HN Peg B: The Most Comprehensive Spectral Energy Distribution of a Moderately Young L/T-Transition Dwarf

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Abstract

We present the most comprehensive spectral energy distribution (SED) of a young brown dwarf at the L/T transition by combining new *Spitzer* mid-infrared spectra and photometry with previous observations of HN Peg B. We use this SED to evaluate the performance of various atmospheric models and find that models with condensates and using non-equilibrium chemistry reproduce better the data. However, these models face challenges in reproducing the observed methane and carbon monoxide absorption strengths mainly over the 3–5 μm region. By using the assembled SED and the Gaia EDR3 parallax of the host star, we derive accurate fundamental parameters of HN Peg B. We find that, on average, young early-T dwarfs are ≈100 K cooler and have a ≈ 20% larger radius compared to field-aged dwarfs with similar spectral types, but they have consistent bolometric luminosities. A comparison among moderate-dispersion near-infrared spectra of HN Peg B and other young and old dwarfs with similar spectral types shows that the J-band potassium line strengths are mostly insensitive to surface gravity in early-T dwarfs.

Introduction

The transition between L and T spectral types is an interesting phase in the evolution of brown dwarfs (BDs) because, at this transition:

- BD atmospheres undergo a cloud clearing process due to the settling of dust condensates.
- CH_4 replaces CO as the dominant carbon-bearing absorber in BD atmospheres.
- It is surface gravity dependant i.e. it happens at cooler temperatures for younger or lower gravity L/T-transition dwarfs (e.g. Metchev+2006, Luhman+2007).
- Directly imaged giant extrasolar planets have the appearance of BDs at this transition.

HN Peg B

An ideal target to study the atmosphere and physical properties at play at this transition is HN Peg B, a T2.5 dwarf companion of a solar-type star (Luhman+2007).

HN Peg B is a moderately young dwarf (≈ 300 Myr) just 18.13 ± 0.01 pc away and well-separated from its host star (43") to allow integrated-light studies (Luhman+2007).

We aim to study the role of surface gravity in the sedimentation of dust and emergence of CH_4 absorption in substellar atmospheres through the analysis of optical to mid-infrared spectrophotometry of HN Peg B.

