# Spectroscopic Characterization of Ultracool Brown Dwarfs and Implications for Exoplanet Model Atmospheres

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## Context

**★ Challenges of studying exoplanet atmospheres:**

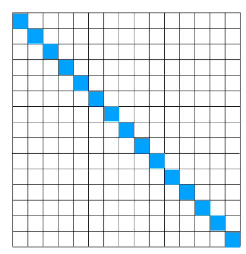
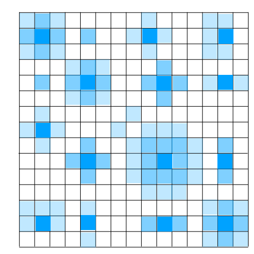
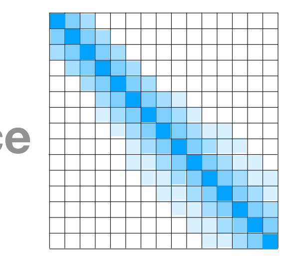
- Direct spectroscopic data of exoplanets are rare, insufficient signal-to-noise, low resolution, and/or non-contiguous wavelength coverage.
- Model atmospheres needed to interpret these spectra are imperfect.

**★ Opportunities offered by brown dwarfs and free-floating planets:**

- Numerous high-quality spectra are available (e.g., the SpeX Prism Library; Burgasser 2014).
- This large spectral library provides fertile ground for validating models of ultracool atmospheres and thereby deriving robust properties from exoplanet spectra.

## Our Forward-Modeling Framework

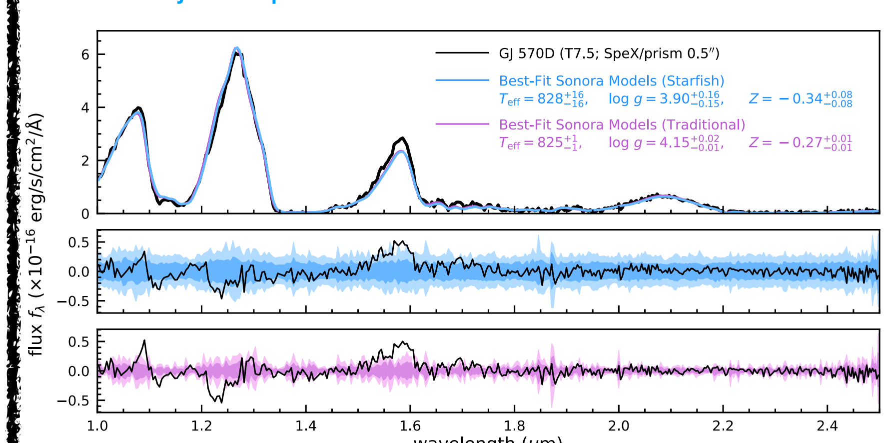
- We use the Cloudless Sonora Model Atmospheres (Marley et al. 2017) and the Bayesian inference tool Starfish (Czekala et al. 2015)
- We infer effective temperature ($T_{eff}$), surface gravity (log $g$), metallicity ($Z$), radii ($R$), and mass ($M$) for near-infrared (1.0-2.5μm) low-resolution (R~50-250) spectra.
- We account for uncertainties from model interpolation and correlated residuals due to instrumental effects and model systematics.
- We validate our framework by fitting the original model spectra using Starfish and finding negligible offsets between derived and input parameters.

Final Covariance Matrix = Traditional Covariance Matrix  + Emulator Covariance Matrix  + Global Covariance Matrix 

## Forward-Modeling Analysis of Late-T Dwarfs

**★ The Largest Spectroscopic Analysis of Brown Dwarfs**

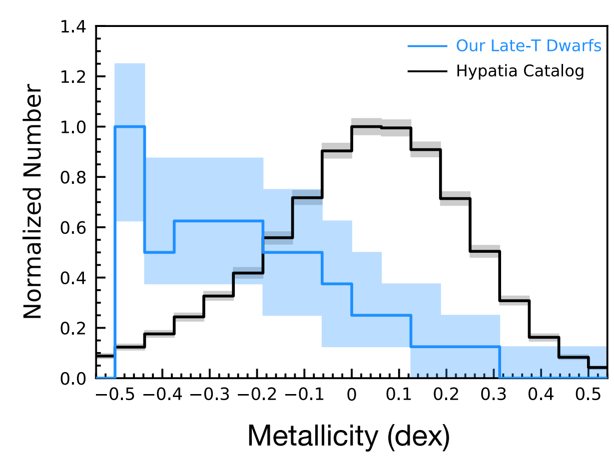
- We study 55 T7—T9 Dwarfs with IRTF/SpeX spectra and parallaxes.
- We find inferred {$T_{eff}$, log $g$, $Z$} errors are ~1/3–1/2 of model grid spacing.
- We quantify the log $g$-$Z$ degeneracy, as $\Delta$log $g$ ~ 3.4 x $\Delta Z$.
- We assess the systematics of the cloudless Sonora models are ~2%—4% of the objects' peak J-band fluxes.

