Fundamental Properties of 1000+ Ultracool Dwarfs using Optical to Mid-infrared Spectral Energy Distributions

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Sanghi et al. 2023, *ApJ*, 959, 63 – asanghi@caltech.edu – cosmicoder.github.io

Scientific Goals

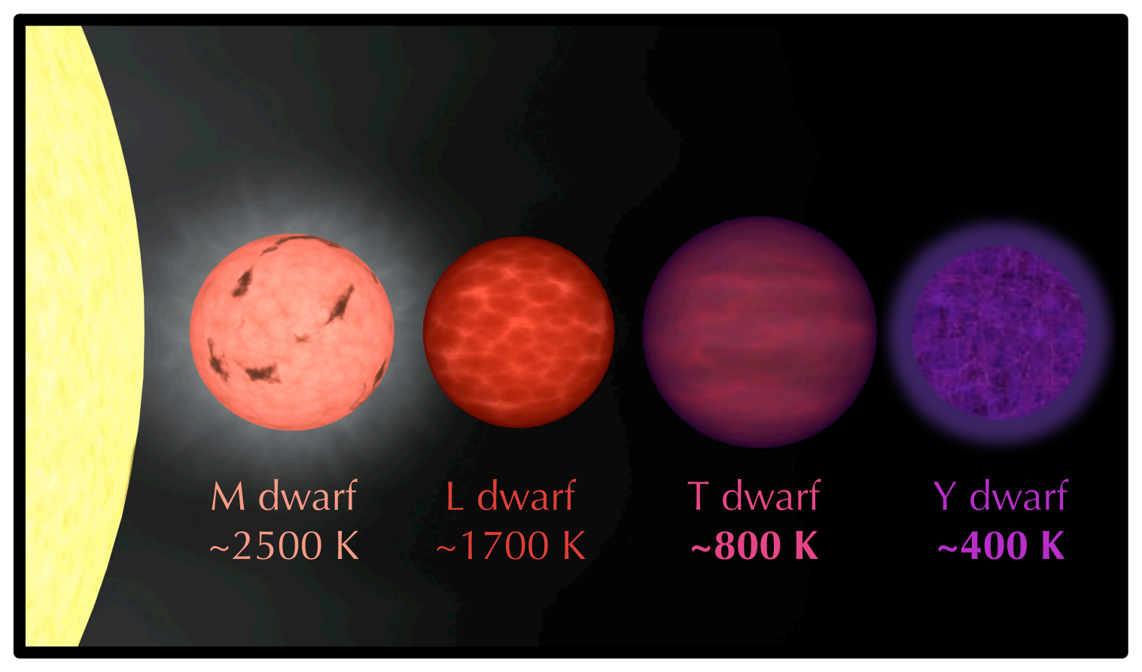


Figure 1. *Artist's rendition of the ultracool dwarf sequence with approximate surface temperatures. Credit: Robert Hurt/Michael Liu.*

- ✓ **Ultracool dwarfs** (UCDs) are objects with spectral type >M6, encompassing low mass stars, brown dwarfs, and giant planets.
- ✓ Investigating the **physical properties** of UCDs is crucial to understanding our Galaxy's star formation history and even characterizing exoplanets.
- ✓ Literature measurements of UCD properties rely on atmospheric model fits that are susceptible to numerous systematics. **Empirical measurements** are needed to better understand the nature of UCDs and calibrate models.

Techniques

Step 1:

Integrate the SED to get $f_{\rm bol}$

$$\int F_\lambda \, d\lambda = f_{bol}$$

Step 2:

Use distance to obtain $L_{\rm bol}$

$$f_{bol} \cdot 4\pi d^2 = L_{bol}$$

Step 3:

