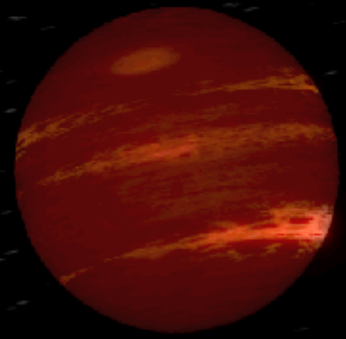
Rotational modulations of a rare planetary-mass object at the end of the L/T transition



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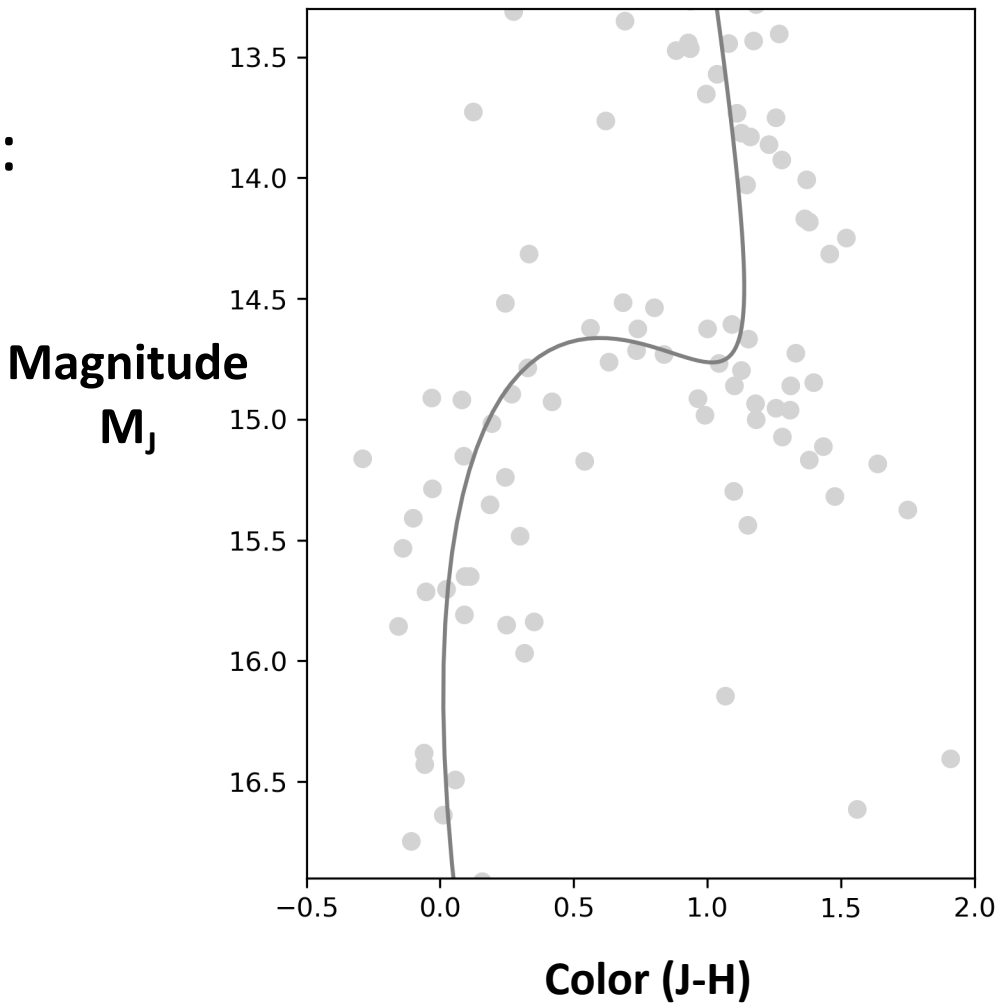
The drastic color change in the L/T transition

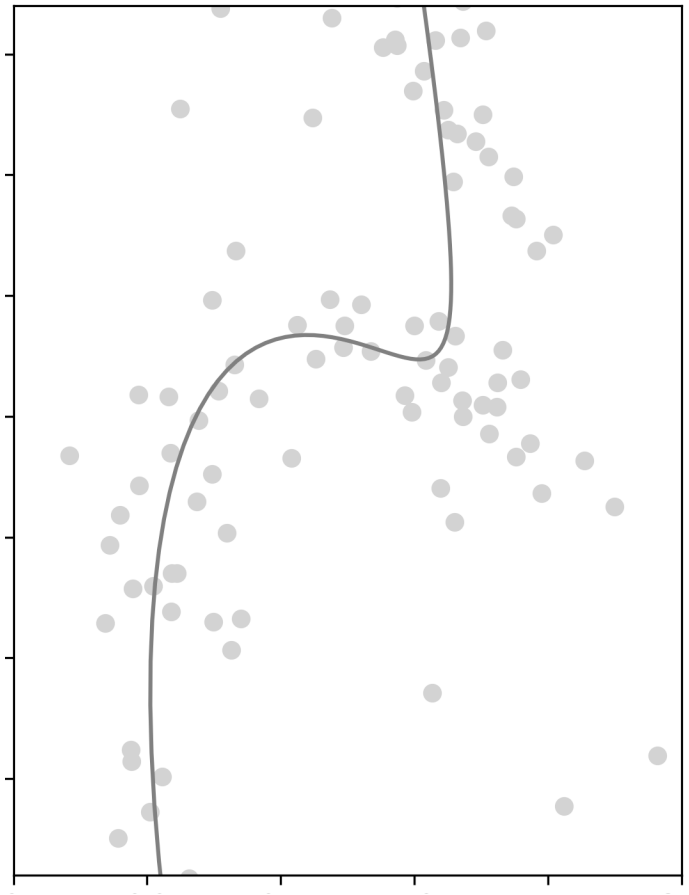
Possible explanations for L/T transition:

