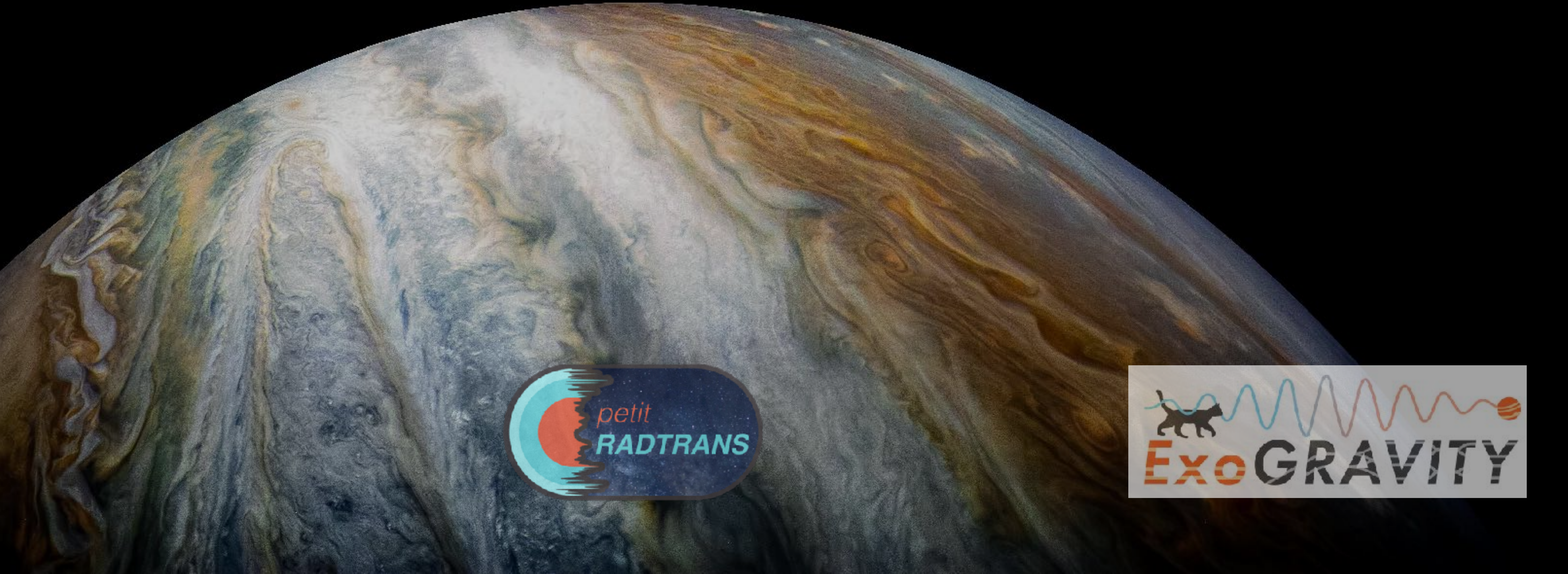
Four of a Kind: HR8799

Exploring the atmospheres of the HR 8799 system with GRAVITY



Evert Nasedkin
ATMO 2021
August 25, 2021

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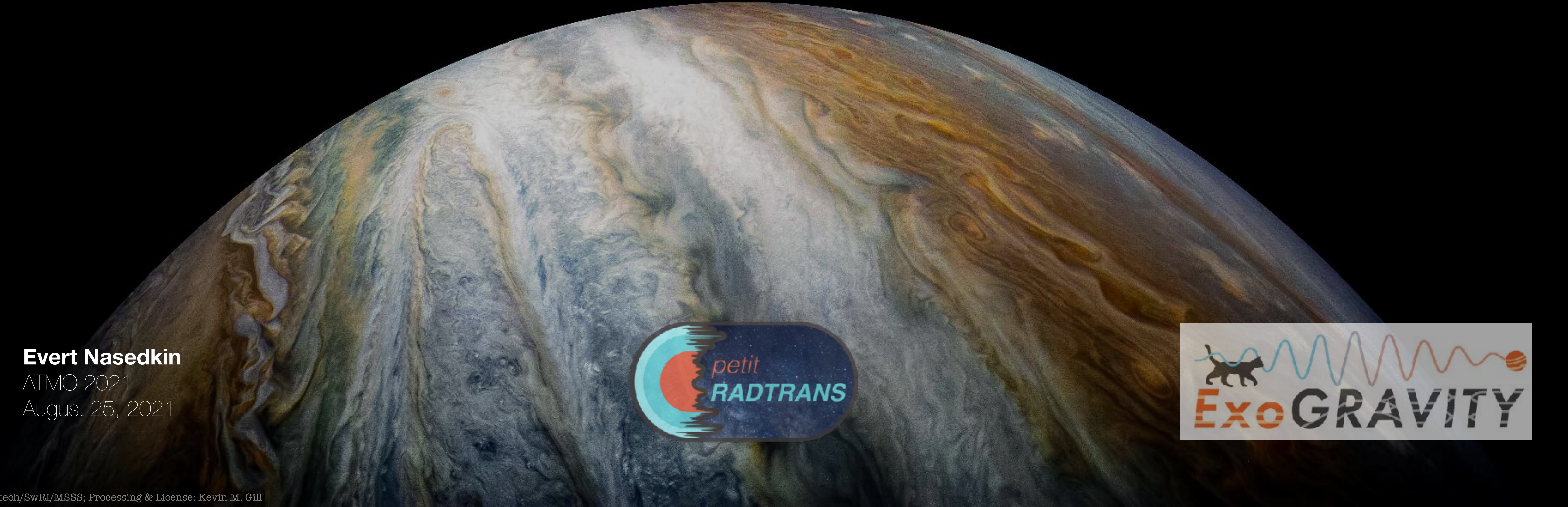

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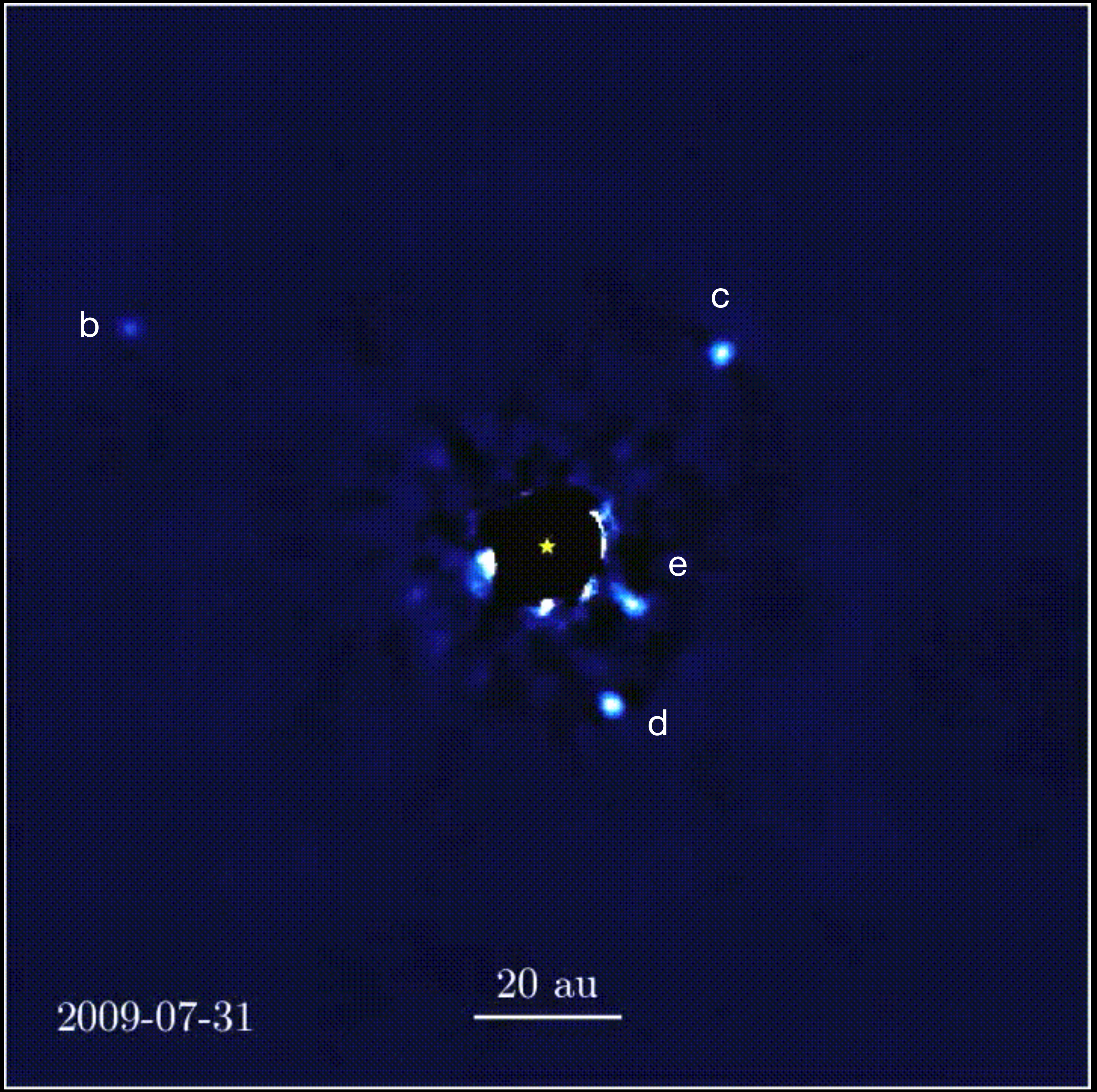
petit RADTRANS

ExoGRAVITY

NASA/JPL-Caltech/SwRI/MSSS; Processing & License: Kevin M. Gill

This is HR8799



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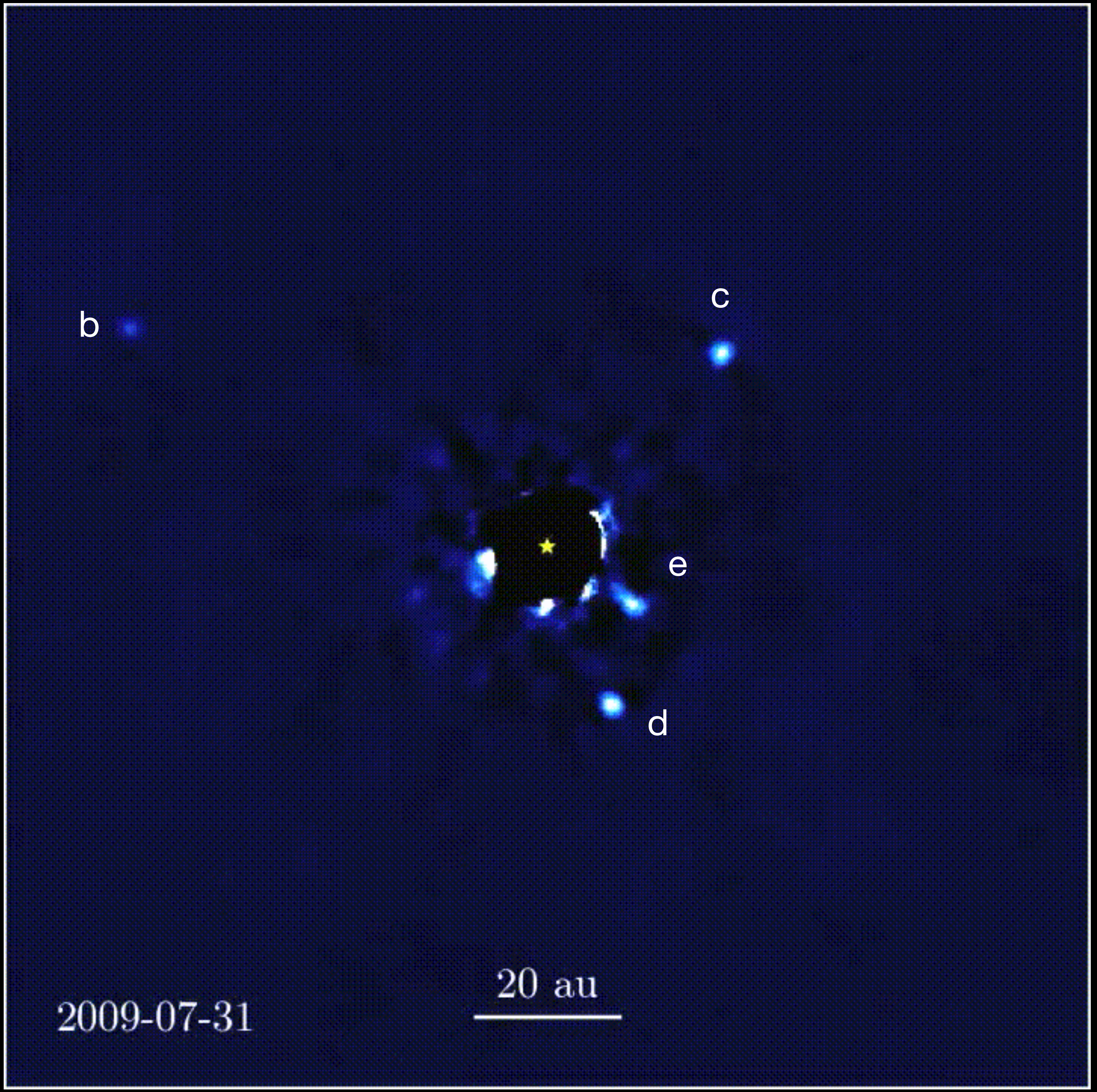

Jason Wang (Caltech)/Christian Marois (NRC Herzberg)

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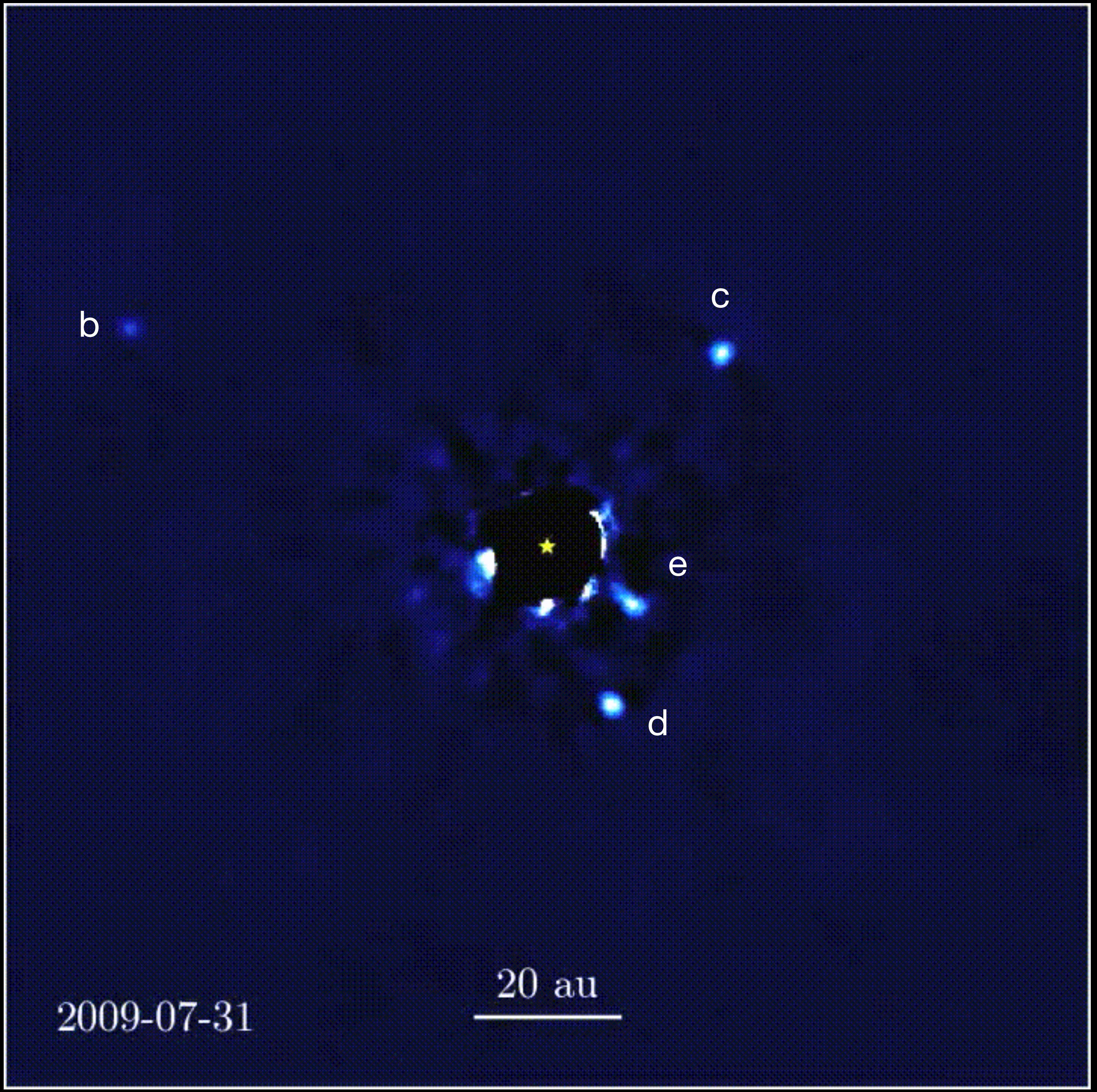
- Originally detected by Marois et al. (2008)



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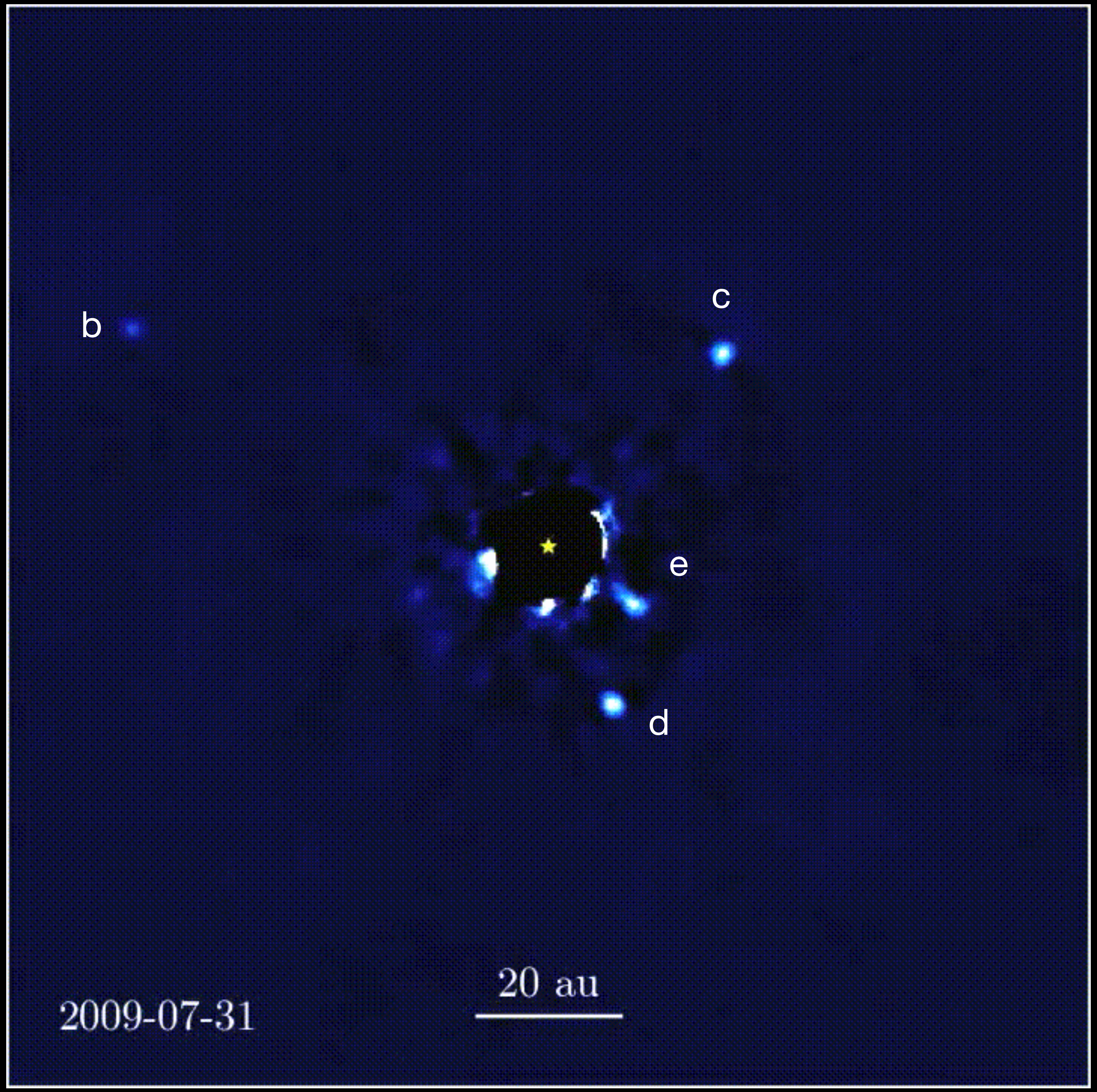

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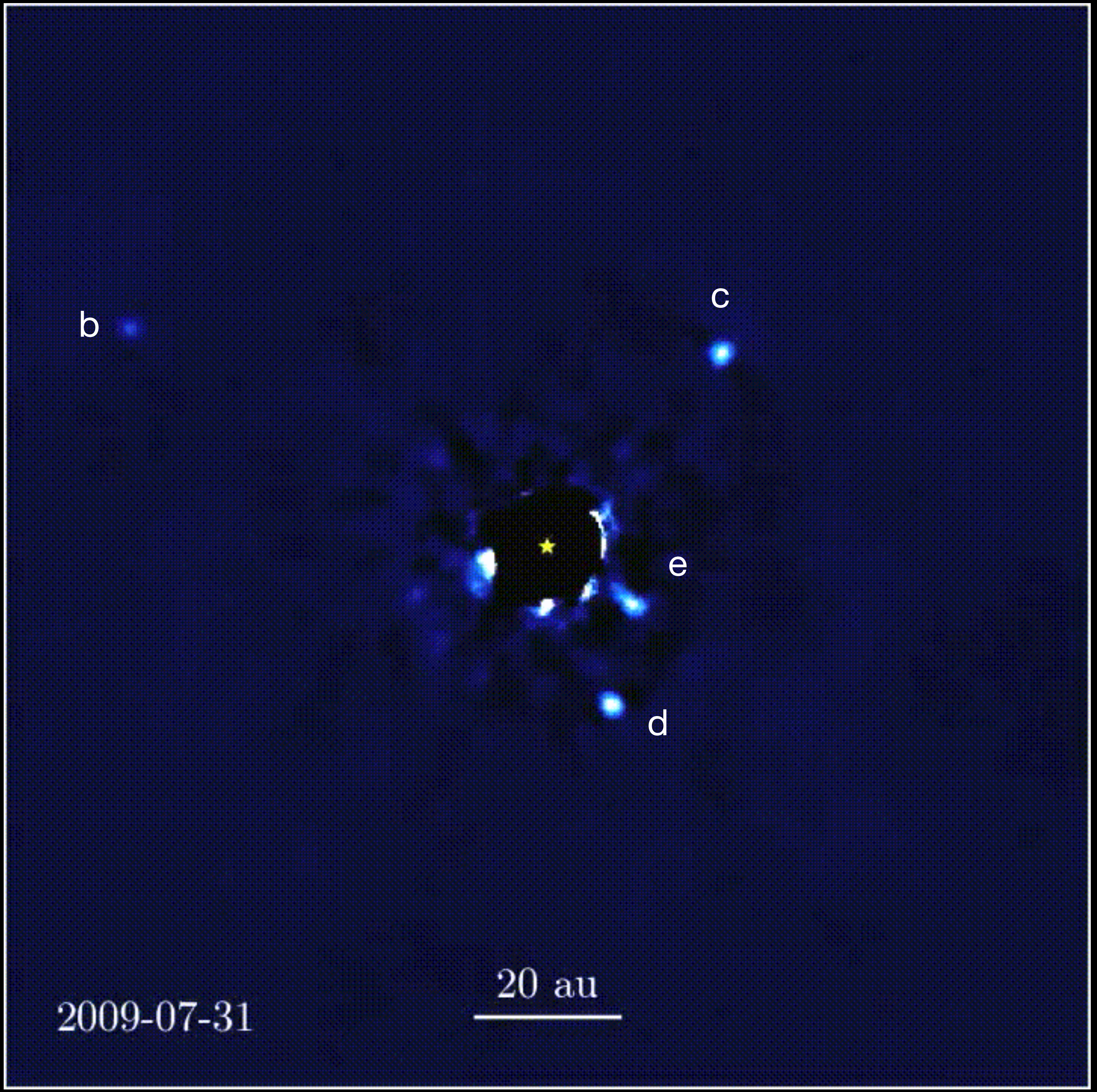
- Originally detected by Marois et al. (2008)
- Only directly imaged system with more than two planets
- Upper limits on planet masses from dynamical and stability arguments (Wang et al 2018, Brandt et al 2021)



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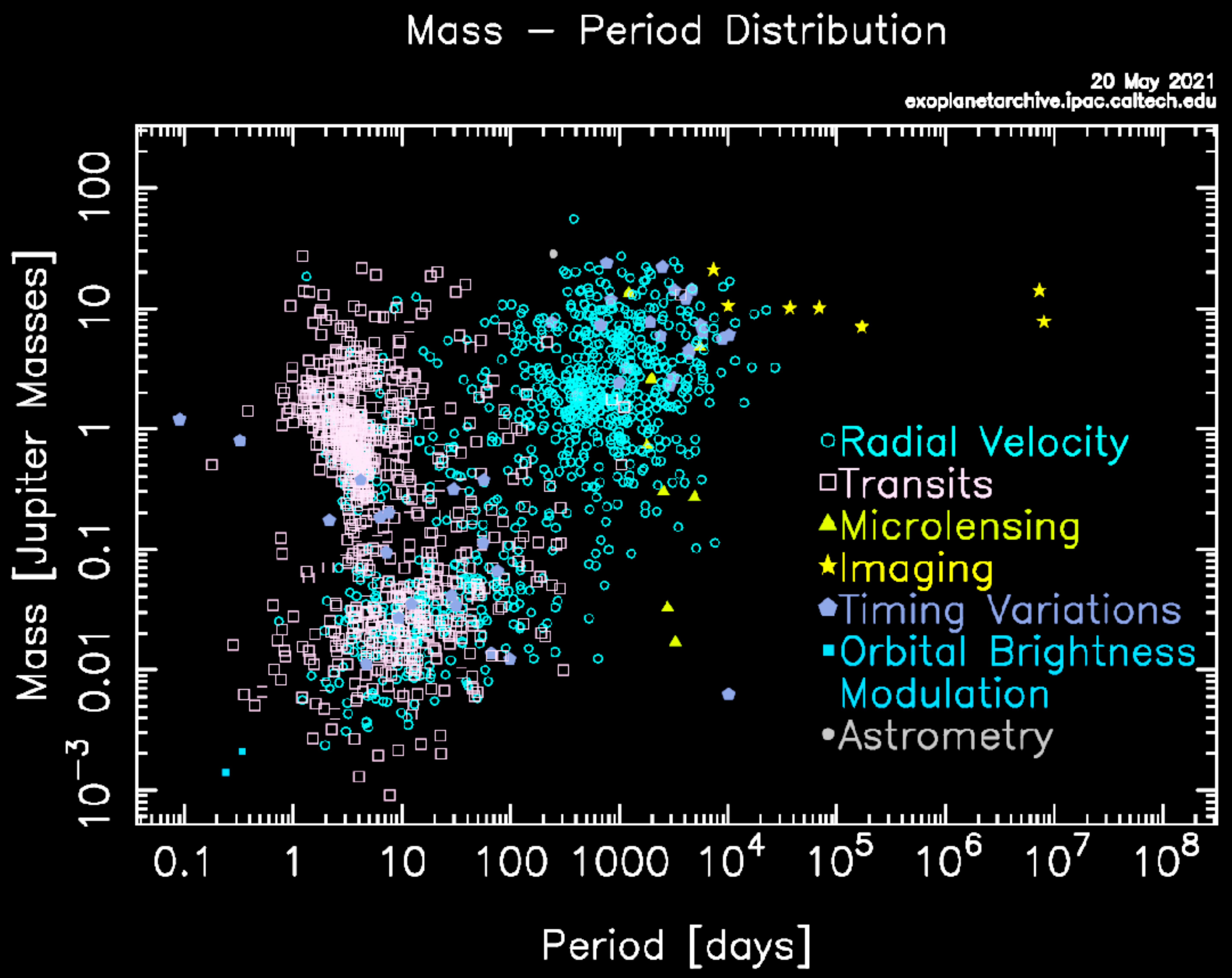

Mass – Period Distribution
20 May 2021
exoplanetarchive.ipac.caltech.edu
Mass [Jupiter Masses]
100
10
1
0.1
0.01
10^{-3}
0.1
1
10
100
1000
10^4
10^5
10^6
10^7
10^8
Period [days]
Radial Velocity
Transits
Microlensing
Imaging
Timing Variations
Orbital Brightness Modulation
Astrometry

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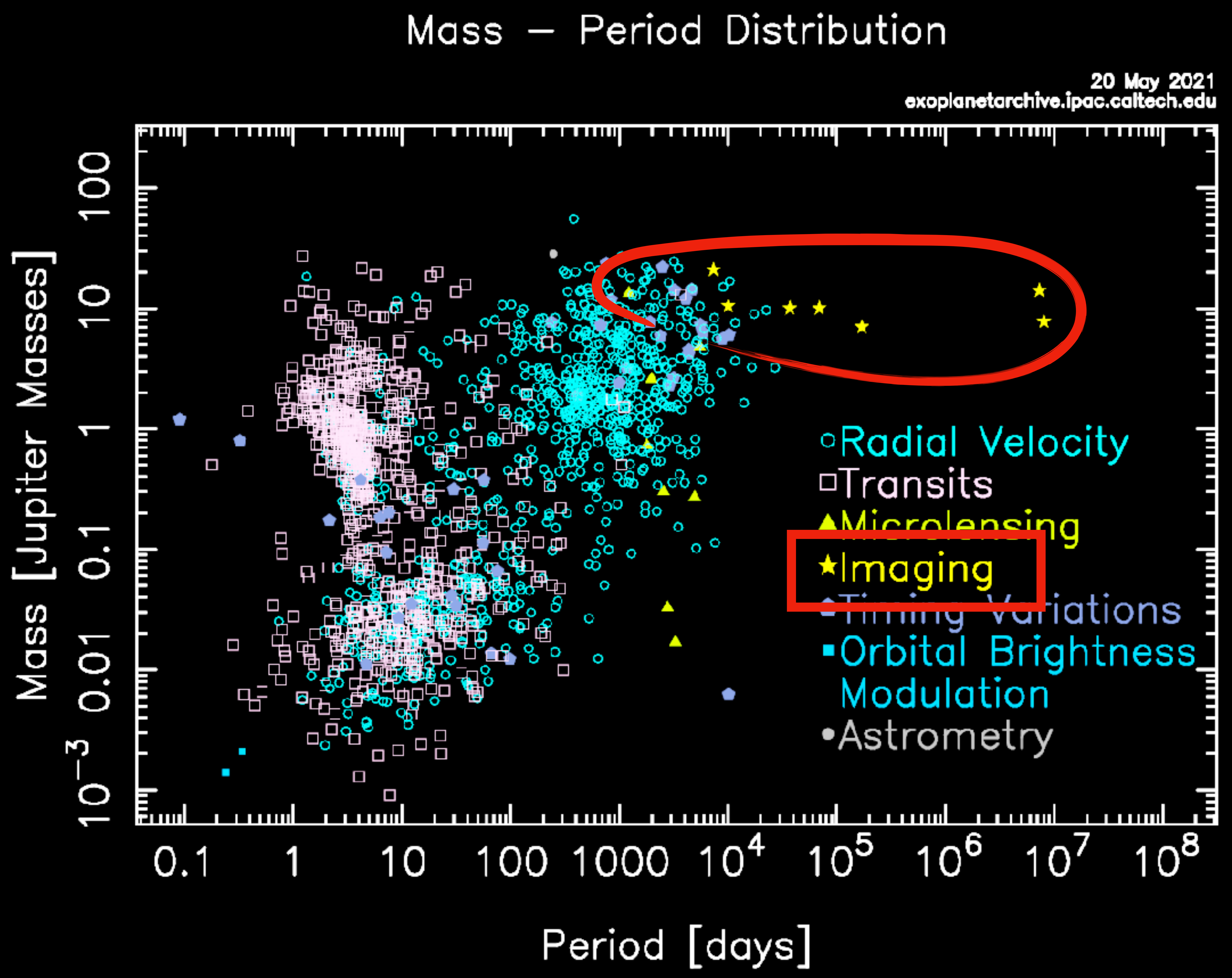