$L_{\rm bol}$ + ***Age***

Evolutionary Model

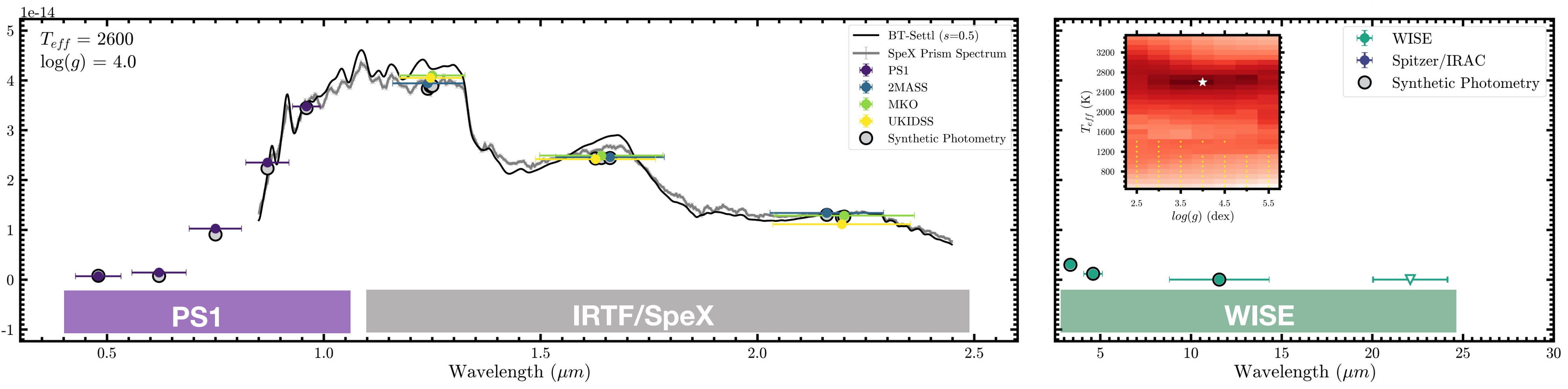
Mass, Radius, Gravity

Step 4:

S-B Equation

$$T_{\rm eff} = \left(\frac{L_{bol}}{4\pi R^2 \sigma_{SB}}\right)^{1/4}$$

Results



$$\int F_\lambda \, d\lambda = f_{bol} \quad \longrightarrow \quad f_{bol} \cdot 4\pi d^2 = L_{bol}$$

Figure 2. *Flux-calibrated SpeX spectrum (slit size = 0.5") of 2MASSI J0335020+234235 in gray with the corresponding photometry. The gray points represents model synthesized photometry. The black curve corresponds to the best-fit model. The inset figure shows the χ^2 surface for the atmospheric model fits to the SpeX spectrum in $T_{\rm eff}$ – log g space. The white star marks the location of the model-fit with the smallest χ^2. Yellow plus signs mark the $T_{\rm eff}$ – log g values at which the ATMO model-fit was preferred over the BT-Settl models based on its lower χ^2.*

> We generated the **largest sample** of ultracool dwarfs with ***empirically determined fundamental parameters*** (***$L_{\rm bol}$, M, R, log g, $T_{\rm eff}$***).

