Weather on Other Worlds:
Implications for JWST Phase Mapping of Variable Brown Dwarfs

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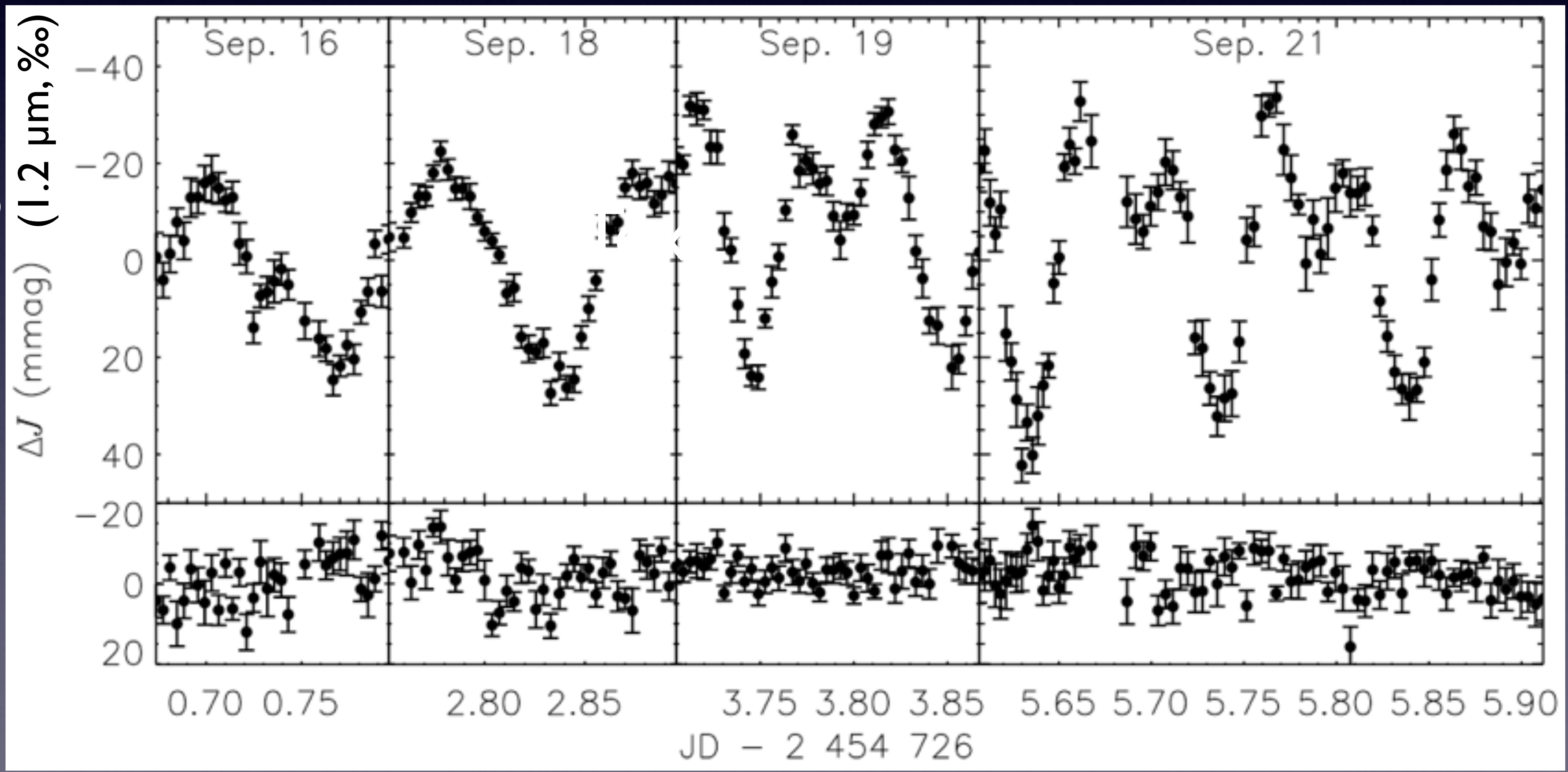
Illustration by Tim Pyle (NASA/IPAC)

First unambiguous detection of patchy clouds: at the L/T transition

P = 2.4 hr   amplitude = ~5%

SIMP 0136+09 (T2.5)

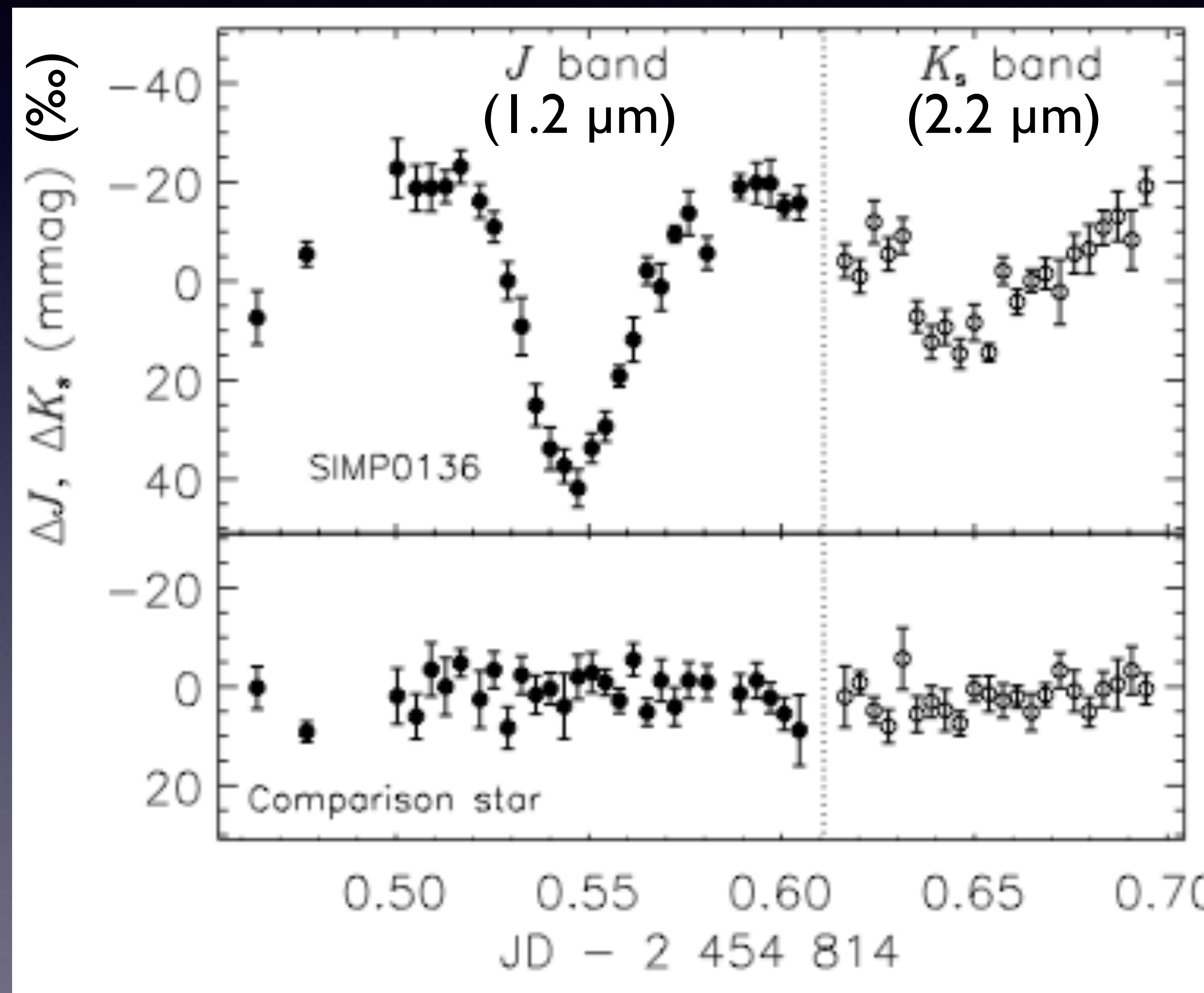
reference star



Artigau et al. (2009)

