Brown Dwarf Variability: What's Varying and Why?

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Variability

L DWARF VARIABILITY: *I*-BAND OBSERVATIONS

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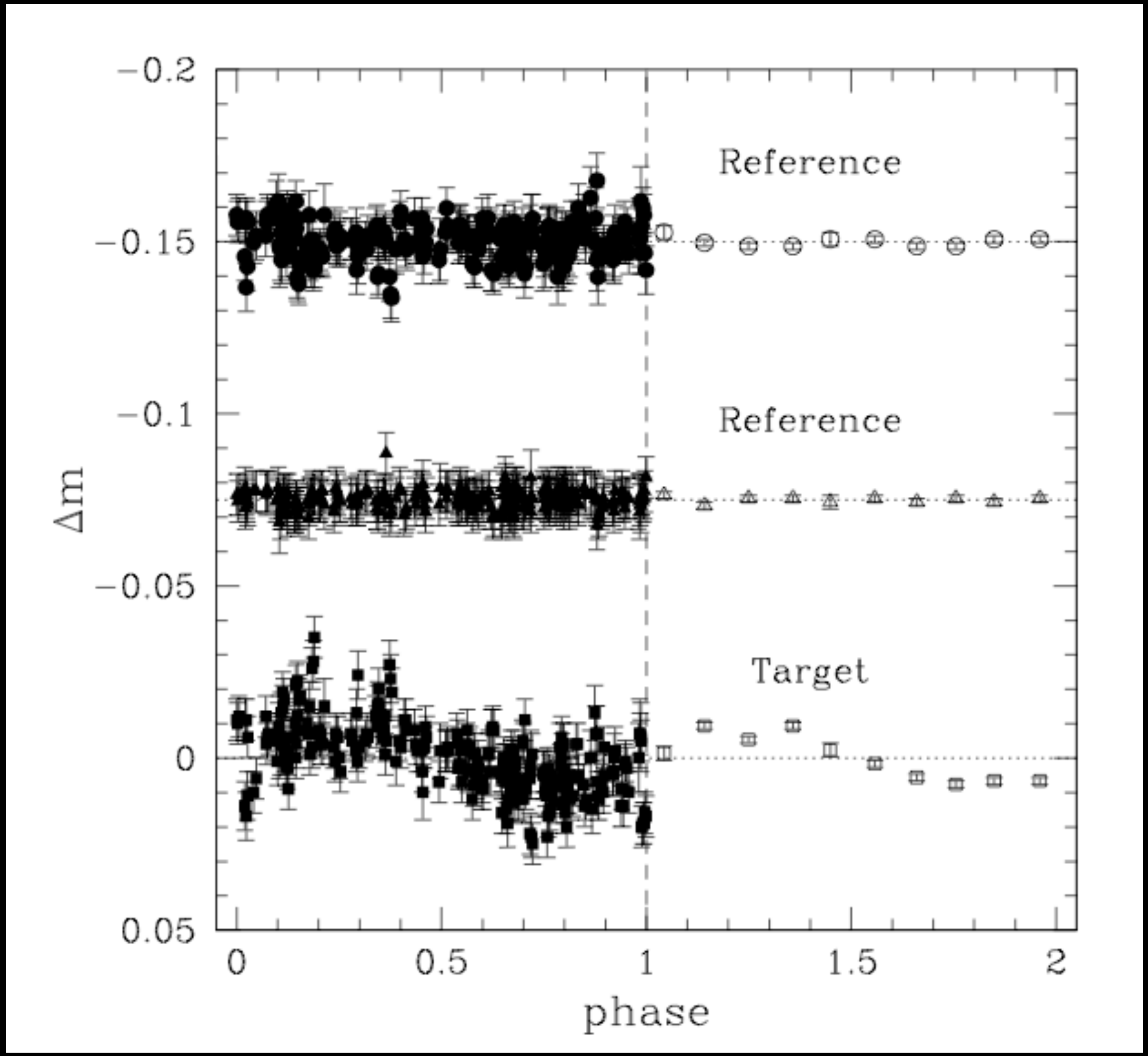
KATHARINA LODDERS

Gelino et al. (2002) following Tinney & Tolley (1999) and Bailer-Jones & Mundt (1999, 2001)
also Caballero & Rebolo (2002), Koen et al. (2003, 2004, 2005), Zapatero Osorio et al. (2003)

About half show some variability, typically a few percent

I-band



31 hr

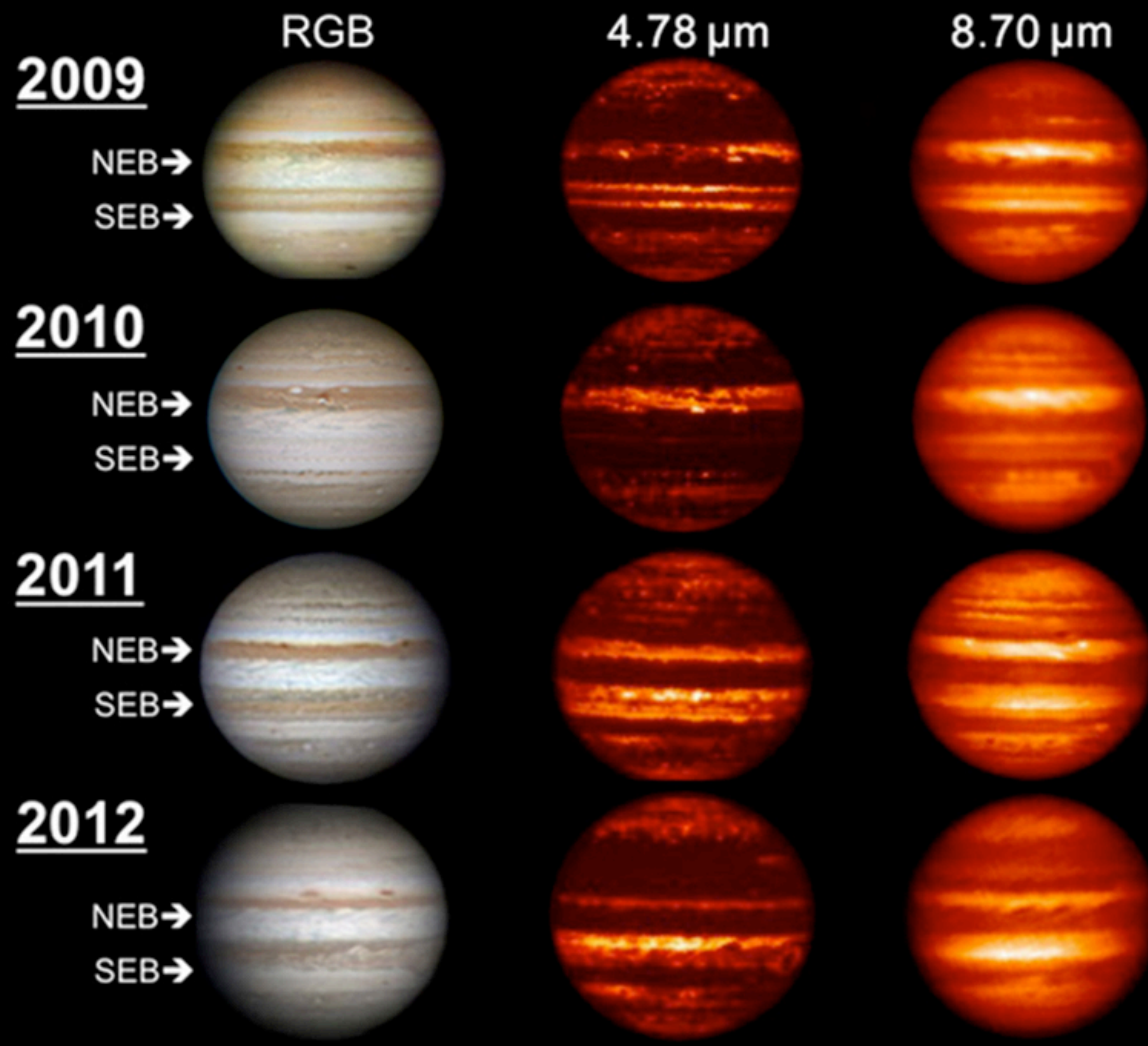
Gelino et al. (2002)

Spitzer Era

Plot Redacted

preliminary results from the Weather on Other Worlds Spitzer Exploration Science survey (Metchev et al. 2013, in preparation)

What is Varying?