- Cloud patchiness (Marley+2010)
- Cloud thinning (Saumon+ 2008)
- Other cloud structure evolution (Tsuji&Nakajima2003, Burrows2006, Charney+ 2018)
- Diabatic Convection driven by CO/CH_4 transition (Tremblin+2019)



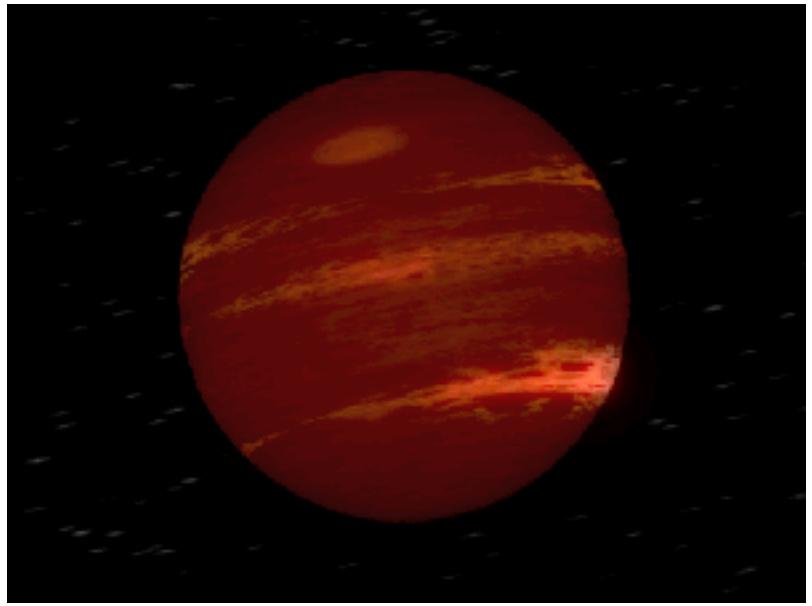
Key Question

As cloud structure evolves across the L/T transition, how does the cloud heterogeneity varies with spectral type?

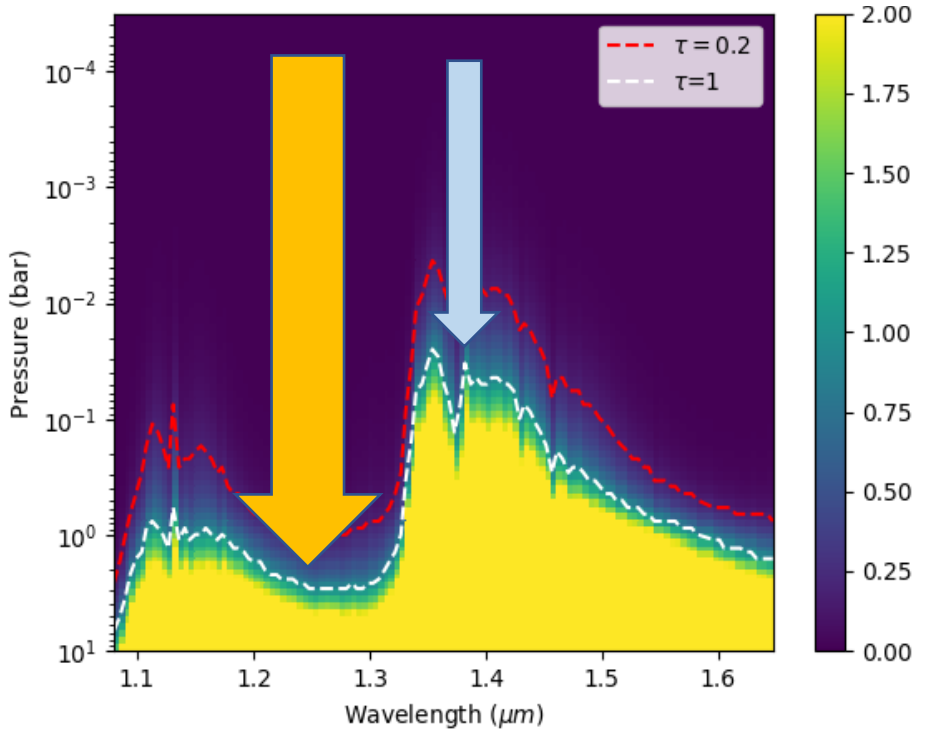


Probe atmospheric heterogeneity with rotational modulation

Rotational Asymmetric Brightness Distribution



Molecular Opacity as Indirect Pressure Probe



Lew+ in prep

Rotation-modulated flux variation + wavelength dependence

GU Psc

M3 star (Riaz+2006)