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100
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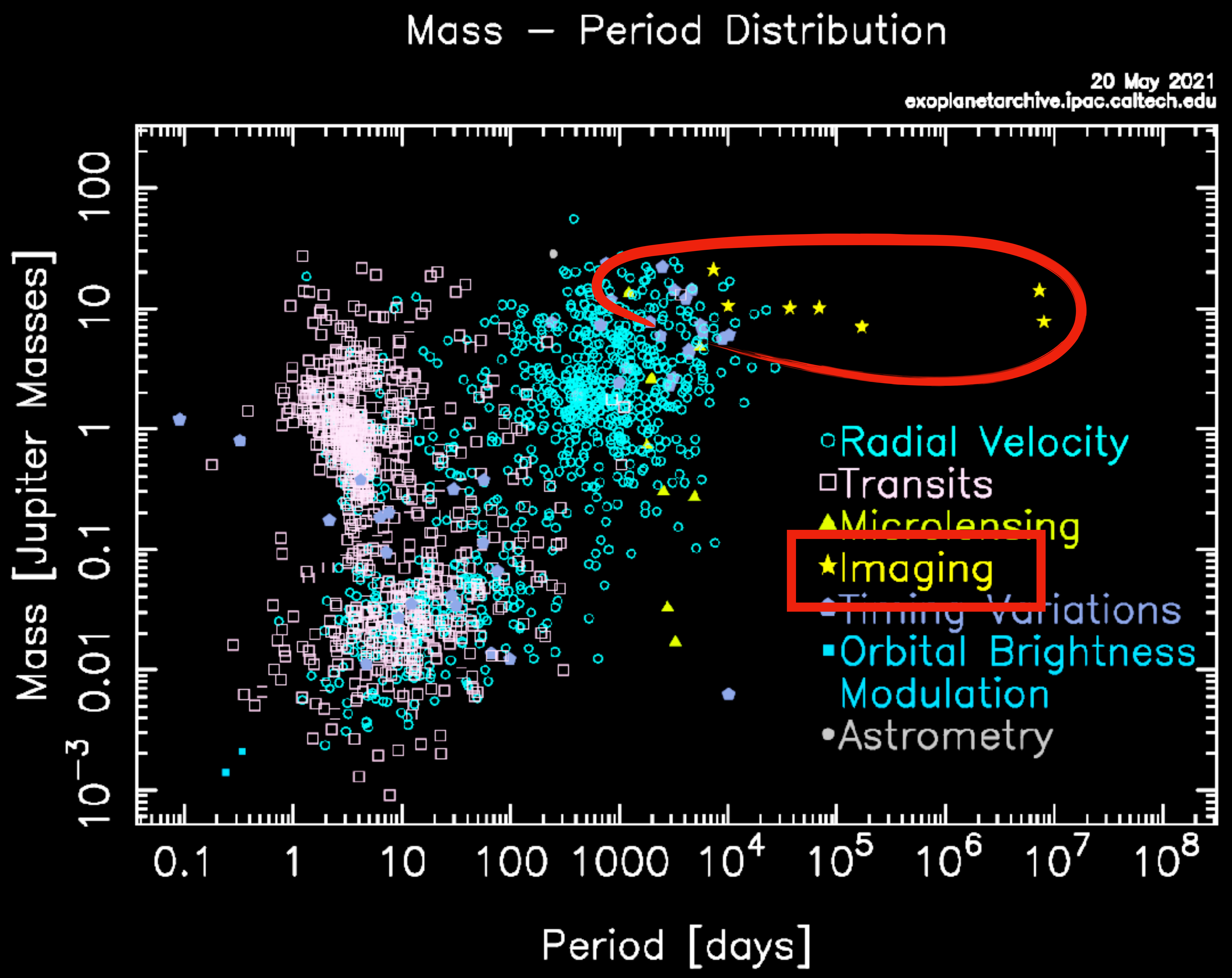
- Directly imaged planets are young, hot and massive



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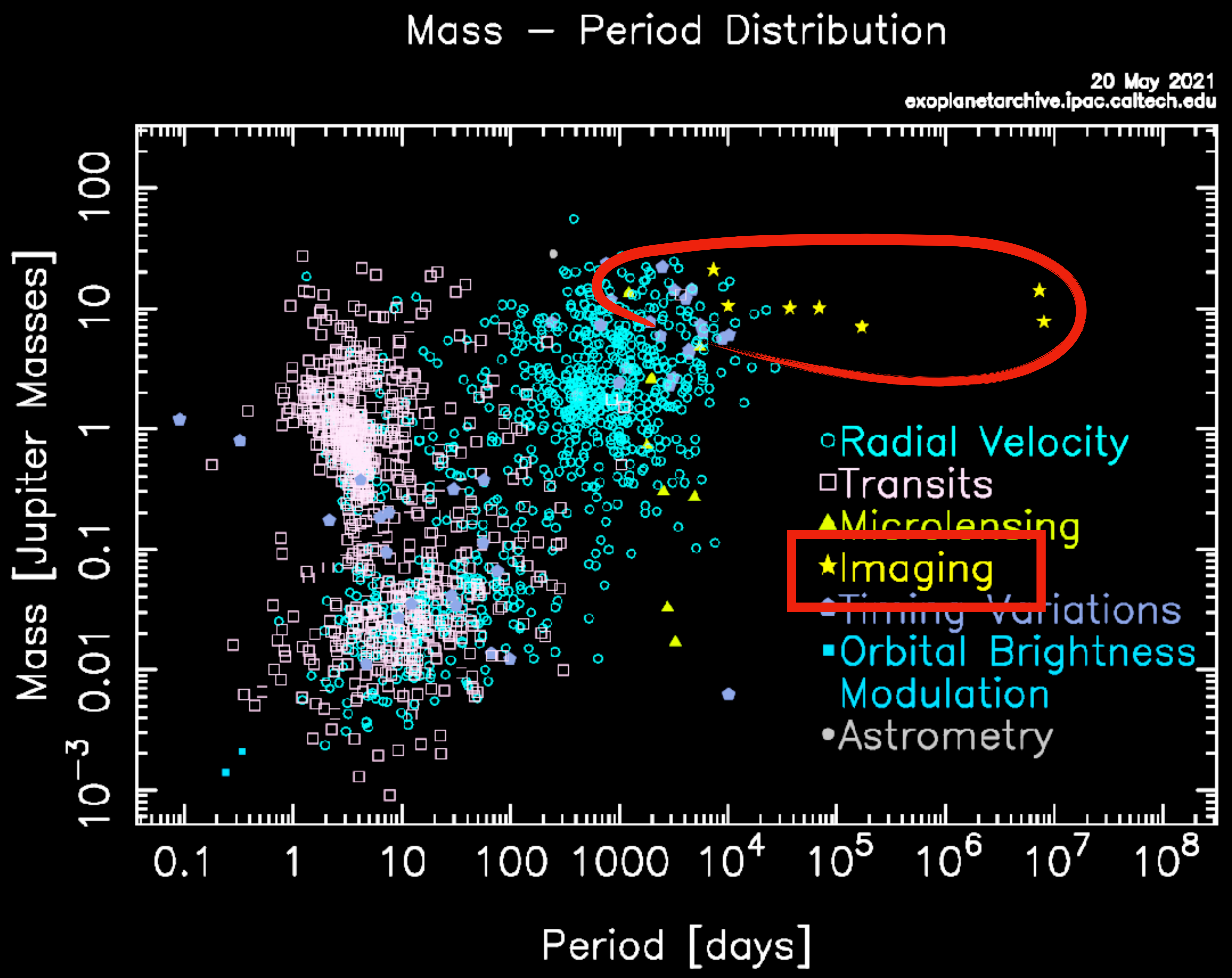
- Their mass and temperature range is more similar to brown dwarfs than most exoplanets.



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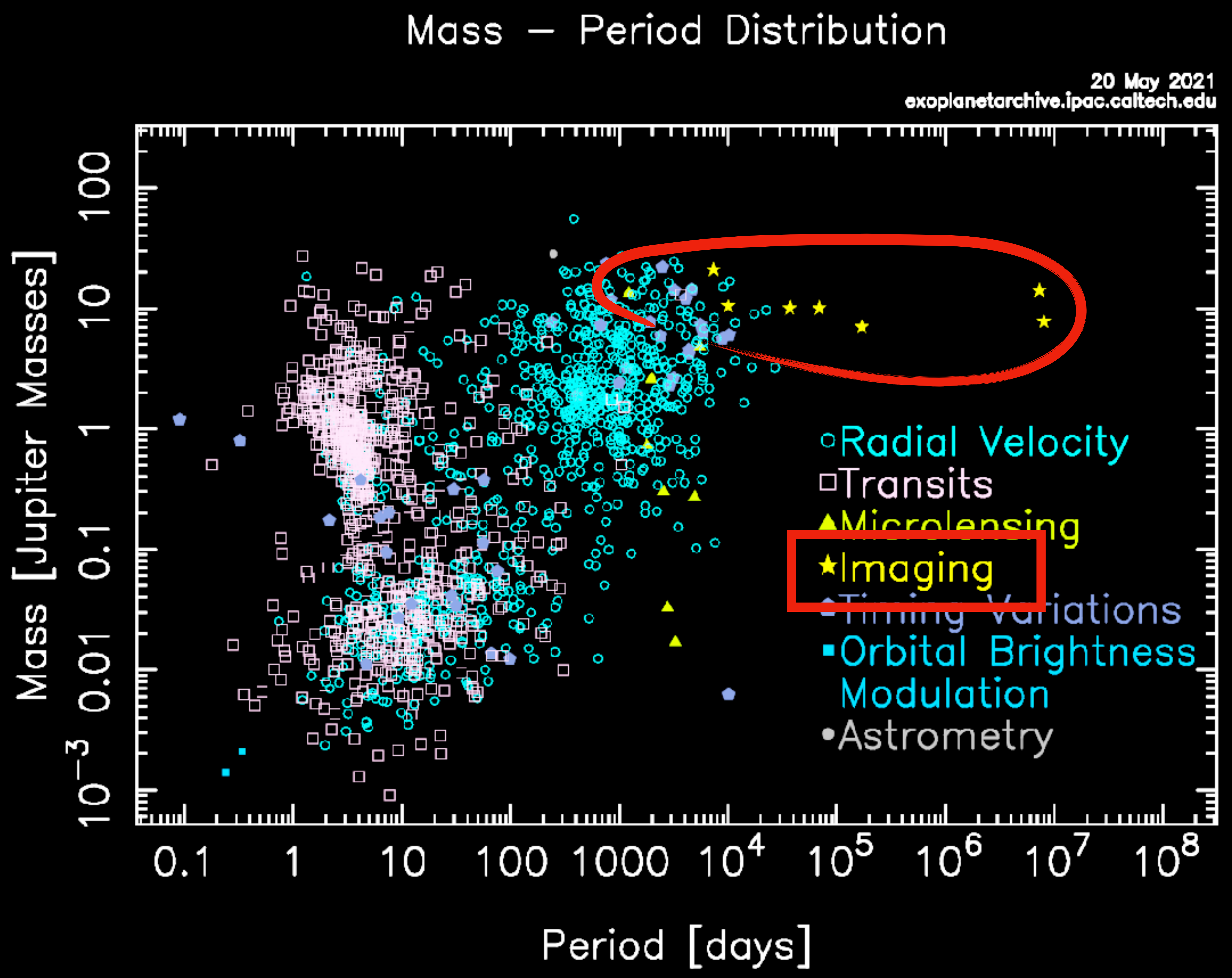
- Directly imaged planets are young, hot and massive
- Their mass and temperature range is more similar to brown dwarfs than most exoplanets.
- **Most** planets are not transiting, and can only be accessed with future direct imaging missions.



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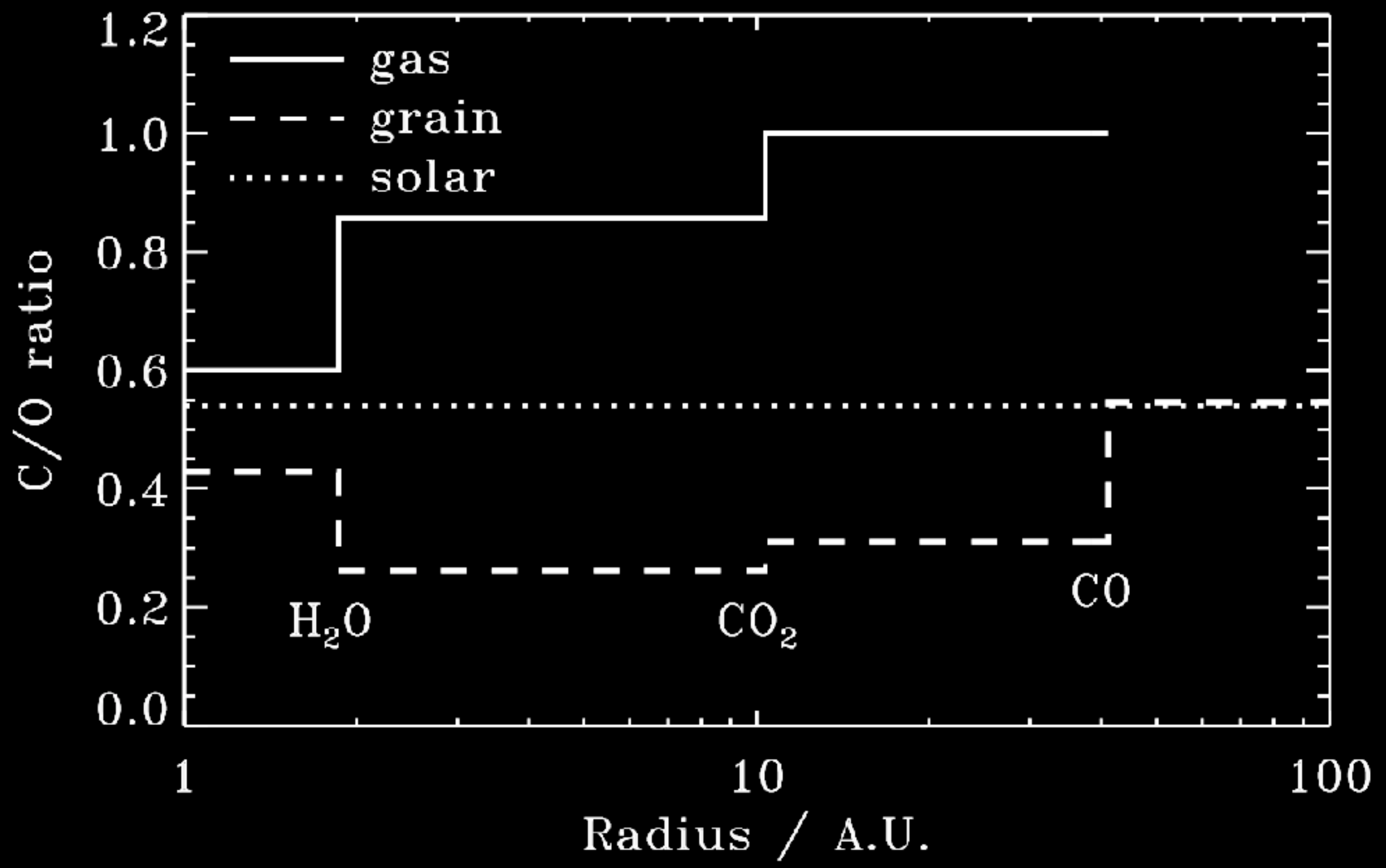
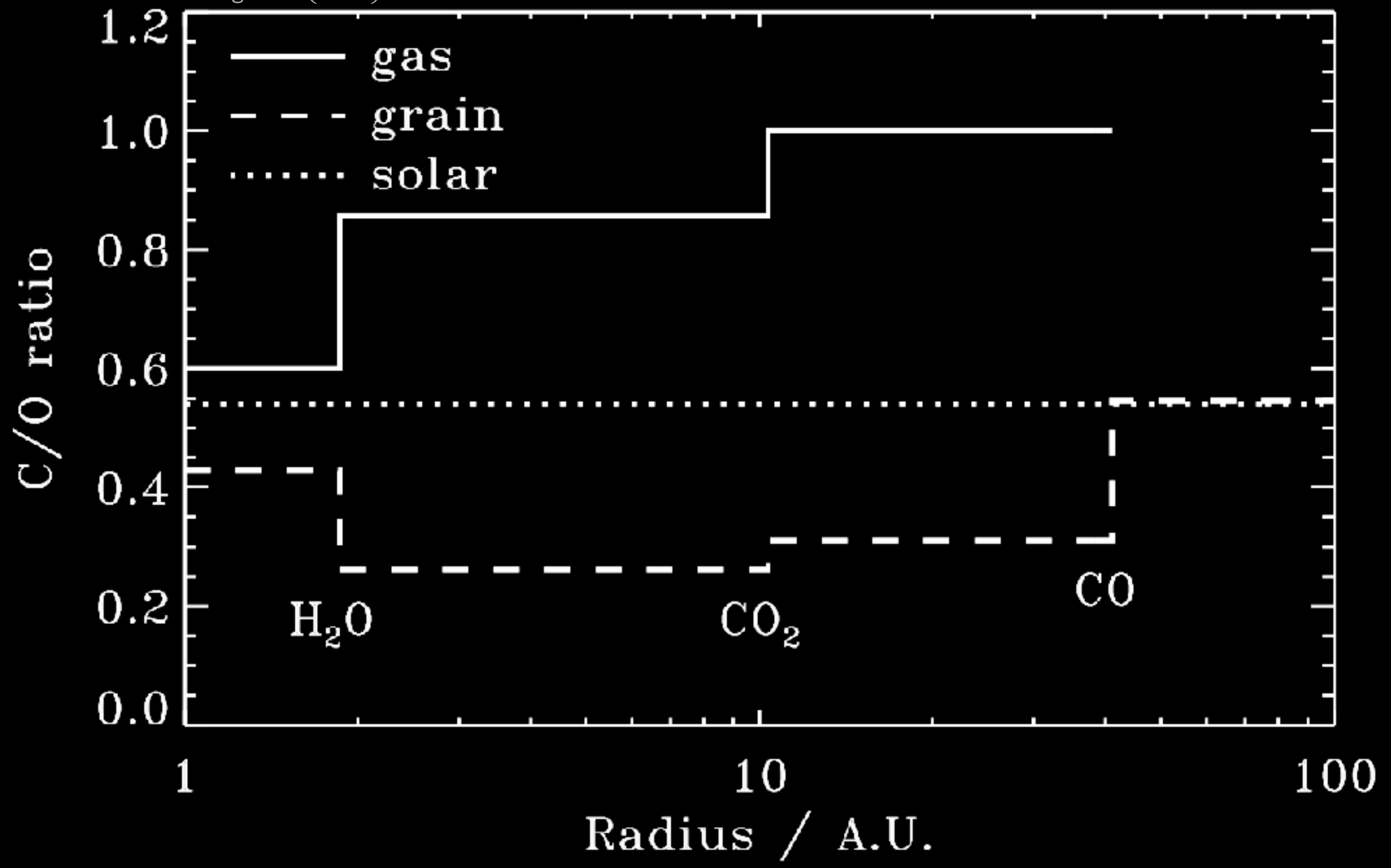


Fig. 1.— The C/O ratio in the gas and in grains, assuming the temperature structure of a 'typical' protoplanetary disk around a solar-type star (T_0 is 200 K, and $q = 0.62$). The H_2O, CO_2 and CO snow-lines are marked for reference.

Context

Öberg et al. (2011) APJ 743 1 L16



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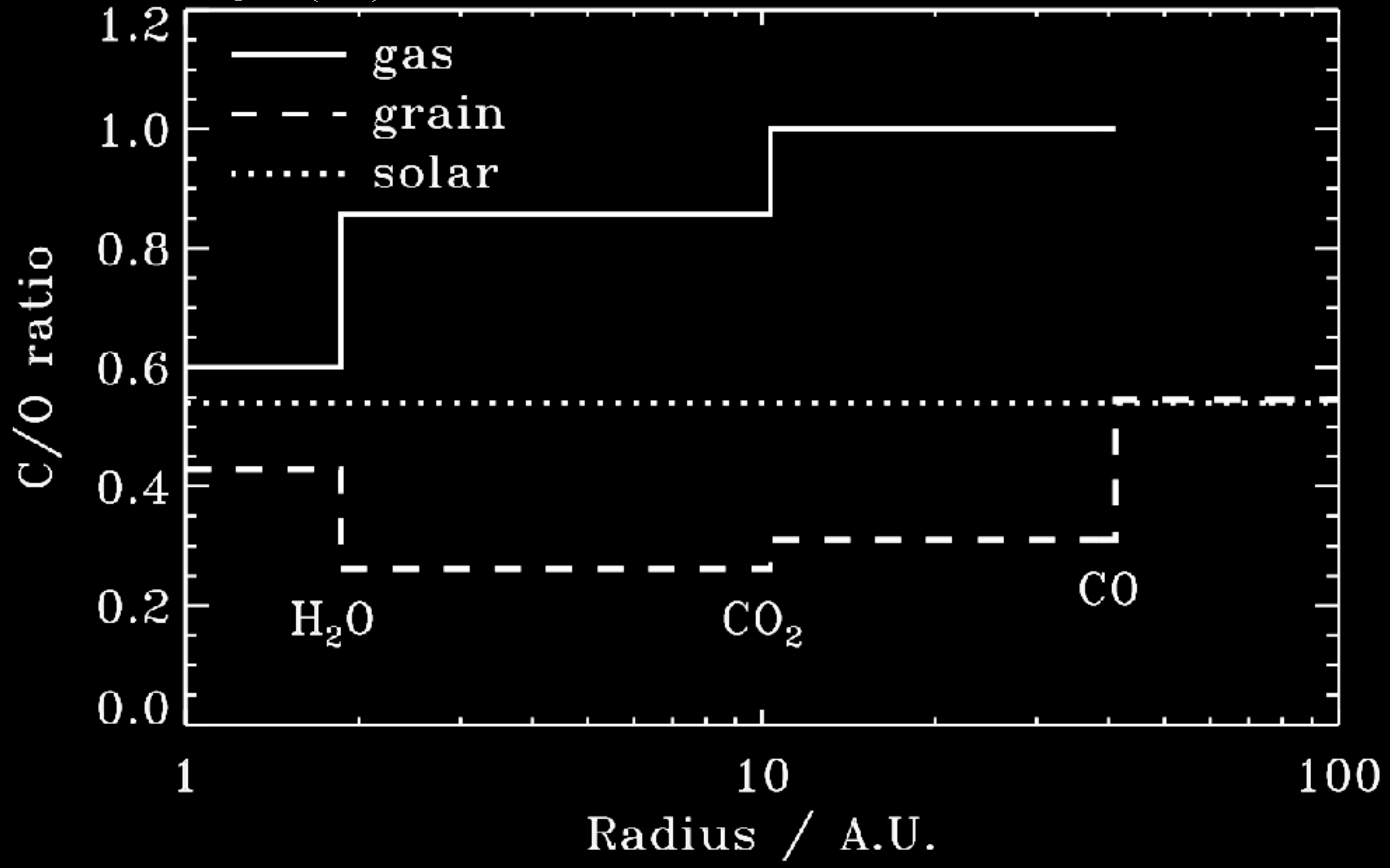

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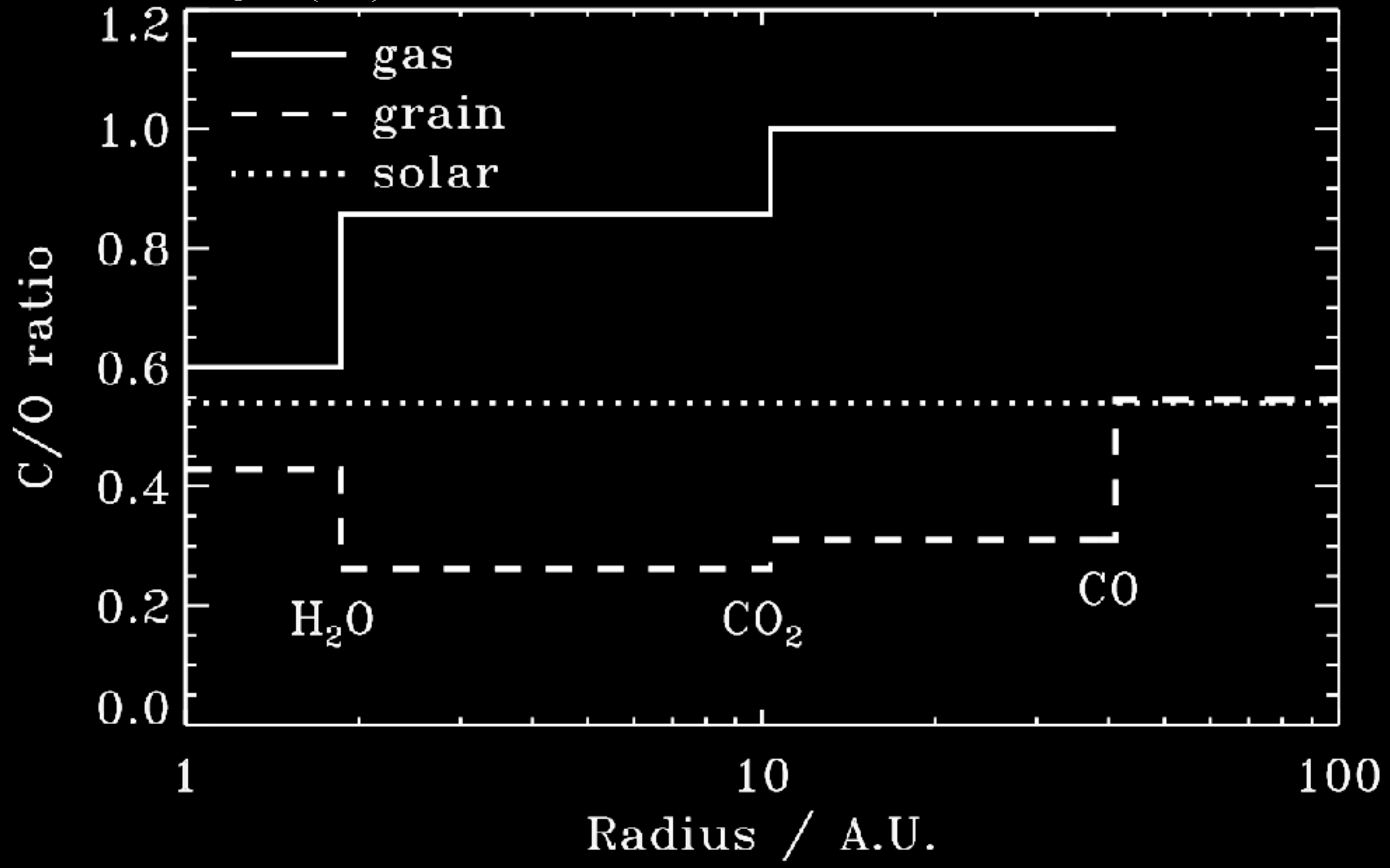
- The composition of these planets, particularly the carbon-to-oxygen number ratio (C/O) traces the location of formation, which can help us infer the mechanism

Öberg et al. (2011) APJ 743 1 L16



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So how do we measure that?

Atmospheric Retrieval

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Parameter Selection	Data	Molecular + Atomic line lists

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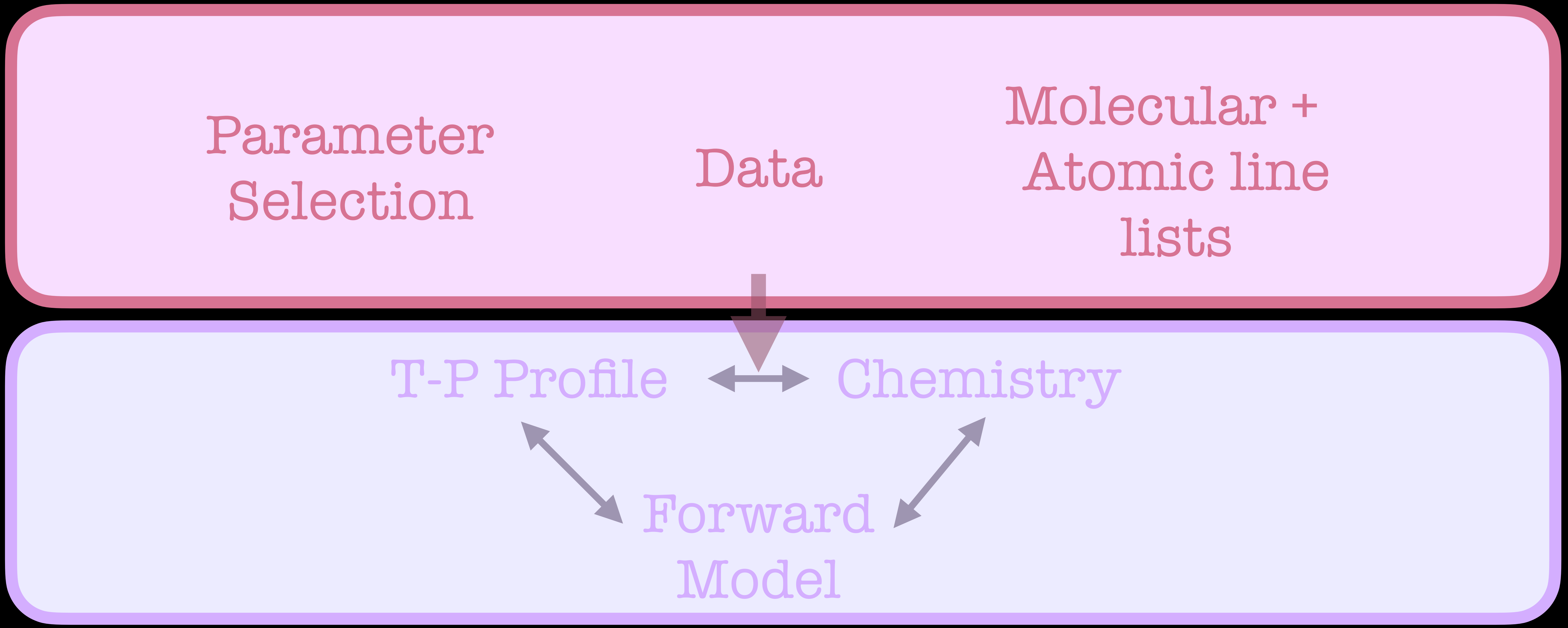

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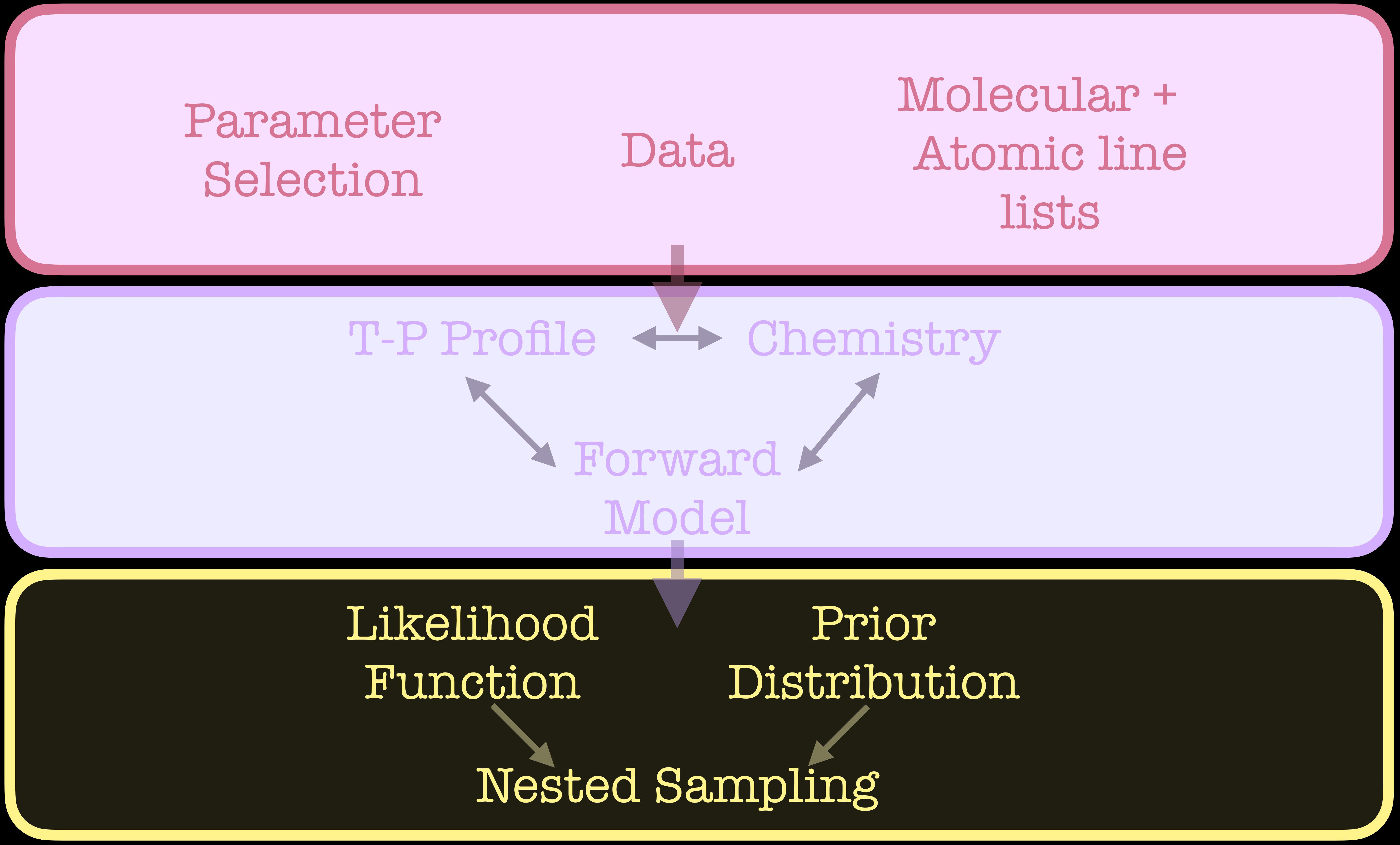

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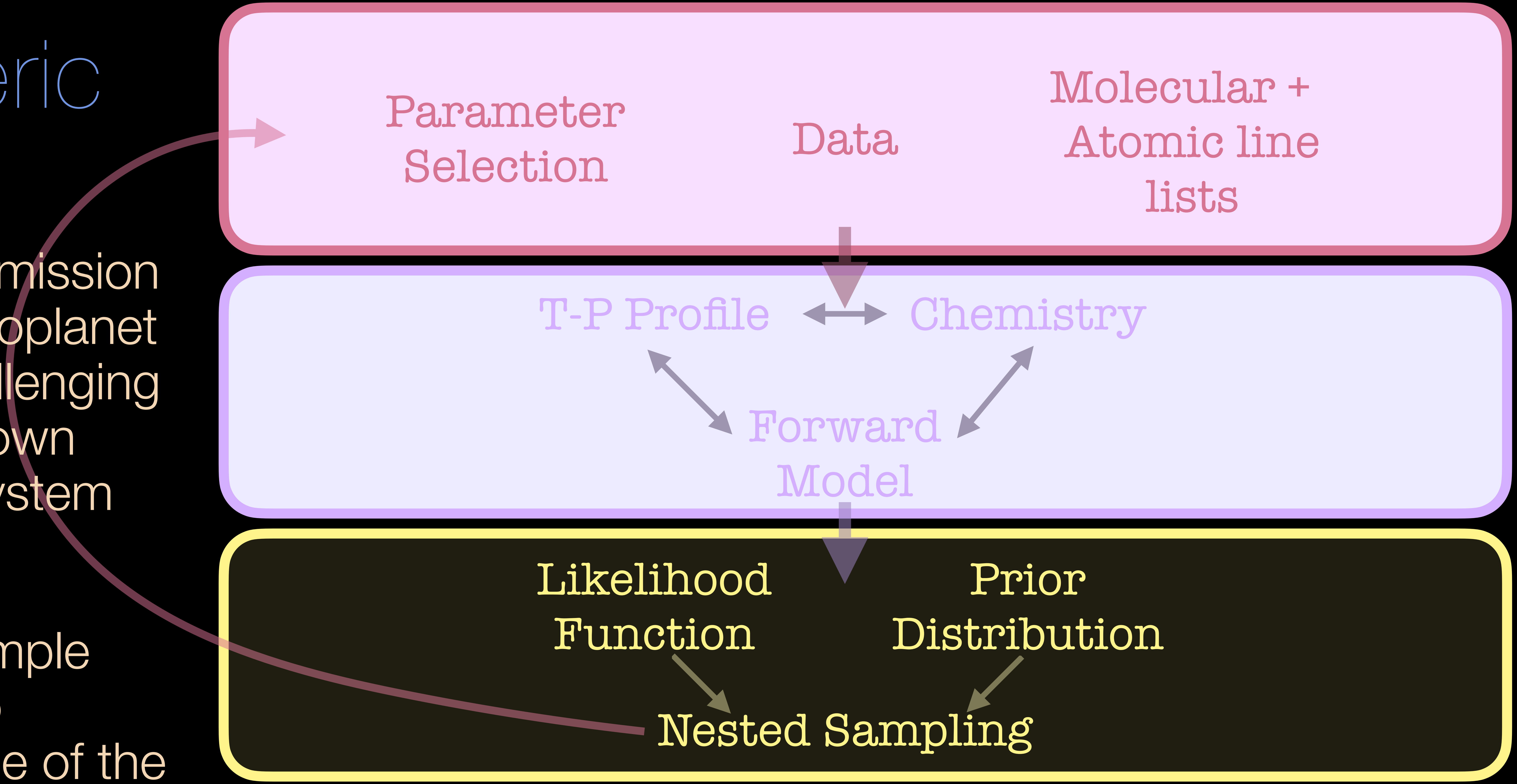