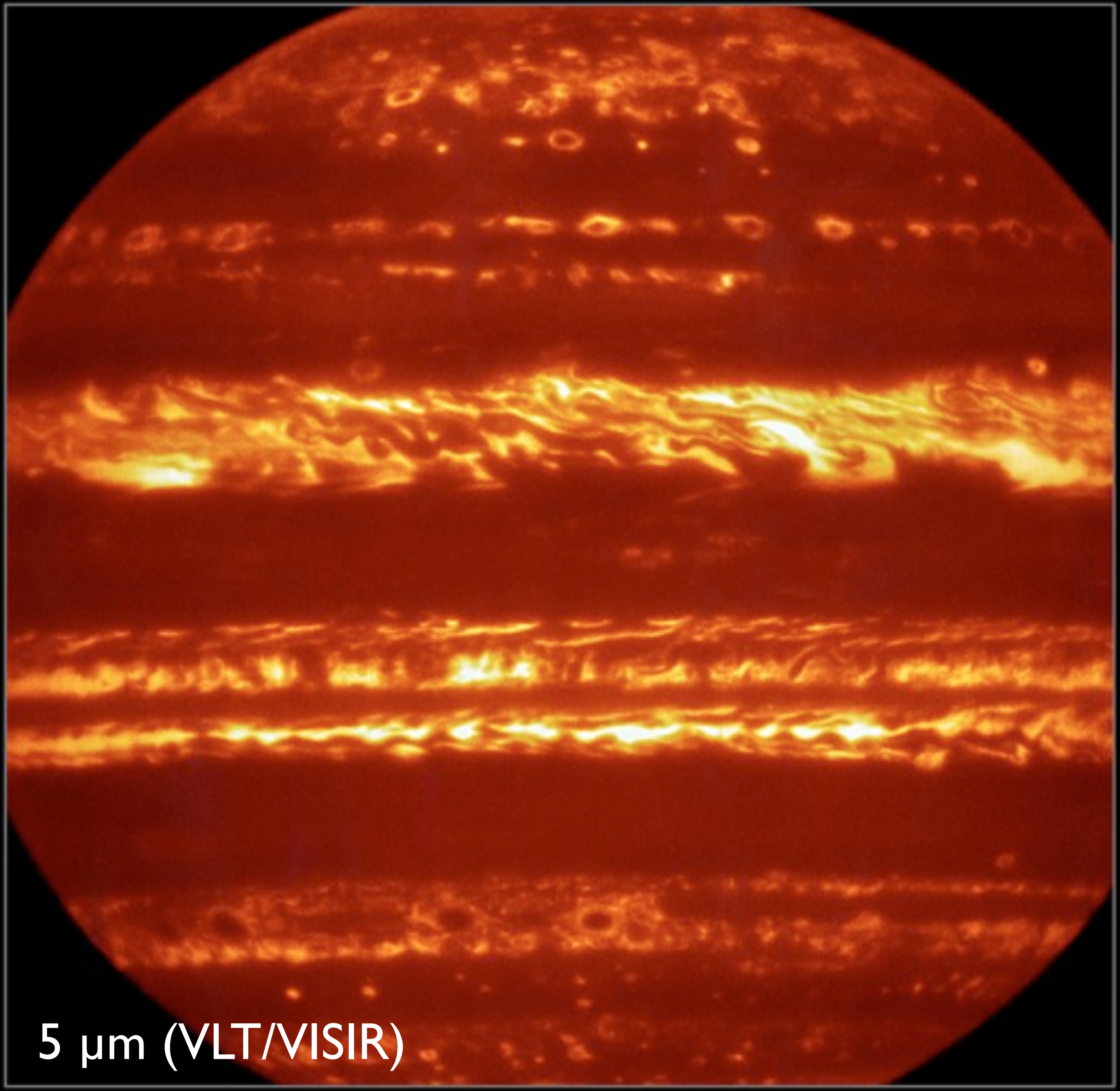
A two-temperature surface: e.g., clouds vs. cloud holes

- Δf ~10% change in cloud fill factor
- combination of grain-free and ~100 K cooler cloudy regions
- *Radigan et al. (2014)* confirm near-IR variability is most common and strongest at L/T transition.



Artigau et al. (2009)

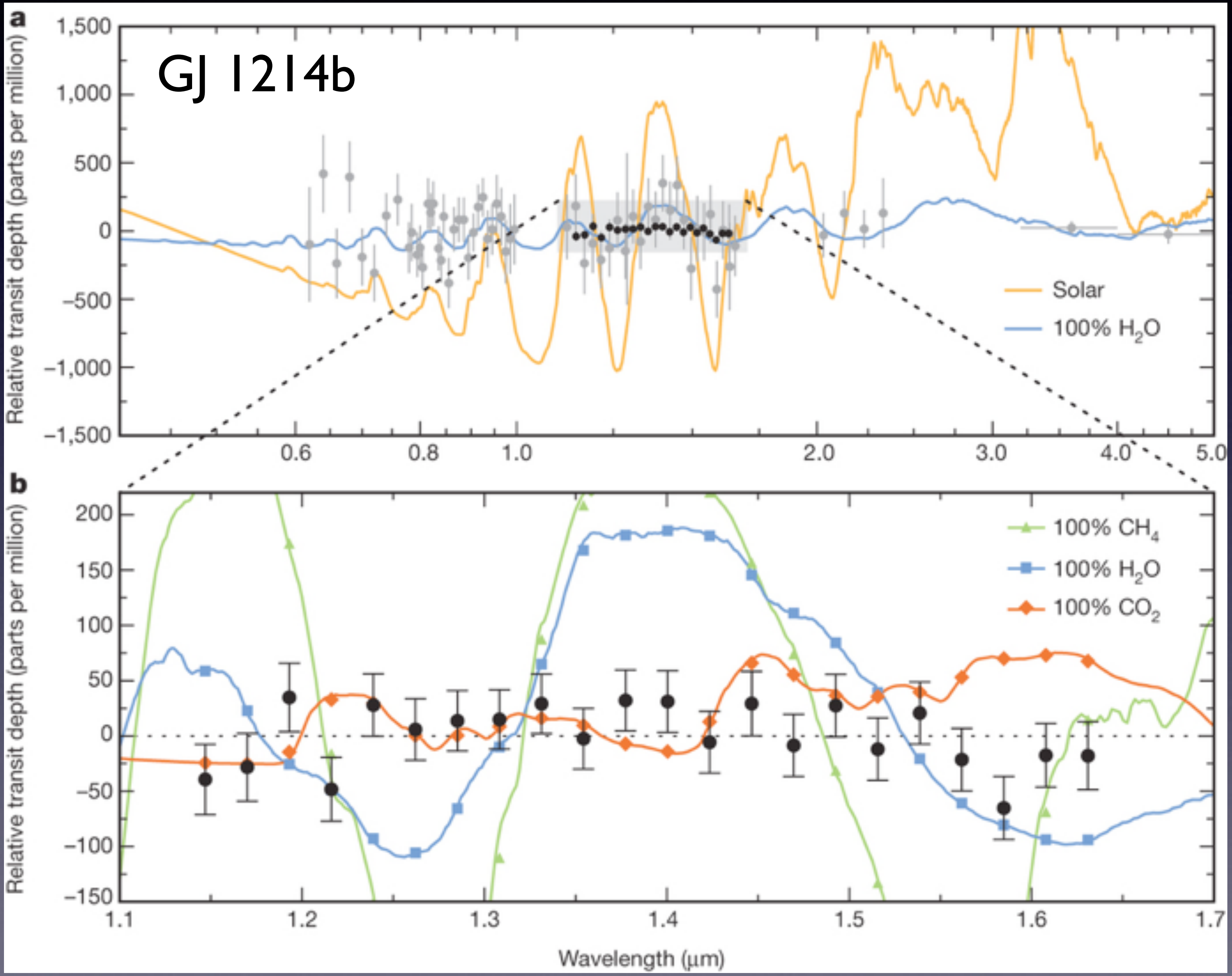
Example of a similar dichotomy in our favourite brown dwarf!



