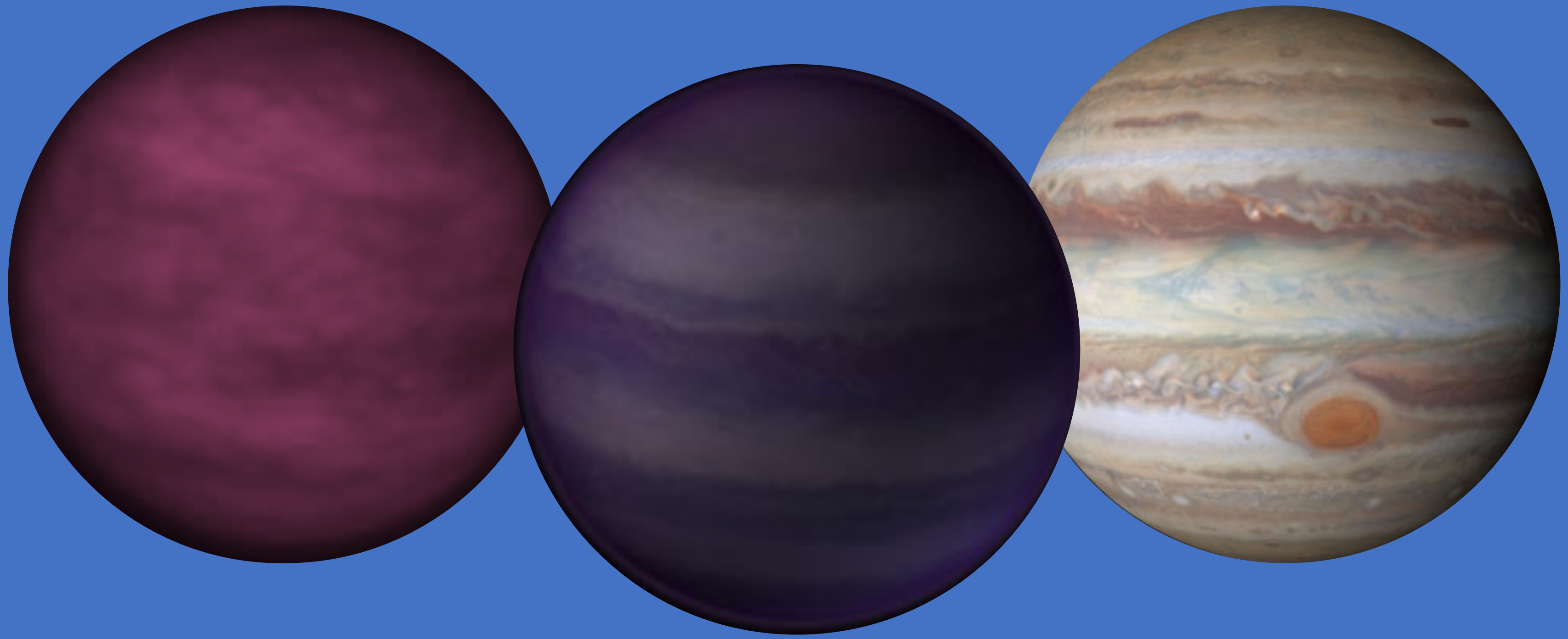
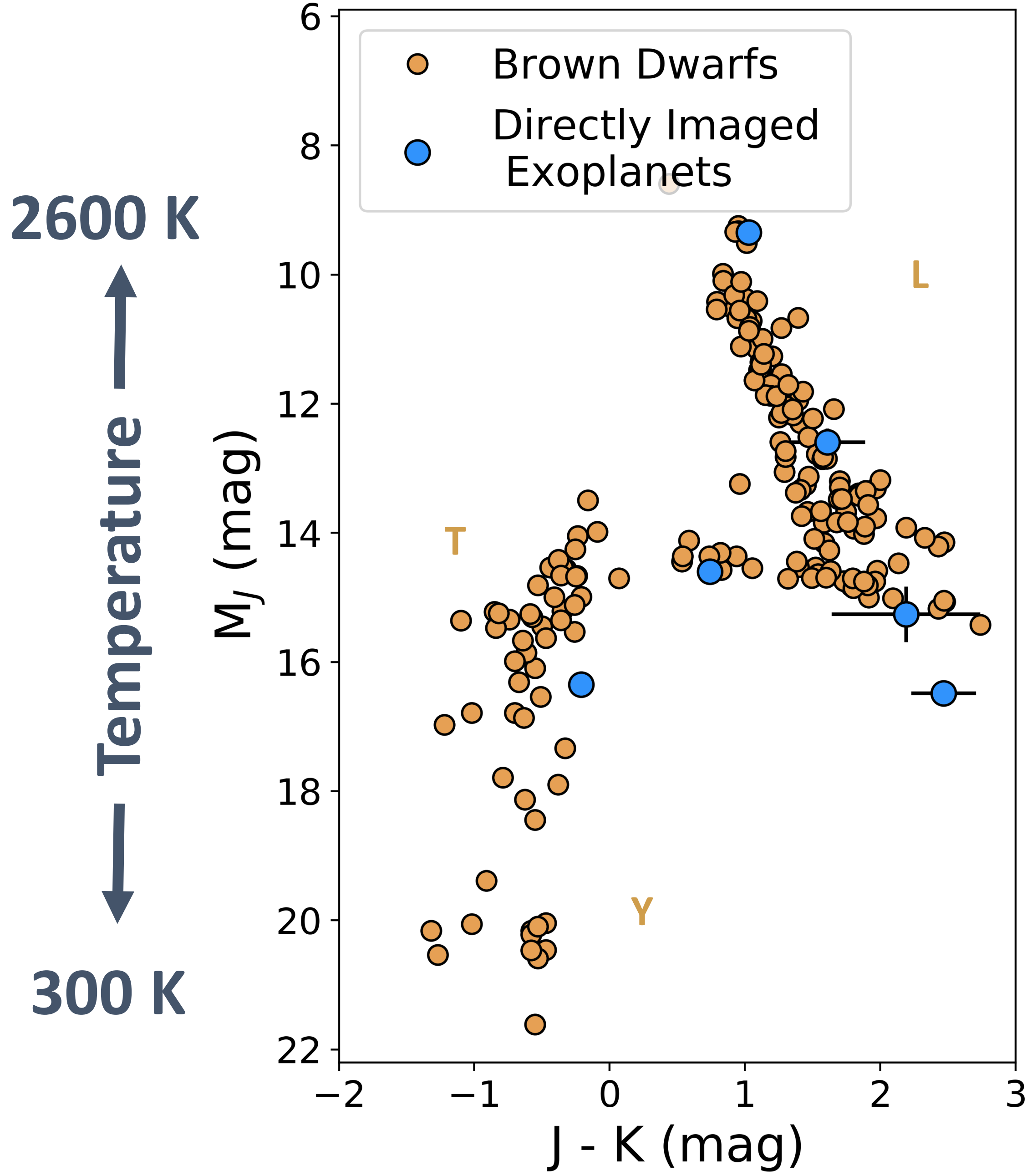
M-Band Observations of the Coldest Brown Dwarfs



Brittany E. Miles (UCSC)

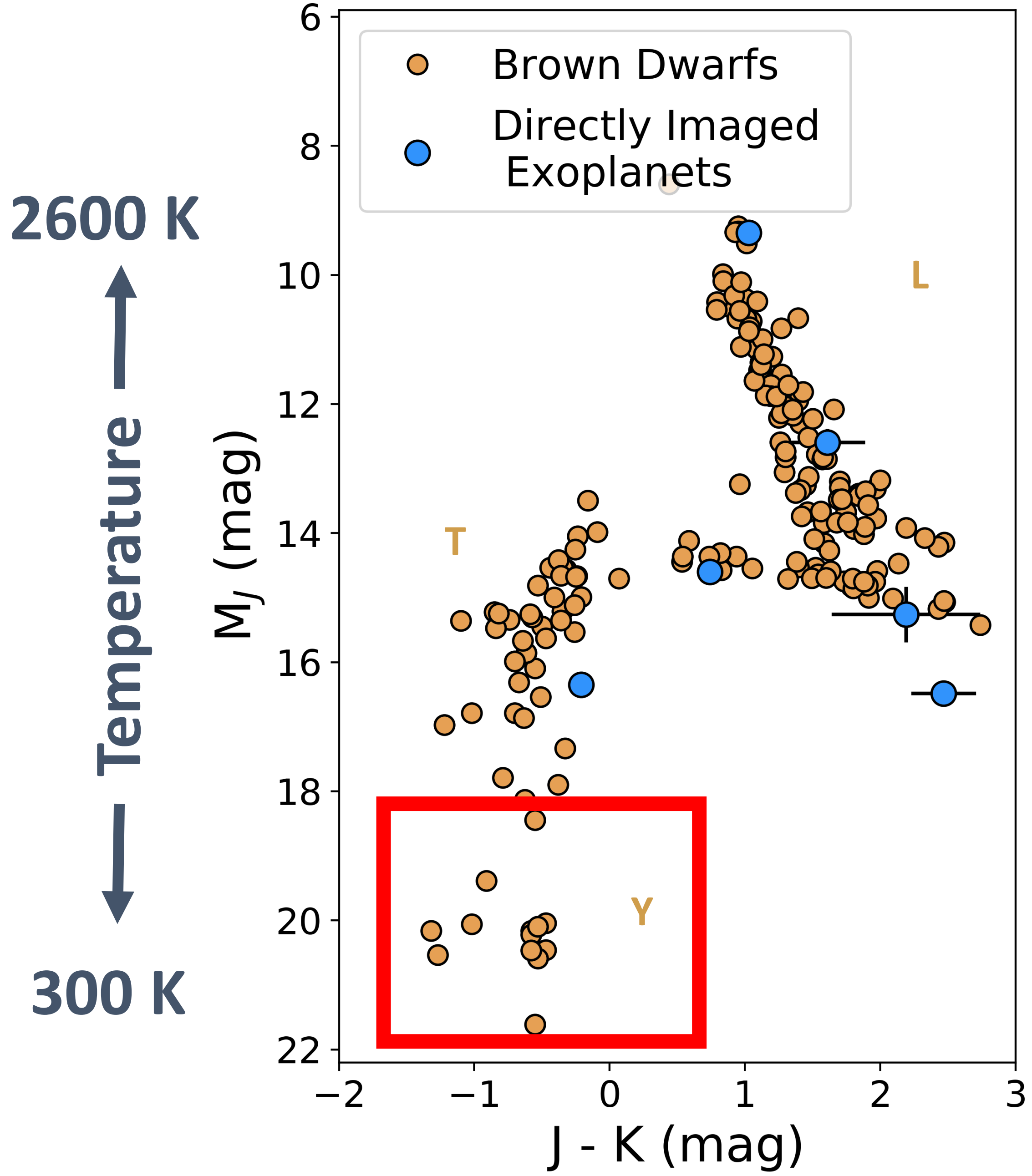
ExoPAG
June 18, 2020

__Collaborators:__ Andy Skemer, Caroline Morley, Mark Marley, Jonathan Fortney, Katelyn Allers, Jackie Faherty, Tom Geballe, Channon Visscher, Adam Schneider, Roxana Lupu, Richard Freedman, Gordy Bjoraker