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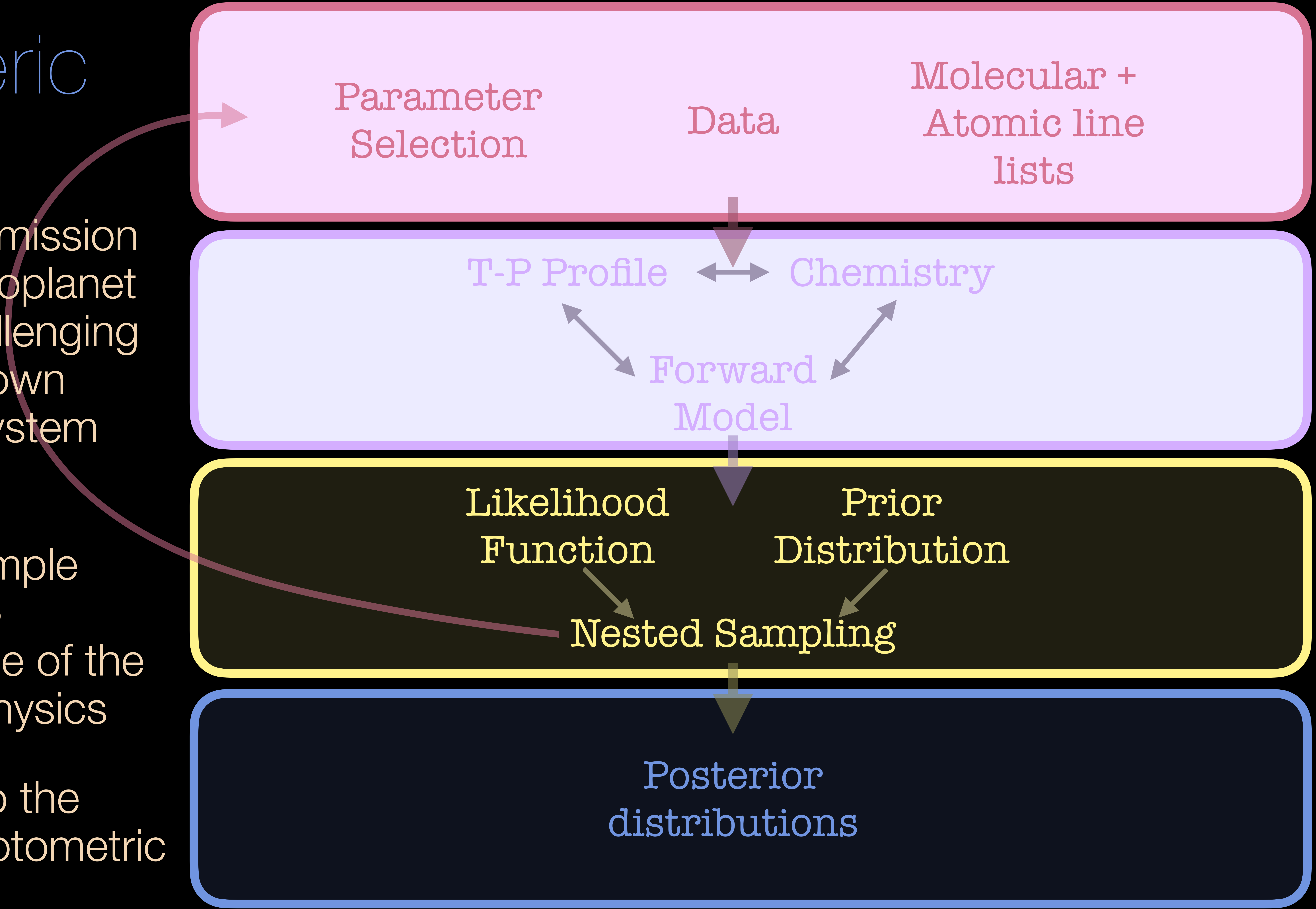
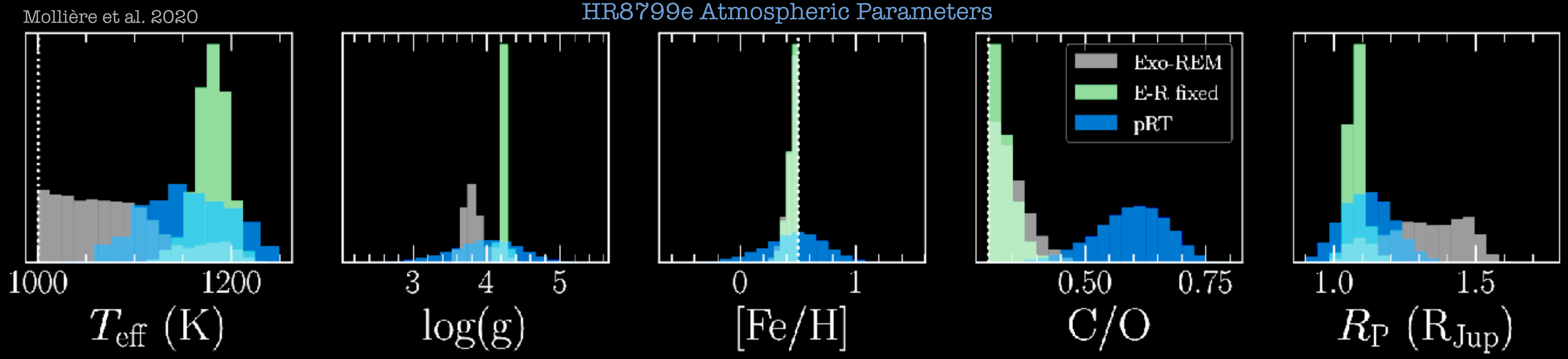


Modelling the HR8799 planets

Mollière et al. 2020

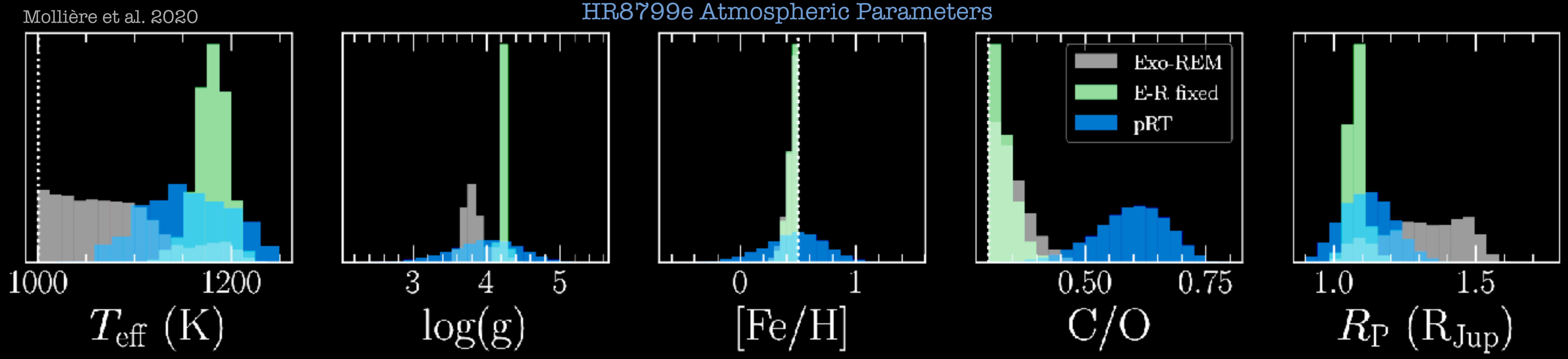
HR8799e Atmospheric Parameters

Modelling the HR8799 planets



- Our model is based on Mollière et al. (2020), using petitRADTRANS.

Modelling the HR8799 planets



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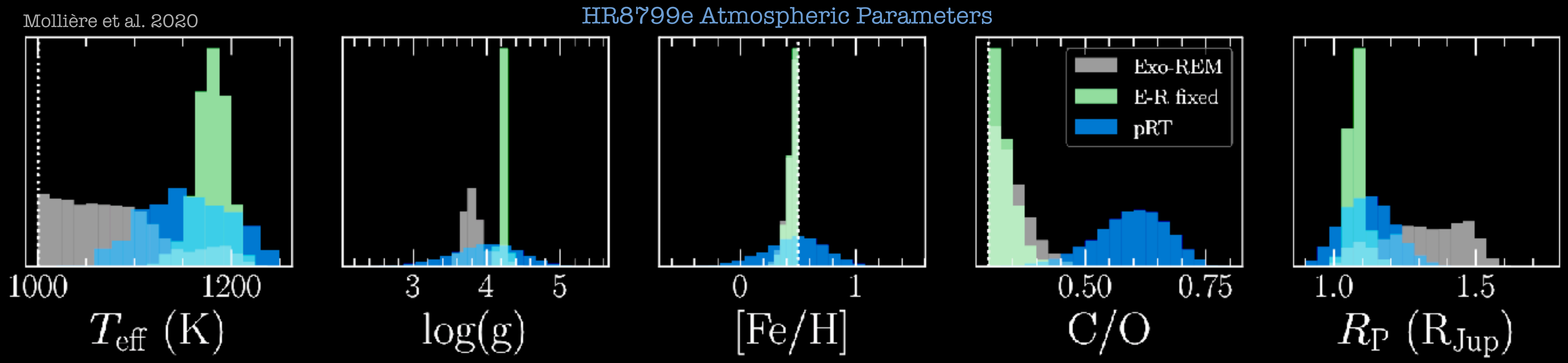

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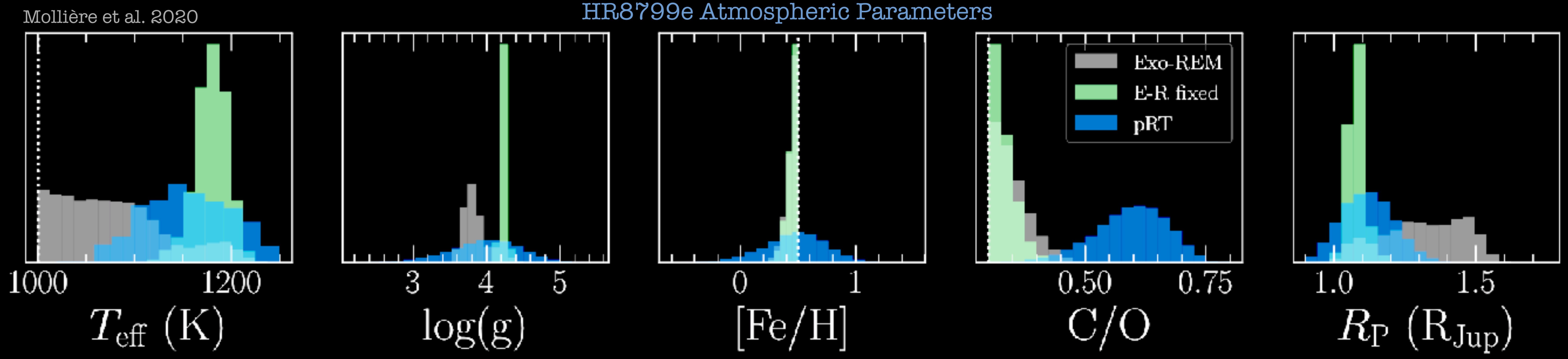

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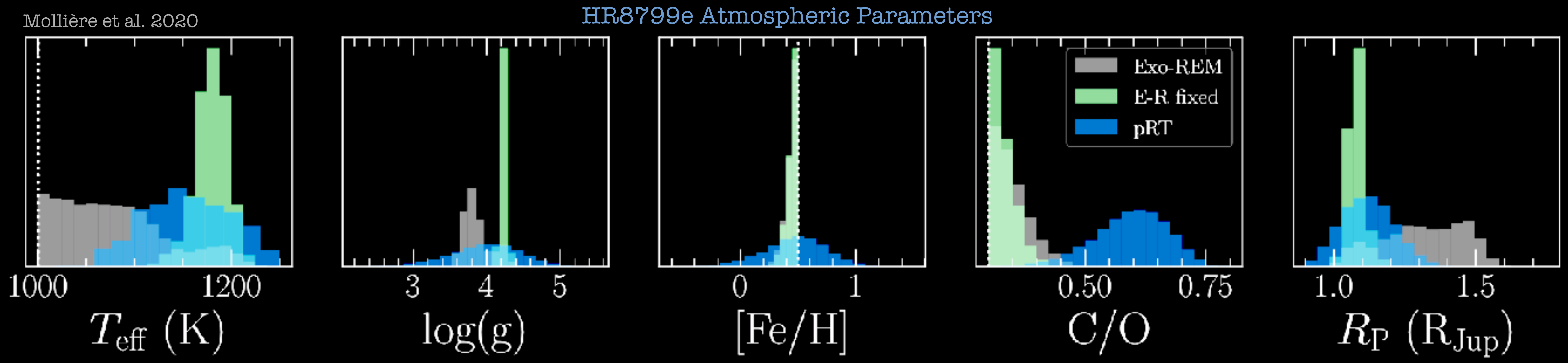

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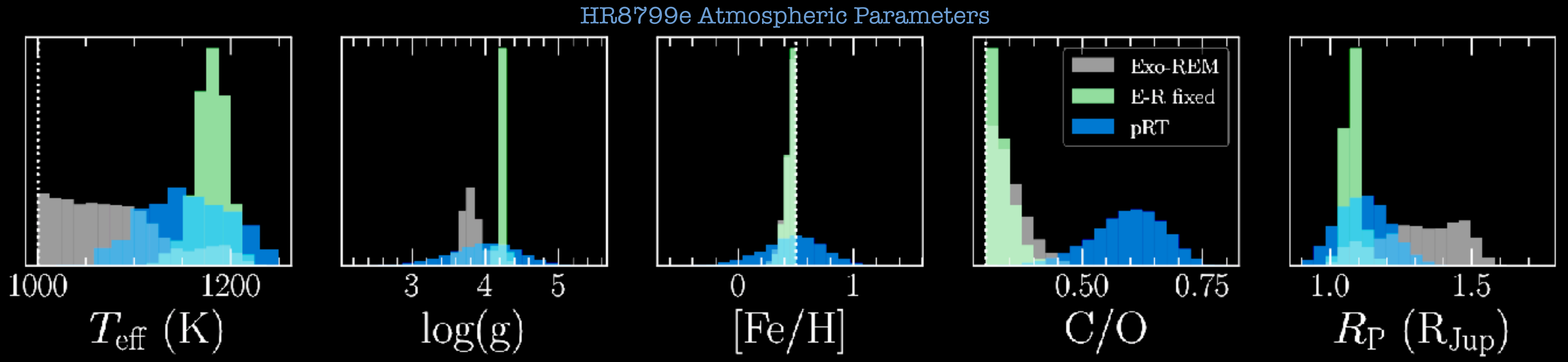

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- Recent updates to pRT include improved adaptive pressure grids, Hansen clouds coupled to AM01, and improved CIA handling.

We’re only as good as our data!

GRAVITY

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- The current observations have a spectral resolution of 500, but 4000 is possible.

ExoGRAVITY

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- **HD 206893:** Kammerer: et al. 2021

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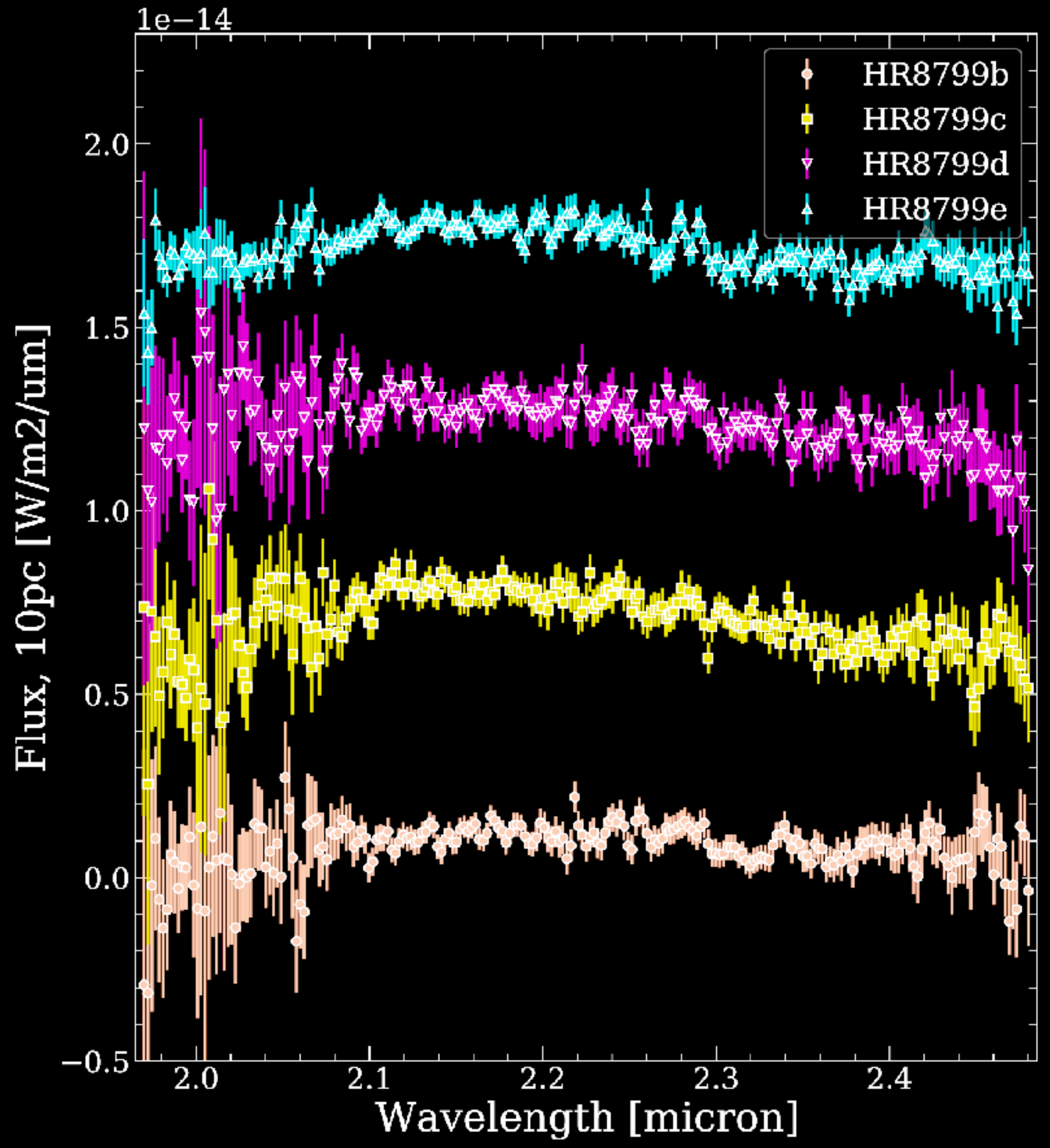
- The first GRAVITY data for HR8799e was taken in 2018 (Gravity Collaboration et al. 2019)



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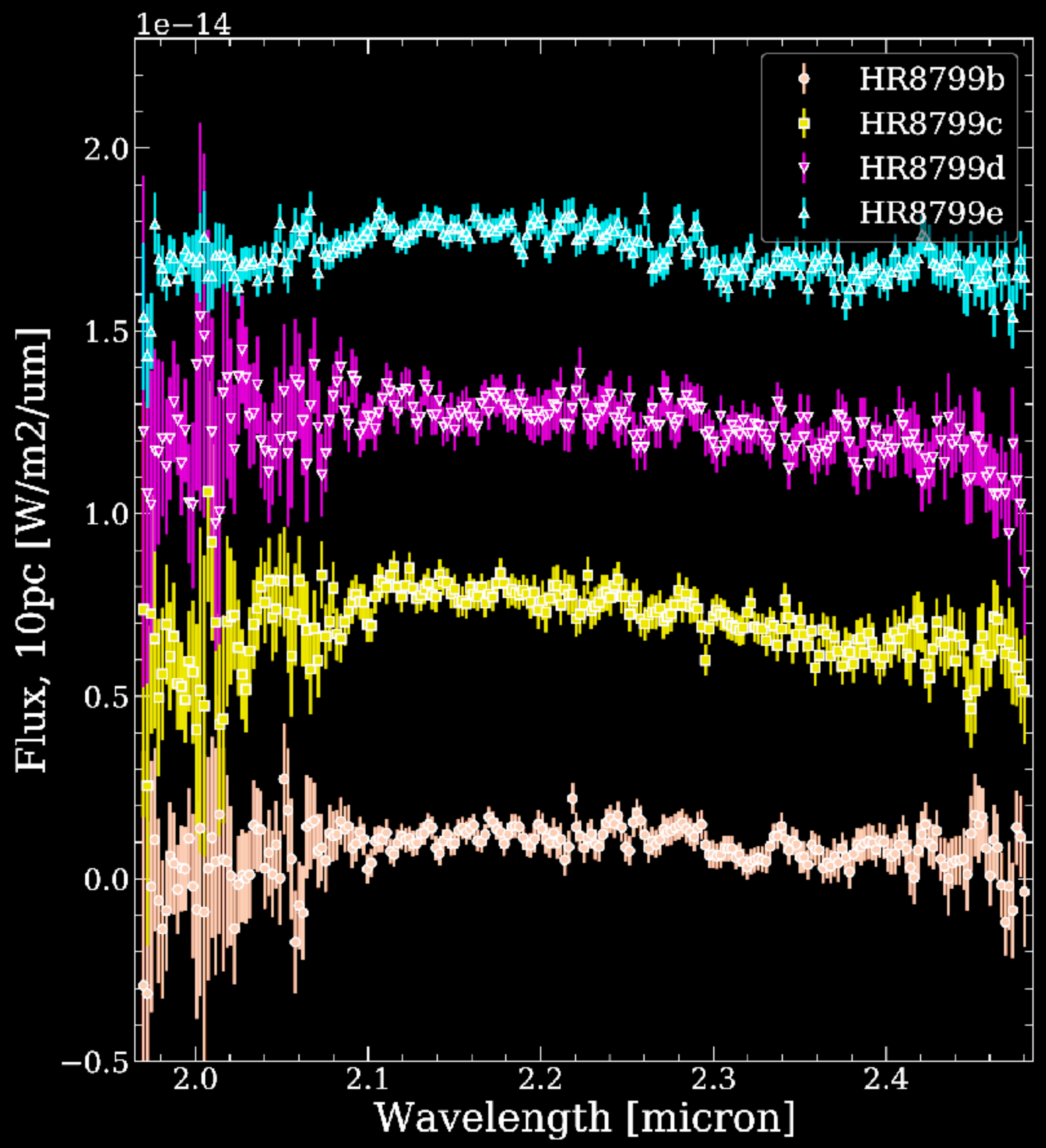

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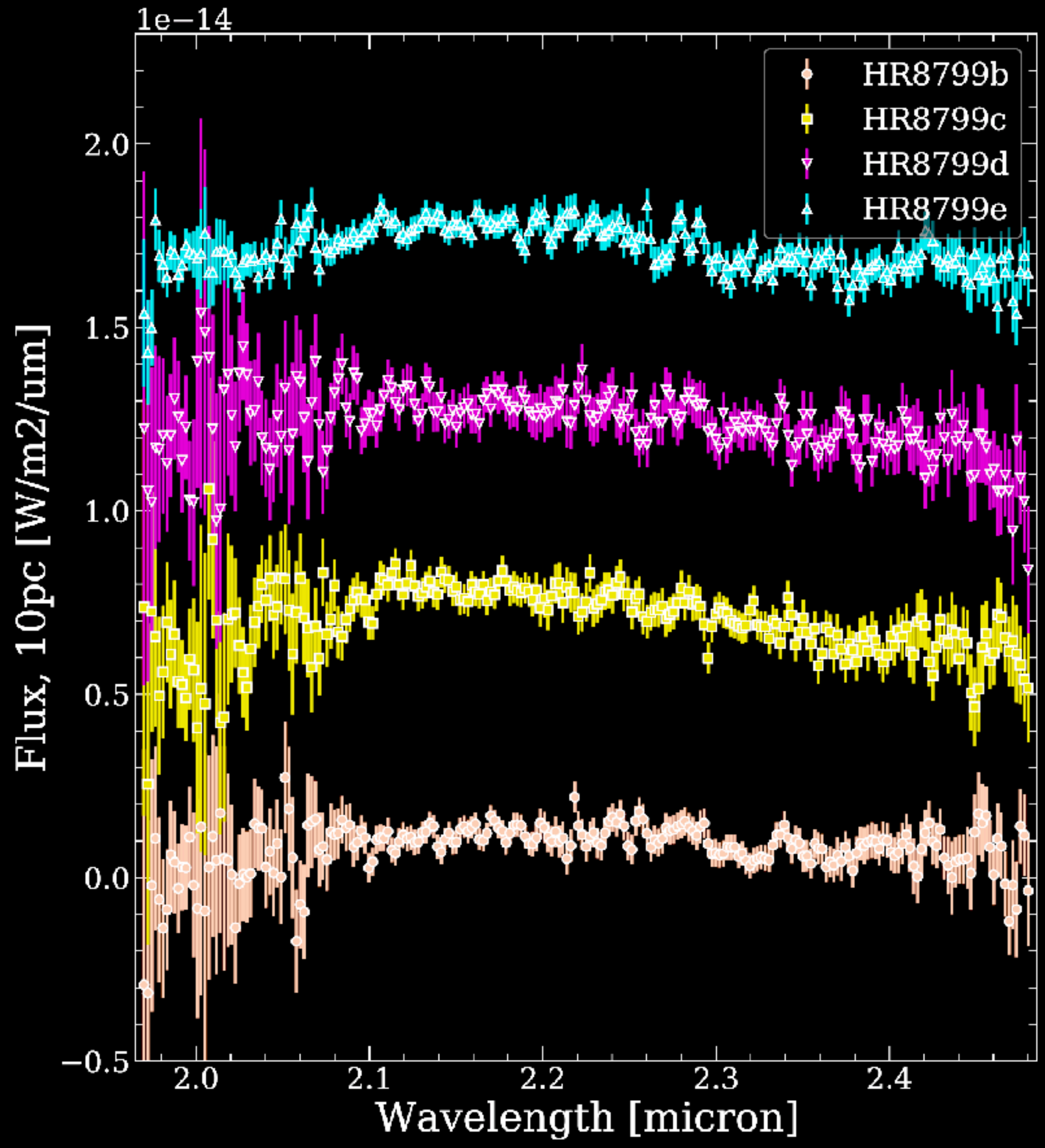
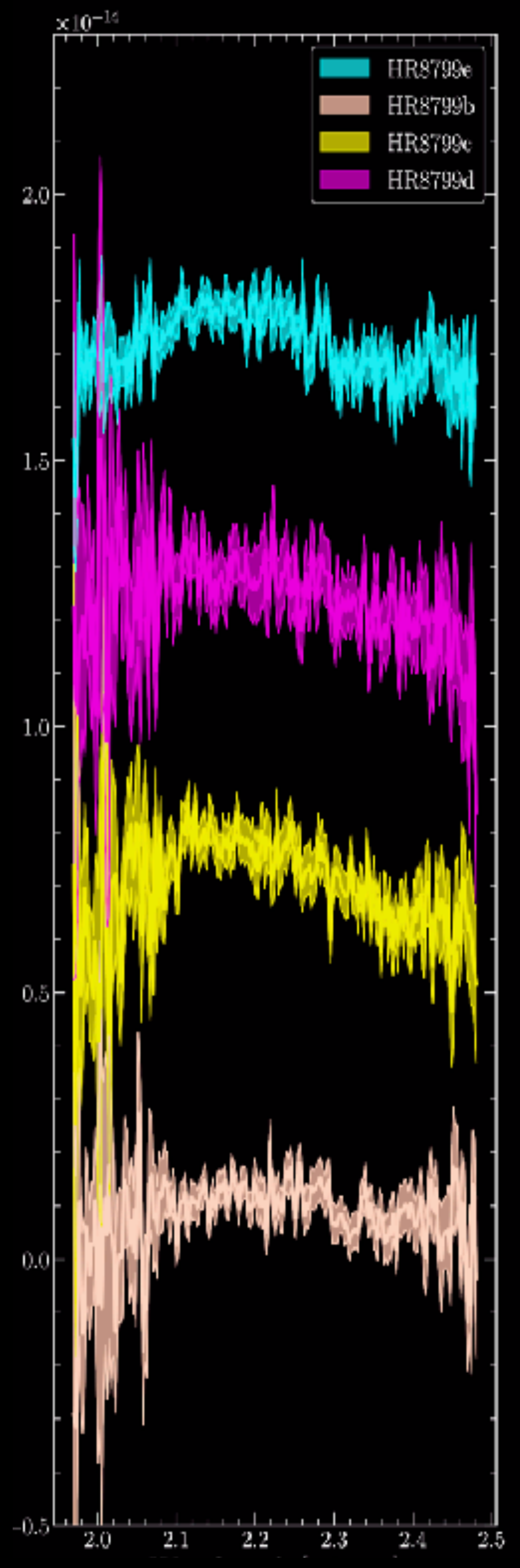
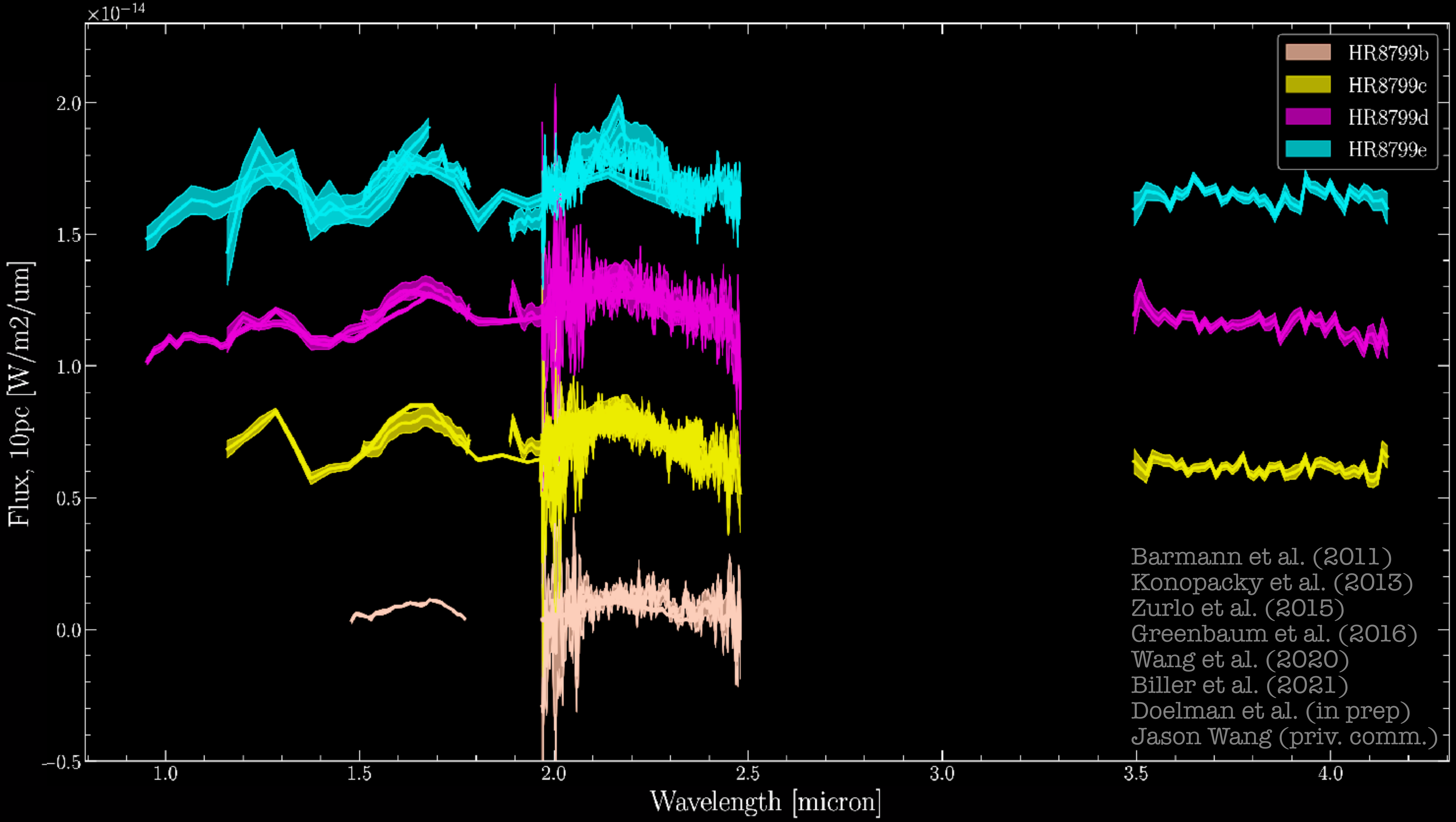
- All observations are taken at R~500, with an SNR of ~5 per channel.



Spectra!


Flux, 10pc [W/m2/um]
HR8799e
HR8799b
HR8799c
HR8799d
Wavelength [micron]

Spectra!



