Cloud Formation on Brown Dwarfs & Hot Jupiters

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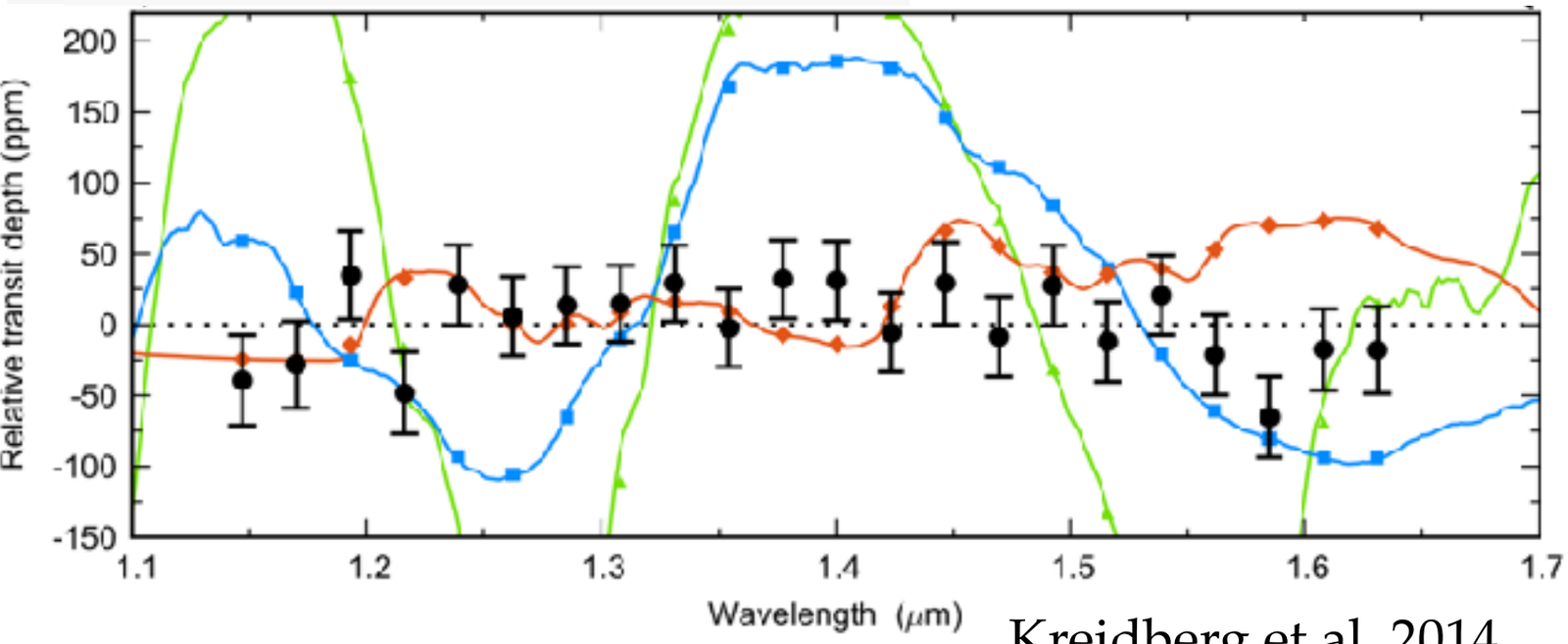
1. UC Santa Cruz, 2. UC Berkeley, 3. NASA Ames, 4. Aix Marseille Univ

Clouds are abundant!

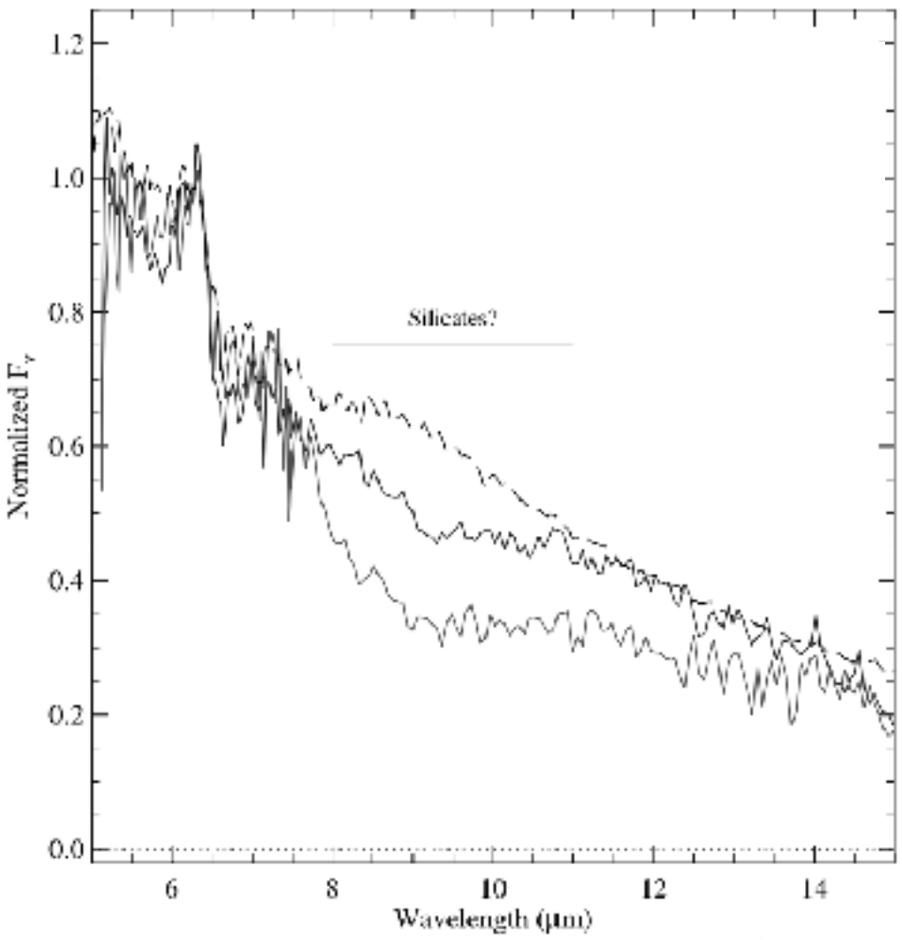
Clouds interfere with observations!

Damped Spectral Features



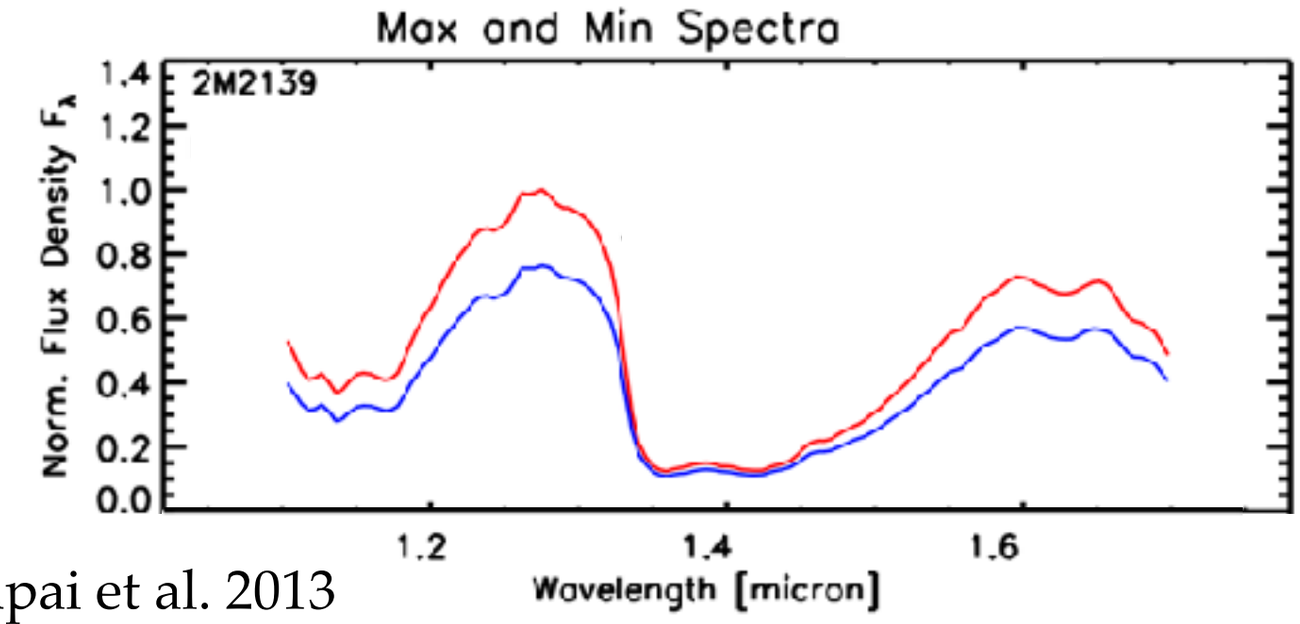
Kreidberg et al. 2014

Silicate Absorption?