Data from: Dupuy + Liu 2012,Dupuy + Kraus 2013, Liu+ 2016

Brown Dwarfs are Analogs of Directly Imaged Gas Giants



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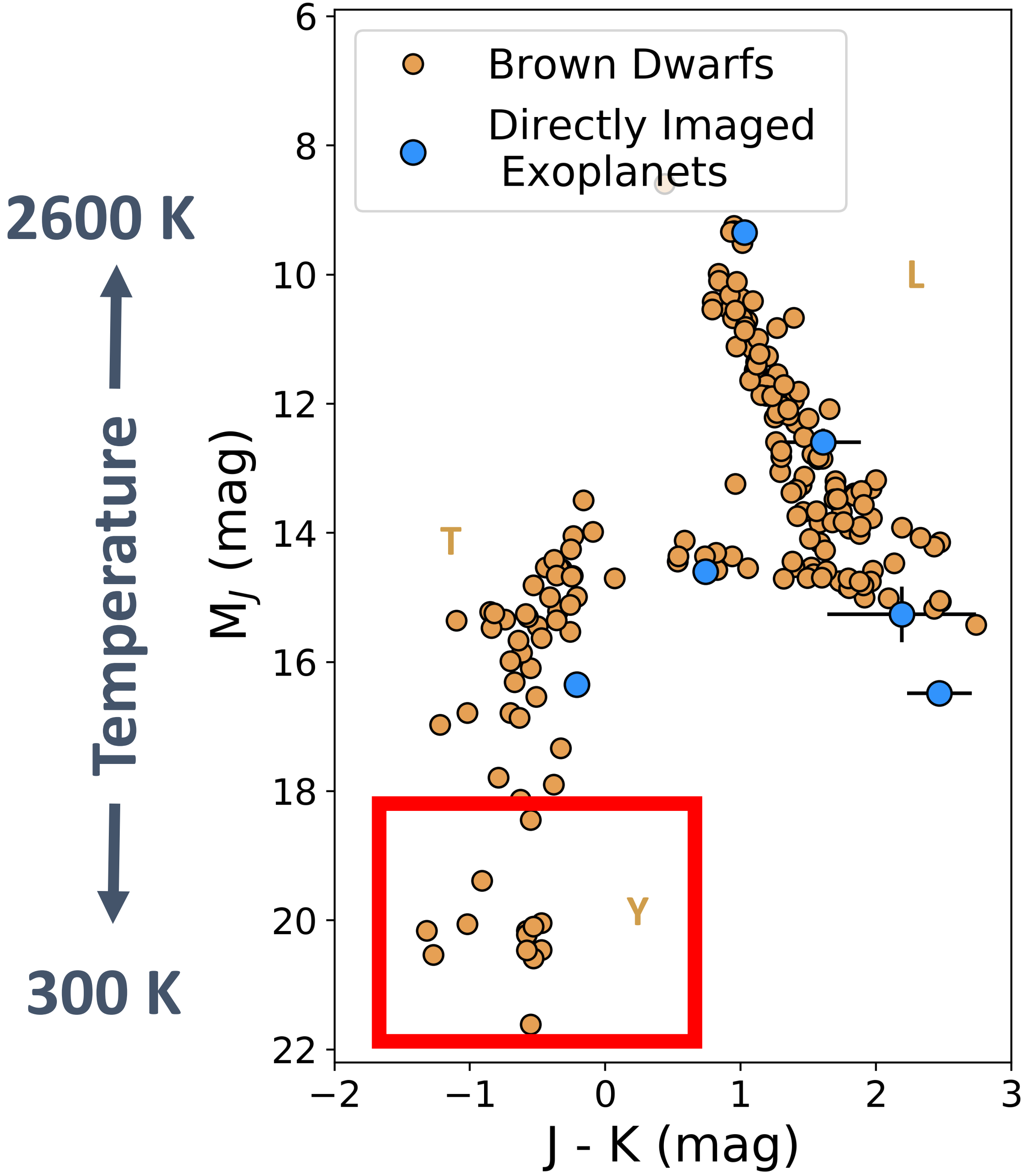

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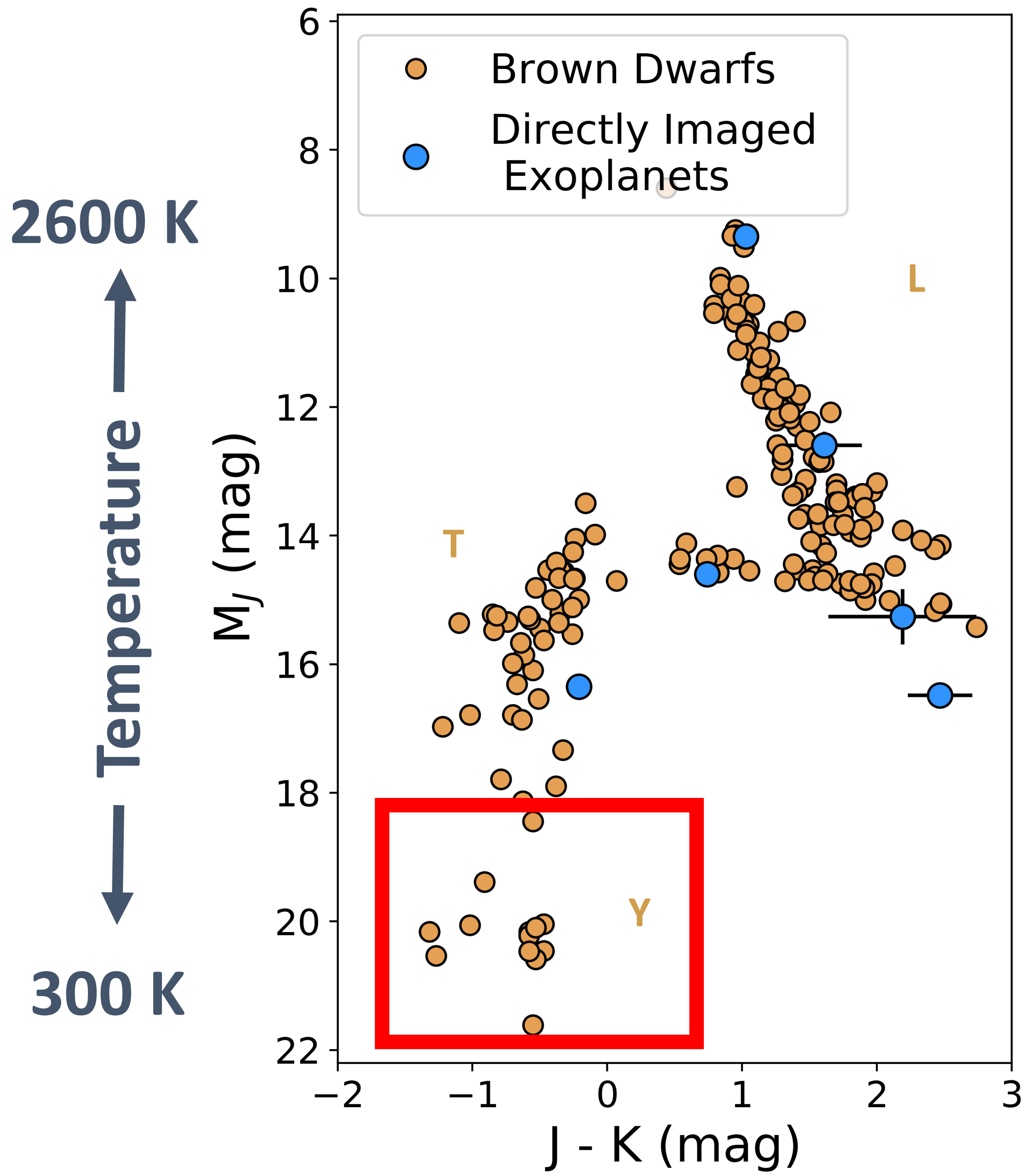
Things We Want to Know:

- What gases or clouds can we expect to see in gas giant atmospheres at cool temperatures?