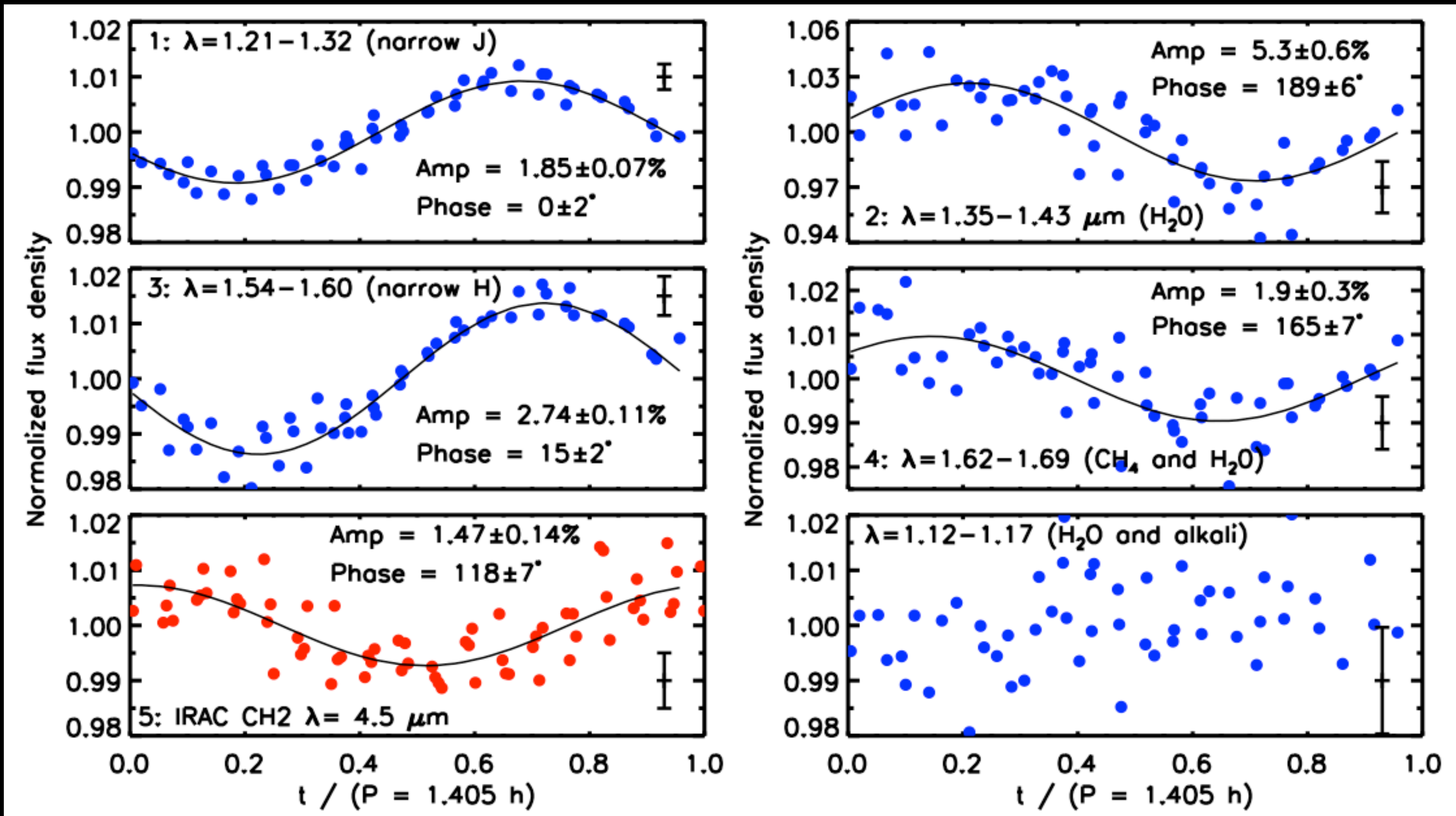
What is Varying?

Three Objects:

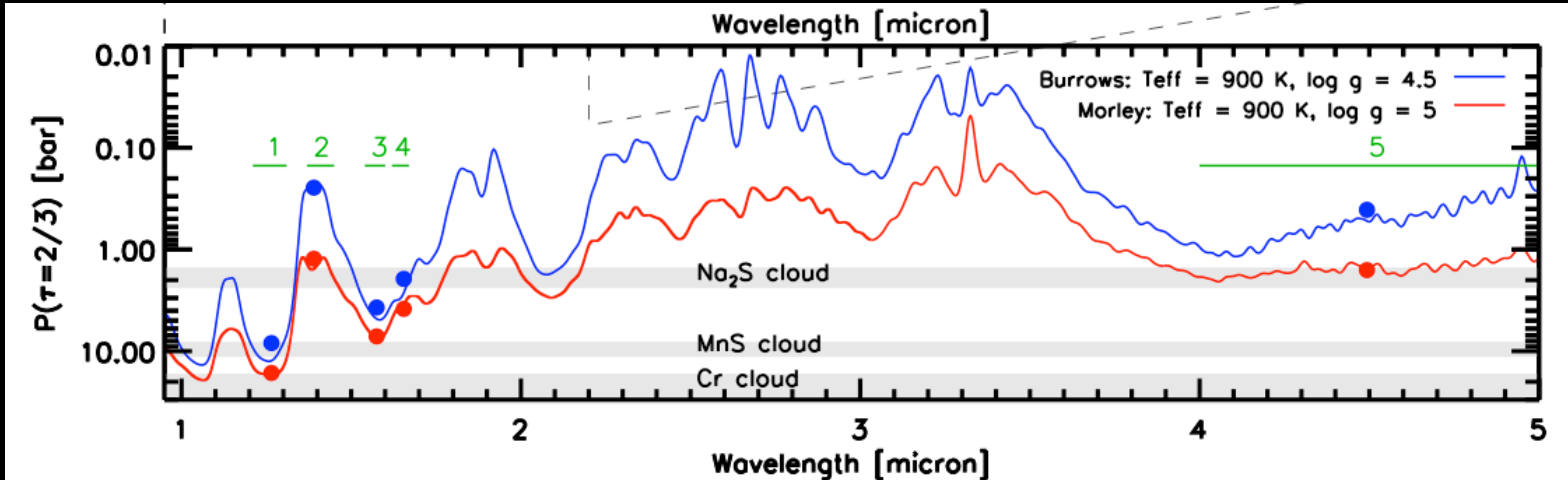
2MASS 2228 T6.5 (Buenzli et al.)
2MASS2139 T1.5 (Radigan et al.)
DENIS XXX L2 (Heinz et al.)

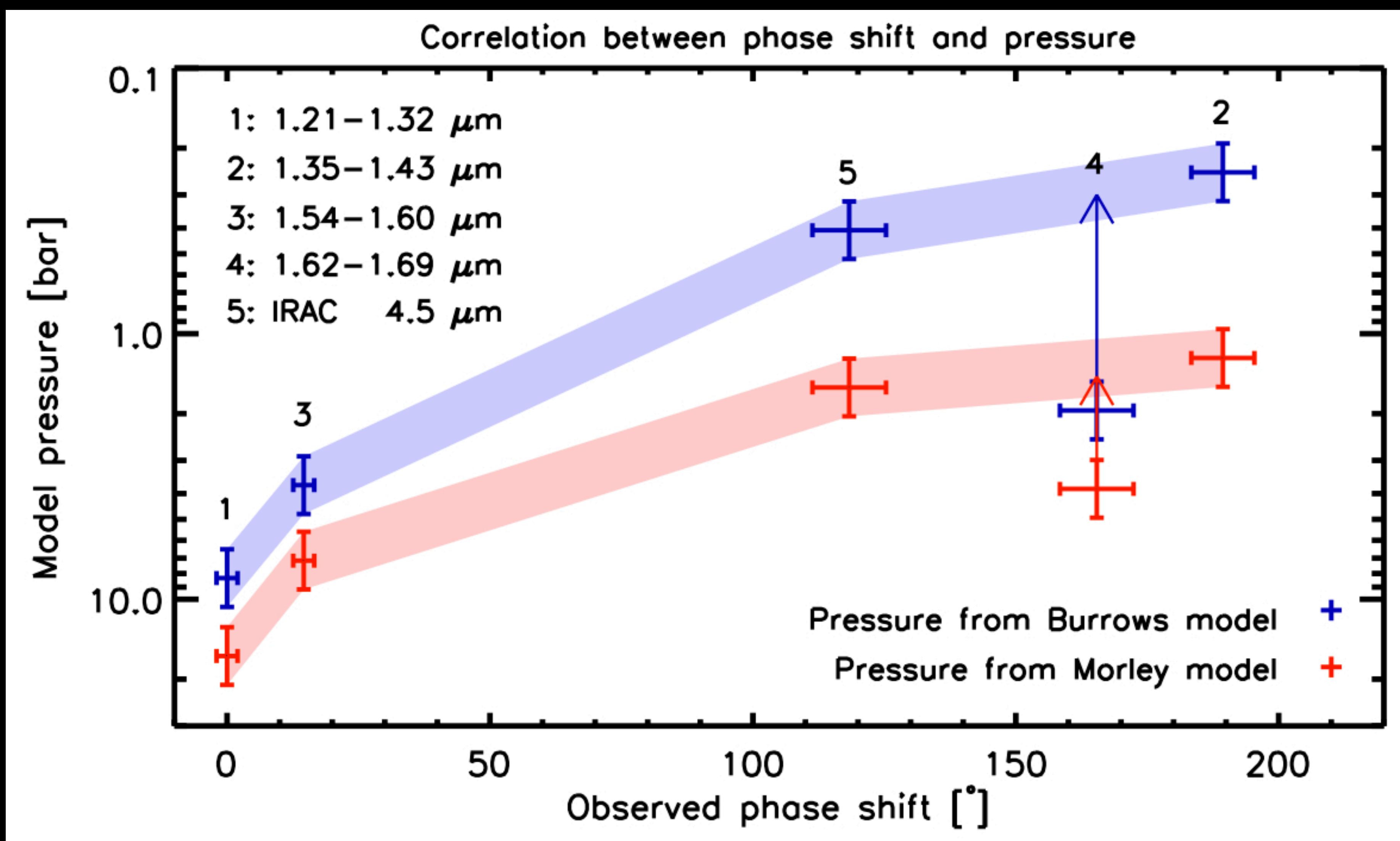
2MASS 2228 T6.5 (Buenzli et al.)
Thermal Variations (?)