Burgasser et al. 2008

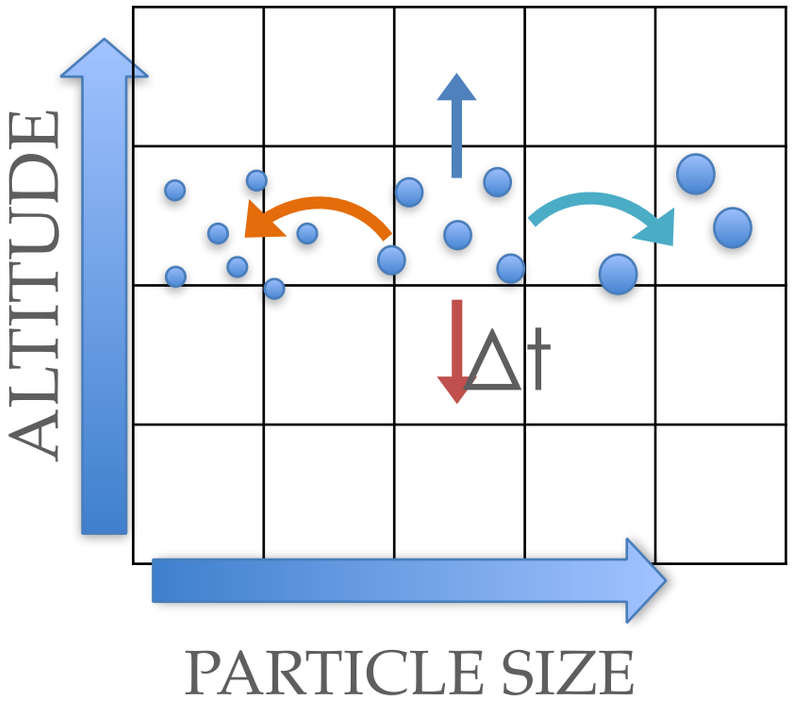
Variability

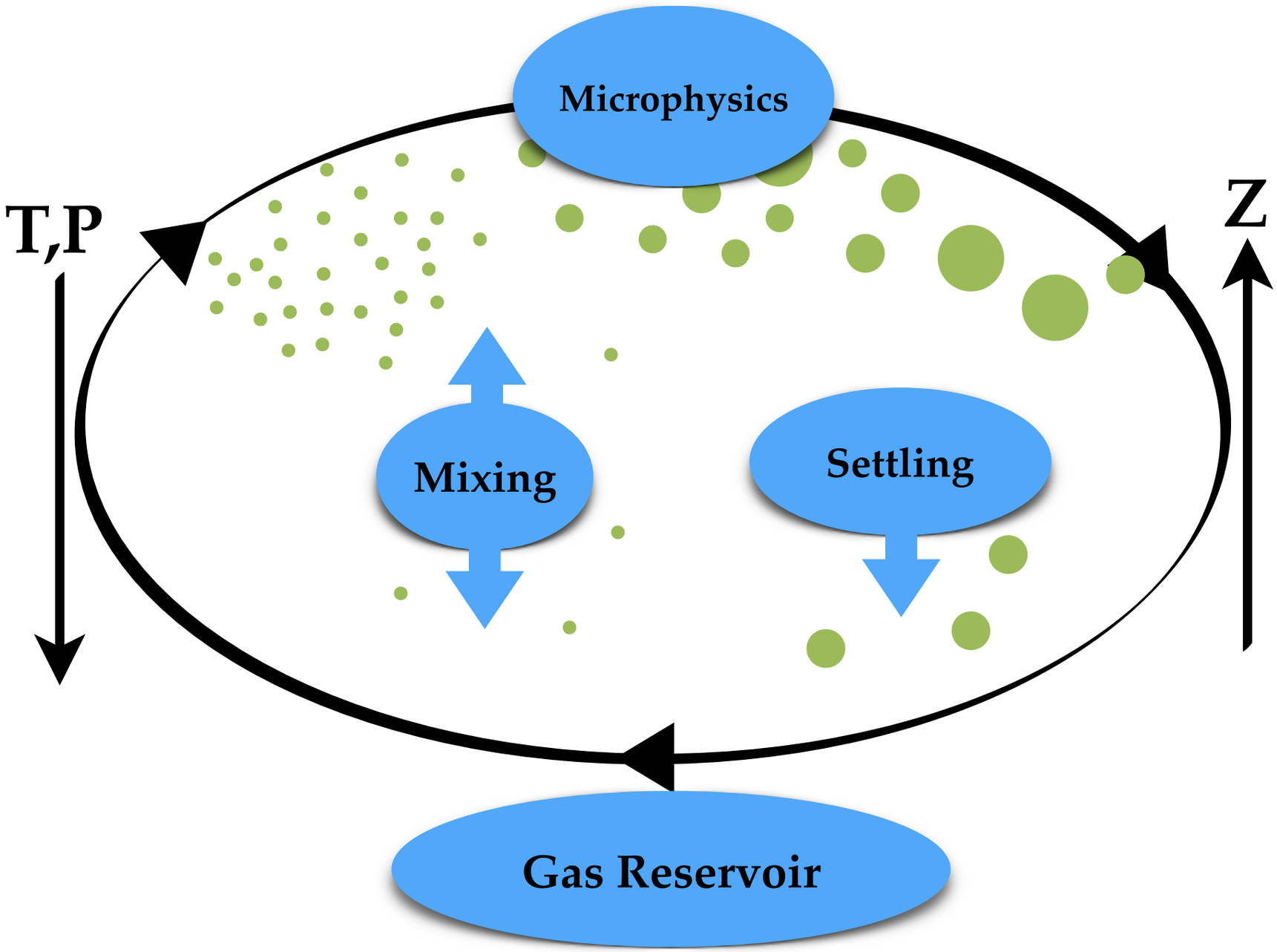


Apai et al. 2013

*See next talk by Johanna Vos!

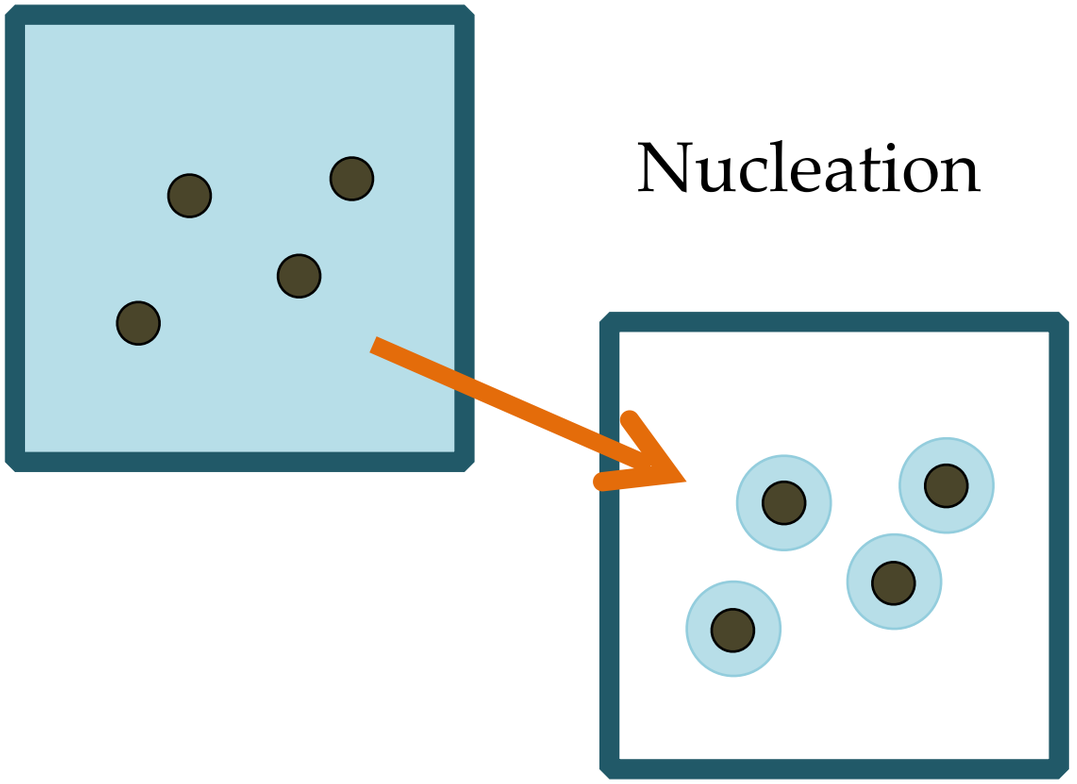
CARMA: Community Aerosol & Radiation Model for Atmospheres





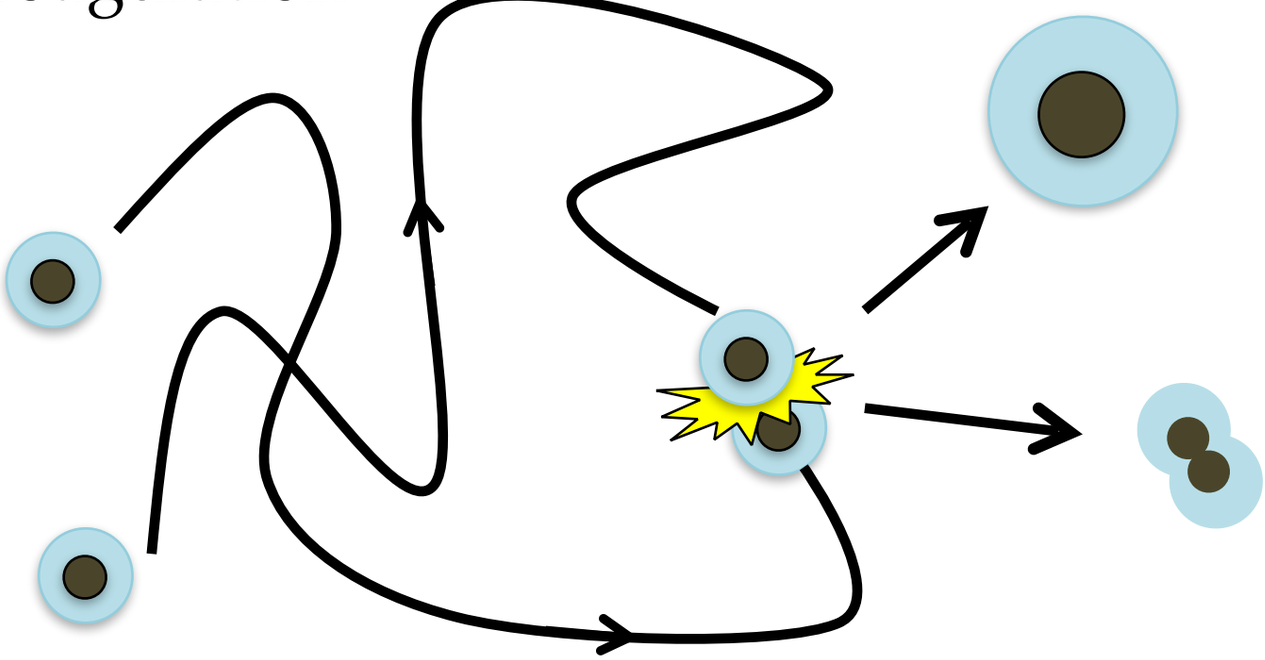
- **Fully resolved size distributions**
- **From first principles**
- **Time dependent**