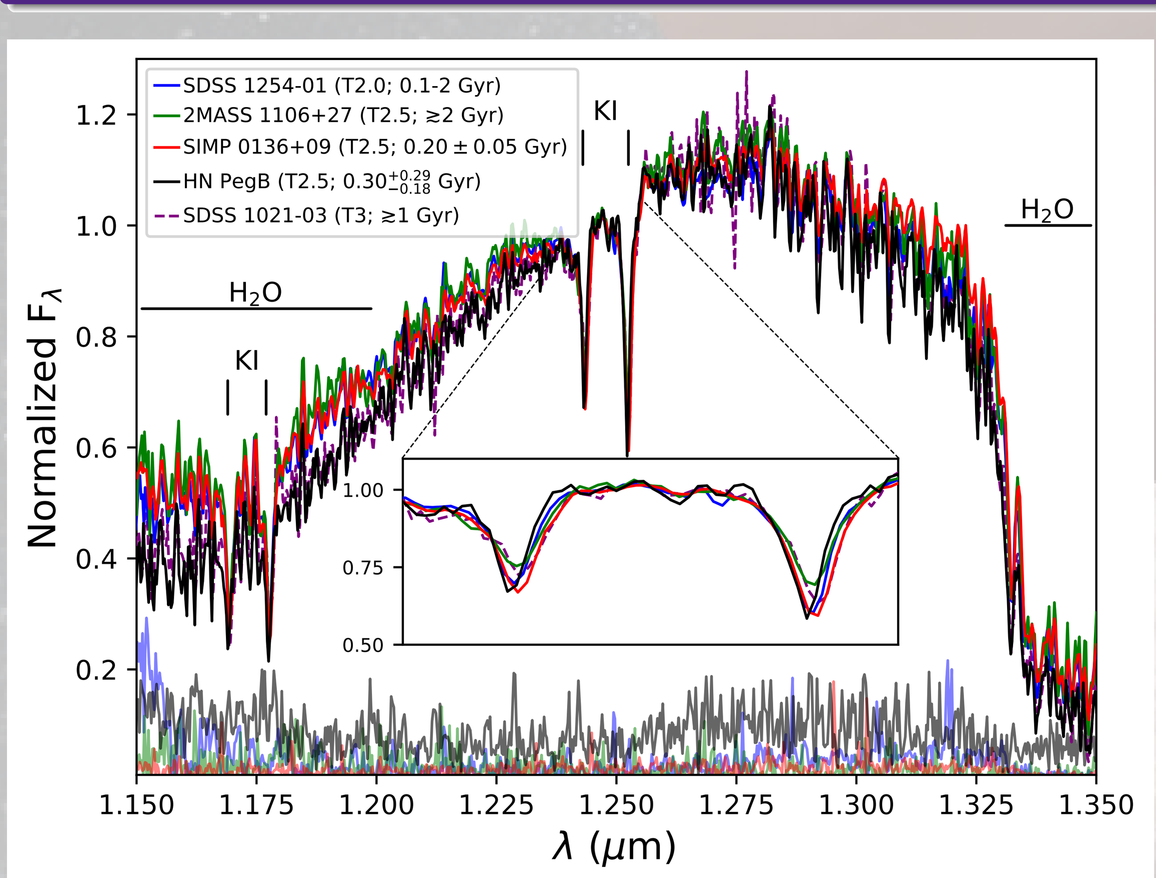
Data

Telescope/Instrument	Band[1]/Wavelength	Resolution	Observation (UT Date)	Reference
Photometry				
PS1/GPC1	z_{P1} and y_{P1}	···	2010–2015	1
IRTF/SpeX	J_{MKO}, H_{MKO} and K_{MKO}	···	2006 Jul 2	2
Spitzer/IRAC	Channels 1–4	···	2004 Jun 10	2
Spitzer/IRS	Blue and Red Peak-up	···	2007 Dec 8	3
Spectroscopy				
IRTF/SpeX	0.8–2.5μm	≈ 100	2006 Jun 15	2
Keck/NIRSPEC	1.15–1.38μm	≈ 2300	2008 Jul 8	4
Gemini/NIRI	2.96–4.07μm	≈ 400	2007 Jul 26, 30;	5
Spitzer/IRS	5.2–14.2μm	∼60–130	2008 Jul 11; Aug 2	1

(1) Chambers et al. (2016); (2) Luhman et al. (2007); (3) Suárez *et al.* (2021); (4) Zhou et al. (2018); (5) Leggett et al. (2008).

This spectrophotometry encompasses 98% of the bolometric luminosity of HN Peg B.

J-band KI doublet



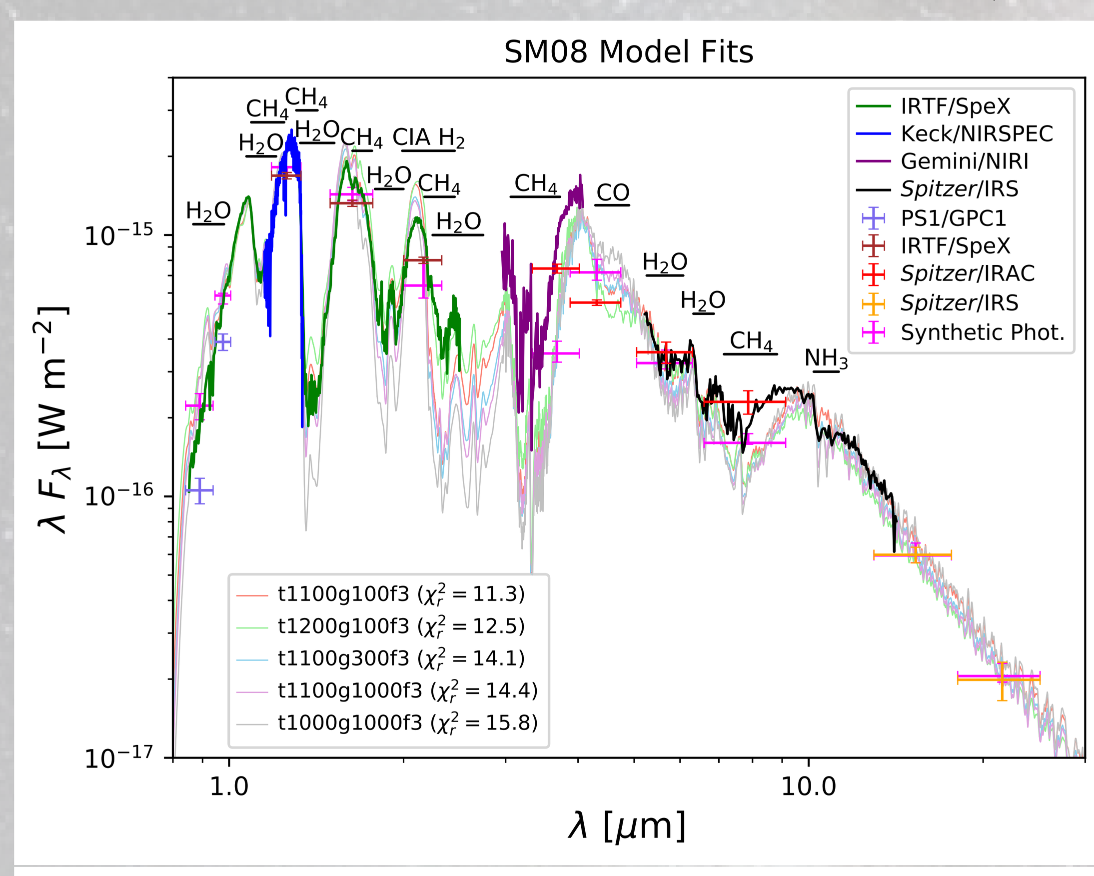
Alkali lines strengthen with surface gravity of late-M and L dwarfs (McGovern+2004, Miles-Páez+2017).