HST Near IR + IRAC Observations of T6.5 Dwarf



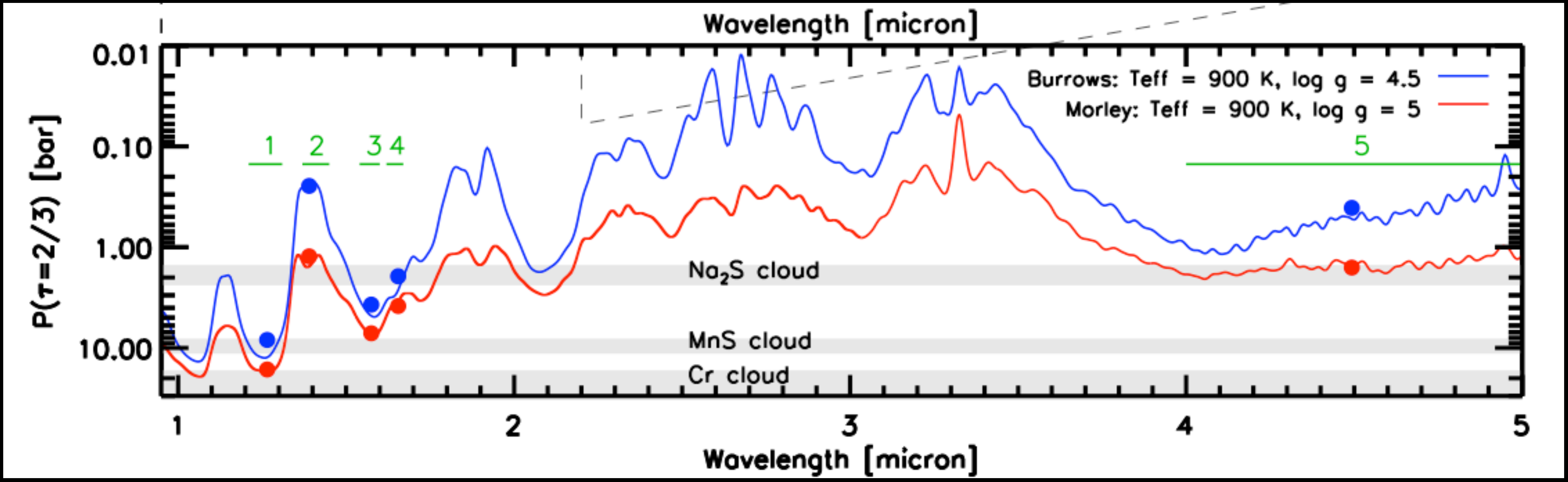
Buenzli et al. (in press)

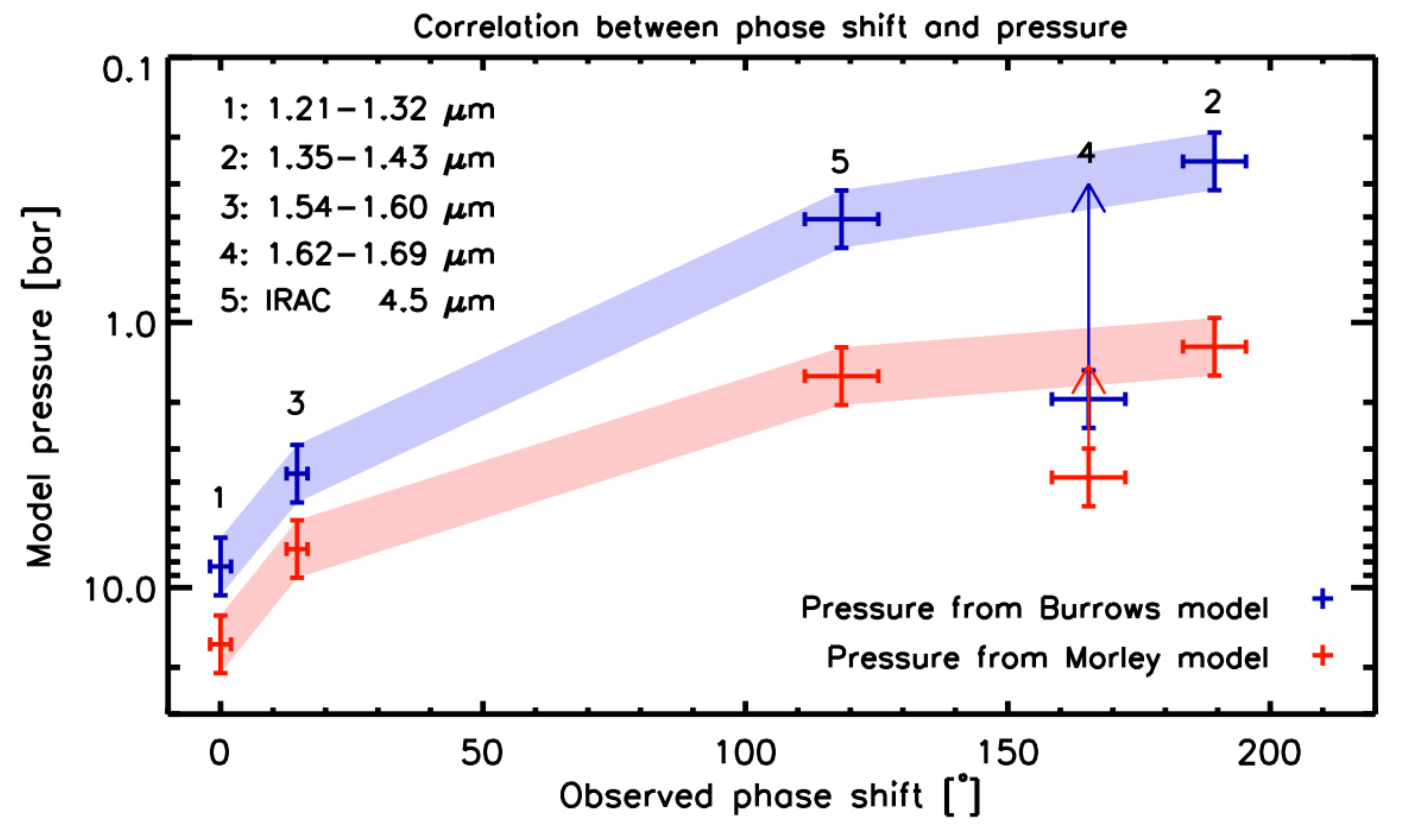




amplitude:
2>3>1>5

Buenzli et al. (in press)

