



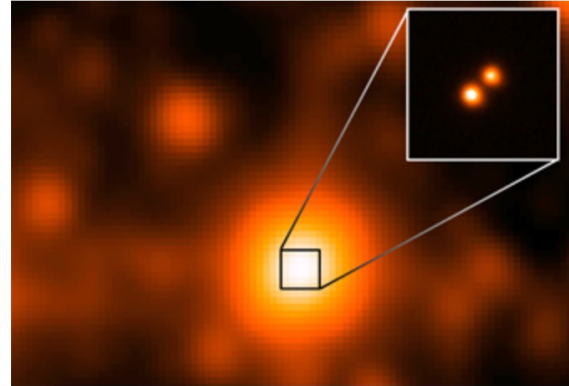
Modelling the spectra of brown dwarfs [and how data drove most updates]

An outlook for exoplanets in the JWST + ELTs era.....

Dr. Theodora Karalidi
University of Central Florida
Atmospheres, Atmospheres!
Do I look like I care about atmospheres?
08/27/2021

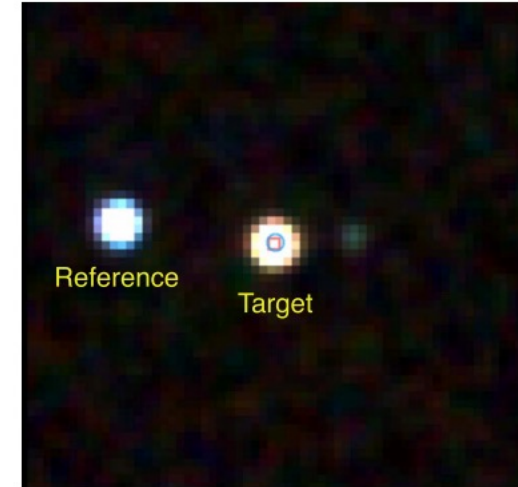
Brown dwarfs

- Not failed stars, just rogue planets
- $13M_J \leq M \leq 80M_J$
- $T_{\text{eff}} \leq 2,000 \text{ K}$
- L – T – Y

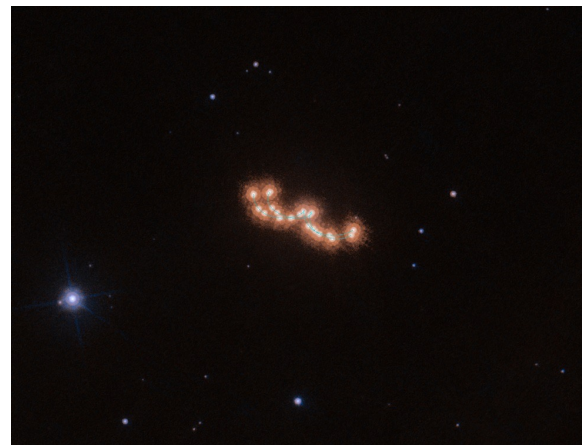


NASA / JPL / Gemini Observatory / AURA / NSF

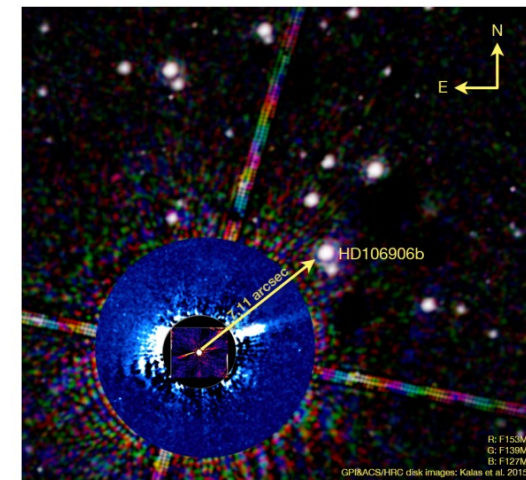
Luhman 2013



Schlawin+ 2017



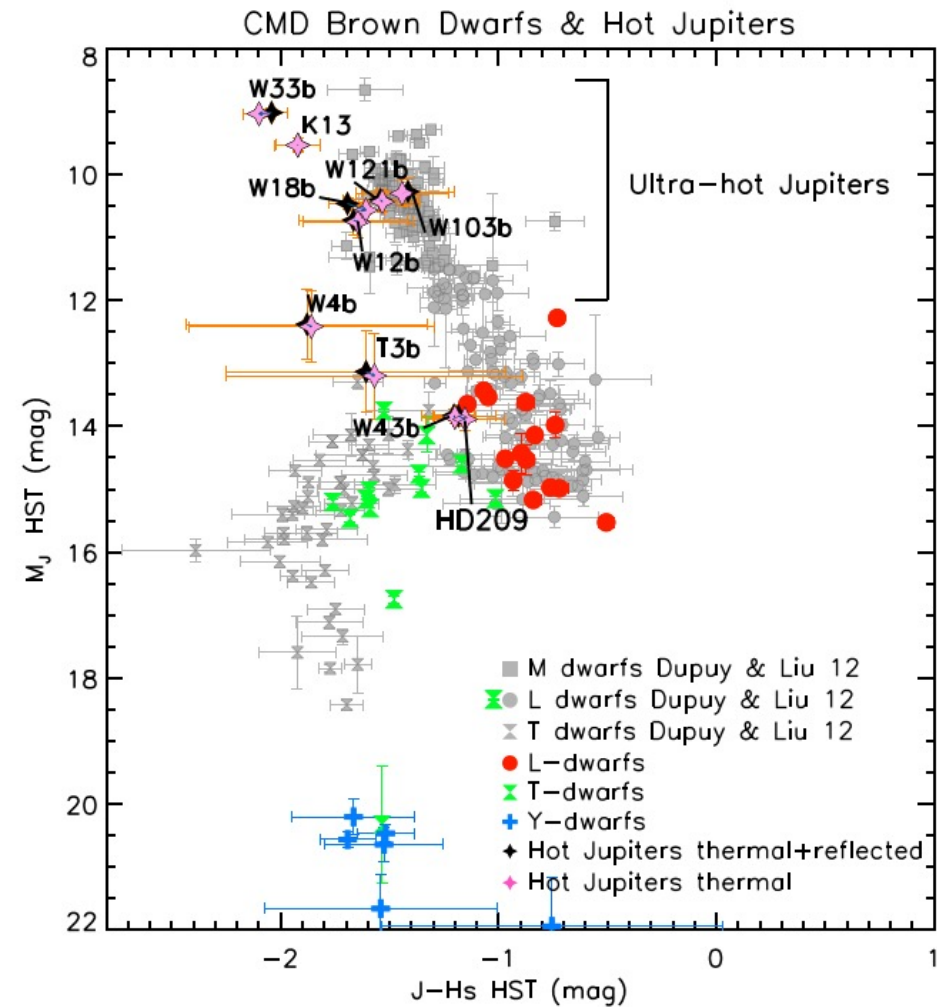
ESA/Hubble & NASA, Bedin+2017



Zhou+2020

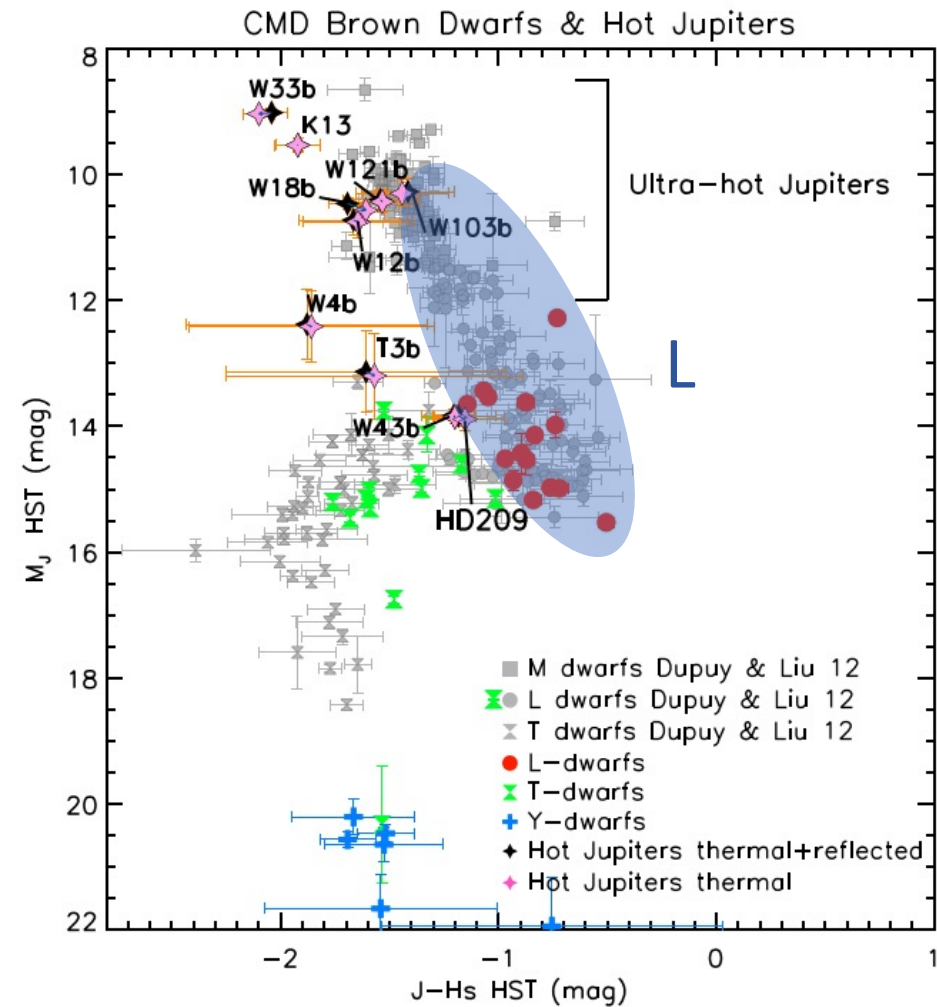
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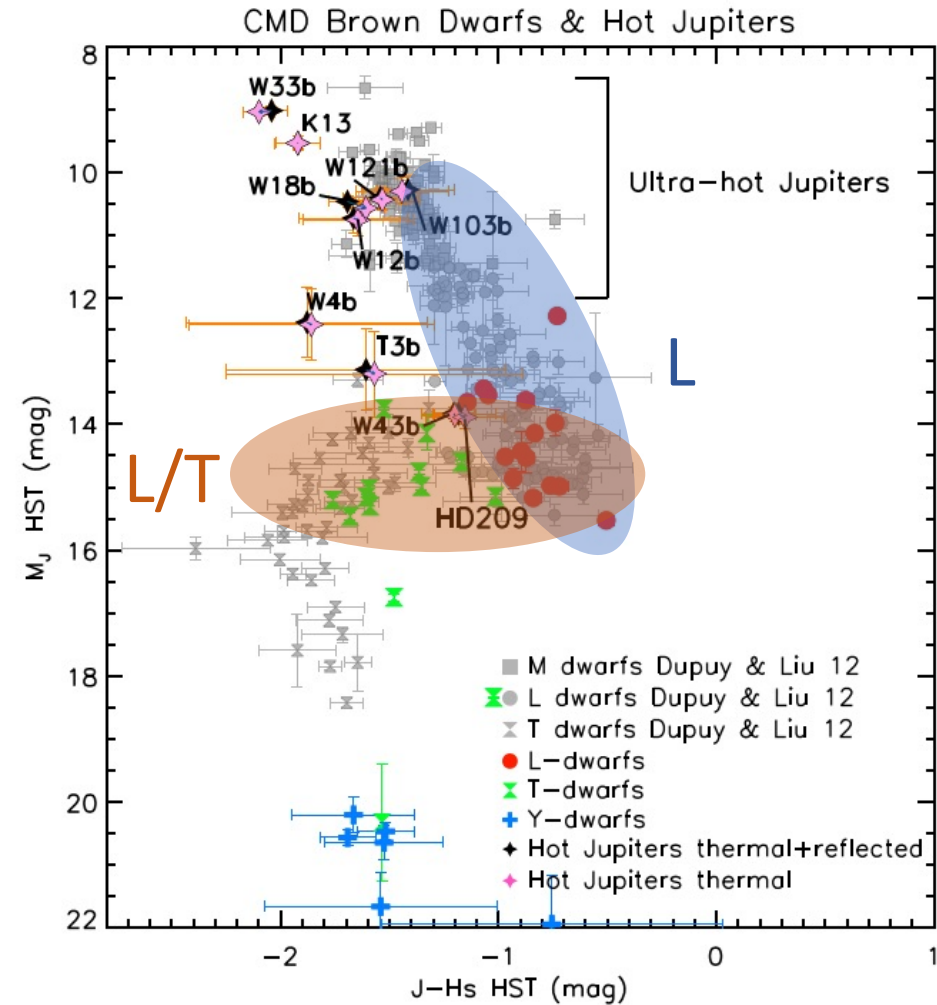
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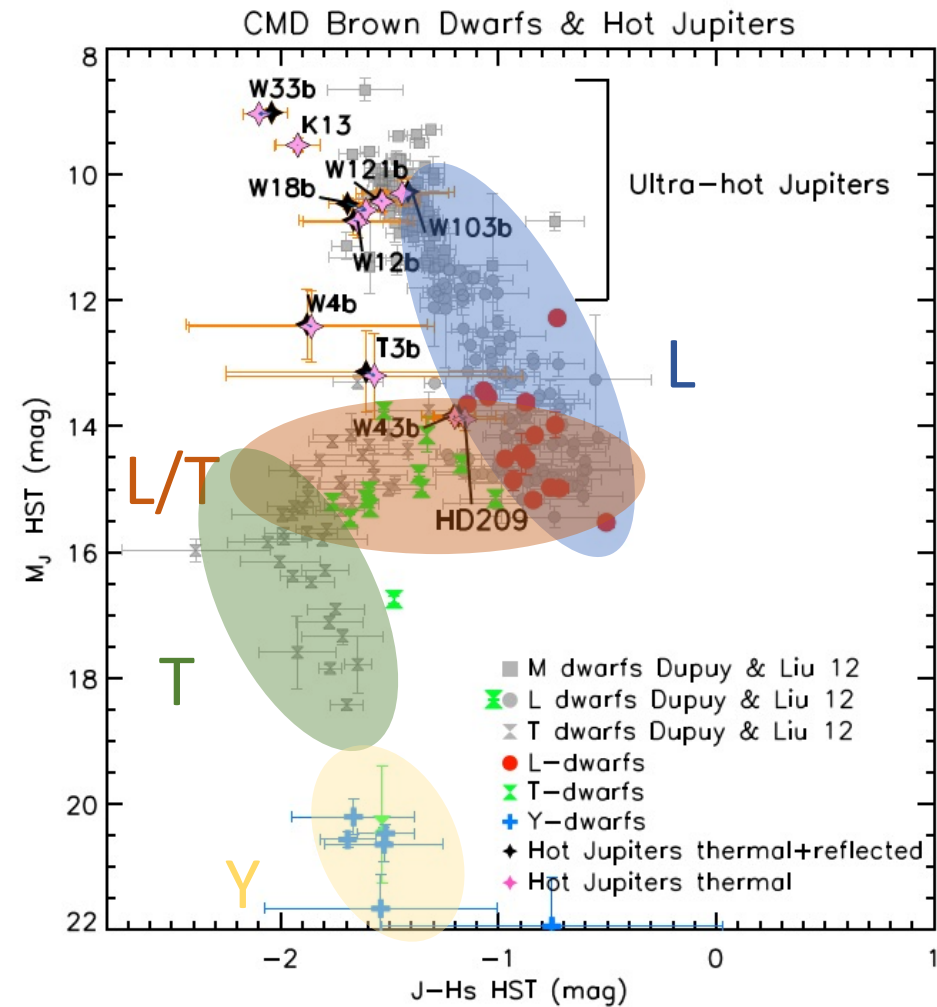
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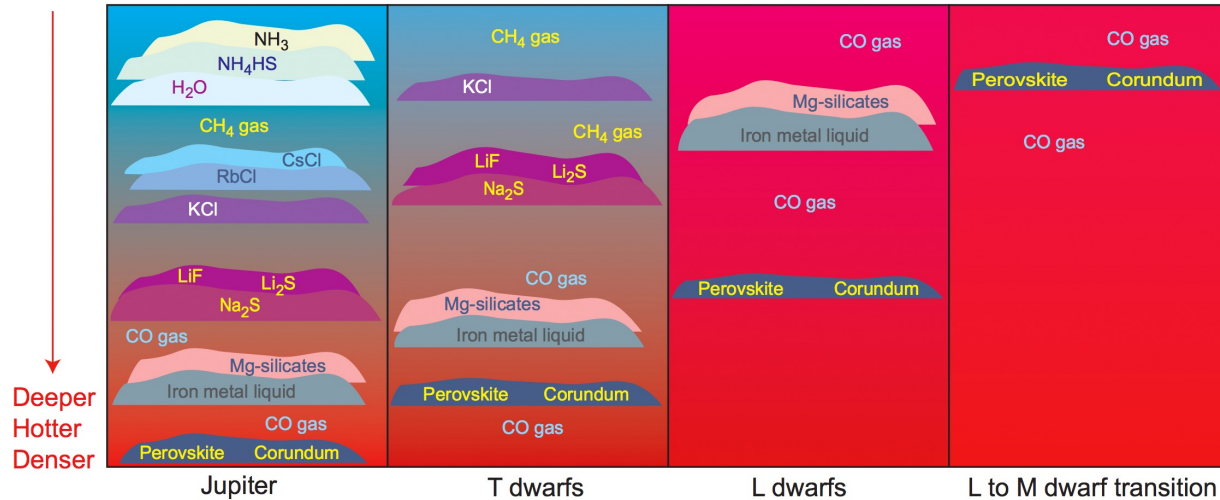
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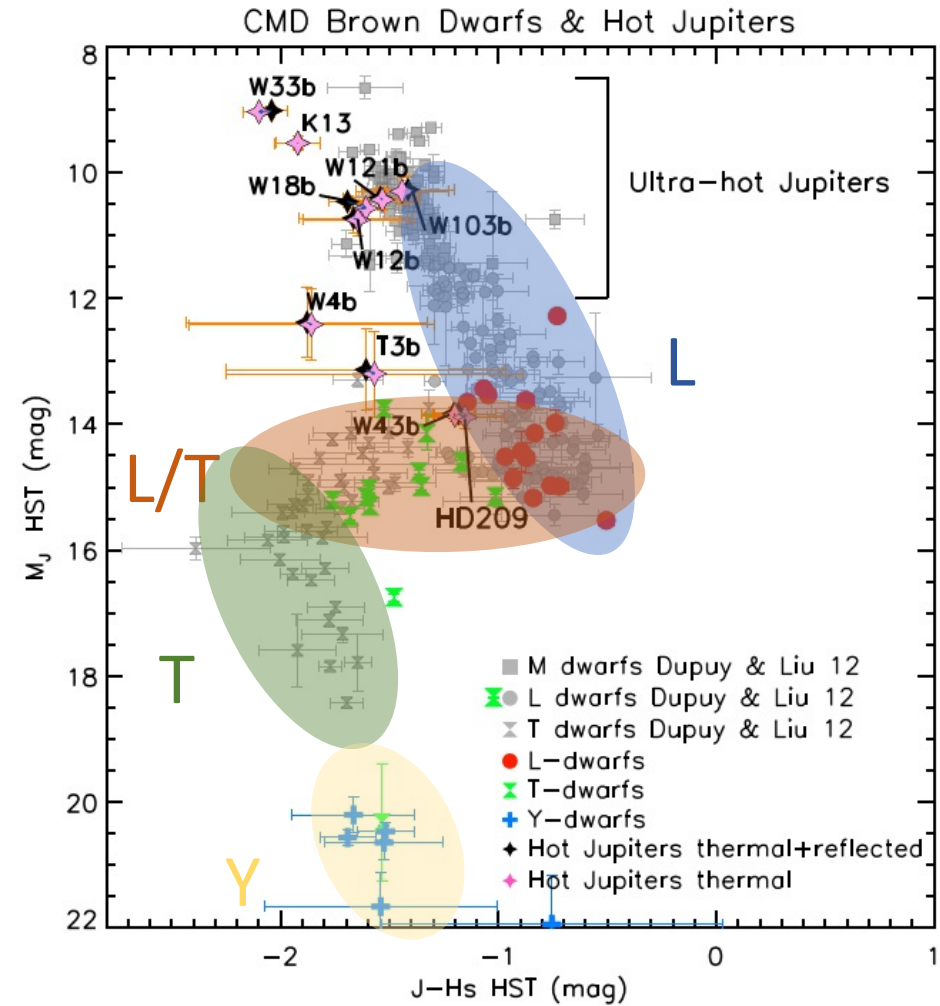