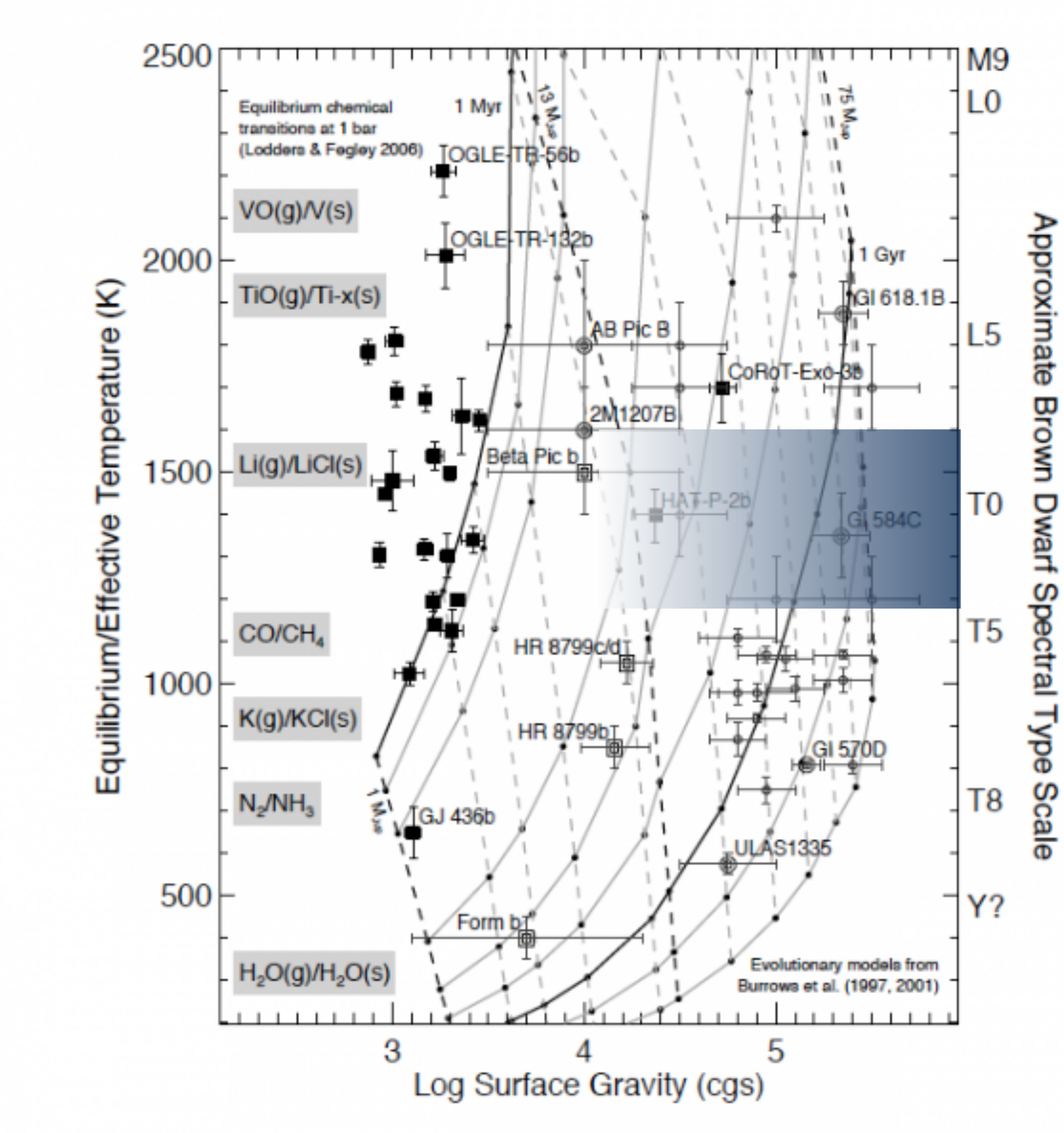
Credit: ESO/L.N. Fletcher/Damian Peach

Exoplanets have clouds, too

- Recall Björn Benneke's talk yesterday
- Nuisance for exoplanet transmission spectroscopists
- *Raison d'être* for (some) brown dwarf observers



Kreidberg et al. (2014)

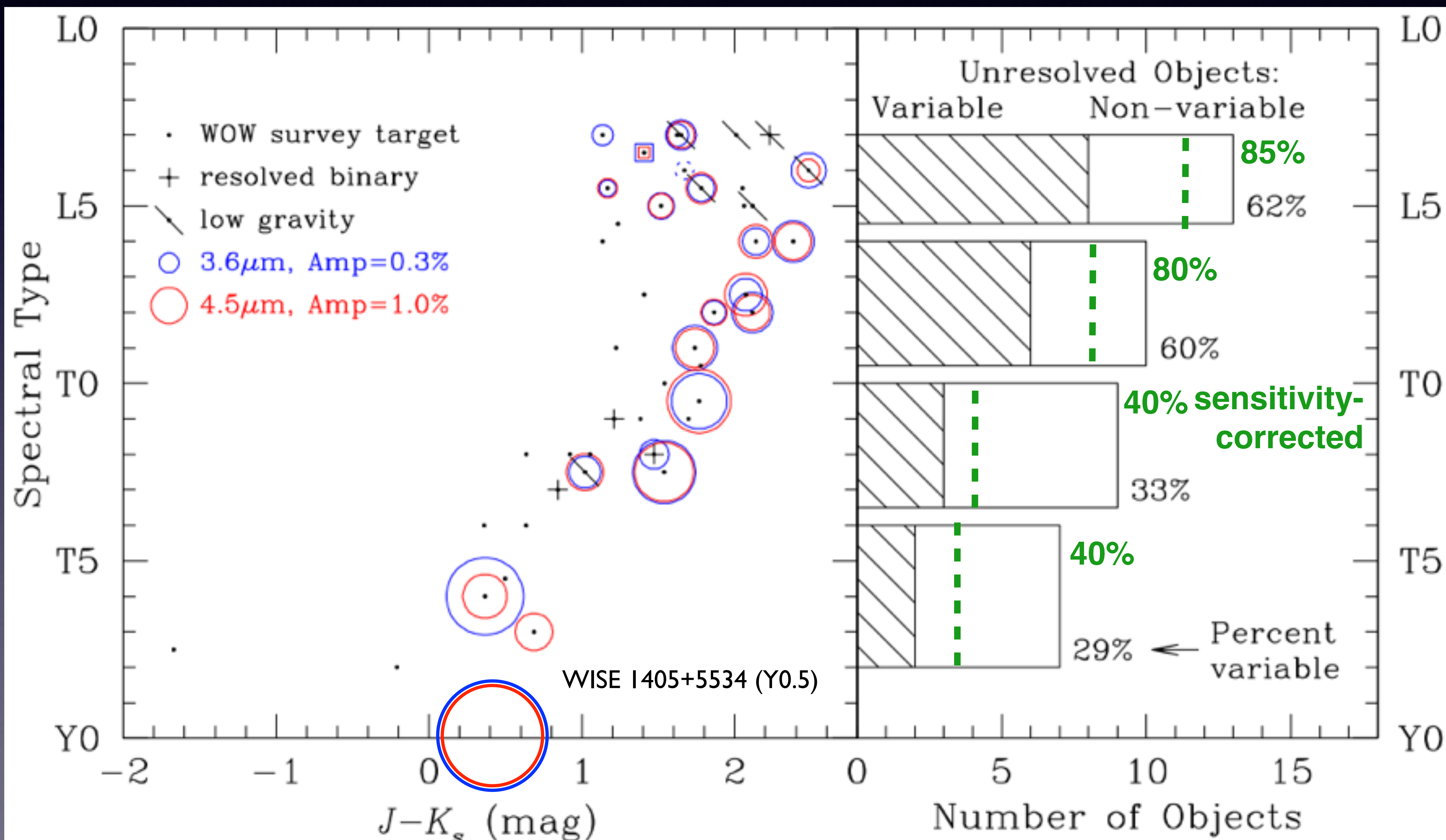


Region of maximum *J*-band variability *(Radigan 2014)*

Burgasser (2009)