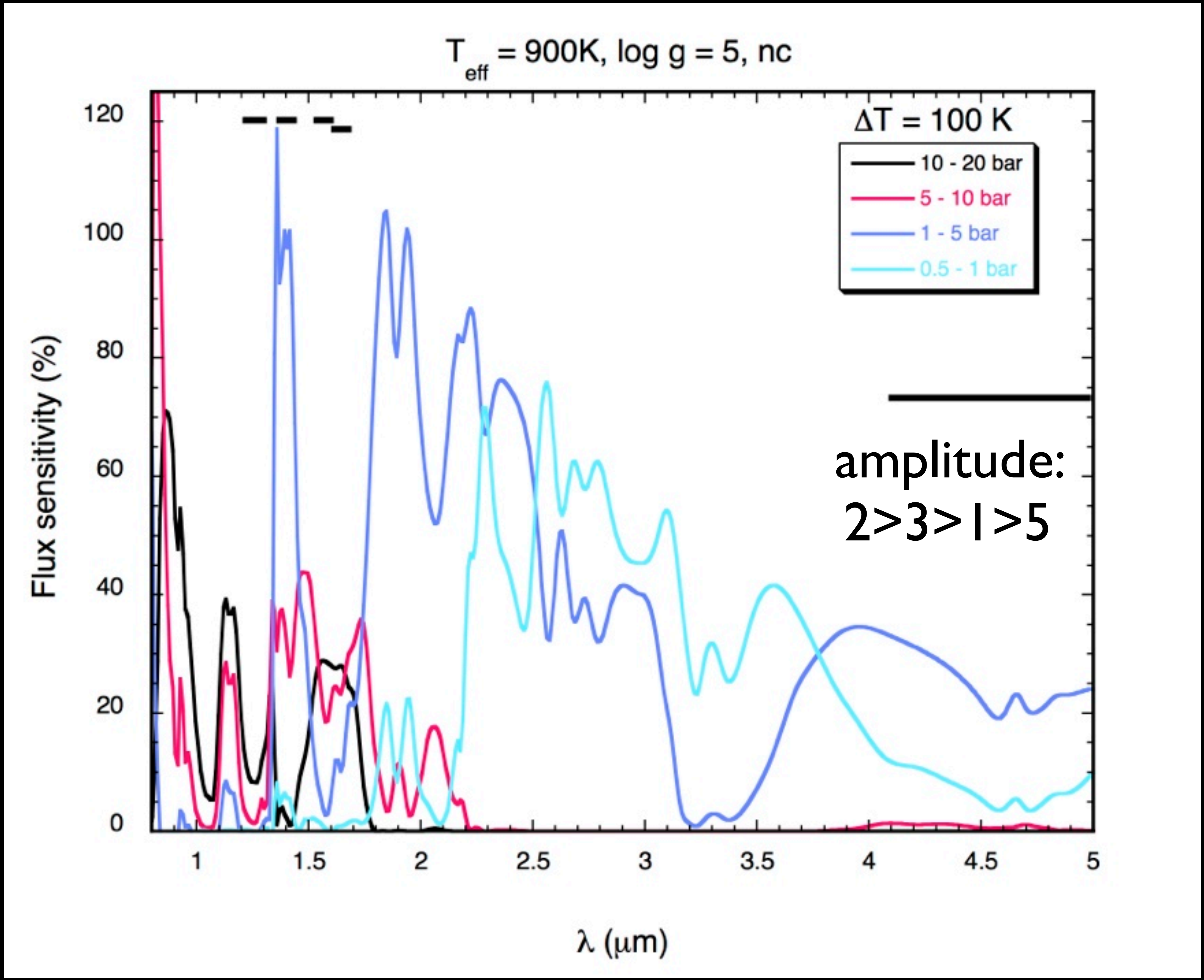




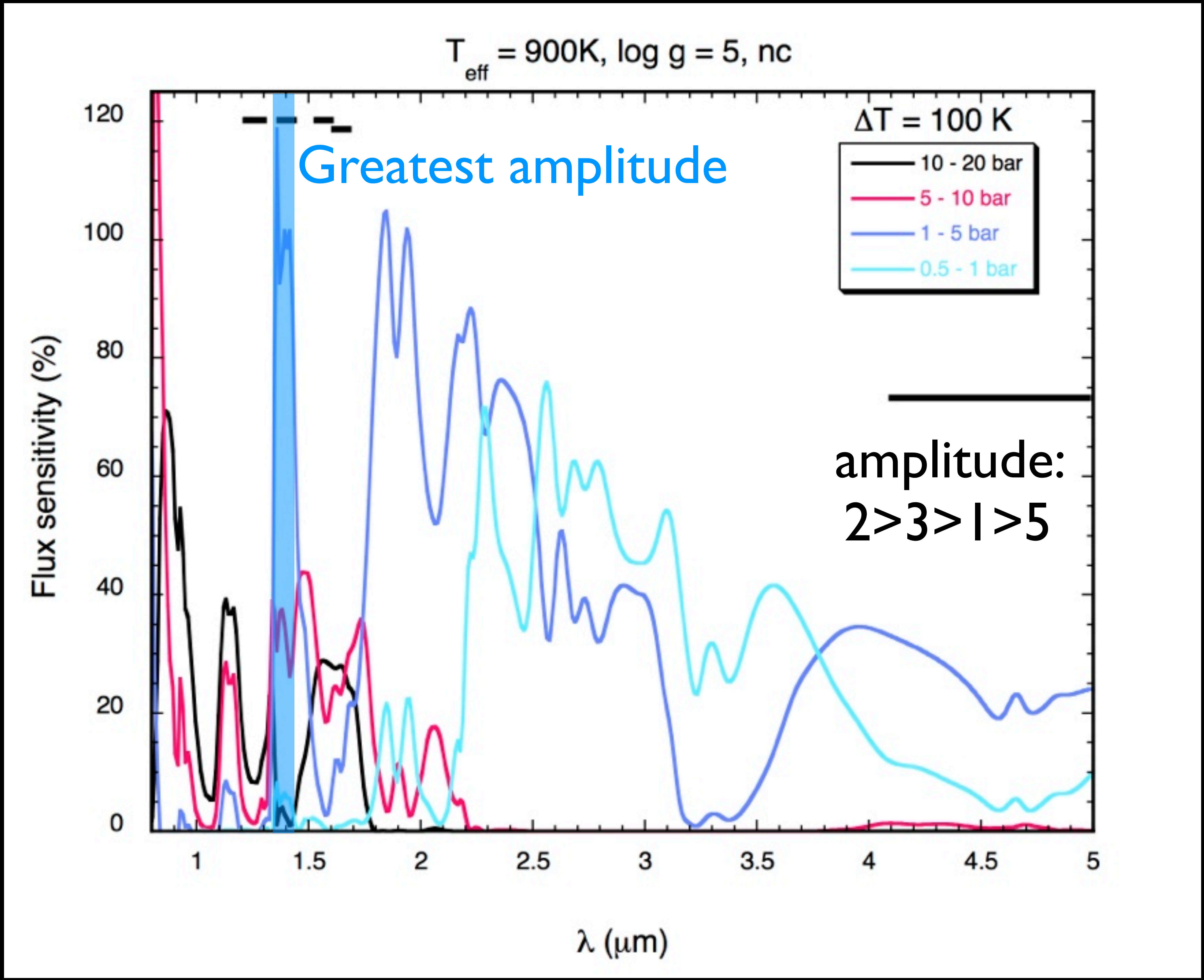
amplitude:
2>3>1>5

Phase shift and amplitude hard to explain only with clouds

Buenzli et al. (in press)



Implies *T* perturbation near 1 to 5 bar



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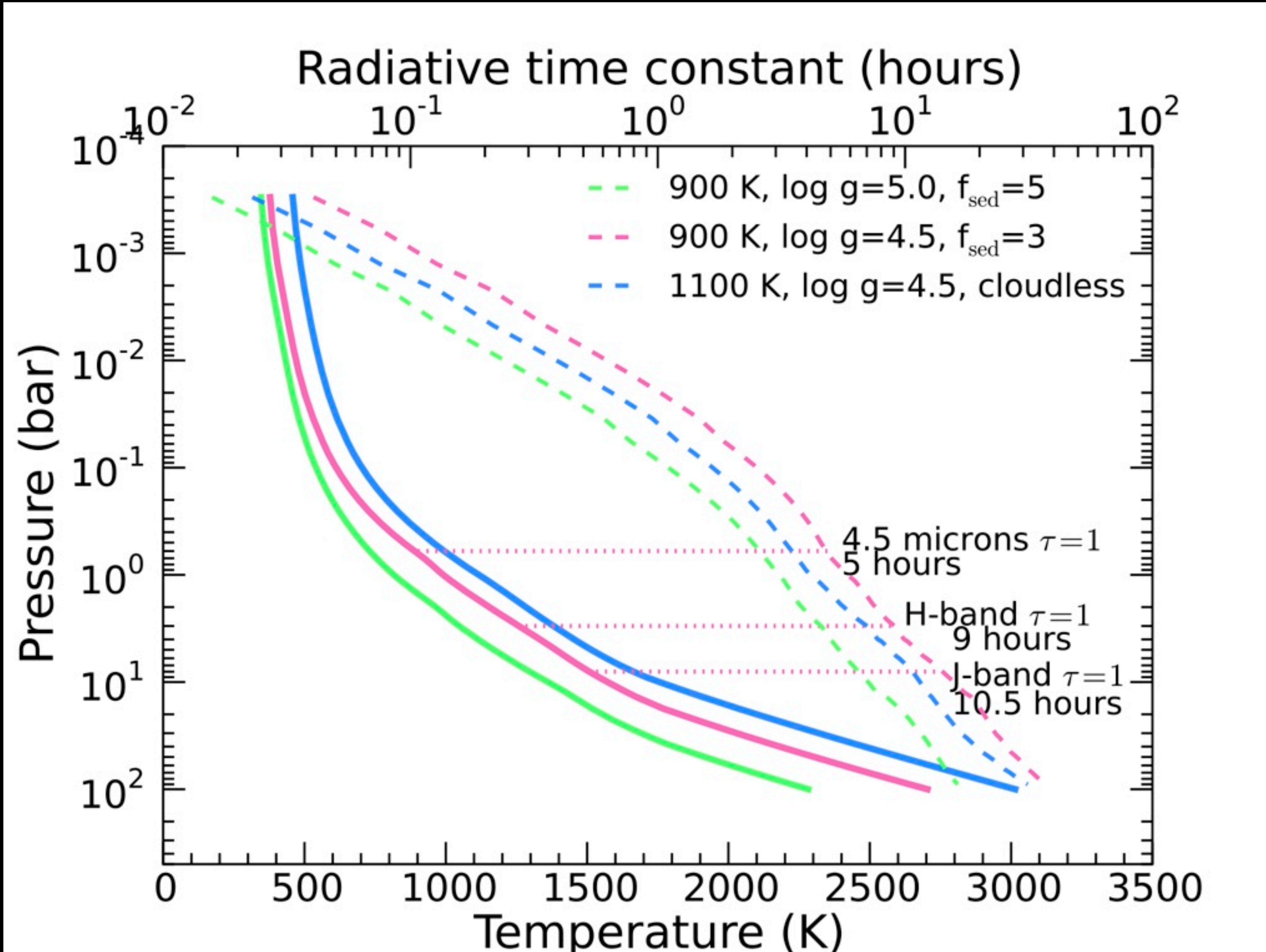
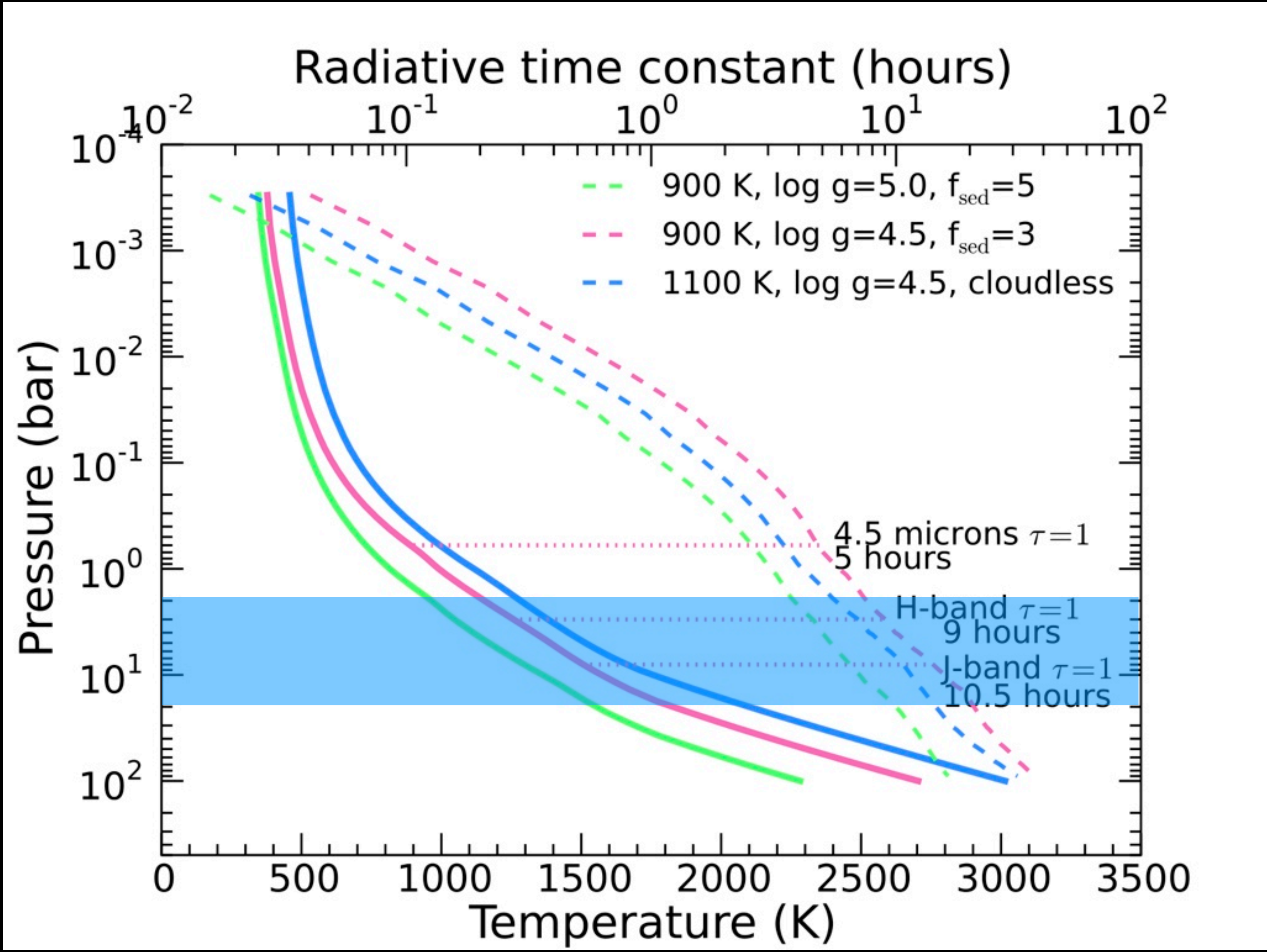