Brown dwarfs

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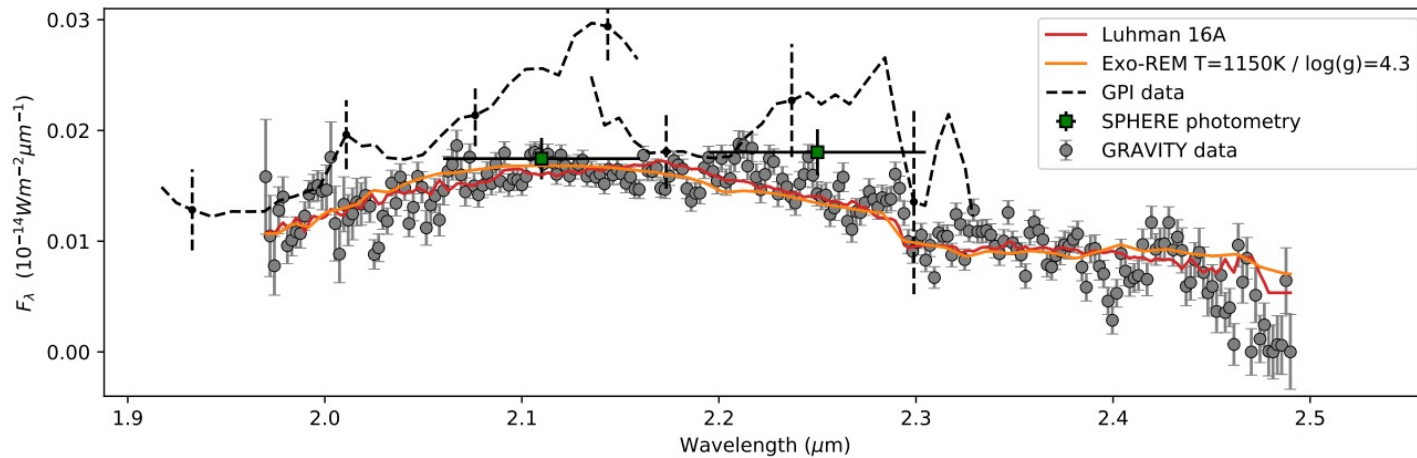
Lodders & Fegley 2006



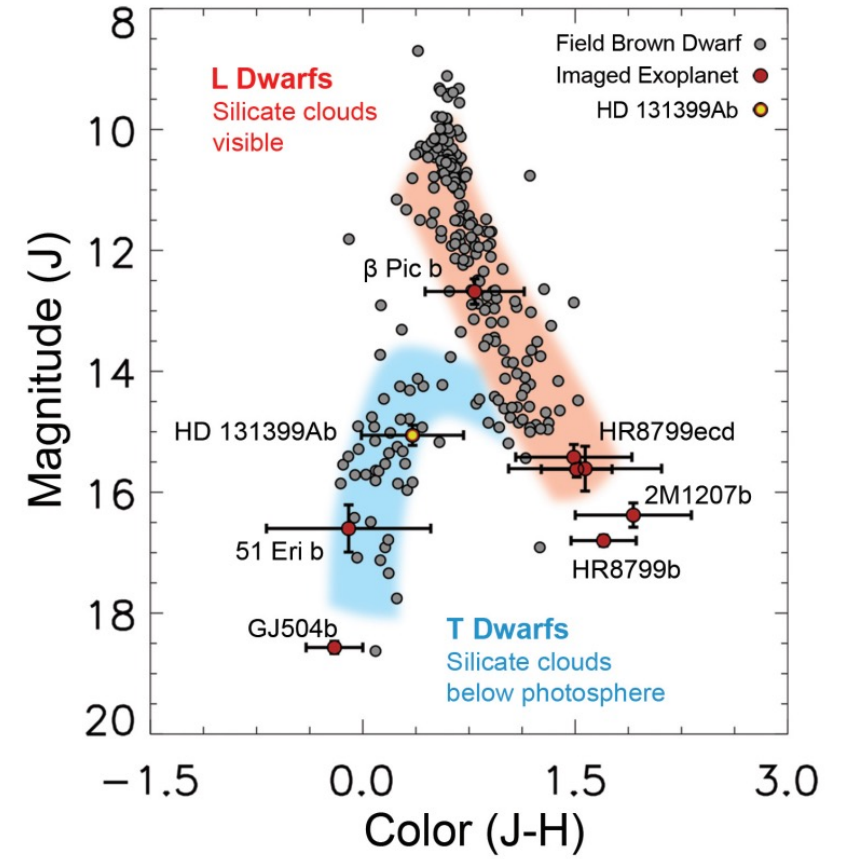
Manjavacas+2019

Brown dwarfs

- Similar to imaged exoplanets



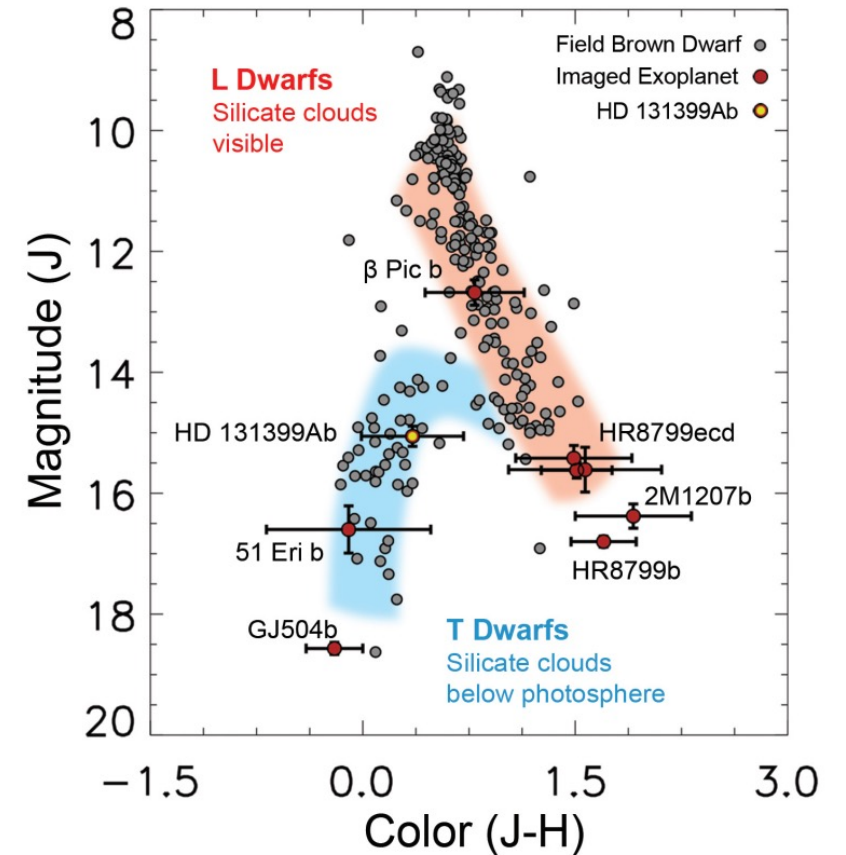
GRAVITY collaboration: Lacour+2019



Wagner+2017

Brown dwarfs

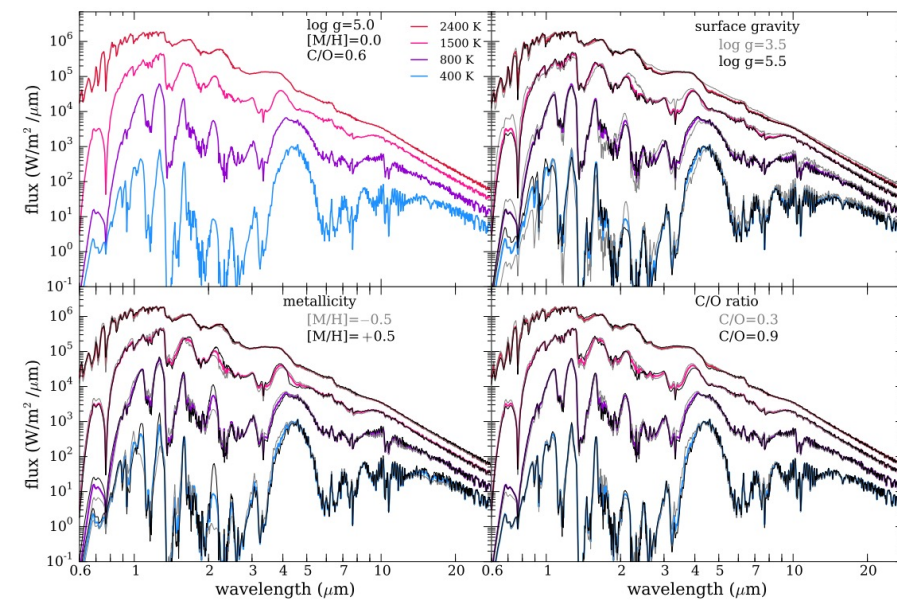
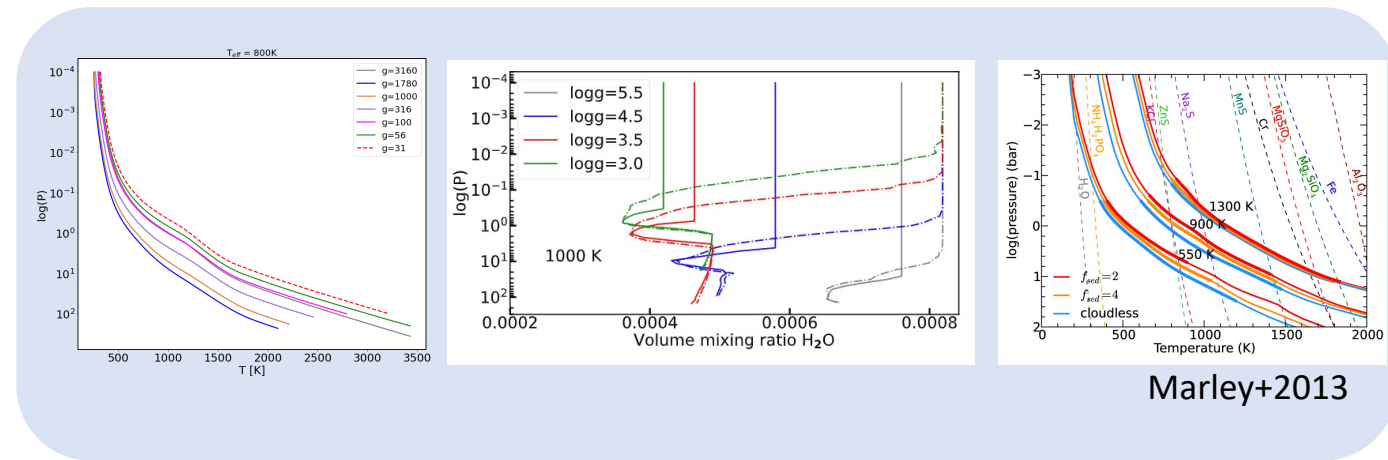
- Constrain atmospheric properties is crucial for:
 - constrain formation (see next talk - Paulina Palma-Bifani)
 - understanding atmospheres (see Callie Hoods's talk)
 - constrain evolution with time
- Need good RT and retrieval algorithms
 - But RT and retrievals are as good as our data are...see next slides



Wagner+2017

Radiative Transfer

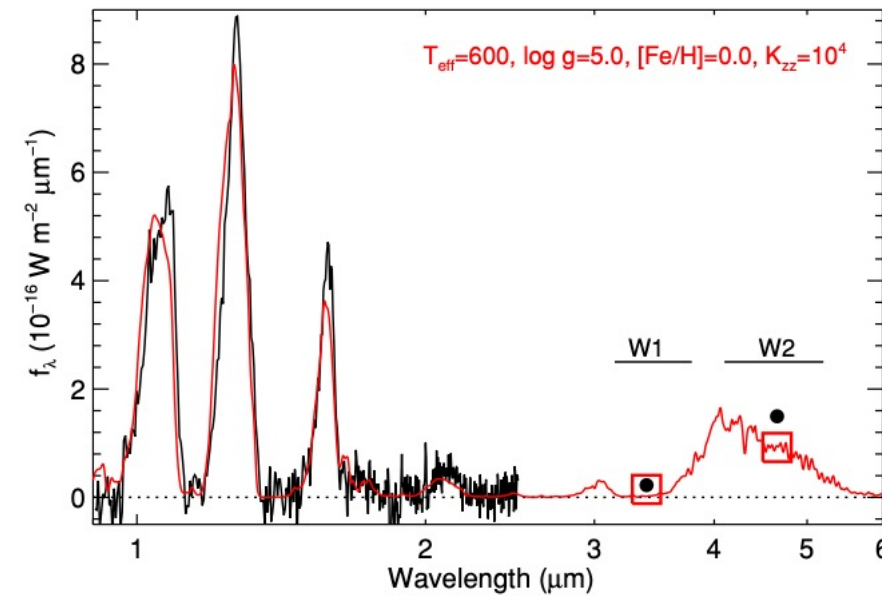
- TP
- Composition
(equilibrium/disequilibrium)
- Clouds (Y/N)



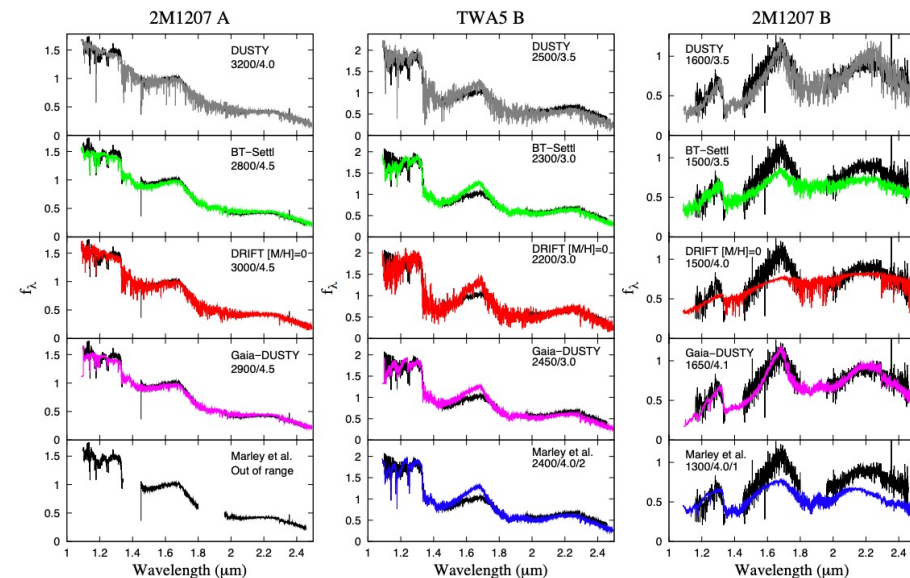
Sonora Bobcat; Marley+2021

Radiative Transfer

- TP
- Composition (equilibrium/disequilibrium)
- Clouds (Y/N)



