

Discovery of Seven Cold and Distant Brown Dwarfs with JWST RUBIES

SARA J. MORRISSEY,^{1,2} ADAM J. BURGASSER,³ ANNA DE GRAAFF,^{4,5}
IAN MCCONACHIE,⁶ AND GABRIEL BRAMMER^{7,8}

¹*Department of Physics, UC San Diego, La Jolla, CA 92093, USA*

²*Department of Physics and Astronomy, University of Notre Dame, Notre Dame, Indiana 46556, USA*

³*Department of Astronomy & Astrophysics, UC San Diego, La Jolla, CA 92093, USA*

⁴*Max-Planck-Institut für Astronomie, Königstuhl 17, D-69117, Heidelberg, Germany*

⁵*Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, MA 02138, USA*

⁶*Department of Astronomy, University of Wisconsin-Madison, 475 N. Charter St., Madison, WI 53706 USA*

⁷*Cosmic Dawn Center (DAWN), Copenhagen, Denmark*

⁸*Niels Bohr Institute, University of Copenhagen, Jagtvej 128, Copenhagen, Denmark*

(Accepted 2025 Nov 11)

Submitted to AJ

ABSTRACT

We report near-infrared spectral model fits to seven distant L- and T-type dwarfs observed with the JWST Near Infrared Spectrograph (NIRSpec) as part of the Red Unknowns: Bright Infrared Extragalactic Survey (RUBIES). Comparison of 0.9–2.5 μm near-infrared spectra of these sources to spectral standards indicates spectral types spanning L1 to T8 and spectrophotometric distances spanning 800–3,000 pc. Fits to three grids of spectral models yield atmosphere parameters and spectrophotometric distances largely consistent with our classifications, although fits to L dwarf spectra indicate missing components to the models. Three of our sources have vertical displacements from the Galactic plane exceeding 1 kpc, and have high probabilities of membership in the Galactic thick disk population. Of these, the L dwarf RUBIES-BD-3 (RUBIES-EGS-3081) is well-matched to subdwarf standards, while the early T dwarf RUBIES-BD-5 (RUBIES-UDS-170428) is best fit by metal-poor atmosphere models; both may be a thick disk or halo brown dwarfs. We critically examine the 1–5 μm spectra of the current sample of 1–2 kpc mid- and late-T dwarfs, finding that temperature, surface gravity, metallicity, and vertical mixing efficiency can all contribute to observed variations in near-infrared spectral structure and the strength of the 4.2 μm CO₂ band. This work aims to guide ongoing JWST, Euclid, and other space-based spectral surveys that are expected to uncover thousands of low-temperature stars and brown dwarfs throughout the Milky Way.

Keywords: Brown dwarfs (185) — L dwarfs (894) — T dwarfs (1679) — Milky Way disk (1050) — Milky Way stellar halo (1060) — Sky surveys (1464)

1. INTRODUCTION

Brown dwarfs are the lowest-temperature and lowest-mass “stars” in the Milky Way, with insufficient mass ($\lesssim 0.075 M_{\odot}$) to sustain core hydrogen fusion (Kumar 1962, 1963; Hayashi & Nakano 1963). While comprising a significant fraction of star-like objects in the Galactic disk ($\sim 20\%$; Reyl   2018; Kirkpatrick et al. 2021), these objects cool and dim over time, becoming exceedingly faint ($M_R \gtrsim 18$, $M_K \gtrsim 10$; Dahn et al. 2017). As such, the majority of low-temperature stars and brown dwarfs—classified as late-M, L, T and Y dwarfs—are detected in the immediate solar neighborhood ($\lesssim 100$ pc), and have predominantly solar elemental compositions. Only a small fraction of local dwarfs are metal-poor members of the Galactic thick disk ($\sim 12\%$) and halo populations ($\sim 0.5\%$; Juri   et al. 2008; Schneider et al. 2020). While rare, these long-lived sources are essential for understanding how metallicity influences the formation, evolution, and hydrogen-burning mass threshold of brown dwarfs, and can potentially trace dynamical evolution and chemical enrichment throughout the history of the Milky Way (Burgasser 2004a; Honaker & Gizis 2025).

The high infrared sensitivity of the current generation of space-based telescopes, including JWST (Rigby et al. 2023) and Euclid (Laureijs et al. 2011), has made it possible to identify and study brown dwarfs at considerably larger distances. Building on tools developed for deep imaging and spectroscopic surveys conducted with the Hubble Space Telescope (Pirzkal et al. 2009; Ryan et al. 2011; van Vledder et al. 2016; Aganze et al. 2022a), deep JWST surveys are now uncovering individual low-temperature stars and brown dwarfs beyond kiloparsec distances (Nonino et al. 2023; Langeroodi & Hjorth 2023; Wang et al. 2023; Burgasser et al. 2024; Holwerda et al. 2024; Hainline et al. 2024a,b; Tu et al. 2025a,b; Hainline et al. 2025). Early Euclid studies are uncovering hundreds of cool dwarfs to similar scales (  erjal et al. 2025; Mohandas et al. 2025; Dominguez-Tagle et al. 2025). Those surveys conducted at high galactic latitudes contain considerably higher fractions of thick disk and halo sources than in the local population, enabling more efficient and comprehensive studies of metal-poor low-mass stars and brown dwarfs.

In this article, we present the identification and spectral analysis of seven L and T dwarfs identified in deep spectroscopic data collected as part of the Red Unknowns: Bright Infrared Extragalactic Survey (RUBIES; de Graaff et al. 2025). In Section 2, we describe the design and data associated with the RUBIES survey, and our method for identifying brown dwarfs from the spectral data. In Section 3, we present an empirical analysis of the spectra, including template classification and spectrophotometric distance estimates. In Section 4, we fit the spectra to three sets of model grids to obtain robust estimates of atmospheric parameters and their uncertainties, and

evaluate the accuracy of the different grids over the broad range of spectral types in our sample. In Section 5, we quantify the probabilities of membership in the Galactic thin disk, thick disk, and halo populations, and critically assess the source of spectral variations among mid- and late-type T dwarfs in our sample. We summarize our results in Section 6.

2. SAMPLE

2.1. *RUBIES Survey Data*

RUBIES is a spectroscopic survey conducted with the JWST Near Infrared Spectrograph (NIRSpec; [Birkmann et al. 2022](#)). The survey is focused on detecting and characterizing massive galaxies at high redshifts, drawing on sources selected from JWST Near Infrared Camera (NIRCam) imaging data obtained in the Extended Groth Strip (EGS) by the Cosmic Evolution Early Release Science Survey (CEERS, JWST-ERS-1345, PI S. Finkelstein), and in the Ultra Deep Survey (UDS) by the Public Release IMaging for Extragalactic Research Survey (PRIMER, JWST-GO-1837, PI J. Dunlap). RUBIES prioritizes very red sources, and thus has a higher chance of observing brown dwarfs than surveys with differing color selection. All RUBIES sources were acquired using the NIRSpec micro-shutter array (MSA; [Ferruit et al. 2022](#)) with a three-shutter slitlet, with total integrations of 48 minutes acquired in each of the low-resolution Prism/Clear mode ($0.6\text{--}5.3\ \mu\text{m}$, $\lambda/\Delta\lambda = 30\text{--}300$) and the medium-resolution G395M/F290LP mode ($2.9\text{--}5.3\ \mu\text{m}$, $\lambda/\Delta\lambda = 1000$), using a three-point nodding pattern. Spectra were reduced using the JWST calibration pipeline version 1.12.5 ([Bushouse et al. 2023](#)) and `msaexp` ([Brammer 2023](#)) as described in detail in [Heintz et al. \(2025\)](#) and [de Graaff et al. \(2025\)](#). Here, we focus on the NIRSpec/Prism data which provide the highest signal-to-noise (S/N) for our faint targets.

2.2. *Selection of Brown Dwarfs*

Our seven sources were selected among point sources identified in the CEERS/EGS and PRIMER/UDS NIRCam imaging data, with spectral data grades ≥ 2.5 (a quality assessment metric indicating the reliability of spectral features) and automated redshift estimates of $z < 0.1$. These criteria initially narrowed our selection to six sources in the EGS field and three sources in the UDS field. We visually inspected NIRCam images to ensure the sources were consistent with point sources, and visually confirmed that the NIRSpec/Prism spectra were consistent with low-temperature dwarf morphologies as opposed to active galactic nuclei or other compact extragalactic sources. This evaluation allowed us to reject two duplicate EGS sources⁹, resulting in a final sample of seven low-temperature stars and brown dwarfs, summarized in Table 1. We list fluxes in the NIRCam F115W, F150W, F200W, F277W, F356W,

⁹ The duplicate sources were the same spectra but processed by different versions of the `msaexp` code. We used the most recent reductions for the analysis presented in this article.

Table 1. Properties of the RUBIES Brown Dwarfs

Name	BD-1	BD-2	BD-3	Survey Information				BD-5	BD-6	BD-7
RUBIES ID	RUBIES-EGS-944743	RUBIES-EGS-35616	RUBIES-EGS-41280	RUBIES-EGS-30081	RUBIES-UDS-170428	RUBIES-UDS-170824	RUBIES-UDS-140125			
ASTRODEEP ID	CEERS-43510	CEERS-39492	CEERS-47111	CEERS-33796	PRIMER-UDS-133345	PRIMER-UDS-127017	PRIMER-UDS-95456			
Other ID	o006.s00089 ^a	o006.s35616 ^a	o005.s41280 ^a	...	...	...	...			
	CEERS-EGS-BD-4 ^b	...	...	...	...	...	...			
R.A. (J2000)	214°9'102828	214°9'38816	214°8'28434	214°9'29872	34°2'1396	34°2'58098	34°3'15054			
Decl. (J2000)	+52°8'60077	+52°8'73855	+52°8'10819	+52°8'56079	−5°10'655	−5°10'6006	−5°14'9353			
			NIRCam Photometry							
F115W f_{ν} (nJy)	71.1±2	933±4	224±3	21±2	22±6	24±7	160±7			
F150W f_{ν} (nJy)	38±3	1308±6	226±3	21±4	28±5	8±6	127±6			
F200W f_{ν} (nJy)	27±2	1520±6	233±3	23±3	30±4	6±5	109±5			
F277W f_{ν} (nJy)	13.3±1.9	1080±5	154±2	16±3	24±3	2±4	69±3			
F356W f_{ν} (nJy)	40.0±1.5	1386±3	207±2	40±2	63±3	22±3	153±4			
F444W f_{ν} (nJy)	114±3	1134±5	182±3	38±3	79±4	83±5	371±5			
mF115W (AB mag)	26.77±0.06	23.97±0.05	25.53±0.05	28.11±0.13	28.06±0.28	27.9±0.3	25.89±0.07			
mF150W (AB mag)	27.45±0.10	23.61±0.05	25.52±0.05	28.10±0.21	27.78±0.19	≥28.3	26.14±0.07			
mF200W (AB mag)	27.81±0.11	23.45±0.05	25.48±0.05	27.99±0.16	27.71±0.15	≥28.5	26.31±0.07			
mF277W (AB mag)	28.59±0.16	23.82±0.05	25.93±0.05	28.39±0.21	27.94±0.15	≥28.8	26.80±0.07			
mF356W (AB mag)	27.39±0.06	23.55±0.05	25.61±0.05	27.39±0.07	26.90±0.07	28.04±0.18	25.94±0.06			
mF444W (AB mag)	26.26±0.06	23.76±0.05	25.75±0.05	27.44±0.10	26.66±0.07	26.61±0.08	24.98±0.05			
			NIRSpec/Prism Spectroscopy							
1.2 μm S/N	5	54	14	3.2	6	1.9	17			
4.0 μm S/N	8	22	7	1.2	8	5	12			

^a As reported in Tu et al. (2025a).^b As reported in Hainline et al. (2024a).

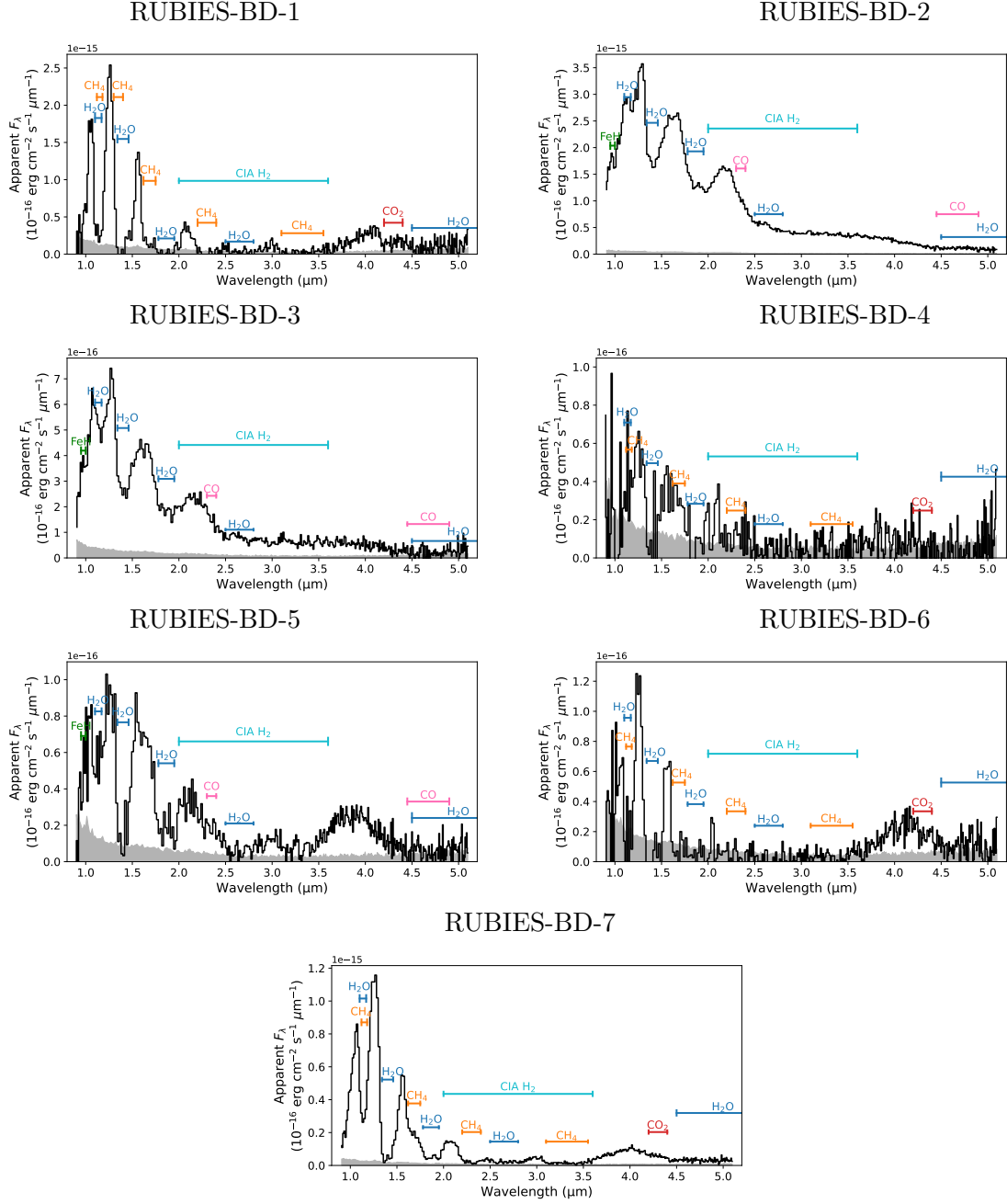


Figure 1. NIRSpec/Prism spectra of the seven RUBIES brown dwarfs identified in this study (black lines). Spectra are shown in apparent F_{λ} flux densities after scaling to their F444W magnitudes, and uncertainties are indicated in grey. Key spectral features present in the 1–5 μm spectra of L and T dwarfs are labeled.

and F444W filters from the CEERS/EGS and PRIMER/UDS surveys as compiled in the ASTRODEEP-JWST catalog (Merlin et al. 2024). For the corresponding magnitudes, we conservatively include a systematic uncertainty of 0.05 mag to account for zeropoint errors. Three of the sources—RUBIES-BD-1, -2, and -3—were reported previously by Hainline et al. (2024a) and Tu et al. (2025a), whose results we discuss below in comparison with our findings.