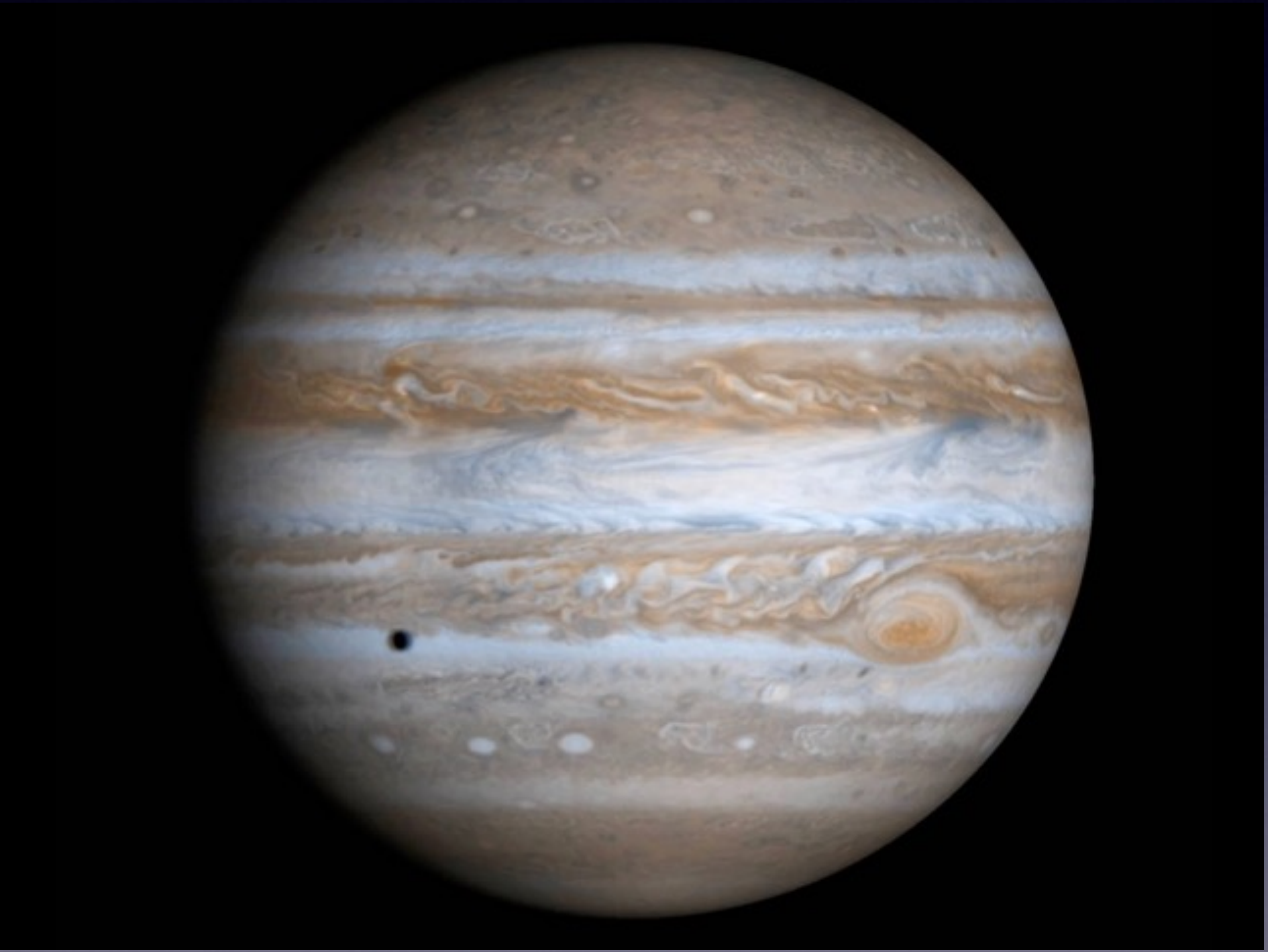

Spitzer Exploration Science Programs (all post-cryo!):
Weather on Other Worlds (WOW; Cy 8)
Extrasolar Storms (Cy 9)
Brown Dwarf and Exoplanet Weather Forecasts (Cy 9)
Weather on Other Worlds 2 (Cy 11)
• Advantage: x10 higher photometric precision compared to ground
• Goal: detect Great Red Spot analogs on brown dwarfs
• Observed ~80 LTY dwarfs, ~20 hrs each.

L3–T8 dwarfs are commonly variable with 0.2%–5% amplitudes at 3–5 micron



Metchev et al. (2015)
Cushing et al. (2016)

Zeroth order estimate for variability detection



Projection:

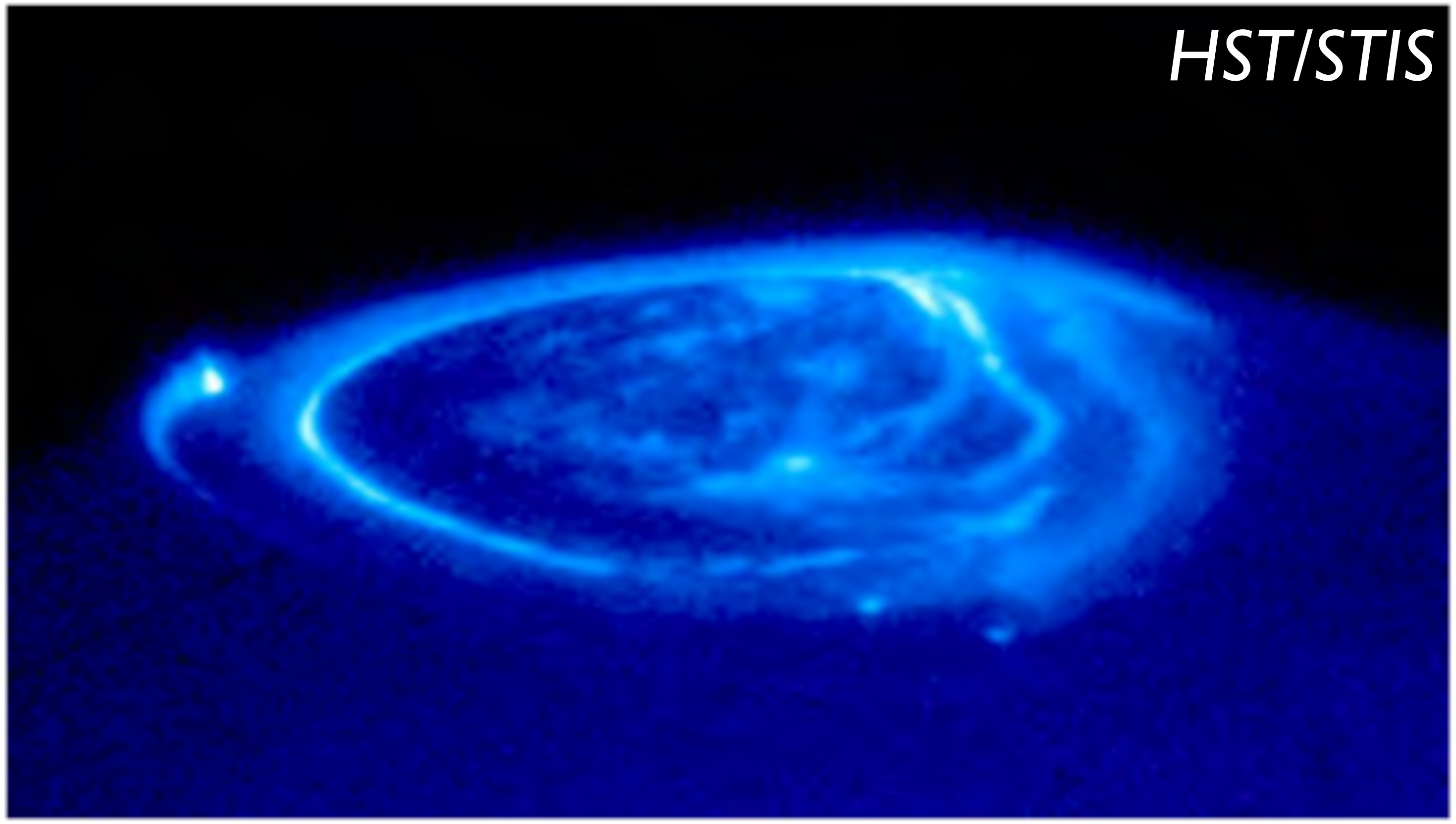
- If all brown dwarfs have GRS-sized spots, expect to detect variability in ~50% of cases

Result:

