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CONFIRMED DETECTION OF LITHIUM IN NEARBY YOUNG LATE-M DWARFS

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Abstract. *Brown dwarfs in nearby young associations and moving groups are excellent benchmarks for studying physical properties of these substellar objects at different ages as well as their formation mechanism. In our previous search for nearby young brown dwarfs, we reported the first clear detection of the lithium absorption line in three late-M dwarfs and a marginal detection in one late-M dwarf. Based on our new spectroscopic observations, we confirm our previous detection of lithium in the four late-M dwarfs. We also confirm the presence of lithium in one brown dwarf binary that has previously been reported in the literature. Using theoretical models, we estimate the age and the mass of these late-M dwarfs. We then use a Bayesian analysis tool for determining the membership probability of these young late-M dwarfs to nearby young moving groups.*

Keywords: brown dwarfs, formation of stars, spectroscopy.

Classification numbers: 97.20.Vs; 97.10.Bt; 95.55.Qf.

I. INTRODUCTION

Young associations and moving groups are streams of stars with a common age and motion in our Galaxy. The stars in these young associations or moving groups originated from the same star forming regions but they have become very loosely bound in the case of young associations or gravitationally unbound for moving groups. Nearby young associations and moving groups (hereafter NYAMGs) that have been identified so far have ages from 1 to 750 Myr and distances from 10 to 150 pc (see [1,2] and references therein). Each of NYAMGs contains about from a dozen to hundreds of stars. Some NYAMGs might be fragments of dissolving open clusters (see [3,4] and references therein). The NYAMGs spread over a wide range of ages and they contain different stellar populations with masses ranging from a few Jupiter masses (planetary mass objects) to a few dozen solar masses (O stars). Up to date, many brown dwarfs (BDs, 13−75 M_J) and planetary mass objects (<13 M_J) have been discovered in NYAMGs. This makes NYAMGs excellent laboratories to study physical properties and the formation process of these very low-mass objects. Recently, a 1 Myr-old BD member of Upper Scorpius association with a sporadic accretion has been discovered [5]. The discovery has provided us with important implications for the formation mechanism of BDs.

According to the BD theory [6], BDs with masses below 60 M_J that corresponds to spectral types later than ∼M9 will never reach the core temperature needed to burn the primodial lithium content in these objects. Therefore, this undestroyed lithium is present in the atmosphere of the BDs and it exhibits as the Li I resonance doublet absorption line at 6708 Å [7, 8]. However, the lithium depletion also depends on the age of stellar objects. Mid- and late-M dwarfs with spectral types from ∼M5.5 to M9 that show lithium should be young BDs [9]. Therefore, the lithium indicator has been used to detect young BDs among nearby late-M dwarfs (see [10] and references therein).

In our previous lithium search in 28 nearby late-M dwarfs with the Dual-Beam Spectrograph (DBS) on the 2.3 m telescope at Siding Spring Observatory, the lithium absorption line was clearly detected in four and marginally detected in one of the 28 targets [10]. In this paper, we report our new observations of eight of these 28 targets with the integral-field Wide-Field Spectrograph (WiFeS), the more efficient replacement of the DBS. We detect the presence of lithium in five targets. We present our sample and spectroscopic observations in Sect. II. We then estimate the mass and age of these young late-M dwarfs, and determine their NYAMG membership probability in Sect. III. Section IV summarizes our results.

II. SAMPLE AND SPECTROSCOPIC OBSERVATIONS

II.1. Sample

We selected eight late-M dwarfs (see Table 1) from the sample published in [10]. The lithium absorption line was detected in three of them: DENIS-P J0144318−460432 (hereafter DENIS0144−4604), DENIS-P J1809068−761324 (hereafter DENIS1809−7613), and DENIS-P J2022480−564556 (hereafter DENIS2022−5645). One of them, DENIS-P J0518113−310153 (hereafter DENIS0518−3101) has shown lithium at a marginal detection level. DENIS-P J0041353 −562112 (hereafter DENIS0041−5621) is a BD binary (M6.5+M9.0) [11]. The detection of lithium in this binary has been reported in [12]. However, we did not detect lithium in the BD binary due to its low signal-to-noise (S/N) ratio spectrum obtained in the previous observations [10]. We reobserved all these targets with WiFeS to confirm the presence of lithium in the objects. We also added three more targets as they were observable during our observations.

II.2. Spectroscopic observations

We observed the eight targets in Nov. 2016 (see Table 1) with WiFeS [15] on the ANU 2.3 m telescope at Siding Spring Observatory. The R7000 grating was used over a wavelength range from 5280 to 7050 Å, providing a spectral resolution of ∼7000. We used FIGARO [16] to reduce data. The R7000 spectra were corrected for mean telluric absorption using a smooth spectrum star. We used a NeAr arc for the wavelength calibration. We then used the IRAF task

Table 1. Hα and Li I 6708 Å equivalent widths of 8 nearby late-M dwarfs.