Figure 1 displays the NIRSpec/Prism spectra for these sources, flux-calibrated to their apparent F444W magnitudes and presented in F_λ flux density units.¹⁰ RUBIES-BD-1, -6, and -7 exhibit sharp flux peaks at 1.0, 1.25, 1.6, and 2.1 μm , and a broad peak at 4 μm , all shaped by strong H_2O and CH_4 bands that are typical of T dwarfs (Burgasser et al. 2006; Sorahana & Yamamura 2012; Beiler et al. 2024a). RUBIES-BD-2 displays broader flux peaks at 1.2, 1.65, and 2.15 μm between strong H_2O absorption bands; and a blue, relatively featureless spectral slope toward longer wavelengths, typical of L dwarfs (Cushing et al. 2005; Sorahana & Yamamura 2012). RUBIES-BD-3, -4, and -5 have features intermediate between these morphological types (only marginally discernible in the spectrum of our faintest target RUBIES-BD-4), suggesting that they are late-L or early-T dwarfs. RUBIES-BD-3 also shows a peculiar split in the 1.2 μm band and a bluer overall spectral morphology which may be associated with subsolar metallicity, as discussed below.

2.3. Classification and Distance Estimation

Spectral classifications for these sources were determined by comparing their 0.9–2.4 μm spectra to L and T dwarf spectral standards defined in Kirkpatrick et al. (2010) and Burgasser et al. (2006), respectively. Near-infrared spectral data for these standards were drawn from the SpeX Prism Library Analysis Toolkit (Burgasser & Splat Development Team 2017); see associated references in Table 7 of the Appendix. We also selected low-metallicity L and T dwarf spectral standards encompassing mild subdwarf (d/sd), subdwarf (sd), and extreme subdwarf (esd) classes as defined in Zhang et al. (2017b, 2018a); Greco et al. (2019); and Burgasser et al. (2025b), drawing on published near-infrared spectral data acquired with various instruments for comparison (see Appendix). All spectra were smoothed and interpolated onto the same wavelength grid corresponding to the NIRSpec/Prism data. For our source spectra, we also applied small fractional pixel shifts of up to 1.5 pixels before interpolation, as determined by visual comparison to the best-fit standards, to account for variations in the projection of spectral data on the NIRSpec detector from the MSA slits.

For RUBIES-BD-1, -2, -3, -6, and -7, the best-fitting standard was identified by minimizing the χ^2 statistic:

$$\chi^2 = \sum_{i=1}^n \left(\frac{O[\lambda_i] - \alpha S[\lambda_i]}{\sigma[\lambda_i]} \right)^2 \quad (1)$$

where $O[\lambda]$ is the observed flux density of the source, $\sigma[\lambda]$ are the associated uncertainties, $S[\lambda]$ is the standard spectrum flux density, and α is an optimal scaling factor that minimizes χ^2 :

$$\alpha = \left(\sum_{i=1}^n \frac{O[\lambda_i] S[\lambda_i]}{\sigma^2[\lambda_i]} \right) / \left(\sum_{i=1}^n \frac{S^2[\lambda_i]}{\sigma^2[\lambda_i]} \right) \quad (2)$$

¹⁰ Flux-calibrated spectra for these sources are provided as data behind the figure in the online version of this article.

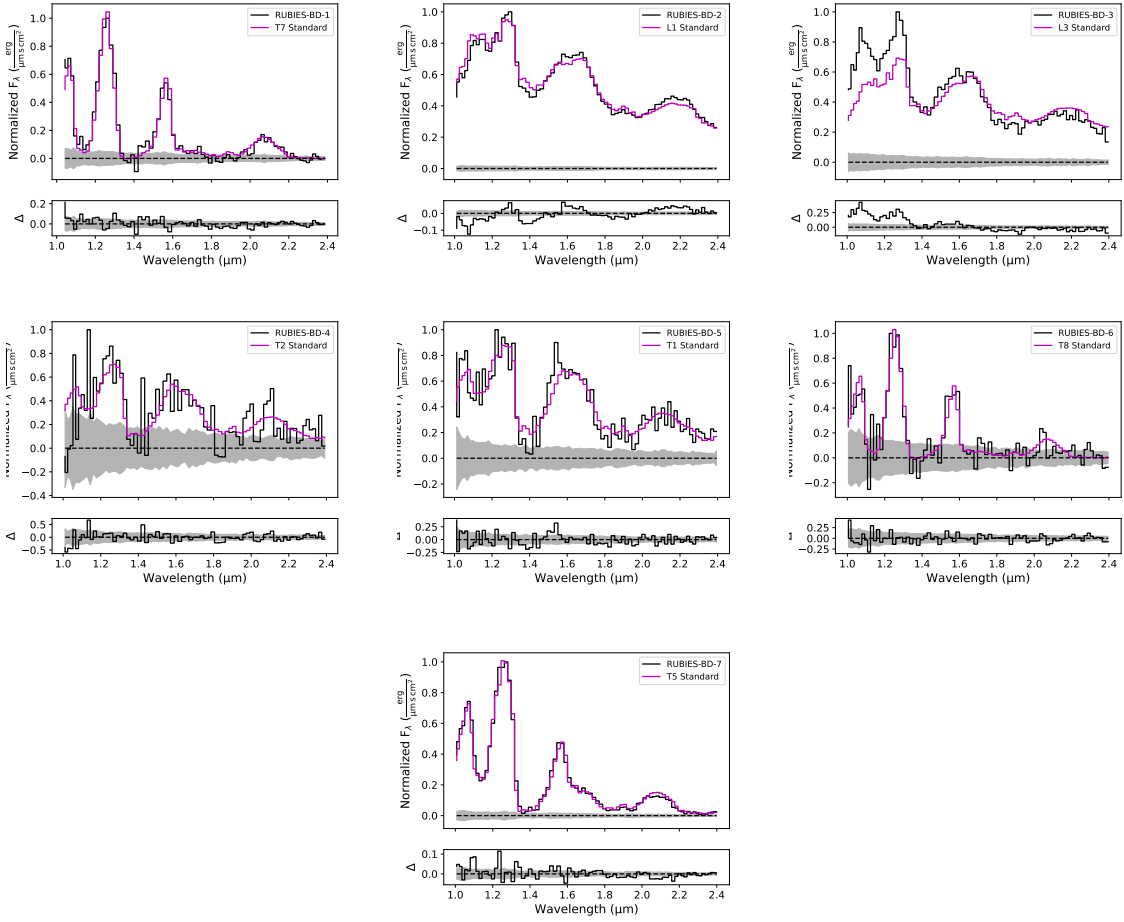


Figure 2. RUBIES brown dwarf spectra in the 0.9–2.5 μm range (black lines with uncertainties as grey shading) compared to best fit dwarf spectral standards (magenta lines). RUBIES spectra are normalized to the 1.2–1.3 μm peak, and standards are scaled to minimize χ^2 (Eqn. 2). The bottom panels of each plot show the difference between source and standard spectra (Δ) in black, compared to the uncertainty shaded in grey.

(cf. Cushing et al. 2005). For RUBIES-BD-4 and -5, the spectral S/N is sufficiently low that the χ^2 statistic cannot differentiate between adjacent standards, so we conducted a “by-eye” comparison to the spectral standards to identify an approximate best fit while allowing for generous uncertainties.

Sources and their associated best-fit standards are shown in Figure 2 and summarized in Table 2. RUBIES-BD-1, -2, -6, and -7 are well-matched to T7, L1, T8, and T5 dwarf standards, respectively, and we estimate uncertainties of 0.5 subtypes for these sources. For RUBIES-BD-4 and -5, our best “by-eye” fits are to the T2 and T1 standards, respectively, with deviations generally consistent with the lower S/N of the spectra. For these sources, we estimate larger classification uncertainties of ± 3 and ± 2 subtypes, respectively. For RUBIES-BD-3, the minimum χ^2 among the dwarf standards is achieved for the L3 dwarf, but there are significant discrepancies in the 1.0–1.4 μm J -band region. We therefore compared this spectrum to the broader

Table 2. Classification and Distances of RUBIES Brown Dwarfs

Name	Unit	BD-1	BD-2	BD-3	BD-4	BD-5	BD-6	BD-7
Classifications								
$\Delta\lambda^a$	(μm)	−0.010	−0.020	−0.032	+0.046	−0.018	0	−0.029
SpT		T7 $\pm$ 0.5	L1 $\pm$ 0.5	sd:L6 $\pm$ 1	T2 $\pm$ 3	T1 $\pm$ 2	T8 $\pm$ 1	T5 $\pm$ 0.5
Spectrophotometric Distance Estimates								
d_{F115W}	(pc)	1010 $^{+330}_{-270}$	1580 $^{+250}_{-210}$	1230 $^{+240}_{-200}$	2980 $^{+270}_{-220}$	2790 $^{+430}_{-370}$	1270 $^{+290}_{-250}$	1070 $^{+130}_{-110}$
d_{F150W}	(pc)	1000 $^{+890}_{-490}$	1520 $^{+240}_{-190}$	1580 $^{+300}_{-270}$	3270 $^{+690}_{-550}$	2860 $^{+320}_{-280}$	> 560	1010 $^{+220}_{-180}$
d_{F200W}	(pc)	950 $^{+980}_{-490}$	1410 $^{+160}_{-140}$	2050 $^{+340}_{-290}$	3130 $^{+1500}_{-1040}$	3020 $^{+660}_{-550}$	> 450	920 $^{+230}_{-190}$
d_{F277W}	(pc)	1070 $^{+700}_{-380}$	1060 $^{+180}_{-150}$	1870 $^{+190}_{-170}$	3400 $^{+1890}_{-1190}$	3080 $^{+780}_{-630}$	> 650	960 $^{+310}_{-220}$
d_{F356W}	(pc)	1280 $^{+600}_{-380}$	1320 $^{+140}_{-130}$	2290 $^{+180}_{-170}$	3200 $^{+1400}_{-1020}$	2820 $^{+620}_{-470}$	1070 $^{+290}_{-250}$	1050 $^{+220}_{-190}$
d_{F444W}	(pc)	960 $^{+220}_{-180}$	1250 $^{+140}_{-130}$	1850 $^{+190}_{-160}$	2700 $^{+640}_{-530}$	2010 $^{+270}_{-250}$	870 $\pm$ 120	690 $\pm$ 70
$\langle d \rangle$	(pc)	1000 $\pm$ 170	1320 $\pm$ 100	1870 $\pm$ 180 ^a	2990 $\pm$ 230	2500 $\pm$ 250	940 $\pm$ 140	830 $\pm$ 90

NOTE— $\Delta\lambda$ corresponds to the wavelength shift applied to the spectrum to align features with the best-fit standard. This shift is applied as a fractional pixel shift before spectra are interpolated onto a common wavelength grid, and accounts for variations in spectral projection on the NIRSpec detector by the MSA pixel mask.

^aSignificant variance among the individual filter distance estimates.

subdwarf grid (Figure 3), finding the d/sdL7 mild subdwarf and sdL5 subdwarf standards to be the best fits (minimum χ^2). We adopt a classification of sd:L6 $\pm$ 1 for this source.

With these classifications, we estimated distances to each source from NIRCcam photometry, using the spectral type/absolute magnitude conversions from Burgasser et al. (2024) based on the Sonora Bobcat models (Marley et al. 2021). For RUBIES-BD-1, -2, -4, -5, -6, and -7 we assumed a metallicity $[M/H] = 0.0$; for RUBIES-BD-3 we assumed $[M/H] = -0.5$. Uncertainties include contributions from the measured photometry and spectral classifications, and were combined using Monte Carlo techniques. Distance estimates are listed in Table 2, and are in agreement across all six filters for all of the sources with the exception of RUBIES-BD-3, which varies from 1230 $^{+240}_{-200}$ pc for F115W photometry to 2290 $^{+180}_{-170}$ pc for F356W photometry. This 3.6 σ discrepancy is likely associated with the metal-poor nature of the source. We computed uncertainty-weighted average distance estimates by using the higher of the lower and upper error bounds as the weighting factor ($w_i = 1/\sigma_i^2$), and computed the combined uncertainty as

$$\langle \sigma^2 \rangle = \left(\frac{\chi^2}{n-1} + 1 \right) / \left(\sum_{i=1}^n \frac{1}{\sigma_i^2} \right) \quad (3)$$

where $n = 3-6$ is the number of filters with distance estimates. This expression accounts for both the scatter among distance estimates and individual distance uncertainties. Distances range from 830 $\pm$ 90 pc for RUBIES-BD-7 to nearly 3 kpc for RUBIES-BD-4, with five of the sources having estimated distances exceeding 1 kpc.

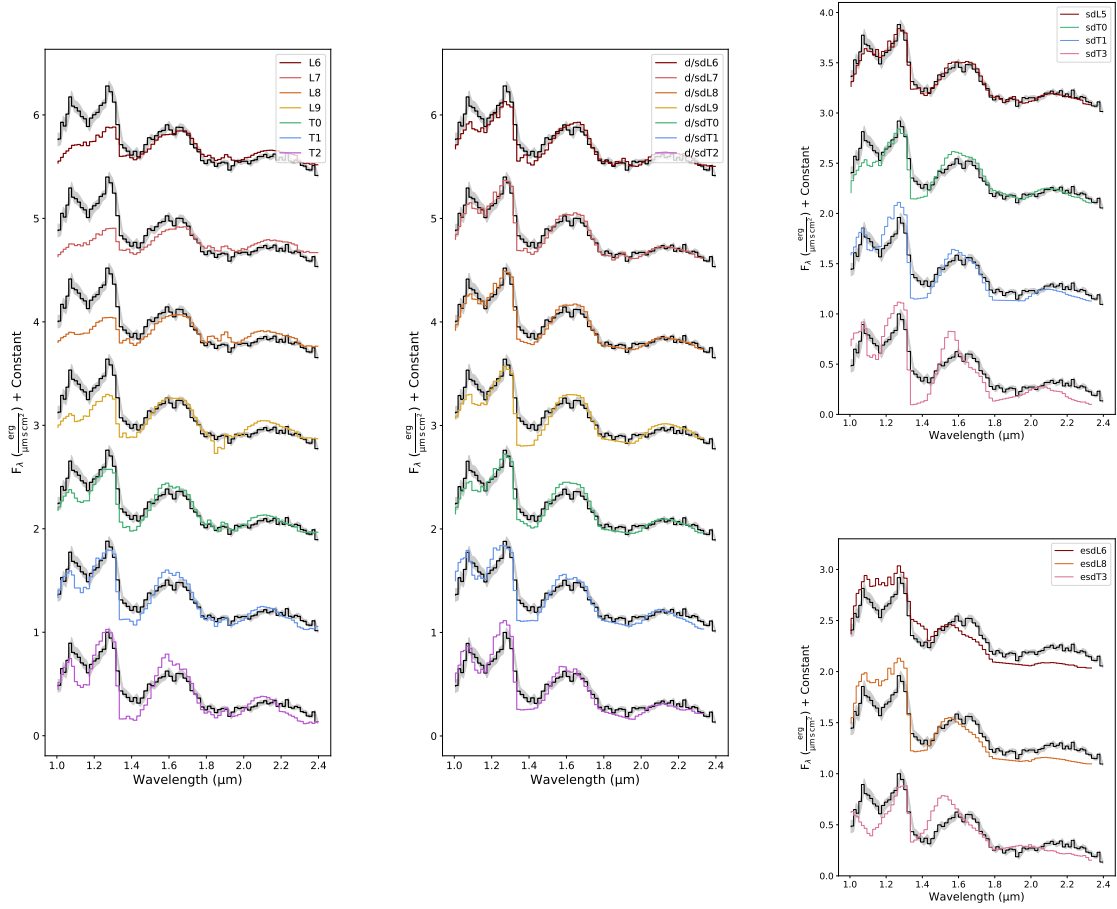


Figure 3. Comparison of the 0.9–2.5 μm NIRSpec/Prism spectrum of RUBIES-BD-3 (black line) to L6 to T2 dwarf standards (left panel); d/sdL6 to d/sdT2 mild subdwarf standards (center panel); sdL5, sdT0, sdT1, and sdT3 subdwarf standards (top right panel); and esdL6, esdL8, and esdT3 extreme subdwarf standards (bottom right panel). Standards are color-coded by spectral type. All spectra are normalized and offset by constants to facilitate comparison.

At the Galactic latitude $|b| \approx 60^\circ$ of the EGS and UDS fields, these distances correspond to vertical offsets from the disk plane $|Z| = d \sin |b| = 720$ to 2600 pc, extending into the volume dominated by thick disk objects (Jurić et al. 2008; Burgasser et al. 2024).

