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Keck NIRES Spectral Standards for L, T, and Y Dwarfs

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Abstract

We present medium-resolution ($\lambda/\Delta\lambda$=2700), near-infrared spectral standards for field L0–L2, L4, and L7–Y0 dwarfs obtained with the Near-Infrared Echellette Spectrometer on the Keck II 10 m telescope. These standards allow for detailed spectral comparative analysis of cold brown dwarfs discovered through ongoing ground-based projects such as Backyard Worlds: Planet 9, and forthcoming space-based spectral surveys such as the James Webb Space Telescope, SPHEREx, Euclid, and the Nancy Grace Roman Space Telescope.

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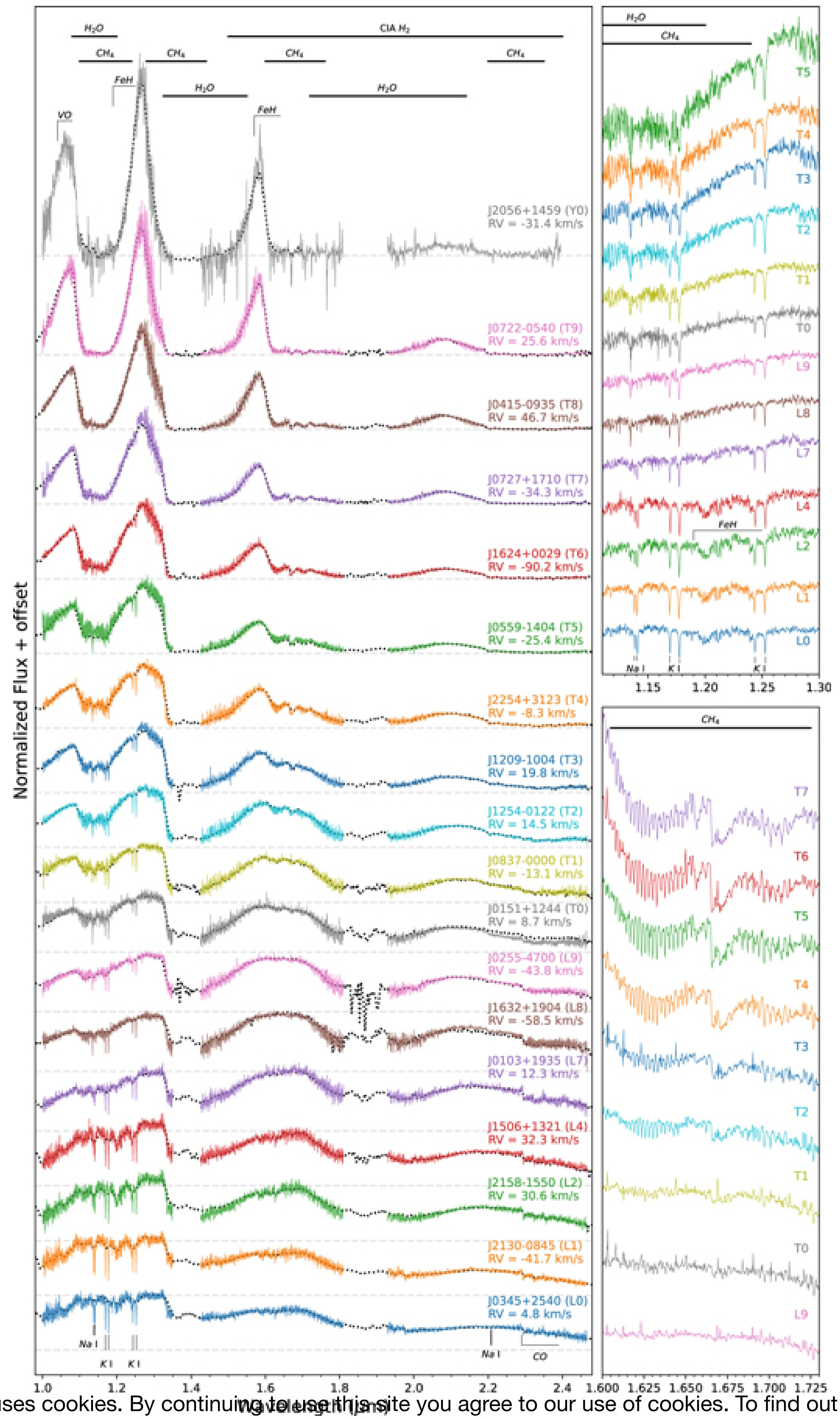
1. Introduction

In recent years, the accumulation of data from the multi-epoch, all-sky Wide-field Infrared Survey Explorer (WISE; Wright et al. 2010) and NEOWISE (Mainzer et al. 2014) has produced large catalogs of deep, all-sky mid-infrared photometry and astrometry, encapsulated in CatWISE (Eisenhardt et al. 2020; Marocco et al. 2021). This resource has enabled proper motion searches for faint and cold substellar neighbors through projects such as Backyard Worlds: Planet 9 (BYW; Kuchner et al. 2017). Astro-photometric searches require spectroscopic follow-up to determine if discoveries are true brown dwarfs, and to characterize their physical attributes such as temperature, age, and composition. In addition, developments in the atmospheric modeling of cold brown dwarfs, including condensate chemistry, cloud formation, and vertical mixing, require well-characterized spectral samples to test the models (Morley et al. 2014; Tremblin et al. 2016; Burningham et al. 2017). Only a handful of the largest ground-based facilities are capable of observing these faint objects in the near-infrared (NIR) with high precision.