100 +/- 30 Myr (ABDMG, Malo+2013)

47.6 pc (Gaia)

[Fe/H] ~ -0.14 – 0.10 (Naud+2014)

GU Psc b (Naud+2014)

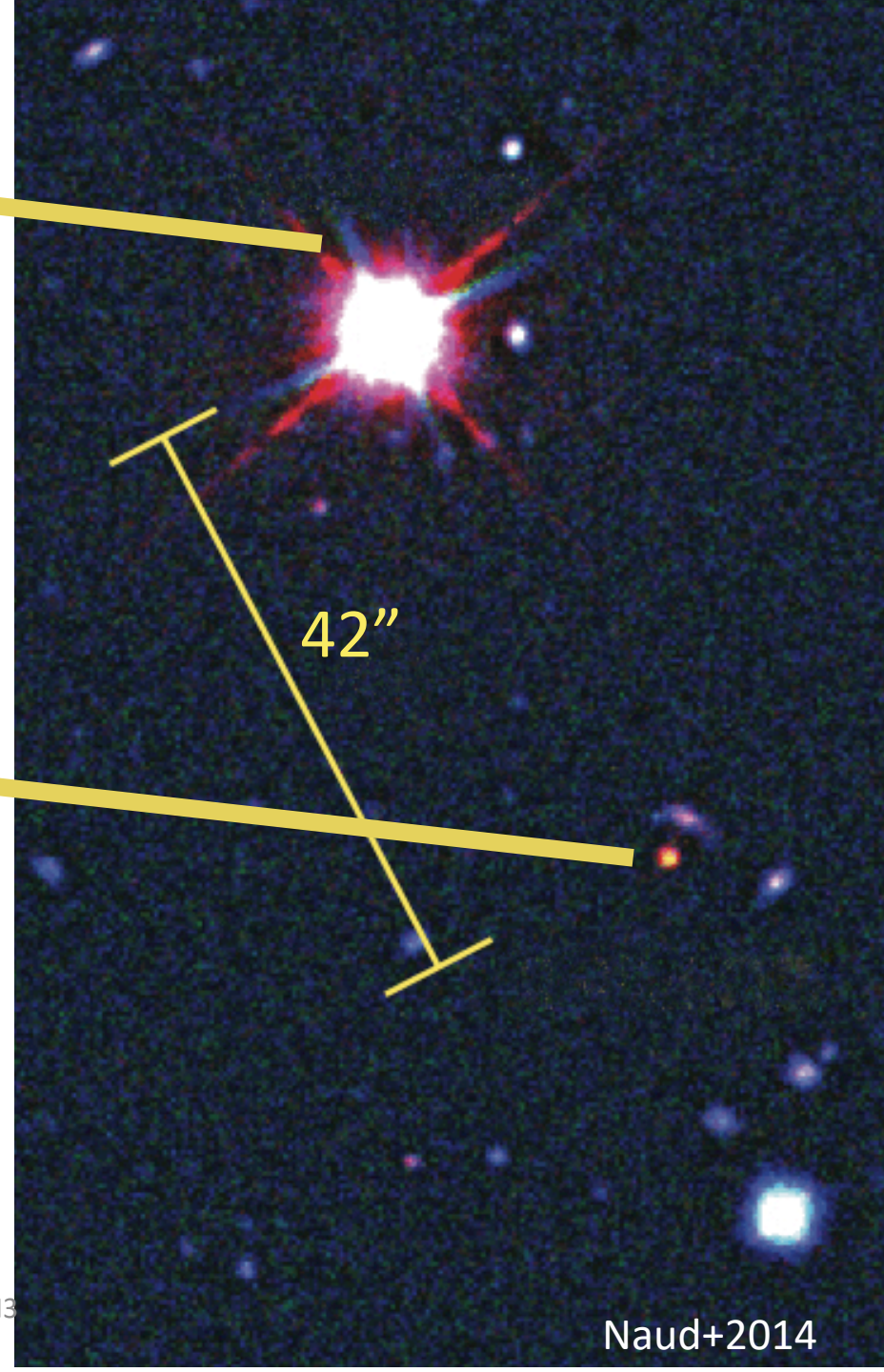
2000 ± 200 au

T3.5 ± 1

T_{eff} ~ 1000-1100 K (Morley+2012,Allard+2013)