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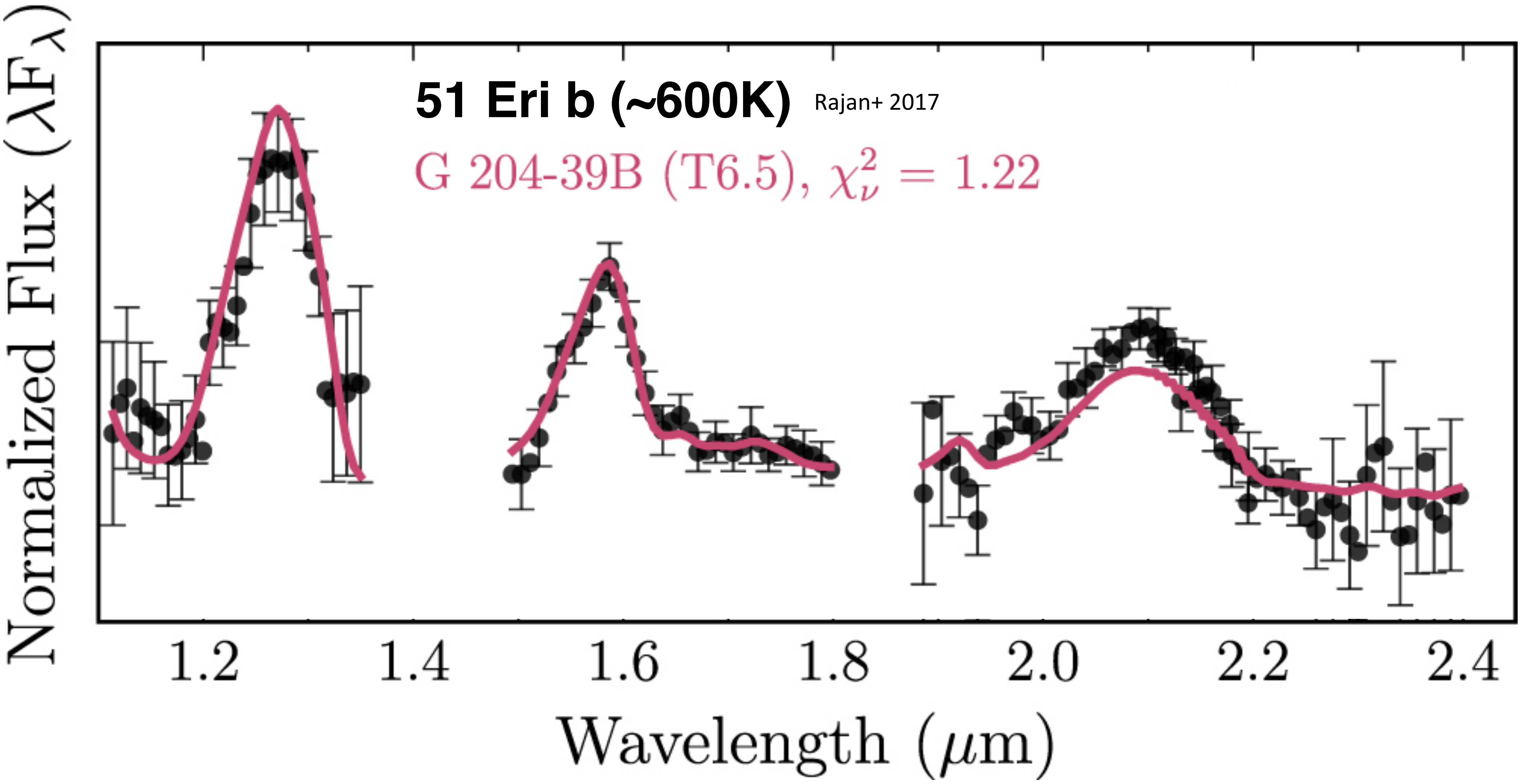
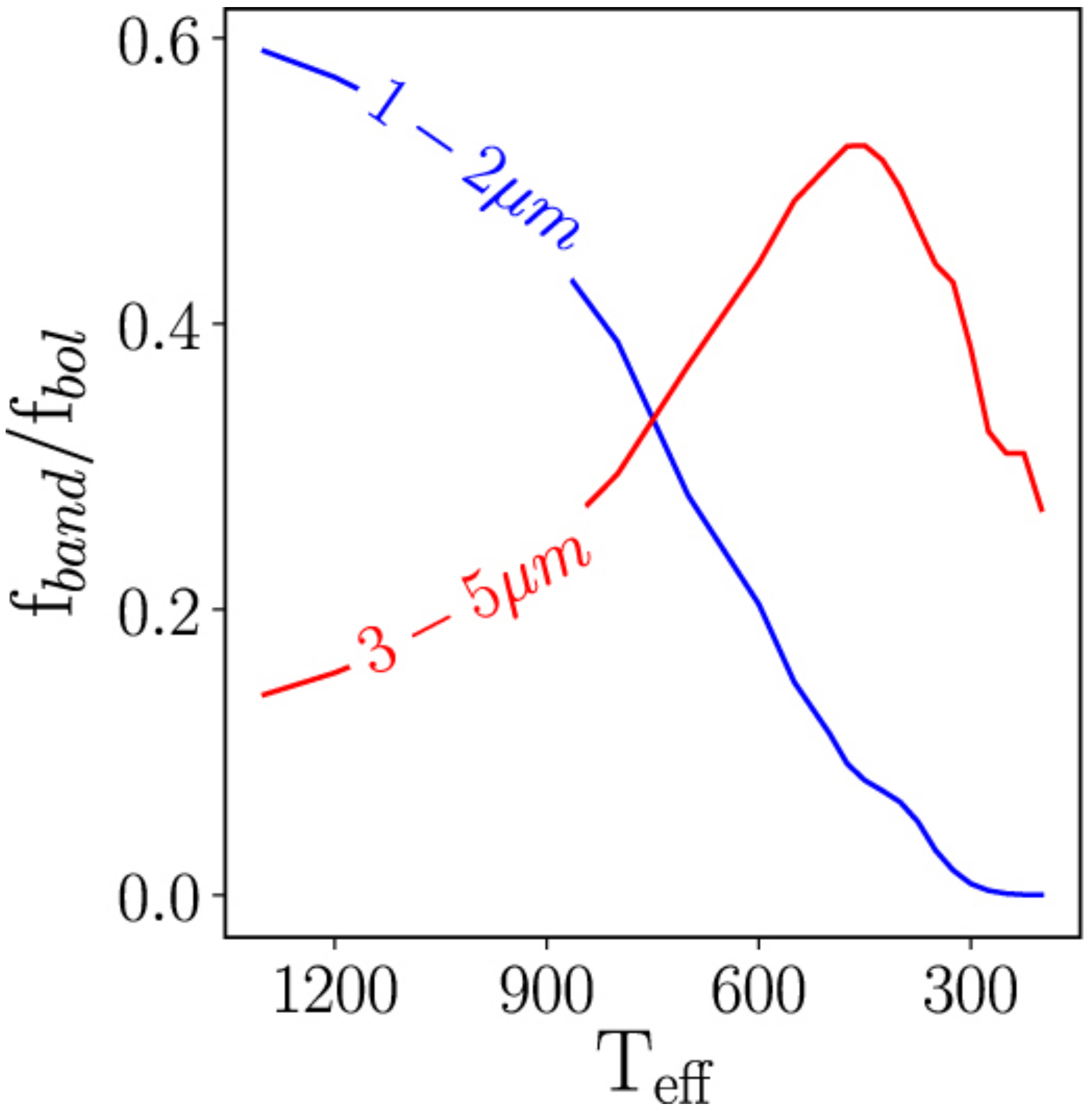
Things We Want to Know:

- What gases or clouds can we expect to see in gas giant atmospheres at cool temperatures?
- What wavelength coverage and resolutions are needed for future direct imaging instruments.

Future Directly Imaged Gas Giants Could Resemble Y-dwarfs



The Mid-IR is Essential for Characterizing Colder, Gas Giant Exoplanets



Briesemeister+ 2019 using models from Morley+ 2012, Morley+ 2014
see also Skemer+ 2014

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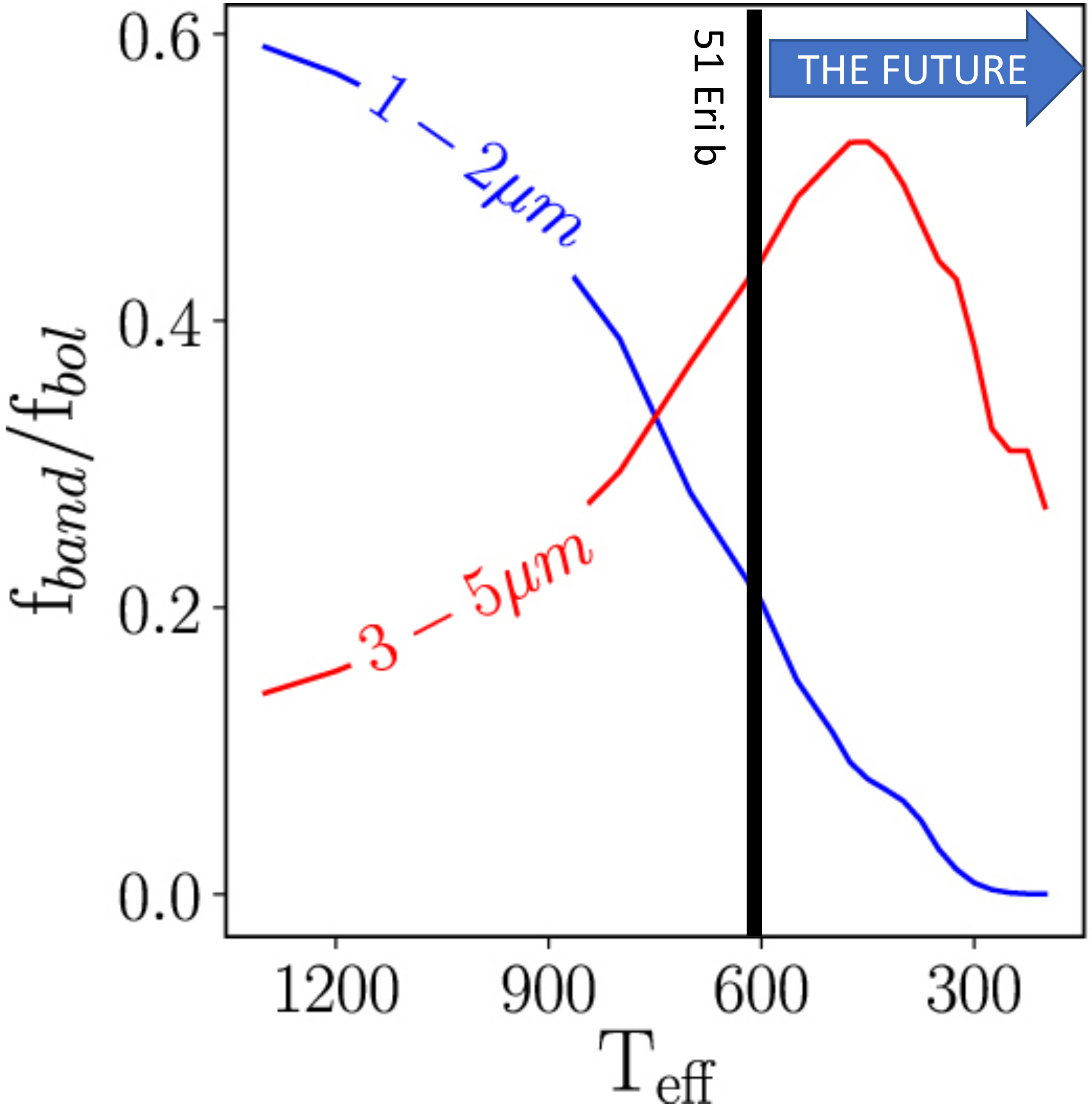