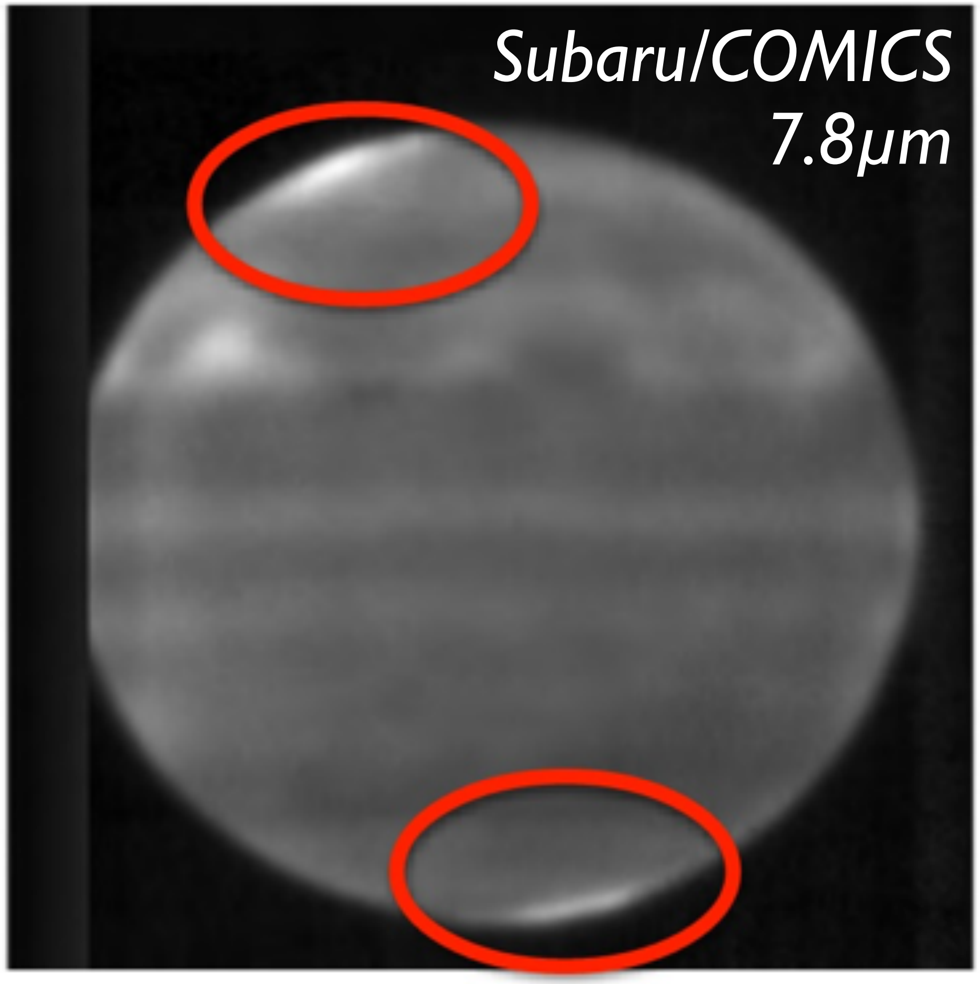
- ~40% of T dwarfs are variable at >0.4%
- ~80% of L dwarfs are variable at >0.2%

Majority of T dwarfs are spotted. L dwarfs have multiple spots.

Aurorae also create spots



Sinclair et al. (2016; Jupiter Aurora Workshop)

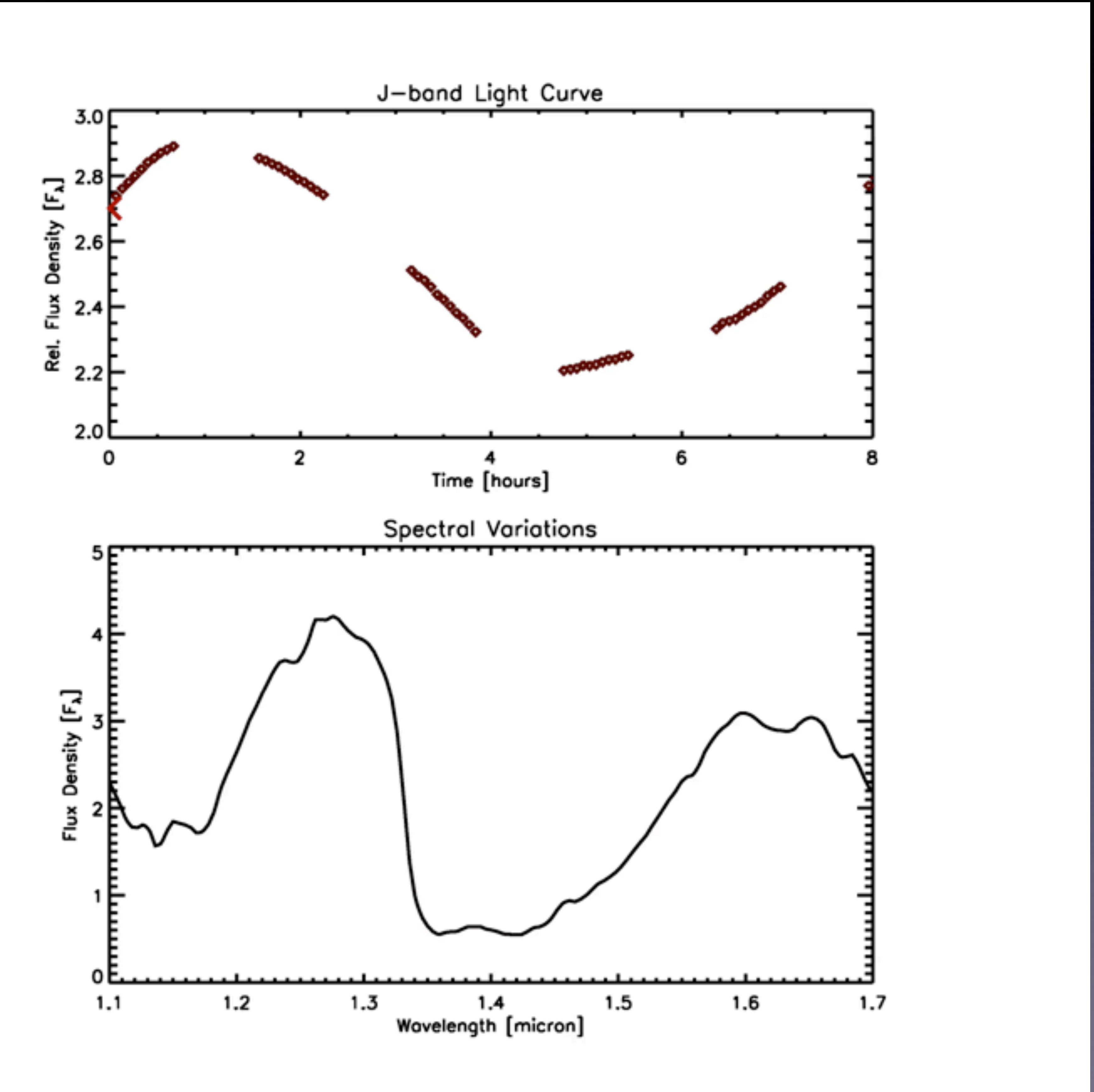


- Aurorae known on M, L, and T dwarfs from radio emission:
  - Berger (2002), Route & Wolszczan (2012); Hallinan et al. (2015)
- Effect may combine with clouds to create the observed nearly ubiquitous spottedness.
  - Clouds possibly favoured as spots at lower latitudes.
  - Hα chromospheric emission? (Pineda et al. 2016)

Next logical step: spectroscopic variability studies of L and T dwarfs

2MASS 2139–0220 (T1.5):