3. SPECTRAL MODEL FITS

3.1. Model Grids

To characterize the physical properties of these sources, we compared the NIRSpec spectra to three different model sets, allowing us to assess the quality of the fits across different model assumptions. Table 3 summarizes the models and associated parameter ranges explored. The Sonora Elf Owl models (Mukherjee et al. 2024) are cloud-free radiative-convective equilibrium models that include the effects

Table 3. Model Parameters

Parameter	Unit	Elf Owl [1]	Diamondback [2]	SAND [3,4]	σ_{var}^a
T_{eff}	(K)	500 to 2400	900 to 2400	700 to 3000	35
$\log g$	(cm s ⁻²)	4.5 to 5.5	4.5 to 5.5	4.5 to 6.0	0.2
$[M/H]$	(dex)	-0.5 to +0.5	-0.5 to +0.5	-0.35 to +0.3	0.2
$\log \kappa_{zz}$	(cm ² s ⁻¹)	2.0 to 9.0	...	...	0.25
C/O ^b	...	0.5 to 1.5	...	...	0.05
f_{sed}^c	...	...	1 to 10	...	0.25
$[\alpha/Fe]$	(dex)	...	...	-0.05 to +0.40	0.1

^aWidth of normal distribution for parameter updated in MCMC fitting.

^bRelative the Sun, for which we adopt a value of C/O = 0.458 (Lodders 2003).

^cA value of $f_{sed} = 10$ is adopted for Diamondback models without clouds; see Morley et al. (2024).

References— [1] Mukherjee et al. (2024); [2] Morley et al. (2024); [3] Alvarado et al. (2024); [4] Gerasimov et al. (2024).

of disequilibrium chemistry due to vertical mixing, and allow for variations in temperature (T_{eff}), surface gravity ($\log g$), bulk metallicity ($[M/H]$), the C/O elemental abundance ratio, and the vertical diffusion coefficient ($\log \kappa_{zz}$). We use the version of these models that have artificially suppressed PH₃ abundances (see Beiler et al. 2024b and Wogan et al. 2025). The Sonora Diamondback models (Morley et al. 2024) are based on the same framework but include refractory clouds in both the chemistry and atmospheric opacity using the approach of Ackerman & Marley (2001). These models are computed in chemical equilibrium and include an f_{sed} parameter to account for the efficiency of condensate sedimentation. Here, we adopt a value of $f_{sed} = 10$ to denote models without clouds. The SAND (Spectral ANalog of Dwarfs) model set (Gerasimov et al. 2024; Alvarado et al. 2024) is based on the PHOENIX code (Hauschildt et al. 1997), and was designed to explore the non-solar abundances of brown dwarfs in globular clusters and the Milky Way’s thick disk and halo. This grid samples variations in alpha element enrichment ($[\alpha/Fe]$), accounts for self-consistent condensation and gravitational settling of clouds following Allard et al. (2012), and assumes chemical equilibrium.

All data and models were interpolated onto a common wavelength scale that matches the variable resolution and wavelength sampling of the NIRSpec/Prism mode, and were evaluated in F_λ flux density units scaled to each source’s apparent F444W magnitudes. Because the models are computed in surface flux densities, the optimal scaling factory α between data and models (Eqn. 2) is equal to the ratio $(R/d)^2$, where R is the radius of the source and d its distance. We assumed a fixed radius of 0.8 R_{Jup} , as expected for an evolved, relatively massive brown dwarf.¹¹ (Marley

et al. 2021) This scale factor provides a second estimate of the source distance of $d = 1.85 \times 10^{-9} \alpha^{-0.5}$ pc.

3.2. Markov Chain Monte Carlo Fitting

We used the `ucdmcmc` package v1.2 (Burgasser et al. 2025) to fit the three model sets to our brown dwarf spectra. Spectra and models were compared using the same chi-square statistic as Eqn. 1. A first fit was conducted to identify the best individual model within a model set based on the minimum χ^2 value. These model parameters were then used to initiate a Metropolis-Hastings Markov Chain Monte Carlo (MCMC) algorithm (Metropolis et al. 1953; Hastings 1970) to determine the overall best-fit parameters and their uncertainties from the posterior distributions. Model logarithmic flux densities were linearly interpolated between grid points over logarithmic parameter values (e.g., T_{eff} interpolates as $\log T_{eff}$). The MCMC algorithm proposes a new set of parameters by varying the previous set using normal distributions with the fixed widths σ_{var} listed in Table 3. The difference between the χ^2 values of the proposed ($i + 1$) and previous (i) parameters were compared to the overall minimum χ^2 , which in turn was compared to a random number drawn from a uniform distribution between 0 and a threshold value T :

$$\frac{\chi_{i+1}^2 - \chi_i^2}{\chi_{min}^2} \leq U(0, T). \quad (4)$$

If this condition was satisfied, the proposed parameters were adopted; otherwise, the current parameters were retained. Through experimentation, we found an optimal value of $T = 0.1$. The MCMC algorithm proceeds over 5,000 steps in a single chain, and the first 25% of the chain was removed for burn-in. Convergence was assessed based on the consistency of the chains and the existence of single optimal values for well-fit parameters in the posterior distributions. Parameters and their uncertainties were computed as weighted quantiles of the marginalized distribution across the chain, using the weighting function:

$$w_i = \frac{DOF}{DOF + \chi_i^2 - \chi_{min}^2} \quad (5)$$

which accounts for the degrees of freedom $DOF = (740 \text{ spectral data points}) - (5-6 \text{ model parameters})$ for each model fit. We adopted the 50% quantile (median) as the fit value and the 16% and 84% quantiles as estimates of the lower and upper uncertainty bounds. For each set of models, we conducted separate fits for both the 0.9–2.4 μm near-infrared (NIR) range and the full 0.9–5.1 μm range of the NIR-Spec/Prism data.

¹¹ The assumed radius value was estimated from evolutionary models to account for the ages and observed properties of our sources. We simulated 10,000 low-mass stars and brown dwarfs with $0.01 M_{\odot} \leq M \leq 0.1 M_{\odot}$, assuming a uniform age distribution of 7–12 Gyr appropriate for the thick disk and halo (Xiang & Rix 2022), a mass distribution that scales $\frac{dN}{dM} \propto M^{-0.6}$ (Kirkpatrick et al. 2021), and solar metallicity evolutionary models from Burrows et al. (2001) and Baraffe et al. (2003) that are used to evolve observables to the present day. We further selected only those simulated sources with current effective temperatures $800 \text{ K} \leq T_{eff} \leq 2200 \text{ K}$ that encompasses our sample. The median radii of these samples are $0.078_{-0.001}^{+0.005} R_{\odot}$ and $0.080_{-0.001}^{+0.004} R_{\odot}$ for the two evolutionary models, respectively, indicating a 5% systematic uncertainty on our distance estimates, although there may be a larger systematic bias if model radii are incorrect.

4. RESULTS

Best fit models for each source and model set are displayed in Figures 4 and 5 and fit parameters are listed in Tables 4 and 5 for the 0.9–2.4 μm (NIR) and 0.9–5.1 μm (NIRSpec) regions, respectively. A summary of fit parameters across models is provided in Table 6, while a full list of parameter values and distribution visualizations are provided in a separate Zenodo link.¹² Here, we describe the outcomes of the fits and the physical interpretation of the fit parameters for individual sources.

4.1. RUBIES-BD-1

The best NIR and NIRSpec fits for this T7 dwarf are from the Elf Owl and Diamondback models, with a slight preference for the former with modest vertical mixing ($\log \kappa_{\text{zz}} = 3.1 \pm 1.0$ averaged between NIR and NIRSpec fits). The Diamondback models require very efficient sedimentation or no clouds ($f_{\text{sed}} = 9.5 \pm 0.4$). Averaging the results of the NIRSpec fits for these models yields $T_{\text{eff}} = 930^{+100}_{-80}$ K, $\log g = 4.9 \pm 0.4$, and $[\text{M}/\text{H}] = +0.1^{+0.3}_{-0.4}$, with Elf Owl models indicating a solar C/O ratio. The inferred effective temperature is slightly higher but consistent with previously established trends in spectral type (e.g., $T_{\text{eff}} = 830 \pm 130$ K for a $\text{T}7 \pm 0.5$ dwarf based on Filippazzo et al. 2015). This modest overshoot may be due to the best-fitting models failing to match the depth of the 1.6 μm CH_4 band or the strong CO_2 band at 4.1 μm (see discussion below). Nevertheless, the agreement in classification and model fit parameters indicate that this is a normal late T-type brown dwarf.

RUBIES-BD-1 was reported previously as CEERS-EGS-BD-4 in Hainline et al. (2024a), identified from multi-band JWST/NIRCam photometry. The photometric measurements were fit to three sets of atmosphere models: Sonora Bobcat and Sonora Cholla (Karalidi et al. 2021), precursors to Diamondback and Elf Owl models; and ATMO (Phillips et al. 2020). The fits yield $T_{\text{eff}} = 1000\text{--}1050$ K and $\log g = 5.0$, but no evaluation of metallicity. The authors infer a distance of 1350–1831 pc for estimated radii of 0.92–1.2 R_{Jup} , somewhat further than our estimate of 1030 ± 140 pc using a smaller radius estimate. RUBIES JWST/NIRSpec spectral data of this source were reported in Tu et al. (2025a), where the source is identified as o006_s00089. These authors compared the NIRSpec spectrum to Elf Owl and ATMO 2020++ (Meisner et al. 2023) model sets, the latter an updated version of the ATMO models. For the Elf Owl fits, the authors inferred a similar $T_{\text{eff}} = 955^{+16}_{-17}$ K but a considerably smaller $\log g = 4.34^{+0.18}_{-0.20}$, the latter outside the range considered in these fits, albeit formally consistent with our uncertainties. The authors also infer a much larger distance for this source, 2.0 ± 0.2 kpc, by assuming a radius of 1.2 R_{Jup} as suggested by the low surface gravity, but estimate a shorter distance of 1.4–1.7 kpc if the radius is constrained to 0.8–0.9 R_{Jup} . The authors find a significantly supersolar metallicity of $[\text{M}/\text{H}] = +0.41 \pm 0.05$ from their model fits, above but again formally consistent

¹² <https://zenodo.org/records/17585135>.

with our fits. [Tu et al. \(2025a\)](#) note that their parameter uncertainties, which are considerably smaller than those reported here, may be underestimated.

4.2. RUBIES-BD-2

The NIR spectrum for this L1 dwarf is best fit by the Diamondback models, while the full NIRSpec spectrum has equal χ_r^2 values between the Diamondback and SAND models. As both models include a prescription for cloud condensation and scattering, it is likely the presence of clouds that rules out the condensate-free Elf Owl models as a reliable fit. Indeed, Diamondback model fits to both the NIR and NIRSpec spectra require relatively thick clouds ($f_{sed} = 1.8 \pm 1.0$). However, despite providing the best fits, Figure 5 shows that the Diamondback and SAND models have difficulty reproducing the 0.9–2.4 μm spectral slope of RUBIES-BD-2, the former underestimating the 1.6 and 2.1 μm flux peaks and the latter overestimating the 1.2 and 1.6 μm peaks. We also find that the fits between the NIR and NIRSpec ranges yield marginally distinct temperatures, with $T_{\text{eff}} = 1760^{+140}_{-80}$ K for the former (Diamondback only) and $T_{\text{eff}} = 2040^{+60}_{-80}$ K for the latter (average of Diamondback and SAND), a 1.7σ difference. The higher temperature is more in line with local L1 $\pm$ 0.5 dwarfs ($T_{\text{eff}} = 2100 \pm 130$ K from [Filippazzo et al. 2015](#)). We also find a 3σ difference in the inferred $\log g$ value between the SAND models ($\log g = 4.22^{+0.26}_{-0.18}$) and Diamondback models ($\log g = 5.30^{+0.20}_{-0.25}$) based on fits to the NIRSpec data; and a 4σ discrepancy between our model-scaled distance estimate of 860^{+50}_{-60} pc and our spectrophotometric distance estimate of 1320 ± 100 pc. These deviations suggest that the Elf Owl, Diamondback, and SAND models all have difficulty reproducing the spectrum of RUBIES-BD-2, indicating potentially missing elements to the models.

RUBIES JWST/NIRSpec spectral data of this source were reported previously in [Tu et al. \(2025a\)](#), where the source is identified as o006_s35616. The authors compared these data to Elf Owl and BT-Settl CIFIST models ([Allard et al. 2012](#); [Caffau et al. 2011](#)), finding $T_{\text{eff}} = 1810\text{--}1910$ K, lower but consistent with our NIRSpec fits. However, the authors again infer a very low $\log g = 3.25 \pm 0.01$ and a supersolar $[\text{M}/\text{H}] = +1.00 \pm 0.01$ from their Elf Owl fits, inconsistent with our findings. [Tu et al. \(2025a\)](#) note significant residuals in their model fits, recognizing that neither the Elf Owl nor BT-Settl models include condensate opacity. They introduce a reddening parameter based on the interstellar extinction law of [Wang & Chen \(2024\)](#), and find that $A_V = 3$ mag substantially improves their Elf Owl model fits while yielding a substantially higher $T_{\text{eff}} = 2286^{+9}_{-8}$ K and subsolar $[\text{M}/\text{H}] = -0.71 \pm 0.02$. It is likely that a combination of atmospheric condensate opacity and interstellar reddening are required to accurately reproduce these data.

4.3. RUBIES-BD-3

As discussed in Section 2, RUBIES-BD-3 is better matched to subdwarf standards, suggesting that it should be well-matched to metal-poor atmosphere models. However, both NIR and NIRSpec fits yield consistently better fits to supersolar metallicity

models. In the NIR range, Elf Owl, Diamondback, and SAND models all yield comparable best-fit χ_r^2 values; in the NIRSpec range, the Elf Owl models are somewhat less reliable. Primary fit parameters of T_{eff} , $\log g$, and $[M/H]$ are in agreement across all three models and fit ranges, with a relatively high $T_{\text{eff}} = 2170 \pm 130$ K from the NIRSpec fits, notably warmer than the earlier-type L dwarf RUBIES-BD-2. Secondary parameters are similar to NIRSpec fits for RUBIES-BD-2, with all three models indicating relatively low surface gravities ($\log g = 4.7 \pm 0.4$), and for the Diamondback models thick clouds ($f_{\text{sed}} = 2.1^{+1.7}_{-0.9}$). The Elf Owl model fits also indicate a high C/O = $0.73^{+0.08}_{-0.10}$ and modest vertical mixing ($\log \kappa_{\text{zz}} = 3.6^{+2.2}_{-1.3}$). However, like RUBIES-BD-2, all three models have clear flaws in reproducing the observed spectrum, particularly in the NIR range where Elf Owl models show excess flux shortward of $1.3 \mu\text{m}$, and SAND models fail to match the shape of the $1.6 \mu\text{m}$ peak. None of the models accurately reproduce the $1.2 \mu\text{m}$ “notch” absorption feature that is characteristic of L- and T-type subdwarfs (Figure 3). Again, the models deployed for this seemingly metal-poor L dwarf may be missing a critical element of atmospheric chemistry, composition, or dynamics that may be skewing the fits toward higher metallicities.

Tu et al. (2025a) reported RUBIES JWST/NIRSpec spectral data for this source, identified as o005_s41280, and compared the data to Elf Owl and BT-Settl models. The authors find a similar $T_{\text{eff}} = 2160\text{--}2260$ K from these fits without taking into account reddening, with an approximately 200 K increase when a modest reddening of $A_V = 1.0\text{--}1.5$ mag is taken into account. In both cases, the authors find a very low surface gravity for this source, $\log g = 3.3\text{--}3.5$, well outside our fitting parameter range. As with RUBIES-BD-2, such a low surface gravity is highly unlikely for a field brown dwarf as it would require an age < 1 Myr (Chabrier et al. 2023).