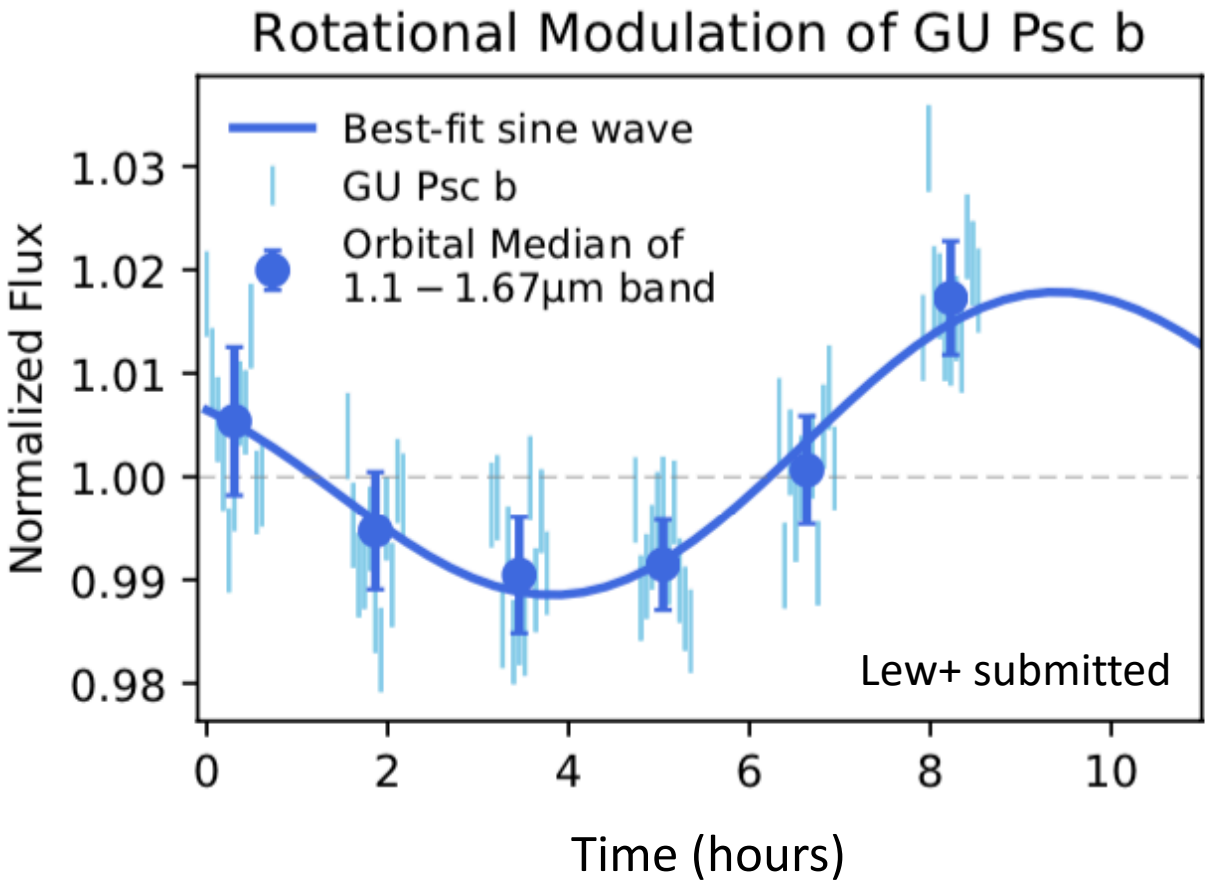
Planetary mass: 9-13 M_{jup}

(Saumon&Marley2008, Baraffe+2003)