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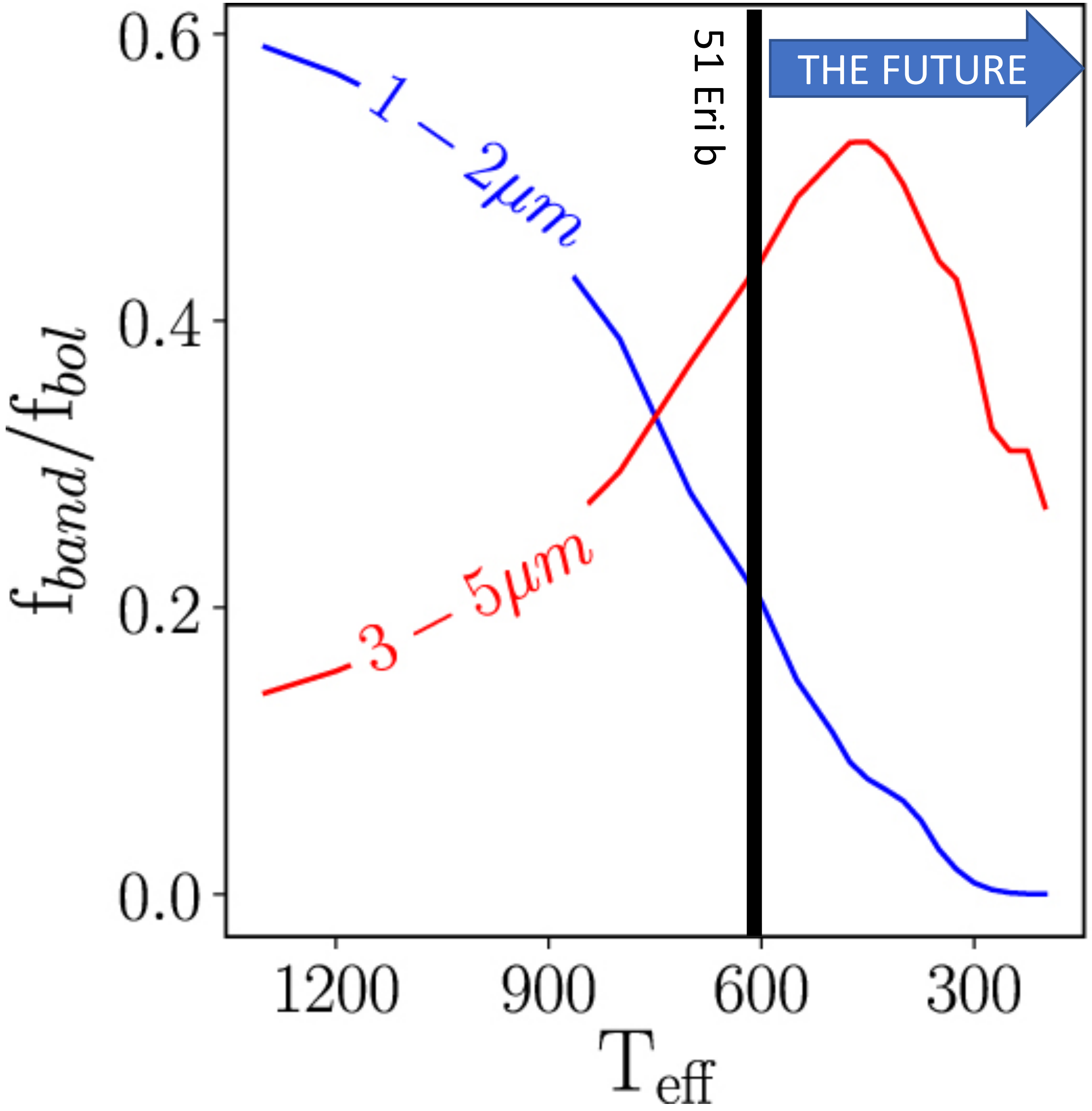

Briesemeister+ 2019 using models from Morley+ 2012, Morley+ 2014
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The Mid-IR is Essential for Characterizing Colder, Gas Giant Exoplanets

- The best star-planet contrast is achieved between 3 to 5 microns.
- Numerous potential opacity sources can be detected/constrained: PH_3,CO, CO_2, CH_4, NH_3, etc (Morley+ 2018)
- Future instruments need to capitalize on this wavelength region (SCALES/KECK)

Previous M-band Studies of WISE 0855

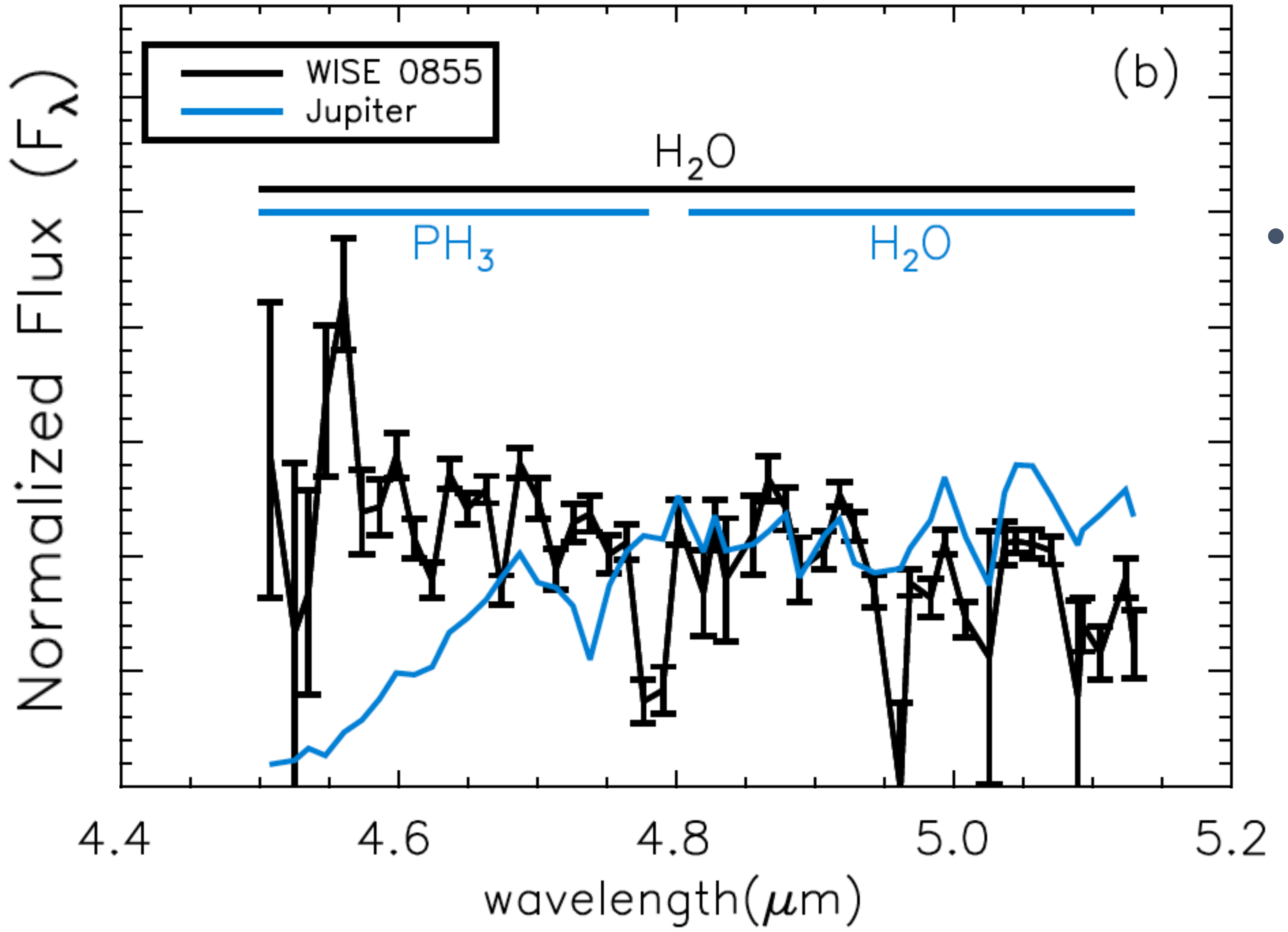
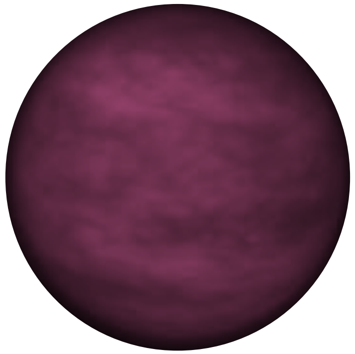


Figure from Skemer+ 2016 and see Morley+ 2018

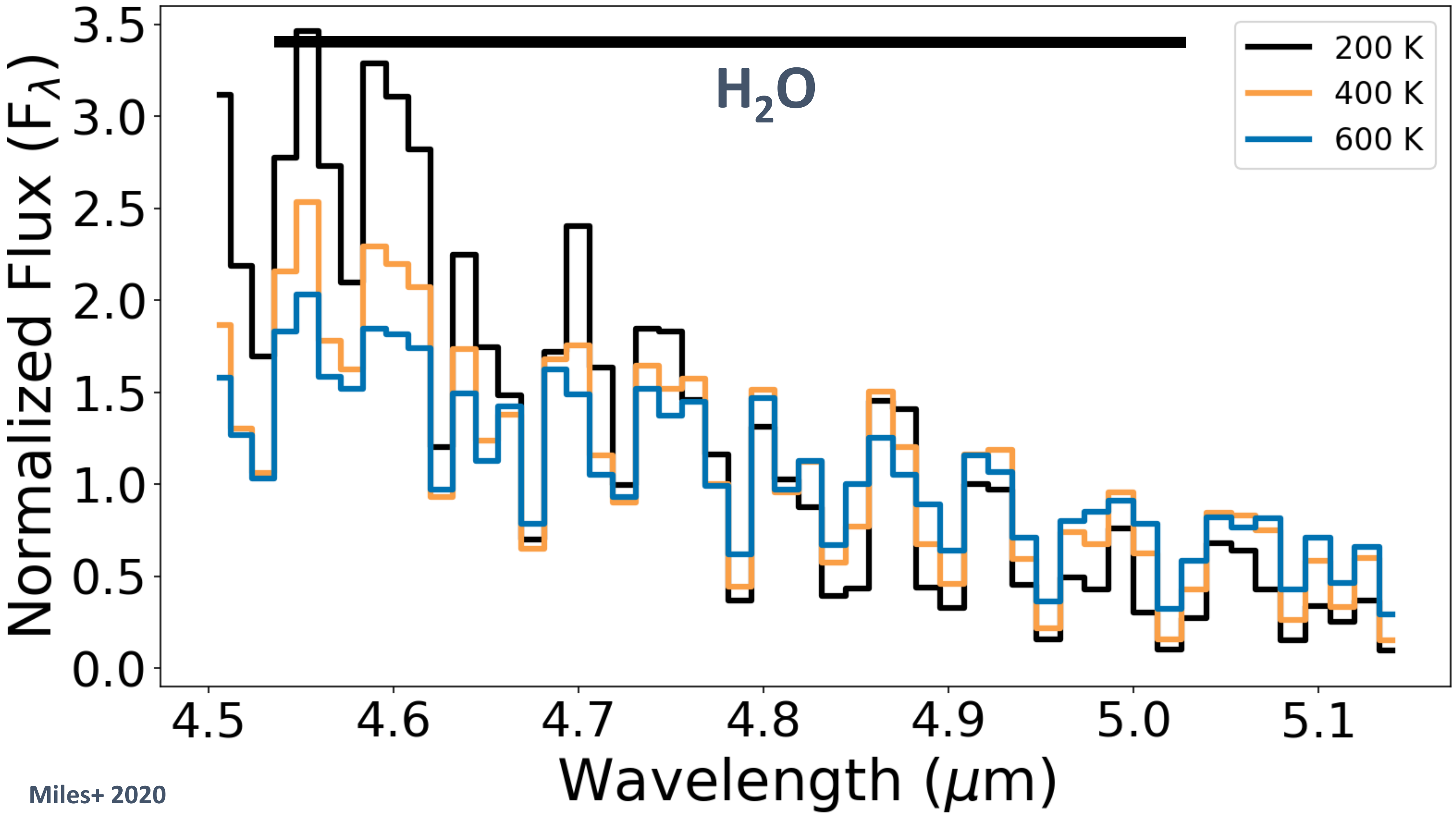
- **WISE 0855 (250 K)** and **Jupiter (126 K)** are similar in temperature, but display different molecular features across the M-band.