4.4. RUBIES-BD-4

The relatively low S/N of the RUBIES-BD-4 spectrum results in equivalent matches among all three models in both NIR and NIRSpec ranges, and relatively large uncertainties in inferred parameters. The poorly-constrained $T_{\text{eff}} = 1800^{+300}_{-700}$ K is higher but not inconsistent with trends among solar metallicity dwarfs for its T2 $\pm$ 3 classification ($T_{\text{eff}} = 1180 \pm 200$ K; Filippazzo et al. 2015). Notably, SAND model fits to the NIRSpec data yield a considerably lower $T_{\text{eff}} = 1050^{+260}_{-230}$ K as compared to the other models, even though the best-fit model has a $T_{\text{eff}} = 1506$ K (Figure 5). Secondary parameters indicate efficient vertical mixing ($\log \kappa_{\text{zz}} = 7.8 \pm 1.0$ from Elf Owl models), thin clouds ($f_{\text{sed}} = 8.4 \pm 0.7$ from Diamondback models), and near-solar elemental abundances ($[M/H] = -0.1^{+0.6}_{-0.5}$ from all models, C/O = $0.54^{+0.21}_{-0.19}$ from Elf Owl models, and $[\alpha/M] = +0.17^{+0.17}_{-0.13}$ from SAND models). The large range in temperatures across the models results in a comparably large uncertainty in the estimated distance, from ~ 2000 pc for SAND to ~ 6400 pc for Diamondback, which straddle the highly uncertain 5400^{+2200}_{-3400} pc distance estimate inferred from its spectral type and NIRCам photometry (Table 2).

4.5. RUBIES-BD-5

RUBIES-BD-5 is best fit in both the NIR and NIRSpec ranges by the SAND models, yielding an atmospheric temperature $T_{\text{eff}} = 1270^{+80}_{-60}$ K that is in line with its T1 $\pm$ 2 classification ($T_{\text{eff}} = 1220 \pm 150$ K; Filippazzo et al. 2015). Figure 5 shows that the SAND models do a better job reproducing the 1–2.2 μm and 4.0 μm peaks compared to the Elf Owl and Diamondback models, both of which produce overly blue spectra. The NIRSpec SAND fits also yield a significantly subsolar metallicity ($[M/H] = -0.7^{+0.4}_{-0.3}$) and modest alpha enrichment ($[\alpha/M] = +0.19^{+0.14}_{-0.17}$), both indicative of a thick disk or halo origin.

4.6. RUBIES-BD-6

RUBIES-BD-6, like RUBIES-BD-4, has a relatively low S/N spectrum and is equally-well fit by all three models in both NIR and NIRSpec ranges, with a slight preference for the Elf Owl models in the latter. The NIRSpec fits yield an average $T_{\text{eff}} = 830 \pm 130$ K, high but consistent with its T8 $\pm$ 1 classification ($T_{\text{eff}} = 680 \pm 190$ K; Filippazzo et al. 2015). Given the large uncertainties, there is no evidence of a metallicity or elemental compositions significantly distinct from solar, while the Diamondback models require efficient sedimentation ($f_{\text{sed}} = 8.0^{+1.4}_{-0.7}$) as is typical for late T dwarfs.

4.7. RUBIES-BD-7

RUBIES-BD-7 is best fit in both the NIR and NIRSpec ranges by the Elf Owl and Diamondback models, the latter requiring very efficient sedimentation ($f_{\text{sed}} = 9.6 \pm 0.4$, consistent with no clouds). The inferred $T_{\text{eff}} = 1180 \pm 80$ K is consistent with other T5 $\pm$ 0.5 dwarfs ($T_{\text{eff}} = 1030 \pm 120$ K; Filippazzo et al. 2015), while the metallicity ($[M/H] = -0.2 \pm 0.3$) and Elf Owl C/O = $0.48^{+0.16}_{-0.12}$ are consistent with solar composition. The excellent agreement between the model scaling and spectrophotometric distances further indicate that this is likely a normal thin disk brown dwarf.

Table 4. MCMC Parameters for 0.9–2.4 μm Fits (NIR Range)

Model	T_{eff} (K)	$\log g$ (cm s^{-2})	$[M/H]$ (dex)	C/O	$\log \kappa_{\text{zz}}$ ($\text{cm}^2 \text{s}^{-1}$)	f_{sed}	$[\alpha/Fe]$ (dex)	d (pc)	Min. χ_r^2
RUBIES-BD-1 (T7 $\pm$ 0.5)									
E	890 $^{+70}_{-80}$	4.9 $\pm$ 0.3	0.2 $\pm$ 0.2	0.44 $^{+0.16}_{-0.10}$	2.9 $^{+1.3}_{-0.7}$	...	...	980 $^{+180}_{-170}$	2.8
D	960 $^{+70}_{-50}$	4.9 $^{+0.4}_{-0.3}$	0.1 $\pm$ 0.3	...	...	9.5 $^{+0.5}_{-0.4}$	...	1150 $^{+200}_{-140}$	3.0
S	770 $^{+130}_{-70}$	4.8 $^{+0.8}_{-0.3}$	0.12 $^{+0.13}_{-0.03}$	...	...	...	0.00 $^{+0.10}_{-0.03}$	660 $^{+370}_{-130}$	3.5
RUBIES-BD-2 (L1 $\pm$ 0.5)									
E	2120 $^{+110}_{-100}$	4.9 $^{+0.4}_{-0.3}$	0.37 $^{+0.13}_{-0.22}$	0.65 $^{+0.04}_{-0.06}$	2.8 $^{+1.5}_{-0.7}$	...	...	920 $^{+100}_{-90}$	77
D	1760 $^{+140}_{-80}$	5.30 $^{+0.17}_{-0.26}$	0.31 $^{+0.18}_{-0.25}$	...	...	2.0 $^{+1.3}_{-0.8}$	...	630 $^{+90}_{-60}$	19
S	1830 $\pm$ 30	5.51 $^{+0.06}_{-0.07}$	0.14 $^{+0.09}_{-0.04}$	...	...	...	−0.01 $^{+0.04}_{-0.03}$	650 $\pm$ 20	29
RUBIES-BD-3 (sd:L6 $\pm$ 1)									
E	2220 $^{+110}_{-90}$	4.7 $^{+0.4}_{-0.2}$	0.33 $^{+0.17}_{-0.21}$	0.62 $^{+0.06}_{-0.09}$	3.1 $^{+1.8}_{-0.9}$	...	...	2690 $^{+270}_{-210}$	3.8
D	1990 $^{+160}_{-120}$	5.0 $\pm$ 0.3	0.2 $\pm$ 0.3	...	...	2.8 $\pm$ 1.3	...	2150 $^{+350}_{-230}$	4.0
S	2250 $^{+140}_{-130}$	4.70 $^{+0.26}_{-0.17}$	0.16 $^{+0.14}_{-0.31}$	...	...	...	−0.01 $\pm$ 0.04	2760 $^{+330}_{-290}$	4.2
RUBIES-BD-4 (T2 $\pm$ 3)									
E	1870 $\pm$ 360	5.0 $\pm$ 0.4	−0.1 $^{+0.4}_{-0.3}$	0.47 $^{+0.14}_{-0.15}$	6 $^{+2}_{-3}$	...	...	6200 $^{+2600}_{-2300}$	1.8
D	1900 $^{+300}_{-370}$	5.0 $\pm$ 0.4	−0.0 $\pm$ 0.4	...	...	8.4 $^{+0.9}_{-1.0}$	...	6400 $^{+2100}_{-2200}$	1.7
S	1510 $^{+630}_{-340}$	5.2 $^{+0.6}_{-0.5}$	−0.0 $^{+0.3}_{-0.2}$	...	...	...	0.04 $^{+0.14}_{-0.09}$	4100 $^{+4100}_{-1800}$	1.7
RUBIES-BD-5 (T1 $\pm$ 2)									
E	1840 $^{+220}_{-190}$	5.0 $\pm$ 0.4	0.2 $\pm$ 0.3	0.48 $\pm$ 0.17	7.9 $\pm$ 0.8	...	...	4720 $^{+1230}_{-960}$	2.1
D	1640 $^{+280}_{-200}$	4.9 $\pm$ 0.3	0.1 $^{+0.3}_{-0.4}$	...	...	8.5 $^{+1.0}_{-1.1}$	...	3790 $^{+1360}_{-890}$	2.1
S	1370 $^{+190}_{-80}$	5.6 $^{+0.2}_{-0.5}$	0.0 $^{+0.2}_{-0.3}$	...	...	...	0.11 $^{+0.08}_{-0.14}$	2540 $^{+830}_{-290}$	1.6
RUBIES-BD-6 (T8 $\pm$ 0.5)									

Table 4 continued on next page

Table 4 (*continued*)

Model	T_{eff} (K)	$\log g$ (cm s^{-2})	$[M/H]$ (dex)	C/O	$\log \kappa_{zz}$ ($\text{cm}^2 \text{s}^{-1}$)	f_{sed}	$[\alpha/Fe]$ (dex)	d (pc)	Min. χ_r^2
E	840^{+210}_{-180}	$5.1^{+0.3}_{-0.4}$	$-0.0^{+0.4}_{-0.3}$	$0.52^{+0.11}_{-0.18}$	$4.1^{+1.9}_{-1.4}$	...	...	1460^{+900}_{-610}	1.0
D	990^{+180}_{-80}	$5.1^{+0.3}_{-0.4}$	-0.1 ± 0.3	...	...	$9.3^{+0.6}_{-1.3}$	...	2110^{+970}_{-360}	1.1
S	890^{+160}_{-180}	$5.6^{+0.3}_{-0.4}$	$0.13^{+0.14}_{-0.21}$	...	...	...	$0.11^{+0.07}_{-0.12}$	1660^{+770}_{-750}	1.0
RUBIES-BD-7 (T5±0.5)									
E	1140 ± 80	4.9 ± 0.4	$-0.2^{+0.3}_{-0.2}$	$0.41^{+0.15}_{-0.12}$	$4.1^{+1.2}_{-1.4}$	...	...	710 ± 100	13
D	1219 ± 100	$5.1^{+0.3}_{-0.4}$	$-0.2^{+0.3}_{-0.2}$	...	...	$9.5^{+0.5}_{-0.4}$	...	850 ± 150	15
S	1100^{+90}_{-150}	$5.75^{+0.18}_{-0.24}$	$-0.1^{+0.3}_{-0.2}$	...	...	...	$0.12^{+0.08}_{-0.17}$	670^{+120}_{-200}	18

NOTE—Model labels are: E = Elf Owl (Mukherjee et al. 2024), D = Diamondback (Morley et al. 2024), and S = SAND (Gerasimov et al. 2024; Alvarado et al. 2024).

Table 5. MCMC Parameters for 0.9–5.1 μ m Fits (NIRSpec Range)

Model	T _{eff} (K)	log g (cm s ⁻²)	[M/H] (dex)	C/O	log κ_{zz} (cm ² s ⁻¹)	f_{sed}	[α/Fe] (dex)	d (pc)	Min. χ_r^2
RUBIES-BD-1 (T7 $\pm$ 0.5)									
E	890 $\pm$ 80	5.0 $\pm$ 0.4	0.2 $^{+0.4}_{-0.3}$	0.46 $^{+0.15}_{-0.12}$	3.3 $^{+1.6}_{-1.0}$	...	...	980 $\pm$ 170	2.6
D	980 $^{+90}_{-60}$	4.9 $^{+0.5}_{-0.6}$	0.0 $^{+0.3}_{-0.4}$	...	...	9.4 $^{+0.5}_{-0.7}$	...	1180 $^{+250}_{-150}$	3.1
S	960 $^{+100}_{-80}$	5.7 $\pm$ 0.2	0.21 $^{+0.09}_{-0.16}$	...	...	...	0.03 $^{+0.13}_{-0.05}$	1190 $^{+280}_{-190}$	4.0
RUBIES-BD-2 (L1 $\pm$ 0.5)									
E	2150 $^{+140}_{-110}$	4.7 $^{+0.4}_{-0.2}$	0.7 $^{+0.3}_{-0.4}$	0.65 $^{+0.04}_{-0.07}$	3.0 $^{+1.8}_{-0.7}$	...	...	940 $^{+120}_{-90}$	49
D	2020 $^{+90}_{-100}$	5.30 $^{+0.20}_{-0.25}$	0.3 $^{+0.2}_{-0.3}$	...	...	1.6 $^{+1.4}_{-0.6}$	...	840 $^{+70}_{-80}$	24
S	2050 $\pm$ 50	4.22 $^{+0.26}_{-0.18}$	-0.0 $^{+0.2}_{-0.4}$	...	...	...	-0.05 ^a	860 $^{+40}_{-30}$	24
RUBIES-BD-3 (sd:L6 $\pm$ 1)									
E	2220 $^{+120}_{-90}$	4.8 $^{+0.4}_{-0.2}$	0.7 $^{+0.3}_{-0.4}$	0.61 $^{+0.06}_{-0.09}$	3.6 $^{+2.2}_{-1.3}$	...	...	2650 $^{+270}_{-210}$	3.3
D	2060 $^{+120}_{-110}$	4.8 $^{+0.5}_{-0.6}$	0.2 $^{+0.3}_{-0.4}$	...	...	2.1 $^{+1.7}_{-0.9}$	...	2290 $^{+260}_{-210}$	2.8
S	2190 $^{+120}_{-90}$	4.4 $^{+0.4}_{-0.3}$	0.1 $^{+0.2}_{-0.5}$	...	...	...	-0.039 $^{+0.068}_{-0.011}$	2600 $^{+260}_{-200}$	2.7
RUBIES-BD-4 (T2 $\pm$ 3)									
E	1890 $^{+300}_{-450}$	5.1 $^{+0.3}_{-0.4}$	0.2 $^{+0.7}_{-0.8}$	0.45 $^{+0.17}_{-0.15}$	8.0 $^{+0.8}_{-0.9}$	...	...	6100 $^{+2000}_{-2400}$	2.2
D	1930 $^{+240}_{-220}$	5.0 $^{+0.4}_{-0.6}$	0.1 $^{+0.3}_{-0.4}$	...	...	8.5 $\pm$ 1.1	...	6400 $^{+1700}_{-1300}$	2.3
S	1050 $^{+260}_{-230}$	5.0 $^{+0.6}_{-0.7}$	-0.4 $^{+0.5}_{-0.6}$	...	...	...	0.17 $^{+0.17}_{-0.13}$	1960 $^{+980}_{-590}$	2.1
RUBIES-BD-5 (T1 $\pm$ 2)									
E	1570 $^{+310}_{-240}$	5.0 $\pm$ 0.4	0.1 $\pm$ 0.5	0.42 $^{+0.20}_{-0.15}$	8.1 $^{+0.7}_{-0.8}$	...	...	3140 $^{+1430}_{-850}$	3.7
D	1410 $^{+210}_{-140}$	4.2 $^{+0.5}_{-0.2}$	0.2 $^{+0.2}_{-0.4}$	...	...	8.0 $^{+0.9}_{-0.7}$	...	2550 $^{+920}_{-440}$	3.0
S	1270 $^{+80}_{-70}$	5.0 $^{+0.5}_{-0.4}$	-0.7 $\pm$ 0.4	...	...	...	0.19 $^{+0.14}_{-0.17}$	2050 $^{+280}_{-210}$	1.6
RUBIES-BD-6 (T8 $\pm$ 0.5)									

Table 5 continued on next page

Table 5 (*continued*)

Model	T _{eff} (K)	log g (cm s ⁻²)	[M/H] (dex)	C/O	log κ_{zz} (cm ² s ⁻¹)	f_{sed}	[α/Fe] (dex)	d (pc)	Min. χ_r^2
E	730 ⁺¹²⁰ ₋₈₀	5.0 ± 0.3	-0.3 ^{+0.6} _{-0.4}	0.39 ^{+0.19} _{-0.12}	3.7 ^{+1.8} _{-1.3}	...	...	1010 ⁺³⁰⁰ ₋₂₀₀	1.1
D	940 ⁺⁸⁰ ₋₄₀	5.0 ^{+0.3} _{-0.5}	-0.2 ± 0.3	...	...	8.0 ^{+1.4} _{-0.7}	...	1600 ⁺²⁸⁰ ₋₁₃₀	1.4
S	800 ⁺¹⁶⁰ ₋₈₀	5.7 ^{+0.2} _{-0.4}	0.11 ^{+0.15} _{-0.53}	...	...	...	0.04 ^{+0.13} _{-0.06}	1220 ⁺⁴⁹⁰ ₋₂₂₀	1.3
RUBIES-BD-7 (T5±0.5)									
E	1170±80	4.8 ^{+0.4} _{-0.3}	-0.3 ± 0.3	0.40 ^{+0.14} _{-0.10}	3.3 ^{+1.2} _{-0.9}	...	...	750 ⁺¹⁰⁰ ₋₉₀	7
D	1186±90	5.0 ± 0.4	-0.1 ± 0.3	...	...	9.6 ± 0.4	...	800 ⁺¹³⁰ ₋₁₁₀	8
S	1170 ⁺⁹⁰ ₋₆₀	5.79 ^{+0.15} _{-0.19}	-1.7 ^{+1.2} _{-0.6}	...	...	...	-0.05 ^a	810 ⁺¹²⁰ ₋₇₀	14

NOTE—Model labels are: E = Elf Owl (Mukherjee et al. 2024), D = Diamondback (Morley et al. 2024), and S = SAND (Gerasimov et al. 2024; Alvarado et al. 2024).