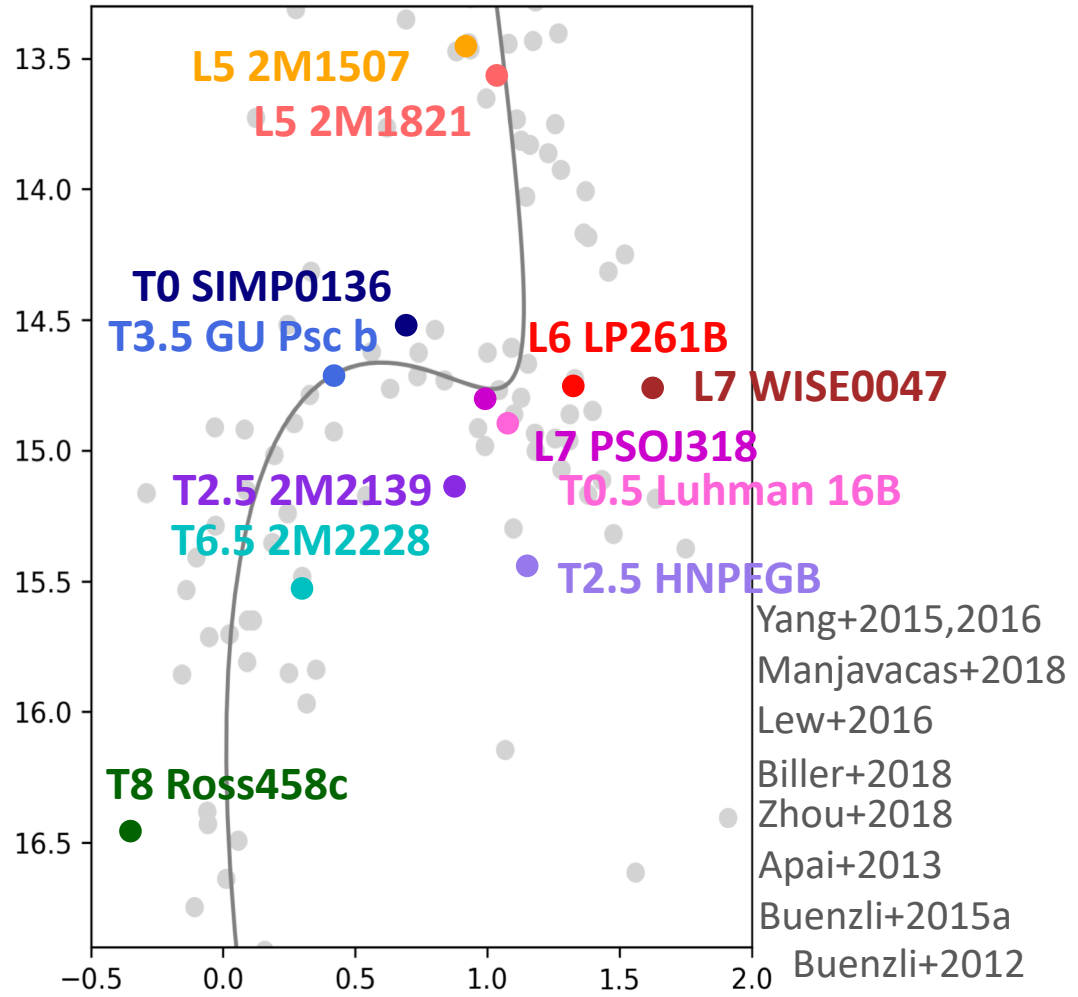
Result 1: Confirmed large rotational modulation amplitude

- 6 HST orbits (8 hours baseline) under HST Large Treasury Program Cloud Atlas (P.I. Dániel Apai)
- Light curve is consistent with a simple sinusoidal wave
- Large modulation amplitude with flux variation > 2.7%
- Confirm previous tentative detection of variability of Naud+2017
- Long rotation period: > 8 hours



A rare mid-T dwarf with detected rotational modulations

The heterogeneous atmosphere of GU Psc b provides an important reference for studying cloud structure evolution of the L/T transition.



(brown dwarf photometry catalog: Dupuy+2012)

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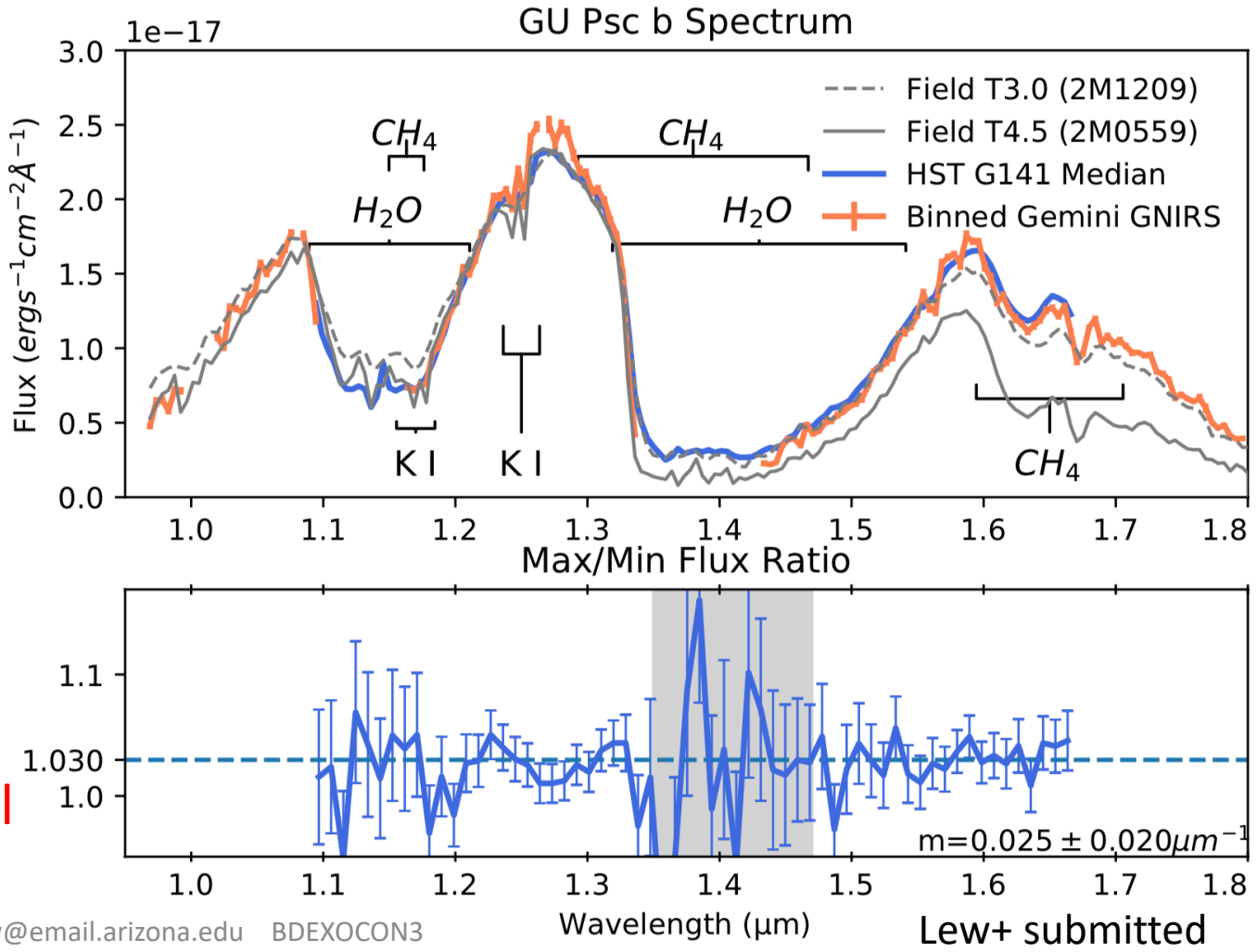
Result 2: No strong wavelength-dependence found in spectral variation