M-band Spectral Sequence: 750 K to Jupiter (Miles+ 2020)

Name	Temp (K)	Observatory
Gl 570 D	750	Gemini/NIRI (Geballe+ 2009)
2MASS 0415	700	AKARI (Sorahana + 2012)
WISE 0313	650	Gemini (this work)
UGPS 0722	550	Gemini (this work)
WISE 2056	500	Gemini (this work)
WISE 1541	400	Gemini (this work)
WISE 0855	250	Gemini (Skemer+ 2016)
Jupiter	126	ISO (Encrenaz+ 1996)

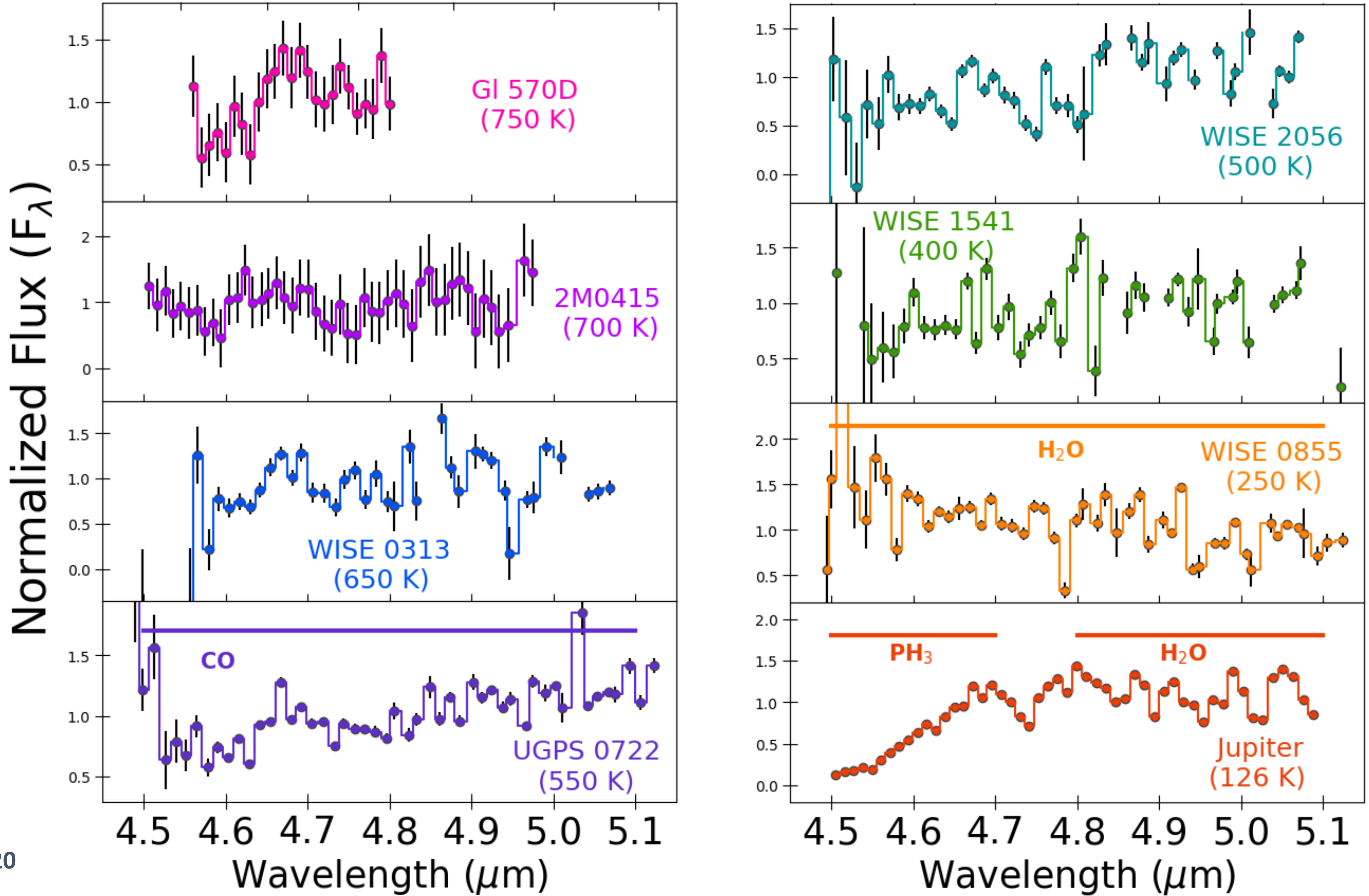


Water is Predicted to Dominate at Equilibrium