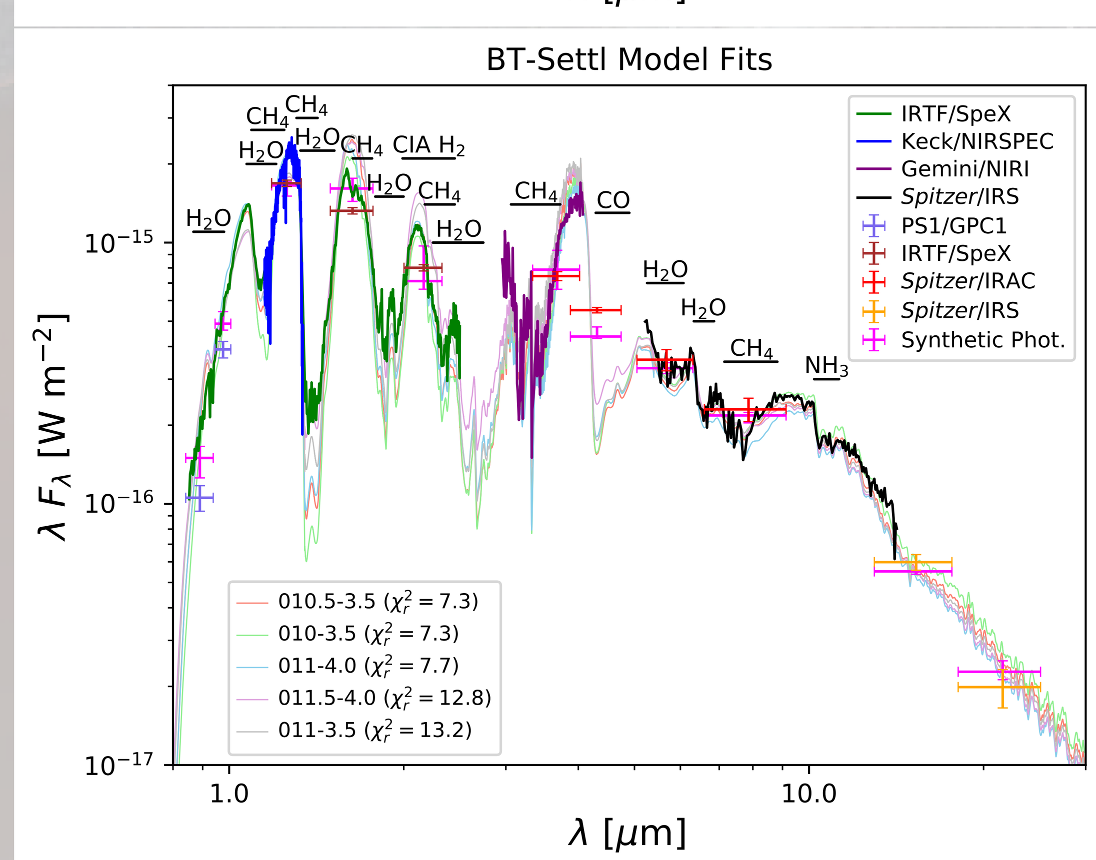
For late-T dwarfs the effect is the opposite (Knapp+2004).

