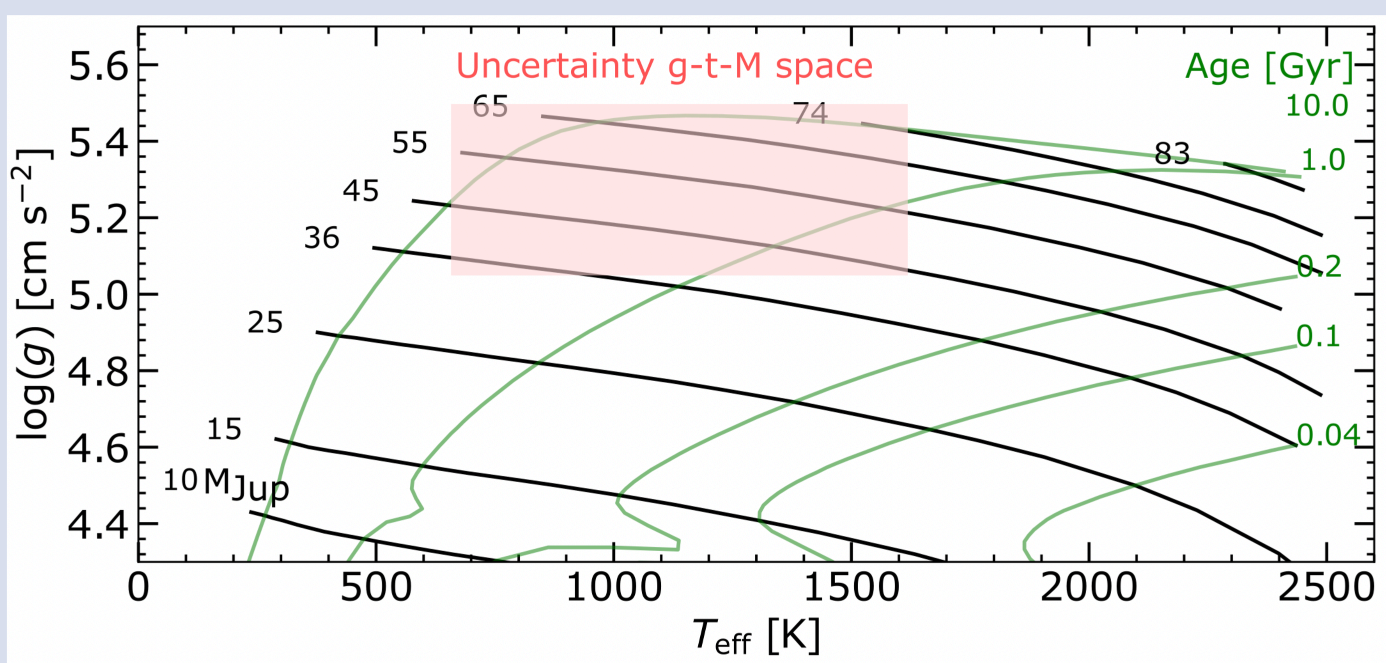
Follow the Lithium: The Correlation Between Li-bearing Molecules with Age, Mass, and Gravity in Brown Dwarfs

Ehsan Gharib-Nezhad [1], Mark S. Marley [1], Natasha E. Batalha [1], Channon Visscher [2,3]
(1) NASA Ames Research Center, Moffett Field, CA, USA (2) Dordt University, Sioux Center, IA, USA (3) Space Science Institute, Boulder, CO, USA

Challenges with Accurate Determination of T-Y Dwarf Mass

Accurate calculation of the mass of ultracool dwarfs has been a serious challenge in understanding brown dwarfs. This uncertainty comes from the degeneracy in age, mass, and gravity parameters. Examples of T-L dwarfs with high uncertainty in their mass provided in the following table.