^aMCMC fits were unable to converge on this parameter.

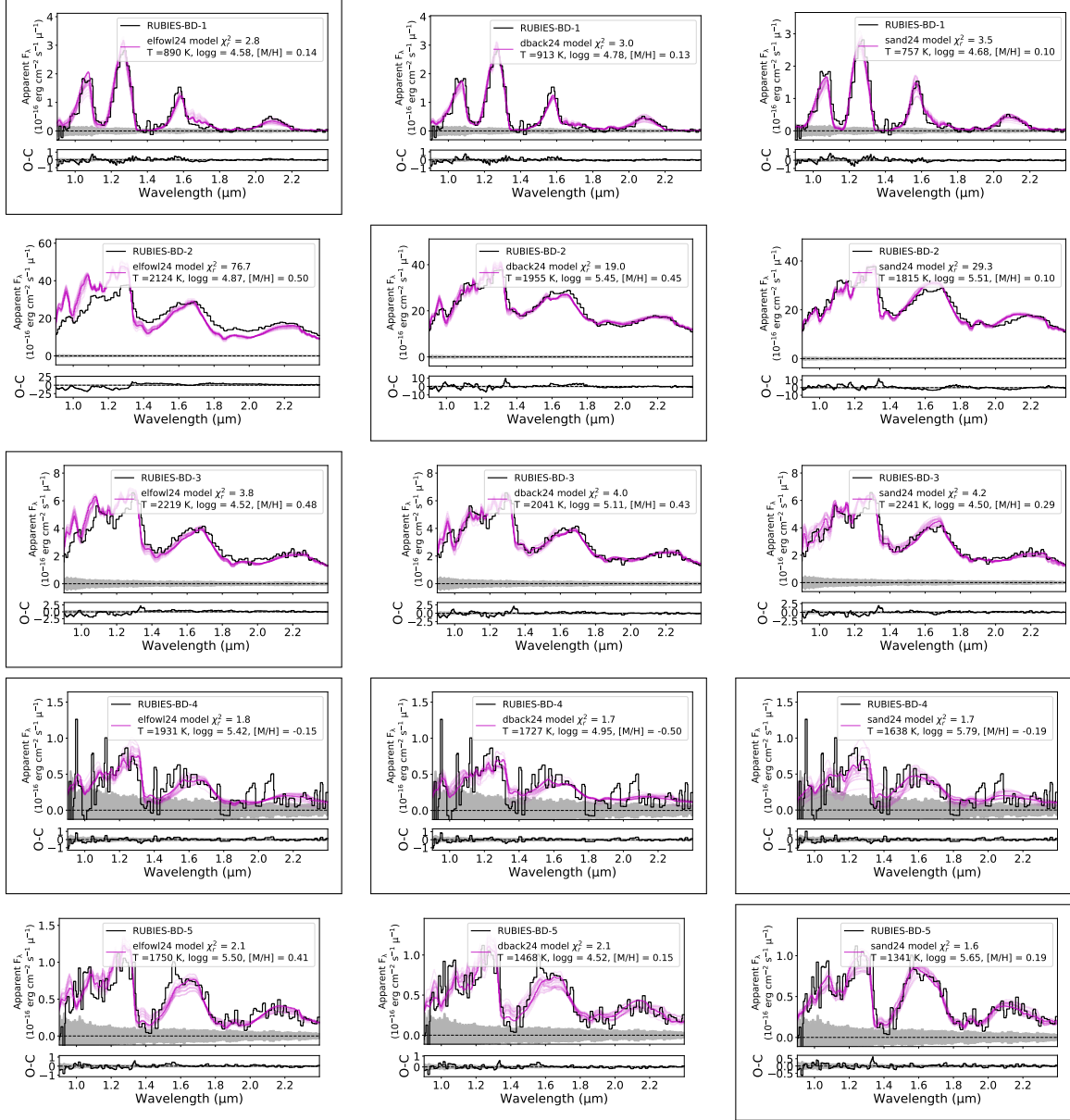


Figure 4. Markov Chain Monte Carlo fits to NIRSpec/Prism data constrained to the NIR (0.9-2.4 μm) range. Each row corresponds to one of the RUBIES brown dwarf spectra scaled to apparent F444W magnitudes (black lines), while the columns separate fits to the Elf Owl (left), Diamondback (middle) and SAND (right) models. Both the best-fit models (solid magenta lines) and draws from the posterior distribution (semi-transparent magenta lines) are shown, and the $\pm 1\sigma$ spectral uncertainties are indicated by the grey band. Below each spectral comparison, we compare the difference between the source and best-fit model fluxes (O-C as black lines) to the $\pm 1\sigma$ spectral uncertainties (grey bands). Panels that are surrounded by boxes indicate models that provide the best fits, including equivalent cases (see Table 6).

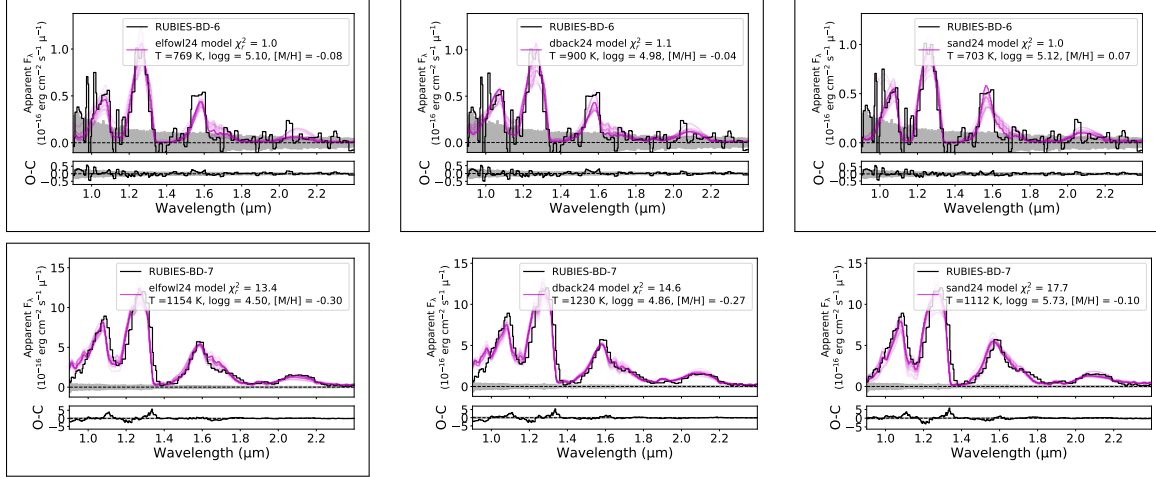


Figure 4. Continued.

Table 6. Properties of RUBIES Brown Dwarfs

Parameter	Unit	BD-1	BD-2	BD-3	BD-4	BD-5	BD-6	BD-7
SpT	...	T7±0.5	L1±0.5	sd:L6±1	T2±3	T1±2	T8±0.5	T5±0.5
Best Model(s)	...	E(D)	DS	(E)DS	EDS	S	E(DS)	E(D)
T_{eff}	(K)	930^{+100}_{-80}	2040^{+60}_{-80}	2170 ± 130	1800^{+300}_{-700}	1270^{+80}_{-60}	830 ± 130	1180 ± 80
$\log g$	(cm s^{-2})	4.9 ± 0.4	$4.7^{+0.7}_{-0.6}$ ^a	$4.6^{+0.5}_{-0.4}$	$5.0^{+0.4}_{-0.5}$	$4.9^{+0.5}_{-0.4}$	5.2 ± 0.5	4.9 ± 0.4
[M/H]	(dex)	$+0.1^{+0.3}_{-0.4}$	$+0.1 \pm 0.3$	$+0.2 \pm 0.4$	$-0.1^{+0.6}_{-0.5}$	$-0.7^{+0.4}_{-0.3}$	$-0.1^{+0.3}_{-0.4}$	-0.2 ± 0.3
d_{model}	(pc)	1070^{+220}_{-160}	860^{+50}_{-60}	2500 ± 300	5400^{+2200}_{-3400}	2050^{+260}_{-200}	1300^{+390}_{-350}	780^{+110}_{-90}
d_{spt}	(pc)	1000 ± 170	1320 ± 100	1870 ± 180	2990 ± 230	2500 ± 250	940 ± 140	830 ± 90
d_{adopted}	(pc)	1030 ± 140	980 ± 210 ^b	2000 ± 300	3000 ± 400	2300 ± 300	980 ± 170	810 ± 70
z	(pc)	890 ± 120	850 ± 180	1700 ± 300	2990 ± 200	2200 ± 200	810 ± 210	720 ± 80
$P(\text{thin disk})$	...	$50 \pm 7\%$	$52 \pm 10\%$	$13 \pm 7\%$	$2.3 \pm 2.2\%$	$9 \pm 5\%$	$56 \pm 8\%$	$64 \pm 3\%$
$P(\text{thick disk})$	...	$45 \pm 5\%$	$43 \pm 8\%$	$68 \pm 3\%$	$62 \pm 6\%$	$67.9 \pm 1.7\%$	$40 \pm 7\%$	$33 \pm 3\%$
$P(\text{halo disk})$	...	$5.1 \pm 1.2\%$	$4.8 \pm 1.2\%$	$18 \pm 5\%$	$35 \pm 7\%$	$23 \pm 5\%$	$4.4 \pm 1.4\%$	$3.0 \pm 0.4\%$

NOTE—Best model(s) are for NIRSpec fits, and are indicated by labels E = Elf Owl (Mukherjee et al. 2024), D = Diamondback (Morley et al. 2024), and S = SAND (Gerasimov et al. 2024; Alvarado et al. 2024). When more than one model is listed, models outside of parentheses have indistinguishable best-fit χ^2_r , while models in parentheses have slightly higher (more poorly fit) best-fit χ^2_r . Model parameters are determined from an uncertainty-weighted mean of the posterior distributions of all the best-fit models listed (see Eqns. 5 and 3). The adopted distance d_{adopted} is an uncertainty-weighted average of the model fit distance (d_{model}) and spectrophotometric distance (d_{spt}) assuming the larger of the error bounds.

^aThe SAND NIRSpec fit included in this average has a significantly discrepant value of $\log g$.

^bModel and spectrophotometric distance estimates differ significantly for this source.

5. DISCUSSION

5.1. Population Assignments

The large distances and high Galactic latitudes of these sources translate into large vertical scaleheights from the plane, giving them a high probability of belonging to

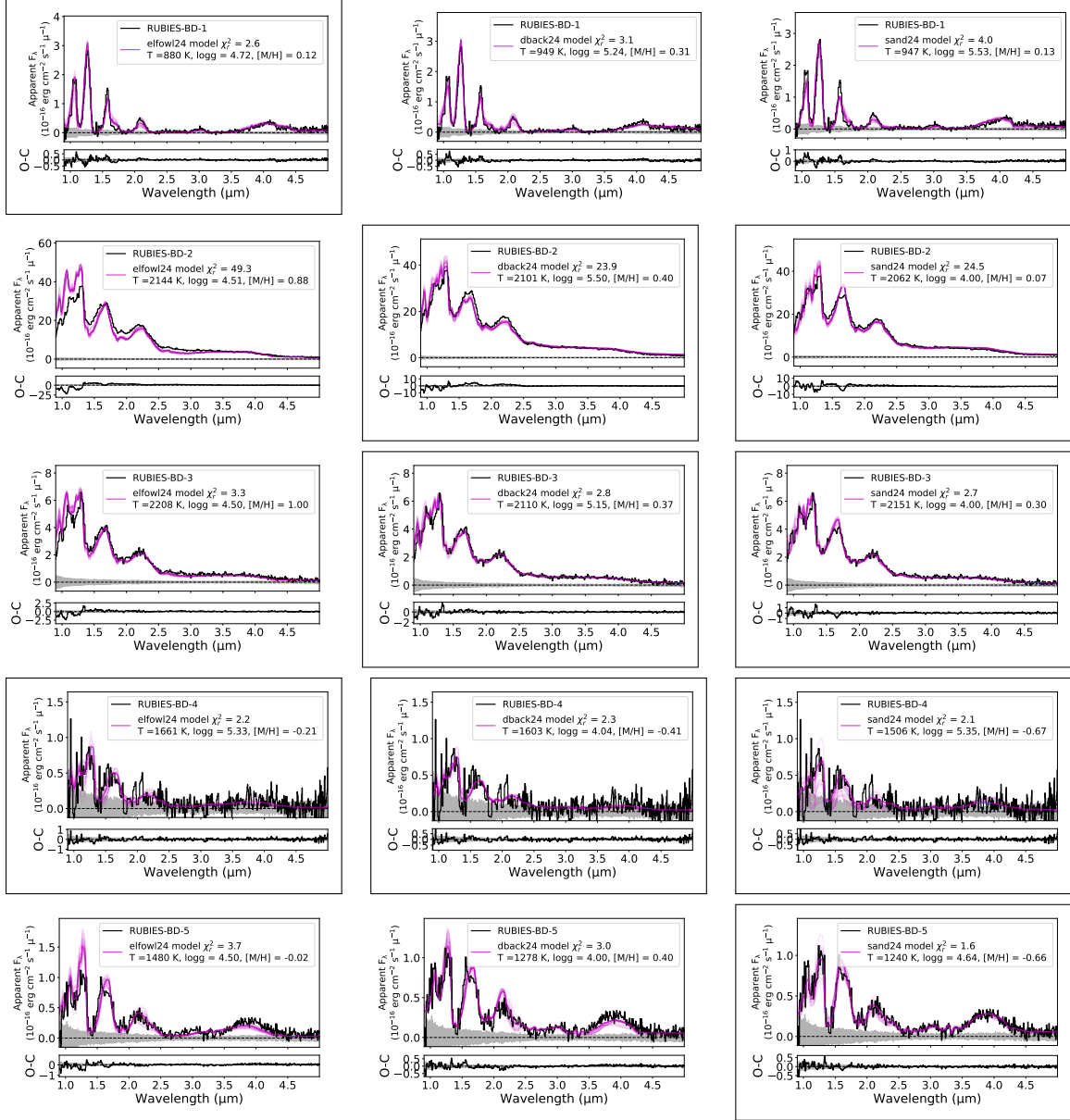


Figure 5. Same as Figure 4 for the full NIRSpec/Prism 0.9–5.1 μm spectral range.

the Milky Way’s thick disk or halo populations (Burgasser et al. 2024). To quantify population membership, we used the star density model of Jurić et al. (2008) to estimate the relative space densities of thin disk, thick disk, and halo sources in the directions and at the distances for each of our targets, sampling distance uncertainties using Monte Carlo methods. The resulting probabilities are listed in Table 6. Not surprisingly, the most distant sources in our sample, RUBIES-BD-3, -4, and -5, have high probabilities of thick disk membership, with RUBIES-BD-4 having a significant probability ($35 \pm 7\%$) of halo membership. This subsample includes both the classified L subdwarf RUBIES-BD-3 and the only source in the sample whose modeled parameters indicate subsolar metallicity, RUBIES-BD-5, although the metallicity values of

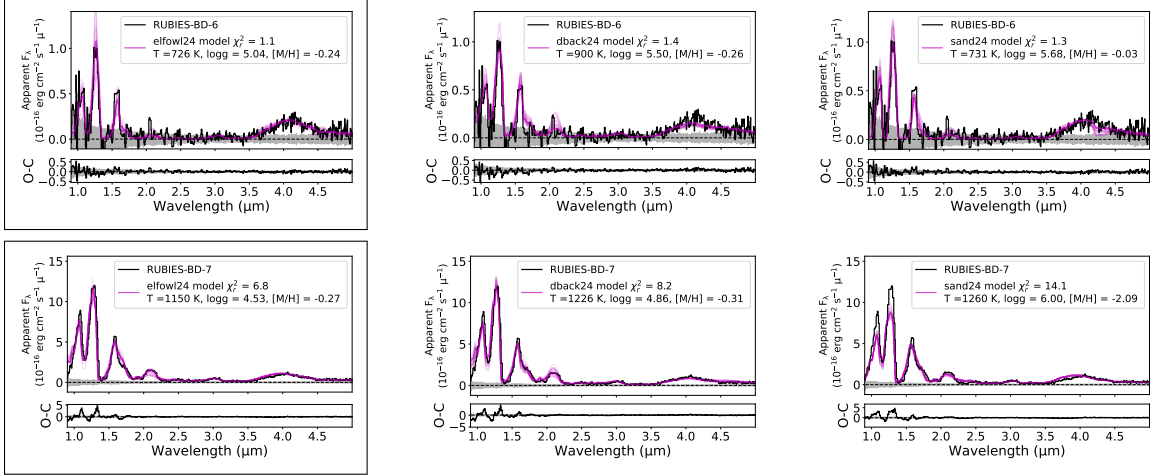


Figure 5. Continued.

all three of these sources are more consistent with thin/thick disk membership than with the halo. The mid- to late-T dwarfs in our sample—RUBIES-BD-1, -6, and -7—are intrinsically fainter and detected at vertical scaleheights $\lesssim 1$ kpc, and are thus more likely to be thin disk dwarfs, as supported by their spectral similarity to local spectral standards. The mix of thin disk, thick disk, and halo brown dwarfs mimics the composition of distant stars and brown dwarfs detected in other deep JWST survey samples (Burgasser et al. 2024; Hainline et al. 2024a,b, 2025).