$\times 10^{-14}$
Flux, 10pc [W/m2/um]
Wavelength [micron]
2.0
1.5
1.0
0.5
0.0
−0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
HR8799b
HR8799c
HR8799d
HR8799e
Barmann et al. (2011)
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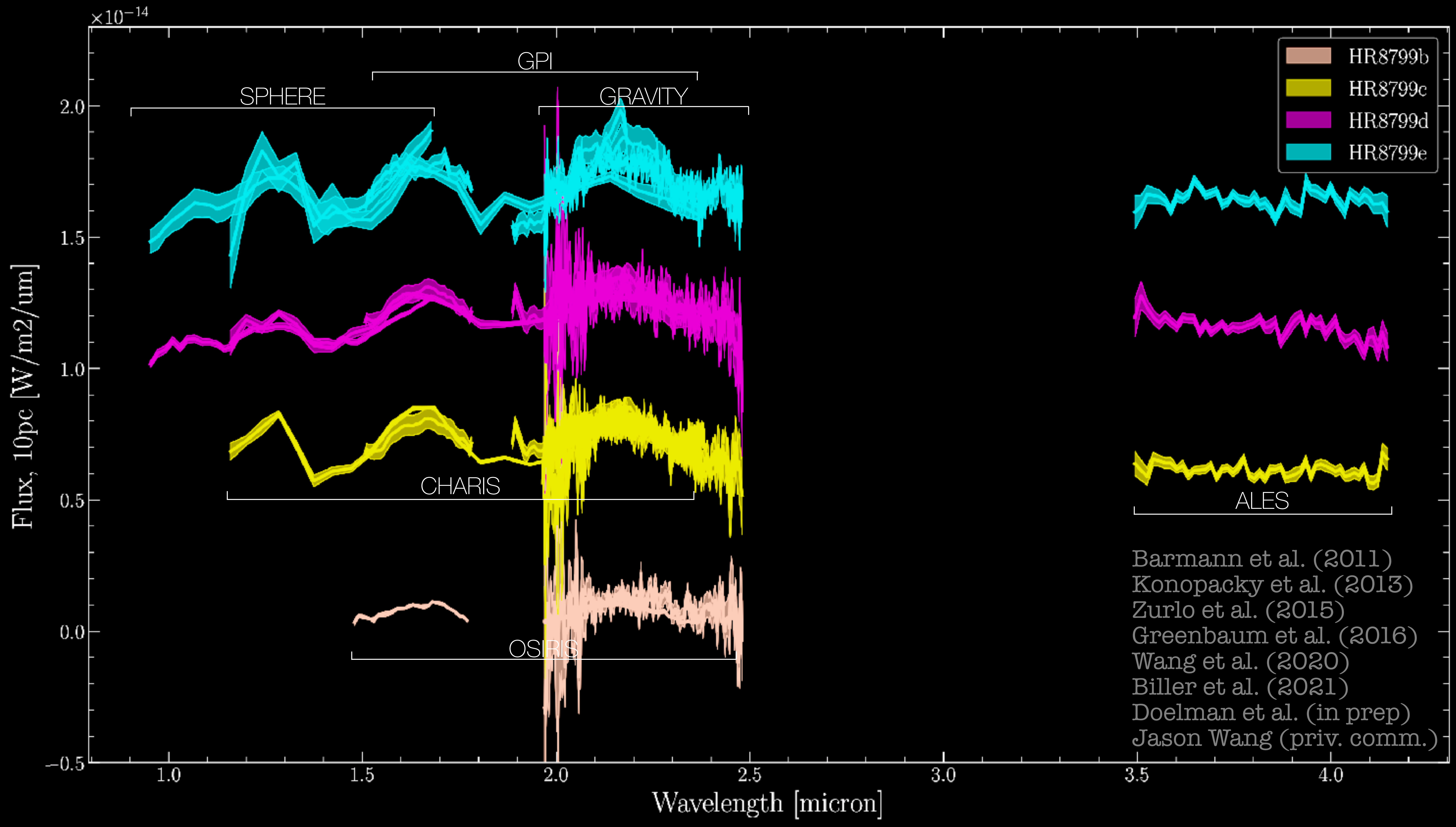

×10^−14
Flux, 10pc [W/m2/um]
Wavelength [micron]
2.0
1.5
1.0
0.5
0.0
−0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
GPI
SPHERE
GRAVITY
CHARIS
OSIRIS
ALES
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Processing archival data

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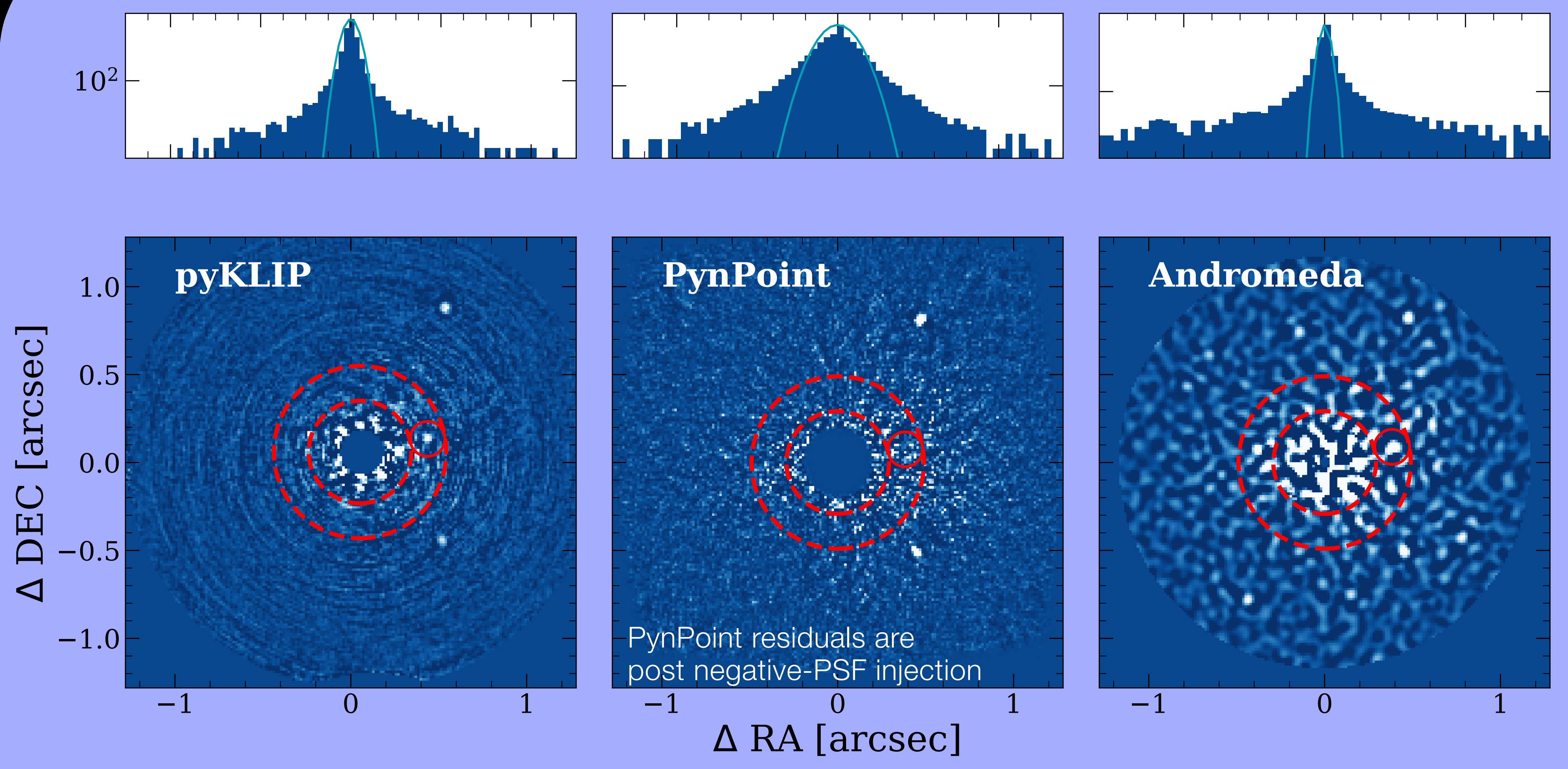

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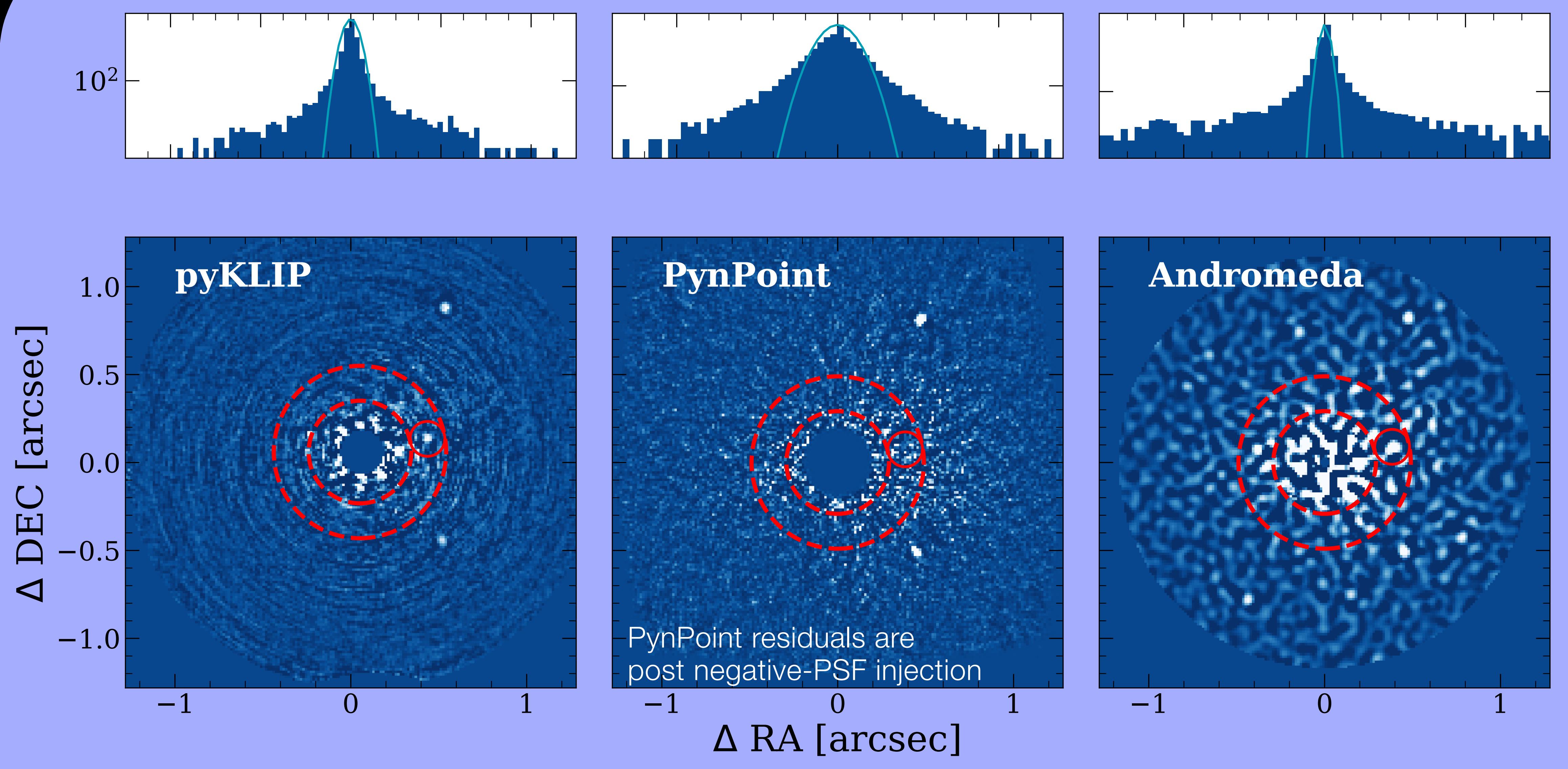

- Retrievals are only as good as the data!

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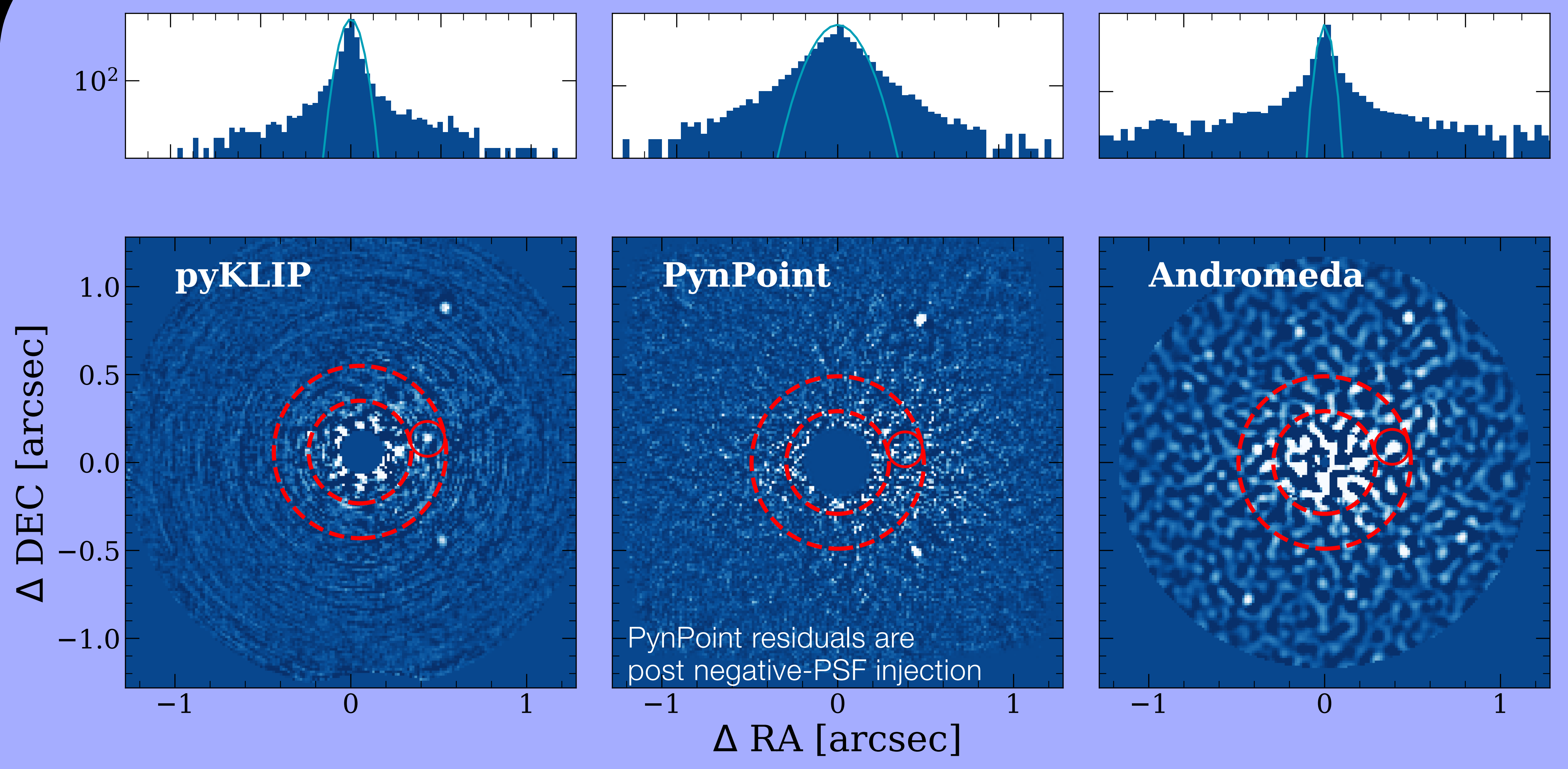

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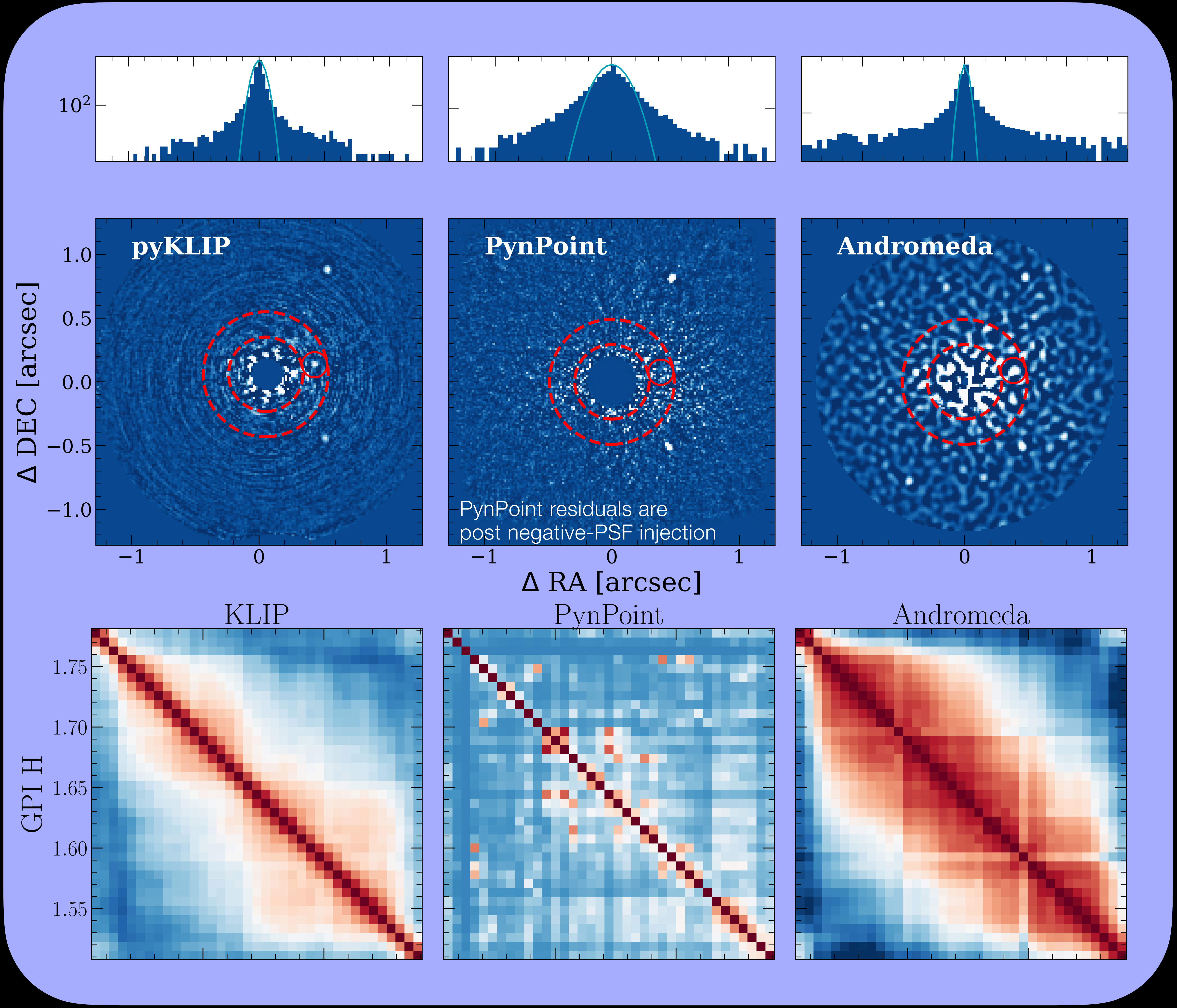

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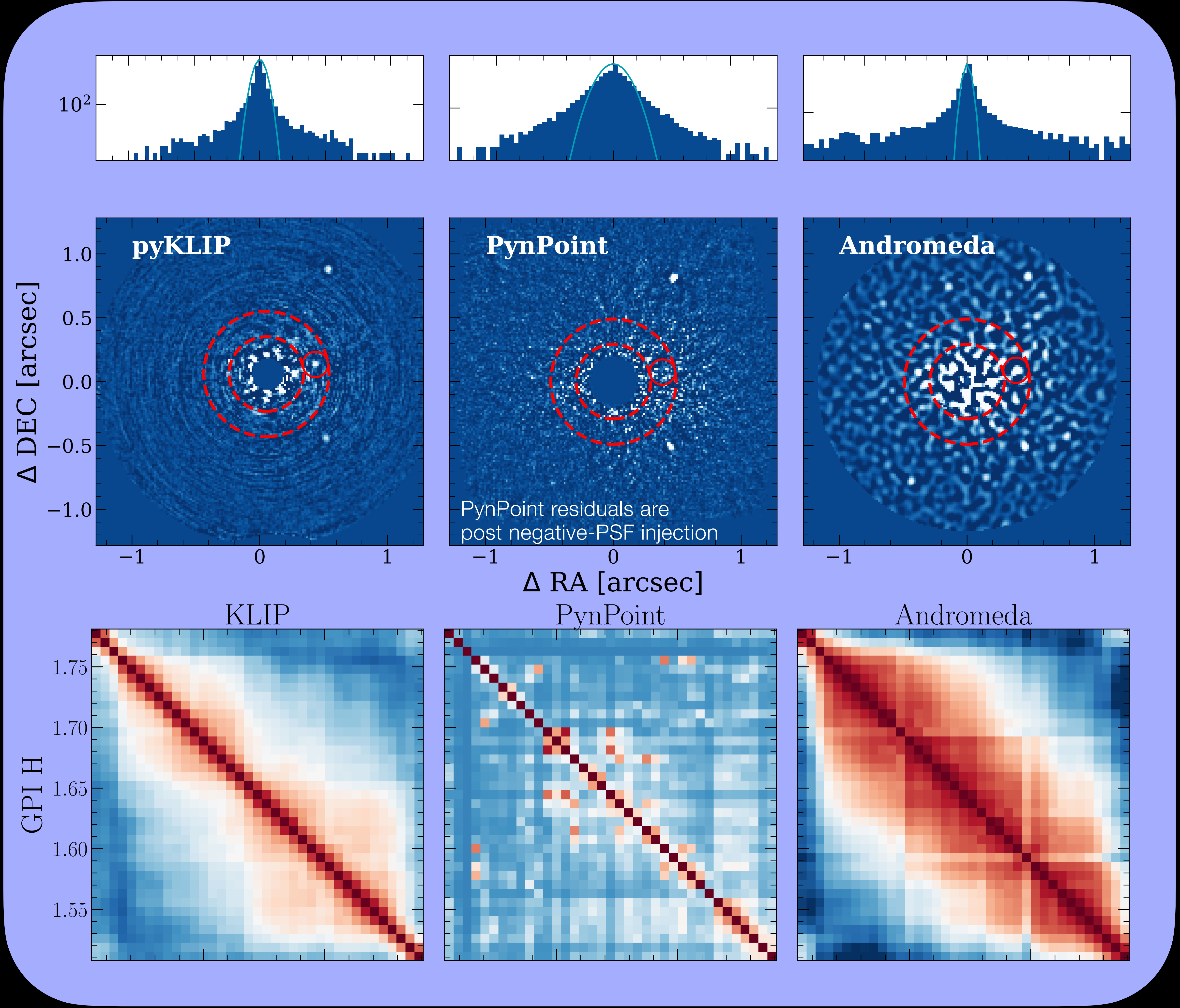

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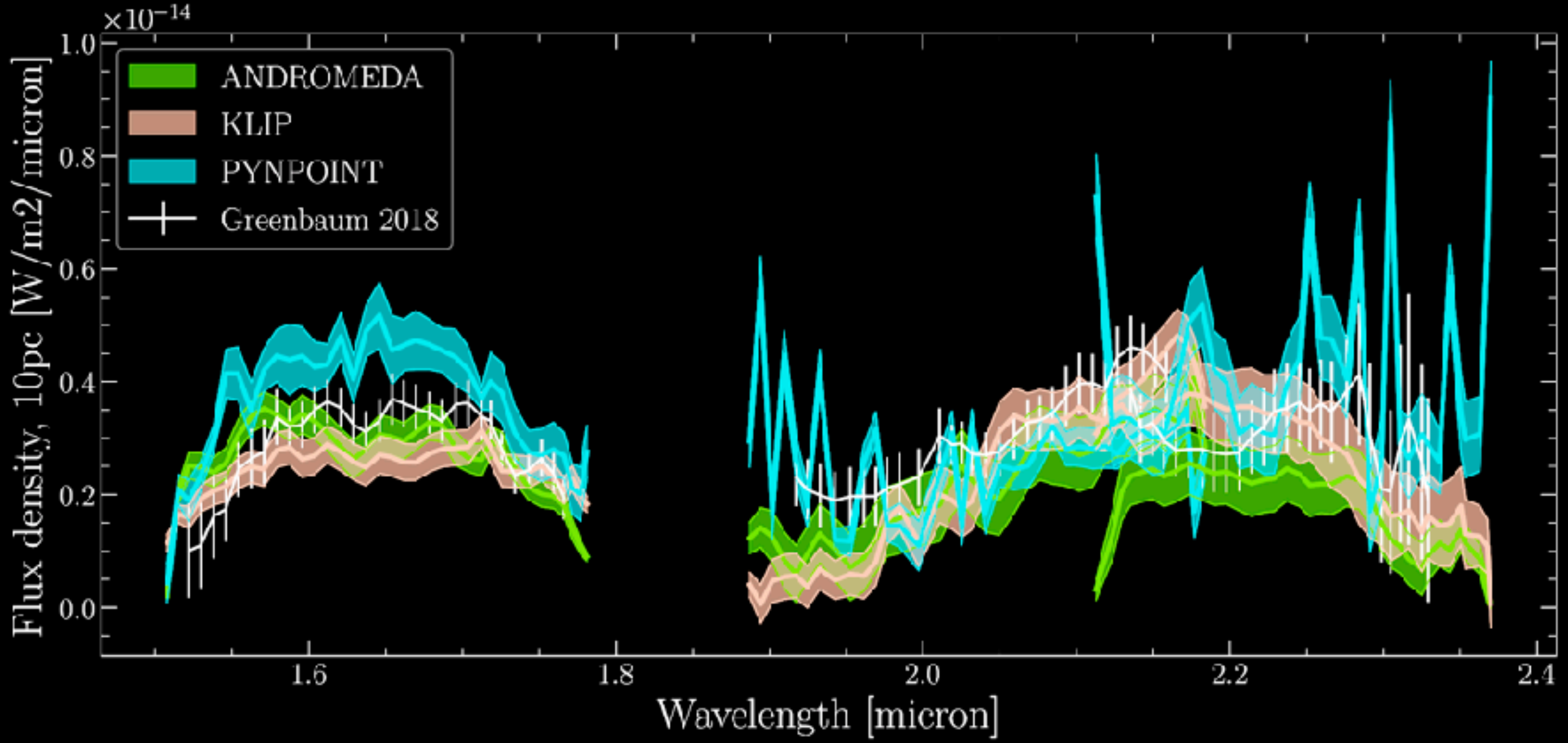
- Algorithm choice also affects the flux calibration and shape of the spectrum



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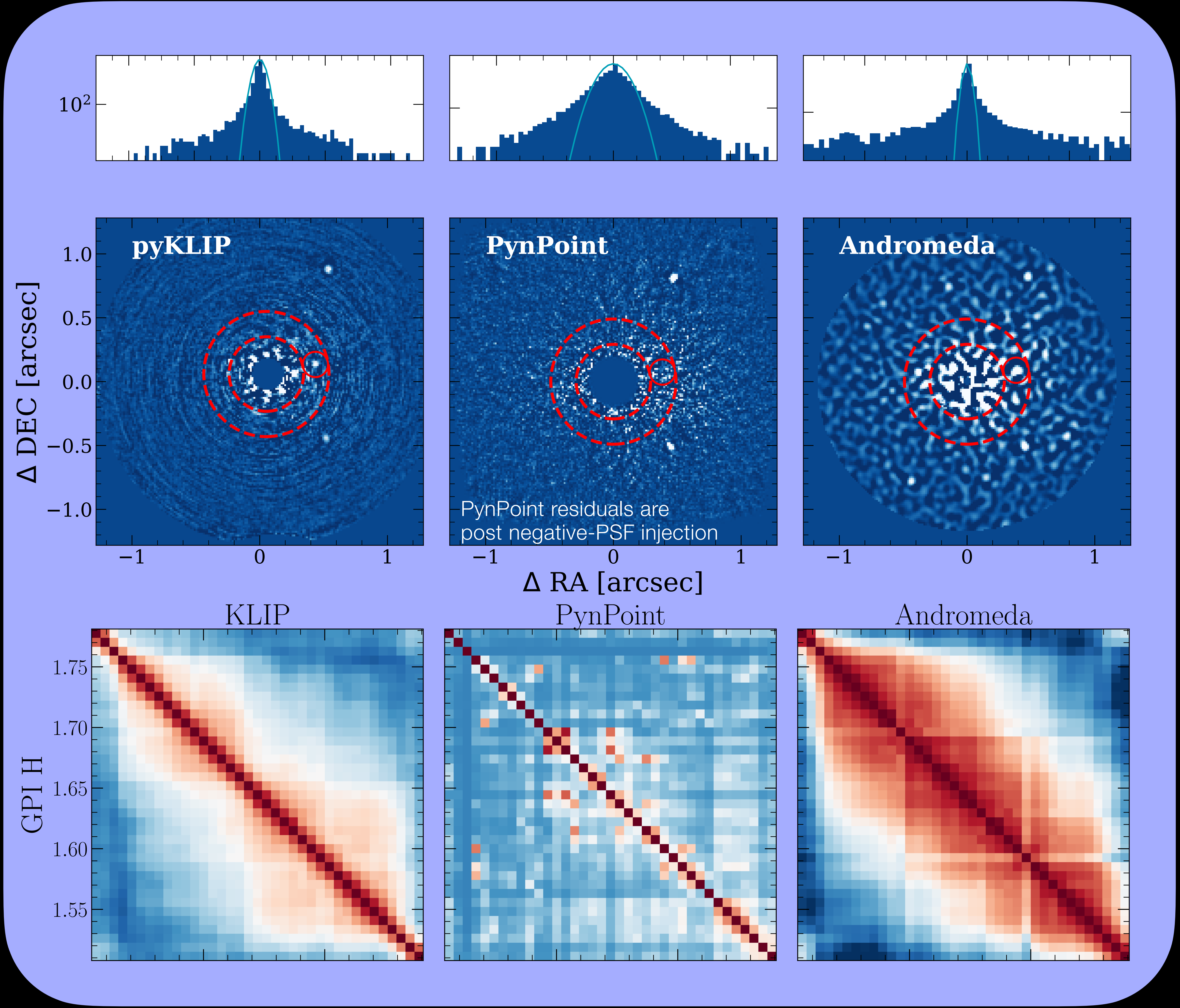
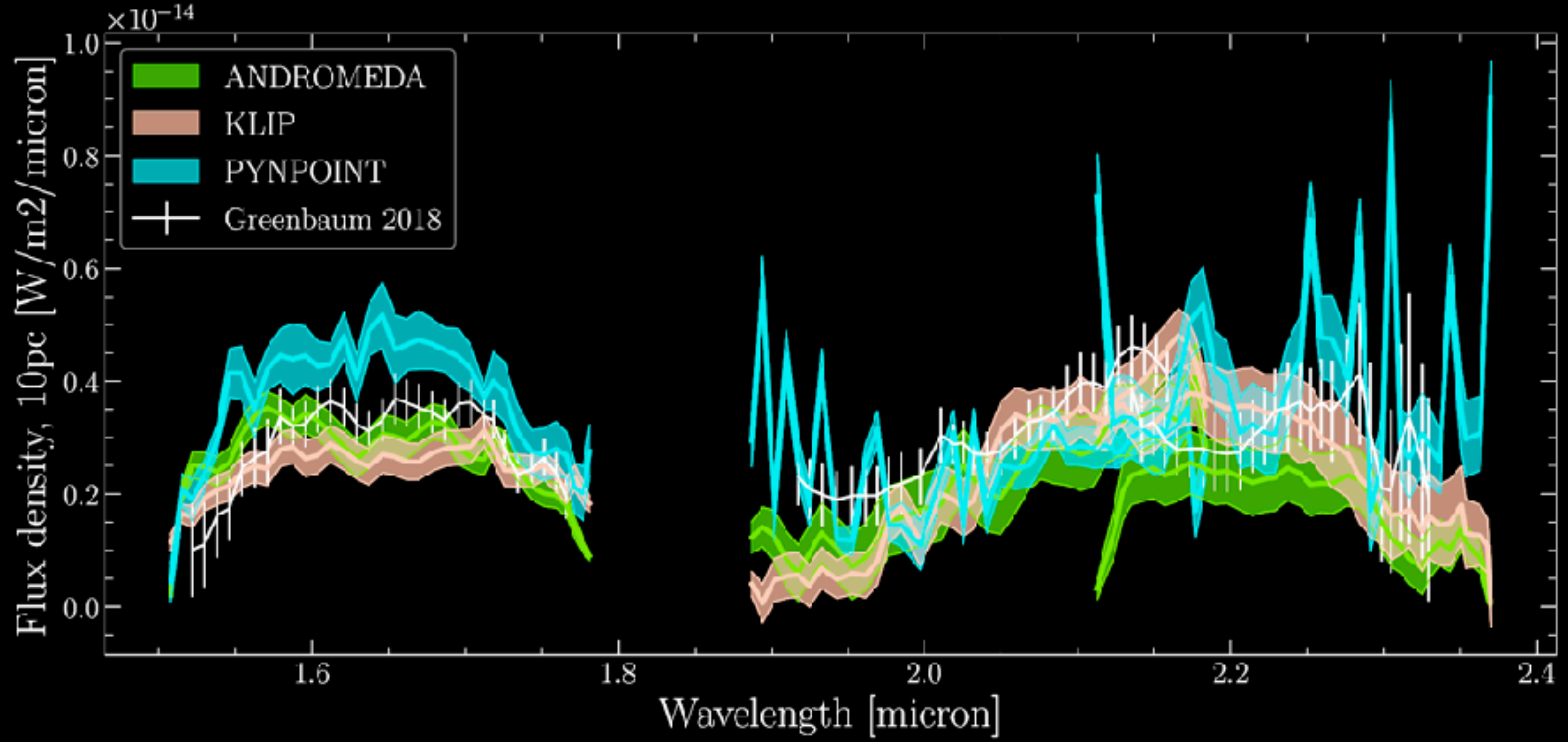


- Further efforts are necessary to quantify how these algorithms impact characterisation, similar to Cantalloube et al (2021) for detection