DENIS-P name	Spectral type	Distance (pc)	UT observing date	S/N	*EW* Hα (Å)	*EW* Li (Å)	References
J0041353−562112	M7.5	36.74±0.96	2016-11-22	30	−40±1	0.5±0.1	(1)
J0144318−460432	M5.5	38.54±0.07	2016-11-21	15	−37±1	0.7±0.1	(1)
J0440231−053009	M7.5	9.78±0.10	2016-11-18	15	−42±1	<0.1	(2)
J0518113−310153	M6.5	45.50±0.12	2016-11-18	13	−10±1	1.2±0.1	(1)
J1809068−761324	M5.0	27.28±0.01	2016-11-23	30	−8±1	0.7±0.1	(1)
J2022480−564556	M5.5	54.20±0.26	2016-11-18	10	−6±1	0.5±0.1	(1)
J2132297−051158	M5.5	19.64±0.19	2016-11-18	18	>−0.5	<0.1	(3)
J2151270−012713	M5.0	19.98±0.02	2016-11-18	21	−2.8±0.2	<0.1	(1)

References for distance derived from trigonometric parallax: (1) Gaia EDR3; (2) [13]; (3) [14].

splot to measure equivalent widths (EWs) of the Hα emission and Li I absorption lines. The S/N ratios estimated around the lithium region for all obtained spectra are from 10 to 30. The EW uncertainties were derived by measuring EWs at different estimated continuum levels or the noise around the spectral regions of interest. We list our measurements in Table 1.

III. RESULTS

III.1. Confirmation of the lithium presence in five late-M dwarfs

The lithium absorption line at 6708 Å is obviously seen in five late-M dwarfs. Table 1 lists our measurements of EWs of the lithium line. First, we confirm our previous detection [10] of lithium in three targets: DENIS0144−4604, DENIS1809−7613, and DENIS2022−5645. Second, in our previous observations [10], we did not detect lithium in DENIS0041−5621 as previously reported in [12]. The previous non-detection of lithium in this object is due to its low spectral S/N of only 3 as mentioned in [10]. Here, with a new spectrum of a high S/N of 10, the lithium is clearly detected. Therefore, we confirm the previous detection of Reiners & Basri [12]. For the case of DENIS0518−3101, the lithium that was marginally detected in our previous observations is now clearly detected. Fig. 1 shows the lithium line in DENIS0041−5621 and DENIS0518−3101. One should note that DENIS0041−5621 is a BD binary (M6.5+M9.0) at an age of ∼10 Myr as reported in [11]. At such an age and spectral types, lithium should be present in both components, DENIS0041−5621A and DENIS0041−5621B. However, component B with spectral type M9.0 at optical wavelengths is much fainter than component A with spectral type M6.5. Therefore, the detected lithium should be mainly attributed to component A. During our observations, DENIS-P J0440231−053009 (hereafter DENIS0440−0530) was also in a flaring state (see Fig. 2) as noted on 2008-03-28 [10]. Thus, we classify DENIS0440−0530 (or LP 655-48) as a flaring M7.5 dwarf.

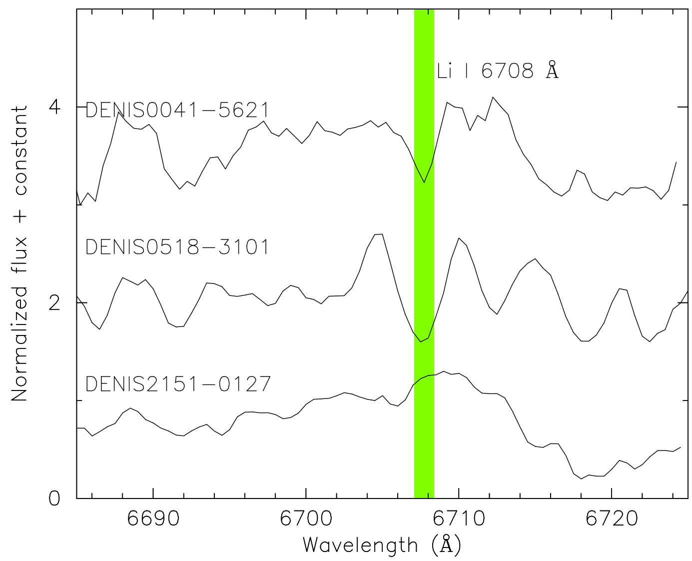

Fig. 1. Spectra of DENIS0041−5621 and DENIS0518−3101 with detected lithium. The spectrum of DENIS2151−0127 with no lithium detection is also plotted. The region of the lithium absorption line at 6708 Å is shown.