5.2. Spectral Variations Among Distant T Dwarfs

The mid- and late-type T dwarfs that have been identified in deep JWST/NIRSpec spectral surveys extend out to 1–2 kpc, a distance that encompasses a diversity of populations, ages, and compositions. As such, these early discoveries provide the opportunity to examine the influence of secondary parameters such as surface gravity and metallicity on cool brown dwarf spectra. To illustrate this, Figure 7 compares the NIRSpec/Prism spectra of five distant mid- and late-type T dwarfs, including RUBIES-BD-1 (T7), -6 (T8), and -7 (T5), the T6 dwarf UNCOVER-BD-2 (estimated distance of 2.1–2.6 kpc; Burgasser et al. 2024), and the T6 dwarf JADES-GS-BD-9 (estimated distance of 1.8–2.3 kpc; Hainline et al. 2024b). All of these sources are similarly normalized to focus on spectral morphology, and are compared to the NIRSpec/Prism spectrum of the T6 dwarf standard SDSS J1624+0029 (Beiler et al. 2024a). We separately evaluate the 0.9–2.4 μm NIR and 3.6–5.0 μm MIR regions to focus on key spectral features. In the NIR, we observe subtle variations between these spectra in several key features, including the depth of the 1.15 μm and 1.6 μm CH_4 bands (shallowest in RUBIES-BD-7, deepest in RUBIES-BD-1), the width of the 1.25 μm peak (widest in RUBIES-BD-7, narrowest in JADES-GS-BD-9 and RUBIES-BD-6), and the shape and brightness of the 2.1 μm peak (broad in RUBIES-BD-7, shifted redward in UNCOVER-BD-2, shifted blueward in RUBIES-BD-1, flat in JADES-GS-BD-9 and RUBIES-BD-6). In the MIR, the broad 4 μm

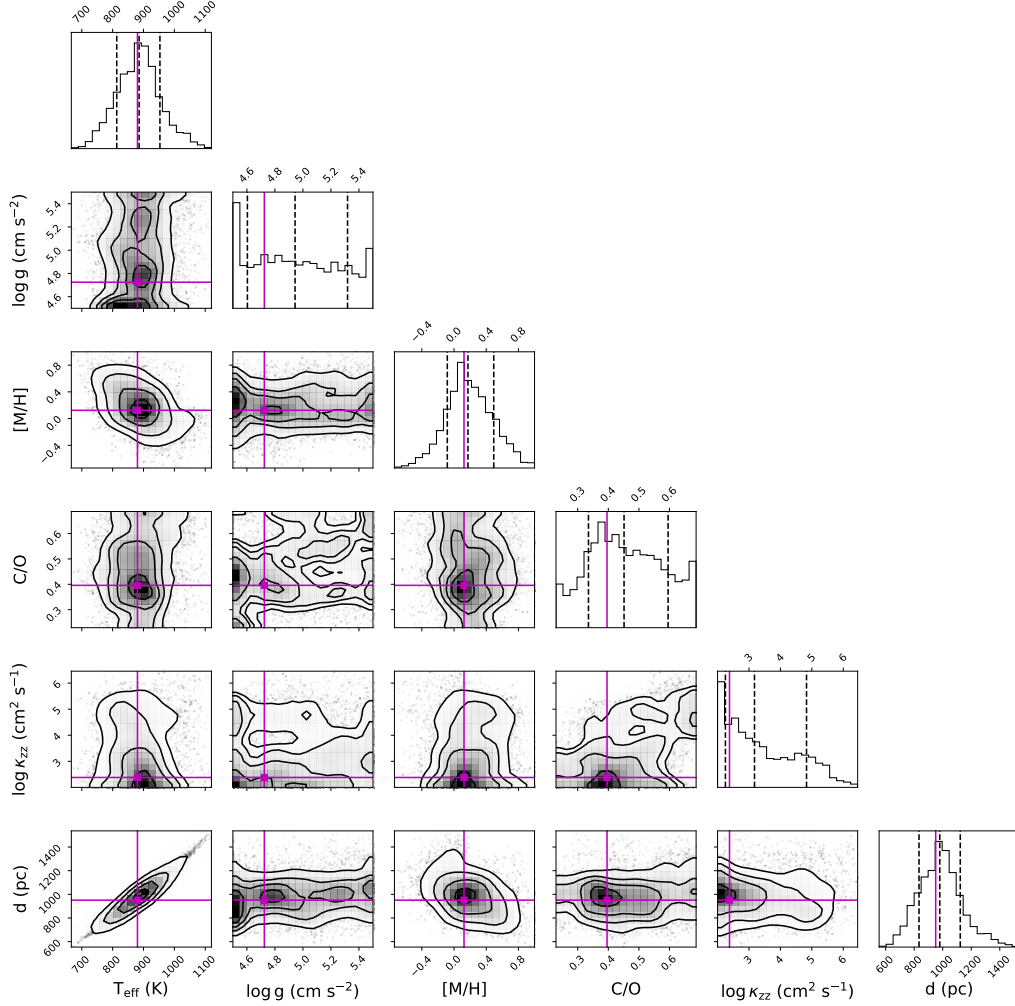


Figure 6. Example corner plot of Elf Owl fits to NIRSpect/Prism data for RUBIES-BD-1. Diagonal panels display the marginalized posterior distributions for T_{eff} , $\log g$, $[M/H]$, C/O , $\log \kappa_{zz}$, and distance, while the inner panels display contour plots of distributions marginalized over parameter pairs to illustrate correlations. Contour shading indicates likelihood values, and lines trace 25%, 50%, and 75% likelihood thresholds. Magenta lines indicate the parameter values for the best-fitting individual model, while the vertical dashed lines in the marginalized distributions indicate the 16%, 50%, and 84% quantiles.

peak shows a variety of shapes among these sources, from a relatively featureless and blueshifted peak in the spectra of RUBIES-BD-7 and UNCOVER-BD-2, to the more structured peaks in the spectra of JADES-GS-BD-9 and RUBIES-BD-7, the latter showing strong CO_2 and CO absorption bands at $4.3 \mu\text{m}$ and $4.6 \mu\text{m}$, also observed in the spectrum of SDSS J1624+0029.

To contextualize these variations, we compare in the right panels of Figure 7 to Elf Owl atmosphere models with variations in temperature, surface gravity, metallicity, and vertical mixing efficiency relative to a baseline model appropriate for a thin disk T6 dwarf ($T_{\text{eff}} = 800 \text{ K}$, $\log g = 4.5$, $[M/H] = 0$, and $\log \kappa_{zz} = 4$). NIR variations sensitive to these features have been discussed extensively in the literature (e.g.,

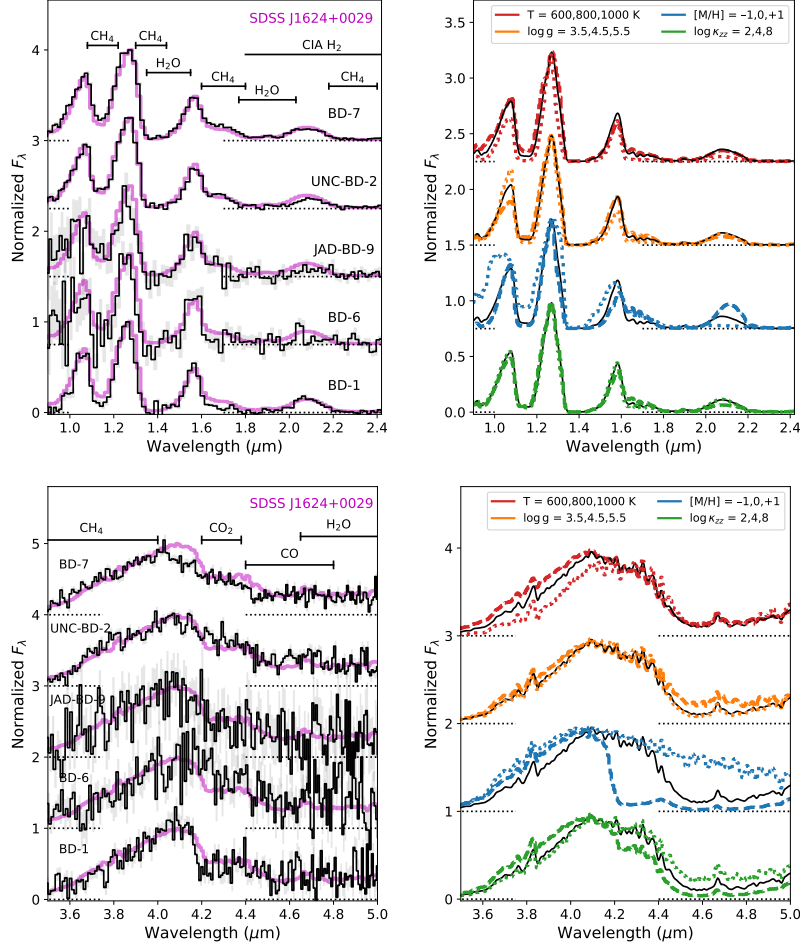


Figure 7. Spectral variations among distant mid- and late-T dwarfs identified by JWST. (Left panels): Comparison of NIRSpect prism spectra of (from top to bottom): RUBIES-BD-7, UNCOVER-BD-2 (UNC-BD-2; data from Burgasser et al. 2024), JADES-GS-BD-9 (JAD-BD-9; data from Hainline et al. 2024b), RUBIES-BD-6, and RUBIES-BD-1 (solid black lines). These spectra are compared to equivalent data for the T6 spectral standard SDSS J1624+0029 (repeated magenta line, data from Beiler et al. 2024a) in the 0.9–2.4 μm (top) and 3.5–5.0 μm (bottom) ranges. All spectra are normalized at the 1.25 μm and 4 μm peaks, and offset for clarity (dotted lines). (Right panels): Comparison of parameter variations in Elf Owl atmosphere models for T dwarf spectra in the same wavelength ranges. The black line is a reference spectrum with $T_{\text{eff}} = 800$ K, $\log g = 4.5$, $[M/H] = 0$, and $\log \kappa_{\text{zz}} = 4$. The colored dashed and dotted lines show the changes in spectral morphologies for $\Delta T_{\text{eff}} = \pm 200$ K (red lines), $\Delta \log g = \pm 0.5$ dex (orange lines), $\Delta [M/H] = \pm 0.5$ dex (blue lines), and $\log \kappa_{\text{zz}} = 2$ and 8 (green lines). Model spectra are normalized and offset in the same manner as the observed spectra.

Burgasser et al. 2002; Leggett et al. 2010; Pinfield et al. 2012; Zhang et al. 2017a; Mukherjee et al. 2024; Burgasser et al. 2025b). Here, we highlight that variations in the depths of CH₄ bands, the width of the 1.25 μm peak, and the shape of the 2.1 μm peak are all driven primarily by temperature and metallicity variations in the models. Surface gravity plays a greater role in setting the relative brightness of the 1.05 μm and 1.6 μm peaks, while vertical mixing plays only a minor role in shaping the 2.1 μm

peak. In the MIR, the models show that metallicity plays the greatest role in shaping the $4\ \mu\text{m}$ peak, with low metallicity models missing the CO_2 and CO bands and producing a relatively featureless broad plateau. Vertical mixing also modulates the CO_2 feature. Temperature primarily shifts the location of the $4\ \mu\text{m}$ peak (blueward for warmer temperatures), while surface gravity only modestly influences the depth of the CO band.

This analysis suggests that all of these parameters can drive the variations observed among these similarly-classified distant T dwarfs. As such, a comparison of multiple features is necessary to isolate metallicity variations from other secondary parameters. There is an important caveat to this analysis, in that current models do not fully capture the complex atmosphere chemistry among the observed molecular constituents. Most importantly, the $4.3\ \mu\text{m}$ CO_2 band is known to be far stronger than can be explained even with efficient vertical mixing (Yamamura et al. 2010; Beiler et al. 2024b). We also note that none of these spectra show clear evidence of PH_3 absorption that was initially claimed in the distant (0.6–1.2 kpc) late T dwarf UNCOVER-BD-3 (Burgasser et al. 2024, see Beiler et al. 2024b for further discussion) and more recently detected in the metal-poor T dwarf companion Wolf 1130C (Burgasser et al. 2025a). The absence or weakness of this feature in most brown dwarf and exoplanet spectra remains a challenge to chemical models (Morley et al. 2018; Rowland et al. 2024).

6. SUMMARY

The key results of this study are as follows:

- We have identified seven brown dwarfs observed with JWST/NIRSpec as part of the RUBIES survey. All seven sources show spectral features characteristic of L- and T-type brown dwarfs in the $1\text{--}5\ \mu\text{m}$ range, including strong H_2O , CH_4 , CO, and CO_2 molecular features.
- We determined spectral types for these sources by comparing their near-infrared ($0.9\text{--}2.4\ \mu\text{m}$) spectra to dwarf and subdwarf standards, inferring classifications spanning L1 to T8. One source, RUBIES-BD-3, is best matched to mild L subdwarf (d/sdL) and L subdwarf (sdL) standards, suggesting that it has a metal-poor atmosphere.
- We compared flux-calibrated spectra to three sets of atmosphere models: Sonora Elf Owl, Sonora Diamondback, and SAND. We find the L dwarf spectra are best matched to the Diamondback and SAND models, likely due to the presence of condensates in their atmospheres; the early-T dwarf spectra are best matched to the SAND models; and the mid- and late-T dwarf spectra are best matched to the Elf Owl and Diamondback models, the latter with efficient sedimentation or no clouds. Spectra of the two L dwarfs, RUBIES-BD-2 and -3, show the most significant deviations from the models, possibly due to incorrect treatment of condensates or the failure to incorporate reddening corrections, as previously

noted by [Tu et al. \(2025a\)](#). Only one source, RUBIES-BD-5, shows significant evidence of being metal-poor based on the model fits.

- Three of our sources—RUBIES-BD-3, -4, and -5—have estimated vertical scale-heights exceeding 1 kpc, and are mostly likely members of the Galactic thick disk population. RUBIES-BD-4, our faintest, most distant, and most poorly characterized source, also has a significant probability of being a member of the Galactic halo population.
- Examination of the present sample of mid- and late-type T dwarfs found in deep JWST spectral surveys at distances of 1–2 kpc show subtle but distinct variations in the strengths of major molecular bands and the shapes of inter-band peaks, most notably the $2.1\ \mu\text{m}$ flux peak and the $4.3\ \mu\text{m}$ CO_2 band. Examination of comparable Elf Owl models point to multiple factors that may be responsible for these variations, requiring further examination to isolate the subsolar metallicities expected for these distant objects.