Microphysics

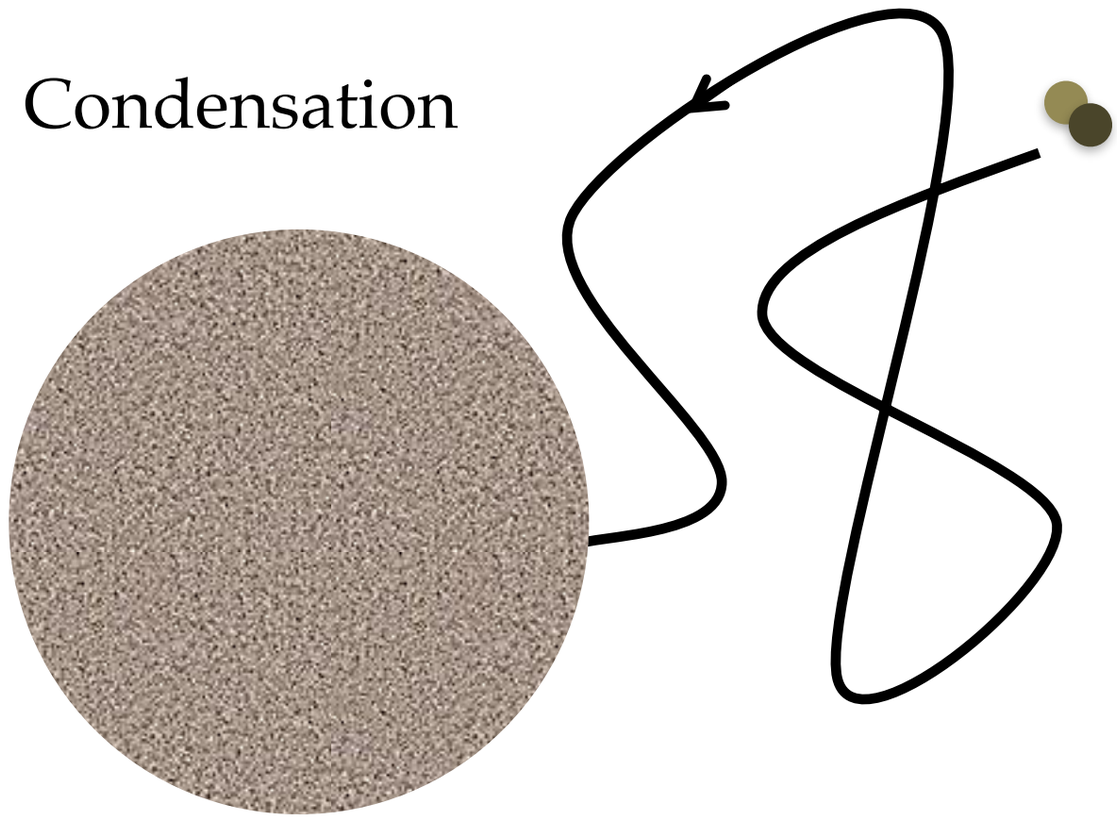


Nucleation

Coagulation



Condensation

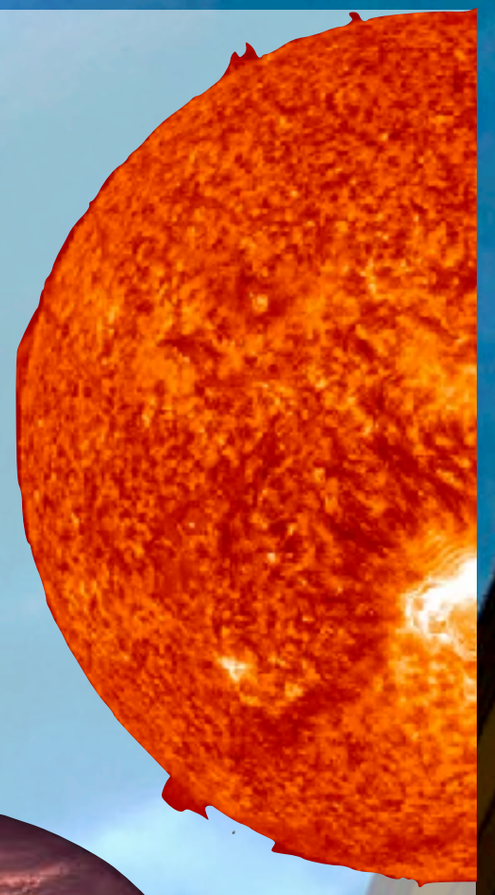


Images: Peter Gao

Roadmap

1. Clouds on **Hot Jupiters:**

Powell, D., et al. 2018, ApJ, 860, 18



2. Clouds on **Brown Dwarfs:**

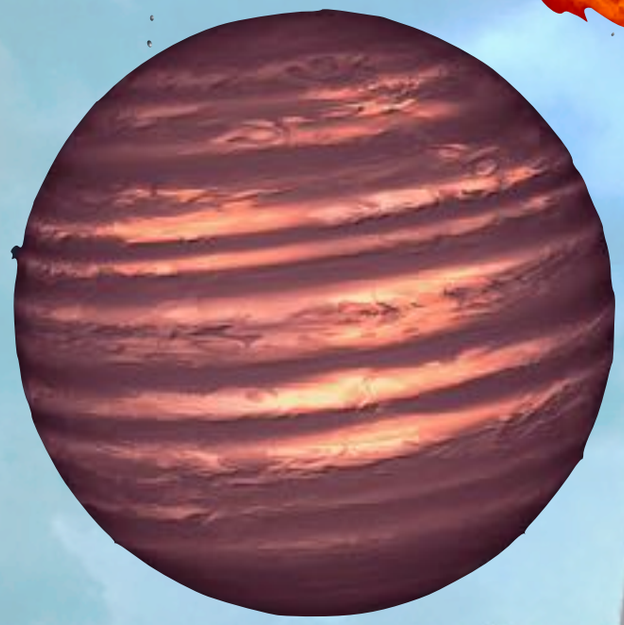