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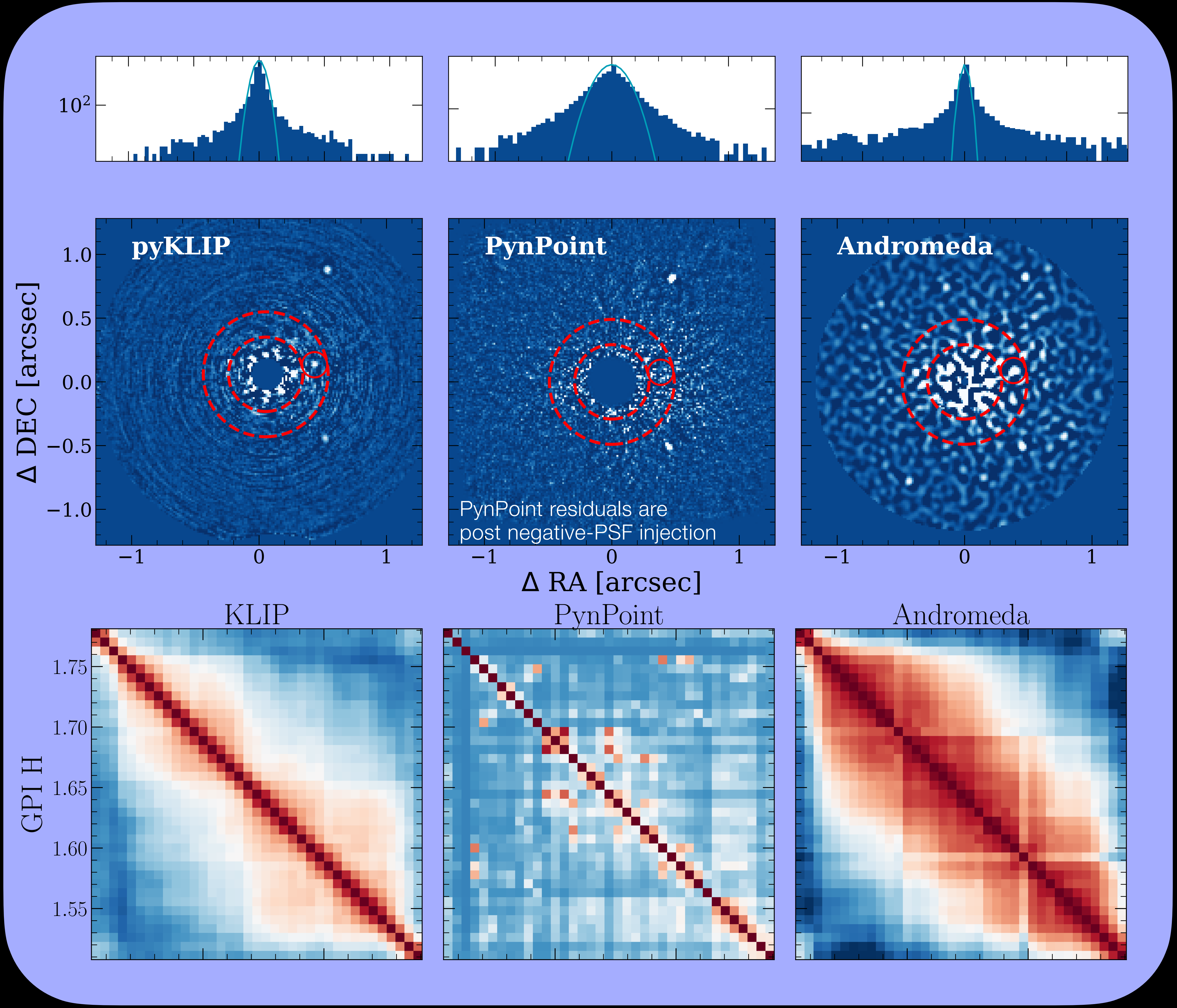

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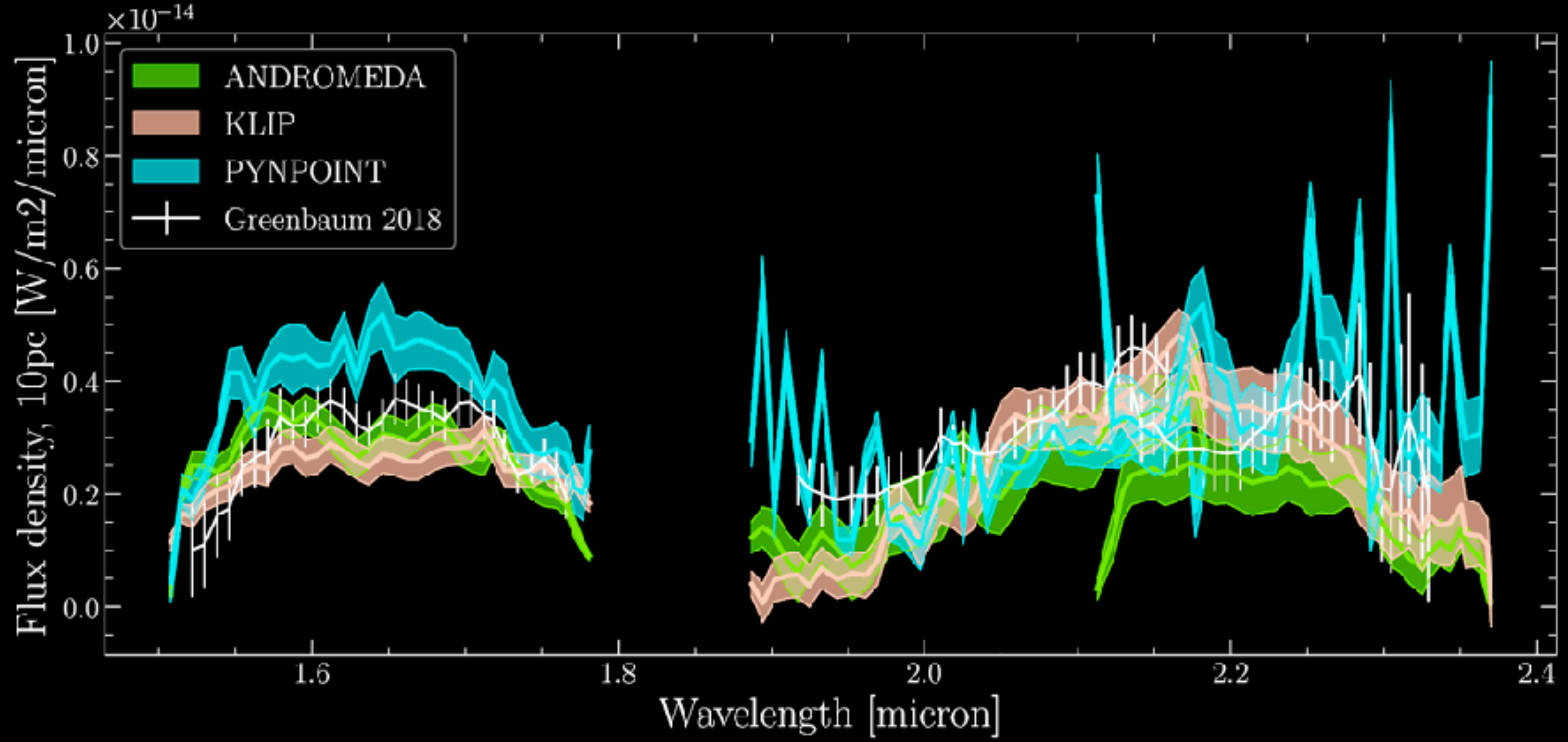
- We chose to use the KLIP reductions in the retrievals due to the performance across datasets and planet separations.



What are these planets like?

Fitting the Data!

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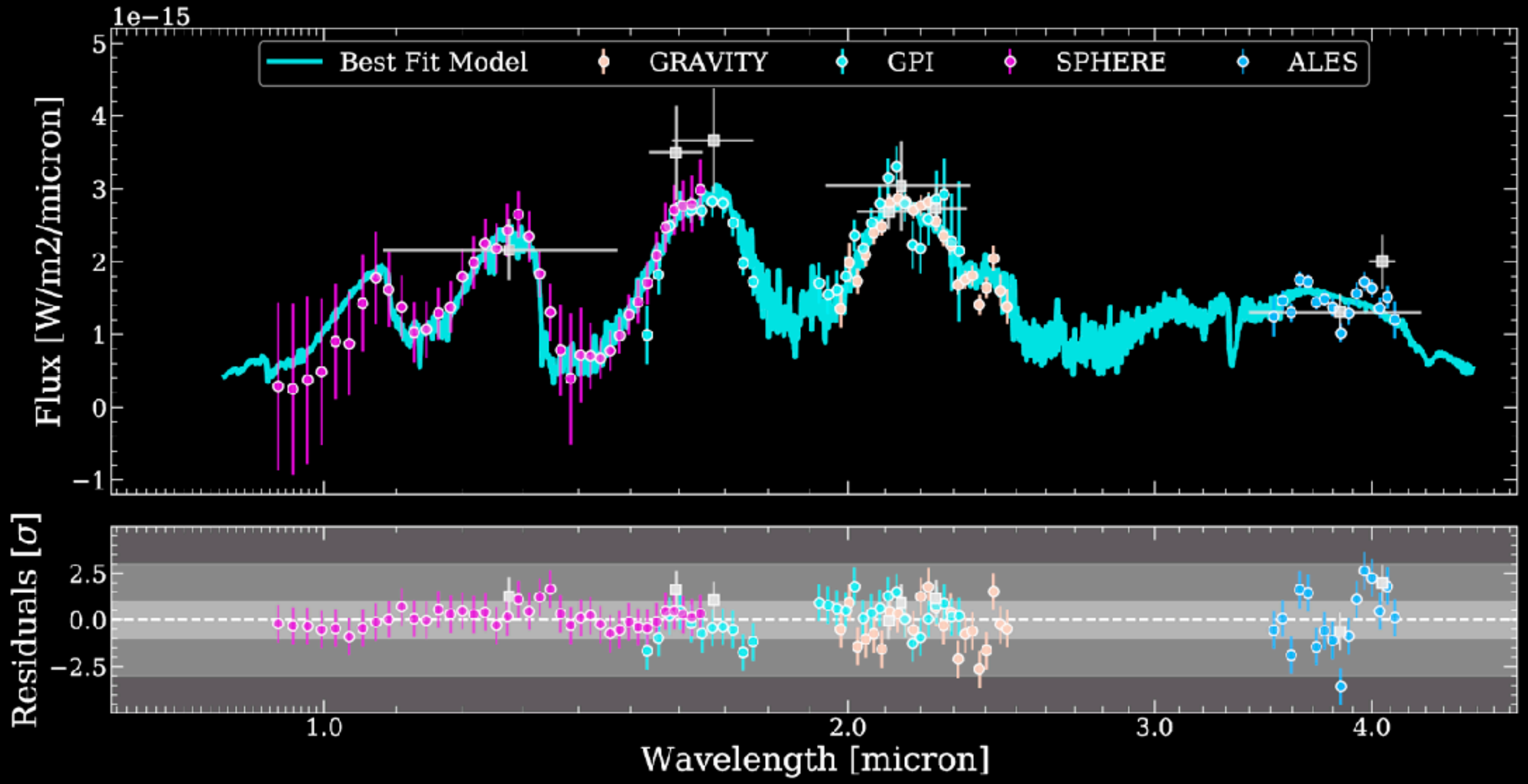

Fitting the Data!

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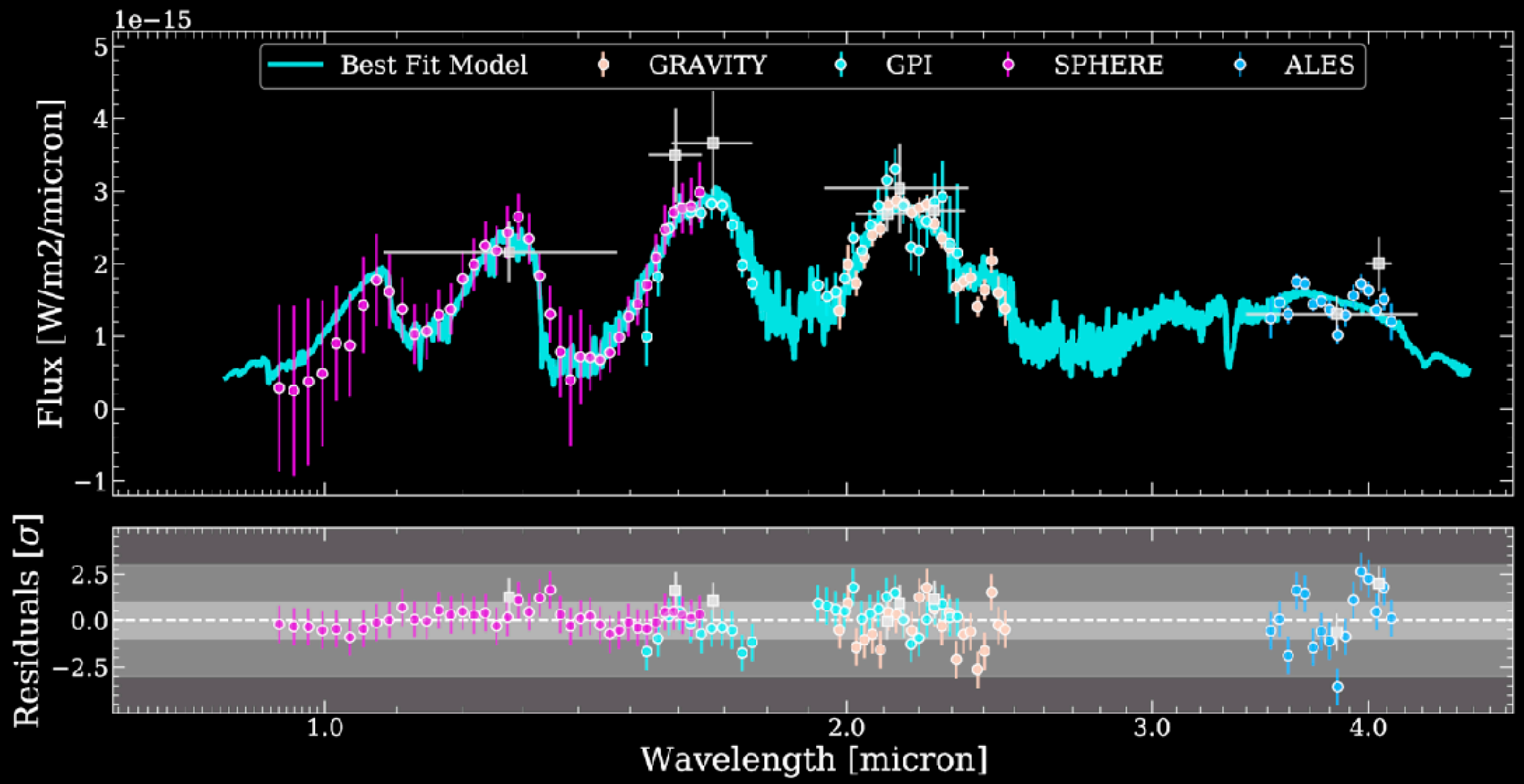

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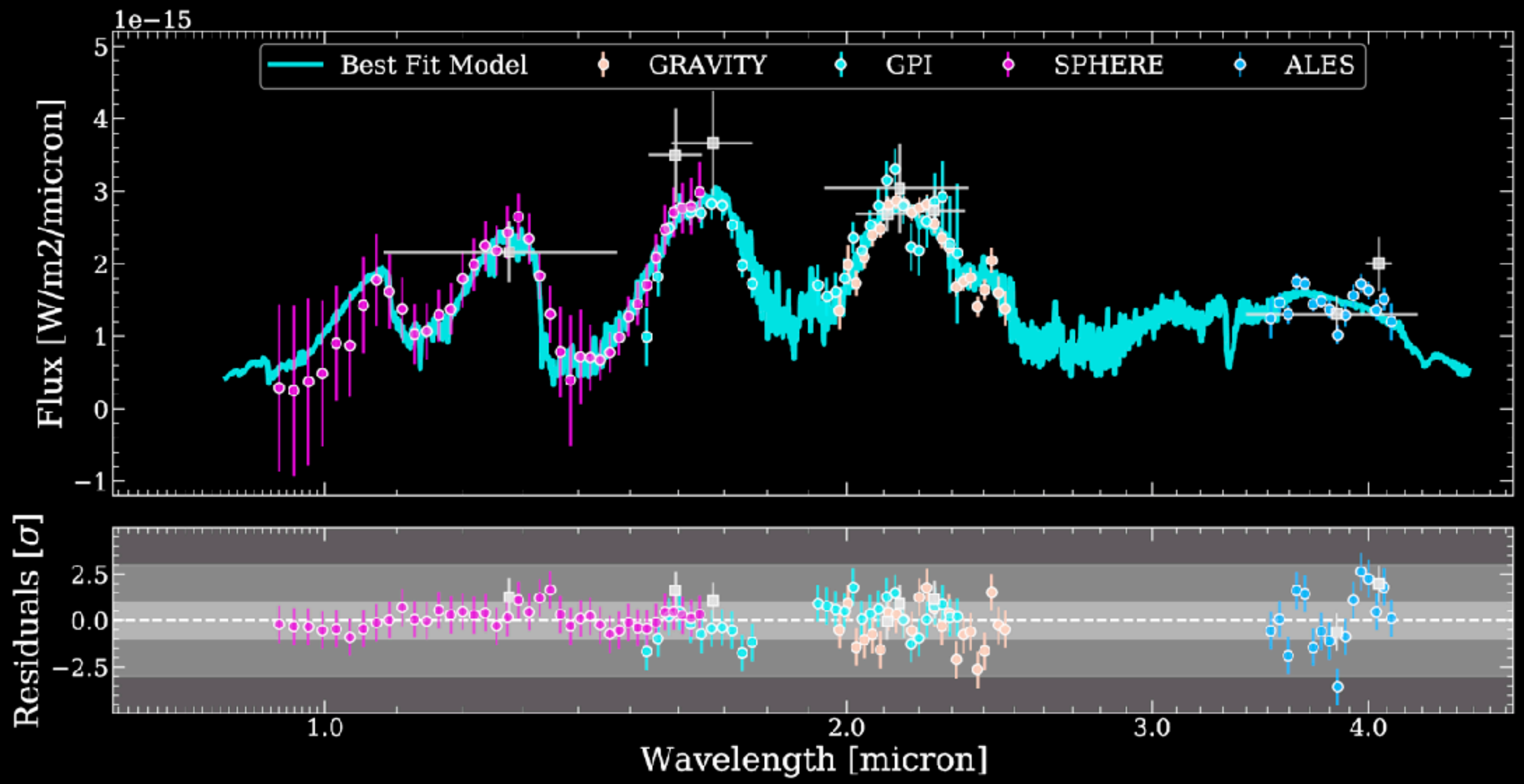

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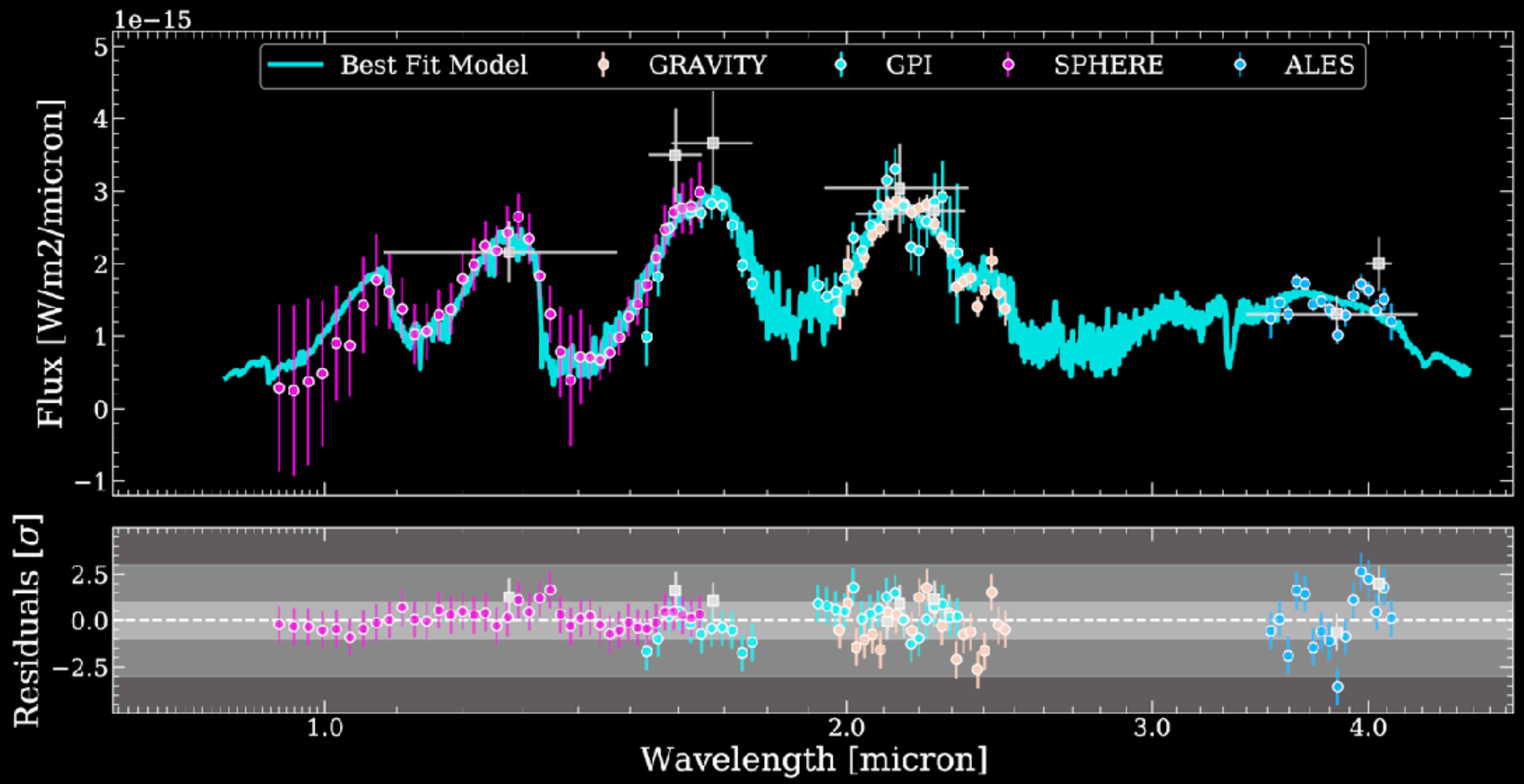
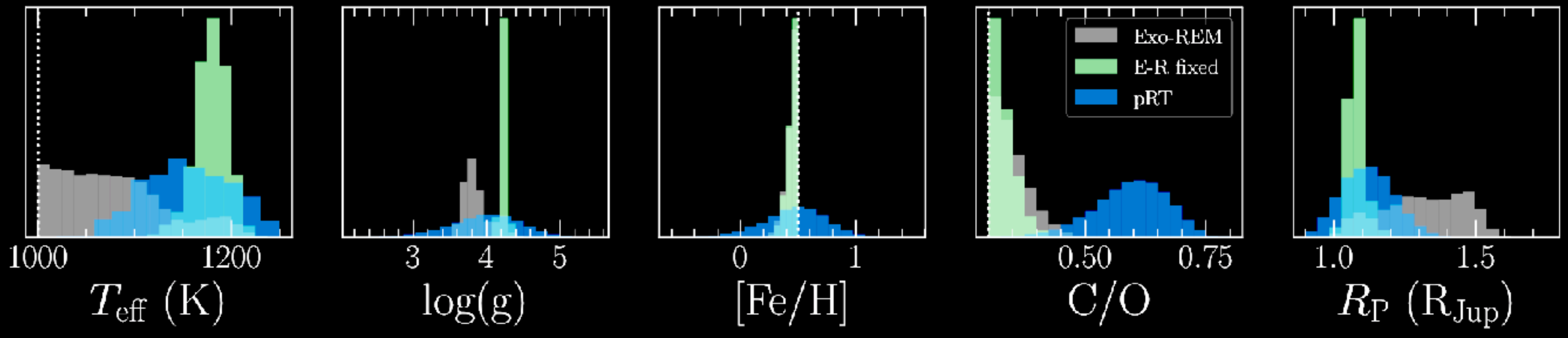


Mollière et al. 2020

HR8799e Atmospheric Parameters



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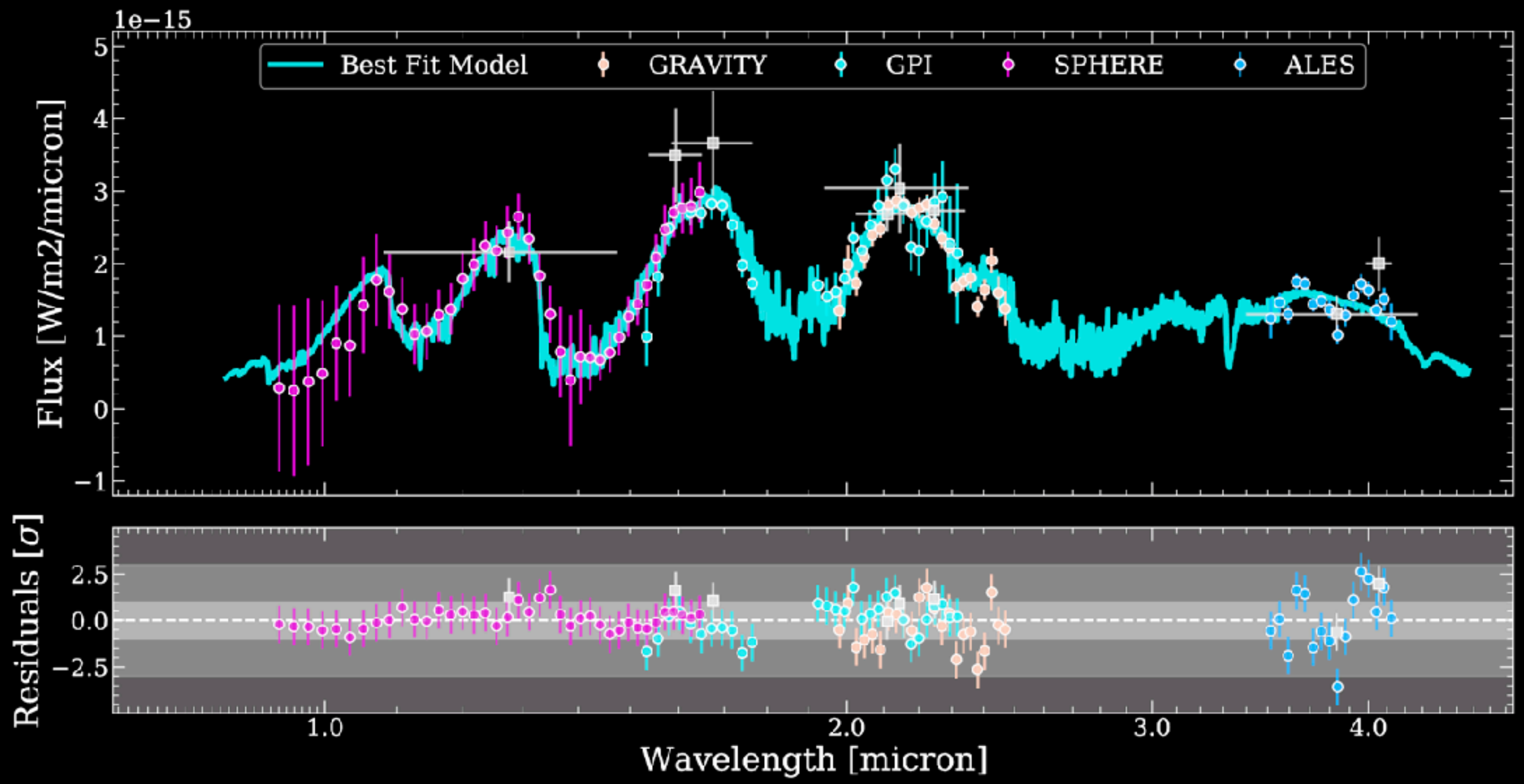

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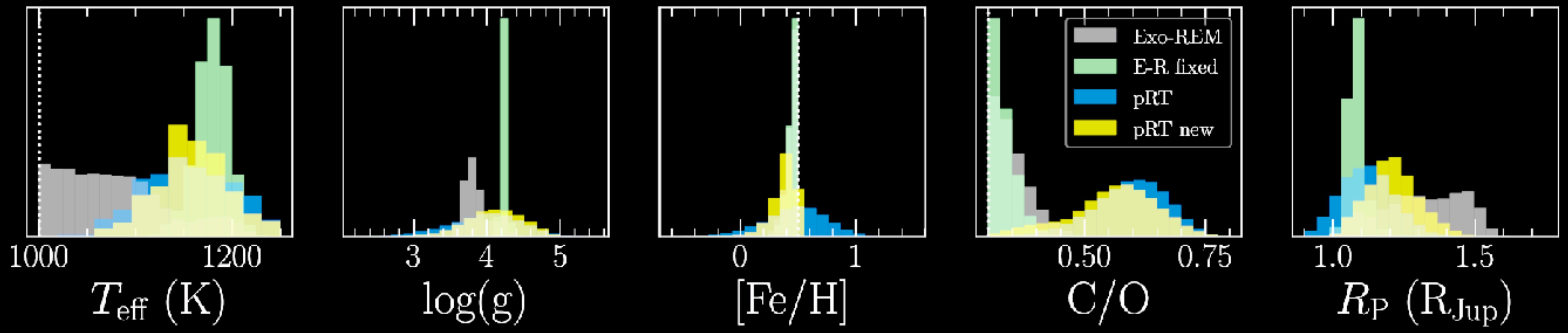

Updated from Mollière et al. 2020

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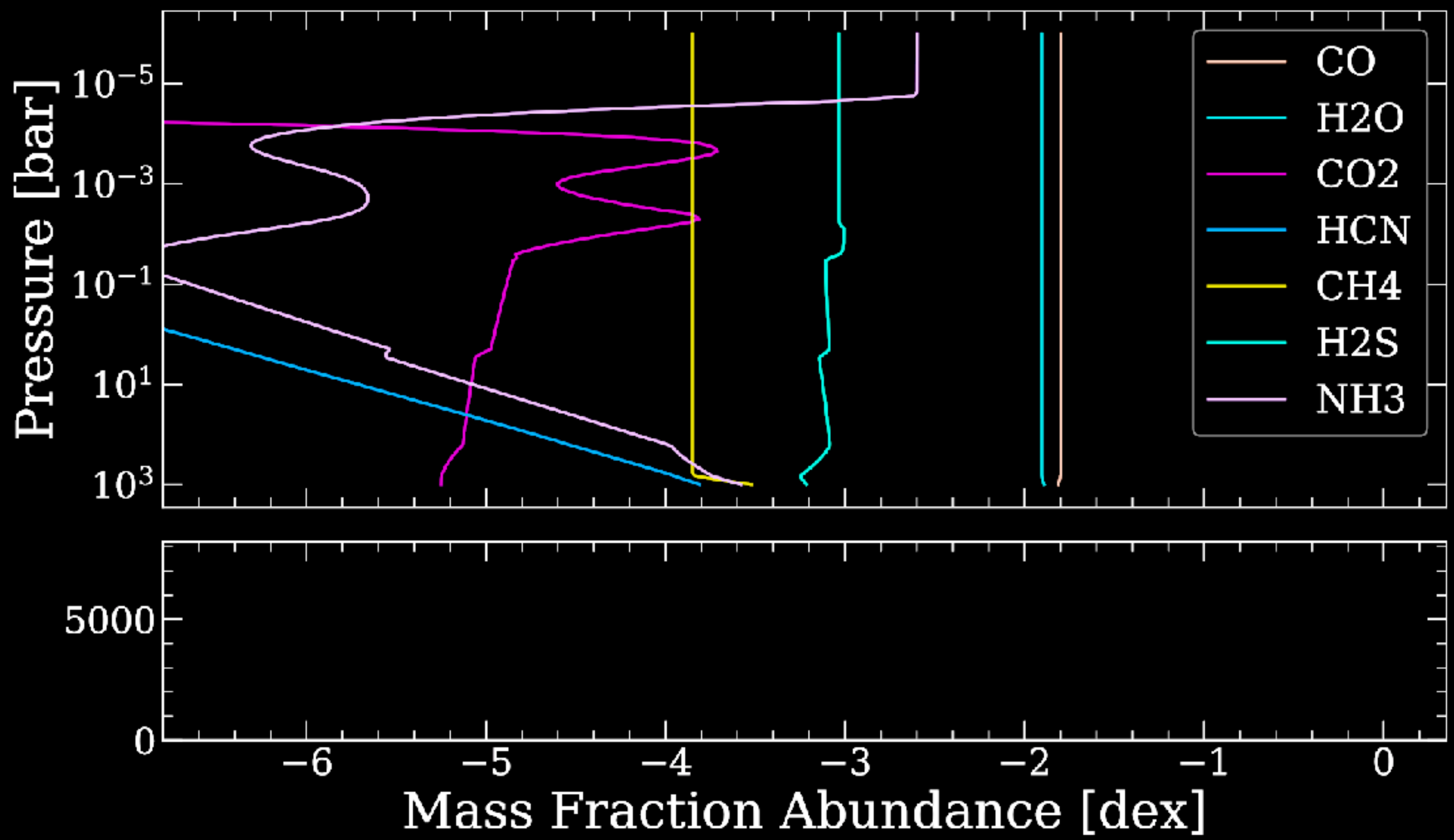