This study adds to the growing sample of deep brown dwarf spectra from JWST/NIRSpec Prism data collected in deep survey programs such as CEERS ([Finkelstein et al. 2023](#)), UNCOVER ([Bezanson et al. 2024](#)), JADES ([D’Eugenio et al. 2025](#)), CANUCS ([Willott et al. 2022](#)), BoRG ([Roberts-Borsani et al. 2025](#)), NEXUS ([Shen et al. 2024](#)), and CAPERS ([Dickinson et al. 2024](#)), among others (cf. [Tu et al. 2025b](#)). Collectively, these discoveries increase the diversity of physical parameters sampled among known brown dwarfs, and provide the opportunity to improve atmosphere and evolutionary models of low-temperature atmospheres more broadly, not only for thick disk and halo brown dwarf but also candidate brown dwarfs identified in globular clusters ([Gerasimov et al. 2024](#)) and stellar stream populations ([Burgasser et al. 2025b](#)), as well as gas giant exoplanets orbiting metal-poor stars ([Barbato et al. 2019](#); [Alves et al. 2022](#)). Building larger and more diverse samples of cool brown dwarfs from these surveys can also facilitate their use to address broader questions in Milky Way science, such as the evolution and distribution of chemical abundances, the Milky Way’s star formation and accretion history, and the dynamical history of various Galactic populations ([Burgasser 2004a](#); [Ryan et al. 2017](#); [Aganze et al. 2022b](#); [Best et al. 2024](#); [Raghu et al. 2024](#); [Honaker & Gizis 2025](#)).

ACKNOWLEDGMENTS

The authors thank our anonymous referee for their prompt and thorough review of the original manuscript. S.M. acknowledges the guidance and financial support received from the UCSD Summer Triton Research & Experiential Learning Scholars (TRELS) program. A.J.B. acknowledges funding support from NASA/STScI through JWST general observer program GO-4668, under NASA contract NAS 5-03127. Some of the data products presented herein were retrieved from the Dawn JWST Archive (DJA).

DJA is an initiative of the Cosmic Dawn Center (DAWN), which is funded by the Danish National Research Foundation under grant DNR140. The Cosmic Dawn Center is funded by the Danish National Research Foundation (DNR140) under grant DNR140. JWST/NIRSpec spectral data reported in this program are available on the Mikulski Archive for Space Telescopes (MAST) and are associated with dataset DOI 10.17909/qk5z-7p30.

Facilities: JWST(NIRCam), JWST(NIRSpec)

Software: `astropy` (Astropy Collaboration et al. 2013, 2018, 2022), `msaexp` (Brammer 2023), JWST Calibration pipeline (Backhaus et al. 2024), `SPLAT` (Burgasser & Splat Development Team 2017), and `ucdmcmc` (Burgasser et al. 2025)

APPENDIX

A. NEAR-INFRARED SPECTRAL STANDARDS

Table 7 lists the near-infrared spectral standards used for the classification of our sources in Section 2.3. Dwarf standards are defined in Burgasser et al. (2006) and Kirkpatrick et al. (2010); subdwarf standards are defined in Zhang et al. (2017b, 2018a); Greco et al. (2019); and Burgasser et al. (2025b). We drew from previously-published data acquired with several different instruments, which were resampled to the wavelength-dependent resolution of the JWST/NIRSpec prism mode (Birkmann et al. 2022). The resampled spectra are included as part of the online materials for the article.

Table 7. Near-Infrared Spectral Standards

SpT	Source	Instrument	Data Ref.
L0	2MASP J0345432+254023	IRTF/SpeX	[1]
L1	2MASSW J2130446−084520	IRTF/SpeX	[2]
L2	Kelu−1AB	IRTF/SpeX	[3]
L3	2MASSW J1506544+132106	IRTF/SpeX	[4]
L4	2MASS J21580457−1550098	IRTF/SpeX	[2]
L5	SDSS J083506.16+195304.4	IRTF/SpeX	[5]
L6	2MASS J1010148−040649	IRTF/SpeX	[6]
L7	2MASS J0103320+193536	IRTF/SpeX	[2]
L8	2MASSW J1632291+190441	IRTF/SpeX	[4]
L9	DENIS-P J0255−4700	IRTF/SpeX	[7]
T0	SDSS J120747.17+024424.8	IRTF/SpeX	[8]
T1	SDSSp J083717.22−000018.3	IRTF/SpeX	[9]
T2	SDSSp J125453.90−012247.4	IRTF/SpeX	[10]

Table 7 continued on next page

Table 7 (*continued*)

SpT	Source	Instrument	Data Ref.
T3	2MASS J12095613−1004008AB	IRTF/SpeX	[10]
T4	2MASS J2254188+312349	IRTF/SpeX	[10]
T5	2MASS J15031961+2525196	IRTF/SpeX	[10]
T6	SDSSp J162414.37+002915.6	IRTF/SpeX	[11]
T7	2MASS J0727182+171001	IRTF/SpeX	[11]
T8	2MASS J0415195−093506	IRTF/SpeX	[10]
T9	UGPS J072227.51−054031.2	IRTF/SpeX	[9]
d/sdL0	2MASS J00412179+3547133	IRTF/SpeX	[10]
d/sdL1	2MASS J17561080+2815238	IRTF/SpeX??	[12]
d/sdL6	SDSS J133148.92−011651.4	IRTF/SpeX	[2]
d/sdL8	2MASS J11582077+0435014	IRTF/SpeX	[12]
d/sdL9	CWISE J202130.11+152418.3	Keck/NIRES	[13]
d/sdT0	2MASS J06453153−6646120	VLT/Xshooter	[14]
d/sdT1	WISE J030119.47−231921.8	IRTF/SpeX	[15]
d/sdT2	WISE J000458.59−133655.2	IRTF/SpeX	[15]
d/sdT2.5	CWISE J211255.59+303037.6	Keck/NIRES	[13]
d/sdT4	ULAS J002135.97+155226.8	VLT/Xshooter	[16]
d/sdT5.5	CWISE J113010.07+313944.7	Keck/NIRES	[13]
d/sdT5.5	GJ 576B	Keck/NIRES	[13]
d/sdT6	CWISE J201342.30−032643.4	Keck/NIRES	[13]
d/sdT7.5	LHS 6176B	Keck/NIRES	[13]
d/sdT8	2MASS J09393548−2448279	IRTF/SpeX	[7]
d/sdT9	ULAS J083338.11+005206.2	Gemini/GNIRS	[17]
sdL0	WISE J04592121+1540592	IRTF/SpeX	[12]
sdL1	ULAS J124947.04+095019.8	VLT/Xshooter	[18]
sdL4	ULAS J021642.97+004005.6	VLT/Xshooter	[18]
sdL5	SDSS J141624.08+134826.7	IRTF/SpeX	[19]
sdT0	WISEA J152443.14−262001.8	Keck/NIRES	[13]
sdT1	CWISE J211250.11−052925.2	Keck/NIRES	[13]
sdT3	CWISE J062316.19+071505.6	Keck/NIRES	[13]
sdT4	CWISE J155349.96+693355.2	Keck/NIRES	[20]
sdT5.5	CWISE J113019.19−115811.3	Keck/NIRES	[21]
sdT6	2MASS J09373487+2931409	IRTF/SpeX	[11]
sdT7	ULAS J141623.94+134836.3	IRTF/SpeX	[22]
sdT7.5	ULAS J001354.85+063445.4	Gemini/GNIRS	[17]
esdL0	SSSPM J10130734−1356204	IRTF/SpeX	[23]
esdL1	SSSPM J144420.67−201922.2	IRTF/SpeX	[2]
esdL3	SDSS J125637.16−022452.2	IRTF/SpeX	[24]
esdL4	2MASS J16262034+3925190	IRTF/SpeX	[23]
esdL6	2MASS J061643.51−640719.8	VLT/Xshooter	[18]
esdL7	2MASS J053253.46+824646.5	Keck/LRIS+NIRES	[13]

Table 7 *continued on next page*

Table 7 (*continued*)

SpT	Source	Instrument	Data Ref.
esdT3	WISEA J181006.18–101000.5	GTC/OSIRIS+Palomar/TSpec	[25,26]
esdT6	WISEA J041451.67–585456.7	Magellan/FIRE	[25]

References—[1] Burgasser & McElwain (2006); [2] Bardalez Gagliuffi et al. (2014); [3] Burgasser et al. (2007); [4] Burgasser (2007); [5] Chiu et al. (2006); [6] Reid et al. (2006); [7] Burgasser et al. (2006); [8] Looper et al. (2007); [9] Burgasser & Splat Development Team (2017); [10] Burgasser et al. (2004); [11] Burgasser et al. (2006); [12] Kirkpatrick et al. (2010); [13] Burgasser et al. (2025b); [14] Zhang et al. (2018b); [15] Greco et al. (2019); [16] Zhang et al. (2019); [17] Pinfield et al. (2014); [18] Zhang et al. (2017b); [19] Schmidt et al. (2010); [20] Meisner et al. (2021); [21] Kirkpatrick et al. (2021); [22] Burgasser et al. (2010); [23] Burgasser (2004b); [24] Burgasser et al. (2009); [25] Schneider et al. (2020); [26] Lodieu et al. (2022).

REFERENCES

- Ackerman, A. S., & Marley, M. S. 2001, *ApJ*, 556, 872, doi: [10.1086/321540](https://doi.org/10.1086/321540)
- Aganze, C., Burgasser, A. J., Malkan, M., et al. 2022a, *ApJ*, 924, 114, doi: [10.3847/1538-4357/ac35ea](https://doi.org/10.3847/1538-4357/ac35ea)
- . 2022b, *ApJ*, 934, 73, doi: [10.3847/1538-4357/ac7053](https://doi.org/10.3847/1538-4357/ac7053)
- Allard, F., Homeier, D., & Freytag, B. 2012, *Philosophical Transactions of the Royal Society of London Series A*, 370, 2765, doi: [10.1098/rsta.2011.0269](https://doi.org/10.1098/rsta.2011.0269)
- Alvarado, E., Gerasimov, R., Burgasser, A. J., et al. 2024, *Research Notes of the American Astronomical Society*, 8, 134, doi: [10.3847/2515-5172/ad4bd7](https://doi.org/10.3847/2515-5172/ad4bd7)
- Alves, D. R., Jenkins, J. S., Vines, J. I., et al. 2022, *MNRAS*, 517, 4447, doi: [10.1093/mnras/stac2884](https://doi.org/10.1093/mnras/stac2884)
- Astropy Collaboration, Robitaille, T. P., Tollerud, E. J., et al. 2013, *A&A*, 558, A33, doi: [10.1051/0004-6361/201322068](https://doi.org/10.1051/0004-6361/201322068)
- Astropy Collaboration, Price-Whelan, A. M., Sipőcz, B. M., et al. 2018, *AJ*, 156, 123, doi: [10.3847/1538-3881/aabc4f](https://doi.org/10.3847/1538-3881/aabc4f)
- Astropy Collaboration, Price-Whelan, A. M., Lim, P. L., et al. 2022, *ApJ*, 935, 167, doi: [10.3847/1538-4357/ac7c74](https://doi.org/10.3847/1538-4357/ac7c74)
- Backhaus, B. E., Trump, J. R., Pirzkal, N., et al. 2024, *ApJ*, 962, 195, doi: [10.3847/1538-4357/ad1520](https://doi.org/10.3847/1538-4357/ad1520)
- Baraffe, I., Chabrier, G., Barman, T. S., Allard, F., & Hauschildt, P. H. 2003, *A&A*, 402, 701, doi: [10.1051/0004-6361:20030252](https://doi.org/10.1051/0004-6361:20030252)
- Barbato, D., Sozzetti, A., Biazzo, K., et al. 2019, *A&A*, 621, A110, doi: [10.1051/0004-6361/201834305](https://doi.org/10.1051/0004-6361/201834305)
- Bardalez Gagliuffi, D. C., Burgasser, A. J., Gelino, C. R., et al. 2014, *ApJ*, 794, 143, doi: [10.1088/0004-637X/794/2/143](https://doi.org/10.1088/0004-637X/794/2/143)
- Beiler, S. A., Cushing, M. C., Kirkpatrick, J. D., et al. 2024a, *ApJ*, 973, 107, doi: [10.3847/1538-4357/ad6301](https://doi.org/10.3847/1538-4357/ad6301)
- Beiler, S. A., Mukherjee, S., Cushing, M. C., et al. 2024b, *ApJ*, 973, 60, doi: [10.3847/1538-4357/ad6759](https://doi.org/10.3847/1538-4357/ad6759)
- Best, W. M. J., Sanghi, A., Liu, M. C., Magnier, E. A., & Dupuy, T. J. 2024, *ApJ*, 967, 115, doi: [10.3847/1538-4357/ad39ef](https://doi.org/10.3847/1538-4357/ad39ef)
- Bezanson, R., Labbe, I., Whitaker, K. E., et al. 2024, *ApJ*, 974, 92, doi: [10.3847/1538-4357/ad66cf](https://doi.org/10.3847/1538-4357/ad66cf)
- Birkmann, S. M., Ferruit, P., Giardino, G., et al. 2022, *A&A*, 661, A83, doi: [10.1051/0004-6361/202142592](https://doi.org/10.1051/0004-6361/202142592)
- Brammer, G. 2023, *msaexp: NIRSpec analysis tools*, 0.6.17, Zenodo, doi: [10.5281/zenodo.8319596](https://doi.org/10.5281/zenodo.8319596)

- Burgasser, A., Brooks, H., Morrissey, S., et al. 2025, ucdmcmc, v1.2, Zenodo, doi: [10.5281/zenodo.17202653](https://doi.org/10.5281/zenodo.17202653)
- Burgasser, A. J. 2004a, ApJS, 155, 191, doi: [10.1086/424386](https://doi.org/10.1086/424386)
- . 2004b, ApJL, 614, L73, doi: [10.1086/425418](https://doi.org/10.1086/425418)
- . 2007, ApJ, 659, 655, doi: [10.1086/511027](https://doi.org/10.1086/511027)
- Burgasser, A. J., Burrows, A., & Kirkpatrick, J. D. 2006, ApJ, 639, 1095, doi: [10.1086/499344](https://doi.org/10.1086/499344)
- Burgasser, A. J., Geballe, T. R., Leggett, S. K., Kirkpatrick, J. D., & Golimowski, D. A. 2006, The Astrophysical Journal, 637, 1067, doi: [10.1086/498563](https://doi.org/10.1086/498563)
- Burgasser, A. J., Geballe, T. R., Leggett, S. K., Kirkpatrick, J. D., & Golimowski, D. A. 2006, ApJ, 637, 1067, doi: [10.1086/498563](https://doi.org/10.1086/498563)
- Burgasser, A. J., Gonzales, E. C., Beiler, S. A., et al. 2025a, Science, accepted
- Burgasser, A. J.,Looper, D., & Rayner, J. T. 2010, AJ, 139, 2448, doi: [10.1088/0004-6256/139/6/2448](https://doi.org/10.1088/0004-6256/139/6/2448)
- Burgasser, A. J.,Looper, D. L., Kirkpatrick, J. D., & Liu, M. C. 2007, ApJ, 658, 557, doi: [10.1086/511518](https://doi.org/10.1086/511518)
- Burgasser, A. J., & McElwain, M. W. 2006, AJ, 131, 1007, doi: [10.1086/499042](https://doi.org/10.1086/499042)
- Burgasser, A. J., McElwain, M. W., Kirkpatrick, J. D., et al. 2004, AJ, 127, 2856, doi: [10.1086/383549](https://doi.org/10.1086/383549)
- Burgasser, A. J., & Splat Development Team. 2017, in Astronomical Society of India Conference Series, Vol. 14, Astronomical Society of India Conference Series, 7–12, doi: [10.48550/arXiv.1707.00062](https://doi.org/10.48550/arXiv.1707.00062)
- Burgasser, A. J., Witte, S., Helling, C., et al. 2009, ApJ, 697, 148, doi: [10.1088/0004-637X/697/1/148](https://doi.org/10.1088/0004-637X/697/1/148)
- Burgasser, A. J., Kirkpatrick, J. D., Brown, M. E., et al. 2002, ApJ, 564, 421, doi: [10.1086/324033](https://doi.org/10.1086/324033)
- Burgasser, A. J., Bezanson, R., Labbe, I., et al. 2024, ApJ, 962, 177, doi: [10.3847/1538-4357/ad206f](https://doi.org/10.3847/1538-4357/ad206f)
- Burgasser, A. J., Schneider, A. C., Meisner, A. M., et al. 2025b, ApJ, 982, 79, doi: [10.3847/1538-4357/adb39f](https://doi.org/10.3847/1538-4357/adb39f)
- Burrows, A., Hubbard, W. B., Lunine, J. I., & Liebert, J. 2001, Reviews of Modern Physics, 73, 719
- Bushouse, H., Eisenhamer, J., Dencheva, N., et al. 2023, JWST Calibration Pipeline, 1.12.5, Zenodo, doi: [10.5281/zenodo.10022973](https://doi.org/10.5281/zenodo.10022973)
- Caffau, E., Ludwig, H.-G., Steffen, M., Freytag, B., & Bonifacio, P. 2011, SoPh, 268, 255, doi: [10.1007/s11207-010-9541-4](https://doi.org/10.1007/s11207-010-9541-4)
- Chabrier, G., Baraffe, I., Phillips, M., & Debras, F. 2023, A&A, 671, A119, doi: [10.1051/0004-6361/202243832](https://doi.org/10.1051/0004-6361/202243832)
- Chiu, K., Fan, X., Leggett, S. K., et al. 2006, AJ, 131, 2722, doi: [10.1086/501431](https://doi.org/10.1086/501431)
- Cushing, M. C., Rayner, J. T., & Vacca, W. D. 2005, ApJ, 623, 1115, doi: [10.1086/428040](https://doi.org/10.1086/428040)
- Dahn, C. C., Harris, H. C., Subasavage, J. P., et al. 2017, AJ, 154, 147, doi: [10.3847/1538-3881/aa880b](https://doi.org/10.3847/1538-3881/aa880b)
- de Graaff, A., Brammer, G., Weibel, A., et al. 2025, A&A, 697, A189, doi: [10.1051/0004-6361/202452186](https://doi.org/10.1051/0004-6361/202452186)
- D'Eugenio, F., Cameron, A. J., Scholtz, J., et al. 2025, ApJS, 277, 4, doi: [10.3847/1538-4365/ada148](https://doi.org/10.3847/1538-4365/ada148)
- Dickinson, M., Amorin, R., Arrabal Haro, P., et al. 2024, The CANDELS-Area Prism Epoch of Reionization Survey (CAPERS), JWST Proposal. Cycle 3, ID. #6368
- Dominguez-Tagle, C., Žerjal, M., Sedighi, N., et al. 2025, ApJ, 991, 84, doi: [10.3847/1538-4357/adf72d](https://doi.org/10.3847/1538-4357/adf72d)
- Ferruit, P., Jakobsen, P., Giardino, G., et al. 2022, A&A, 661, A81, doi: [10.1051/0004-6361/202142673](https://doi.org/10.1051/0004-6361/202142673)
- Filippazzo, J. C., Rice, E. L., Faherty, J., et al. 2015, ApJ, 810, 158, doi: [10.1088/0004-637X/810/2/158](https://doi.org/10.1088/0004-637X/810/2/158)
- Finkelstein, S. L., Bagley, M. B., Ferguson, H. C., et al. 2023, ApJL, 946, L13, doi: [10.3847/2041-8213/acade4](https://doi.org/10.3847/2041-8213/acade4)