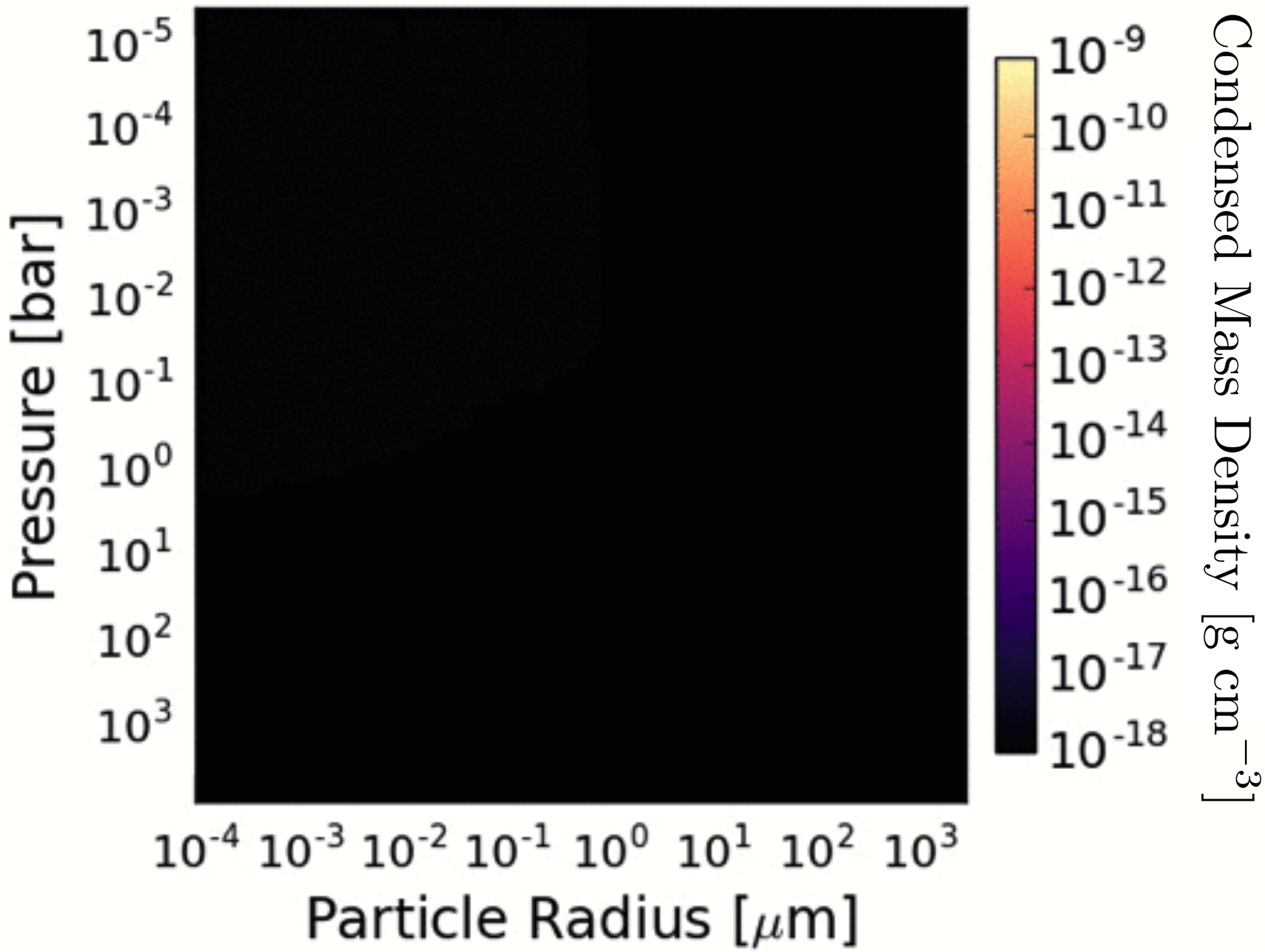
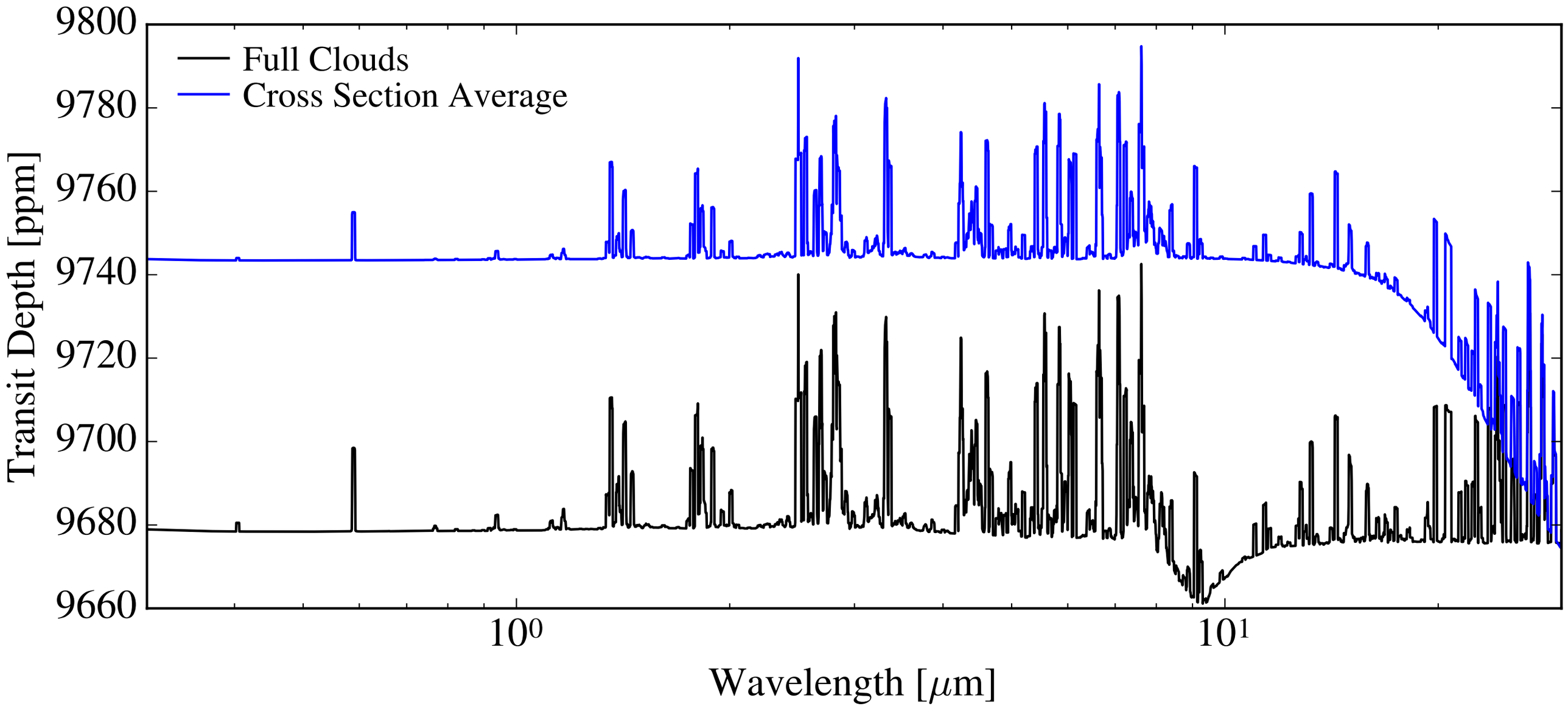


image: NASA/JPL-Caltech

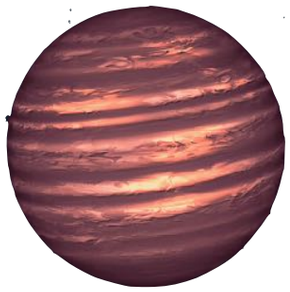


1 frame = 1 Earth month

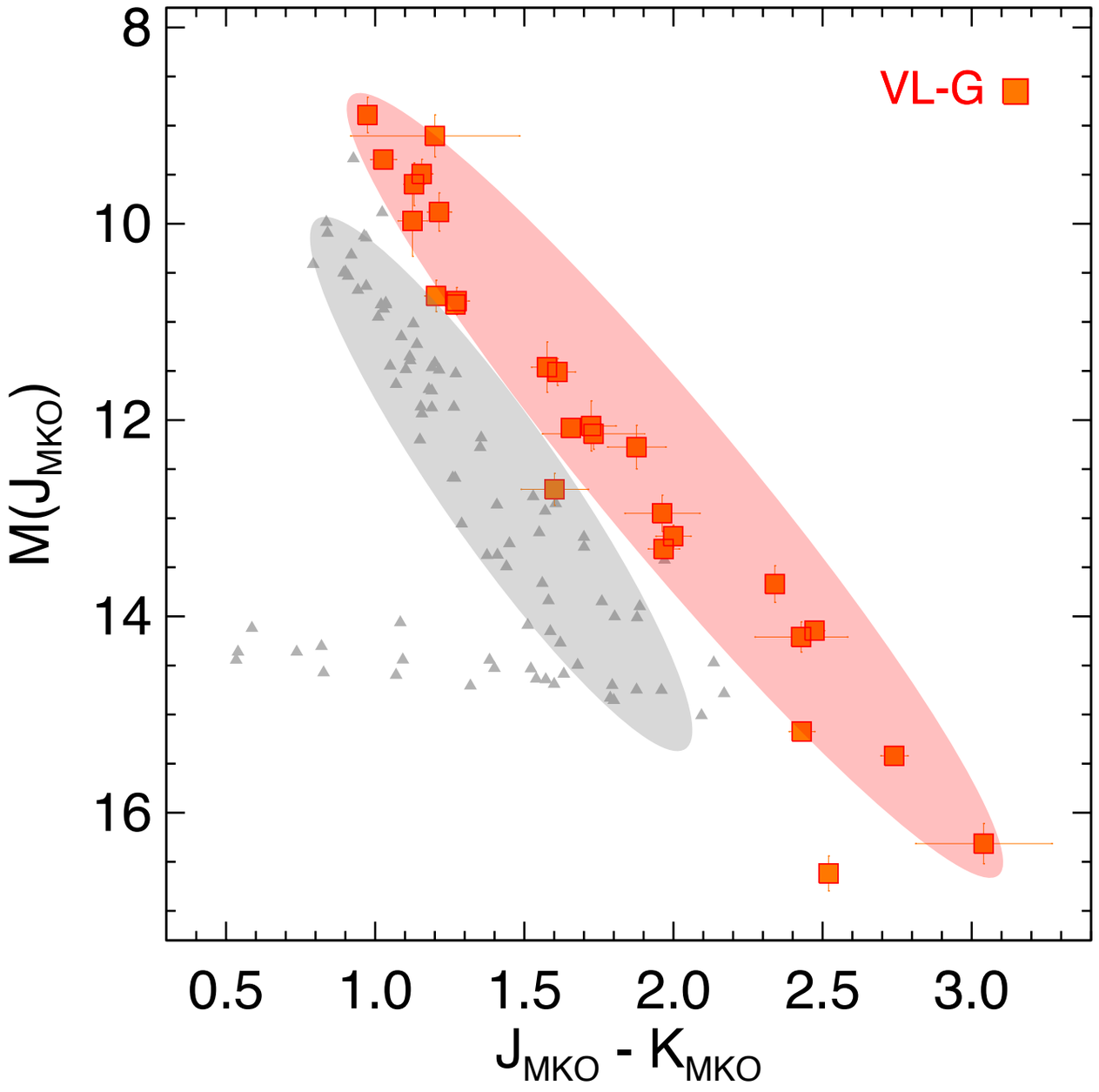
Considering the full particle size distribution distinctly changes the transmission spectra