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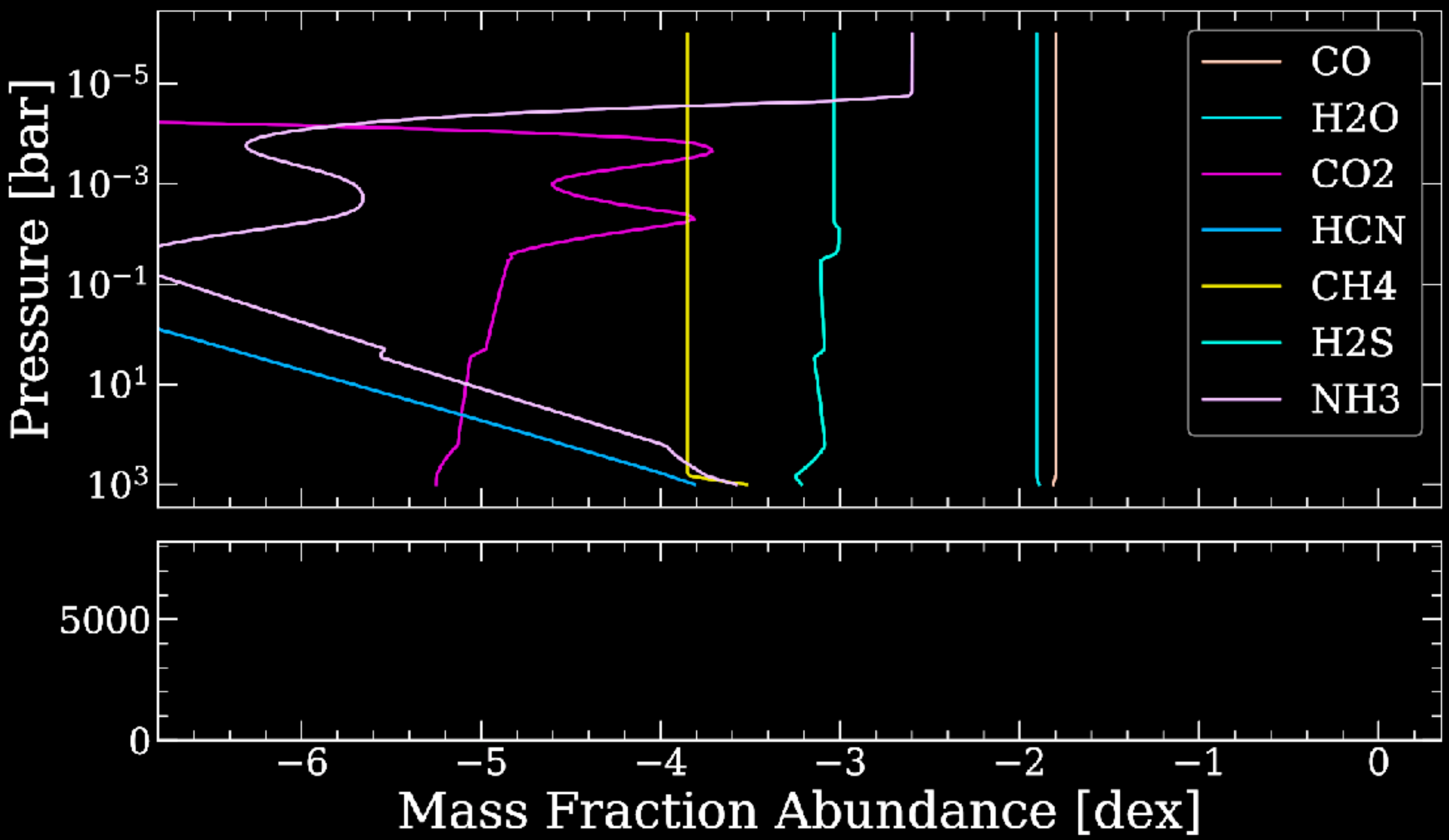

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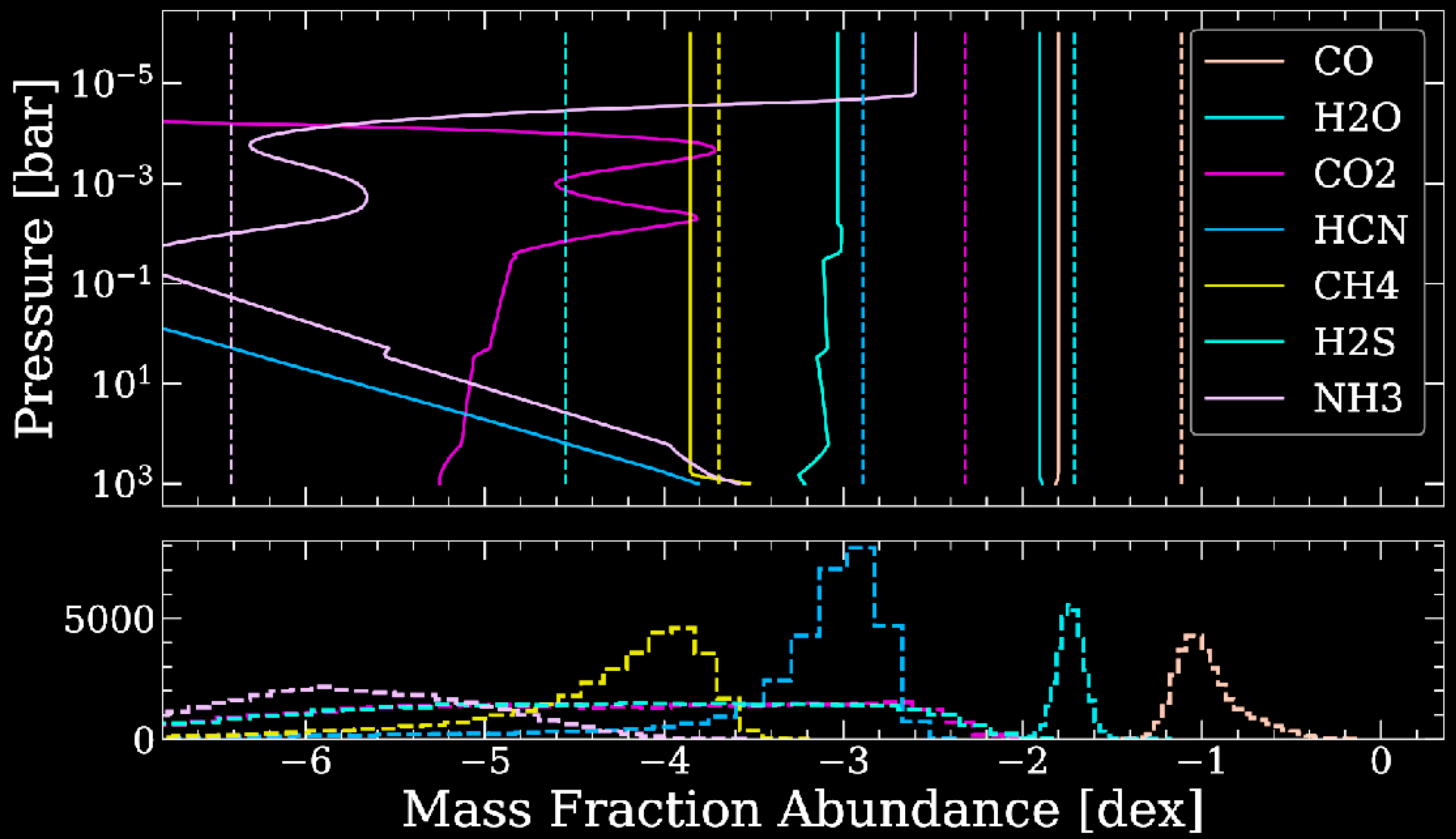

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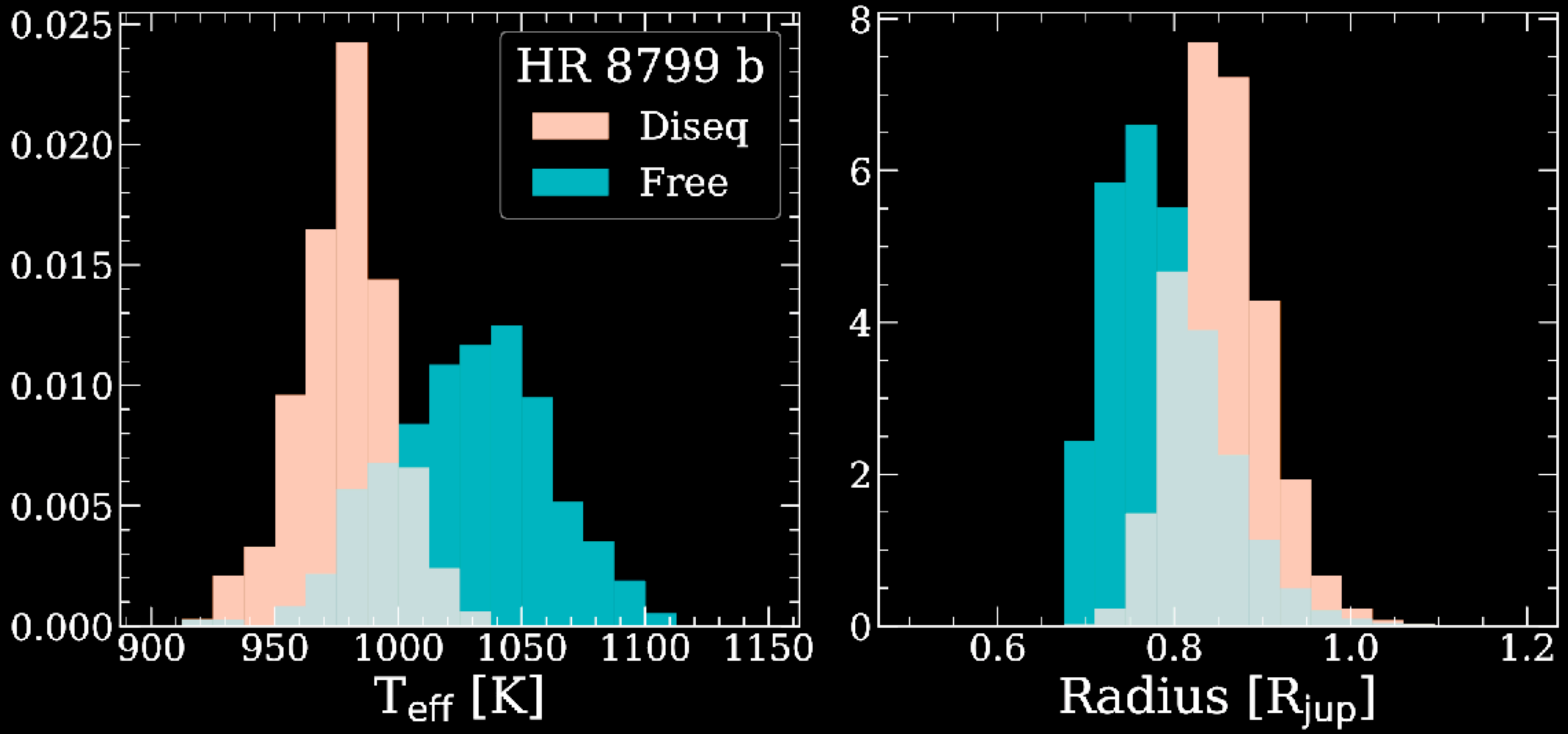
- We also find a ~5x higher CO abundance using free chemistry as compared to the disequilibrium model.



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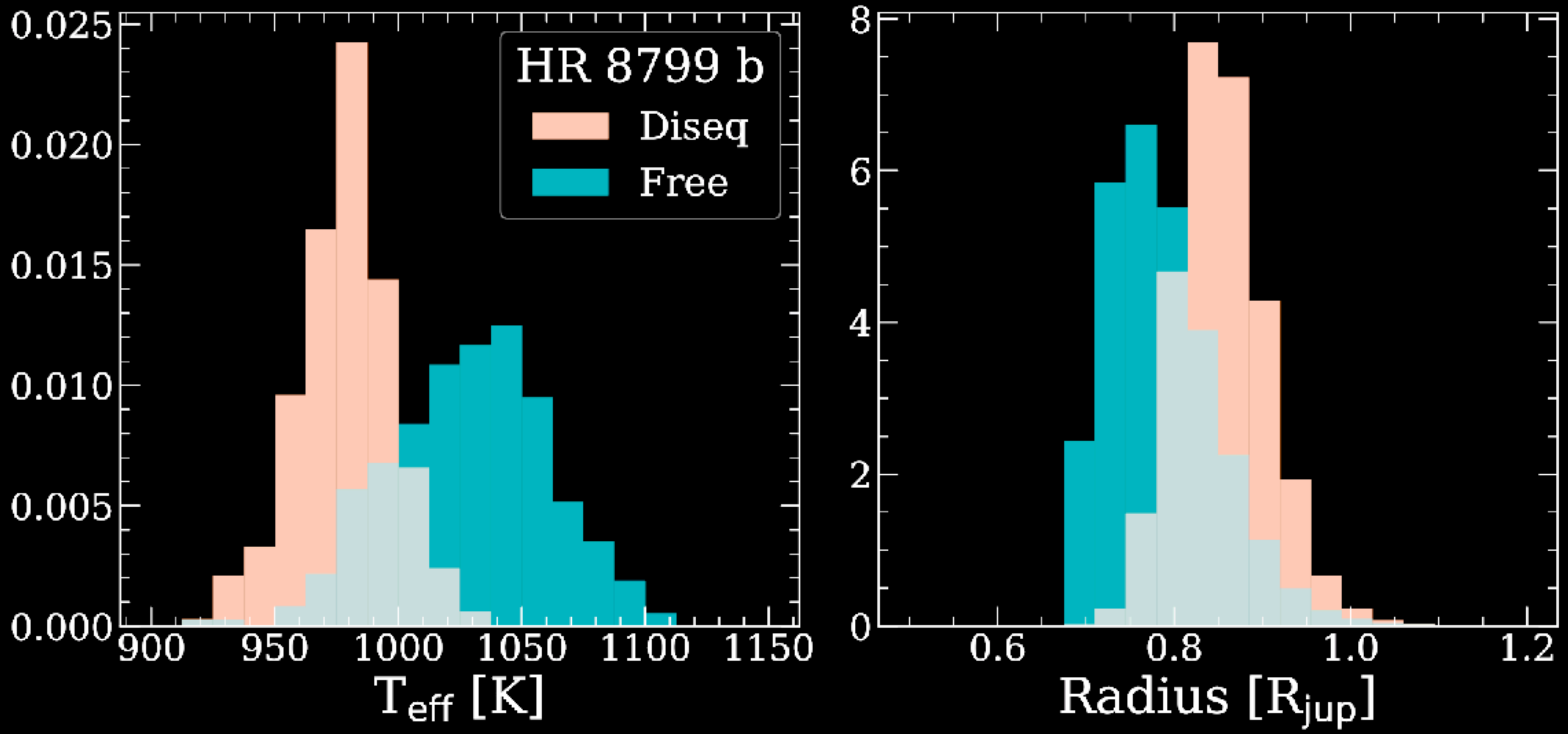
- This may be partially explained due to the differences in the retrieved radius and effective temperature between the two models.



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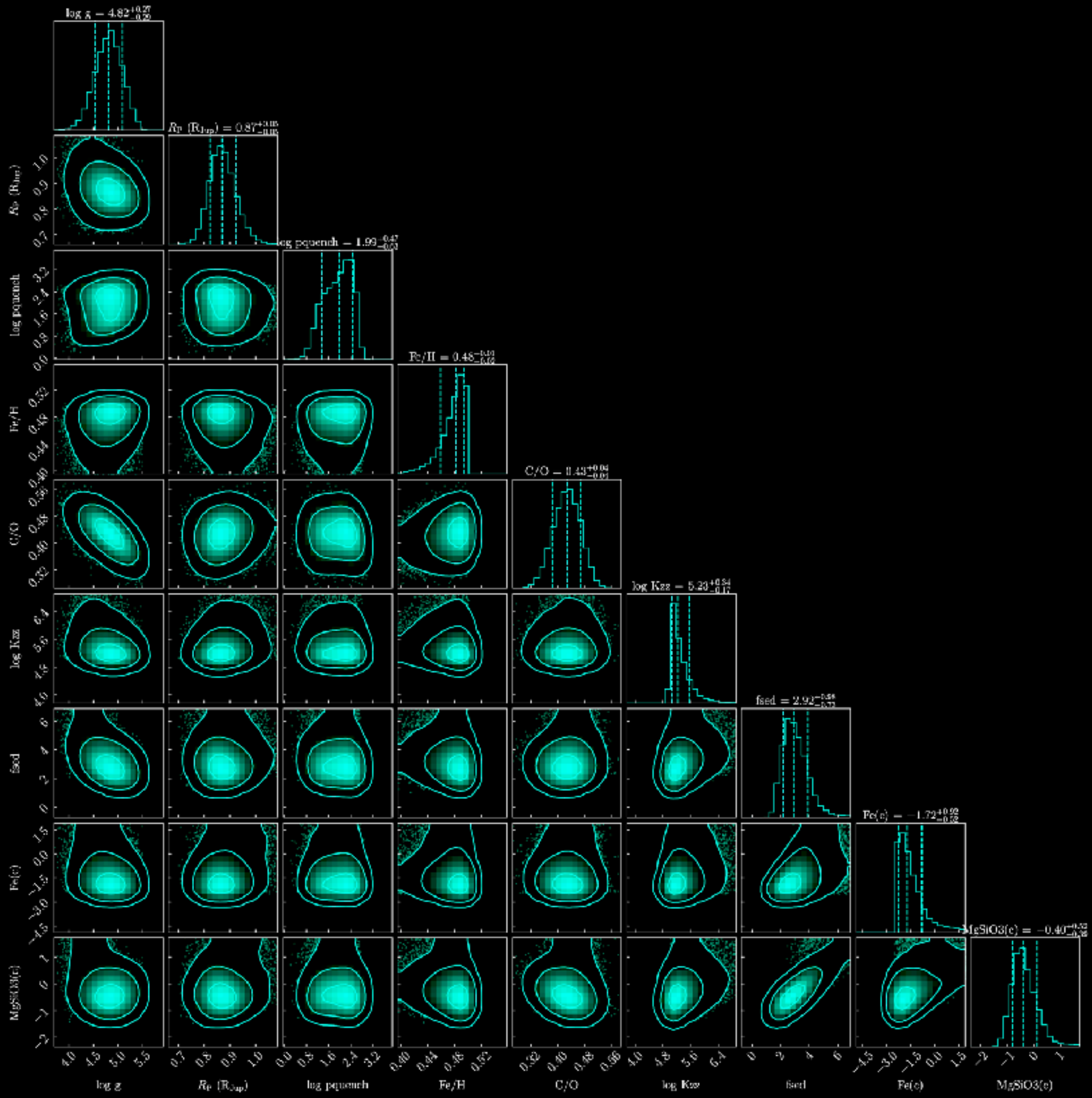

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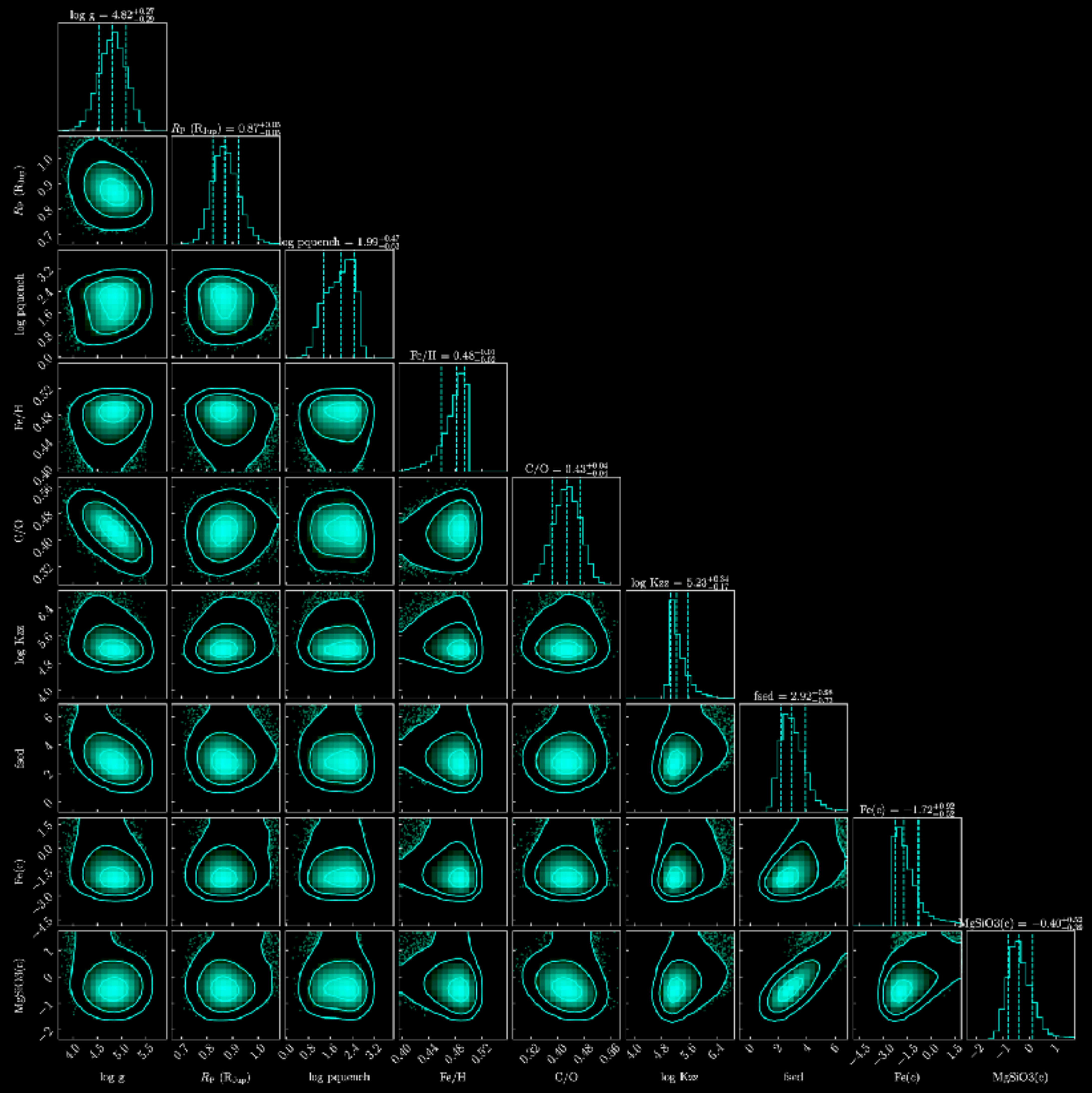

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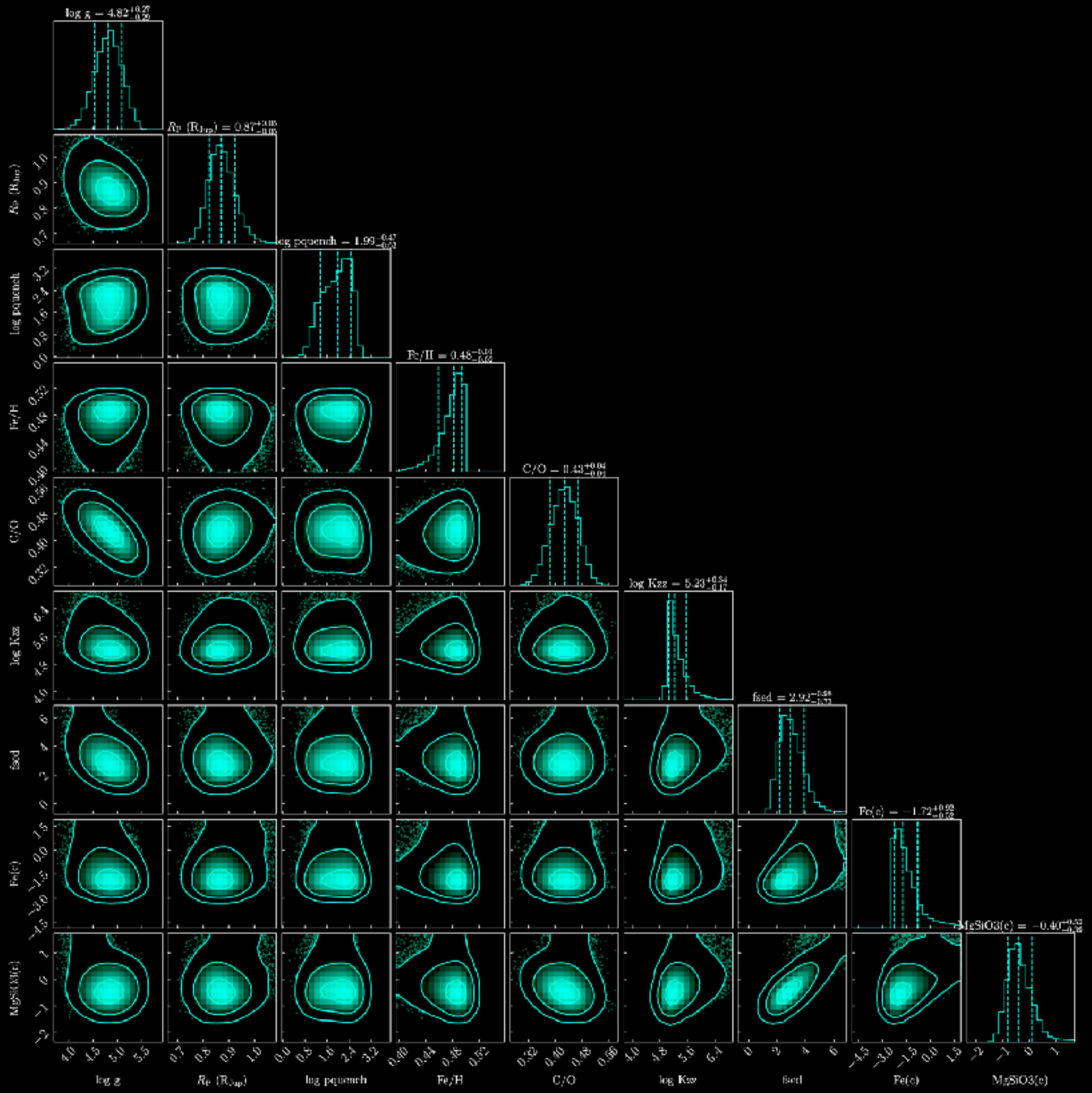
- C/O in particular strongly depends on the chemical model used (disequilibrium or free chemistry).



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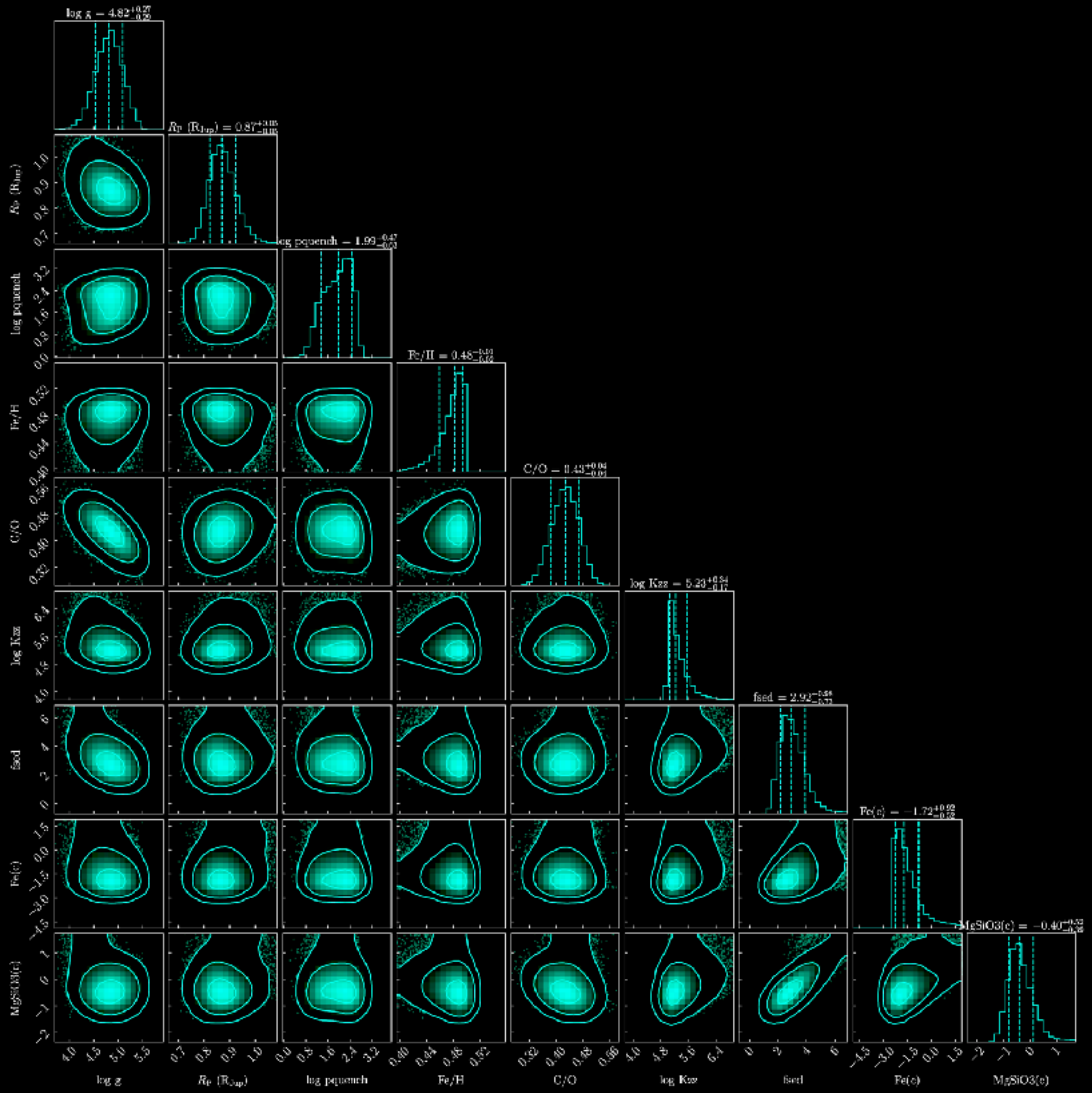

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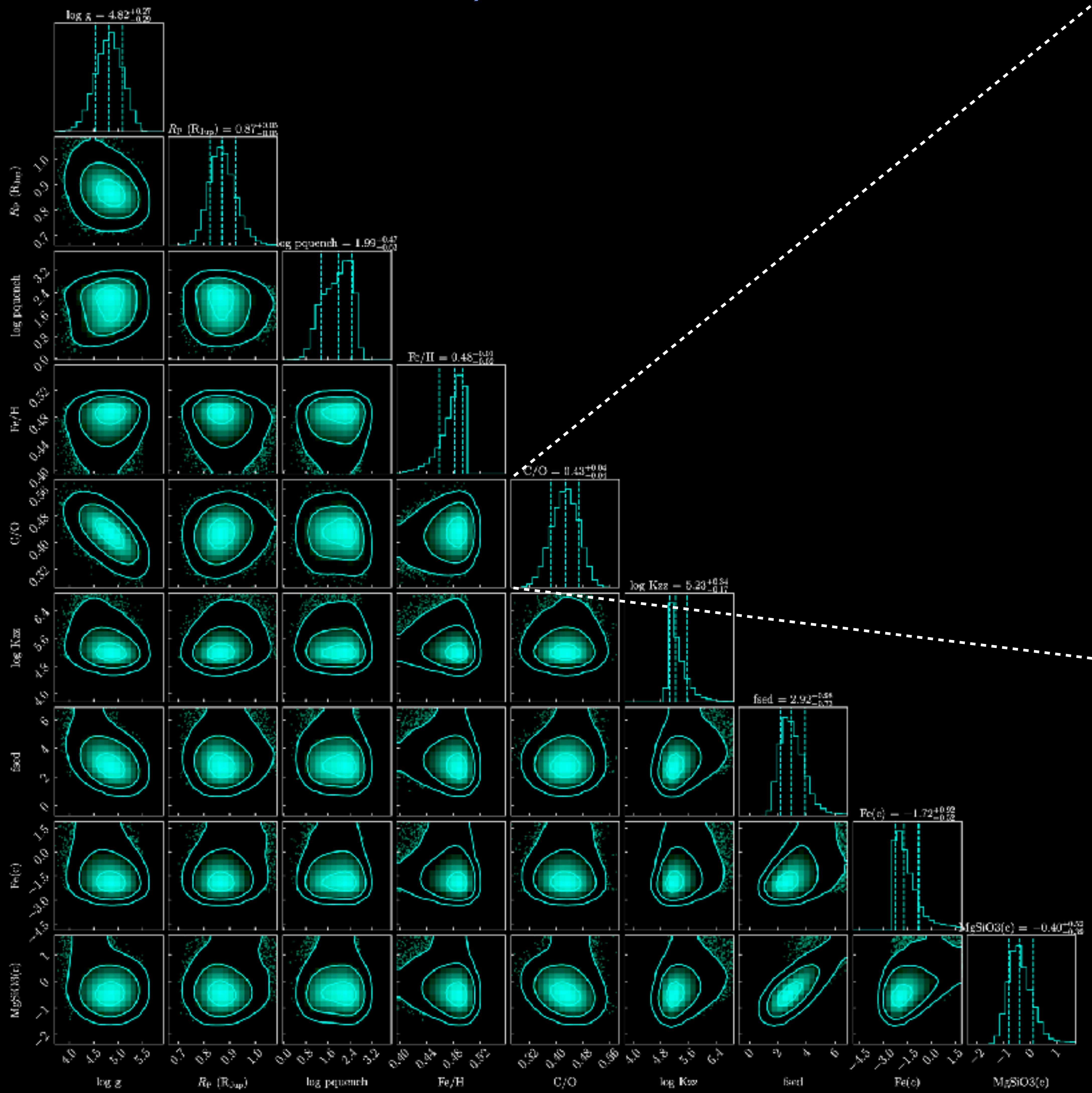

