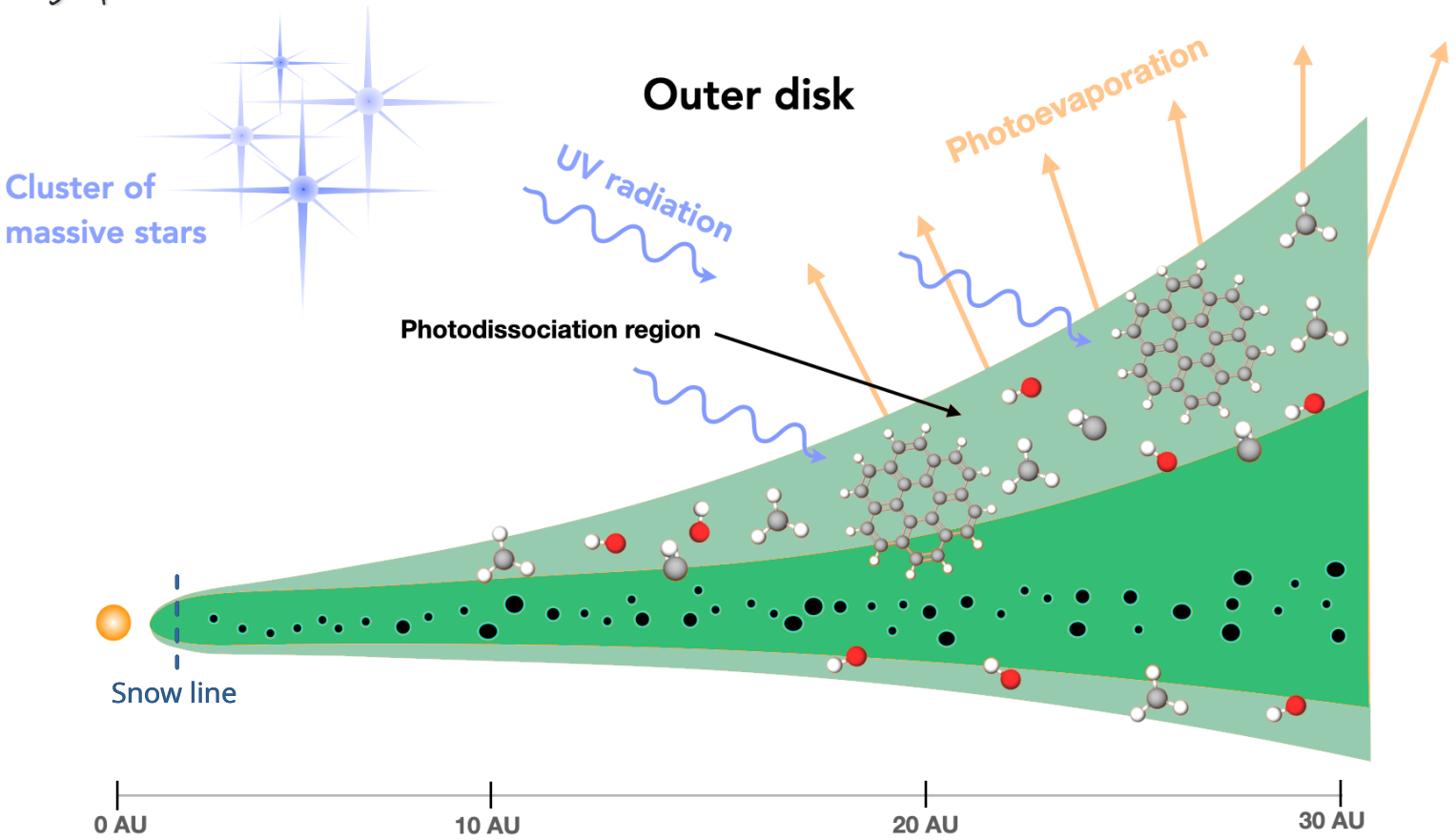
- In the inner disk, C/O ratio is 0.6 +/- 0.08

(Solar System has C/O ratio of 0.6 as well)

A new view on externally UV-irradiated PPDs

[Schroetter, Berné et al. in Prep.]