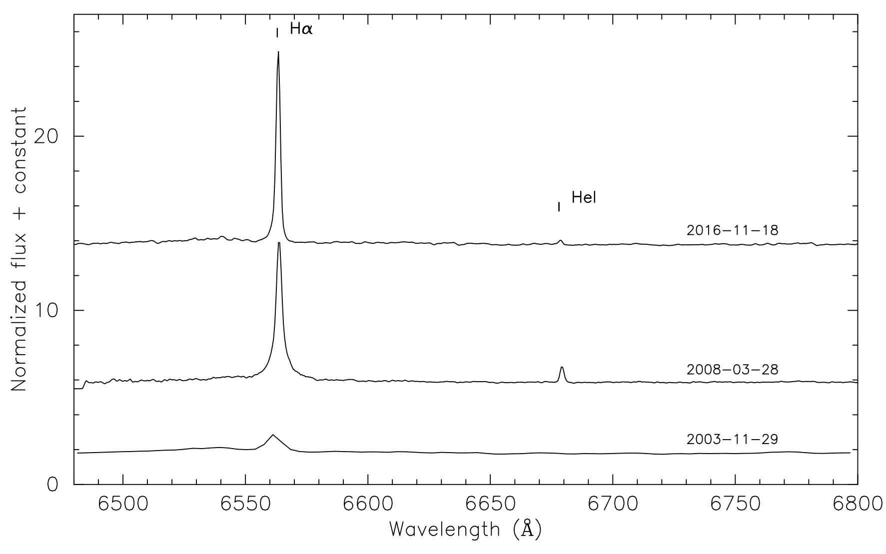

Fig. 2. DENIS0440−0530 in a flaring state during our observations on 2016-11-18 as seen on 2008-03-28. The spectrum on 2003-11-29 taken from [17] shows the late-M dwarf in a low level of magnetic activity.

III.2. Age and mass estimate

To estimate the age and mass of the five young late-M dwarfs with detected lithium, we follow the same manner as described in [5]. We use the *Gaia* EDR3[1] trigonometric parallaxes and the DENIS[2] J-band apparent magnitudes to derive the J-band absolute magnitudes of these objects. For DENIS0041−5621A and DENIS0041−5621B, J-band magnitudes are taken from [11]. The I-band magnitude for each component is derived from the DENIS I-band magnitude for both components and the difference in I-band magnitude $\Delta I \approx 2.12$ between young M6.5 and M9.0 dwarfs [18].

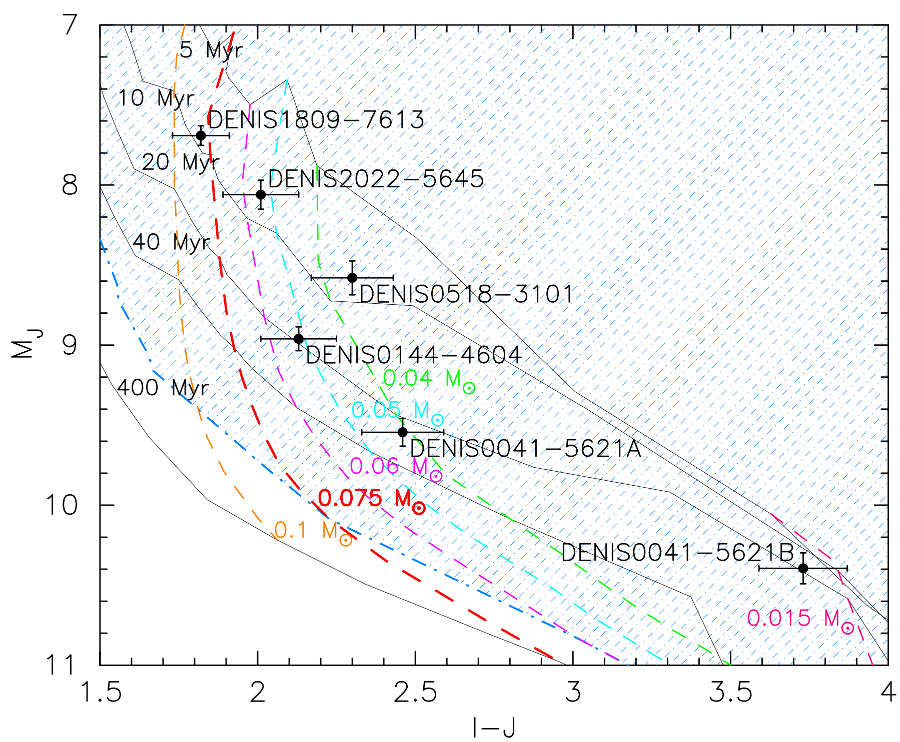

Fig. 3. J-band absolute magnitude versus color $I-J$ diagram for all five late-M dwarfs with detected lithium, including the BD binary DENIS0041−5621AB. Isochrones and mass tracks of the BT-Settl atmosphere models are plotted. The blue hatched area indicates where lithium remains undestroyed and detectable in the stellar atmosphere.