Weak wavelength dependence (slope = $0.025 \pm 0.02\ \mu m^{-1}$)

The J-H color change is much smaller than the observed modulation amplitude
→ Weak color change in modulation

What does this weak color modulation tell us about the L/T transition?



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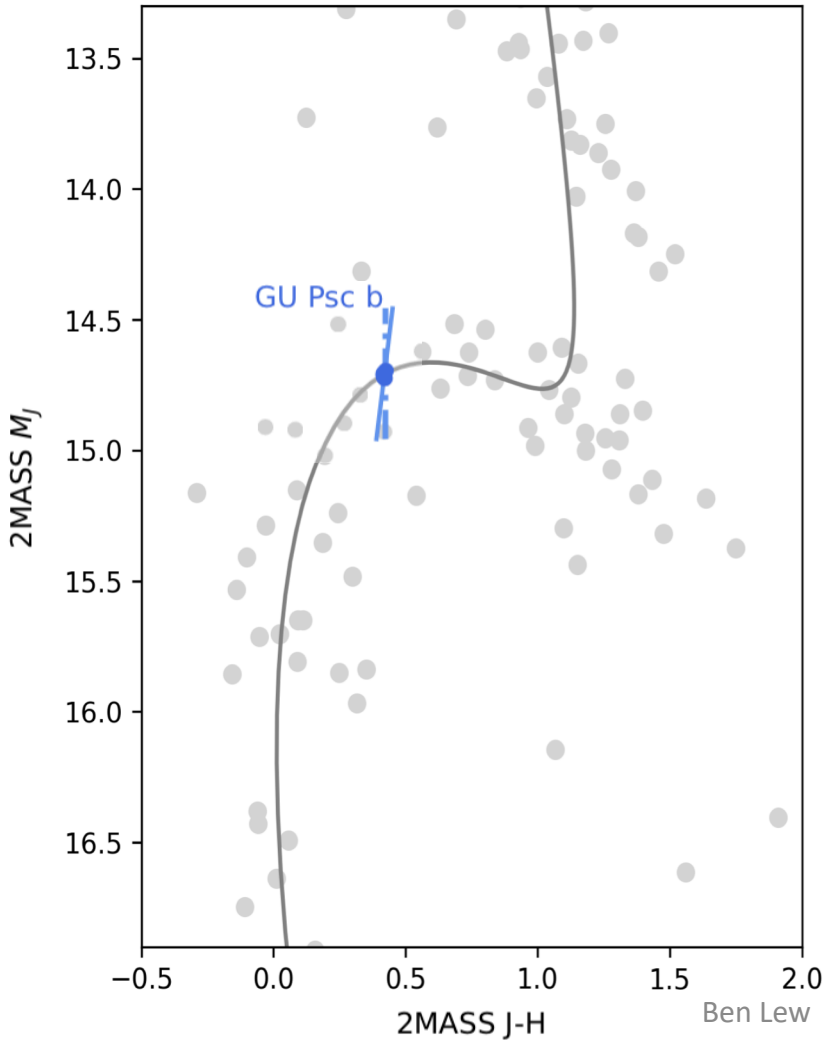
Lew+ submitted