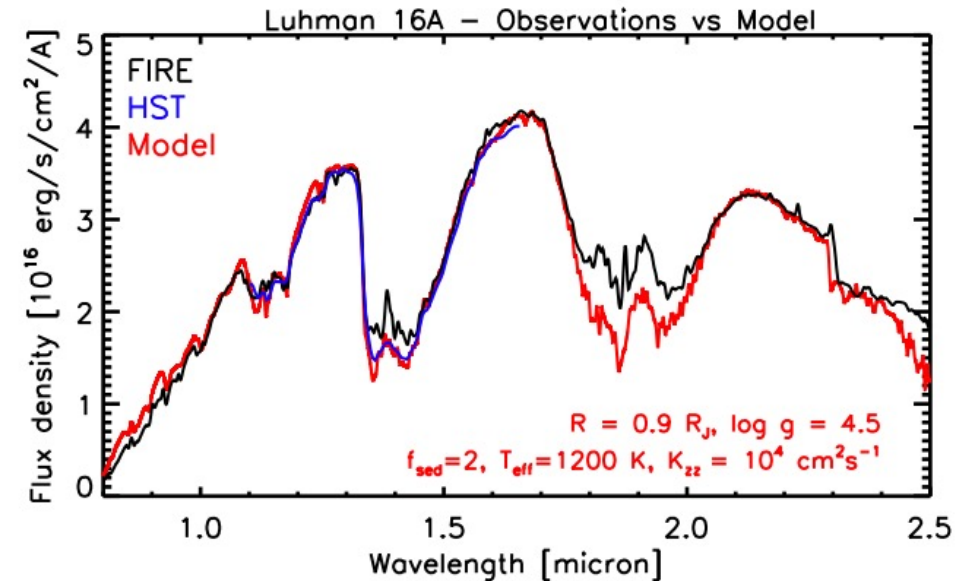
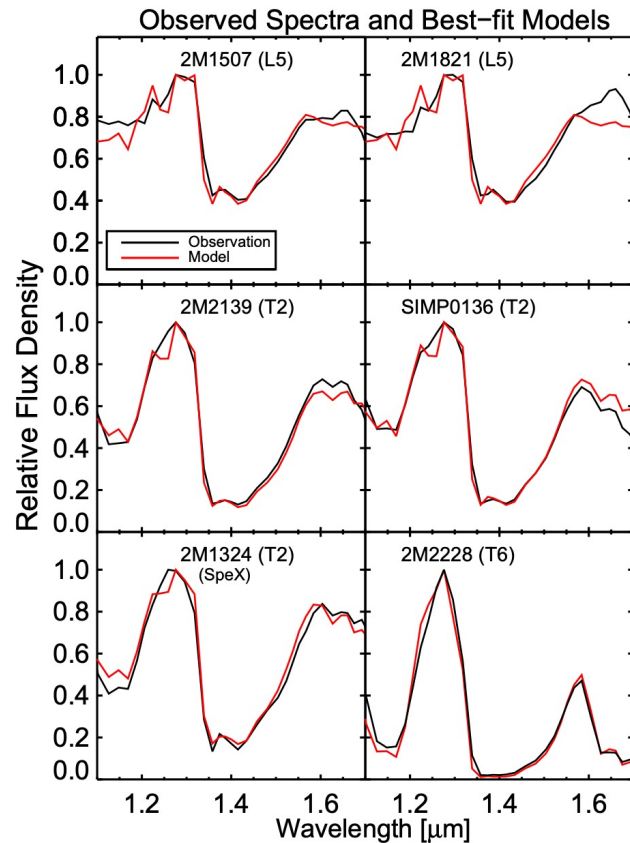
Mainzer+2011



Patience+2012

Mismatch with observations

- Often models don't match observations. Why?

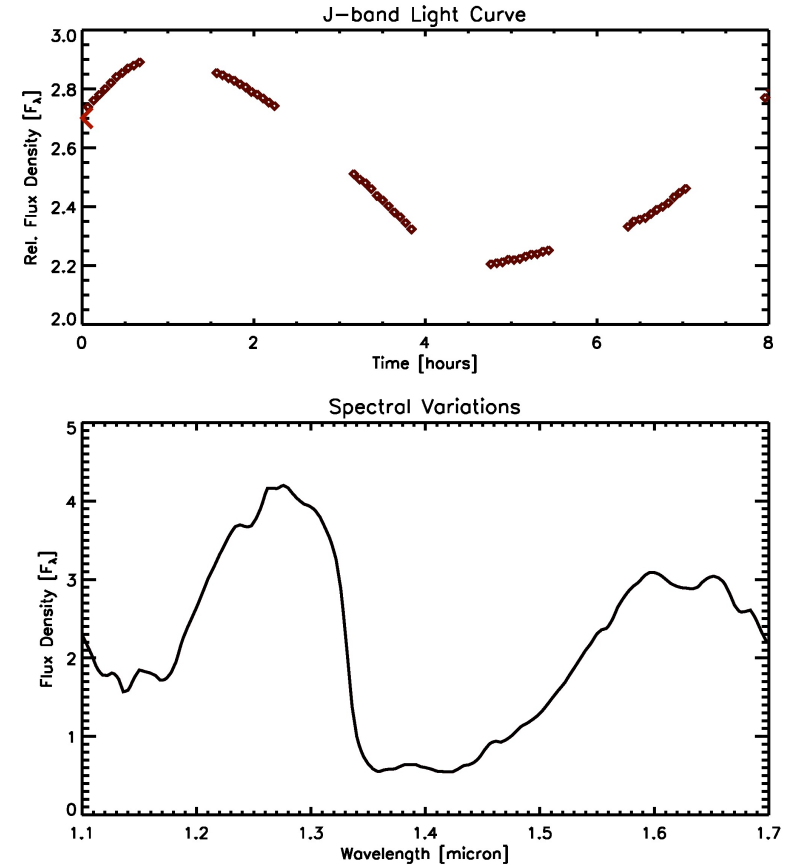


Buenzli+2014

Yang+2016

Observations

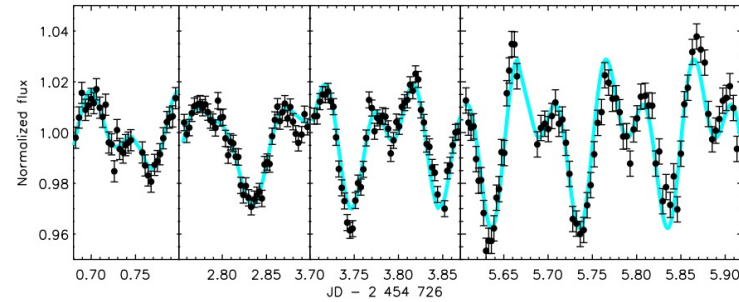
- Spitzer, HST gave new insights in these atmospheres
- Time-resolved observations



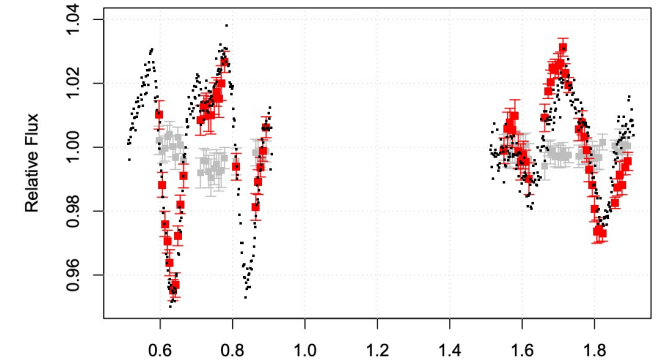
Apai+2013

Observations

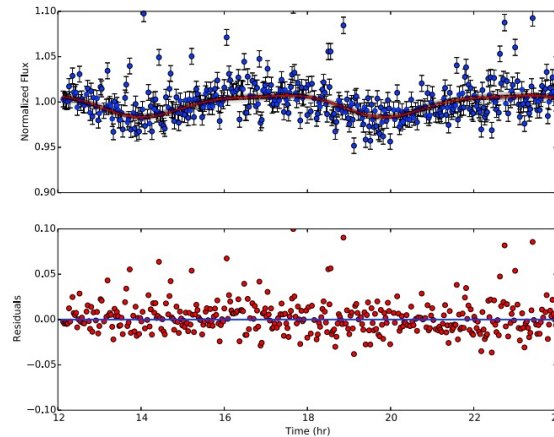
- Some atmospheres vary with time....



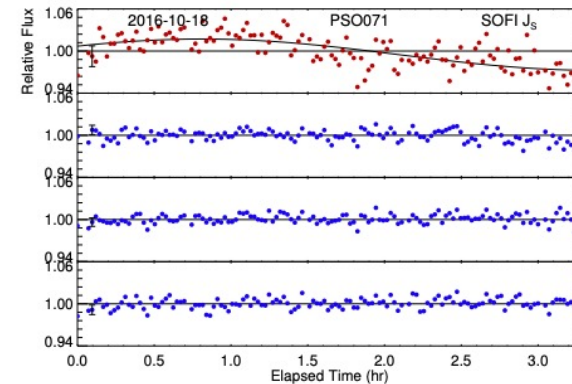
Artigau 2018/Artigau+2009



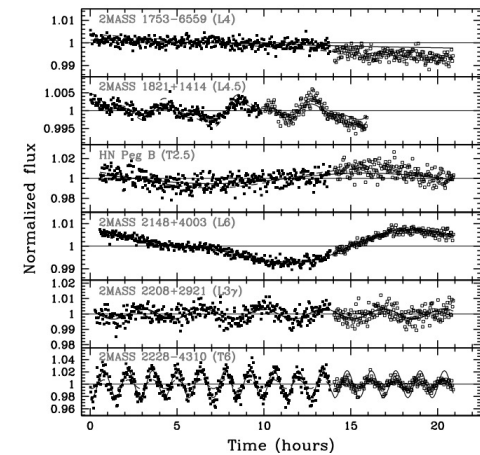
Time (Heliocentric Julian Day - 2456712.0) Heinze+2021



Leggett+2016



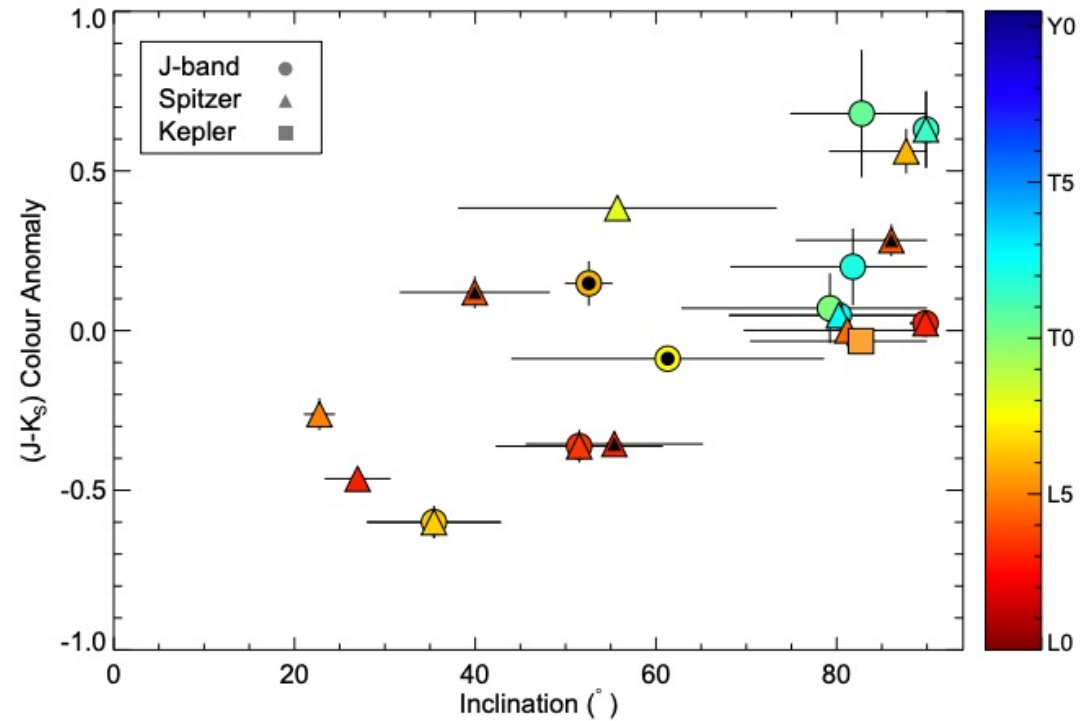
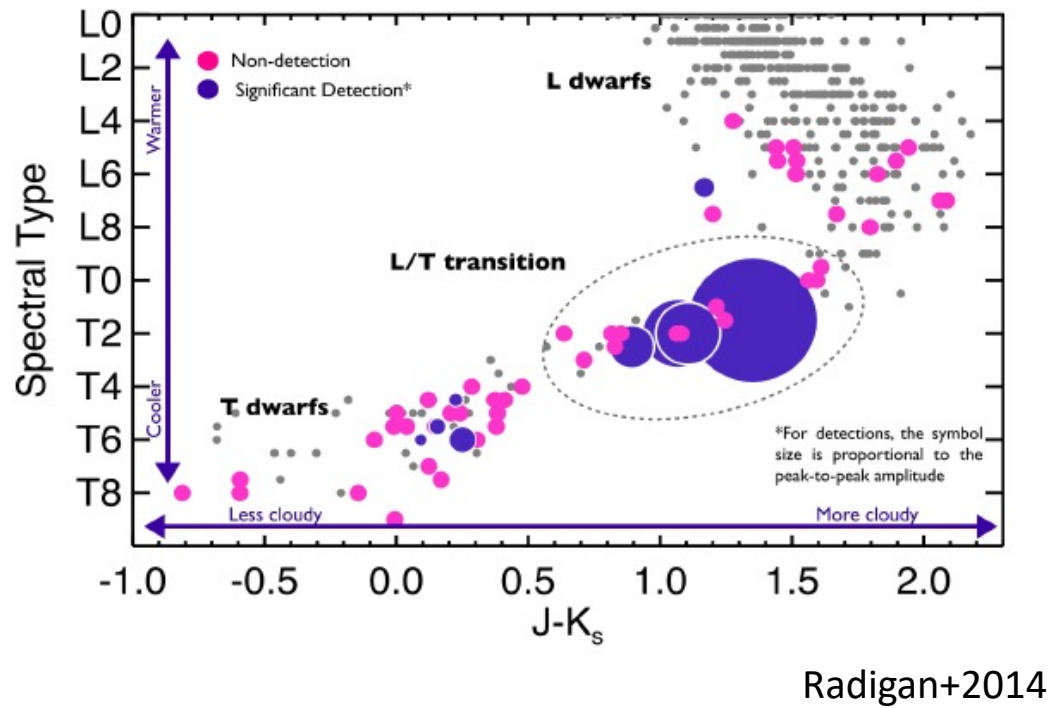
Vos+2021



Metchev+2015

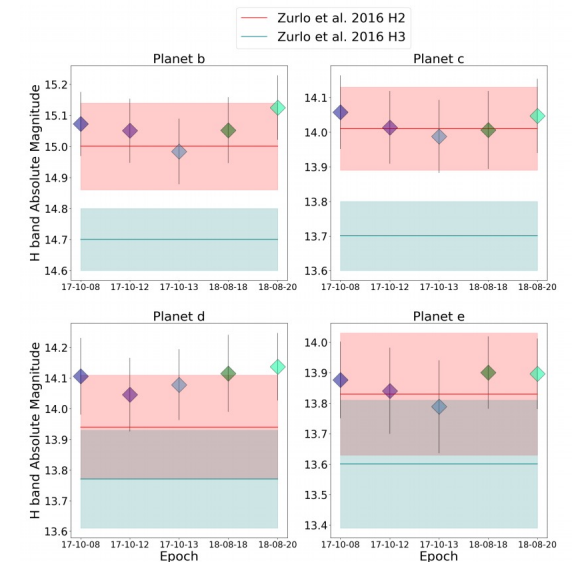
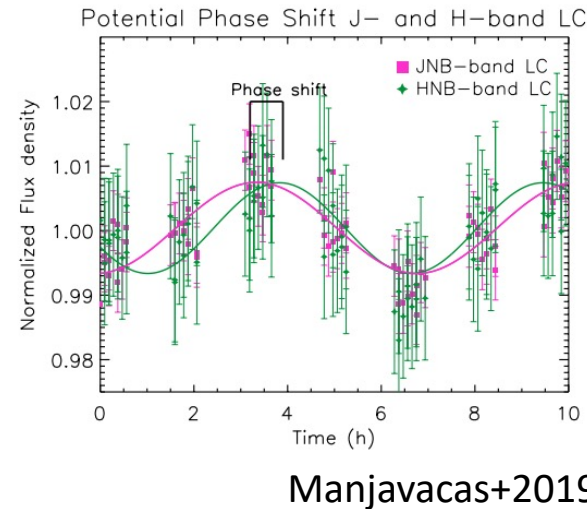
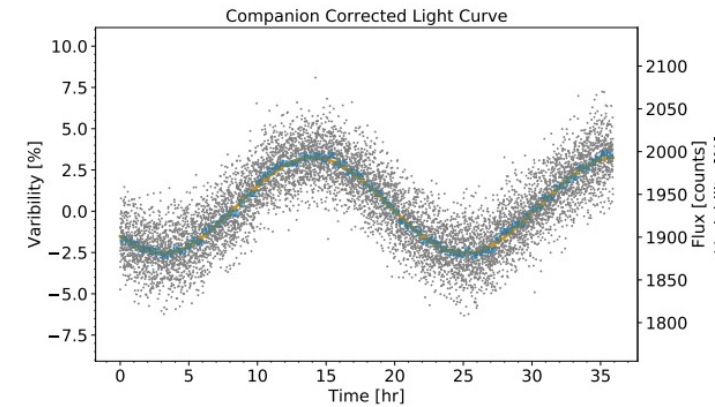
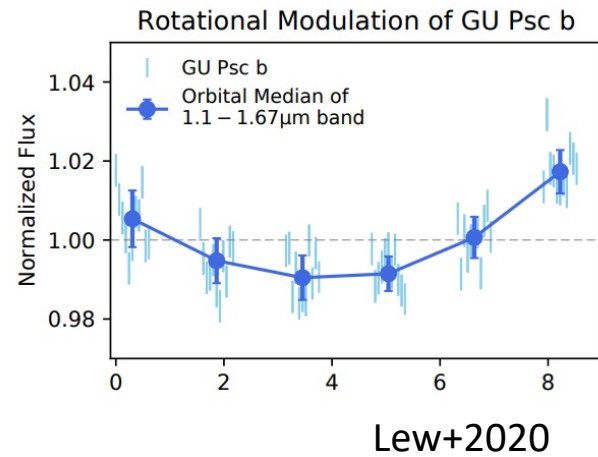
Observations