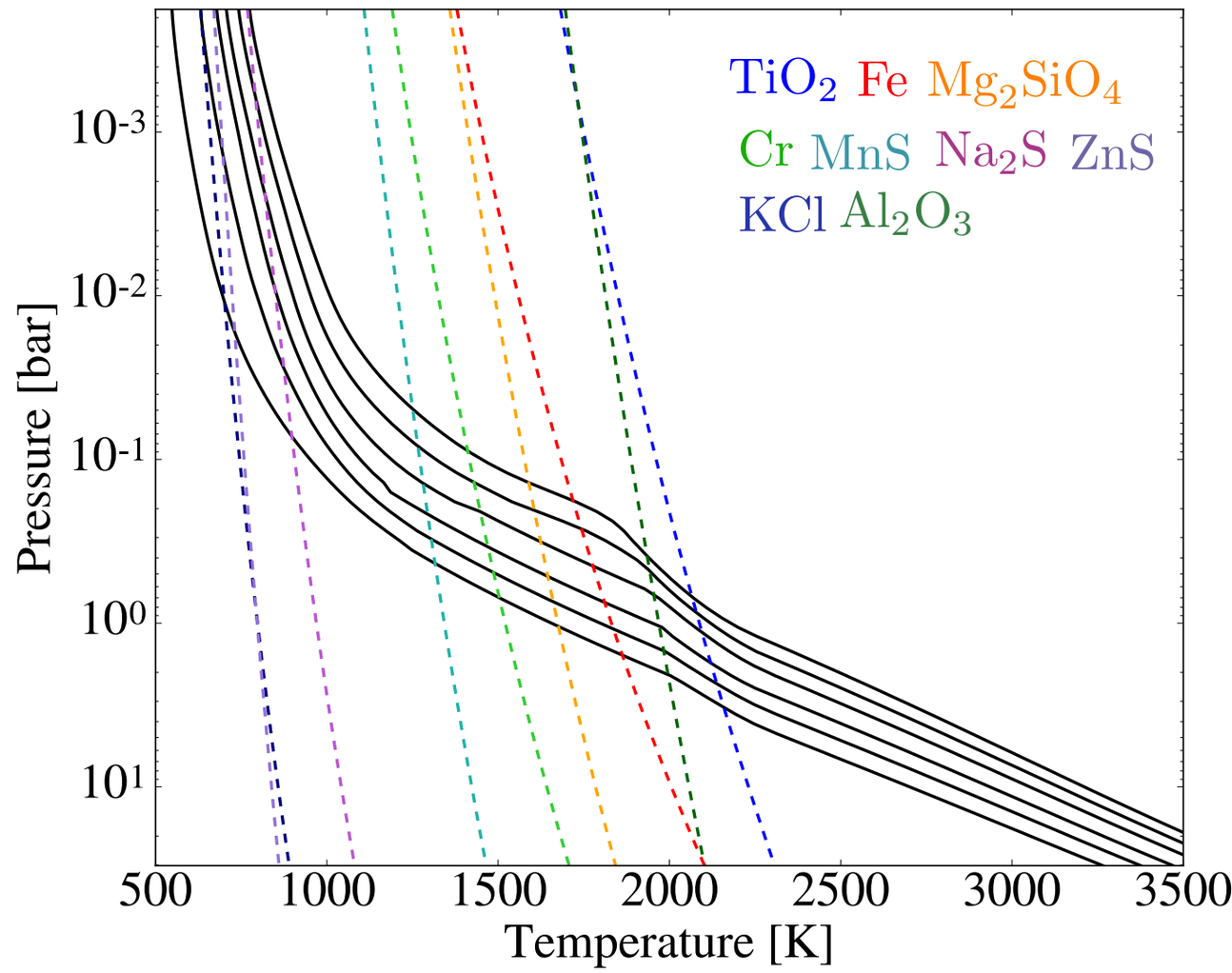


Powell et al. 2018b (in prep)



Very Low Gravity Brown-Dwarfs





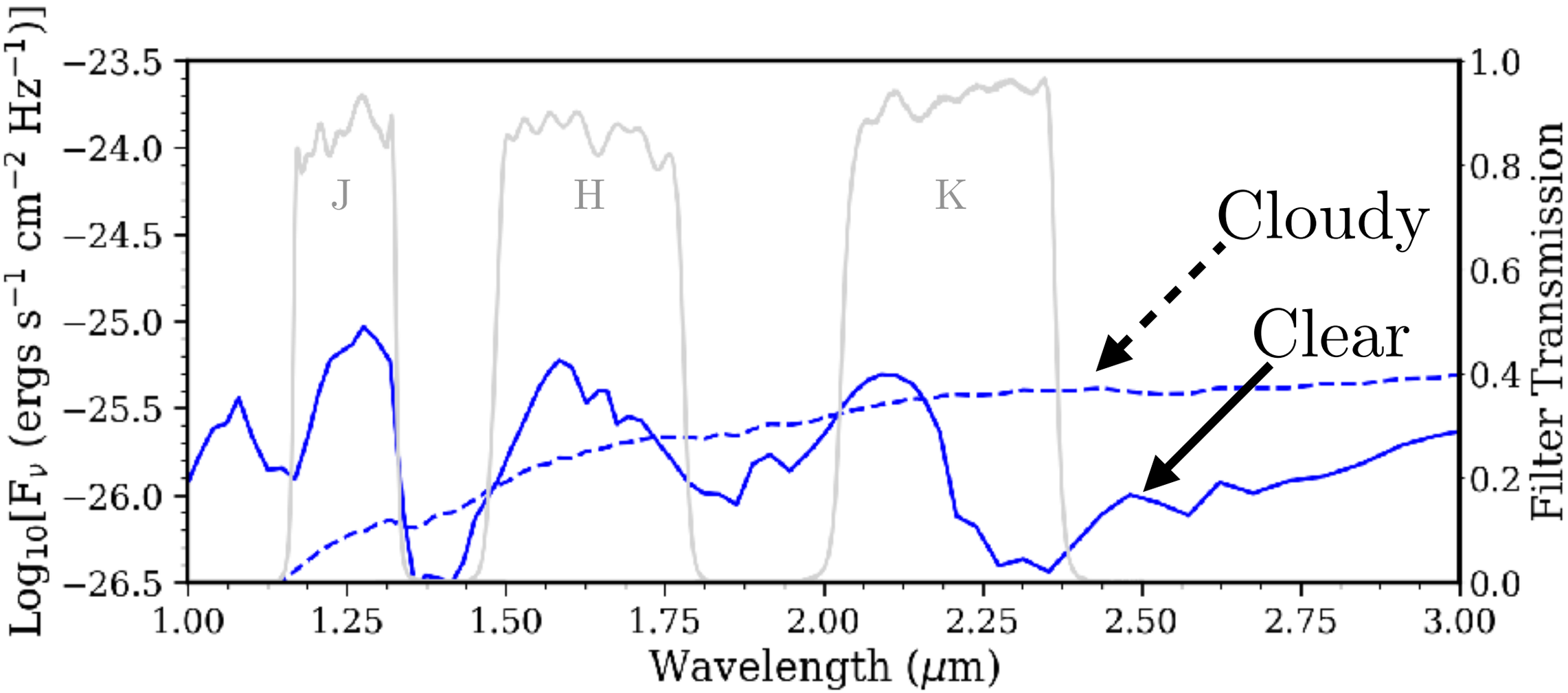
$$\log(g) = 4$$
$$T_{\rm eq} = 1100 - 1600 \text{ K}$$

Preliminary

Data from Liu, Dupuy & Allers (2016)
Plot Courtesy of Mike Liu

Sonora Models
Powell et al. 2018c (in prep)

Flattened Emission Spectra

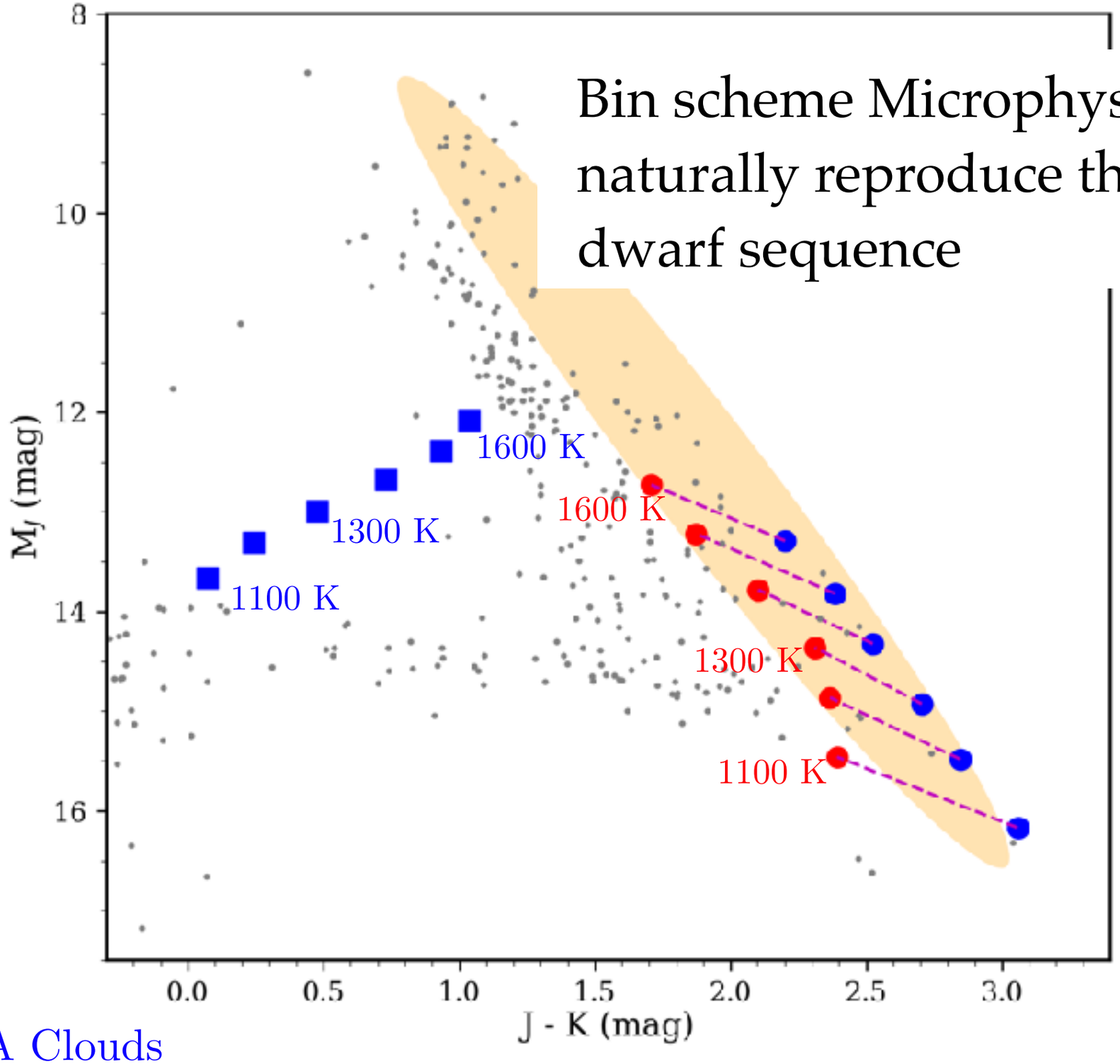


$\log(g) = 4$

$T_{\mathrm{eq}} = 1100\ \mathrm{K}$

Powell et al. 2018c (in prep)