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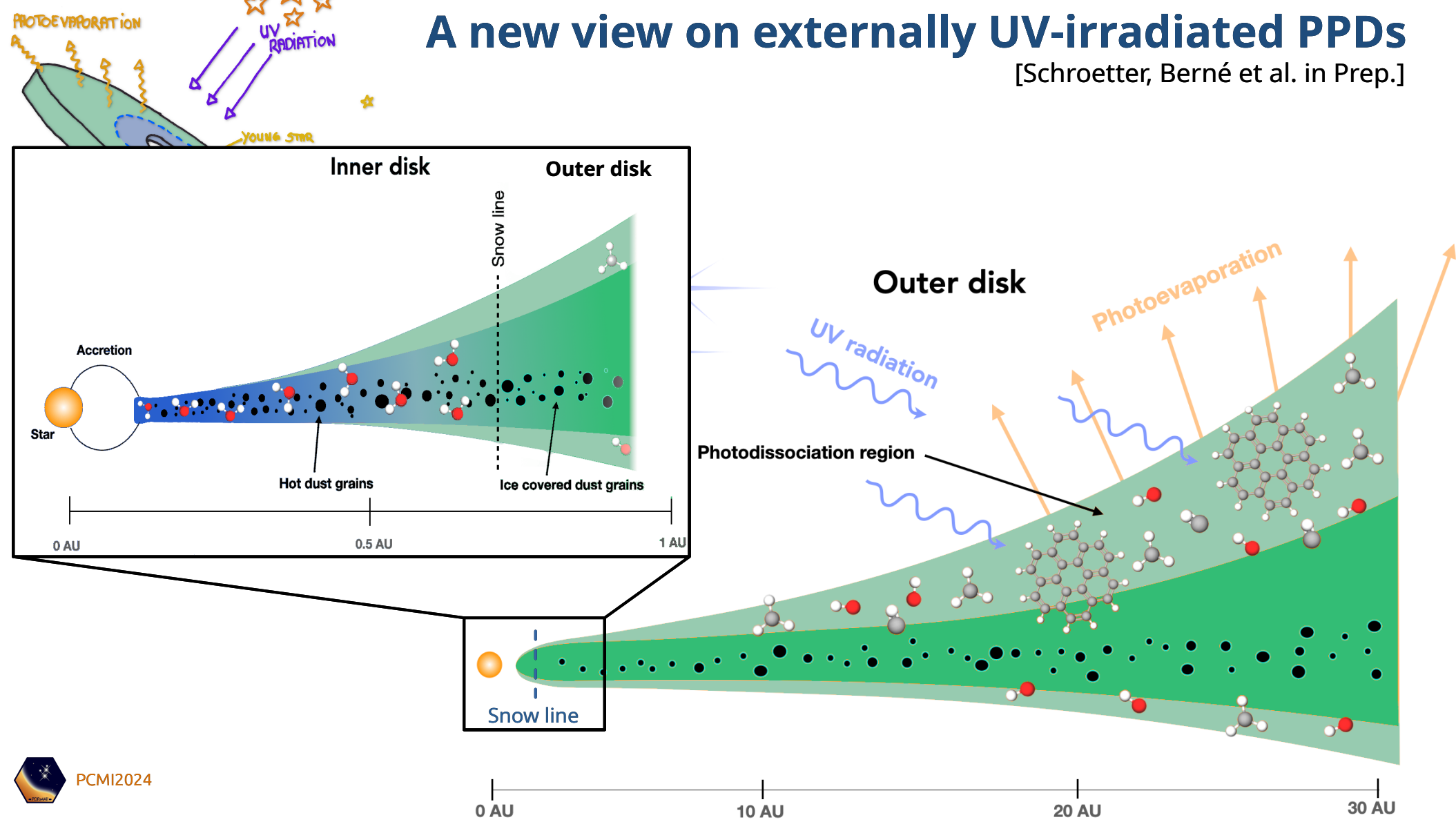

Perspectives

Outer disk: UV is triggering physical (photoevaporation) and chemical (CH_3^+, PAHs) changes.

Inner disk: less affected by UV radiation → simple chemistry (water, CO), will eventually create terrestrial planets!
NEW HINT on how our Solar System formed!

Our results opened-up new branches in observation:

→ the need for more spectroscopy on such objects
→ people are looking for CH_3^+ in their data
→ Many more JWST proposals on PPDs (e.g. R. Boyden, N. Ballering) and with ALMA/NOEMA

Next February:

~70 PPDs in Orion will be observed with NIRSpec
(prog id 5547, Rogers, Berné, De Marchi, Schroetter)

Follow up with MIRI:

" A MIRI spectroscopic atlas of irradiated disks in Orion"

Cycle 4 MIRI medium program submitted (PIs Schroetter+Berné+Boyden)