- ALL atmospheres are variable



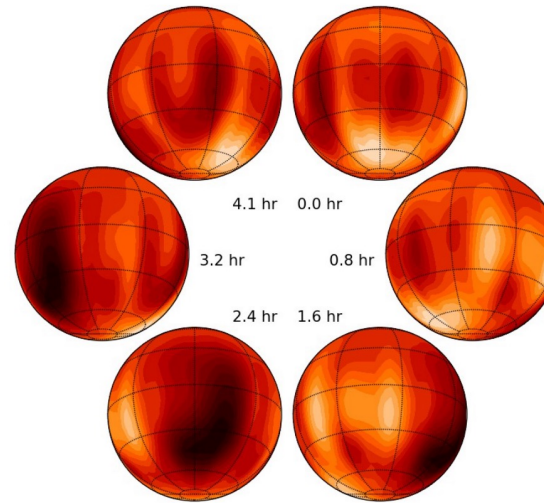
Observations

- ALL atmospheres are variable
- Imaged exoplanets/ planetary mass companions also variable

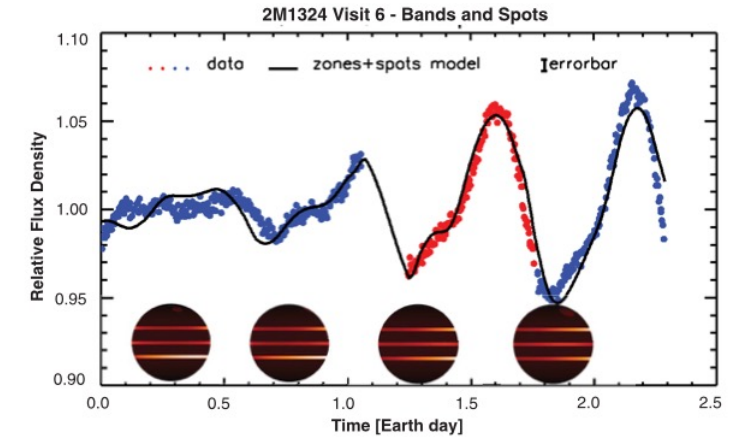


Observations

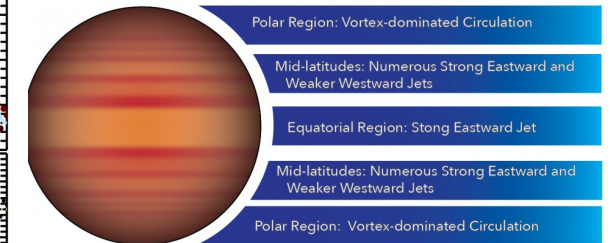
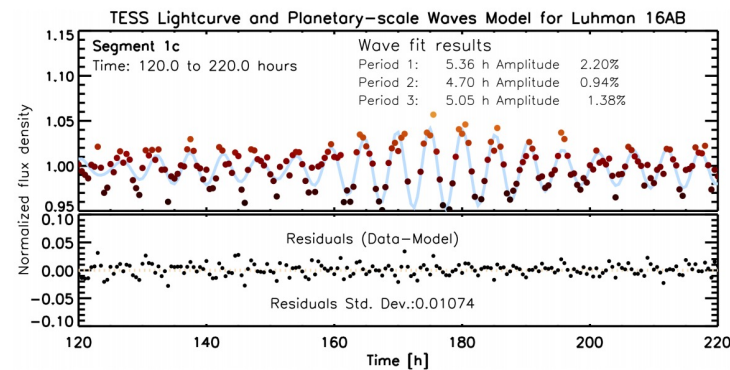
- Spitzer, HST gave new insights in these atmospheres
- Highly variable → maps → atmospheric dynamics



Crossfield+2014



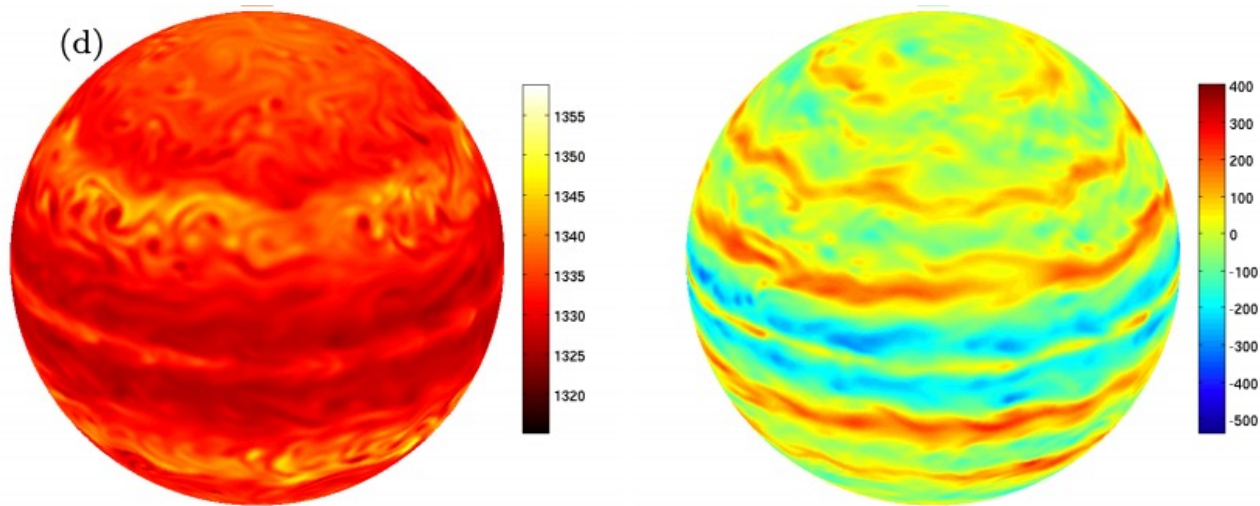
Apai+2017



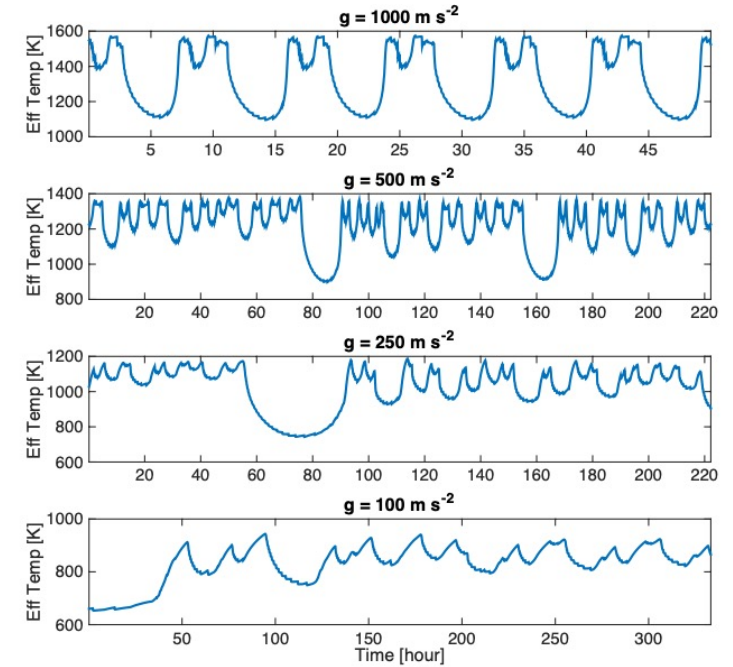
Apai+2021

Observations

- Observational constraints on GCMS



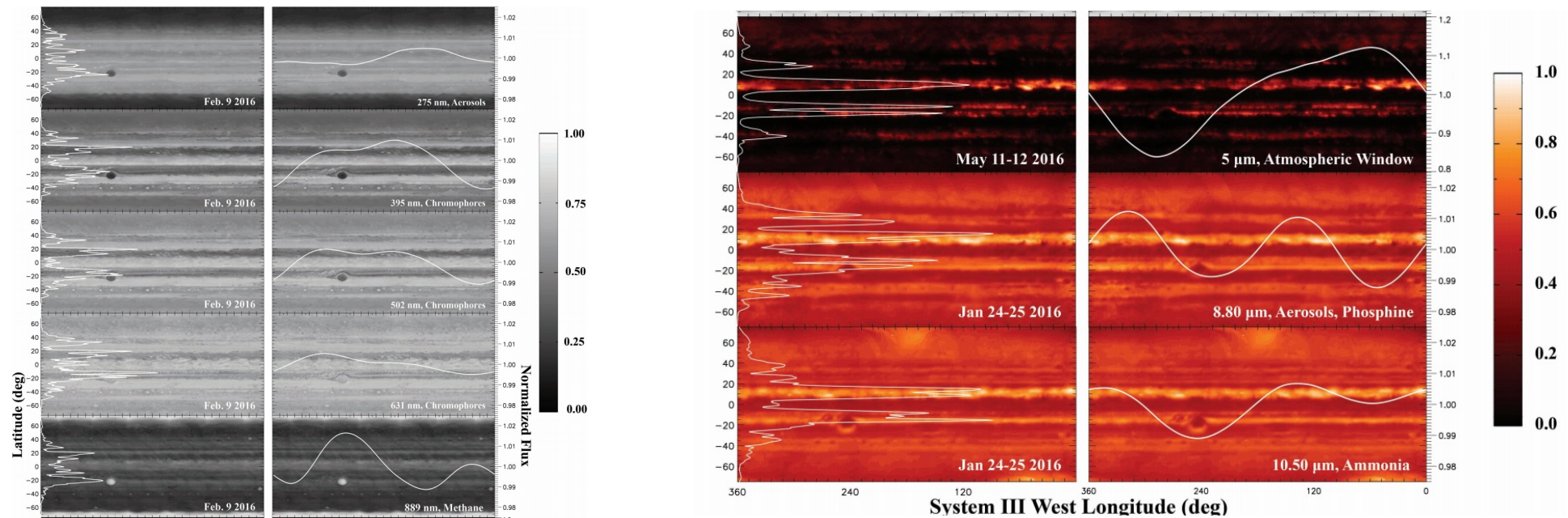
Showman+2019



Tan & Showman 2019

Observations

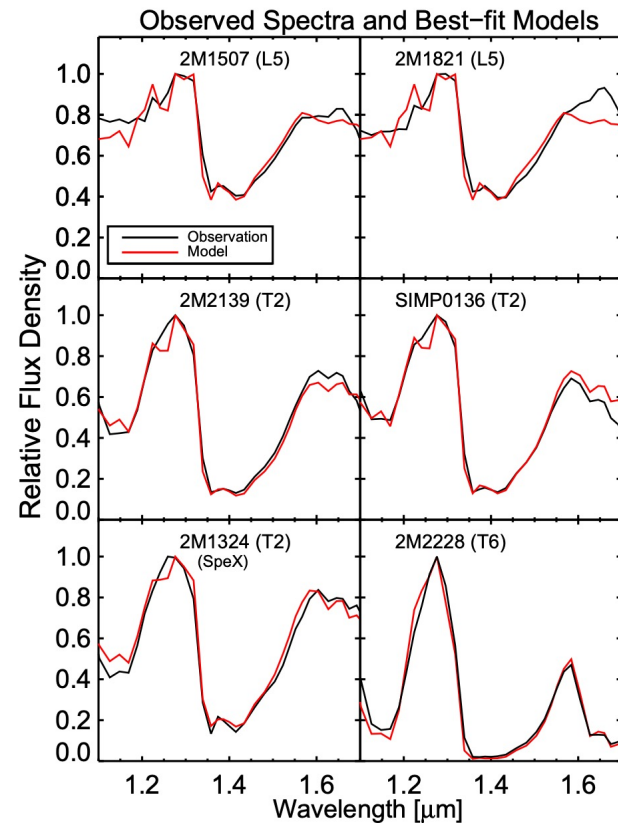
- We should have known... Always look back at the Solar system



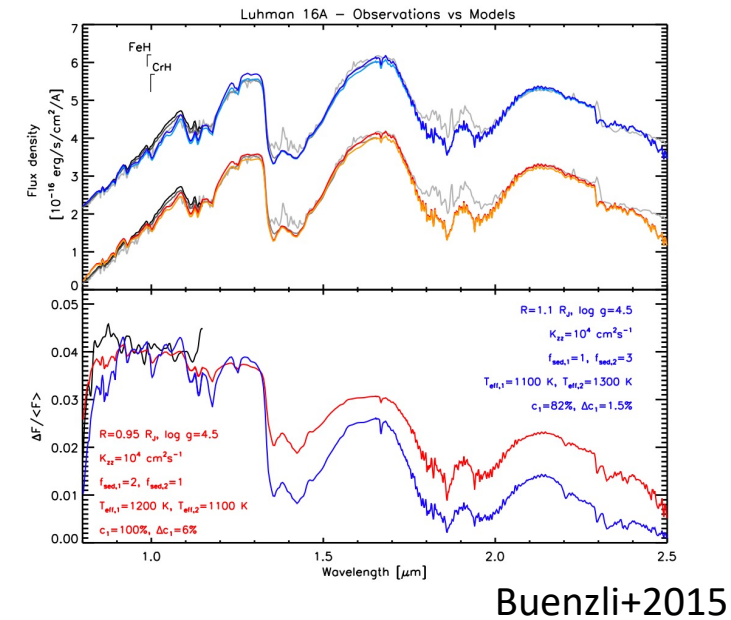
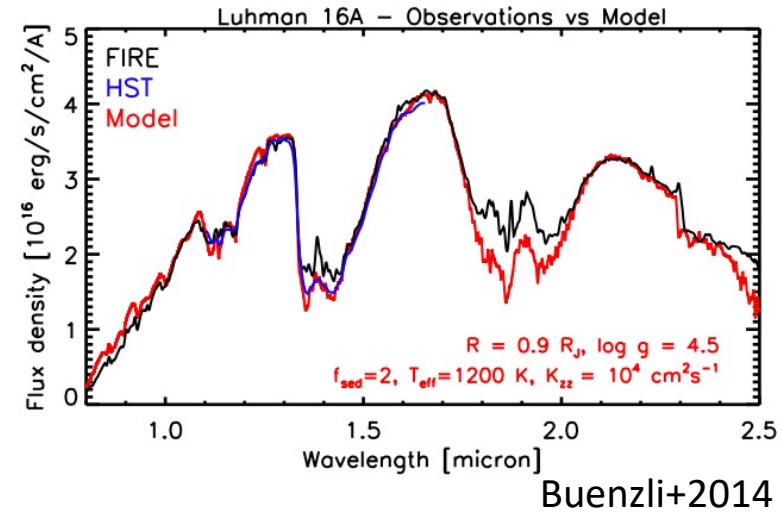
Ge+2019

Mismatch with observations

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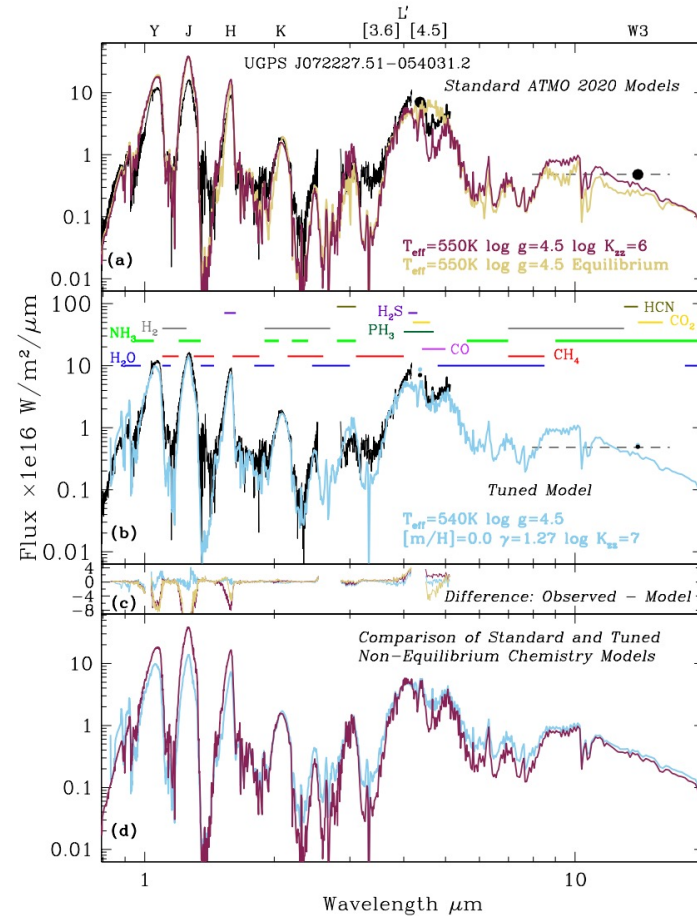
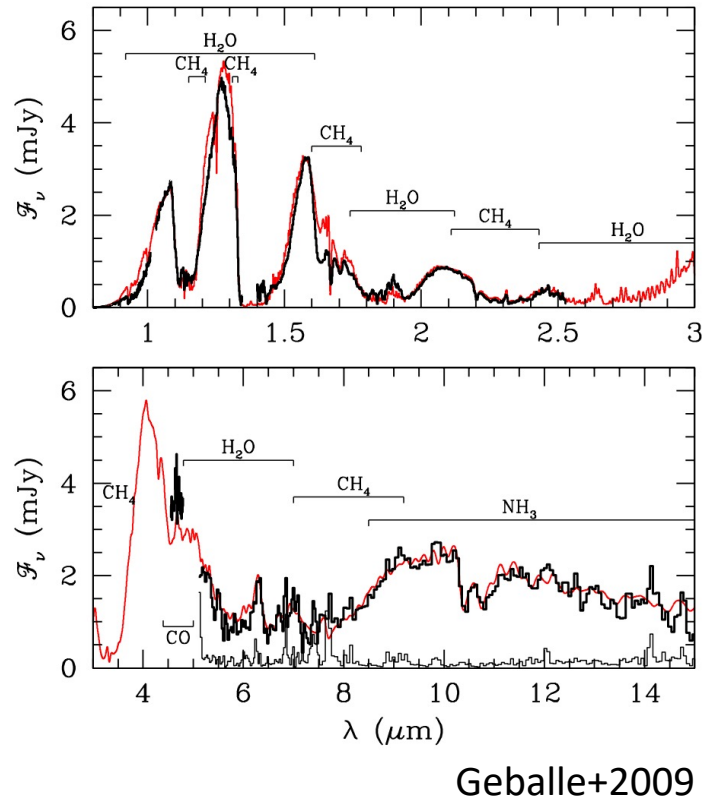