Very Low Gravity CMD



Bin scheme Microphysical clouds naturally reproduce the VL-G brown dwarf sequence

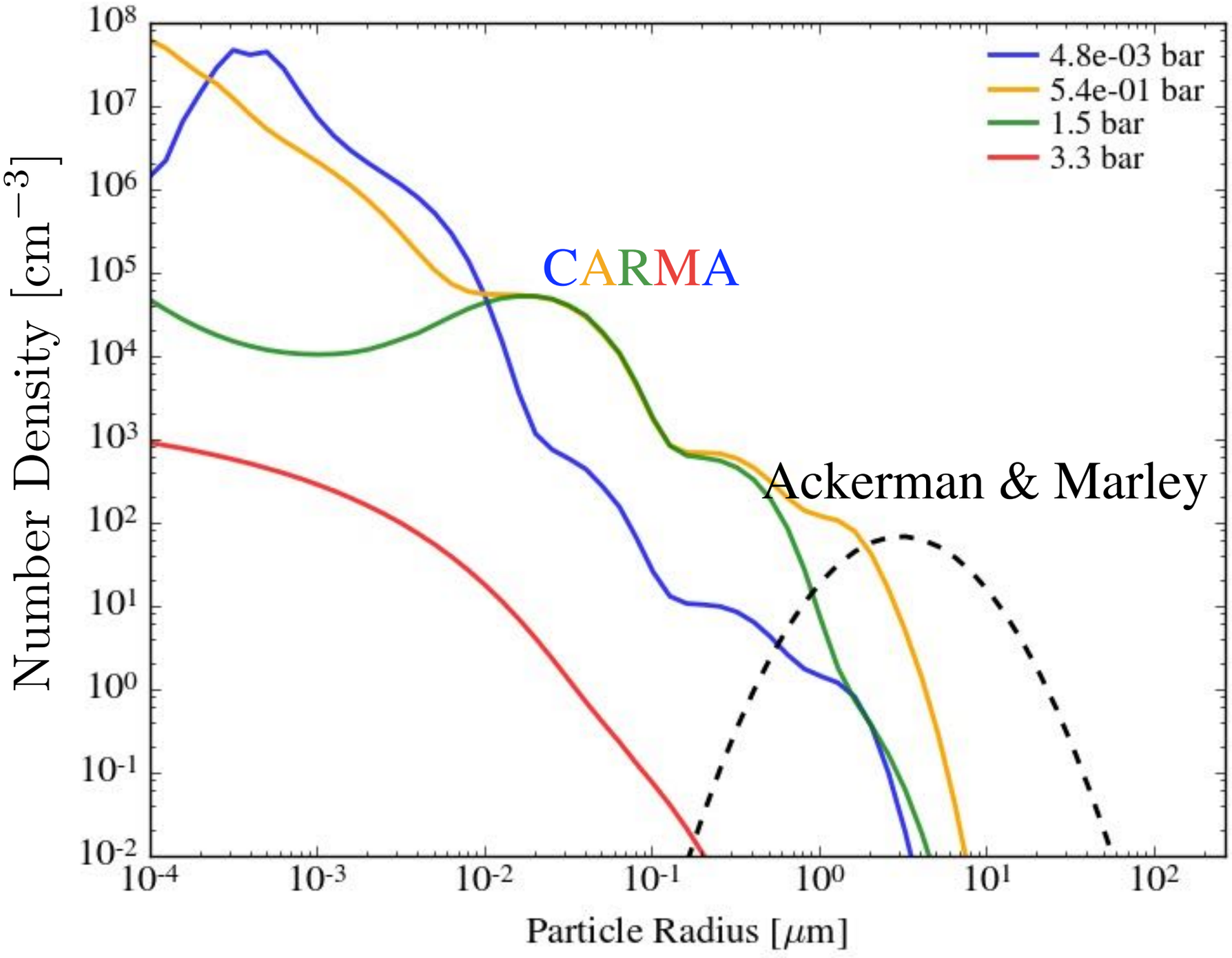
● = CARMA Clouds

● = Ackerman & Marley Clouds

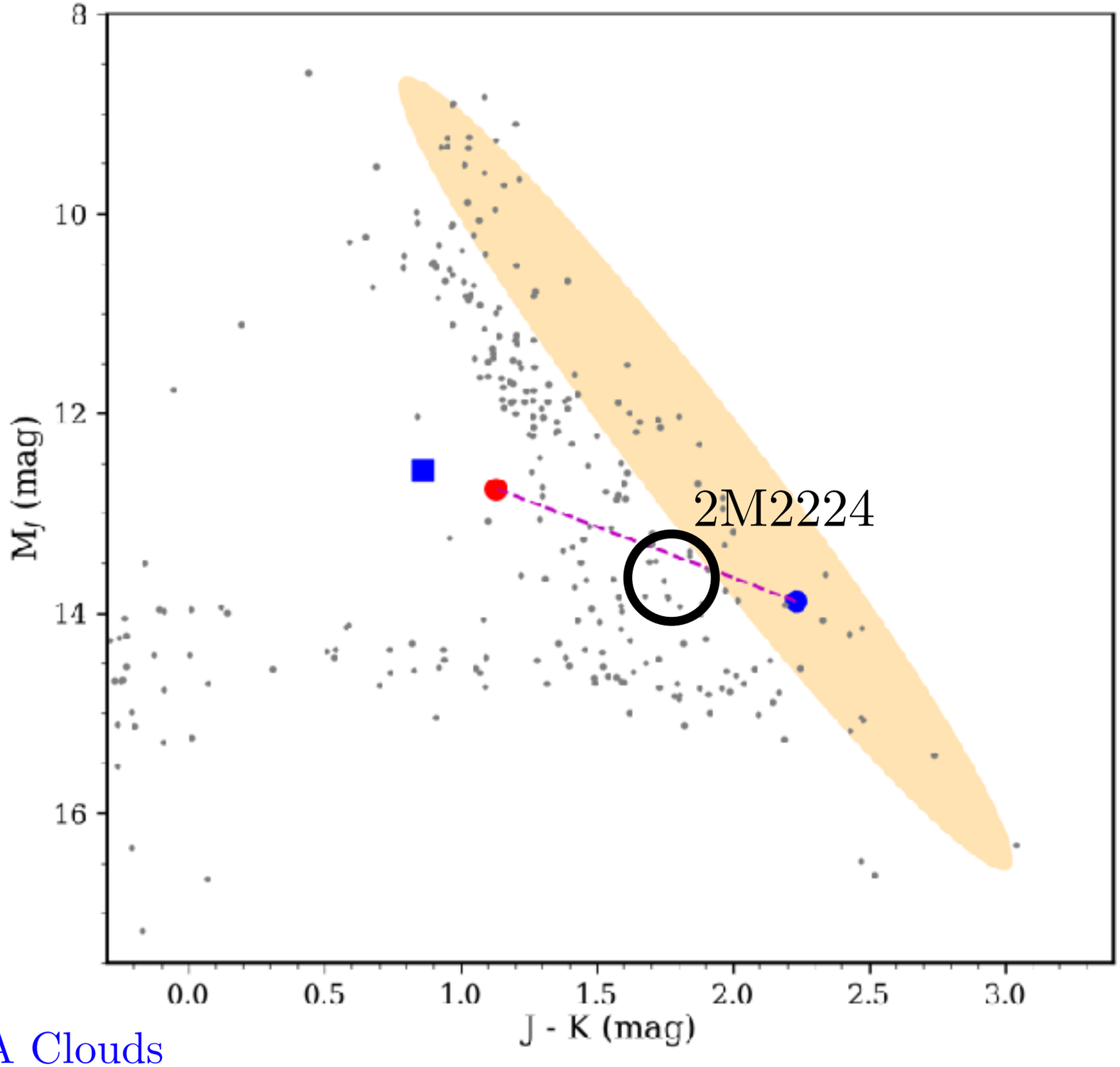
■ = Clear Atmosphere

Powell et al. 2018c (in prep)

Why are these cloud models giving different answers?



What about normal gravity brown dwarfs?