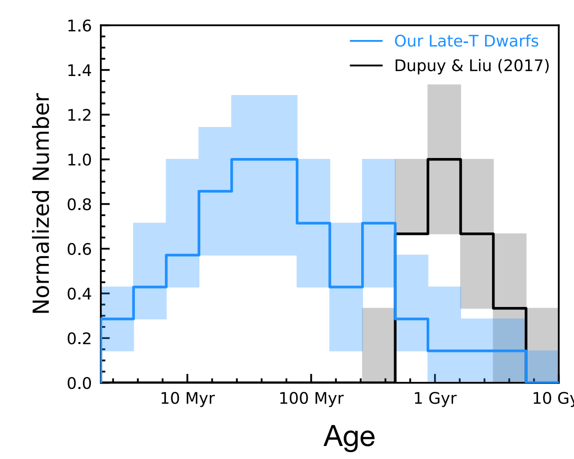



*Our framework derives robust parameters and more realistic errors than the traditional spectral-fitting approach (e.g., Cushing et al. 2008).*

**★ Metallicity & Age Distributions**

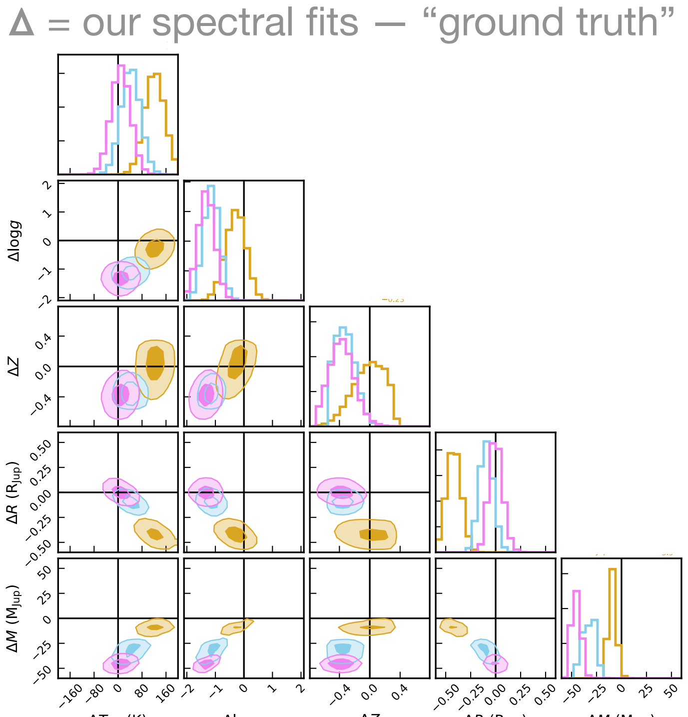
- Our work is the largest homogeneous study of brown dwarf metallicities.
- Our spectroscopically inferred $Z$ are 0.3–0.4 dex lower than nearby FGKM stars from the Hypatia catalog (Hinkel et al. 2014, 2016, 2017).
- Our spectroscopically inferred age are implausibly younger than the robust age based on the M8—T5 dynamical-mass sample (Dupuy & Liu 2017).




**★ Benchmarking against Wide-orbit Companions**

Δ = our spectral fits — "ground truth"




**HD 3651B** **GJ 570D**

Our spectral fits infer:

- accurate $T_{eff}$ and $R$
- underestimated log $g$ (~1.2 dex)
- underestimated $Z$ (~0.35 dex)

likely due to the model systematics from **potassium line profiles.**

**Ross 458C**

Our spectral fits infer:

- accurate log $g$ and $Z$
- overestimated $T_{eff}$ (~120 K)
- underestimated $R$ (~1.6x)

likely because models **lack clouds, reduced temperature gradient, or dis-equilibrium chemistry.**

**★ Stacked Spectral-Fitting Residuals**