Yang+2016

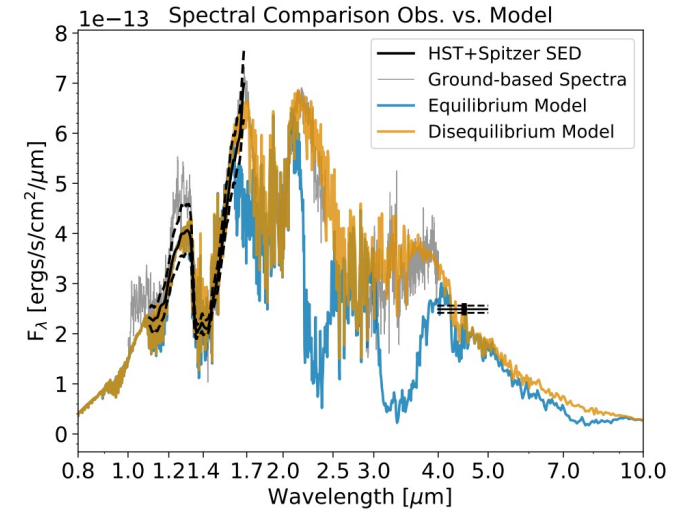


Mismatch with observations

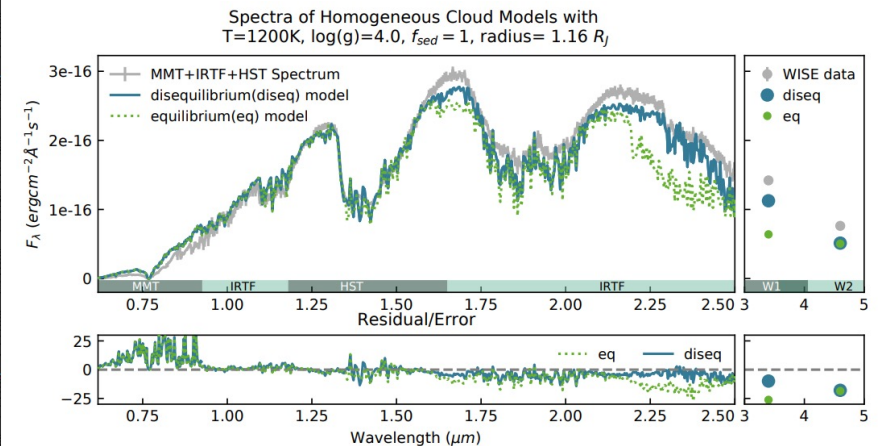
- Models need updates



Leggett+2021



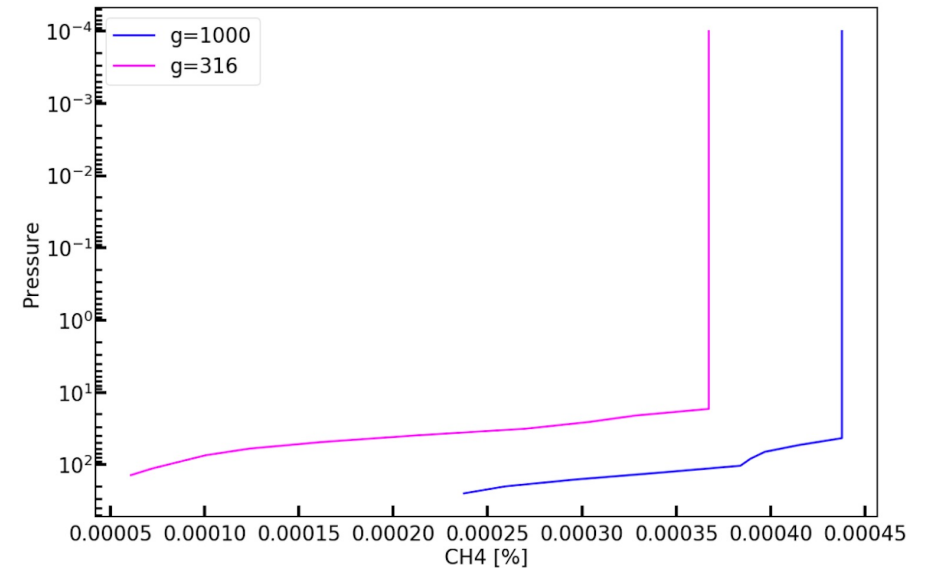
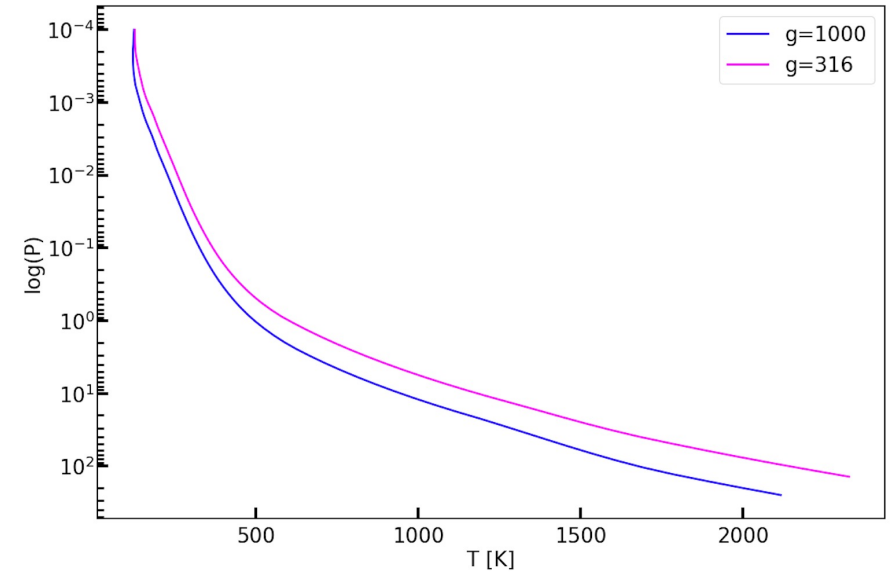
Zhou+2020



Lew+2020

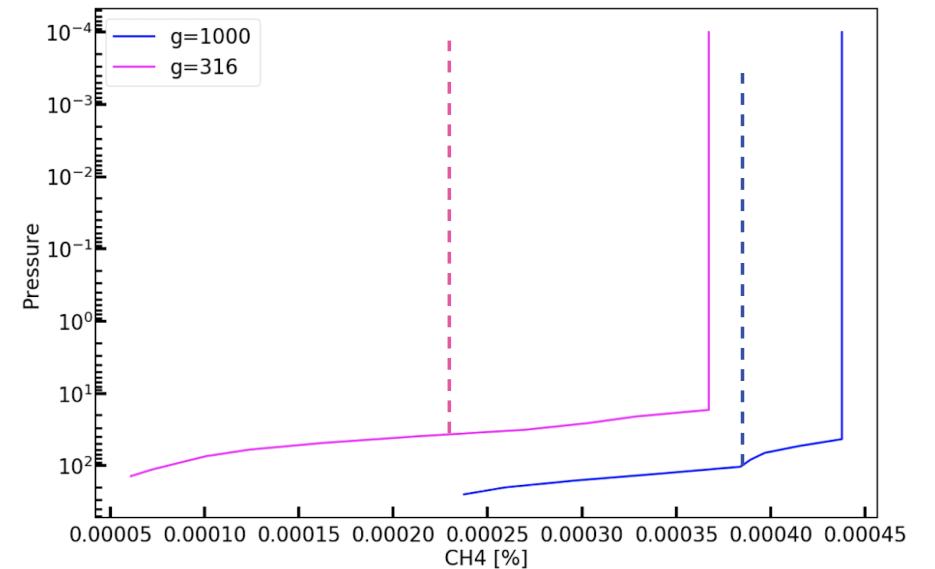
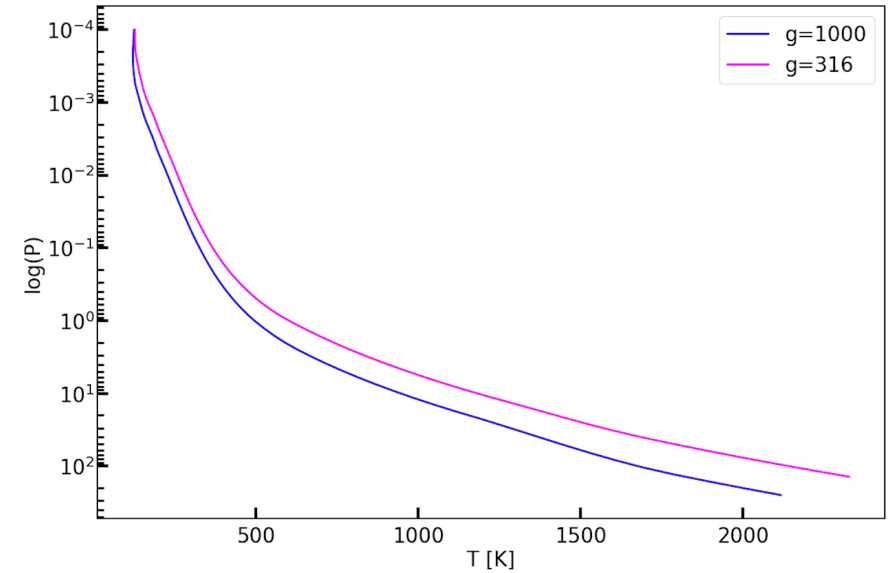
Radiative Transfer updates

- TP \leftrightarrow Composition
 - Post-processed spectra can match data; need caution



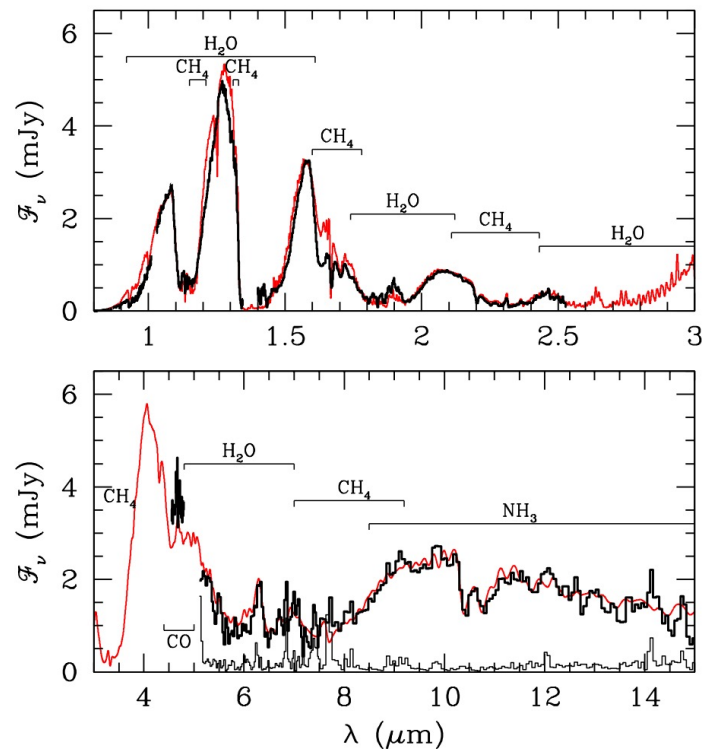
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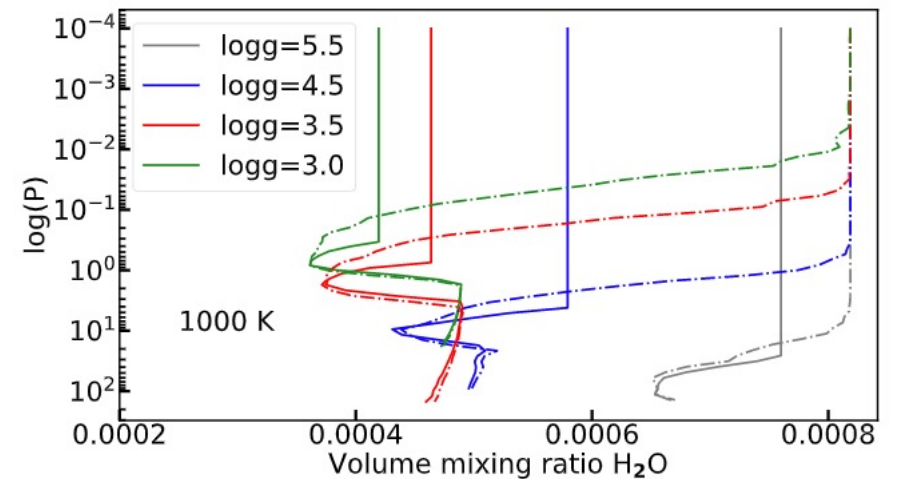
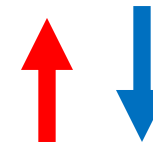
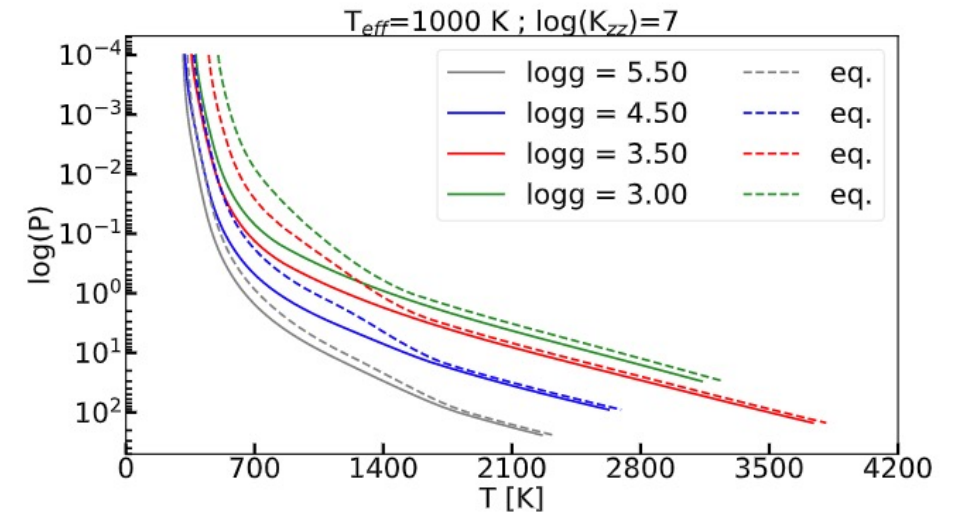


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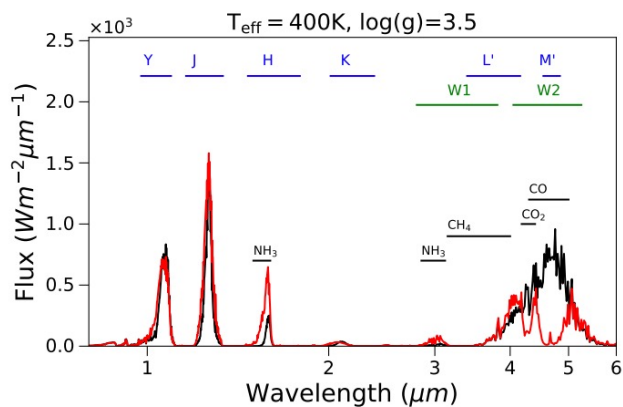


Geballe+2009

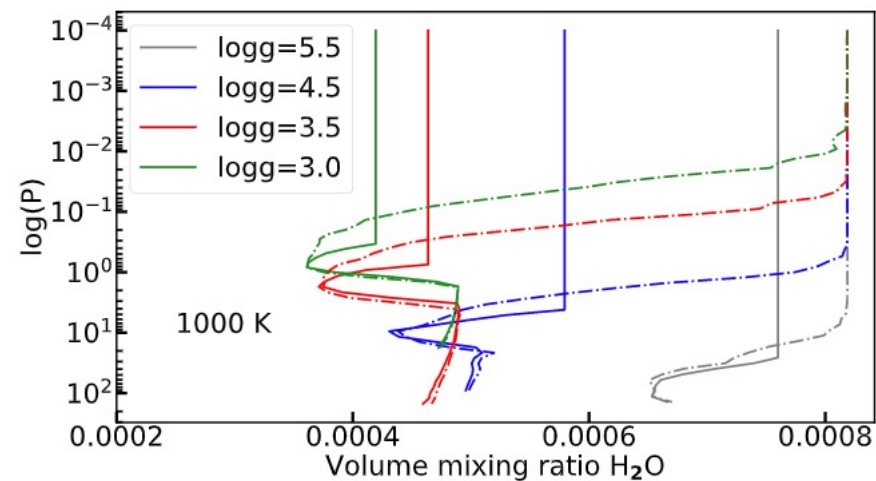
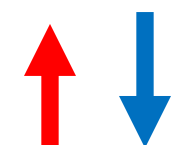
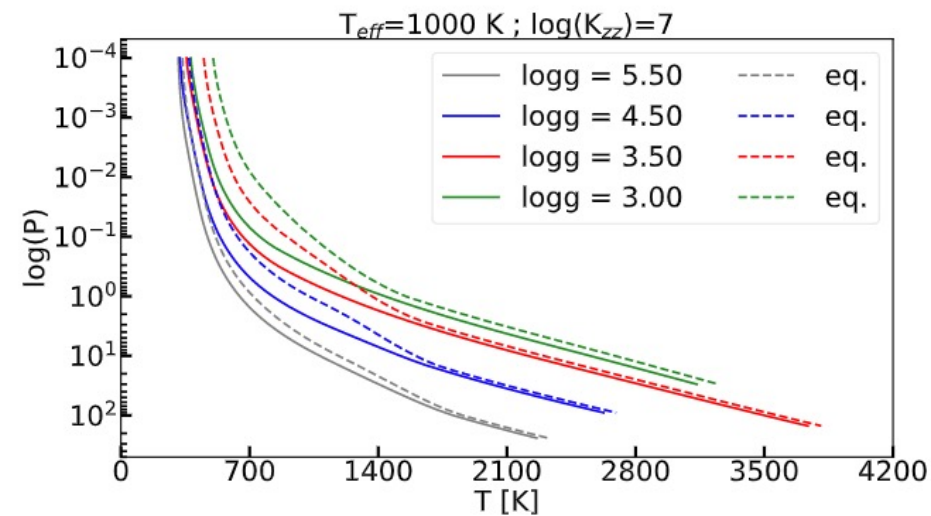
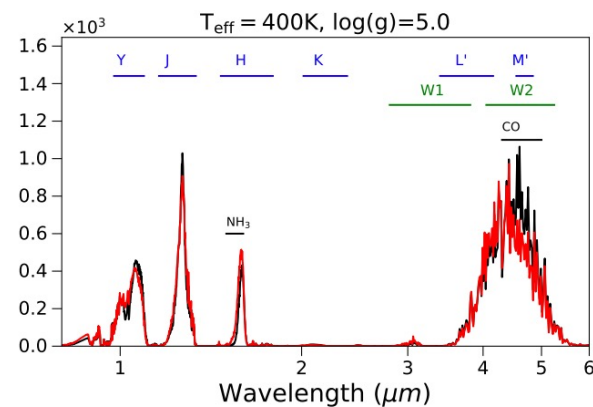