Radiative time constant (hours)
10^-2
10^-1
10^0
10^1
10^2
10^-4
10^-3
10^-2
10^-1
10^0
10^1
10^2
Pressure (bar)
900 K, log g=5.0, f_sed=5
900 K, log g=4.5, f_sed=3
1100 K, log g=4.5, cloudless
4.5 microns τ=1
5 hours
H-band τ=1
9 hours
J-band τ=1
10.5 hours
0
500
1000
1500
2000
2500
3000
3500
Temperature (K)



Radiative time constant (hours)
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10^0
10^1
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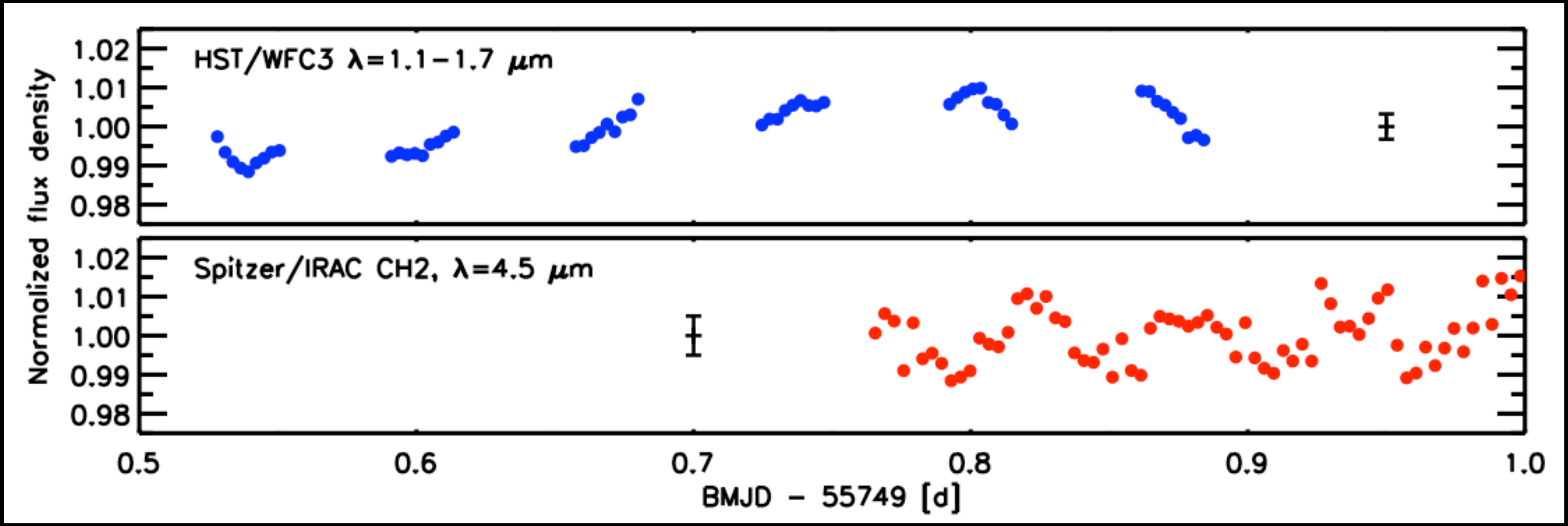
10^-1
10^0
10^1
10^2
0
500
1000
1500
2000
2500
3000
3500
Temperature (K)