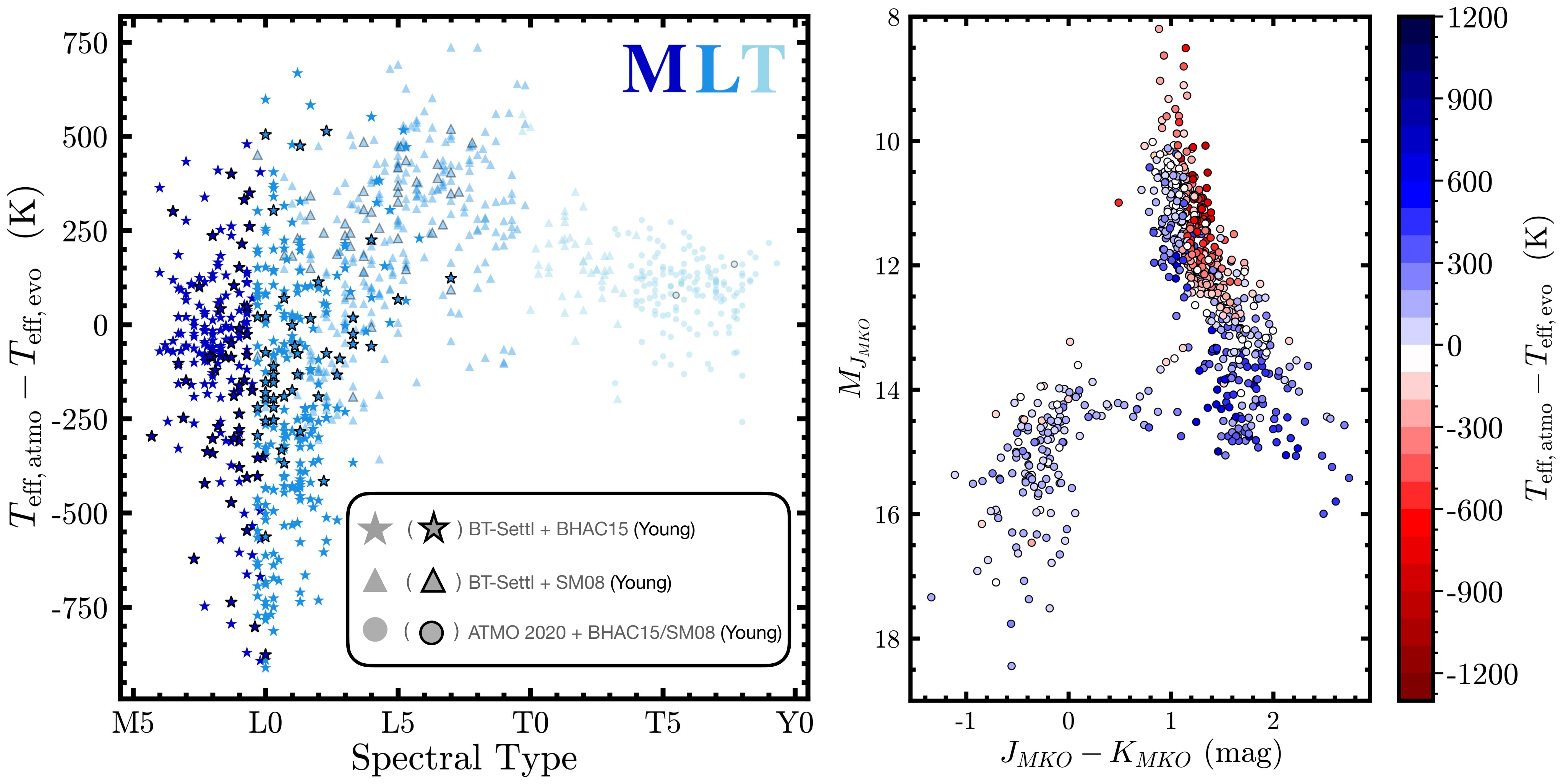


Figure 3. *Left: difference between the atmospheric model-derived effective temperatures and the evolutionary model-derived effective temperatures ($\Delta T_{\rm eff}$) as a function of spectral type. Objects are colored based on their spectral type where the darkest shade corresponds to M-dwarfs, the intermediate shade corresponds to L-dwarfs, and the lightest shade corresponds to T-dwarfs. Objects using the atmospheric-evolutionary model pairings of BT-Settl–BHAC15, BT-Settl–SM08, and ATMO 2020–BHAC15/SM08 are marked with a star, triangle, and circle, respectively. BT-Settl–BHAC15 objects are presented with a higher color opacity than BT-Settl–SM08 and ATMO 2020–BHAC15/SM08 objects to emphasize the greater reliability of $\Delta T_{\rm eff}$ trends for the former (self-consistently computed models). Symbols with black outlines mark young objects based on signatures of low surface gravity. Right: MKO M_J vs. $J - K$ color–magnitude diagram for ultracool dwarfs in our sample with each object colored by its corresponding $\Delta T_{\rm eff}$ value.*