We find that the J-band KI doublet is largely insensitive to surface gravity of early-T dwarfs.

Model Comparisons

Comparisons of the HN Peg B's spectral energy distribution (SED) to atmospheric models with clouds (Saumon & Marley 2008; SM08, and Allard+2012; BT-Settl).





Models using chemical equilibrium (SM08) over-predict the CH_4, mainly at 3.3 and 8.0 μm, and under-predict the CO at 4.6 μm.

Models with non-equilibrium chemistry due to vertical mixing (BT-Settl) fit better the CH_4, but slightly over-predict the CO at 4.6 μm.

Similar comparisons to cloudless atmospheric models (Marley+2018; Sonora 2018, and Phillips+2020; ATMO 2020) do not produce as good predictions of the data as cloudy models.

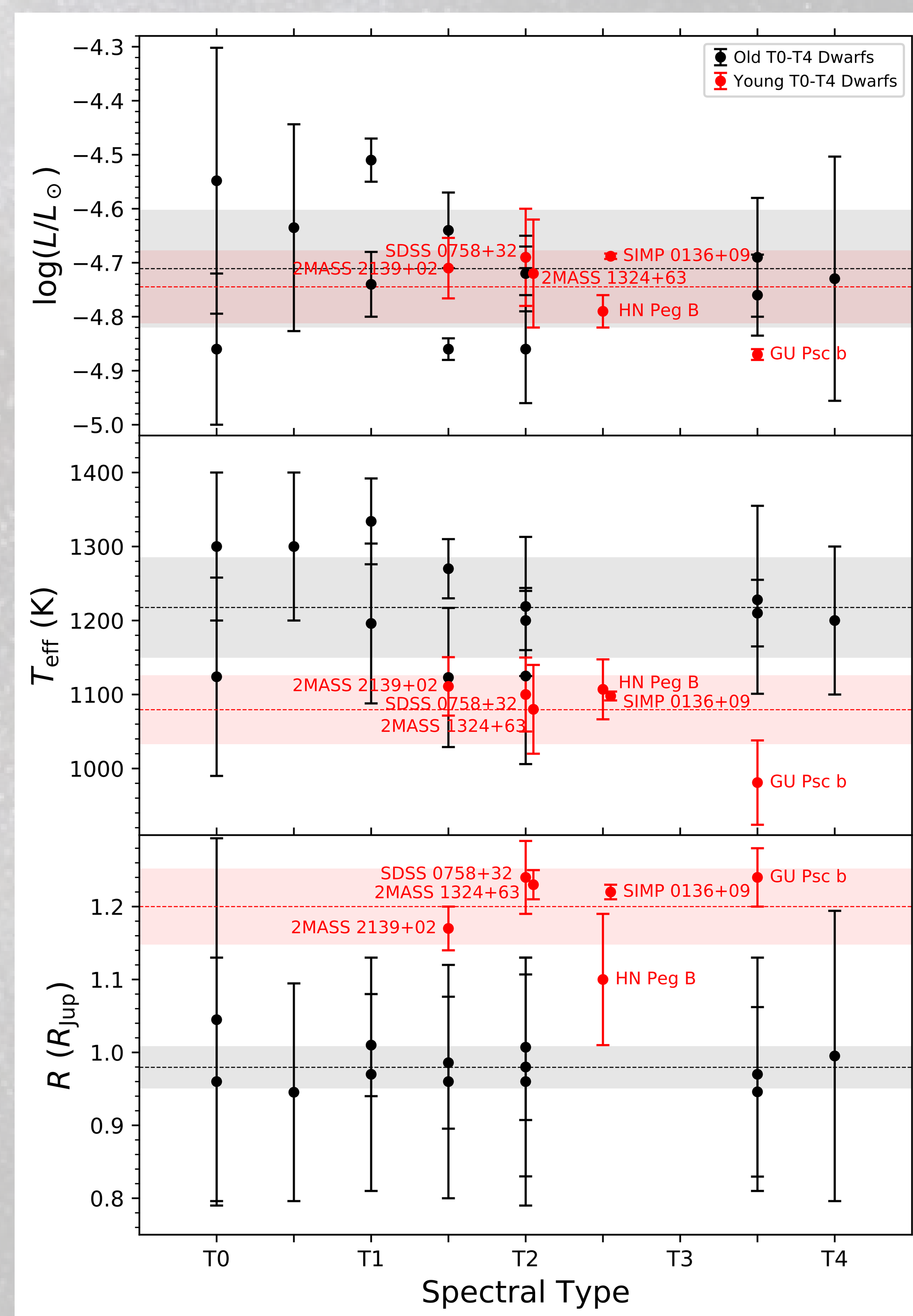
Overall, models with clouds using non-equilibrium chemistry reproduce better the SED of the early-T dwarf HN Peg B.