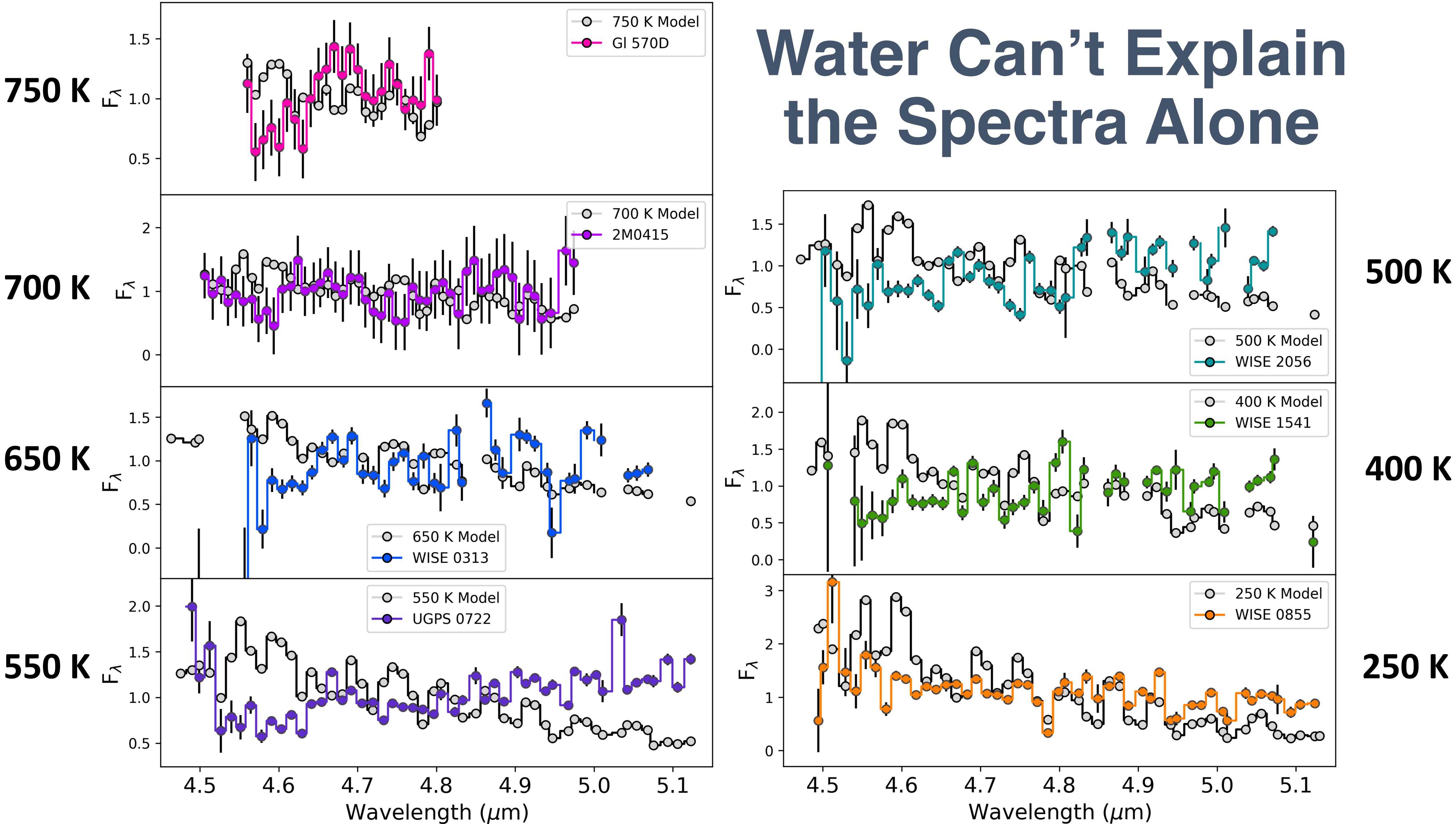
Miles+ 2020

M-band Spectral Sequence: 750 K to Jupiter

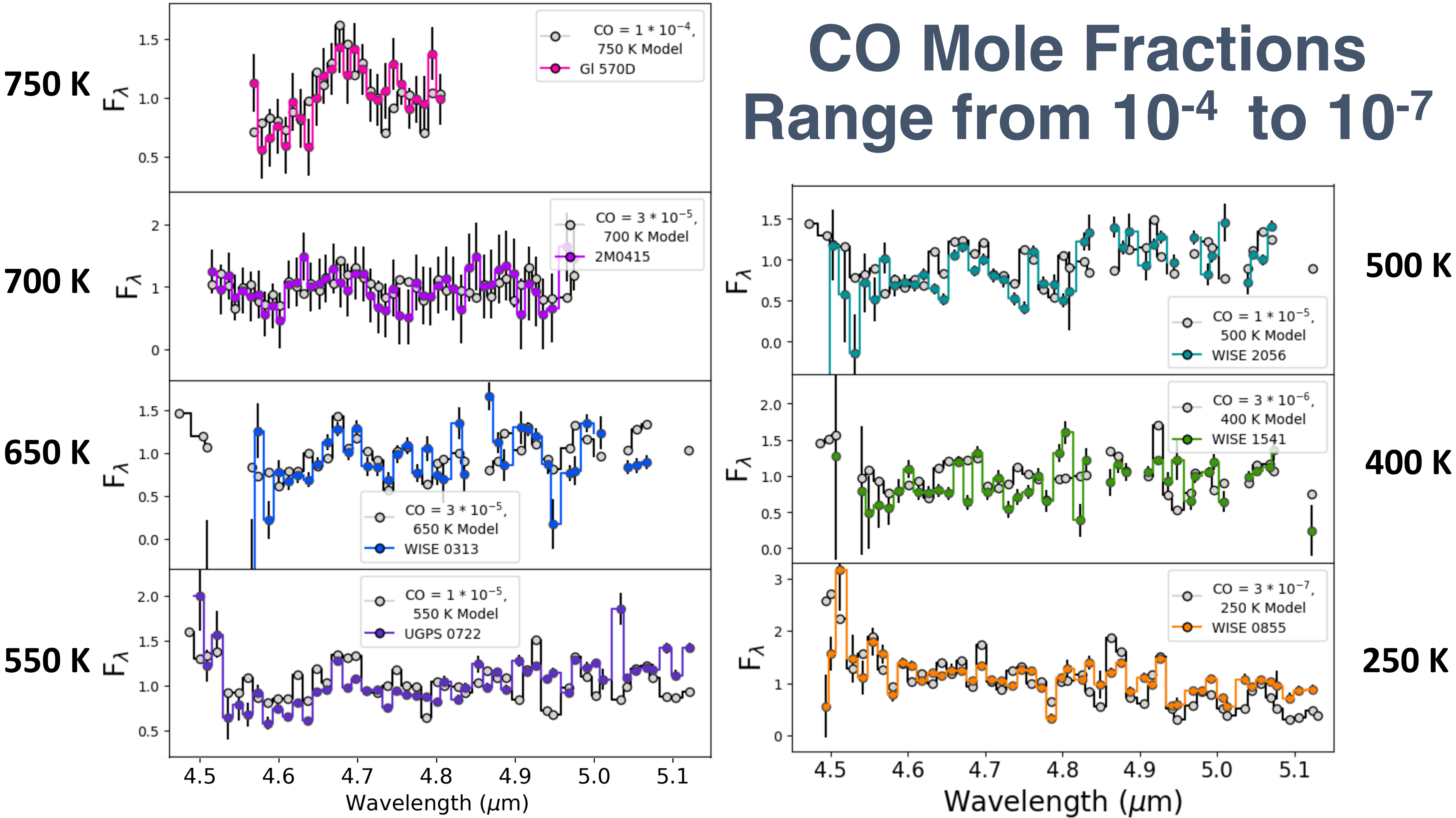


Miles+ 2020

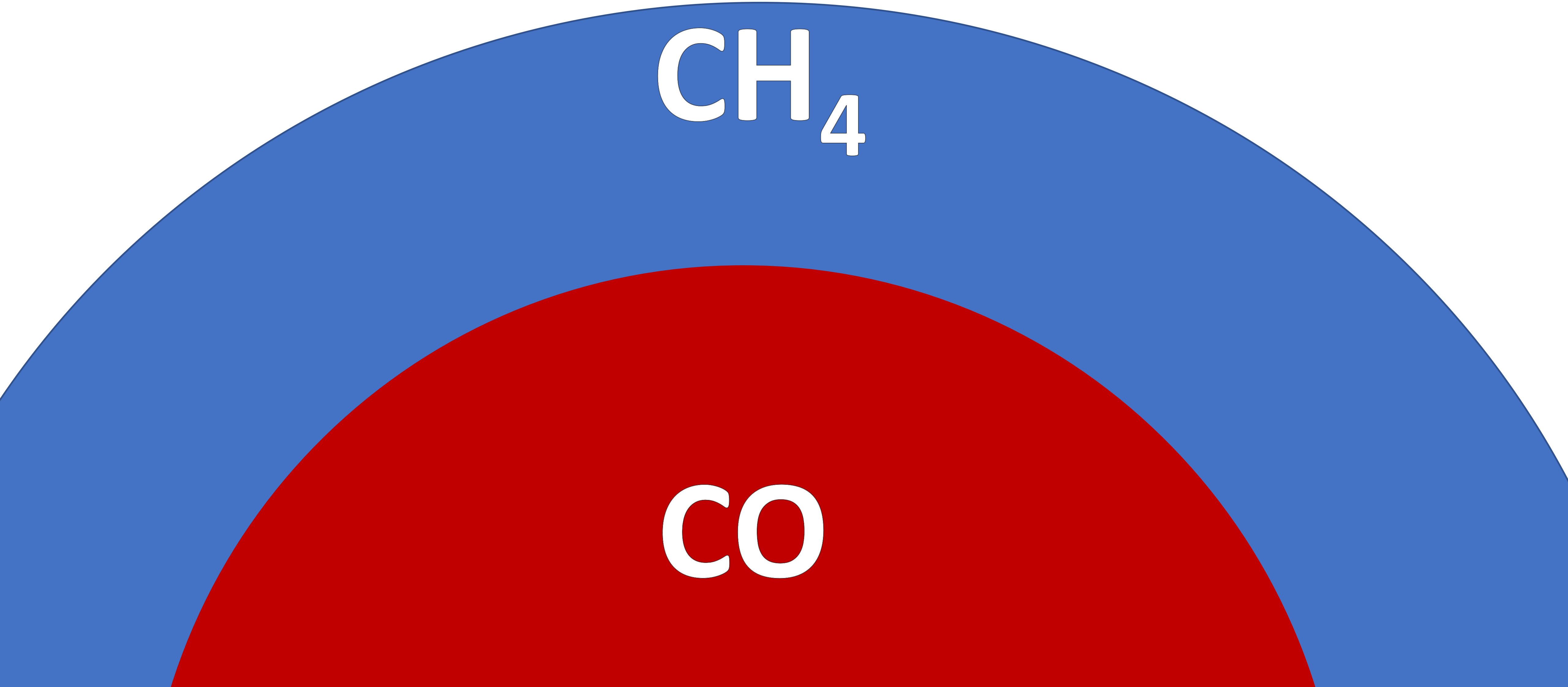
Water Can't Explain the Spectra Alone



CO Mole Fractions Range from 10^{-4} to 10^{-7}



What is Equilibrium Chemistry?



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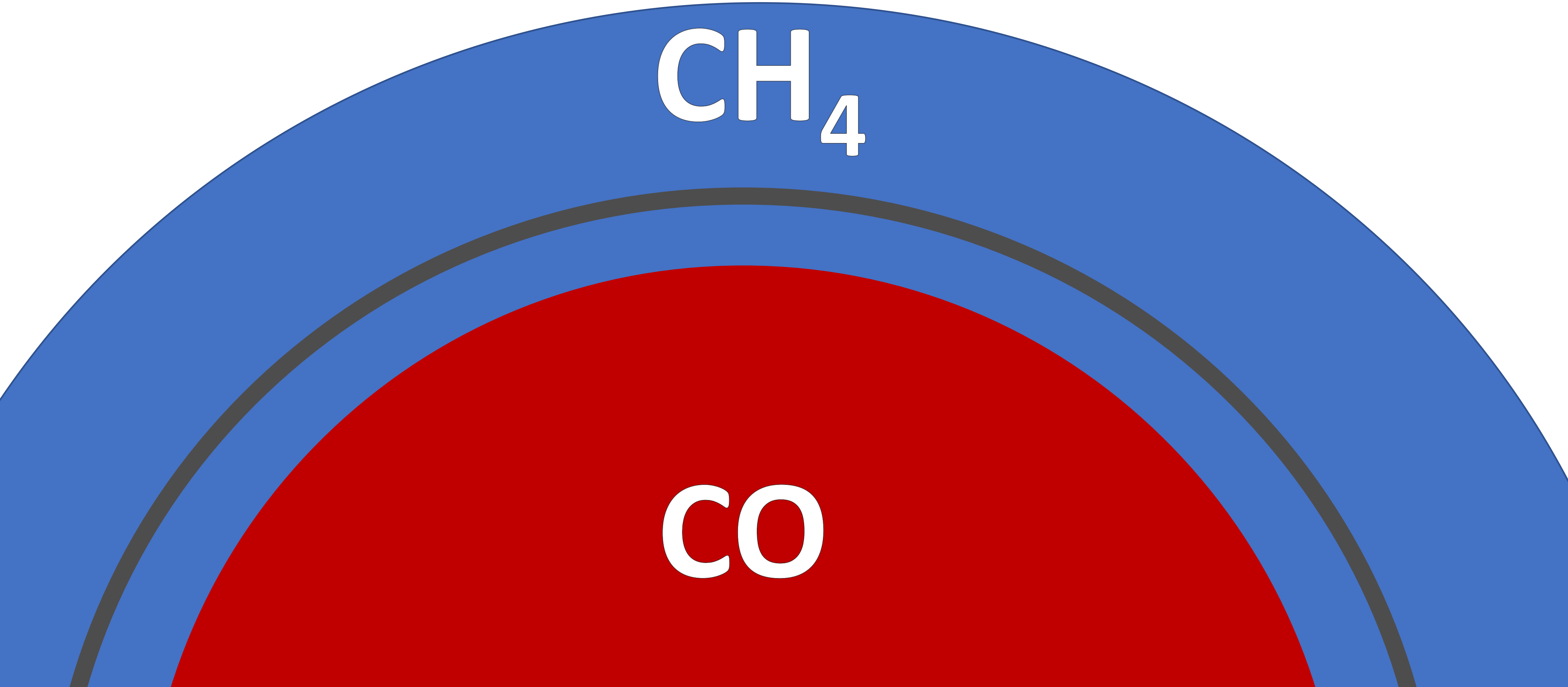
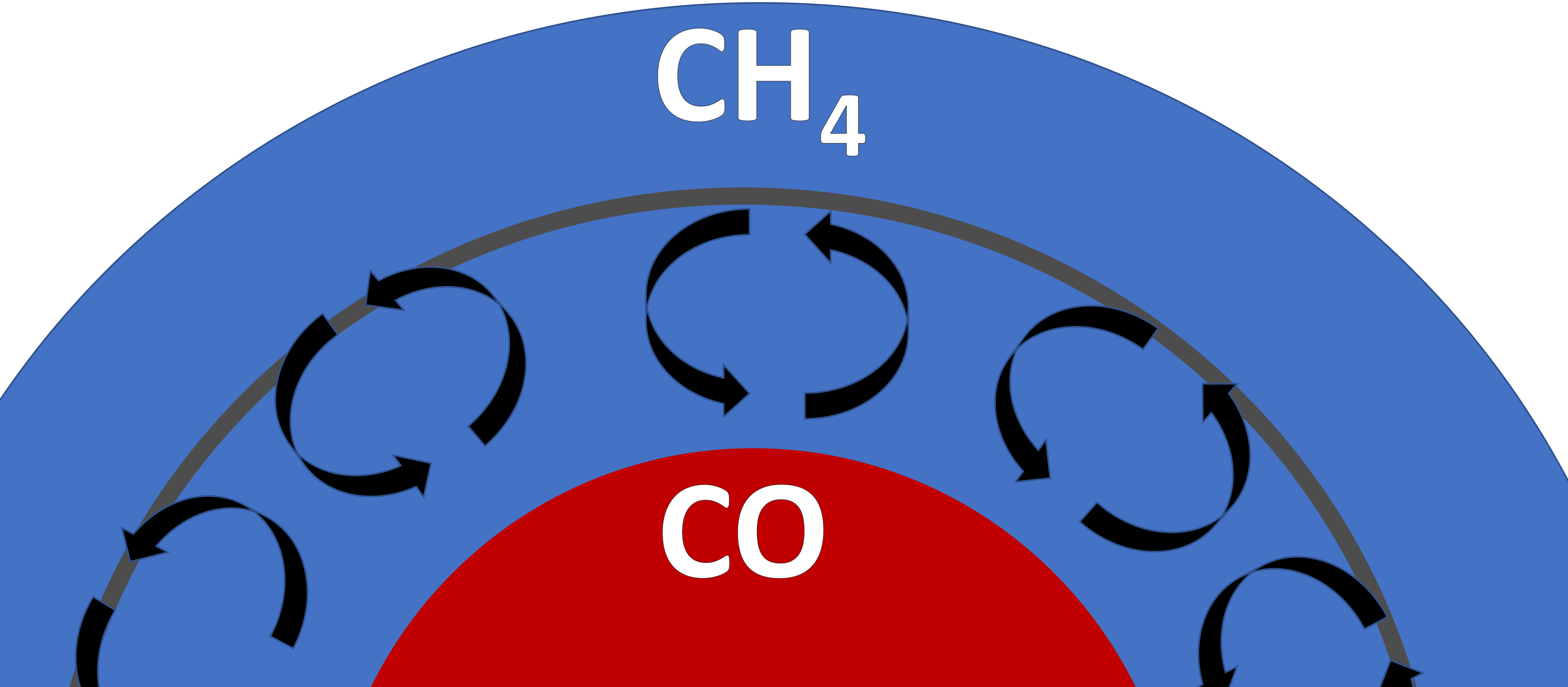
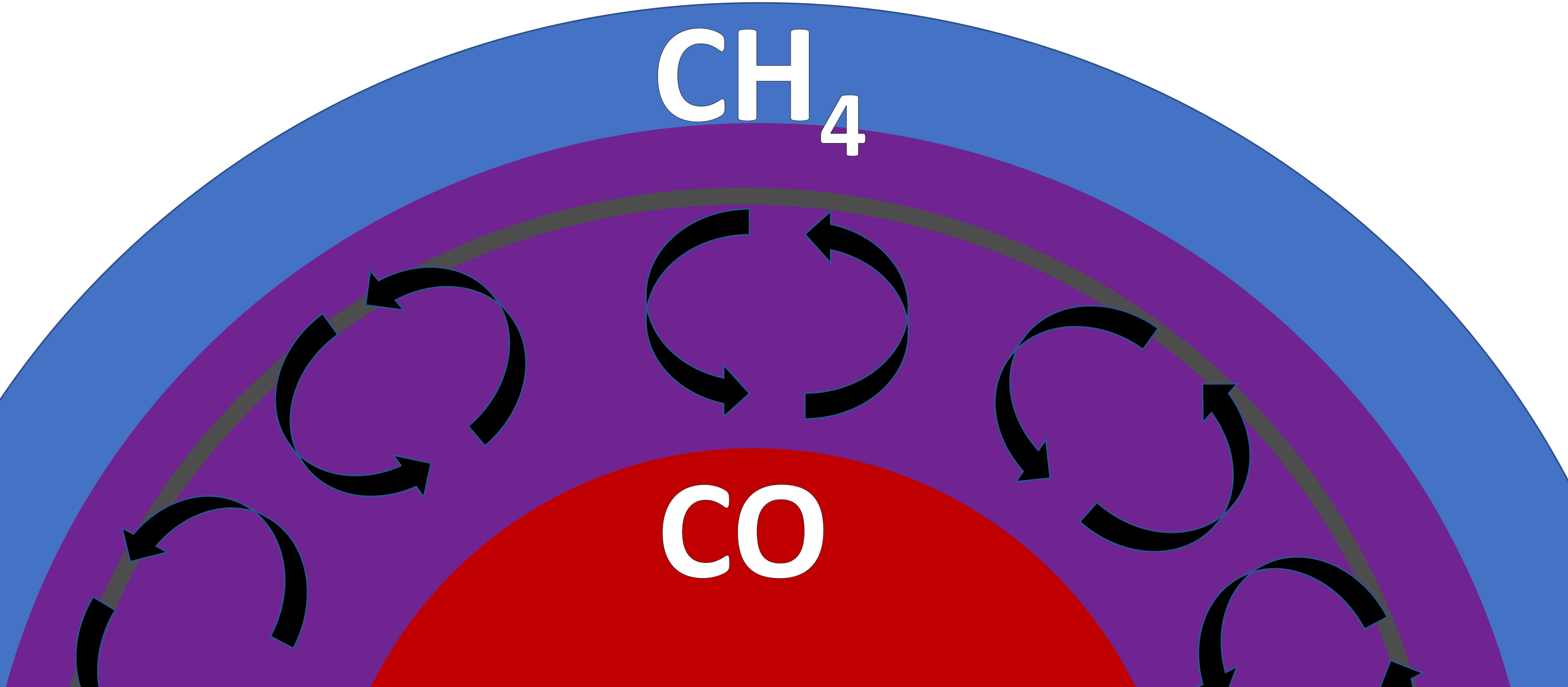