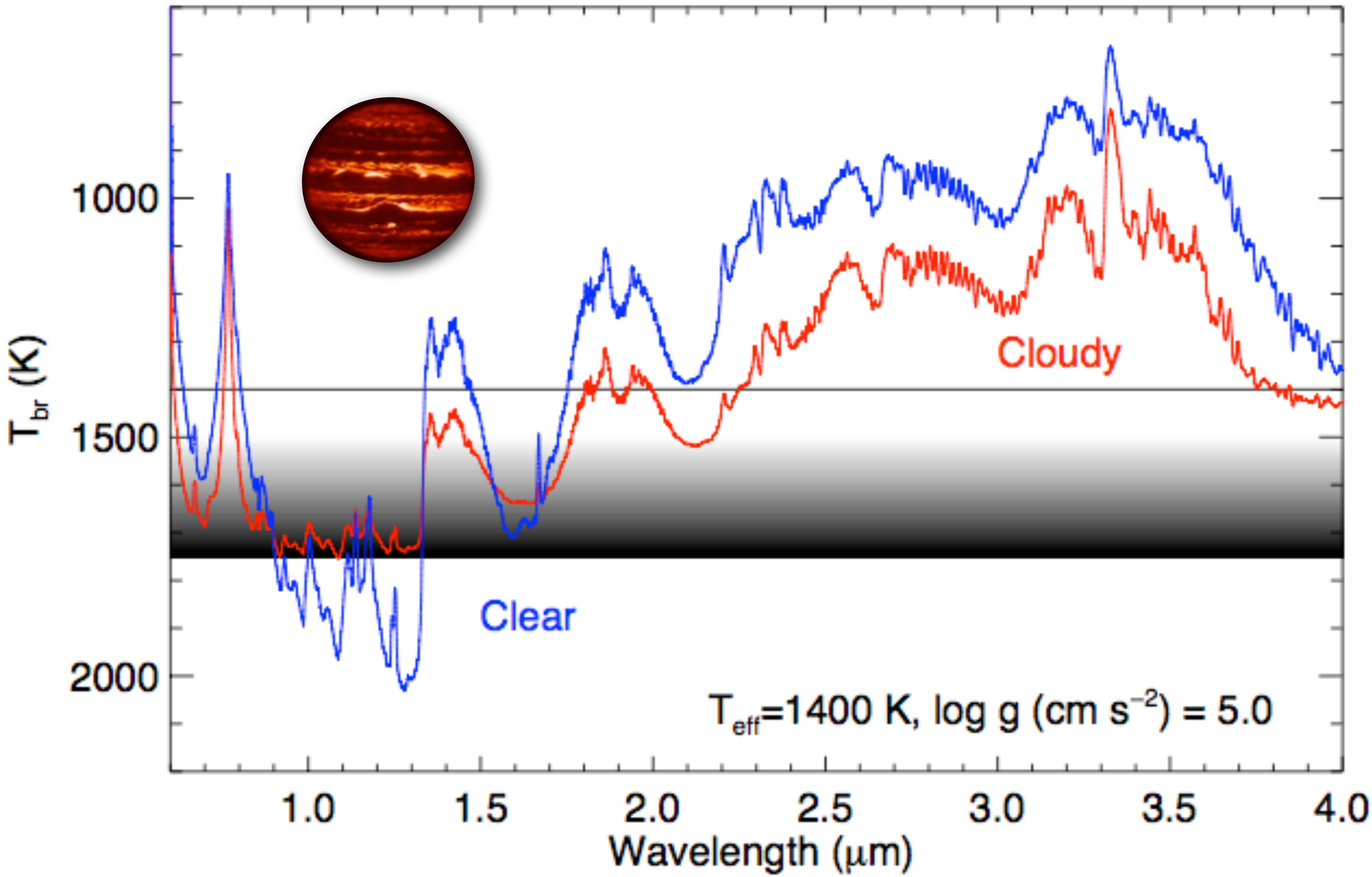
Light Curve Does Evolve



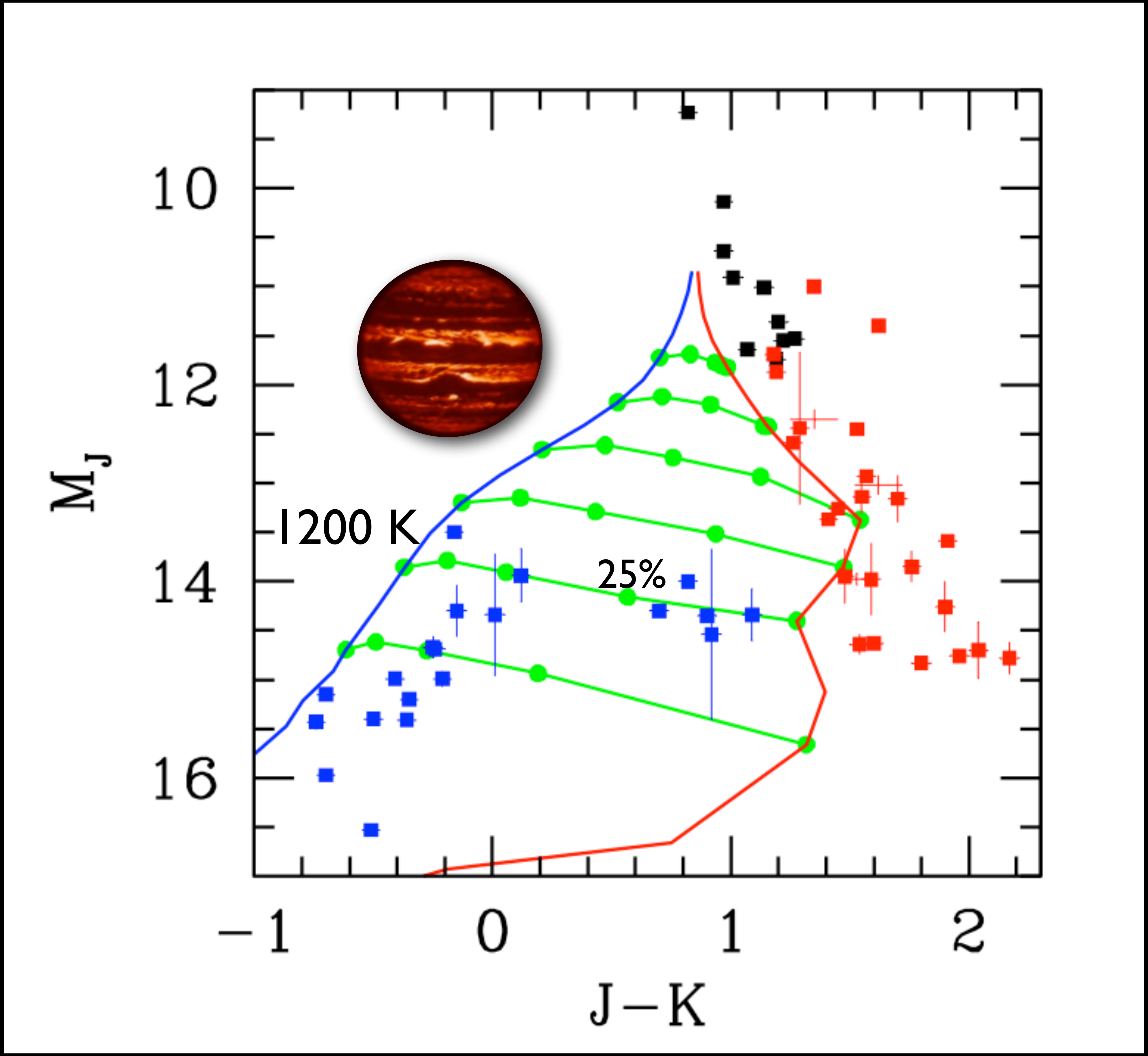
Buenzli et al. (in press)

What is driving *T* perturbation?
Origin of vertical shear?

2MASS2139 T1.5 (Radigan et al.)
Cloud Variations (?)



Cloudy
Clear
T_{eff}=1400 K, log g (cm s^{-2}) = 5.0
T_{br} (K)
1000
1500
2000
1.0
1.5
2.0
2.5
3.0
3.5
4.0
Wavelength (μm)



Marley et al. (2010)

5.2. *Nonuniform Clouds*

Variable brightness in the I band has been detected for some L dwarfs by Bailer-Jones & Mundt (2001), who attribute the variability to evolution of dust clouds. They find some evidence that variability may be more common in later type L dwarfs. Although we do not model horizontally variable clouds, these observations are consistent with aspects of the model presented here. As clouds form in progressively cooler objects, they become more optically thick and form deeper within the convective region of the atmosphere. Thus global scale tropospheric weather patterns, as seen on Jupiter and predicted for brown dwarfs (Schubert & Zhang 2000), can more easily produce photometric variability since the turbulent motions are greater, making local clearings more likely, and enhancing the potential contrast between clear and cloudy air. Indeed, the Great Red Spot of Jupiter produces a photometric signal in both reflected sunlight and emitted thermal radiation (Gelino & Marley 2000).

Horizontally varying silicate clouds, even if not of the appropriate scale to produce a varying photometric signal, may play an important role in the transition from the dusty L dwarfs to the relatively cloud-free T dwarfs. The change in $J-K$ color from the latest red L dwarfs ($J-K \sim 2$) to the blue T dwarfs ($J-K \sim 0$) is quite abrupt. Four L8 dwarfs with known or estimated absolute magnitudes are only 1 mag brighter in the J band (Reid et al. 2001) than Gl 229B. Reid et al. argue that this implies the L8 dwarfs are only about 250 K warmer than Gl 229B. Even with the silicate cloud deck forming at progressively deeper levels with falling $T_{\rm eff}$, it may be difficult to account for such rapid color variation. In fact, the rapid transition may be a signature of horizontally varying clouds. Once tropospheric convective patterns begin to produce substantial horizontal variability, the flux from the more cloud-free regions will begin to dominate the total emitted flux, even if large fractions of the object are still cloudy. For example, Jupiter's 5 μm flux is dominated by the relatively cloud-free "hot spots" (Westphal et al. 1974) that typically cover about 1% of the surface area of the planet (Orton et al. 1996). Thus the apparent rapid change from cloudy L dwarfs to clear T dwarfs may be because of a gradual change in cloud coverage in the visible atmosphere, with the larger flux from the clear regions quickly dominating.