Fundamental Parameters

Origin	$\log(L_{bol}/L_\odot)$	R (R_{Jup})	T_{eff} (K)	$\log g$	f_{sed}	mass ($M_\odot$)	log(age)
SM08 Model Spectra Fits[a]	···	$1.06^{+0.09}_{-0.07}$	1000–1200	4.0–5.0	3	···	···
BT-Settl Model Spectra Fits[a]	···	$1.13^{+0.10}_{-0.08}$	1000–1150	3.5–4.0	···	···	···
Spectral Energy Distribution	-4.79 ± 0.03	···	···	···	···	···	···
S-B Law with R from SM08	···	···	1125^{+35}_{-36}	···	···	···	···
S-B Law with R from BT-Settl	···	···	1089^{+32}_{-41}	···	···	···	···
SM08 Evo. Model[b]	···	···	1127^{+35}_{-38}	$4.78^{+0.14}_{-0.18}$	···	$0.025^{+0.006}_{-0.006}$	$8.75^{+0.22}_{-0.26}$
Sonora 2018 Evo. Model[b]	···	···	1123^{+37}_{-37}	$4.76^{+0.14}_{-0.19}$	···	$0.023^{+0.006}_{-0.006}$	$8.58^{+0.20}_{-0.21}$
COND03 Evo. Model[b]	···	···	1095^{+35}_{-40}	$4.54^{+0.16}_{-0.23}$	···	$0.017^{+0.005}_{-0.006}$	$8.28^{+0.23}_{-0.35}$
ATMO 2020 Evo. Model[b]	···	···	1089^{+36}_{-40}	$4.53^{+0.17}_{-0.24}$	···	$0.016^{+0.005}_{-0.005}$	$8.26^{+0.18}_{-0.50}$
Adopted Parameters[c]	-4.79 ± 0.03	$1.10^{+0.10}_{-0.08}$	1107^{+38}_{-43}	$4.65^{+0.19}_{-0.24}$	3	$0.020^{+0.007}_{-0.007}$	$8.47^{+0.29,f}_{-0.39}$
Systematic Uncertainties[d]	···	±0.035	±18	±0.11	···	±0.004	±0.20
Random Uncertainties[e]	···	$^{+0.095}_{-0.075}$	$^{+33}_{-39}$	$^{+0.16}_{-0.21}$	···	$^{+0.006}_{-0.006}$	$^{+0.21}_{-0.33}$

Both model families produce consistent values, but there are some systematic differences.

Semi-empirical T_{eff} and evolutionary model-based $\log g$ are more accurate than those from the photospheric fits.



Overall, young and old early-T dwarfs have consistent bolometric luminosities, but the young sources have an average temperature ≈ 100 K cooler than and an average radius ≈ 20% larger than old field dwarfs with similar spectral types.

Conclusions

- We present the most comprehensive SED of an intermediate-gravity L/T-transition dwarf, which contains about 98% of the HN Peg B's bolometric luminosity.
- We find that the KI doublet at the J-band is not a good surface gravity indicator for early-T dwarfs as it is for late-M and L dwarfs.
- Atmospheric models with clouds (SM08 and BT-Settl) reproduce better the SED of an early-T dwarf than more recent cloud-free models (Sonora 2018 and ATMO 2020).
- Models face challenges in reproducing the CH_4 and/or CO absorptions of HN Peg B, but the predictions improve when models use non-equilibrium chemistry due to vertical mixing.
- We find that, on average, young and old early-T dwarfs have consistent luminosities.
- On average, young early-T dwarfs are ≈100 K cooler and have a ≈20% larger radius compared to old field early-T dwarfs.

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