Karalidi+ submitted

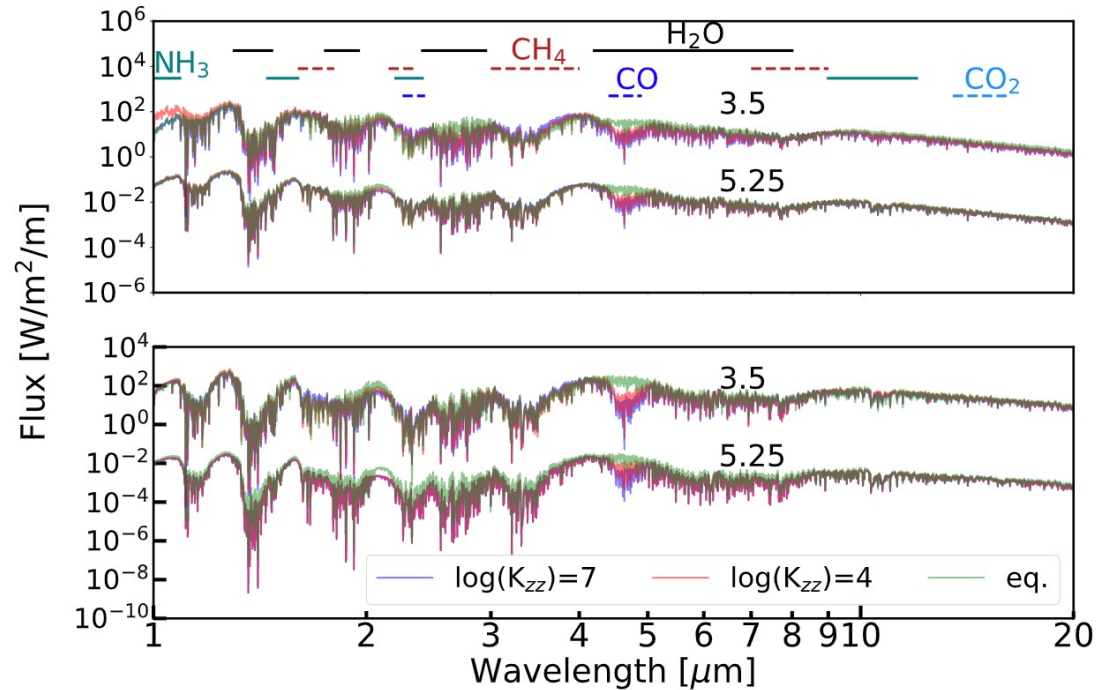
Radiative Transfer updates



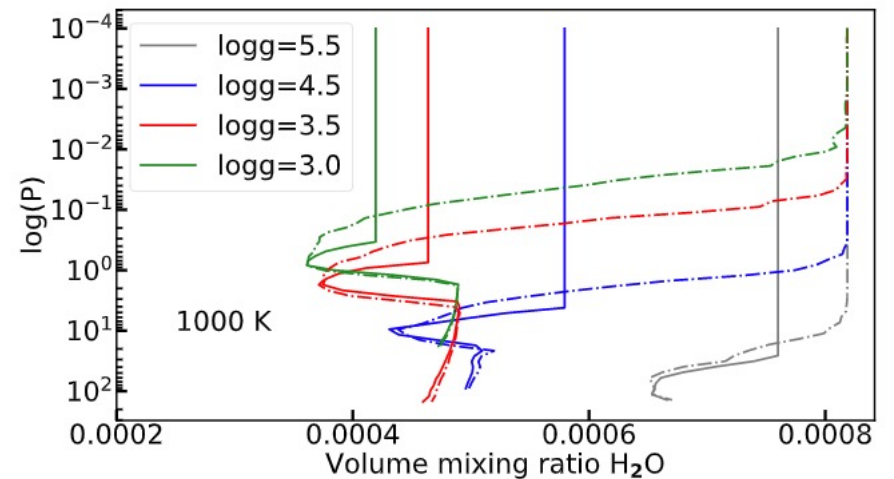
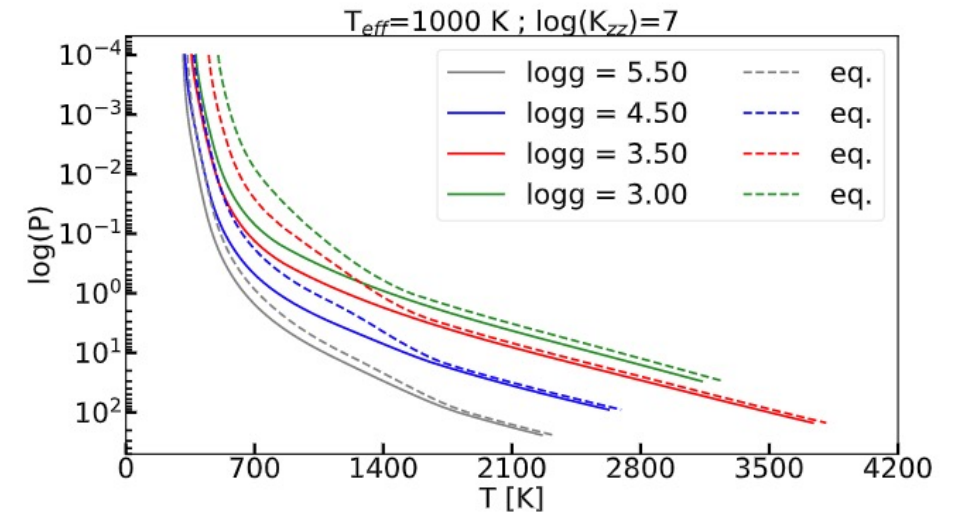
ATMO 2020 - Phillips+2020



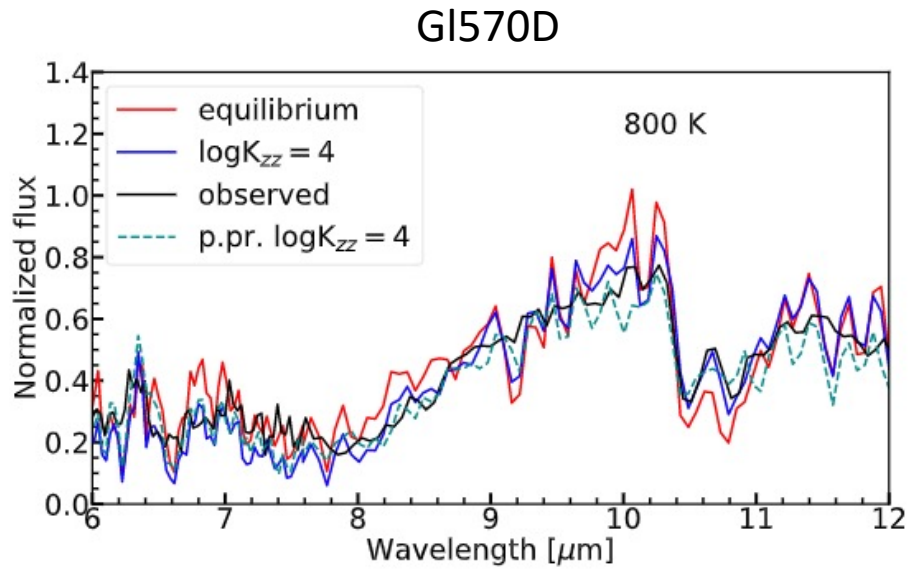
Radiative Transfer updates



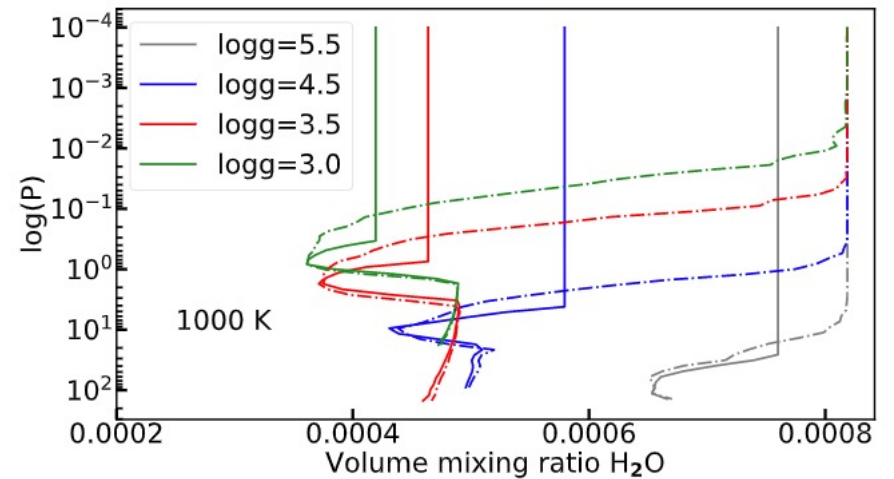
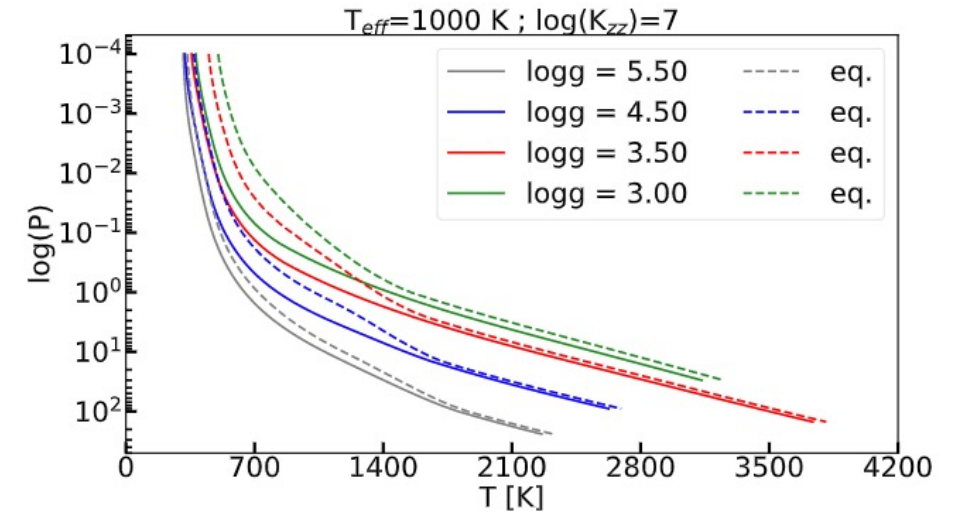
Sonora Cholla models- coming soon to Zenodo;
(Karalidi et al. submitted)



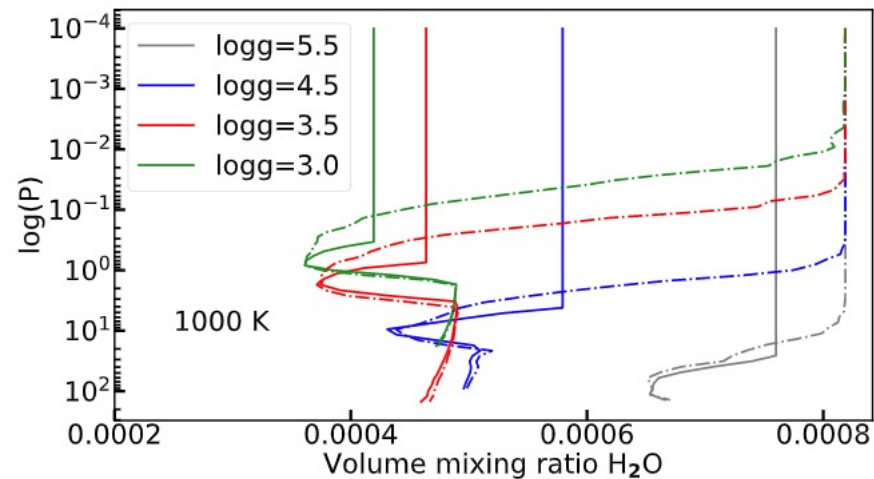
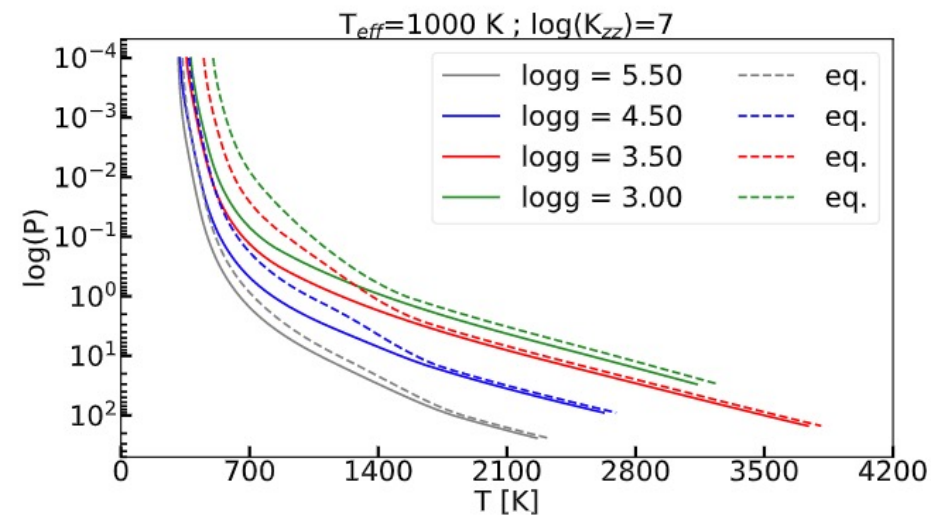
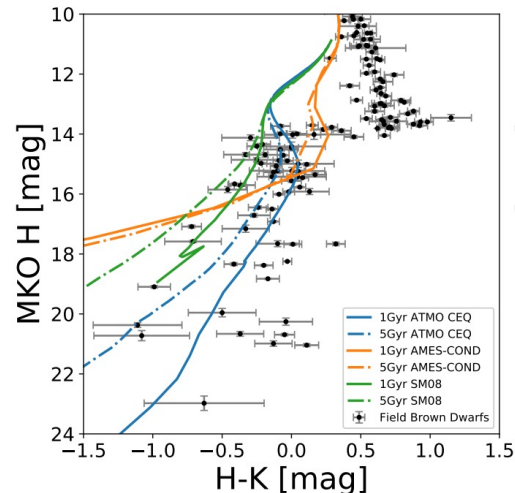
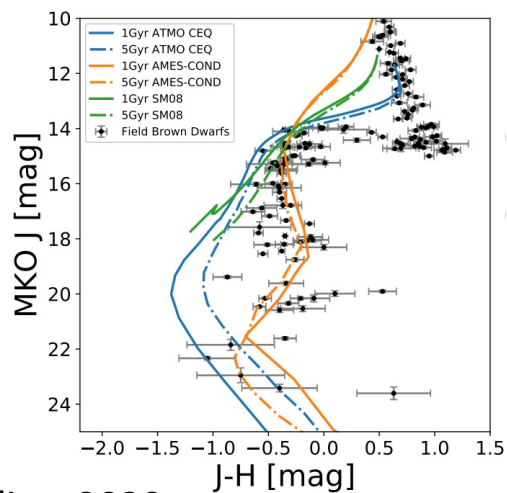
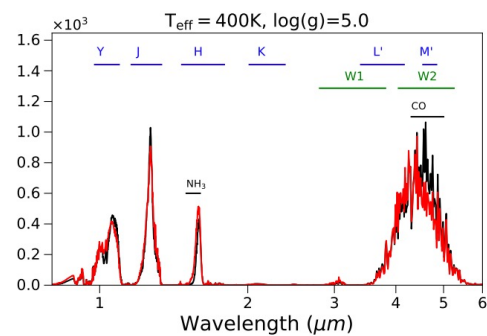
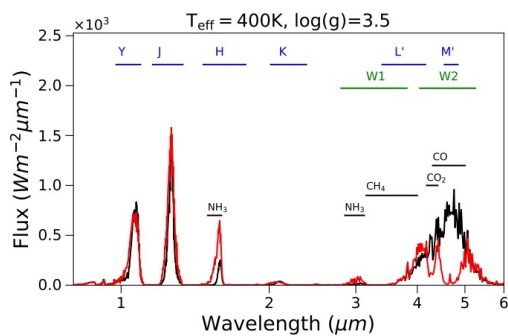
Radiative Transfer updates