PRECIPITATING CONDENSATION CLOUDS IN SUBSTELLAR ATMOSPHERES

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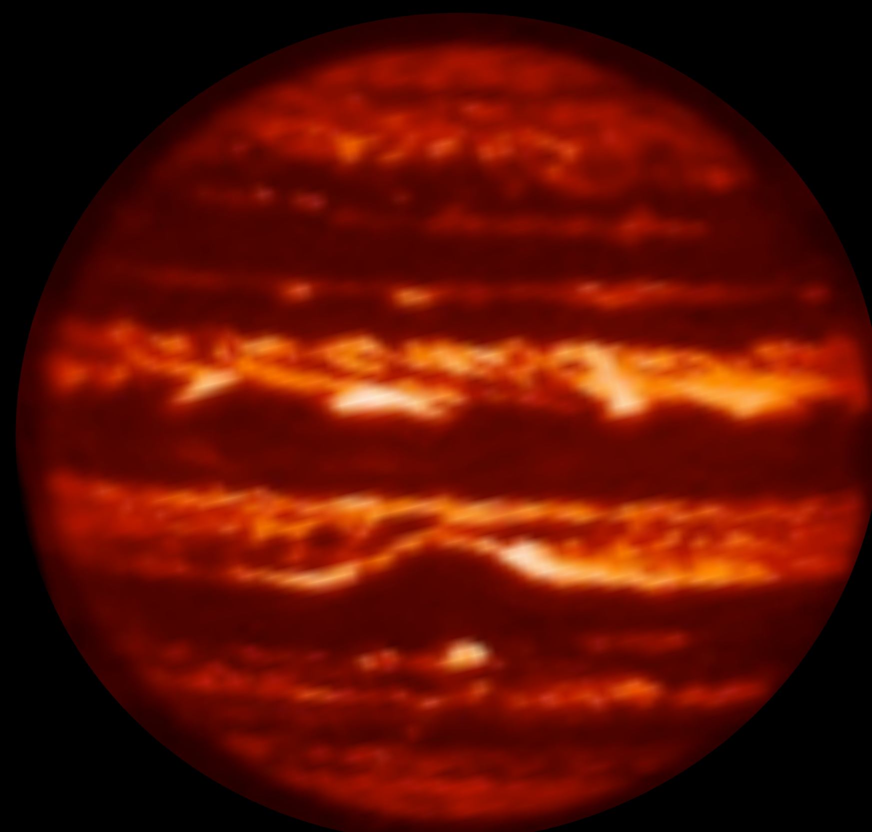

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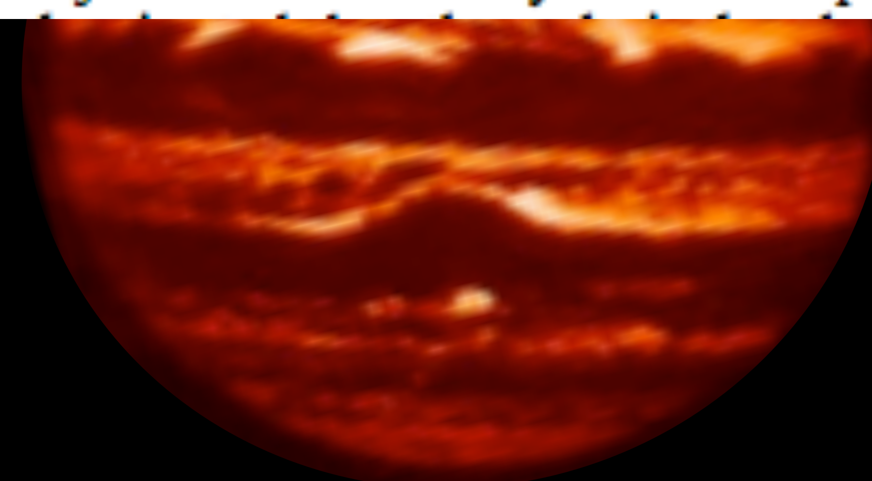
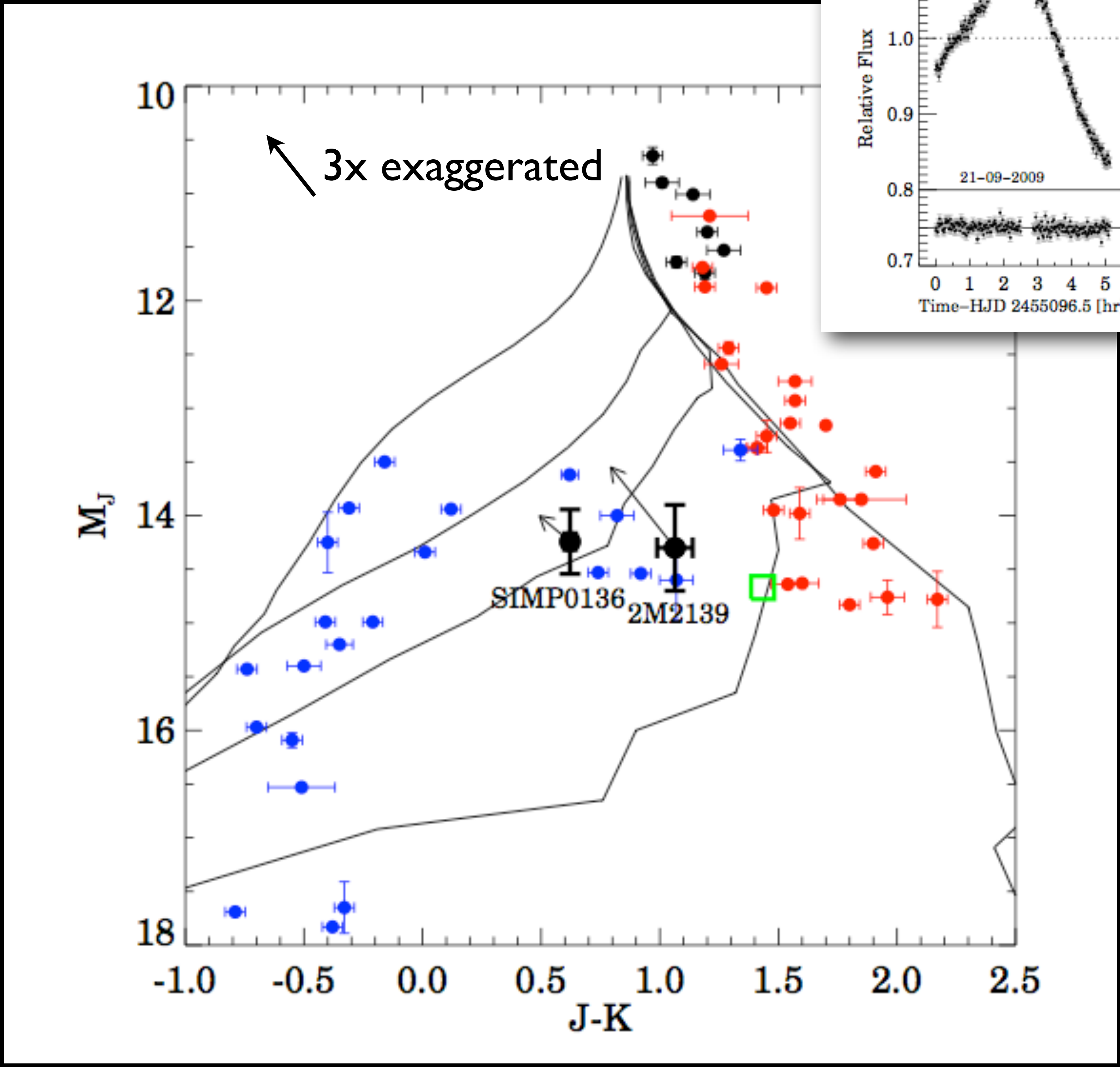
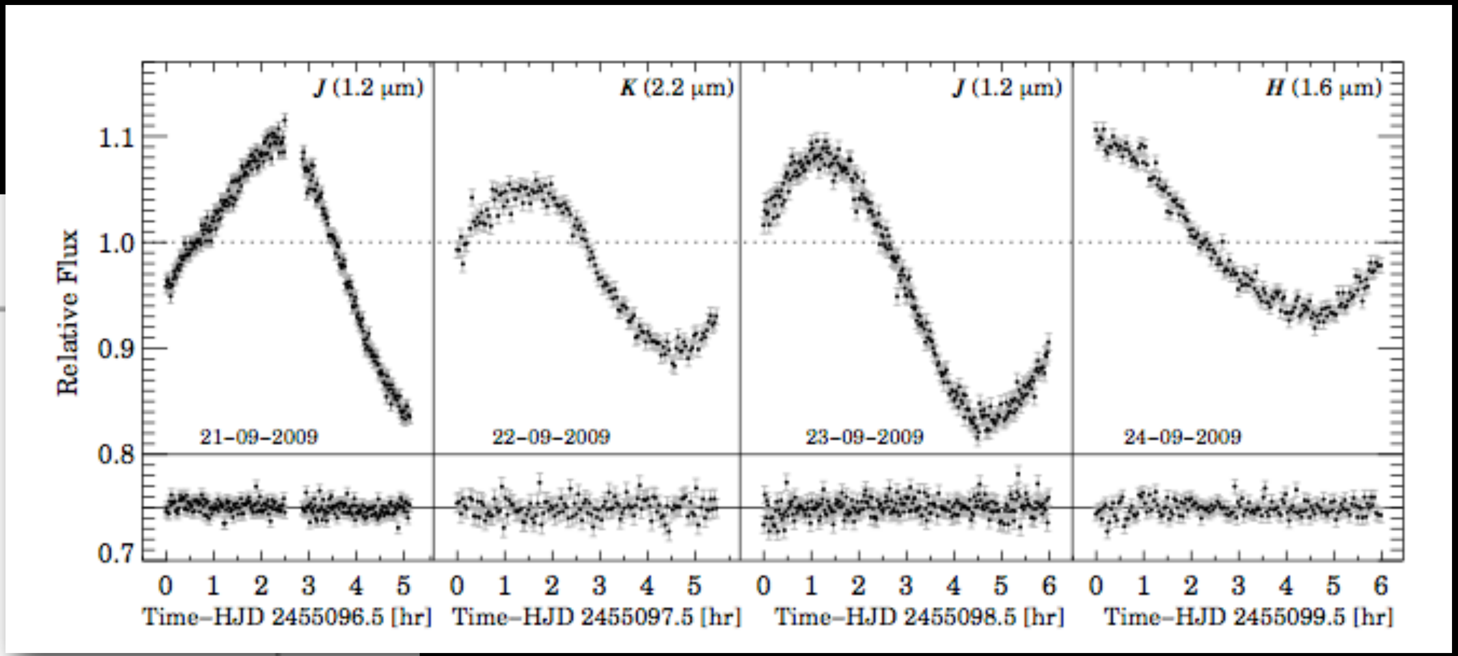