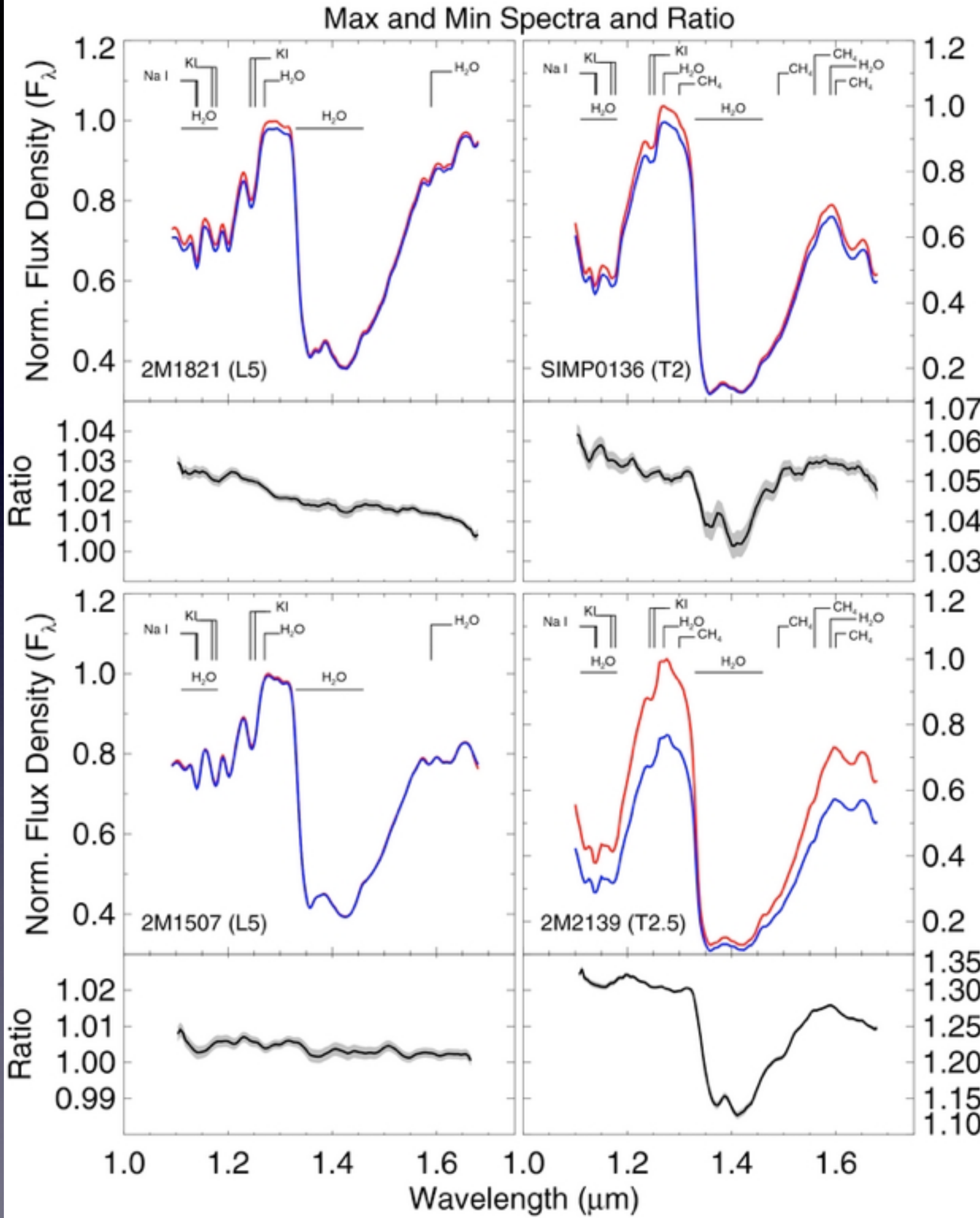
HST/WFC3 grism spectroscopy



Apai et al. (2013)

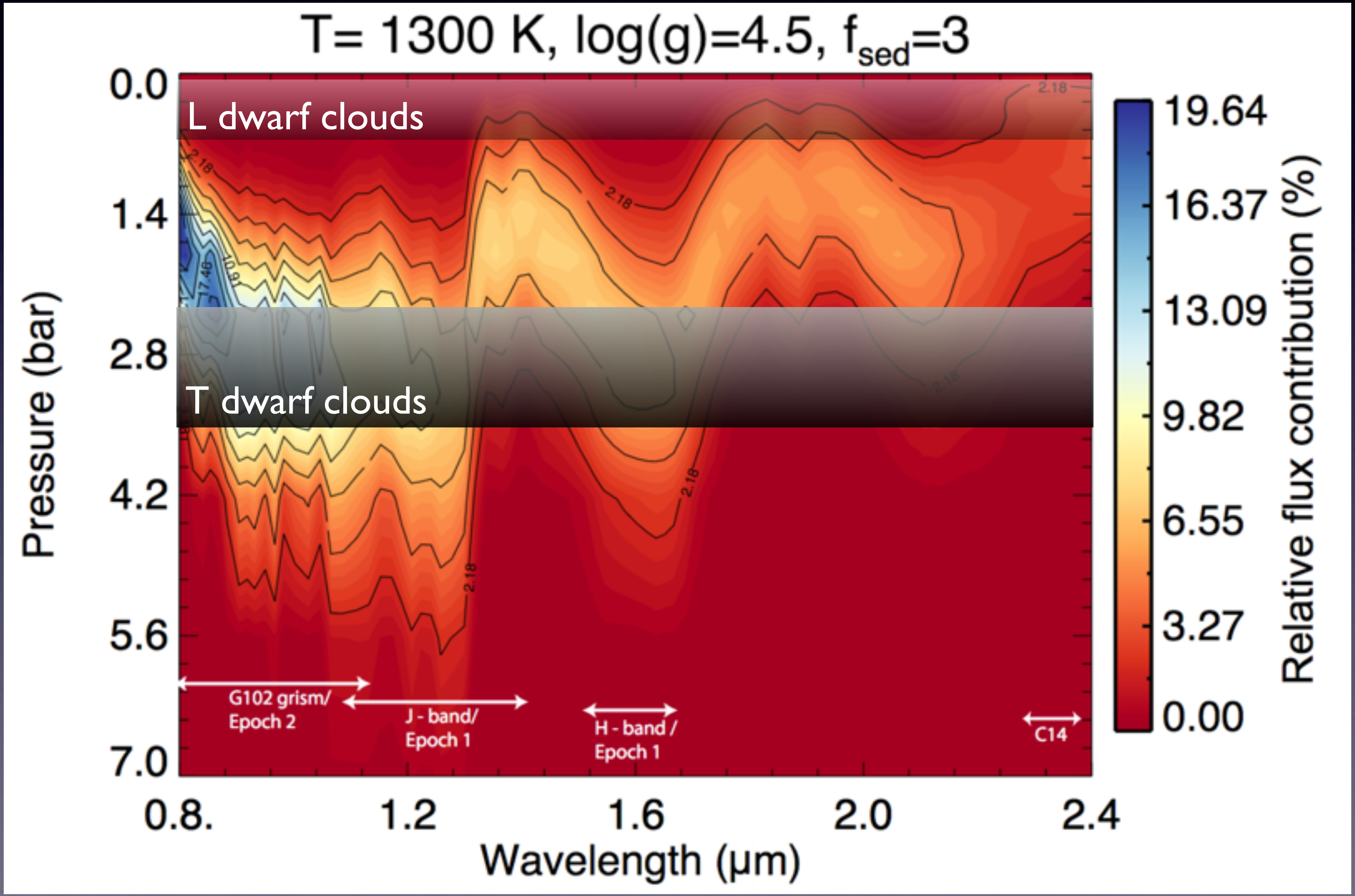
Water-band variations in T dwarfs are weaker

- L dwarfs: clouds are above τ~1 level for 1.4 µm water band.
- T dwarfs: clouds are mostly below τ~1 level for 1.4 µm water band.