● = CARMA Clouds

● = Ackerman & Marley Clouds

■ = Clear Atmosphere

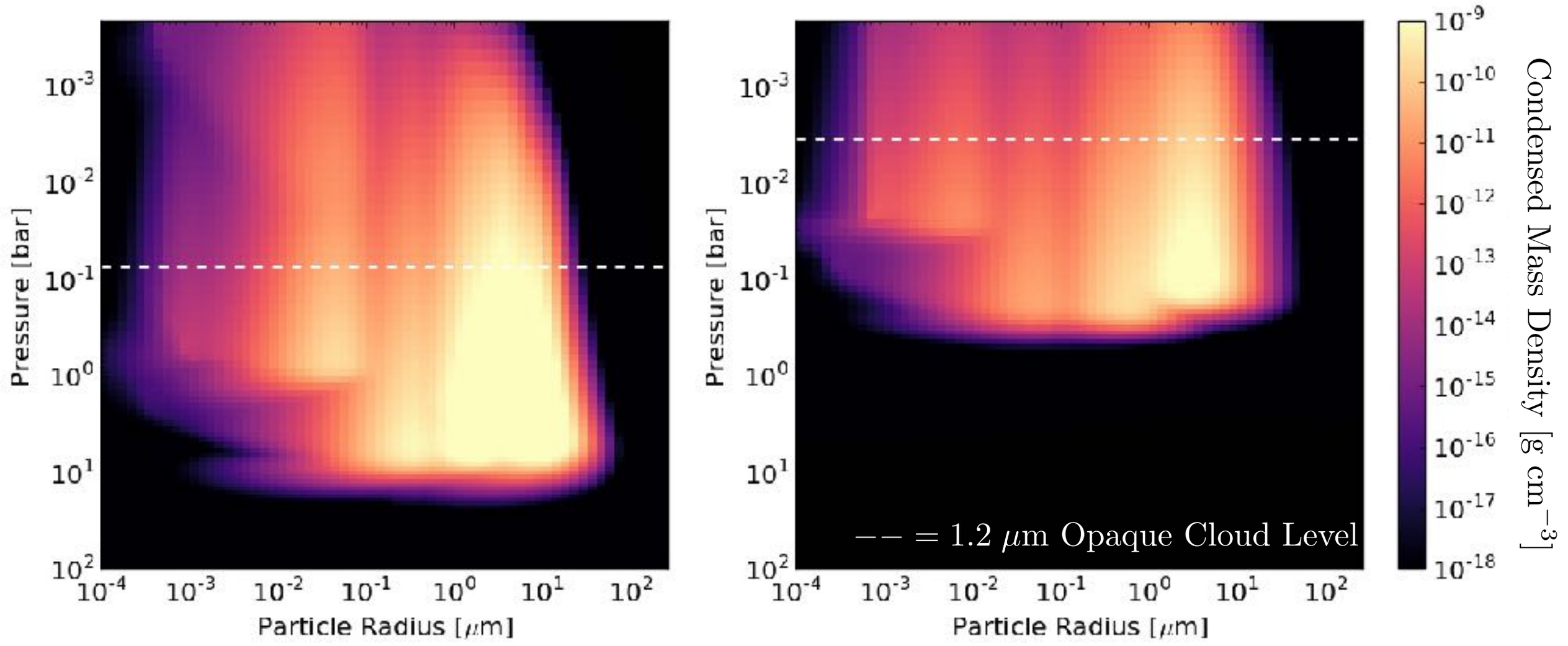
$T_{\rm eq} = 1700$ K

$\log(g) = 5$

Where are the clouds?

Normal-g Brown Dwarf
$\log(g) = 5$

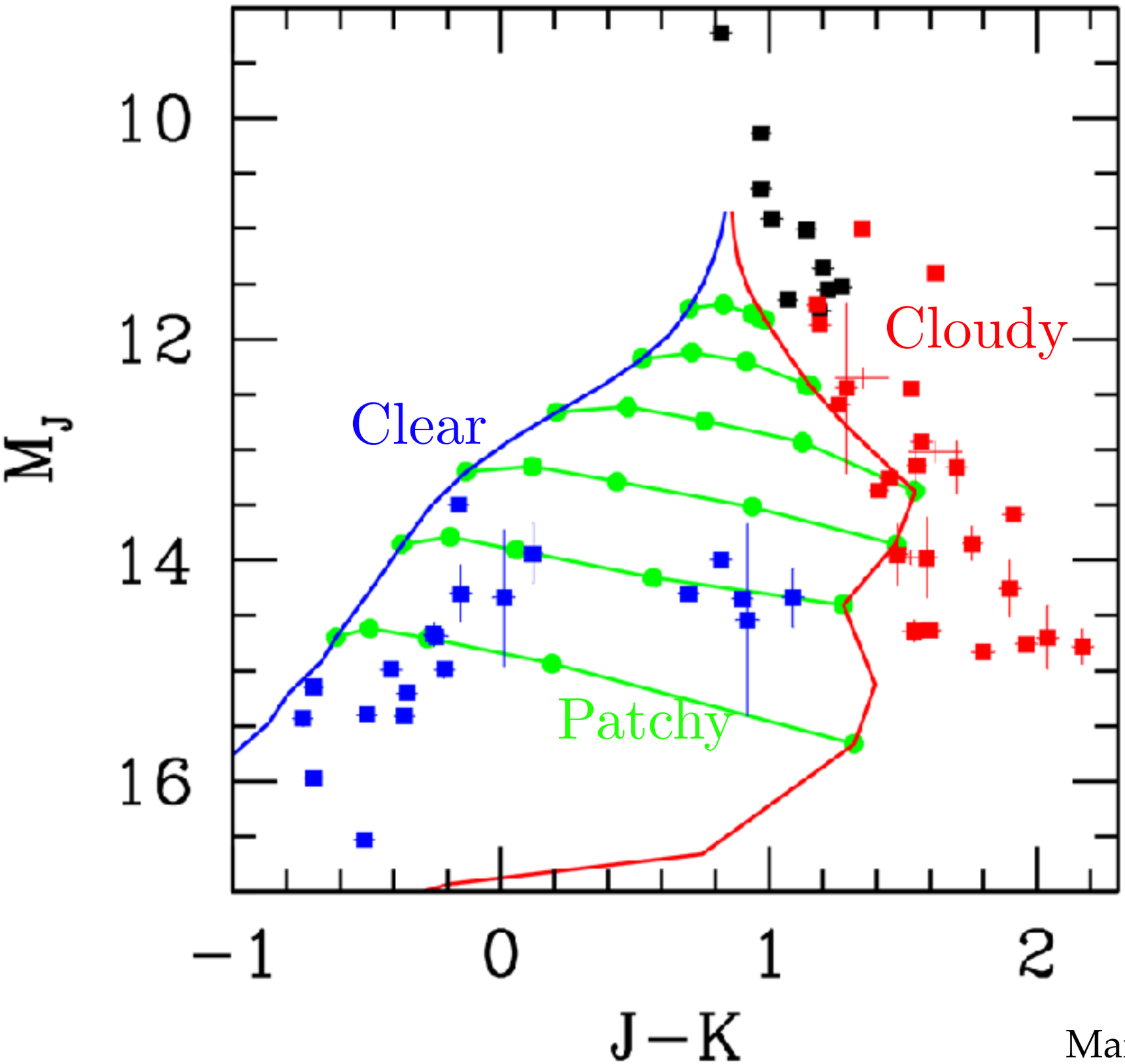
Very Low-g Brown Dwarf
$\log(g) = 4$

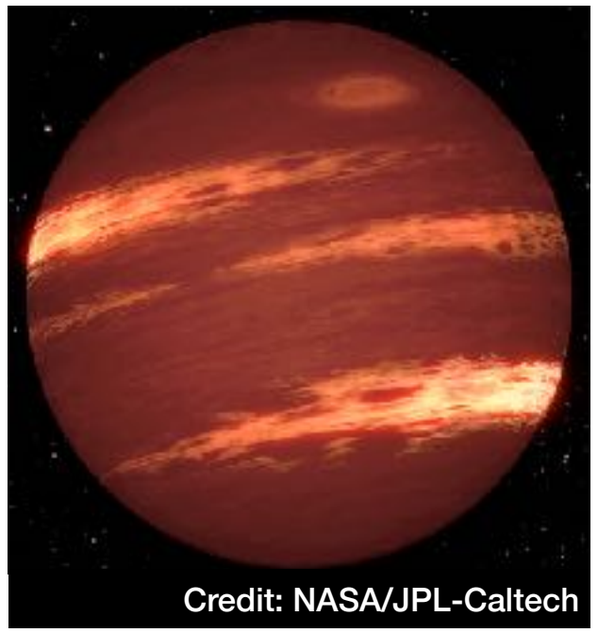


$T_{\rm eq} = 1600$ K

Powell et al. 2018c (in prep)