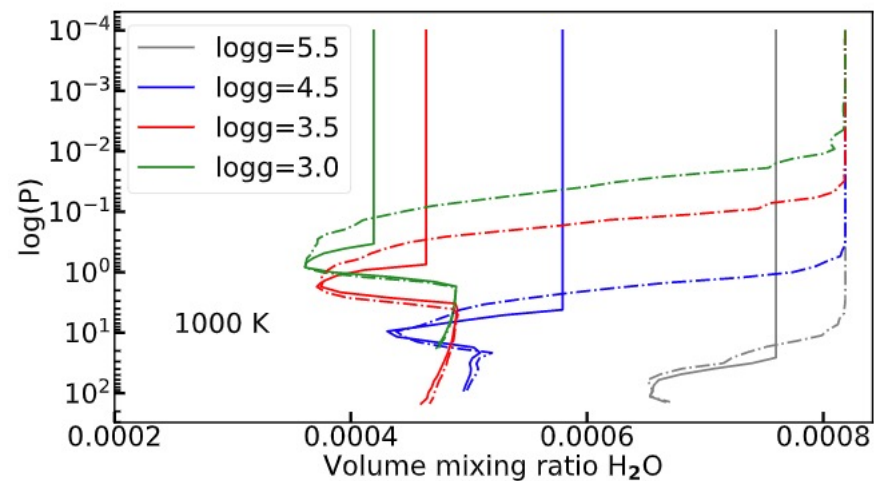
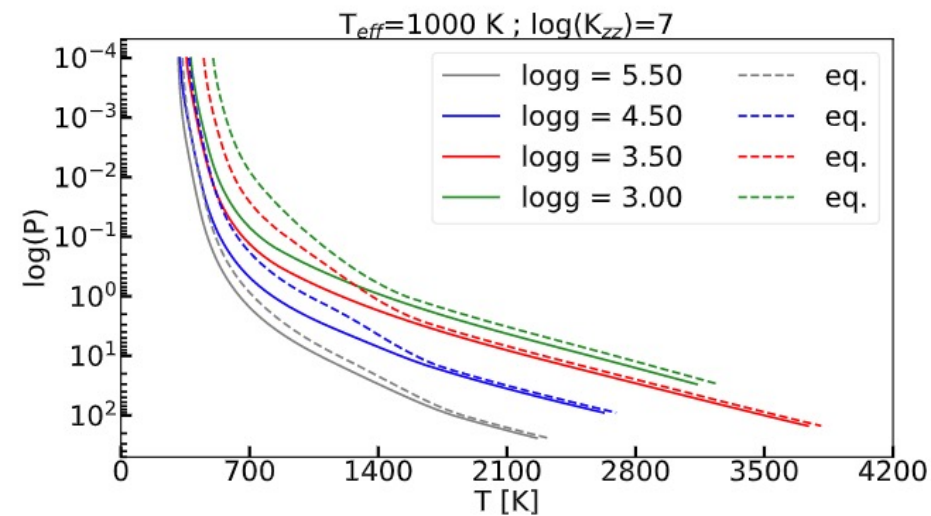
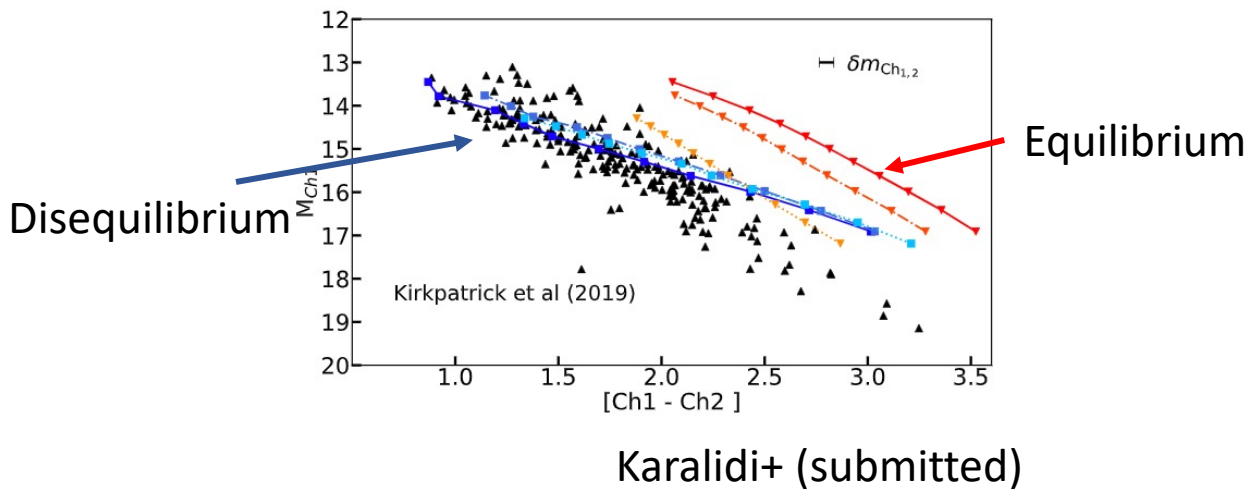
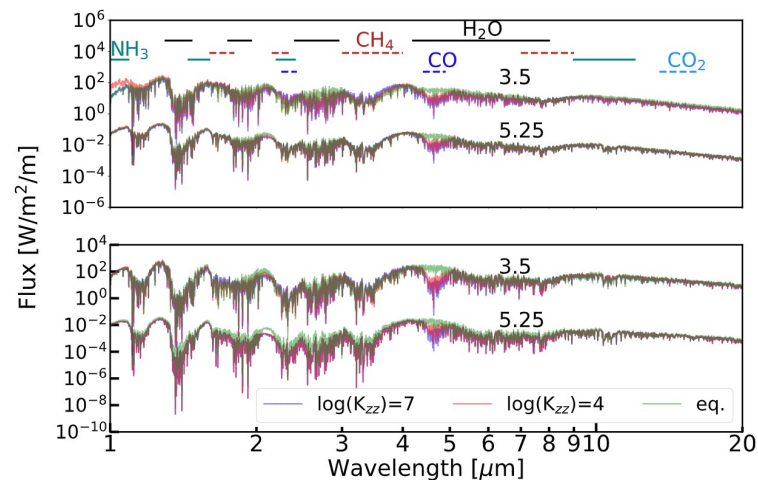
Sonora Cholla models- coming soon to Zenodo;
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Radiative Transfer updates

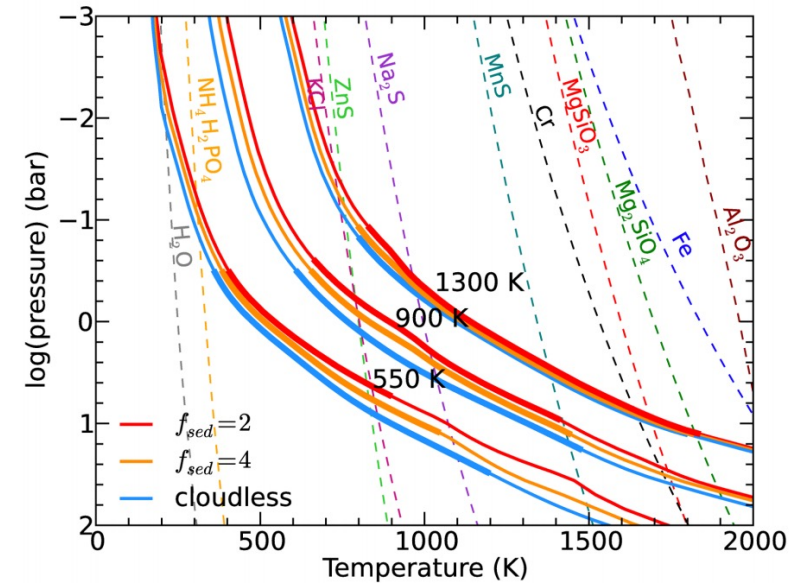


Radiative Transfer updates

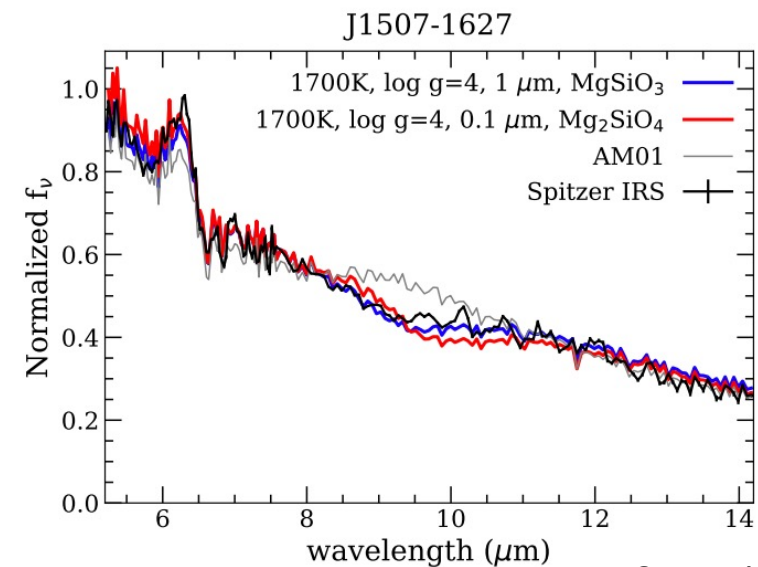


Radiative Transfer updates

- Clouds crucial for atmospheres
- Mismatch spectra
- Need more complex clouds (variable f_{sed} , variable profile with altitude)



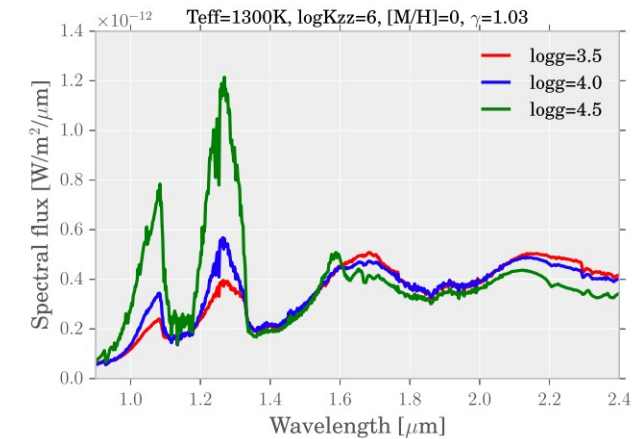
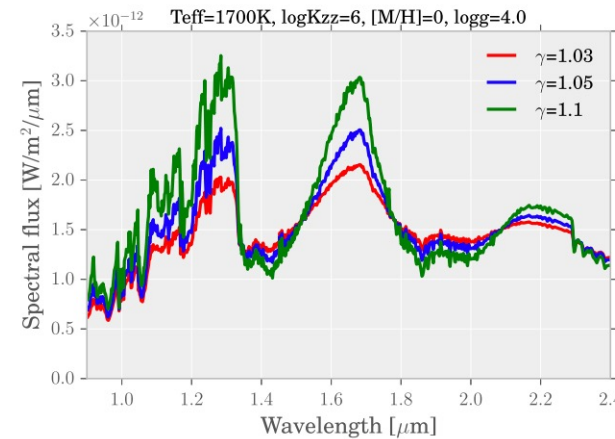
Marley+2013



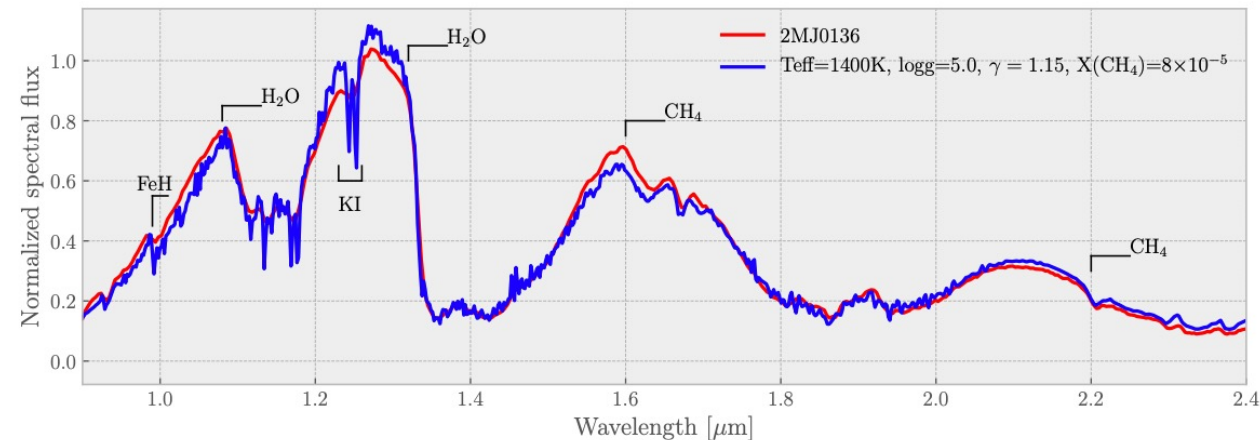
Luna & Morley 2021

Radiative Transfer updates

- Complex chemistry due to convection can reproduce variability
- No need for clouds in L/T?



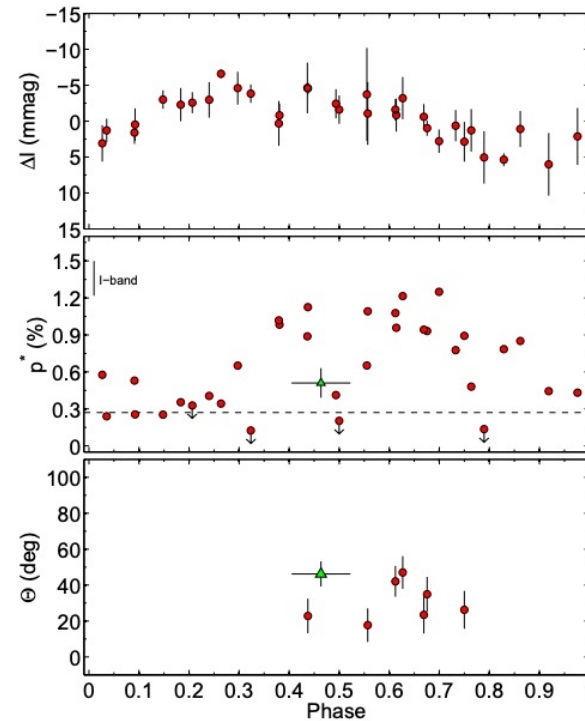
Tremblin+2017



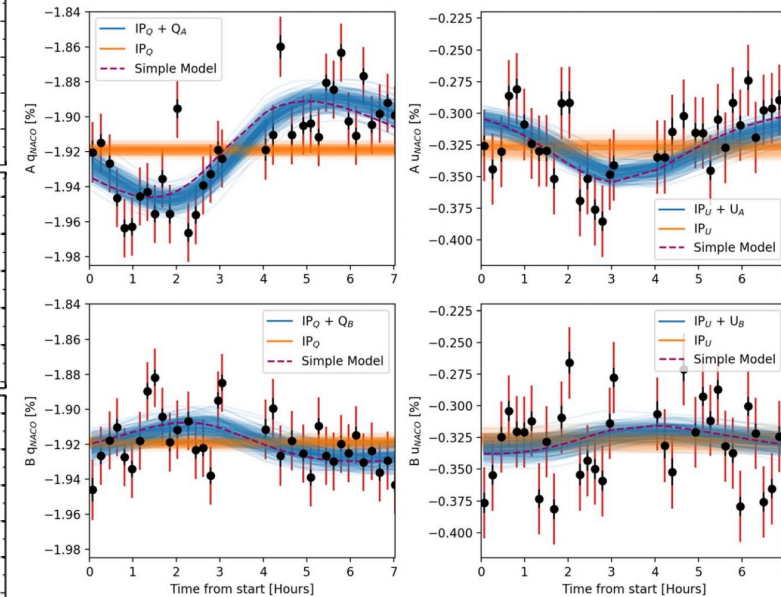
Tremblin+2020

Polarimetry

- Already accessible from ground
- Sensitive to atmosphere (micro)physical properties
- Can break degeneracies (maps, clouds vs chemical changes)



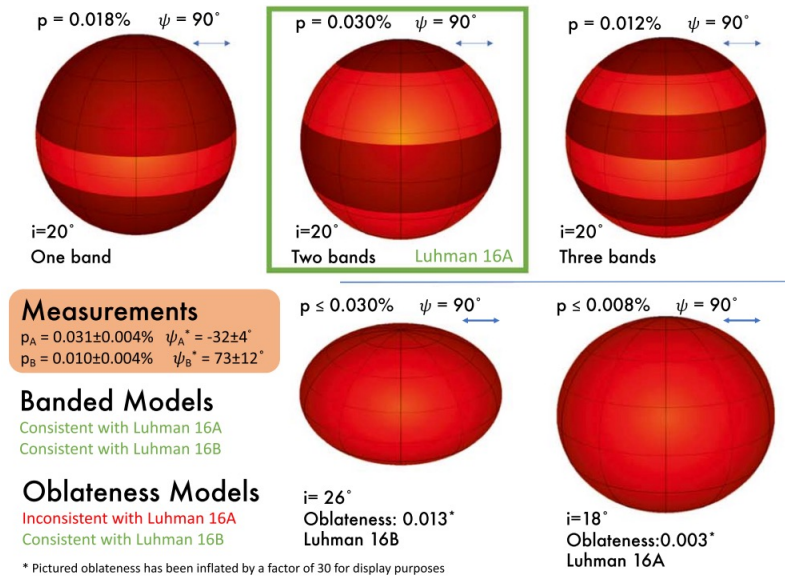
Miles-Paez+2015



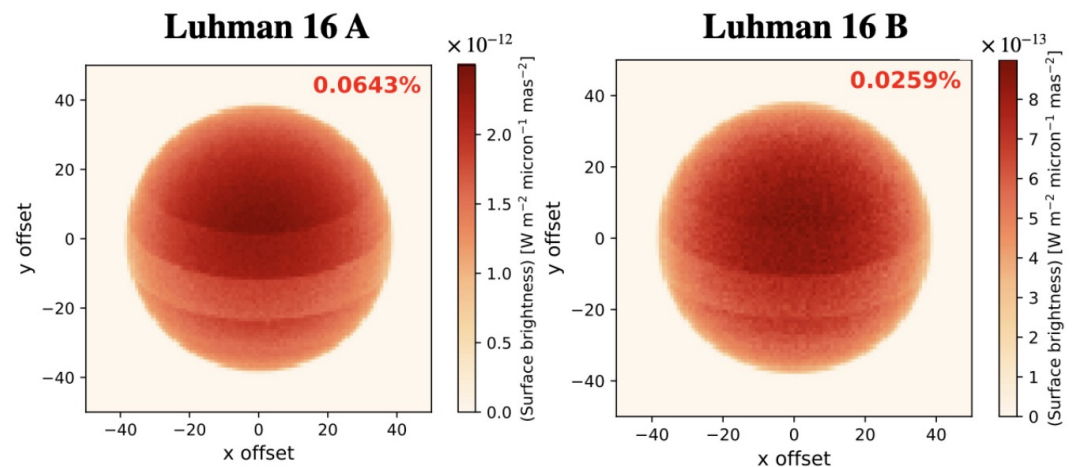
Millar-Blanchaer+2020

Polarimetry

- Comparison of observations against RT models help detect bands
- Models sensitive to atmosphere maps; need to update our modeling techniques