Weak color modulations of GU Psc b



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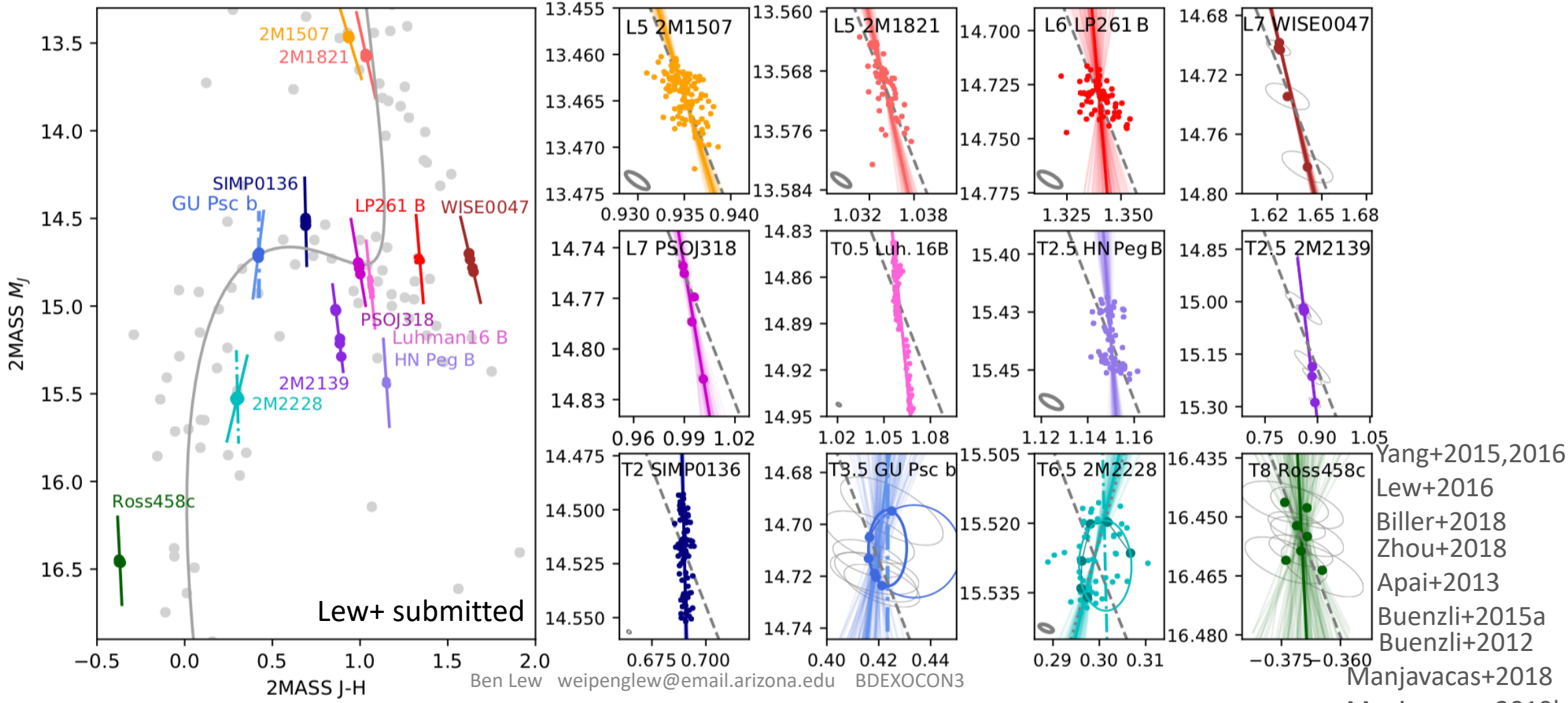
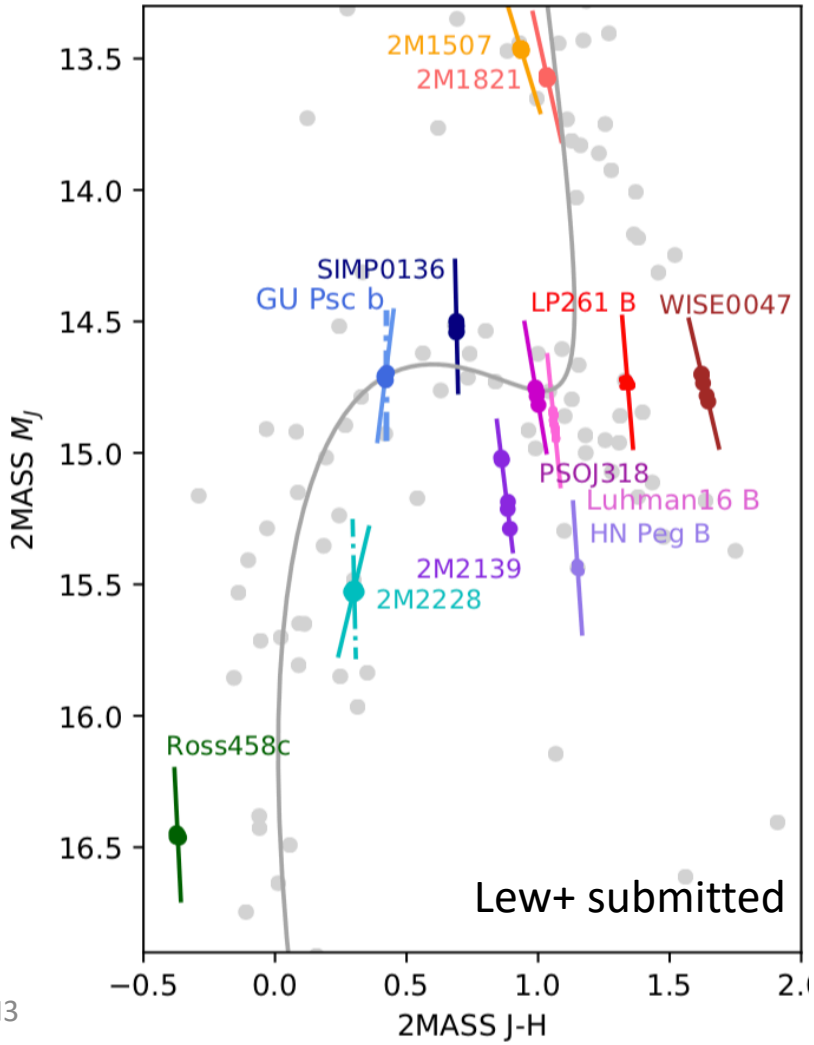
Weak color modulations of GU Psc b and other 11 brown dwarfs