Here we present spectral data for L, T, and Y dwarf NIR spectral standards obtained with the Near-Infrared Echellette Spectrometer (NIRES; Wilson et al. 2004) on the Keck II 10 m telescope. NIRES provides spectra spanning 0.9–2.45μm in five simultaneous orders with λ/

$\Delta\lambda \approx 2700$ ($\Delta v \approx 100 kms^{-1}$), a higher resolution than comparable NIR spectral standard sets, such as the SpeX Prism Libraries (SPL; $\lambda/\Delta\lambda \approx 120$; Burgasser & Splat Development Team 2017). Moderate resolution spectra facilitate investigation of molecular band structure and atomic line features which are particularly sensitive to physical properties (Martin et al. 2017). The standards were selected from the L dwarf optical and NIR standards defined in Kirkpatrick et al. (1999) and Kirkpatrick et al. (2010), T dwarf standards defined in Burgasser et al. (2006), and T9 and Y0 standards defined in Cushing et al. (2011). Observations were conducted over several runs in 2018–2022. All data were reduced using a custom version of the Spextool package (Vacca et al. 2003; Cushing et al. 2004) and followed standard procedures for image calibration and optimal point-source extraction. Individual orders were merged after comparison to equivalent low-resolution spectra of each source from the SPL. Spectra were also corrected for barycentric and radial motions, the latter determined using the Spectral Modeling Analysis and RV Tool (SMART; Hsu et al. 2021) with equivalent-temperature SONORA models (Marley et al. 2021) or PHEONIX ACES models (Husser et al. 2013). Radial velocities were estimated for each order separately. The standard spectra are thus provided in their rest frames.

The NIRES spectral standards are shown in Figure 1 (colored lines), compared to low-resolution standards from the SPL and HST/WFC3 (dotted lines). The reported RVs in Figure 1 are from the *J*-band (1.13–1.48μm) for L0–T5 types, and the *H*-band (1.42–1.85μm) for T6–Y0 types. We include a zoomed-in view of the 1.1–1.3μm region that hosts Na I and K I atomic lines and FeH, H_2O, and CH_4 molecular features. In these data, we see evidence of CH_4 in this region as early as spectral type L8 due to the strong Q-branch of the $3(\nu_1,\nu_3)$ band at 1.135μm. We also show detail around the $2(\nu_1,\nu_3)$ CH_4 feature across 1.6–1.73μm, a useful region for cross-correlation analysis. The spectra are available through the online journal in both fits and comma-separated-value format.



H_2O
CH_4
CIA H_2
FeH
VO
J2056+1459 (Y0)
RV = -31.4 km/s
J0722-0540 (T9)
RV = 25.6 km/s
J0415-0935 (T8)
RV = 46.7 km/s
J0727+1710 (T7)
RV = -34.3 km/s
J1624+0029 (T6)
RV = -90.2 km/s
J0559-1404 (T5)
RV = -25.4 km/s
J2254+3123 (T4)
RV = -8.3 km/s
J1209-1004 (T3)
RV = 19.8 km/s
J1254-0122 (T2)
RV = 14.5 km/s
J0837-0000 (T1)
RV = -13.1 km/s
J0151+1244 (T0)
RV = 8.7 km/s
J0255-4700 (L9)
RV = -43.8 km/s
J1632+1904 (L8)
RV = -58.5 km/s
J0103+1935 (L7)
RV = 12.3 km/s
J1506+1321 (L4)
RV = 32.3 km/s
J2158-1550 (L2)
RV = 30.6 km/s
J2130-0845 (L1)
RV = -41.7 km/s
J0345+2540 (L0)
RV = 4.8 km/s
Na I
K I
CO
Normalized Flux + offset
1.0 1.2 1.4 1.6 1.8 2.0 2.2 2.4
T5 T4 T3 T2 T1 T0 L9 L8 L7 L4 L2 L1 L0
1.15 1.20 1.25 1.30
T7 T6 T5 T4 T3 T2 T1 T0 L9
1.600 1.625 1.650 1.675 1.700 1.725
Wavelength (µm)

Figure 1. NIRES spectral standards (solid colored lines). Low-resolution NIR spectra of the same sources from the SPL are overplotted as dotted gray lines, with the exception of the Y0 standard (HST/WFC3 data from Schneider et al. 2015). Each NIRES spectrum has been shifted to the rest frame wavelength, and NIRES order has been scaled to the low-resolution spectrum and offset by a constant value. Each low-resolution spectrum has been normalized to its median flux between 1.2–1.25 μm. Spectra have also been shifted to the rest frame (see text). Regions of strong telluric absorption have also been masked. Flux zero-points are indicated with the dashed gray lines. The Y dwarf has been downsampled to half its resolution for clarity. Source names, corresponding spectral types, and radial velocities are listed on the right. Key atomic and molecular features are labeled. Subplots highlight features in the 1.1–1.3μm (top right) and 1.60–1.73μm regions (bottom right).(The data used to create this figure are available.)

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Facility: Keck (NIRES). -

Software: Astropy (Astropy Collaboration et al. 2013), SPLAT (Burgasser & Splat Development Team 2017), Spextool (Cushing et al. 2004).