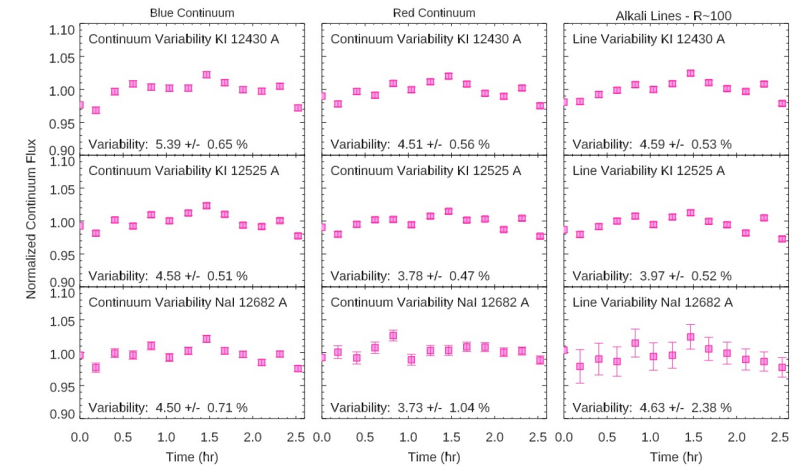
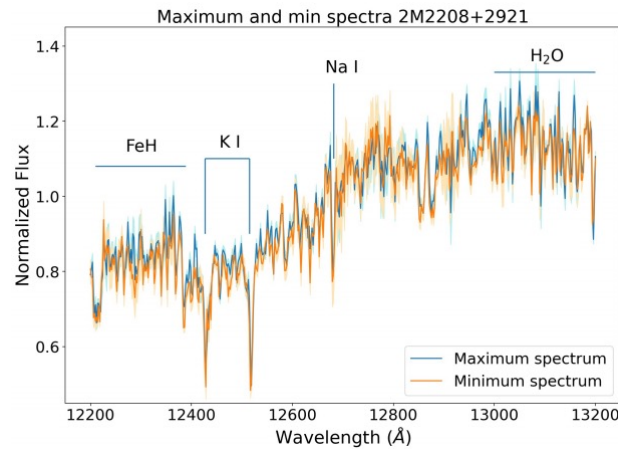
Millar-Blanchaer+2020



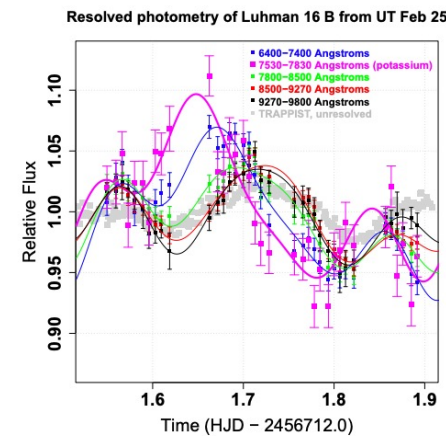
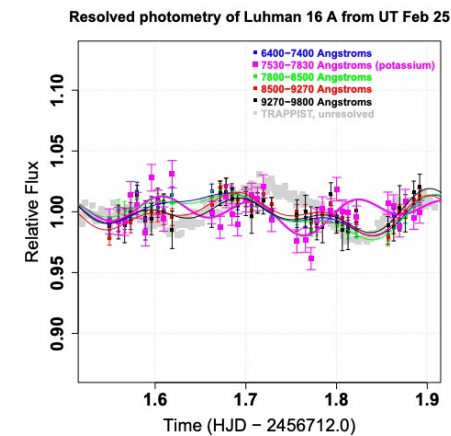
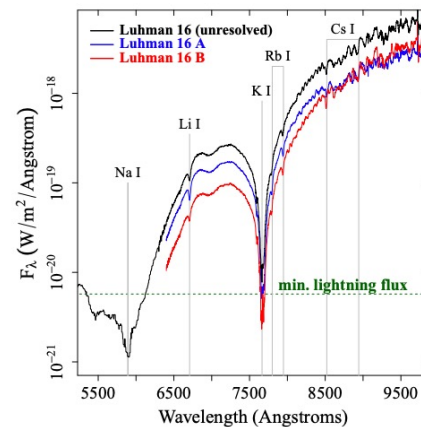
Mukherjee+2021 (submitted)

Why high resolution?

- Observations show that variability varies between continuum and alkali lines



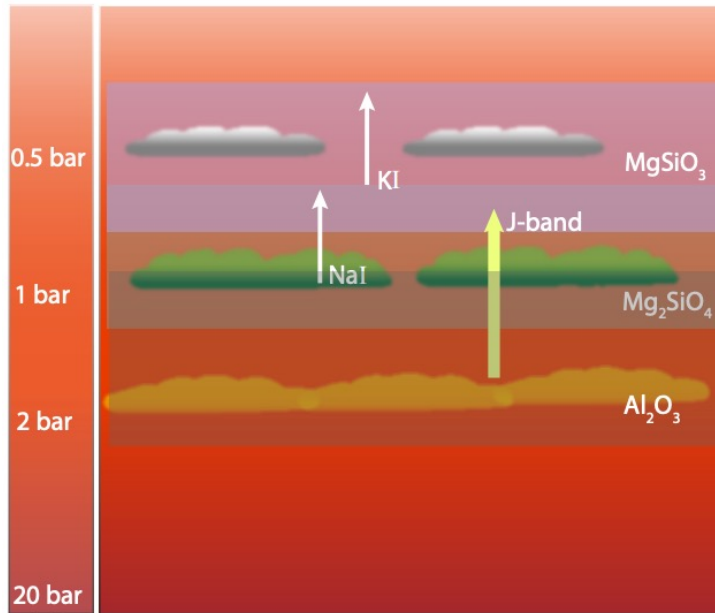
Manjavacas+ 2021



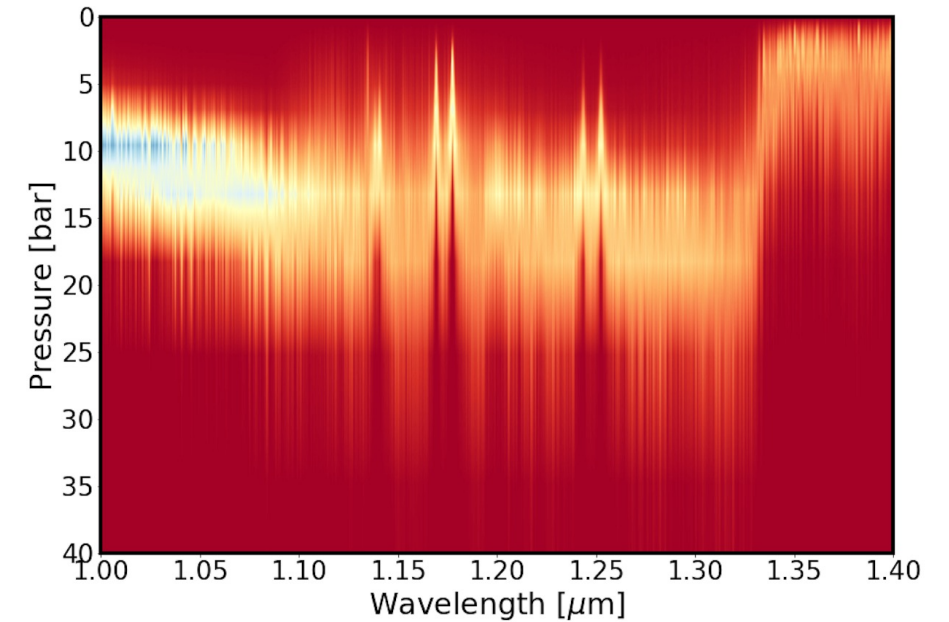
Heinze+ 2021

Why high resolution?

- Probing 3D structure of the atmosphere

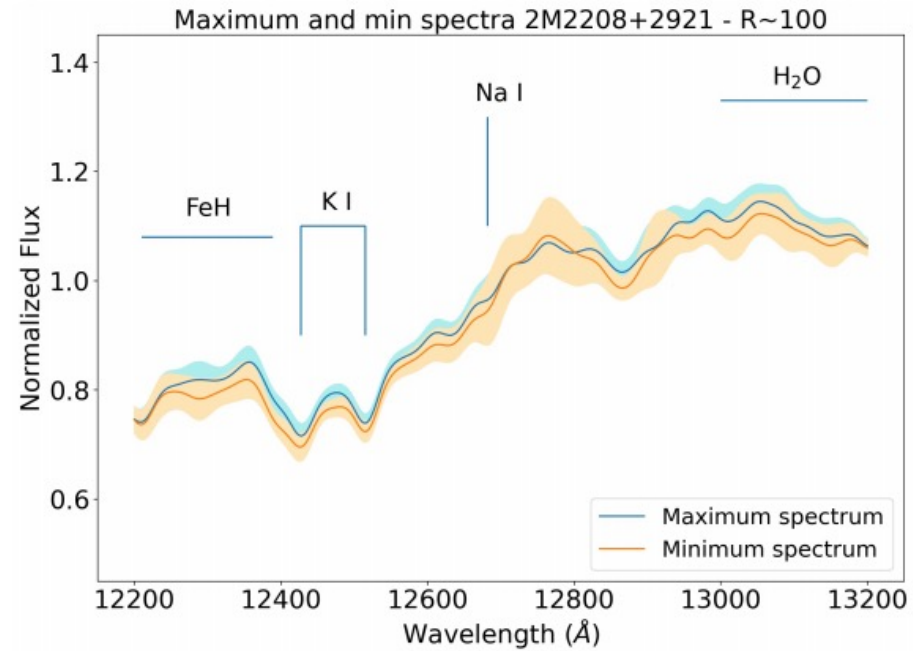
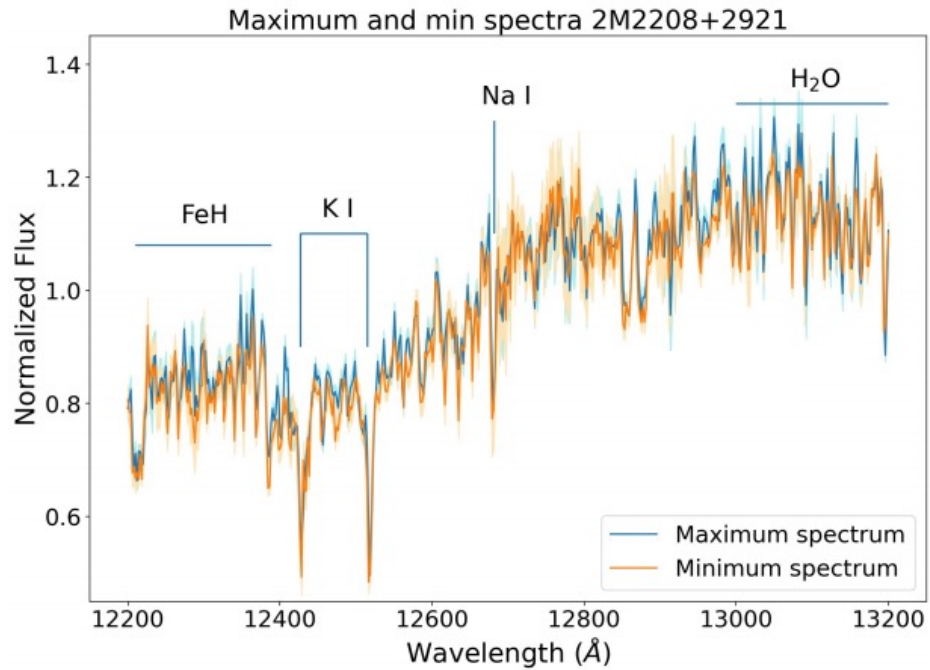


Manjavacas+ 2021



Why high resolution?

- Not visible in HST



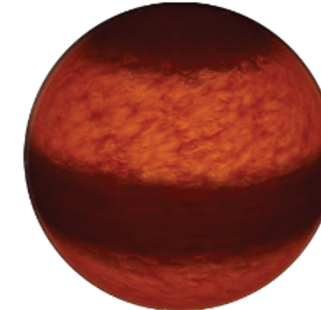
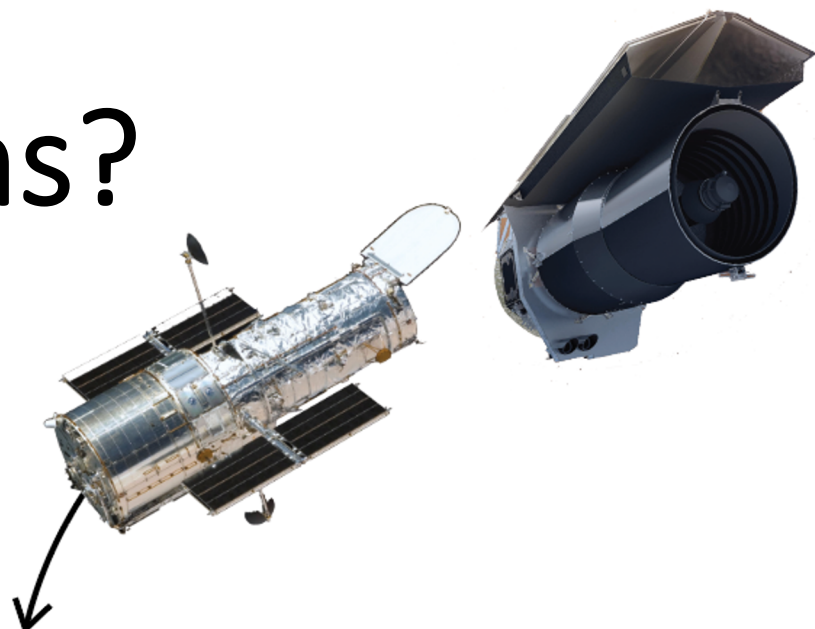
Future outlook

- JWST + VLTs+ ELTs will give us more, better data; expect to be surprised
 - It's not the data, it's your model!
- Updates in RT codes far from done

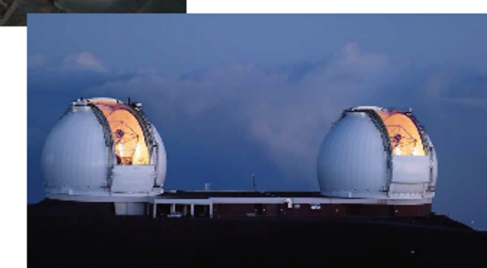


ESO - ELT

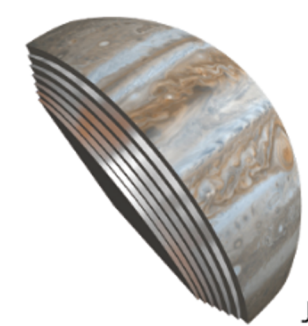
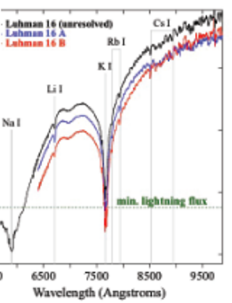
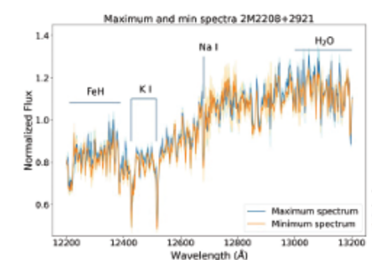
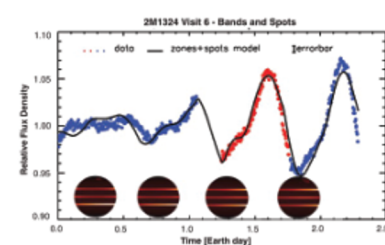
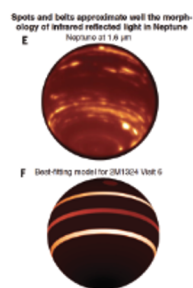
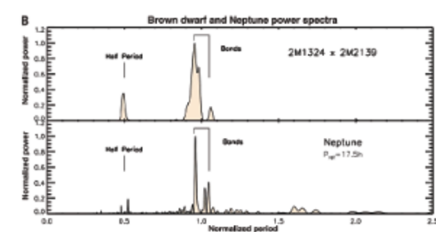
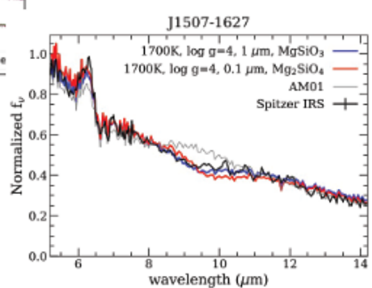
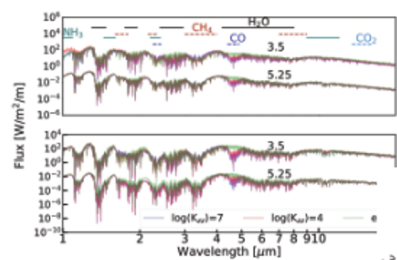
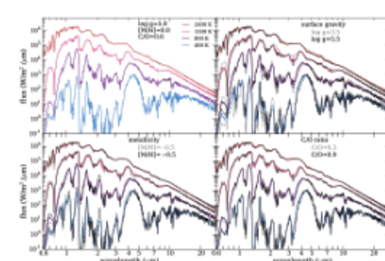
Questions?



ESO



Keck



Juno