What is Disequilibrium Chemistry?



What is **Disequilibrium** Chemistry?



How is Disequilibrium Chemistry Parameterized?

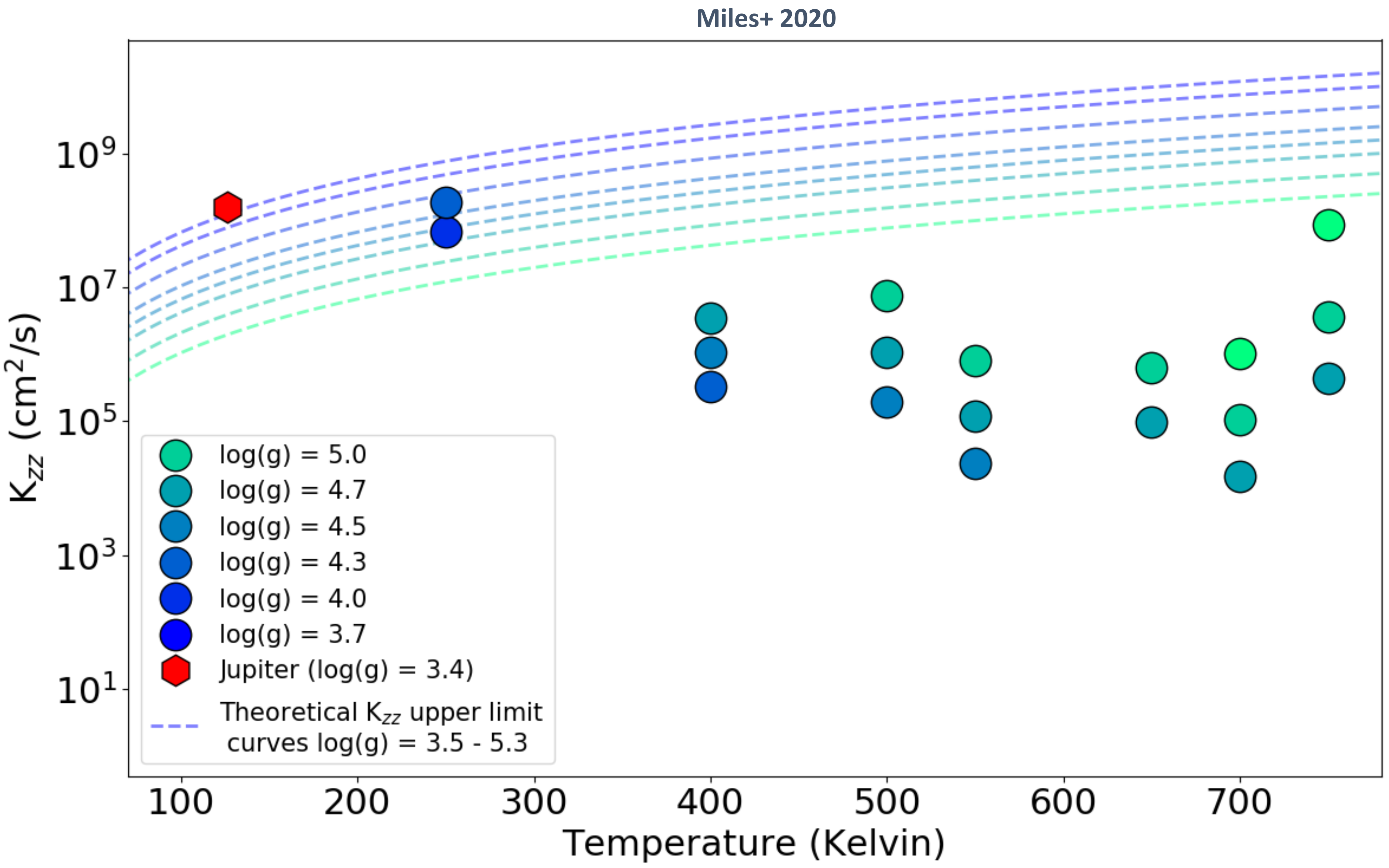
$$K_{zz} = \frac{L^2}{\tau_{mix}} \left[\frac{cm^2}{s}\right]$$

How is Disequilibrium Chemistry Estimated?

$$K_{zz} = \frac{L^2}{\tau_{mix}} \left[\frac{cm^2}{s}\right]$$

1. Find where the measured CO abundance occurs along a P-T profile.
2. Calculate the chemical timescale at that pressure and temperature.
3. Calculate the length scale at that pressure and temperature.
4. Repeat for P-T profiles of different surface gravities.