2MASS2139 T1.5





About 25% cloud holes

Radigan et al. (2011)

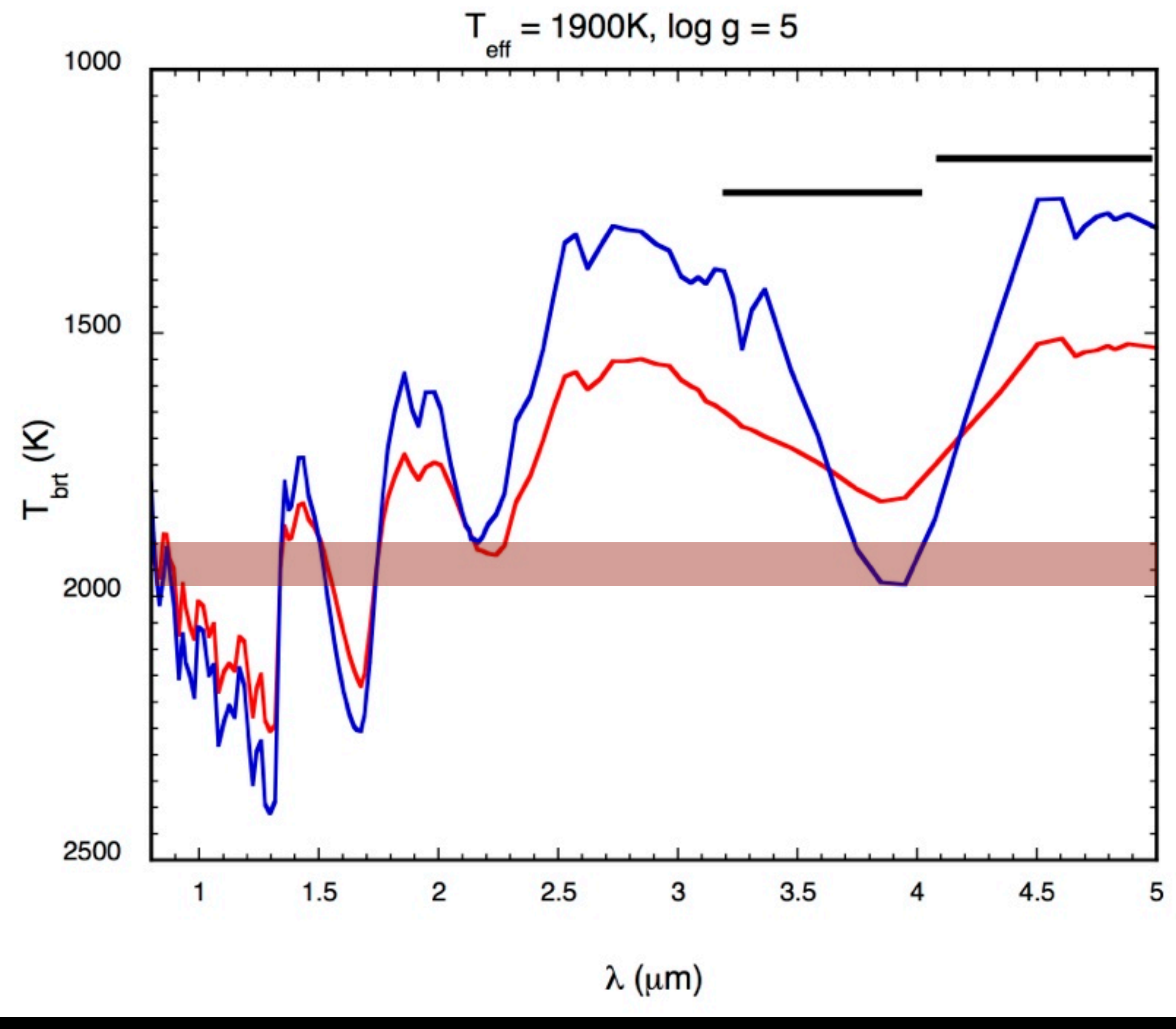
DENIS XXX L2 (Heinz et al.)
Cloud + Thermal Variations (?)

DENIS XXX L2 (Heinz et al.)

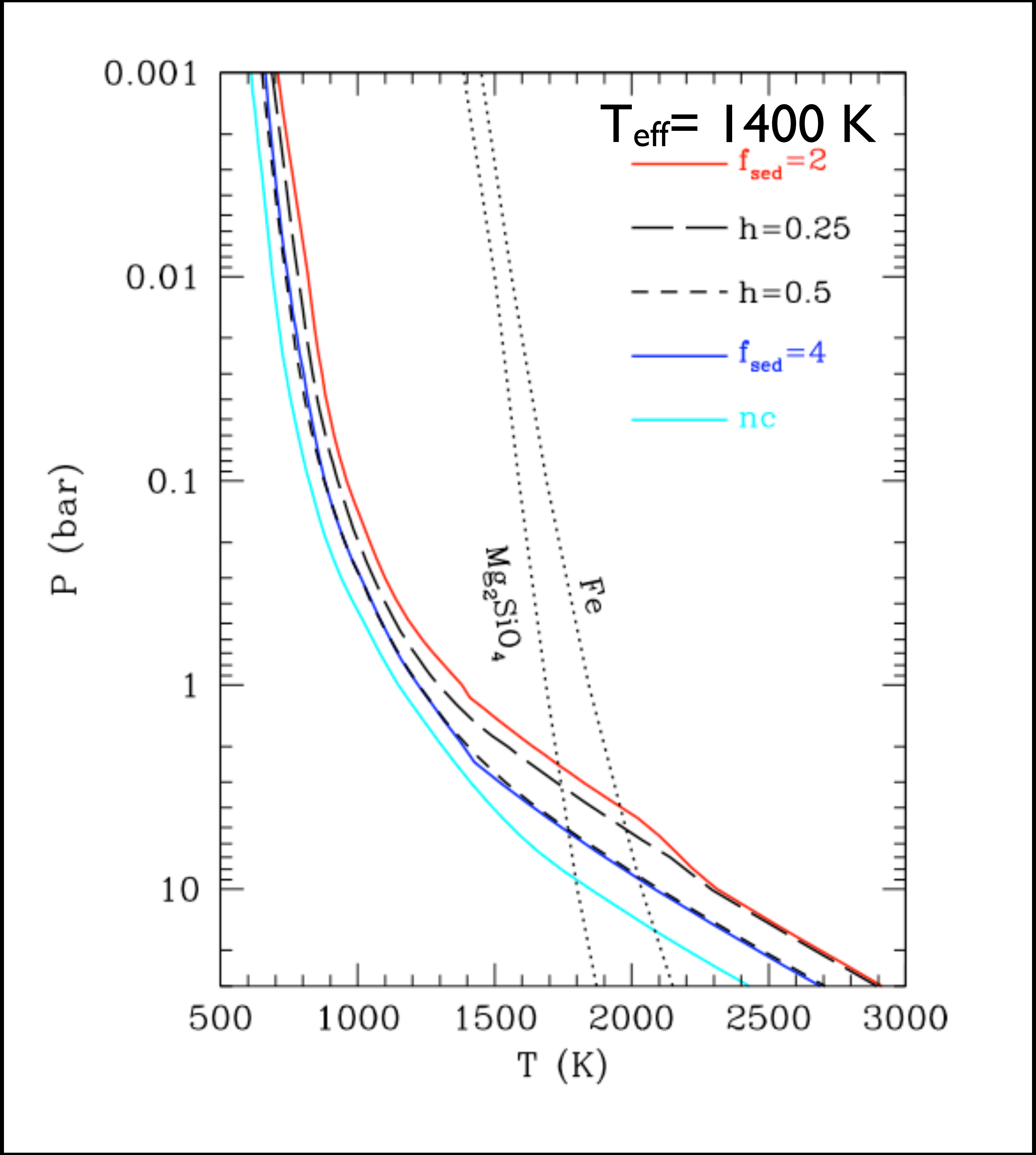
J band 2x larger

Plot Redacted

Heinz et al. (in prep)



T$_{eff}$ = 1900K, log g = 5
T$_{brt}$ (K)
1000
1500
2000
2500
λ (μm)
1
1.5
2
2.5
3
3.5
4
4.5
5



Marley et al. (2010)

Conclusions

- Era of brown dwarf weather is here now
- Variations may be temperature, clouds, perhaps chemistry?
- Thermal changes, cloud opacity, rotation, vertical flows, dynamic and radiative time scales all matter
- Pulsations? (Marley et al. 1987)