Based on the J-band absolute magnitudes and the colors $I-J$ of the five late-M dwarfs, we then use the BT-Settl atmosphere models [19] to estimate their age and mass. Fig. 3 shows the J-band absolute magnitude versus color $I-J$ diagram for all objects. DENIS0144−4604, DENIS0518−3101, and DENIS2022−5645 have masses well below the substellar limit (75 M_J). Our mass estimates (see Table 2) are consistent with the upper limits on the masses of these three

[1]https://vizier.u-strasbg.fr/viz-bin/VizieR-3?-source=I/350/gaiaedr3
[2]https://vizier.u-strasbg.fr/viz-bin/VizieR?-source=B/denis

objects as previously determined in [10]. For DENIS1809−7613 (SIPS J1809−7613), its mass is ∼81 M_J, which is also in excellent agreement with our previously estimated mass range of 81−85 M_J. Thus, DENIS1809−7613 is a young very low-mass star. For the case of the BD binary, Reiners et al. [11] have estimated an age of 10 Myr for DENIS0041−5621. In this paper, with the trigonometric parallax from *Gaia*, we derive an age of 20 Myr for the system. At this age, the masses of components A and B (see Table 2) are higher than those estimated in [11]. Table 2 lists our age and mass estimates for all objects.

Table 2. Estimated age and mass of young late-M dwarfs, and their NYAMG membership probability.

DENIS name	Spectral type	Distance (pc)	I (mag)	err$I$ (mag)	J (mag)	err$J$ (mag)	Mass (M_J)	Age (Myr)	NYAMG	Membership probability
0041−5621A	M6.5	36.74±0.96	14.83	0.10	12.37	0.03	37	20	THA	91.5%
0041−5621B	M9.0	36.74±0.96	16.95	0.10	13.22	0.04	16	20	THA	91.5%
0144−4604	M5.5	38.54±0.07	14.02	0.05	11.89	0.07	54	20	THA	99.8%
0518−3101	M6.5	45.50±0.12	14.17	0.03	11.87	0.10	41	9	COL	99.6%
1809−7613	M5.0	27.28±0.01	11.69	0.03	9.87	0.06	81	9	βPMG	99.7%
2022−5645	M5.5	54.20±0.26	13.74	0.04	11.73	0.08	49	8	THA	97.8%

I- and J-band magnitudes and associated errors from DENIS.

III.3. Membership of NYAMGs

As discussed in [10], nearby young late-M dwarfs are candidate members of NYAMGs. To calculate their membership probability, we use the Bayesian analysis tool BANYAN Σ[3] [20]. The proper motions of the objects are also taken from *Gaia*. Table 2 lists our calculations. The BD binary DENIS0041−5621AB and DENIS0144−4604 have membership probabilities greater than 90% for Tucana-Horologium. This is consistent with the membership determination of these objects as reported in [21]. Typically, the ages of the members of Tucana-Horologium (THA), Columba (COL), and β Pictoris (βPMG) are in the ranges of 20−40 Myr, 20−40 Myr, and 12−22 Myr, respectively (e.g., see [22] and references therein). The estimated age of 20 Myr for DENIS0041−5621AB and DENIS0144−4604 from the BT-Settl models is also consistent with the age range of THA. However, the estimated ages of DENIS0518−3101 (9 Myr, COL), DENIS1809−7613 (9 Myr, βPMG), and DENIS2022−5645 (8 Myr, THA) are younger than the typical ages of NYAMGs of which they are candidate members. It is possible that they are new members younger than the previously known members of these NYAMGs.

[3] http://www.exoplanetes.umontreal.ca/banyan/banyansigma.php

IV. SUMMARY

In this paper, we confirm the detection of lithium in five late-M dwarfs. With the *Gaia* trigonometric parallaxes, we determine the age and the mass of these objects more accurately. Four of them are young BDs and they are members of NYAMGs. One of them is a young very low-mass star. These young BDs are benchmarks for further studies of physical properties of young BDs and the BD formation process at differents stages.

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