The Effect of 3D Cloud Structure

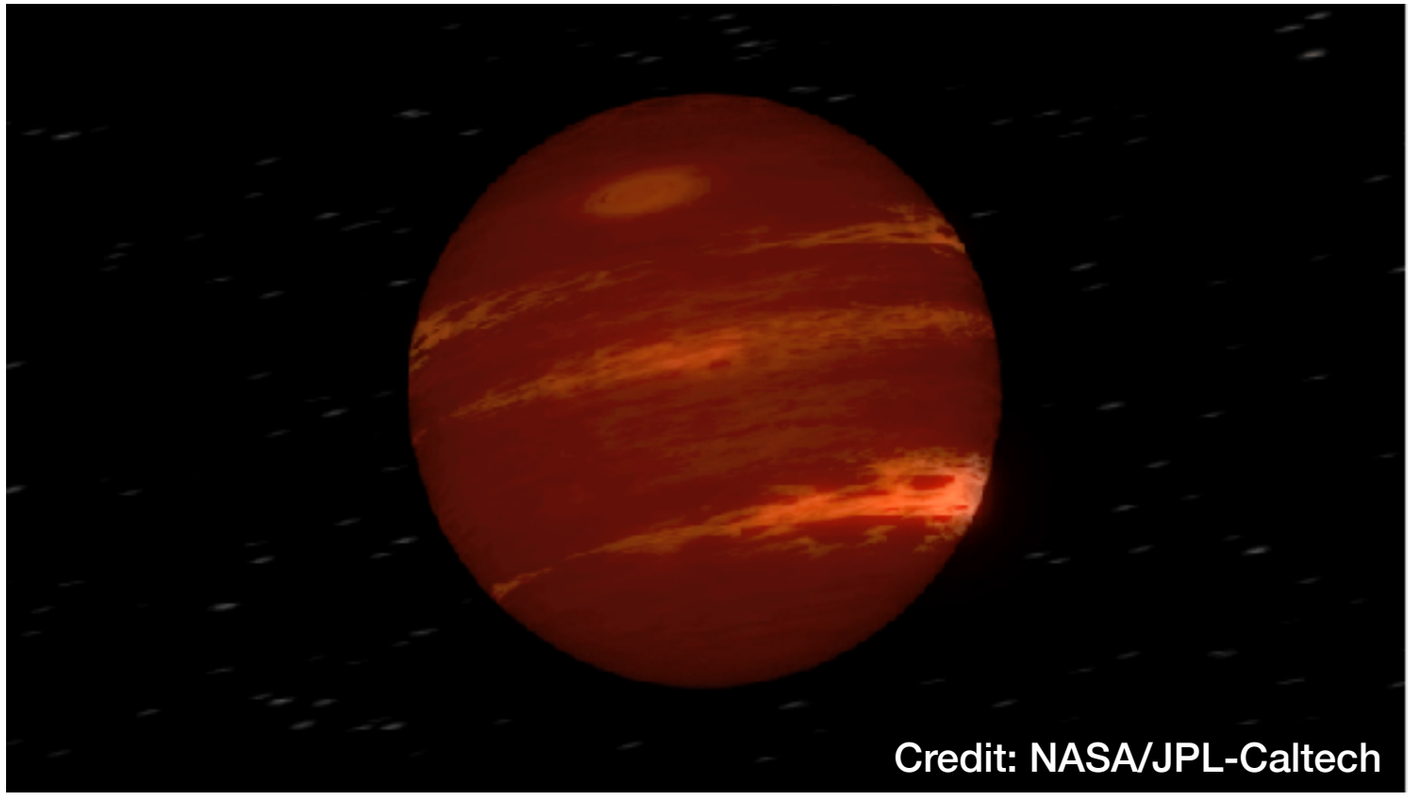




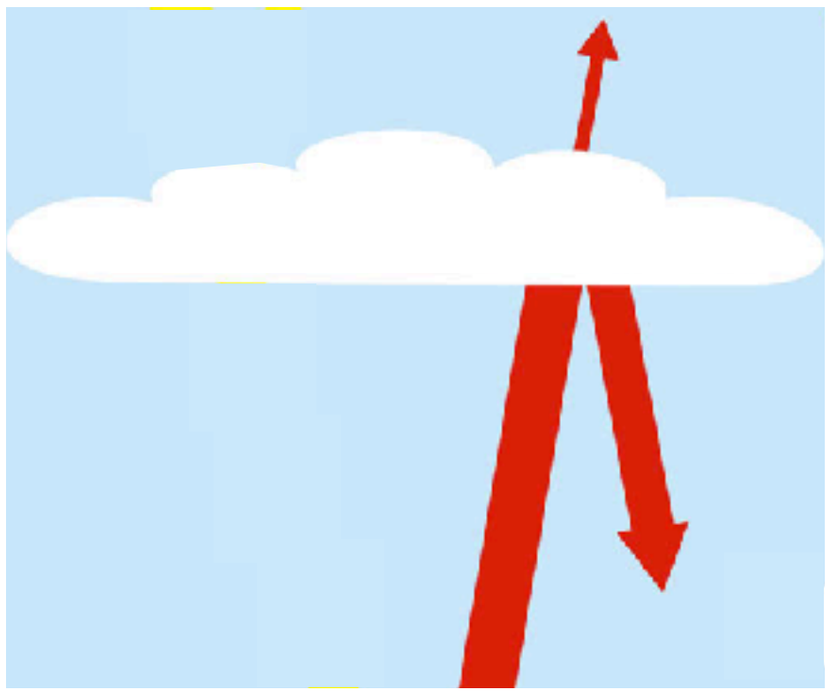
Marley, Saumon, & Goldblatt 2010

Upcoming Work

- 3D Cloud Structure

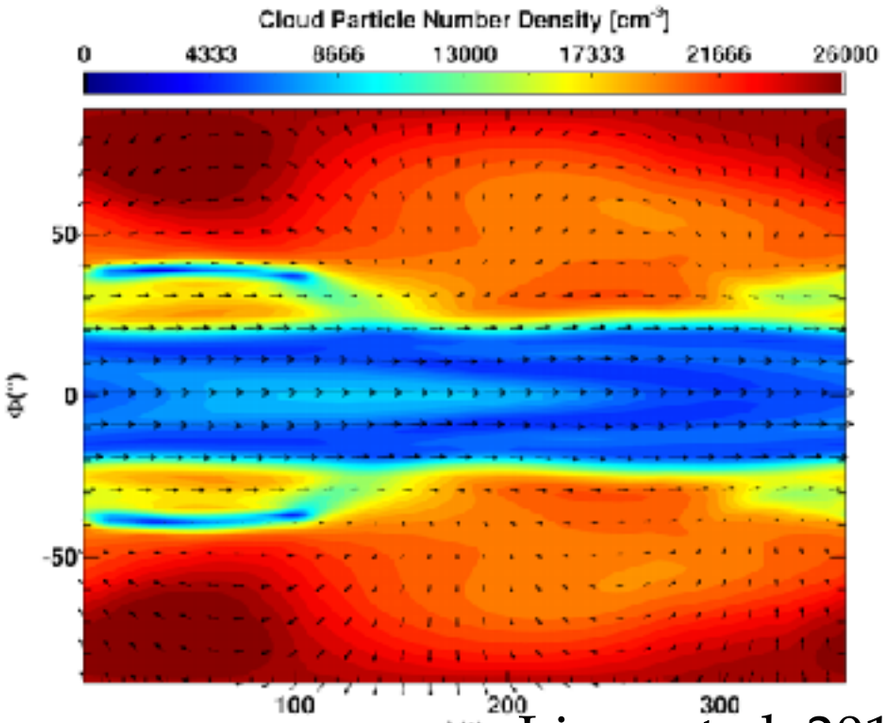


- Self-consistent cloud radiative effects



Clouds moving forward

3D Studies



Lines et al. 2018

Broad wavelength Observations

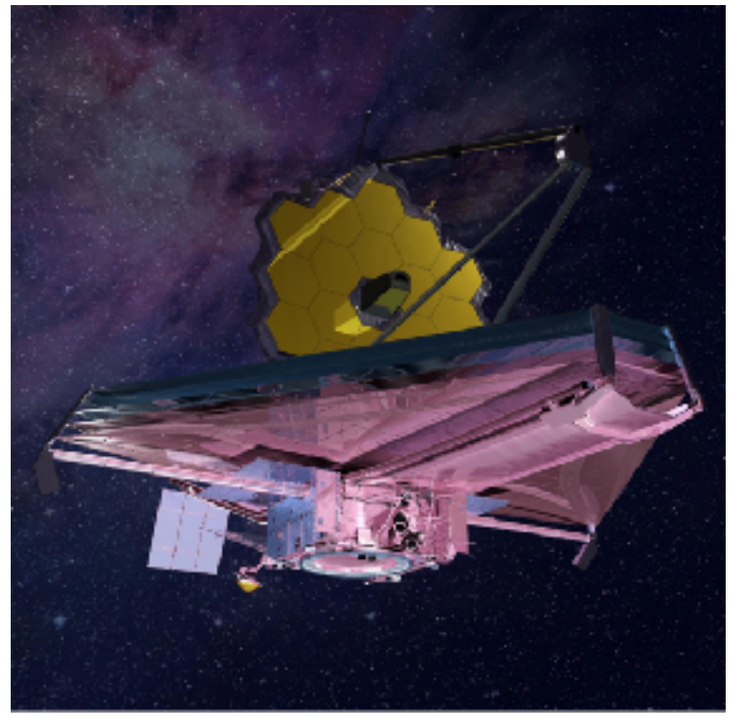


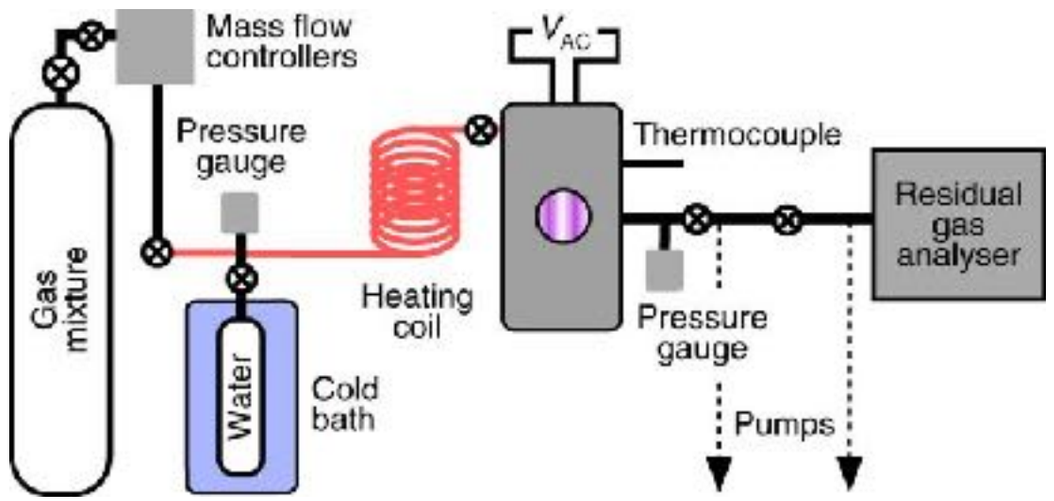
Image: NASA

and much, much more!

Direct Imaging and Polarization Observations

Images: Ethan Tweedie Photography / W. M. Keck Observatory, TMT

Laboratory Experiments



Hörst et al. 2018

Conclusions

- Cloud properties depend strongly on planetary (or brown dwarf) properties
- Considering fully resolved particle size distributions is important in spectral models
- Preliminary results suggest that the bin-scheme microphysical model of clouds naturally reproduces the VL-G brown dwarf sequence
- Stay tuned for model updates and final results!

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