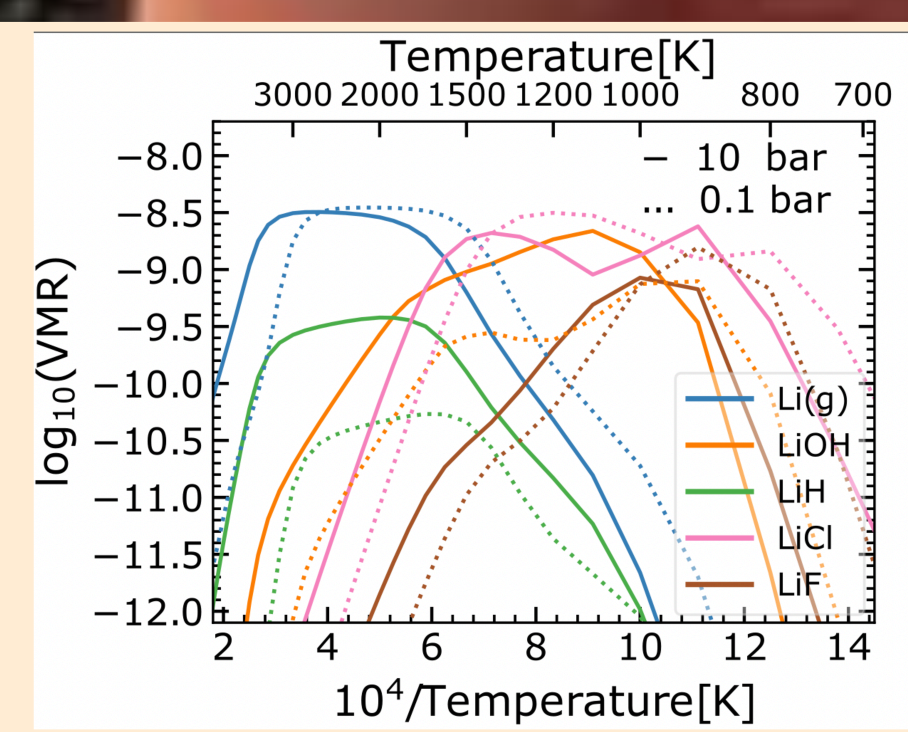


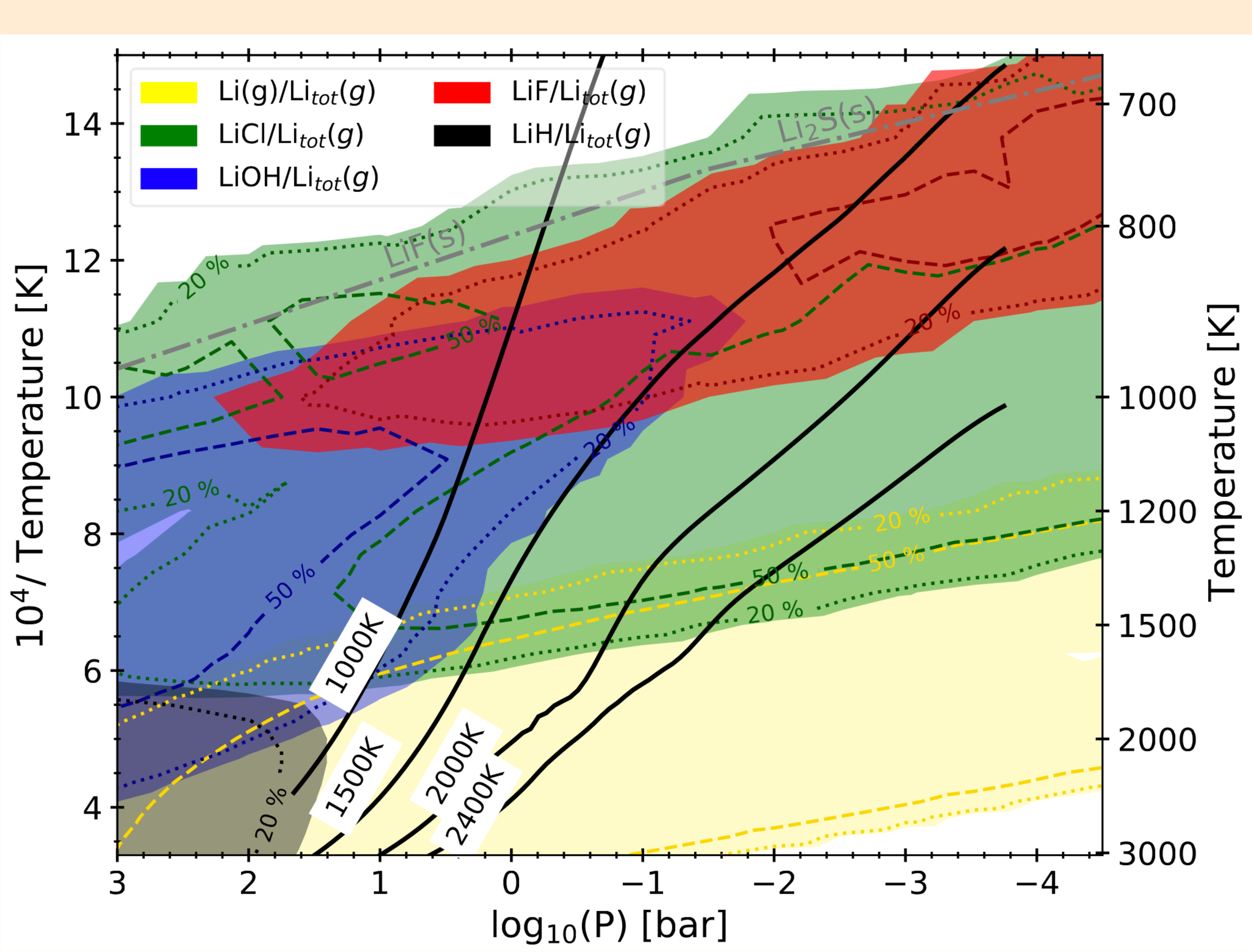
M [M_{Jup}]	t [Gyr]	Method/Model	Ref.
Gl 229B, late-T type, T_{eff} ~1000 K			
65 – 75	7 – 10	RV/imaging/astrometry	Br20
30 – 55	1 – 5	photometry/evolutionary	Ma96
HD 4747B, ~L8 type, T_{eff} ~1700 K			
72^{+3}_{-13}	$3.3^{+2.3}_{-1.9}$	Baraffe et al. (2003)	Cr16
62±3.3	$3.3^{+2.3}_{-1.9}$	astrometry/RV	Cr16
HD 19467B, ~T5-T7 type, T_{eff} ~1050 K			
$56.7^{+4.6}_{-7.2}$	$4.3^{+1.0}_{-1.2}$	Baraffe et al. (2003)	Cr14
$67.4^{+0.9}_{-1.5}$	9 ± 1	Isochronal analysis	Cr14
74^{+12}_{-9}	$8^{+2.0}_{-1.0}$	e.g., Filippazzo et al. (2015)	Ma20
HD 7672B, ~L4.5 type, T_{eff} ~1650 K			
55 – 78	1 – 3	e.g., Chabrier et al. (2000)	Li02
Gl 758 B, late-T type, T_{eff} ~650 K			
42^{+19}_{-7}	1 – 6	astrometry/RV	Bo18