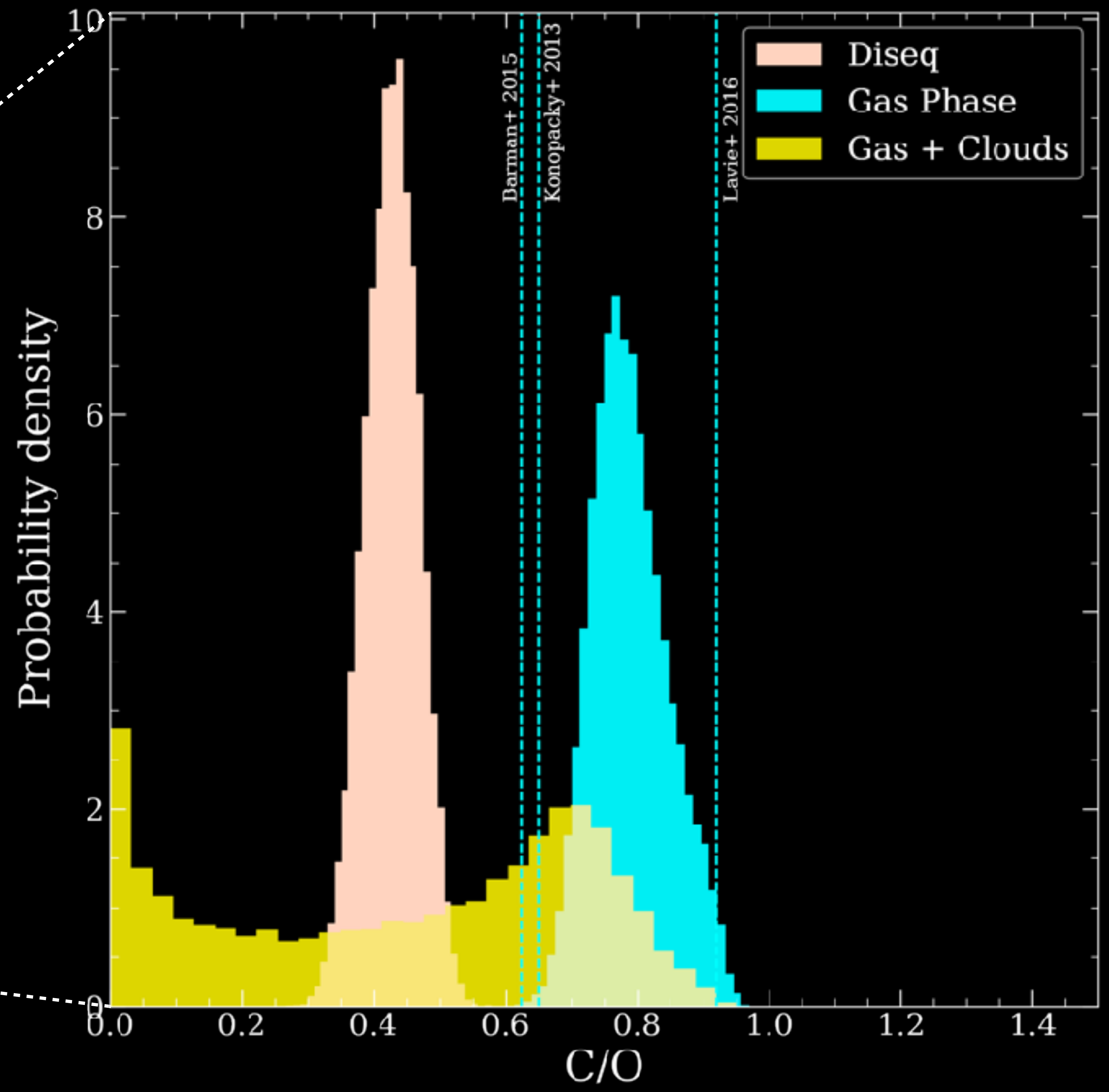

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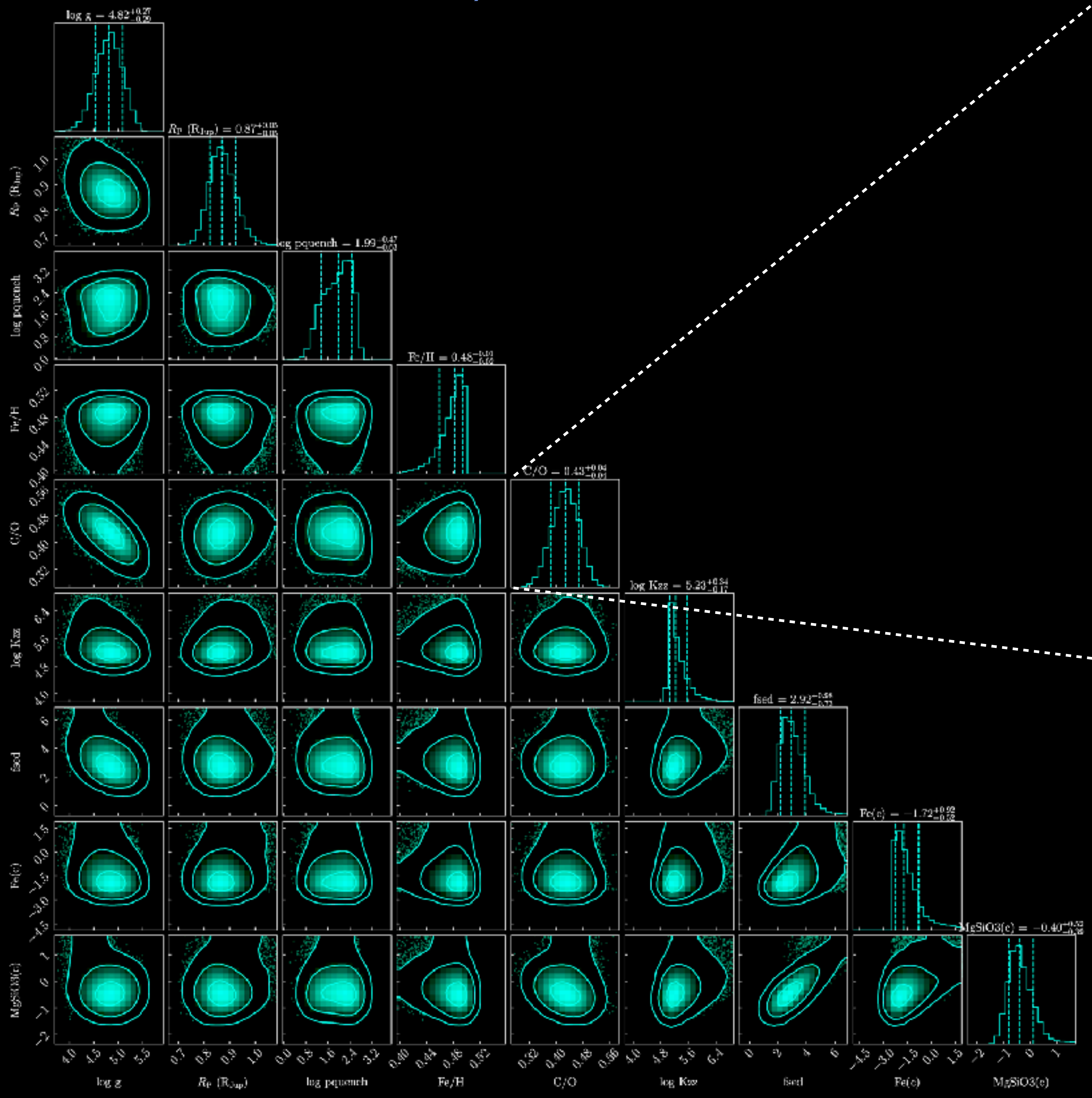
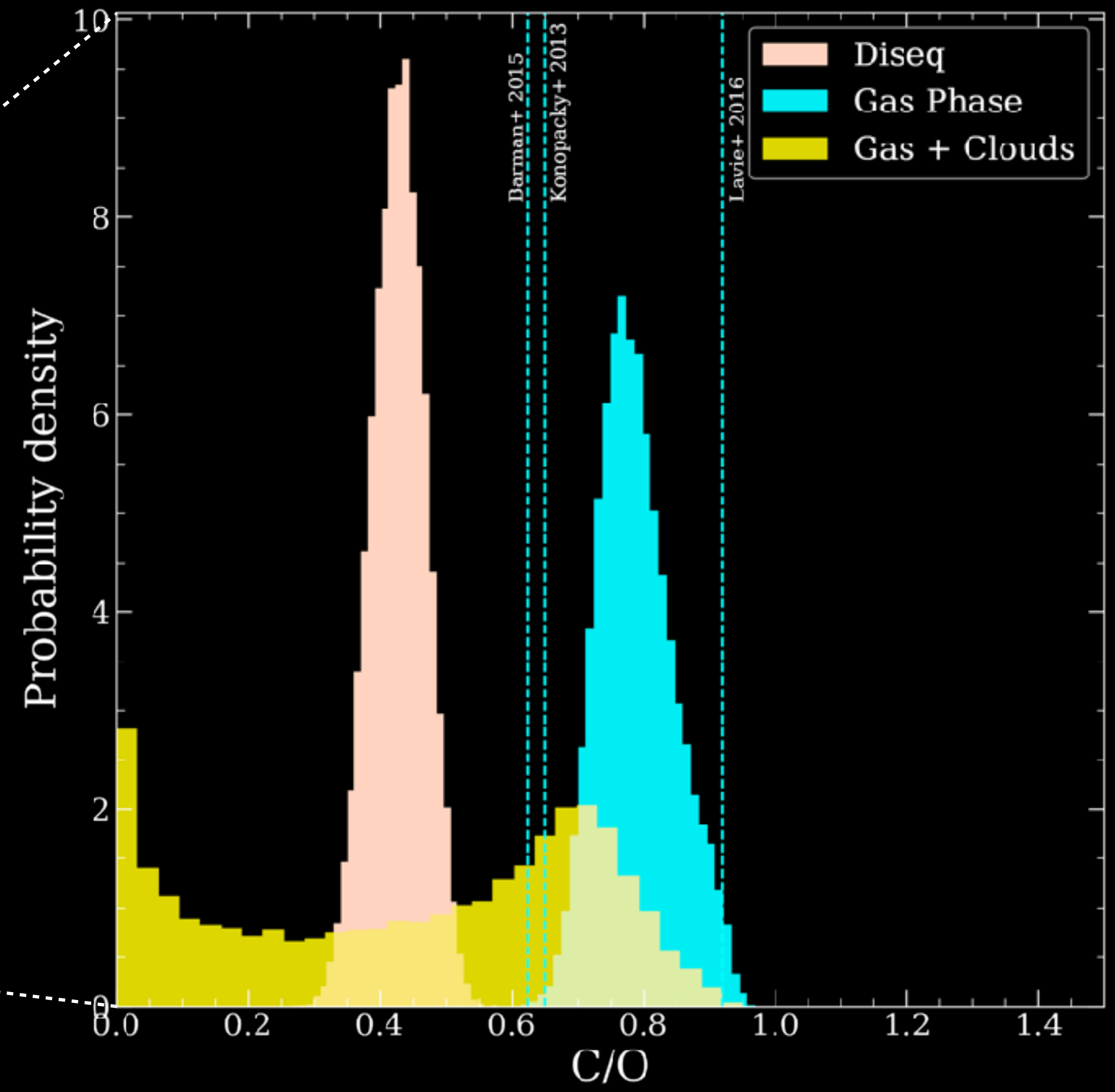
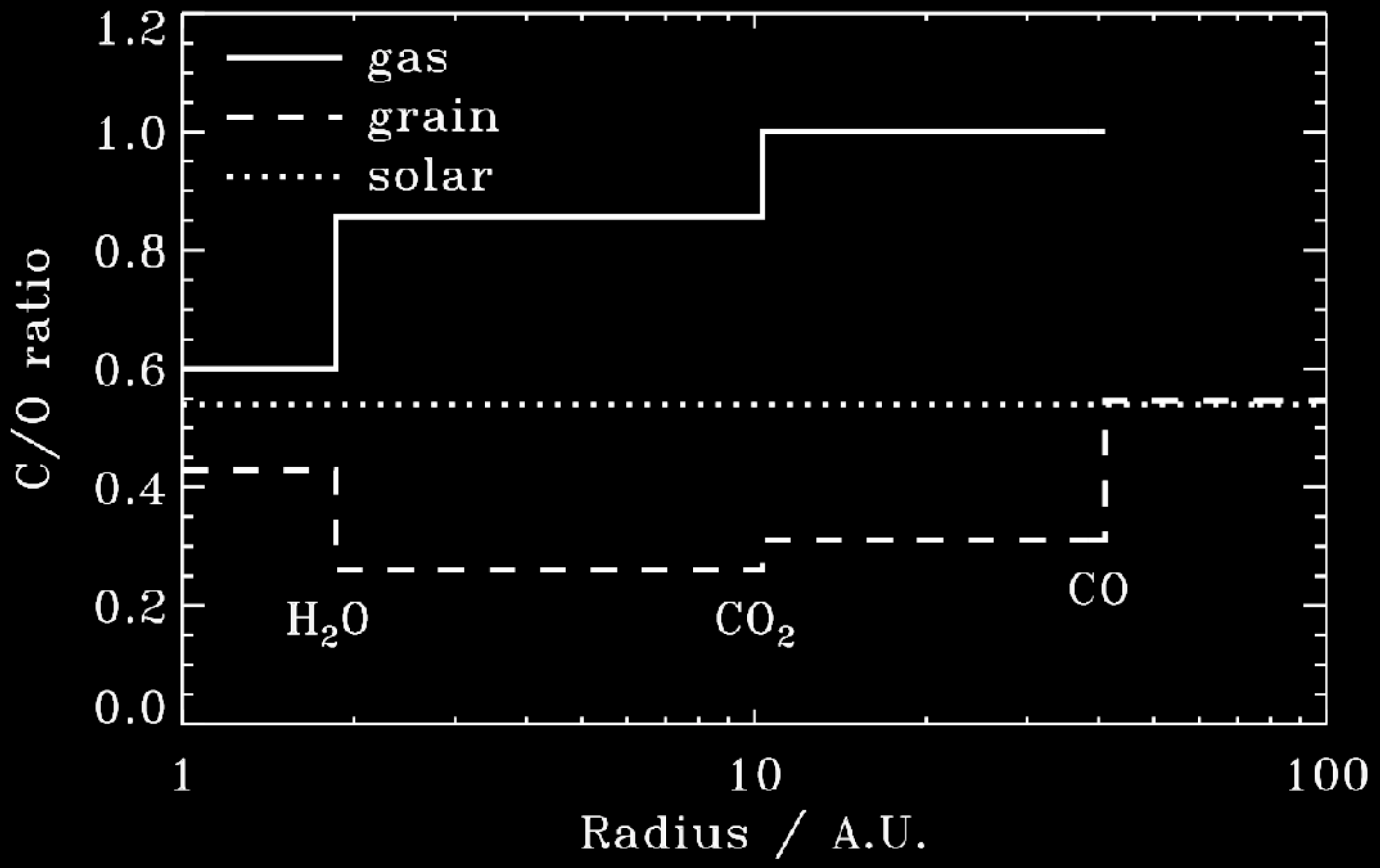




- The free chemistry retrieval predicts a higher CO abundance than disequilibrium chemistry.

Preliminary results: C/O



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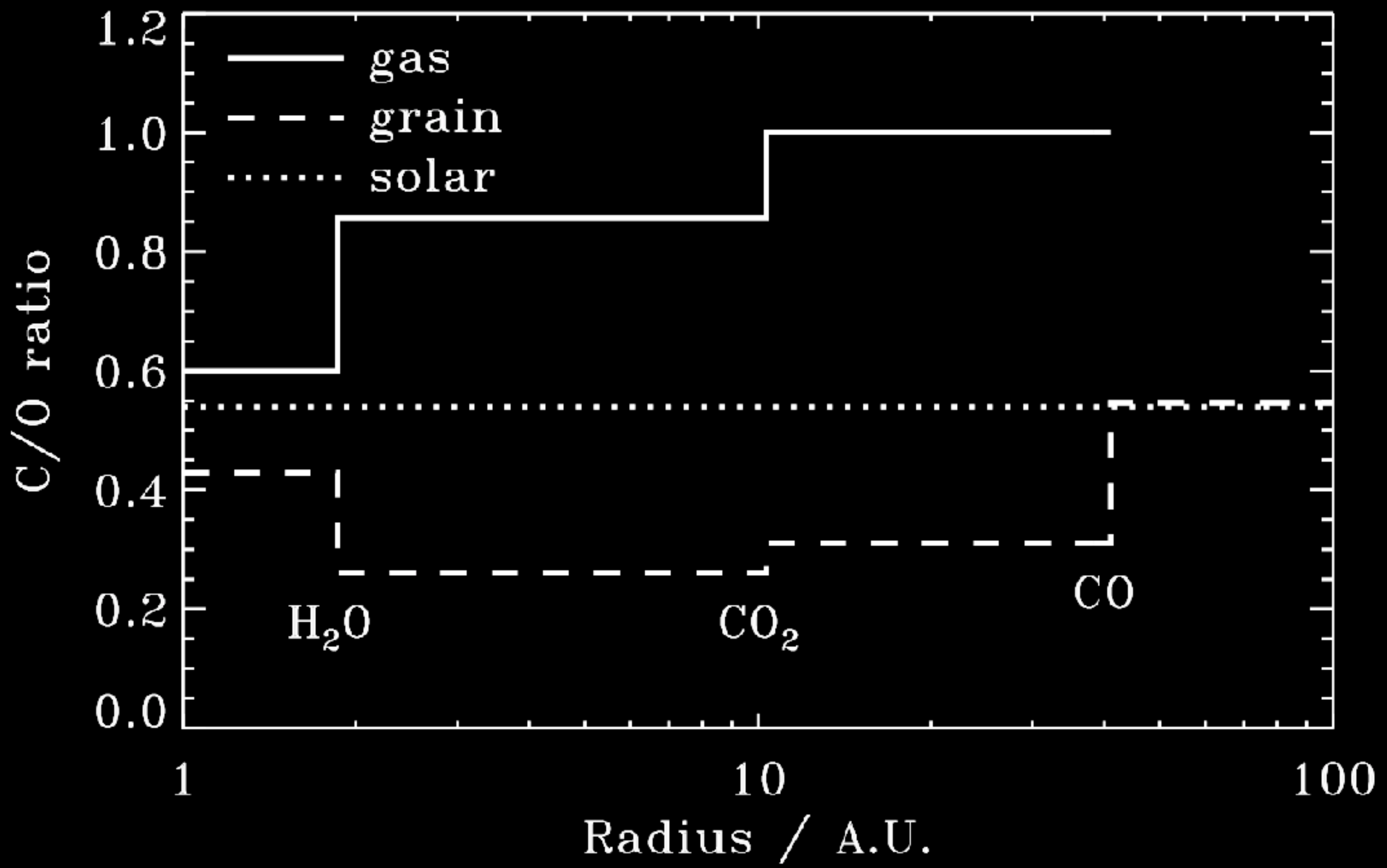

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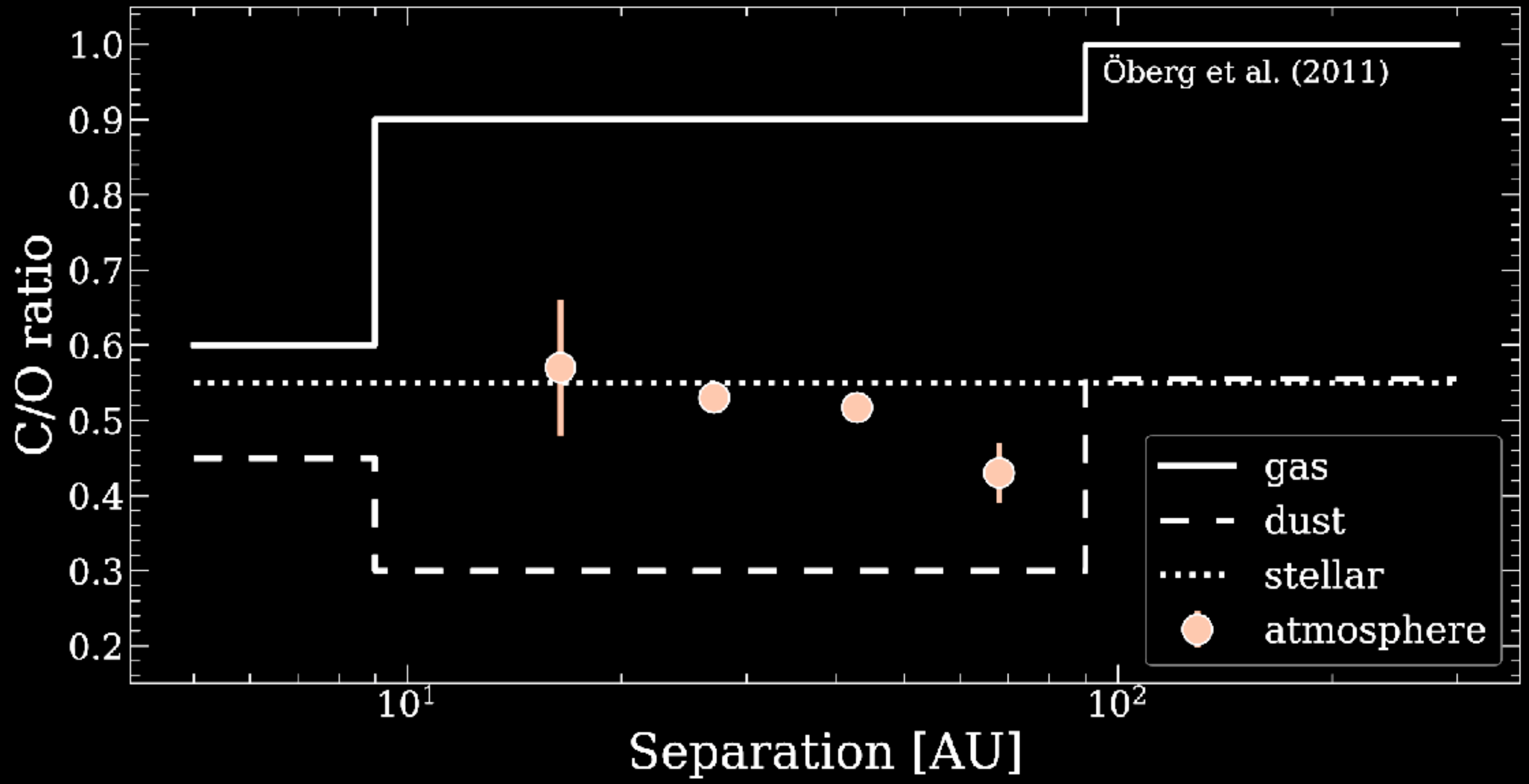

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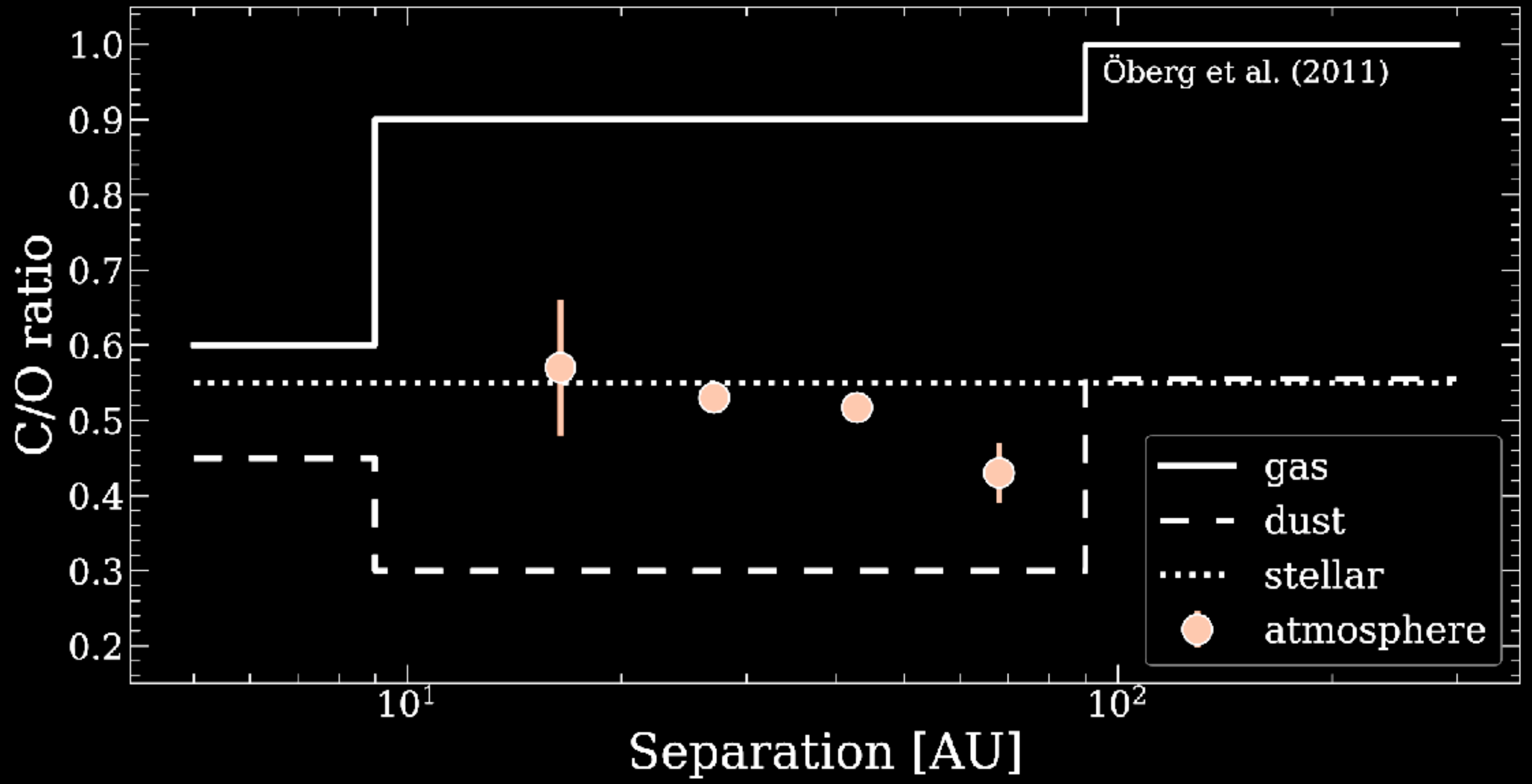

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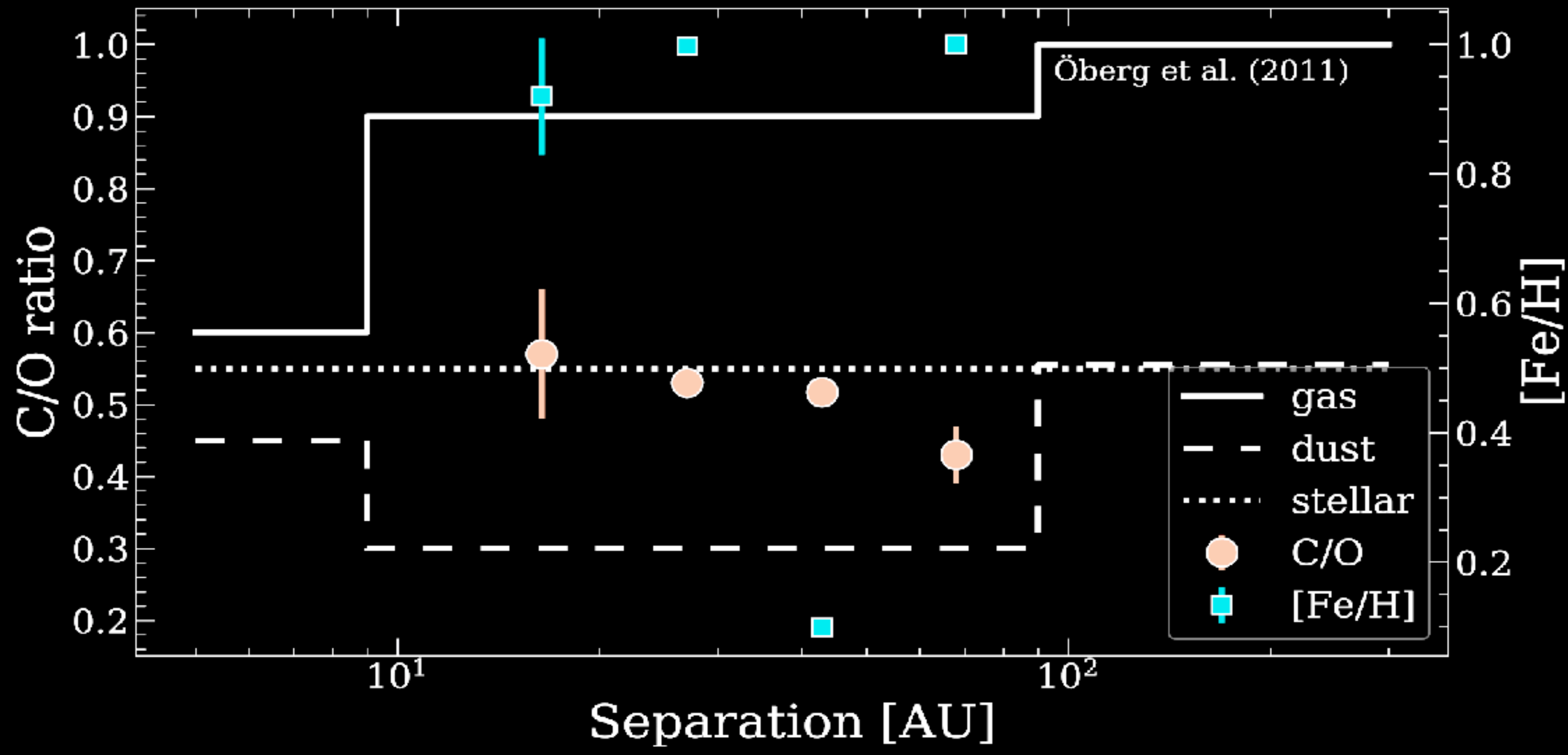

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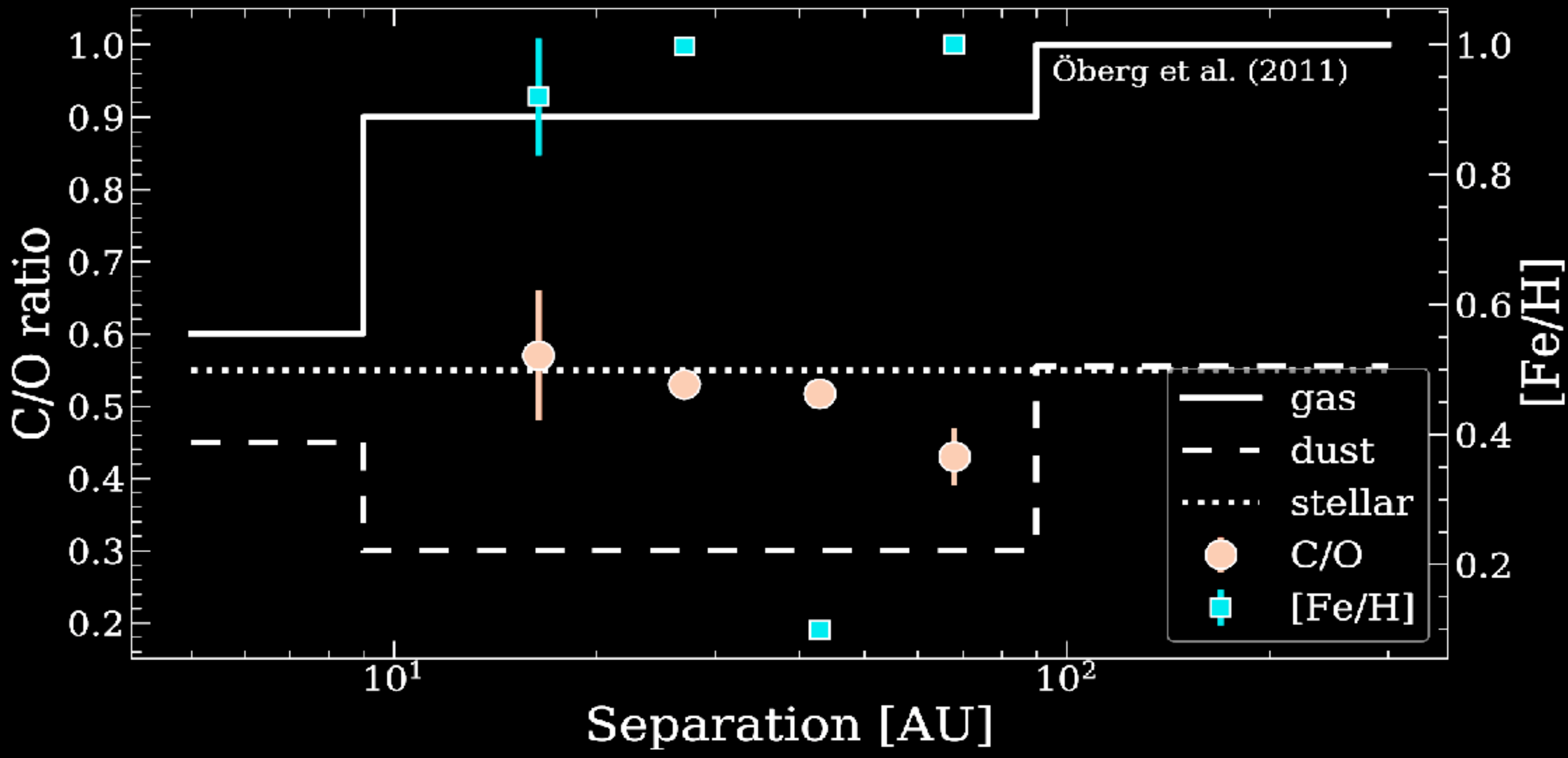
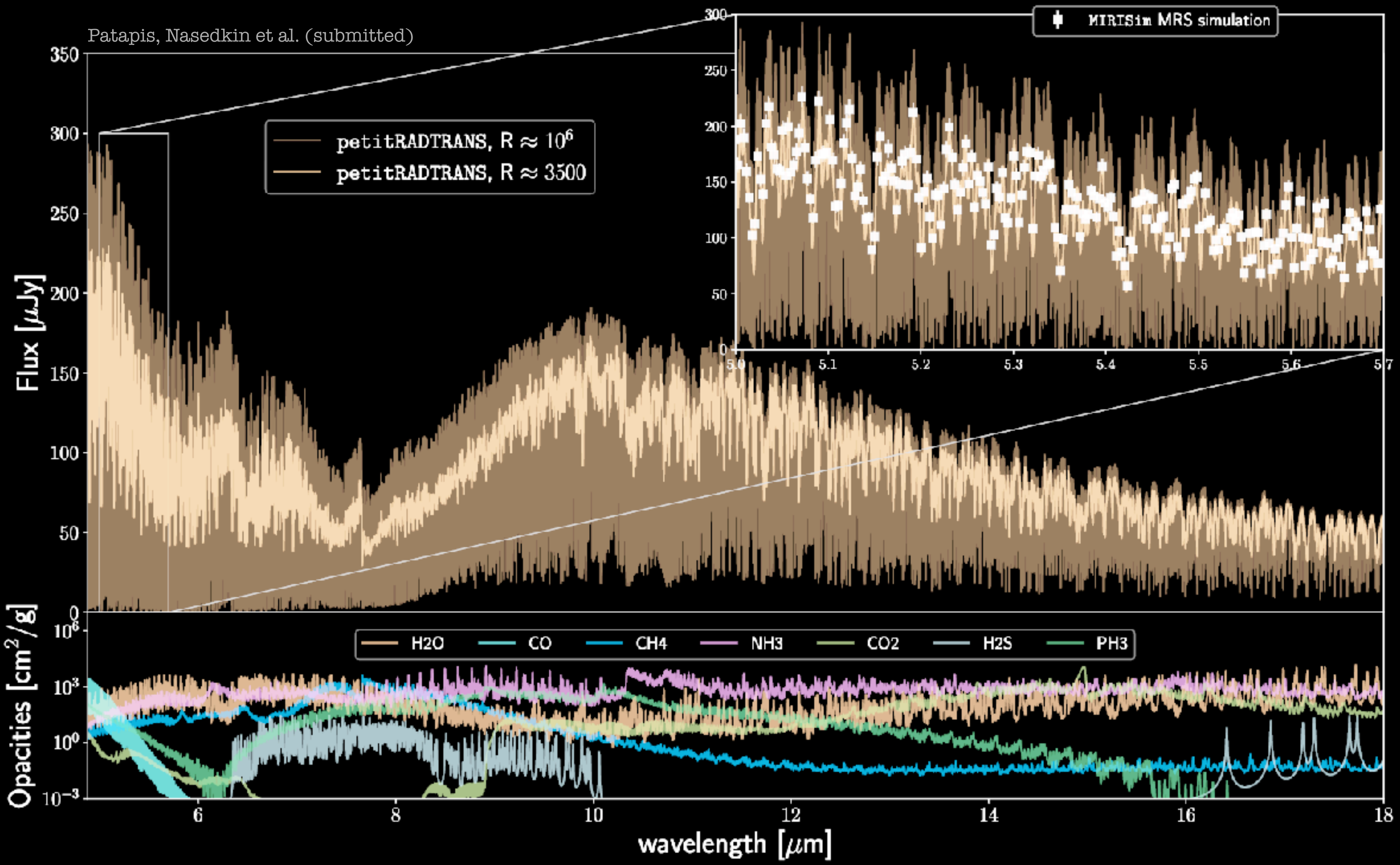
The retrieval for c is still running!