Conclusion

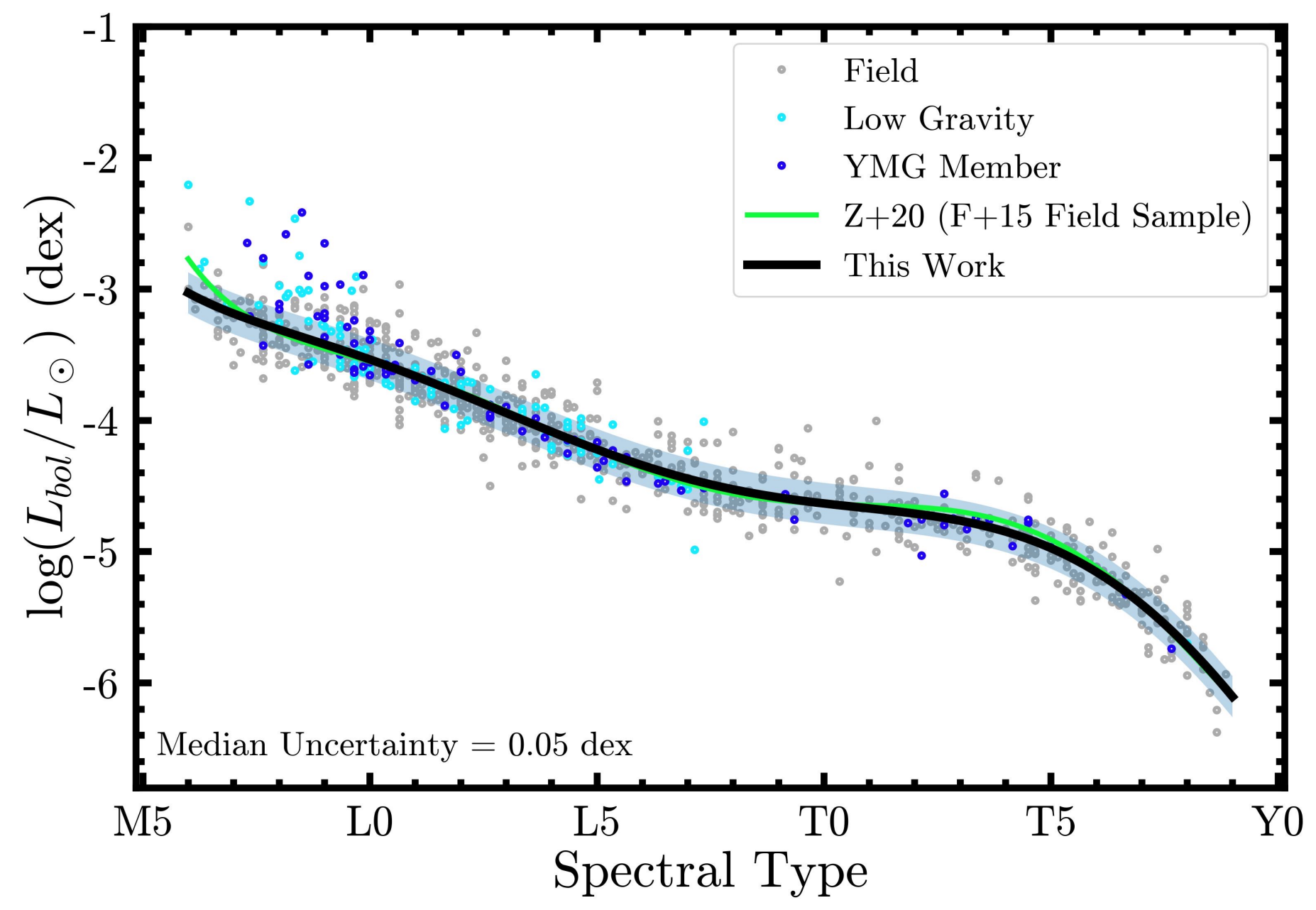


Figure 4. *$L_{\rm bol}$ derived for our sample of 1000+ ultracool dwarfs as a function of their spectral type. The polynomial relation derived using $L_{\rm bol}$ of 198 ultracool dwarfs from Filippazzo et al. (2015) is plotted in green for comparison.*

- ✓ We derived the bolometric luminosities, masses, radii, surface gravities, and effective temperatures of **1000+ ultracool dwarfs**.
- ✓ This work increases the number of ultracool dwarfs with empirically determined fundamental parameters by a **factor of ~5**.
- ✓ We construct **empirical relationships** for $L_{\rm bol}$ and Teff as functions of spectral type and absolute magnitude and determine bolometric corrections in optical and infrared bandpasses.
- ✓ Our sample enables a detailed characterization of BT-Settl and ATMO 2020 **atmospheric model systematics** as a function of spectral type. We find the greatest discrepancies between atmospheric and evolutionary model-derived $T_{\rm eff}$ (up to 800 K) at the M/L spectral type transition boundary.

Our fundamental parameter measurements enable rigorous tests of substellar formation, evolutionary, and atmospheric models.

Acknowledgements

AS acknowledges support from Research Experience for Undergraduate program at the Institute for Astronomy, University of Hawaii-Manoa funded through NSF grant #2050710.

References

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Related Research Note: Ultracool Dwarf Absolute Magnitude–SpT Relations for JWST/NIRCam Filters

Zenodo Dataset: Table of Ultracool Dwarf Fundamental Properties