- Gerasimov, R., Bedin, L. R., Burgasser, A. J., et al. 2024, *ApJ*, 971, 65, doi: [10.3847/1538-4357/ad5551](https://doi.org/10.3847/1538-4357/ad5551)
- Greco, J. J., Schneider, A. C., Cushing, M. C., Kirkpatrick, J. D., & Burgasser, A. J. 2019, *AJ*, 158, 182, doi: [10.3847/1538-3881/ab3ebe](https://doi.org/10.3847/1538-3881/ab3ebe)
- Hainline, K. N., Helton, J. M., Johnson, B. D., et al. 2024a, *ApJ*, 964, 66, doi: [10.3847/1538-4357/ad20d1](https://doi.org/10.3847/1538-4357/ad20d1)
- Hainline, K. N., D'Eugenio, F., Sun, F., et al. 2024b, *ApJ*, 975, 31, doi: [10.3847/1538-4357/ad76a7](https://doi.org/10.3847/1538-4357/ad76a7)
- Hainline, K. N., Helton, J. M., Miles, B. E., et al. 2025, arXiv e-prints, arXiv:2510.00111, doi: [10.48550/arXiv.2510.00111](https://doi.org/10.48550/arXiv.2510.00111)
- Hastings, W. K. 1970, *Biometrika*, 57, 97, doi: [10.1093/biomet/57.1.97](https://doi.org/10.1093/biomet/57.1.97)
- Hauschildt, P. H., Baron, E., & Allard, F. 1997, *ApJ*, 483, 390, doi: [10.1086/304233](https://doi.org/10.1086/304233)
- Hayashi, C., & Nakano, T. 1963, *Progress of Theoretical Physics*, 30, 460, doi: [10.1143/PTP.30.460](https://doi.org/10.1143/PTP.30.460)
- Heintz, K. E., Brammer, G. B., Watson, D., et al. 2025, *A&A*, 693, A60, doi: [10.1051/0004-6361/202450243](https://doi.org/10.1051/0004-6361/202450243)
- Holwerda, B. W., Hsu, C.-C., Hathi, N., et al. 2024, *MNRAS*, 529, 1067, doi: [10.1093/mnras/stae316](https://doi.org/10.1093/mnras/stae316)
- Honaker, E. J., & Gizis, J. E. 2025, *ApJ*, 985, 48, doi: [10.3847/1538-4357/adc689](https://doi.org/10.3847/1538-4357/adc689)
- Jurić, M., Ivezić, Ž., Brooks, A., et al. 2008, *ApJ*, 673, 864, doi: [10.1086/523619](https://doi.org/10.1086/523619)
- Karalidi, T., Marley, M., Fortney, J. J., et al. 2021, *ApJ*, 923, 269, doi: [10.3847/1538-4357/ac3140](https://doi.org/10.3847/1538-4357/ac3140)
- Kirkpatrick, J. D., Looper, D. L., Burgasser, A. J., et al. 2010, *ApJS*, 190, 100, doi: [10.1088/0067-0049/190/1/100](https://doi.org/10.1088/0067-0049/190/1/100)
- Kirkpatrick, J. D., Gelino, C. R., Faherty, J. K., et al. 2021, *The Astrophysical Journal Supplement Series*, 253, 7, doi: [10.3847/1538-4365/abd107](https://doi.org/10.3847/1538-4365/abd107)
- Kirkpatrick, J. D., Gelino, C. R., Faherty, J. K., et al. 2021, *ApJS*, 253, 7, doi: [10.3847/1538-4365/abd107](https://doi.org/10.3847/1538-4365/abd107)
- Kumar, S. S. 1962, *AJ*, 67, 579, doi: [10.1086/108658](https://doi.org/10.1086/108658)
- . 1963, *ApJ*, 137, 1121, doi: [10.1086/147589](https://doi.org/10.1086/147589)
- Langeroodi, D., & Hjorth, J. 2023, *ApJL*, 957, L27, doi: [10.3847/2041-8213/acfeec](https://doi.org/10.3847/2041-8213/acfeec)
- Laureijs, R., Amiaux, J., Arduini, S., et al. 2011, arXiv e-prints, arXiv:1110.3193, doi: [10.48550/arXiv.1110.3193](https://doi.org/10.48550/arXiv.1110.3193)
- Leggett, S. K., Burningham, B., Saumon, D., et al. 2010, *ApJ*, 710, 1627, doi: [10.1088/0004-637X/710/2/1627](https://doi.org/10.1088/0004-637X/710/2/1627)
- Lodders, K. 2003, *Astrophys. J.*, 591, 1220, doi: [10.1086/375492](https://doi.org/10.1086/375492)
- Lodieu, N., Zapatero Osorio, M. R., Martín, E. L., Rebolo López, R., & Gauza, B. 2022, *A&A*, 663, A84, doi: [10.1051/0004-6361/202243516](https://doi.org/10.1051/0004-6361/202243516)
- Looper, D. L., Kirkpatrick, J. D., & Burgasser, A. J. 2007, *AJ*, 134, 1162, doi: [10.1086/520645](https://doi.org/10.1086/520645)
- Marley, M. S., Saumon, D., Visscher, C., et al. 2021, *Astrophys. J.*, 920, 85, doi: [10.3847/1538-4357/ac141d](https://doi.org/10.3847/1538-4357/ac141d)
- Meisner, A. M., Leggett, S. K., Logsdon, S. E., et al. 2023, *AJ*, 166, 57, doi: [10.3847/1538-3881/acdb68](https://doi.org/10.3847/1538-3881/acdb68)
- Meisner, A. M., Schneider, A. C., Burgasser, A. J., et al. 2021, *ApJ*, 915, 120, doi: [10.3847/1538-4357/ac013c](https://doi.org/10.3847/1538-4357/ac013c)
- Merlin, E., Santini, P., Paris, D., et al. 2024, *A&A*, 691, A240, doi: [10.1051/0004-6361/202451409](https://doi.org/10.1051/0004-6361/202451409)
- Metropolis, N., Rosenbluth, A. W., Rosenbluth, M. N., Teller, A. H., & Teller, E. 1953, *JChPh*, 21, 1087, doi: [10.1063/1.1699114](https://doi.org/10.1063/1.1699114)
- Mohandasan, A., Smart, R. L., Reyl'e, C., et al. 2025, arXiv e-prints, arXiv:2503.22559, doi: [10.48550/arXiv.2503.22559](https://doi.org/10.48550/arXiv.2503.22559)
- Morley, C. V., Skemer, A. J., Allers, K. N., et al. 2018, *ApJ*, 858, 97, doi: [10.3847/1538-4357/aabe8b](https://doi.org/10.3847/1538-4357/aabe8b)
- Morley, C. V., Mukherjee, S., Marley, M. S., et al. 2024, *The Astrophysical Journal*, 975, 59, doi: [10.3847/1538-4357/ad71d5](https://doi.org/10.3847/1538-4357/ad71d5)

- Mukherjee, S., Fortney, J. J., Morley, C. V., et al. 2024, *ApJ*, 963, 73, doi: [10.3847/1538-4357/ad18c2](https://doi.org/10.3847/1538-4357/ad18c2)
- Nonino, M., Glazebrook, K., Burgasser, A. J., et al. 2023, *ApJL*, 942, L29, doi: [10.3847/2041-8213/ac8e5f](https://doi.org/10.3847/2041-8213/ac8e5f)
- Phillips, M. W., Tremblin, P., Baraffe, I., et al. 2020, *A&A*, 637, A38, doi: [10.1051/0004-6361/201937381](https://doi.org/10.1051/0004-6361/201937381)
- Pinfield, D. J., Burningham, B., Lodieu, N., et al. 2012, *MNRAS*, 422, 1922, doi: [10.1111/j.1365-2966.2012.20549.x](https://doi.org/10.1111/j.1365-2966.2012.20549.x)
- Pinfield, D. J., Gomes, J., Day-Jones, A. C., et al. 2014, *MNRAS*, 437, 1009, doi: [10.1093/mnras/stt1437](https://doi.org/10.1093/mnras/stt1437)
- Pirzkal, N., Burgasser, A. J., Malhotra, S., et al. 2009, *ApJ*, 695, 1591, doi: [10.1088/0004-637X/695/2/1591](https://doi.org/10.1088/0004-637X/695/2/1591)
- Raghu, Y., Kirkpatrick, J. D., Marocco, F., et al. 2024, *ApJ*, 974, 222, doi: [10.3847/1538-4357/ad62fc](https://doi.org/10.3847/1538-4357/ad62fc)
- Reid, I. N., Lewitus, E., Allen, P. R., Cruz, K. L., & Burgasser, A. J. 2006, *AJ*, 132, 891, doi: [10.1086/505626](https://doi.org/10.1086/505626)
- Reyl  , C. 2018, *aap*, 619, L8, doi: [10.1051/0004-6361/201834082](https://doi.org/10.1051/0004-6361/201834082)
- Rigby, J., Perrin, M., McElwain, M., et al. 2023, *PASP*, 135, 048001, doi: [10.1088/1538-3873/acb293](https://doi.org/10.1088/1538-3873/acb293)
- Roberts-Borsani, G., Bagley, M., Rojas-Ruiz, S., et al. 2025, *ApJ*, 983, 18, doi: [10.3847/1538-4357/adba60](https://doi.org/10.3847/1538-4357/adba60)
- Rowland, M. J., Morley, C. V., Miles, B. E., et al. 2024, *ApJL*, 977, L49, doi: [10.3847/2041-8213/ad9744](https://doi.org/10.3847/2041-8213/ad9744)
- Ryan, R. E., Thorman, P. A., Yan, H., et al. 2011, *ApJ*, 739, 83, doi: [10.1088/0004-637X/739/2/83](https://doi.org/10.1088/0004-637X/739/2/83)
- Ryan, Jr., R. E., Thorman, P. A., Schmidt, S. J., et al. 2017, *ApJ*, 847, 53, doi: [10.3847/1538-4357/aa85ea](https://doi.org/10.3847/1538-4357/aa85ea)
- Schmidt, S. J., West, A. A., Burgasser, A. J., Bochanski, J. J., & Hawley, S. L. 2010, *AJ*, 139, 1045, doi: [10.1088/0004-6256/139/3/1045](https://doi.org/10.1088/0004-6256/139/3/1045)
- Schneider, A. C., Burgasser, A. J., Gerasimov, R., et al. 2020, *ApJ*, 898, 77, doi: [10.3847/1538-4357/ab9a40](https://doi.org/10.3847/1538-4357/ab9a40)
- Shen, Y., Zhuang, M.-Y., Li, J., et al. 2024, arXiv e-prints, arXiv:2408.12713, doi: [10.48550/arXiv.2408.12713](https://doi.org/10.48550/arXiv.2408.12713)
- Sorahana, S., & Yamamura, I. 2012, *ApJ*, 760, 151, doi: [10.1088/0004-637X/760/2/151](https://doi.org/10.1088/0004-637X/760/2/151)
- Tu, Z., Wang, S., Chen, X., & Liu, J. 2025a, *ApJ*, 980, 230, doi: [10.3847/1538-4357/adaf9f](https://doi.org/10.3847/1538-4357/adaf9f)
- . 2025b, arXiv e-prints, arXiv:2510.02026, doi: [10.48550/arXiv.2510.02026](https://doi.org/10.48550/arXiv.2510.02026)
- van Vledder, I., van der Vlugt, D., Holwerda, B. W., et al. 2016, *MNRAS*, 458, 425, doi: [10.1093/mnras/stw258](https://doi.org/10.1093/mnras/stw258)
- Wang, P.-Y., Goto, T., Ho, S. C. C., et al. 2023, *MNRAS*, 523, 4534, doi: [10.1093/mnras/stad1679](https://doi.org/10.1093/mnras/stad1679)
- Wang, S., & Chen, X. 2024, *ApJL*, 964, L3, doi: [10.3847/2041-8213/ad2e98](https://doi.org/10.3847/2041-8213/ad2e98)
- Willott, C. J., Doyon, R., Albert, L., et al. 2022, *PASP*, 134, 025002, doi: [10.1088/1538-3873/ac5158](https://doi.org/10.1088/1538-3873/ac5158)
- Wogan, N. F., Mang, J., Batalha, N. E., et al. 2025, *Research Notes of the American Astronomical Society*, 9, 108, doi: [10.3847/2515-5172/add407](https://doi.org/10.3847/2515-5172/add407)
- Xiang, M., & Rix, H.-W. 2022, *Nature*, 603, 599, doi: [10.1038/s41586-022-04496-5](https://doi.org/10.1038/s41586-022-04496-5)
- Yamamura, I., Tsuji, T., & Tanab  , T. 2010, *ApJ*, 722, 682, doi: [10.1088/0004-637X/722/1/682](https://doi.org/10.1088/0004-637X/722/1/682)
-   zerjal, M., Dominguez-Tagle, C., Sedighi, N., et al. 2025, arXiv e-prints, arXiv:2503.22497, doi: [10.48550/arXiv.2503.22497](https://doi.org/10.48550/arXiv.2503.22497)
- Zhang, Z. H., Burgasser, A. J., G  lvez-Ortiz, M. C., et al. 2019, *MNRAS*, 486, 1260, doi: [10.1093/mnras/stz777](https://doi.org/10.1093/mnras/stz777)
- Zhang, Z. H., Homeier, D., Pinfield, D. J., et al. 2017a, *MNRAS*, 468, 261, doi: [10.1093/mnras/stx350](https://doi.org/10.1093/mnras/stx350)
- Zhang, Z. H., Pinfield, D. J., G  lvez-Ortiz, M. C., et al. 2017b, *MNRAS*, 464, 3040, doi: [10.1093/mnras/stw2438](https://doi.org/10.1093/mnras/stw2438)
- . 2018a, *MNRAS*, 479, 1383, doi: [10.1093/mnras/sty1352](https://doi.org/10.1093/mnras/sty1352)

Zhang, Z. H., Galvez-Ortiz, M. C.,
Pinfield, D. J., et al. 2018b, MNRAS,
480, 5447, doi: [10.1093/mnras/sty2054](https://doi.org/10.1093/mnras/sty2054)