Cooler Atmospheres Have Stronger Mixing



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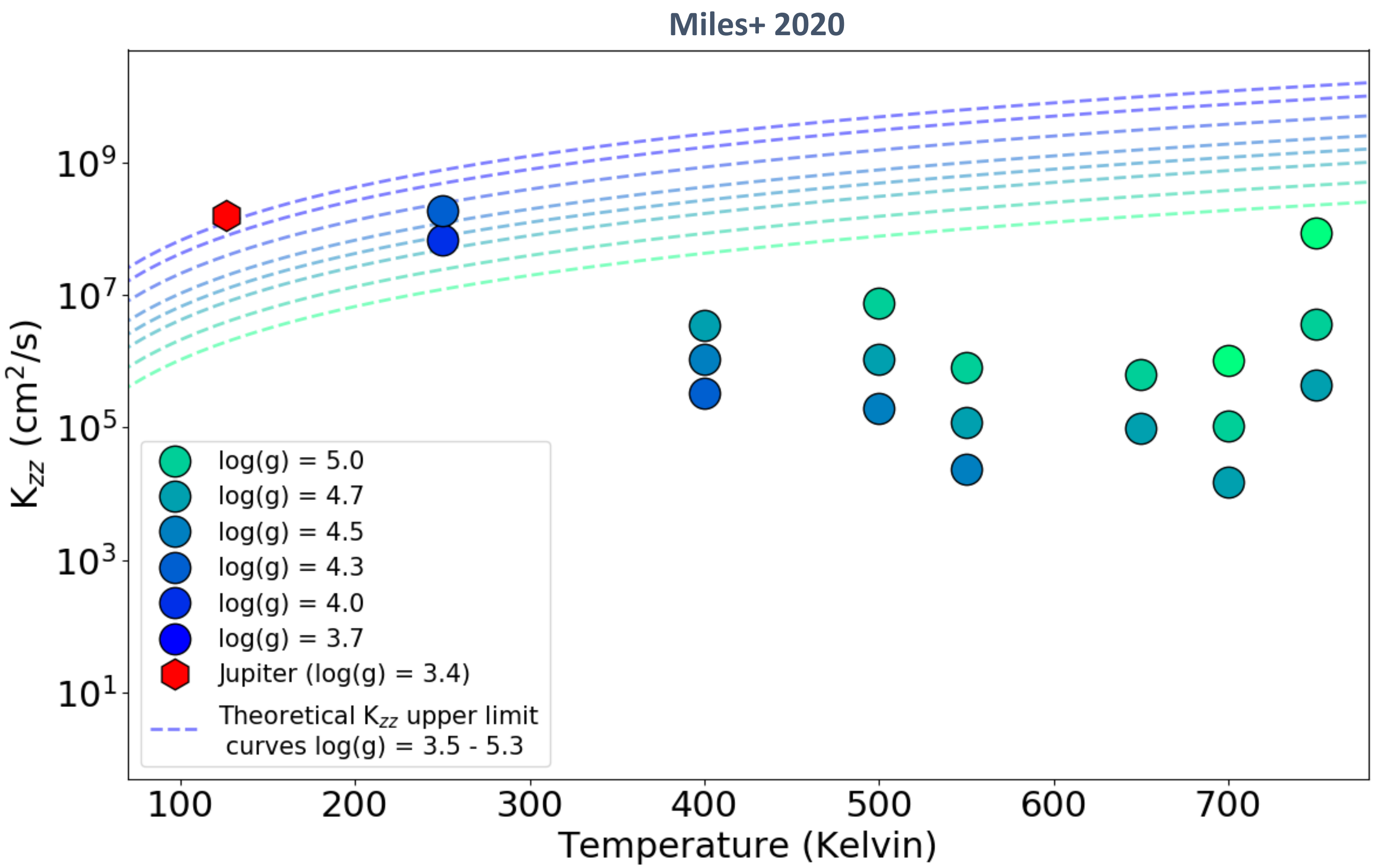
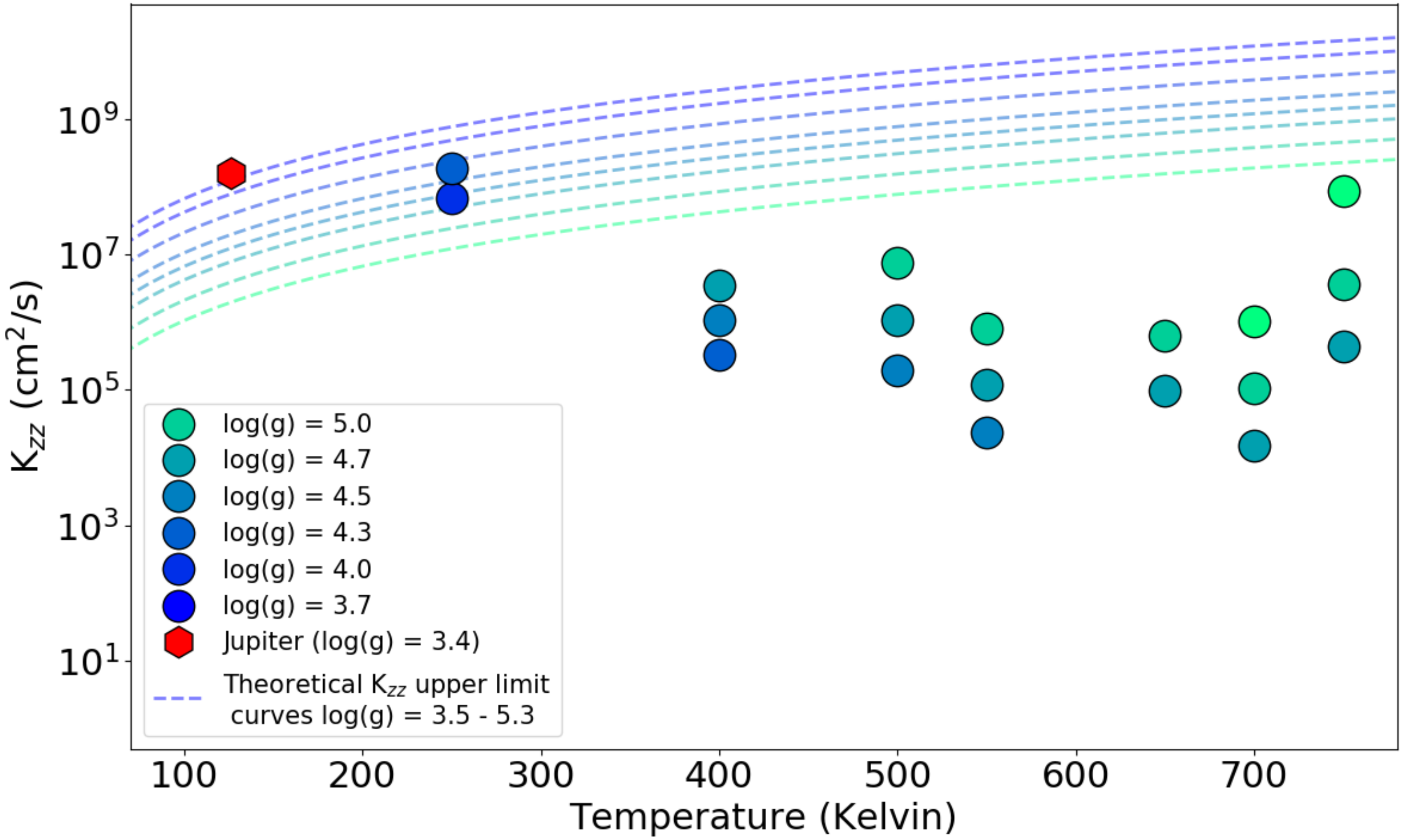


Models predict brown dwarfs and gas-giants colder than 400 K are fully convective, while warmer ones have radiative zones.

Our results show less mixing in the warmer brown dwarfs, which may be due to sluggish convection in their radiative zones.

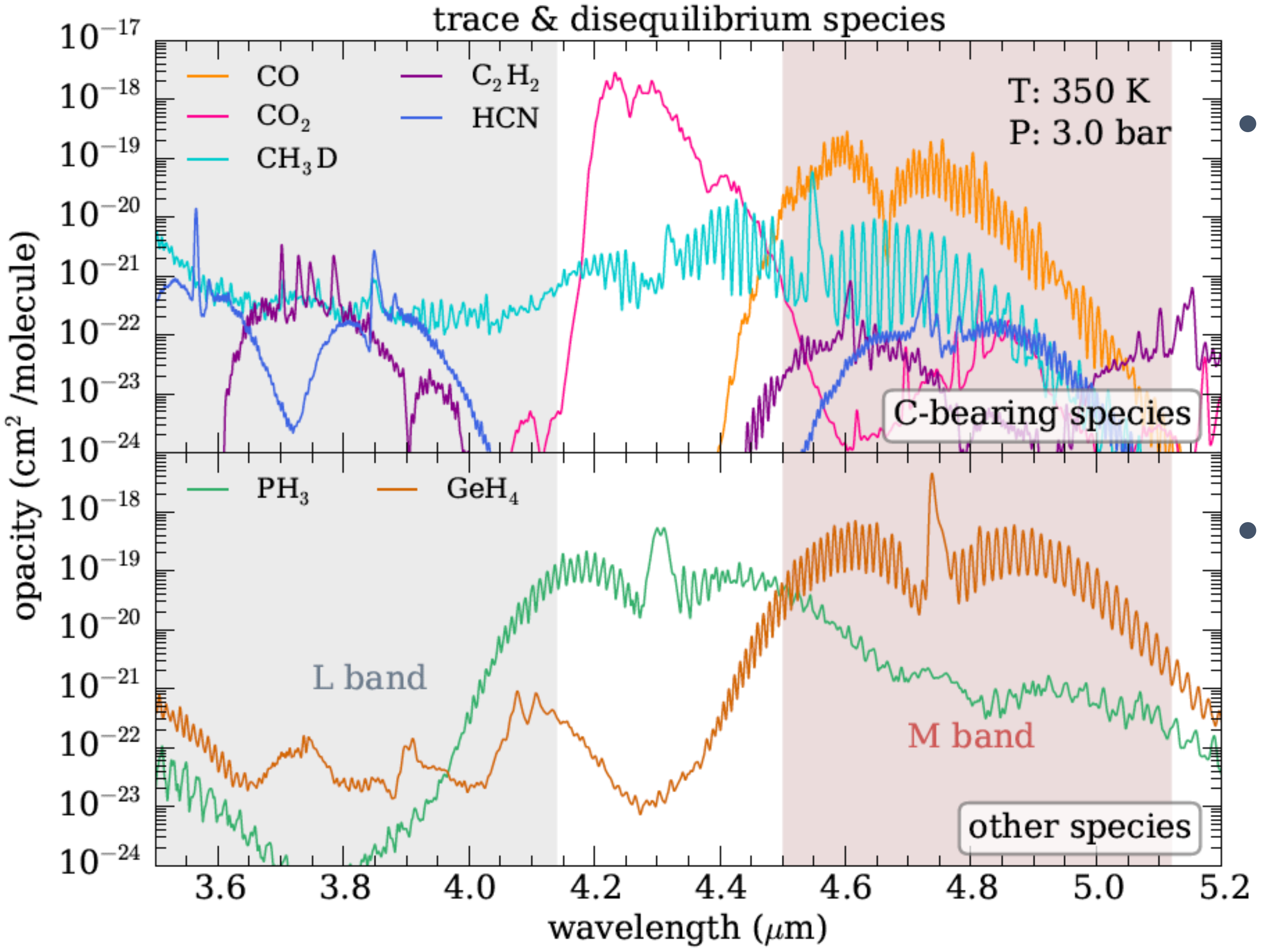
Conclusions and Looking Forward

Miles+ 2020



- Convection driven disequilibrium chemistry is a common feature of cool brown dwarfs. We should expect to see the same for future, directly imaged gas giant planets.

Conclusions and Looking Forward



Morley+ 2018

- JWST Mid-IR observations will likely expand the types of molecules we can detect in the atmospheres of Y-dwarfs.
- The M-band observations shown in Miles+ 2020 are an early opportunity to understand the gas giants the community will image with HabEx/LUVIOR.