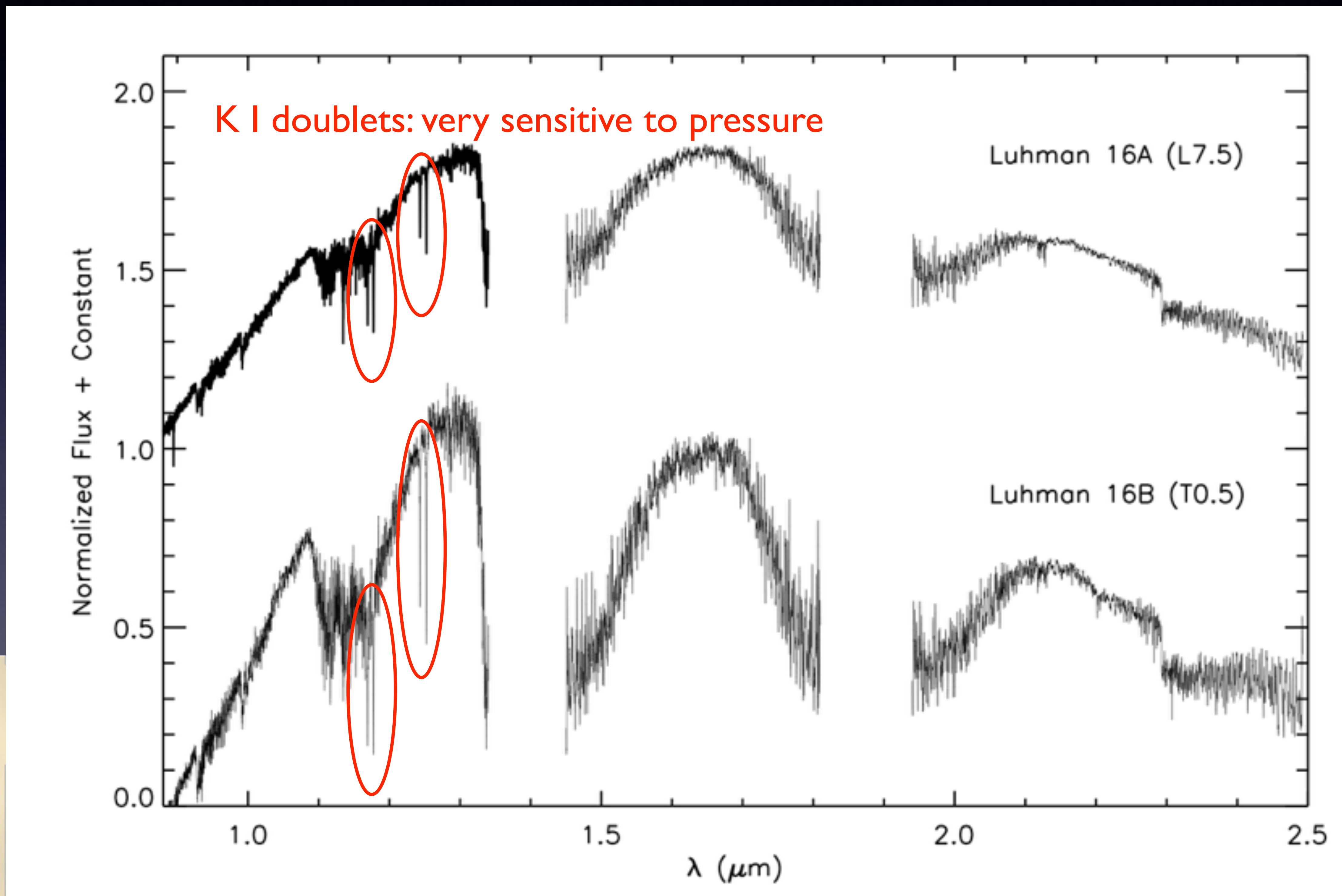
Apai et al. (2013), Yang et al. (2015)

Clouds reside mostly below τ~1 level in the 1.4 μm water band of T dwarfs



Luhman 16B relative flux contributions (Buenzli et al. 2015; Karalidi et al. 2016)

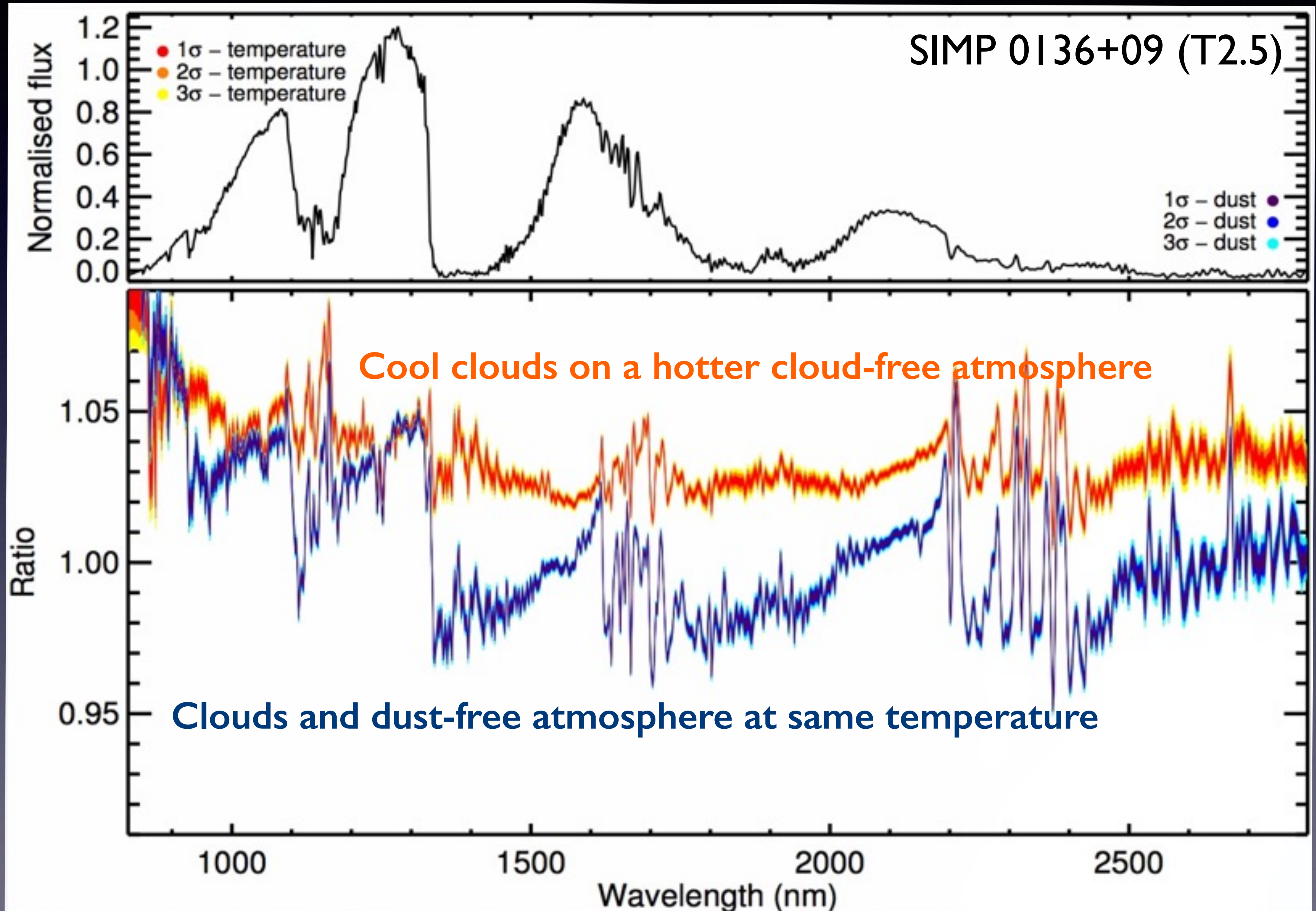
Continuous Luhman 16AB R = 4000 spectroscopy over 2 nights: aiming to determine accurate cloud heights



F I R E

Kellogg et al. (in prep.)