Refs.: Br20=(Brandt et al. 2020), Bo18=(Bowler et al. 2018), Cr14=(Crepp et al. 2014), Cr16=(Crepp et al. 2016), Li02=(Liu et al. 2002), Ma20=(Maire et al. 2020), Th09=(Thalmann et al. 2009)

Li Chemistry in Brown Dwarfs

The right figure is the Volume Mixing Ratios (VMR) of Li-bearing species as a function of temperature. Atomic Li and LiH are dominant species in (ultra-) hot atmospheres with T_{eff} in ~1800-3000~K (e.g., M/L-type dwarfs). In warm atmospheres with T_{eff}~900-1600~K (e.g., L/T-type dwarfs), LiOH, LiCl, and LiF are the most stable Li-bearing species.





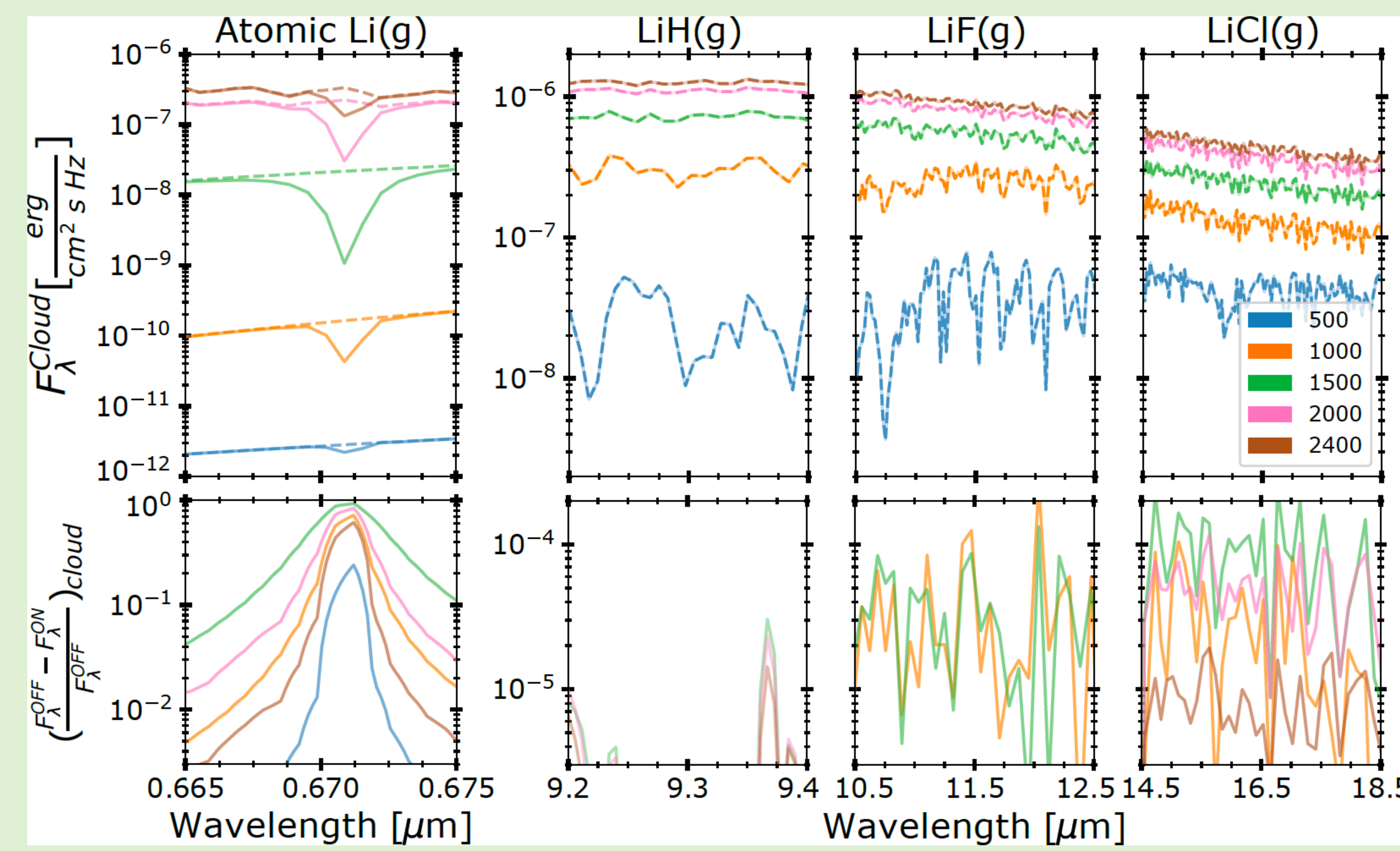
Historically the Li test, searching for the atomic Li line at 670 nm, has been used to distinguish early L-type brown dwarfs from stars, since Li is consumed by fusion processes for masses above 70 M_Jup (Baraffe2015, Charier1996).

To better understand the presence and abundance of the different Li-bearing species in the temperature-pressure space, the Li phase diagram is represented in the left figure. In this plot, each species is shown with different colors. At each area, dashed and dotted contour lines represent 50% and 20% of that species with respect to the total protosolar lithium abundance (i.e., ~3.5x10^{-9}) in the atmosphere. The solid black curves are the temperature-pressure (TP-) profiles of brown dwarfs from the Sonora-Bobcat cloud model created by Marley et al. (2021). **The critical question is whether different Li species could serve as a tool to confirm massive ultracool objects.**

Using LiF and LiCl to Disentangle this Age-Mass-Gravity Degeneracy

We investigate the impact of Li species on the synthetic thermal spectra of candidate T/L/M dwarfs using both cloud (Marley2021) and cloudless Sonora model (Marley2018) for T_{eff} of 500-2400~K and logg=5.0. The presence and the strength of their spectral features on synthetic flux spectra are assessed for different effective temperatures and surface gravities to see if they can productively be used as a high mass indicator in brown dwarfs.

- The presence (F^{ON}) and absence (F^{OFF}) of Li has the highest ([(F^{OFF}) - (F^{ON})] / F^{OFF}) ratio, which is ~1 at the line center for T_{eff} =2400 K, and it reduces to 0.2 for 500K.
- LiF absorption feature is dominant at 10.5-12.5 µm. As it is predicted by thermochemical simulations, LiF mostly forms at 800-1200 K and competes with LiCl and LiOH molecules. The LiF ([(F^{OFF}) - (F^{ON})] / F^{OFF}) ratio is ~10^{-4} for T-L type dwarfs with T_{eff} of 900-1600 K.
- In the range 1600K< Teff <2400K Li should be present as LiCl for masses below 70 M_{Jup}. The lack of LiCl at 14.5-18.5 µm would be an indicator of a larger mass.



Conclusion and Future Work

The traditional Li test can distinguish between low mass stars and brown dwarfs with similar spectral types. Although atomic Li still appears in model spectra down to Teff as low as 500K, this spectral region is exceedingly dark and difficult to measure. Instead, since LiF and LiCl features are located in regions where brown dwarfs are brighter, they could in principle be used as mass indicators at these lower effective temperatures.

References and Contact Information

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Ehsan.gharibnezhad@nasa.gov
ehsangharibnezhad.github.io
@ExoEhsan