Future Work



Patapis, Nasedkin et al. (submitted)
MIRISim MRS simulation
petitRADTRANS, R ≈ 10^6
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Flux [μJy]
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CO
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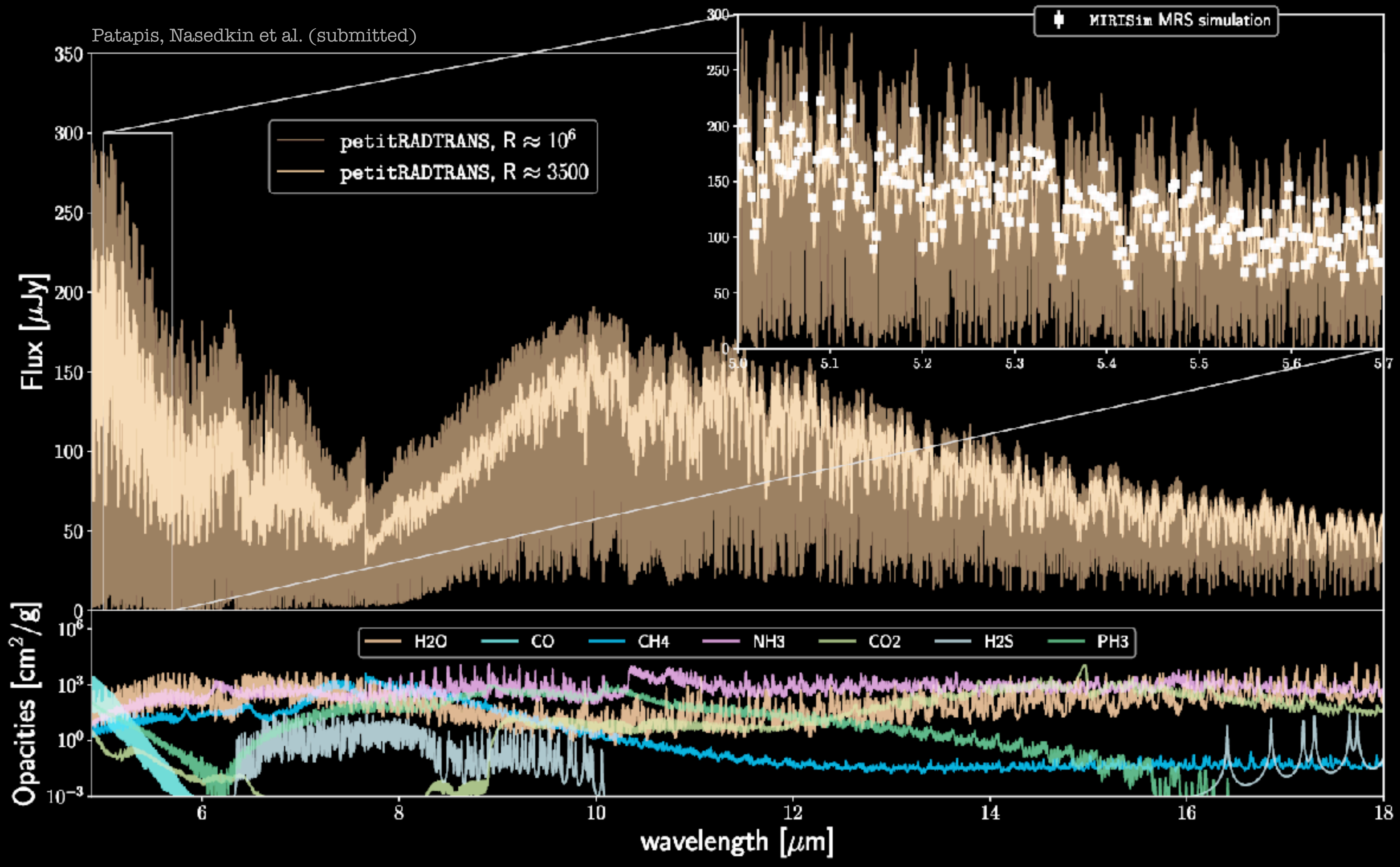

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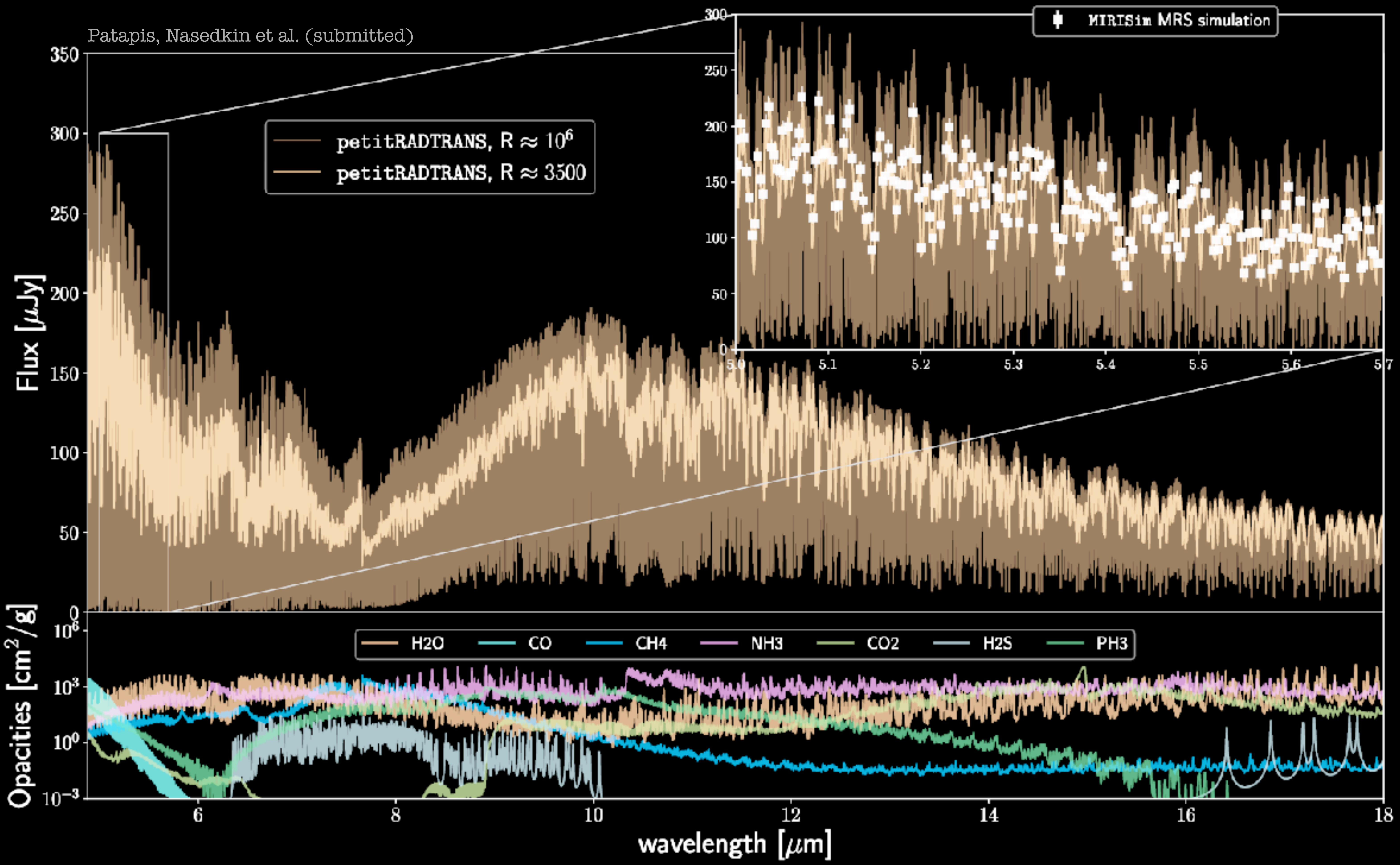

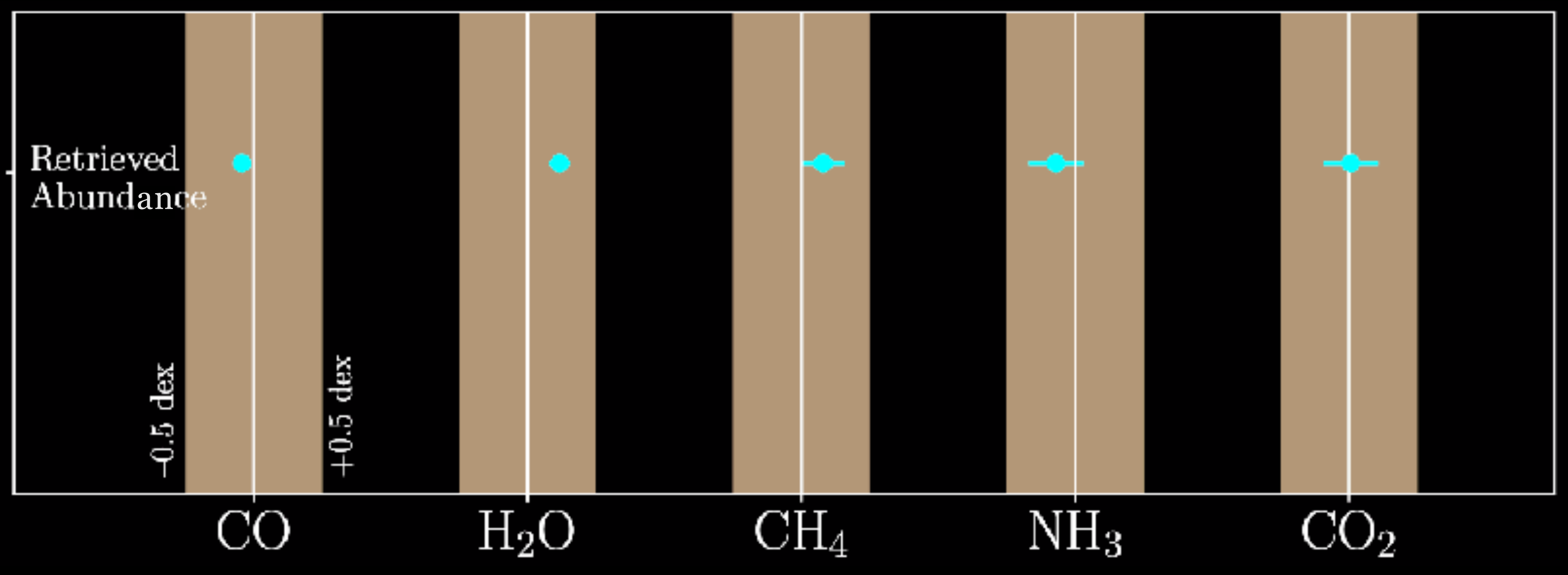

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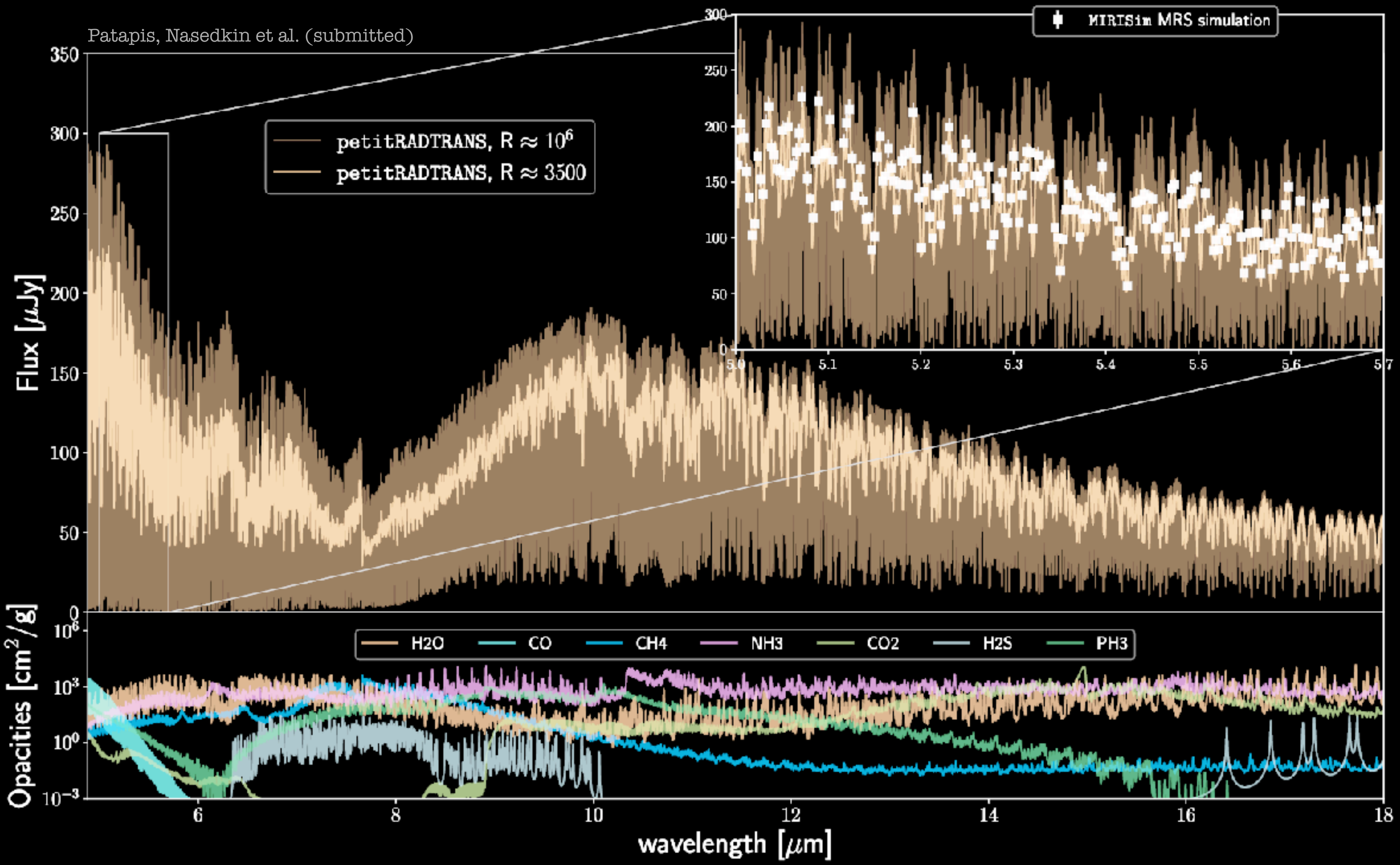

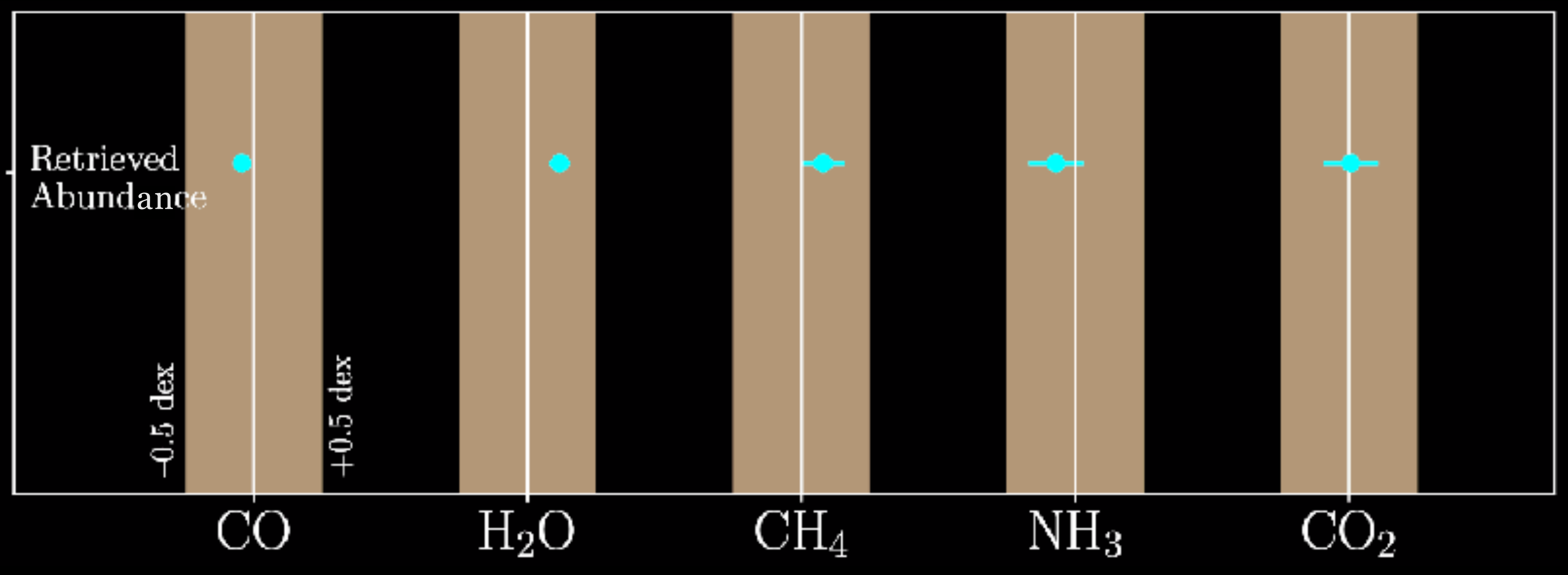

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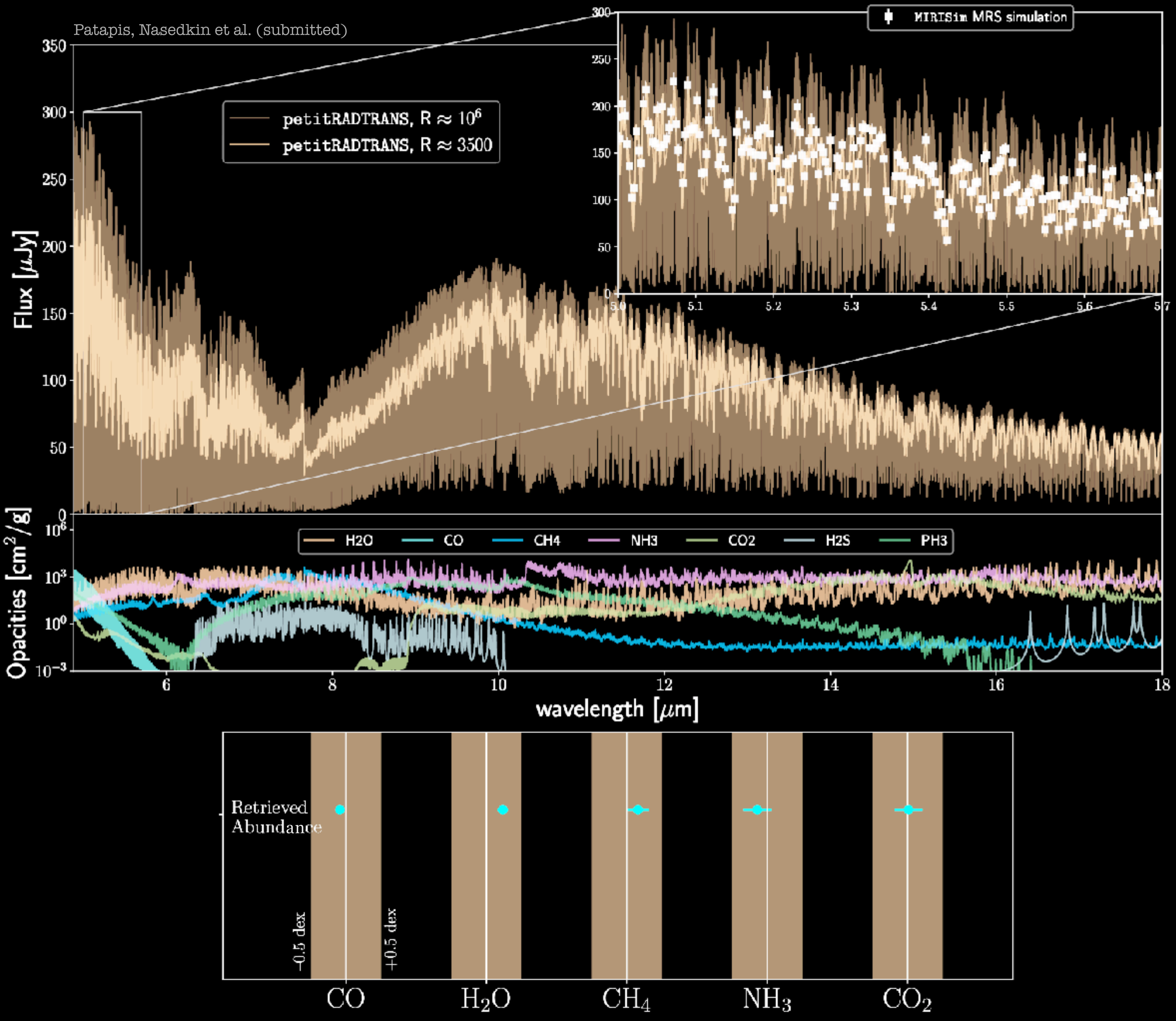

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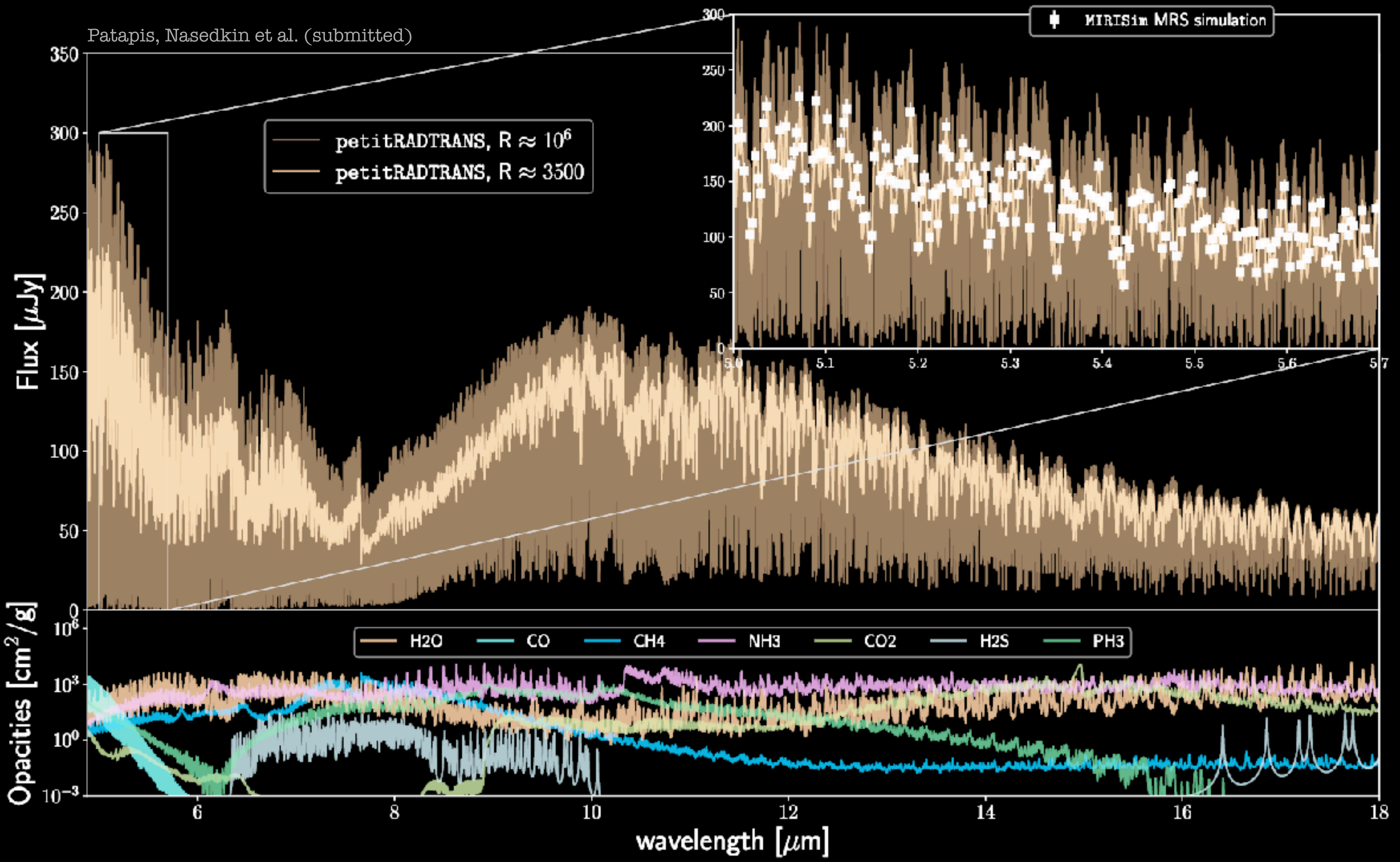

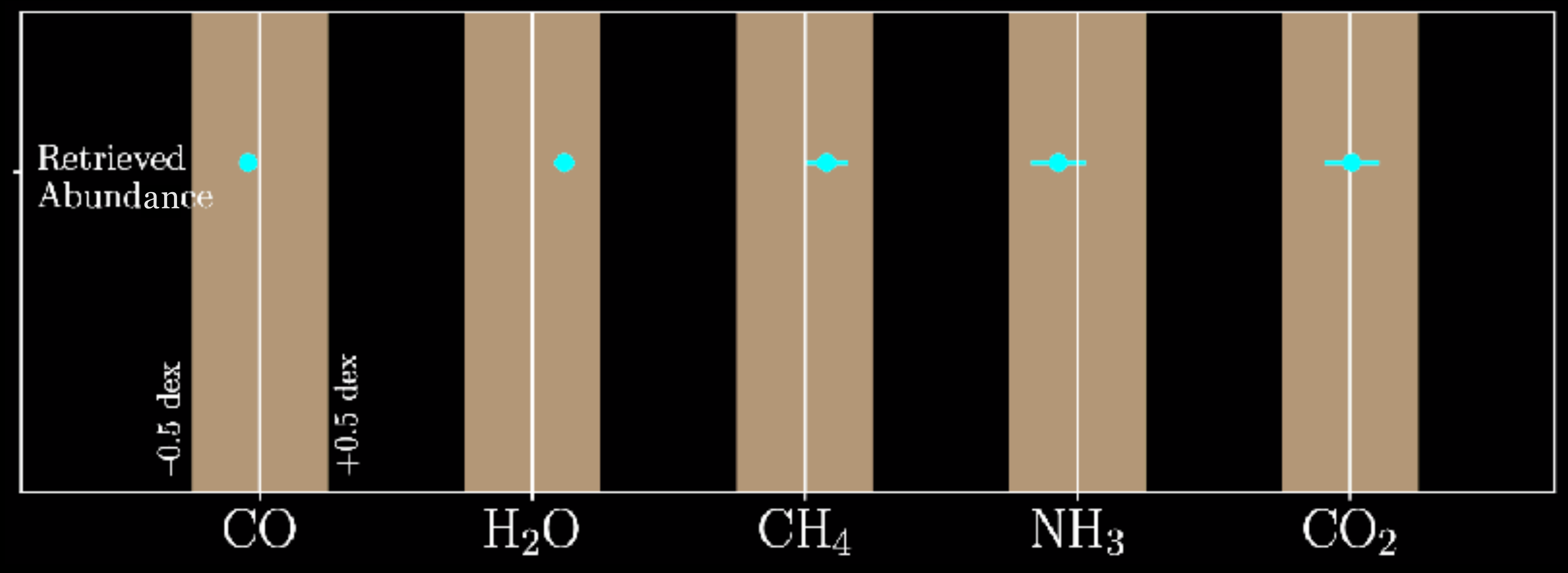

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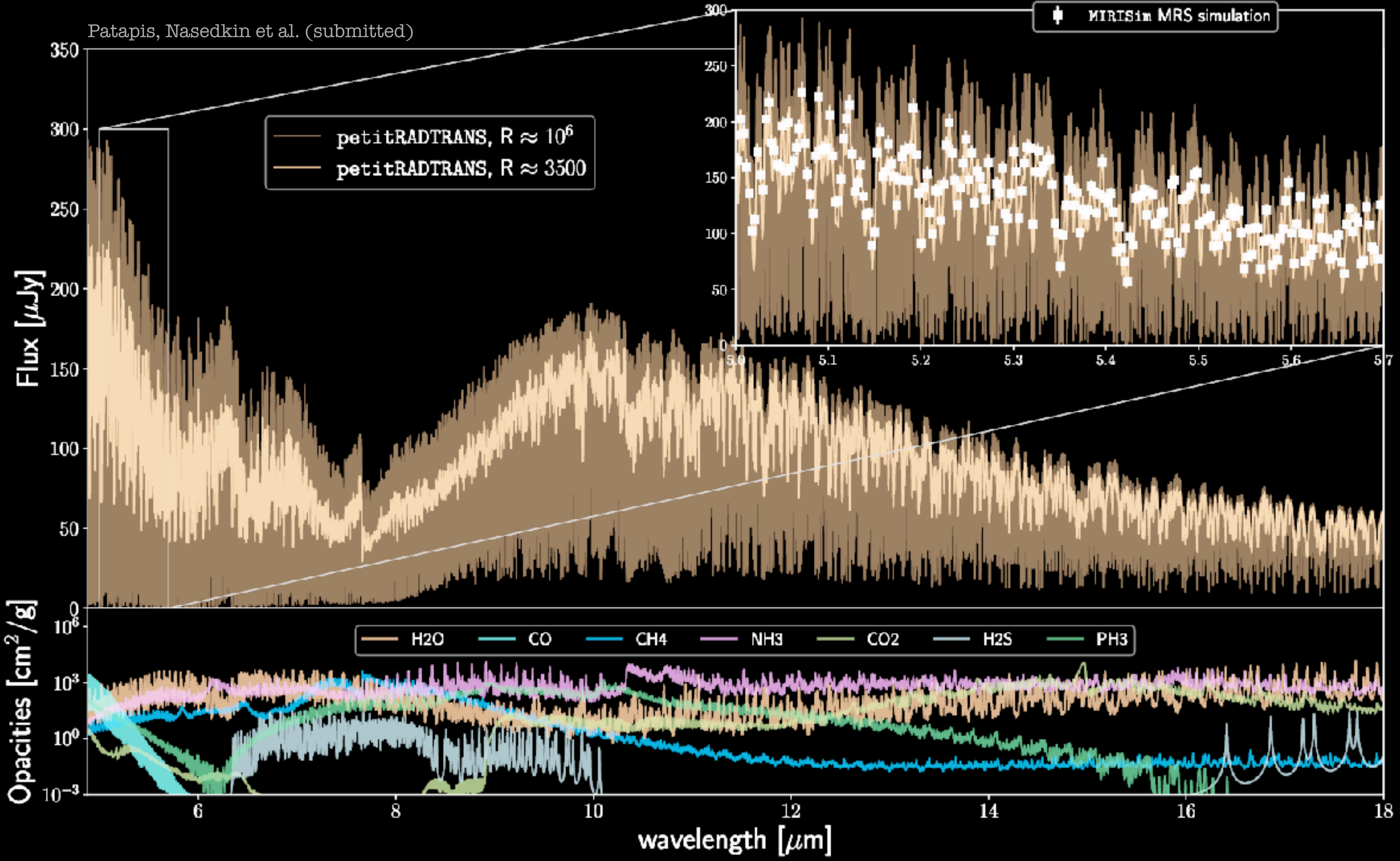

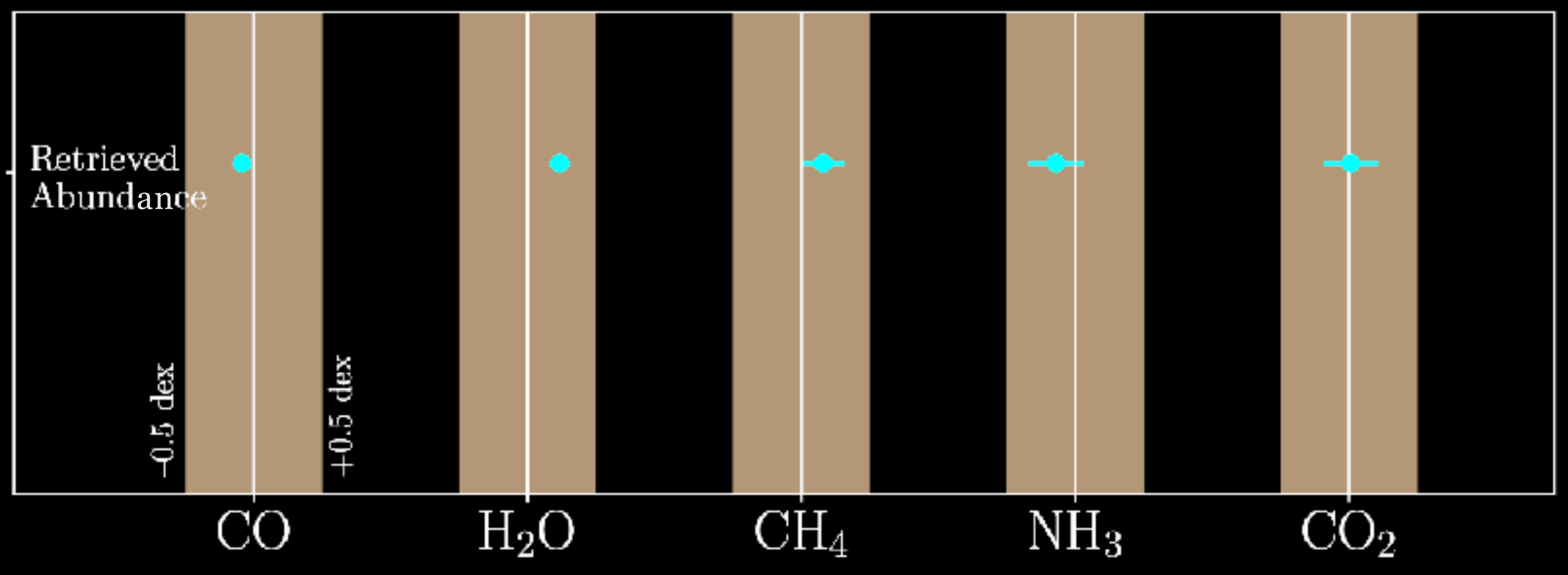

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- There's still lots to do!

References

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