Propsects are much better with JWST: 0.6–2.5μm slitless spectroscopy with NIRISS

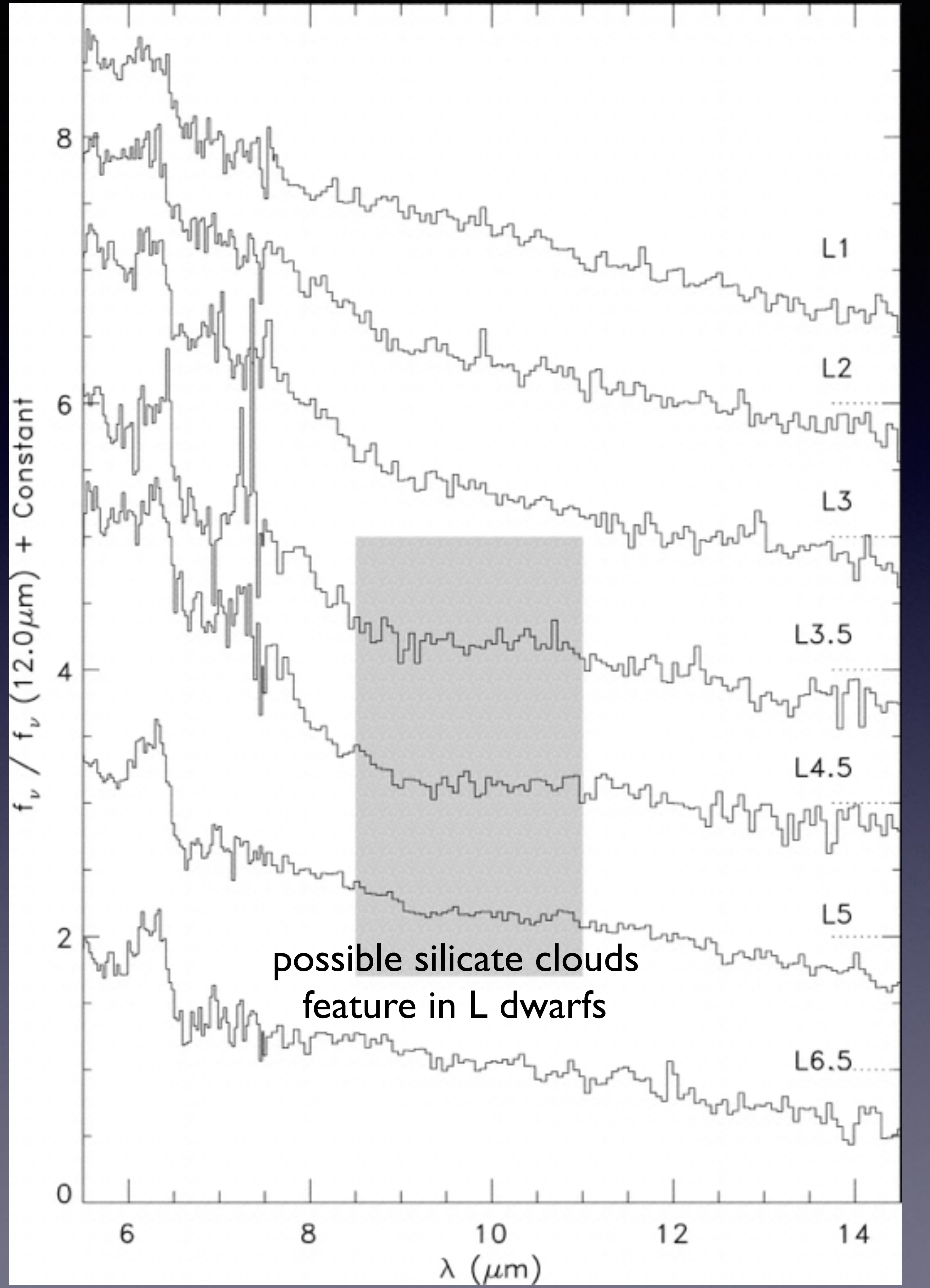


See Étienne Artigau poster!

Propsects are much better with JWST: 5–28μm spectroscopy with MIRI

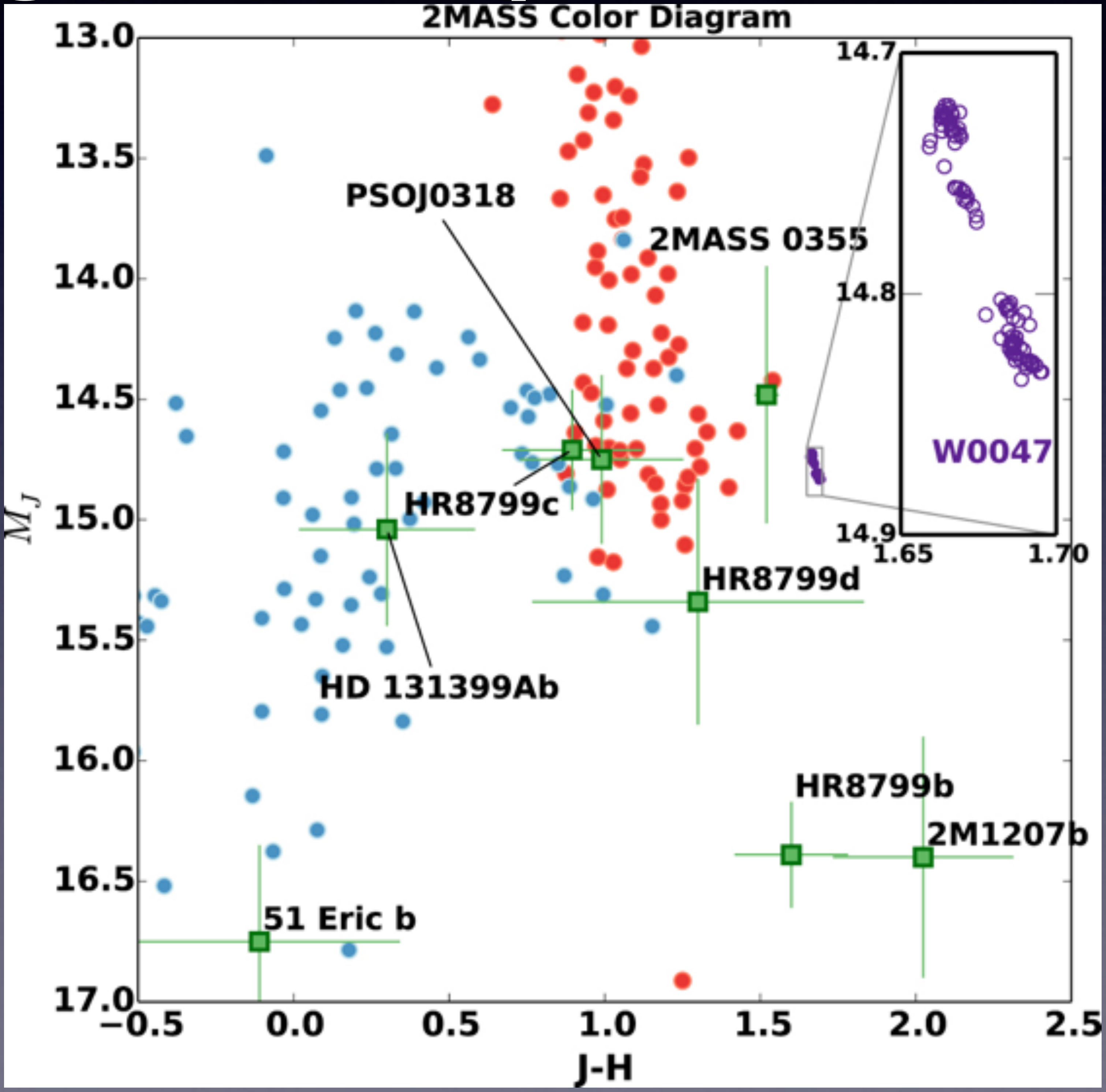
- Probe of the dominant condensate opacity source: dust clouds!

Cushing et al. (2006)



Low-gravity brown dwarfs may have higher amplitudes

- Evidence from Spitzer (Metchev et al. 2015)
  - subsequent high-amplitude variability detections (Biller et al. 2015; **Lew et al. 2016**)
- Low-g brown dwarfs are better analogues of giant planets.
- Being discovered in nearby moving groups (surveys by J. Gagné, K. Kellogg, A. Schneider, W. Best, etc)



Lew et al. (2016)

Summary of findings and prospects

1. Most L and T dwarfs have at least one spot
    - L dwarfs have multiple spots, often rapidly changing
    - likely mechanisms: clouds, aurorae, chromospheric spots
2. Enhanced variability amplitudes / higher energy contrasts:
    - at low gravities in L3–L6 dwarfs
    - observed in cooler objects
3. Variability is wavelength-dependent: information on mechanism
4. JWST wavelength range includes:
    - dominant cloud opacity source: silicates
    - strong auroral emission lines (H_3^+, CH_4).

Artist's rendition: Tim Pyle (Caltech/IPAC)