Yang+2015,2016
Lew+2016
Biller+2018
Zhou+2018
Apai+2013
Buenzli+2015a
Buenzli+2012
Manjavacas+2018
Manjavacas+2019b

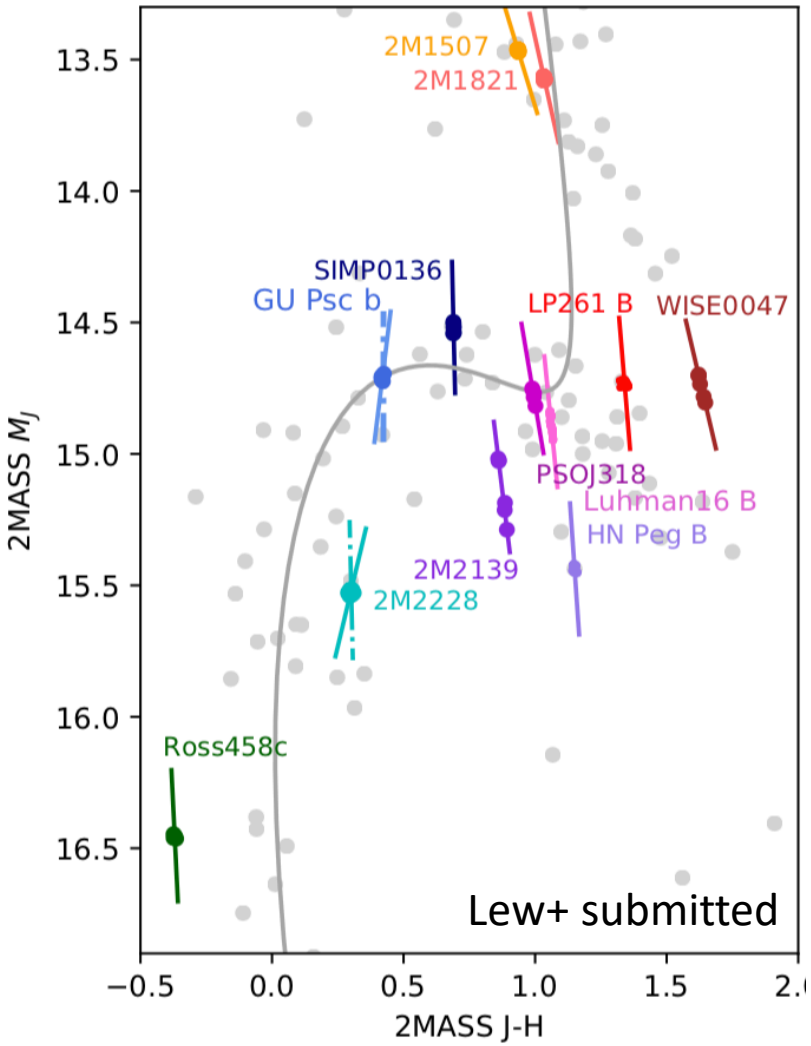
Weak Color modulations of L and T dwarfs

- The brown dwarf's trajectories of color-magnitude variations on CMD are almost vertical – weak color modulations
- The weak color modulations across the L/T transition are consistent with cloud thickness variation scenario (Apai+2013, Radigan+2012)
- The rotational modulations of late-L to mid-T dwarfs provide observational evidence of heterogenous clouds across the L/T transition.



Summary

1. GU Psc b's disk-integrated flux demonstrates a large rotational modulation amplitude of **>2.7%** with a rotational period **>8 hours.**
2. **Weak wavelength-dependence** in GU Psc b's rotational modulations
3. The compiled 12 mid-L-to-late-T dwarf sample show mostly weak color modulations, **consistent with cloud thickness variation scenario**
4. As a **rare mid-T dwarf with large modulation amplitude**, GU Psc b provide an important reference point for studying heterogeneous atmospheres in the L/T transition.



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Additional Slides

Do T dwarfs become brighter and redder in rotational modulations?

L dwarfs: brighter and bluer
T dwarfs: brighter and ... redder?

Are we seeing particle size evolution?
Pressure level difference between J and H bands?
Phase shift?