SIMP J2154—1055: A NEW LOW-GRAVITY L4β BROWN DWARF CANDIDATE MEMBER OF THE ARGUS ASSOCIATION

JONATHAN GAGNÉ1, DAVID LAFRENIÈRE1, RENÉ DOYON1, ÉTIENNE ARTIGAU1, LISON MALO1,2, JASMIN ROBERT1, AND DANIEL NADEAU1

1 Département de Physique, Université de Montréal, C.P. 6128 Succ. Centre-ville, Montréal, QC H3C 3J7, Canada
2 Canada-France-Hawaii Telescope, 65-1238 Mamalahoa Hwy, Kamuela, HI 96743, USA

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ABSTRACT

We present SIMP J21543454—1055308, a new L4β brown dwarf identified in the SIMP survey that displays signs of low gravity in its near-infrared spectrum. Using BANYAN II, we show that it is a candidate member of the Argus association, albeit with a 21% probability that it is a contaminant from the field. Measurements of radial velocity and parallax will be needed to verify its membership. If it is a member of Argus (age 30–50 Myr), then this object would have a planetary mass of $10 \pm 0.5 M_{\text{Jup}}$.

Key words: brown dwarfs – methods: data analysis – proper motions – stars: kinematics and dynamics

Online-only material: color figures, data behind figures

1. INTRODUCTION

In the last decade, several brown dwarfs (BDs) in the field have been identified as displaying low-gravity features attributable to youth (Kirkpatrick et al. 2008; Cruz et al. 2009; Allers & Liu 2013; Liu et al. 2013; Gagné et al. 2014a). One could expect that a fraction of those young objects are unrecognized members of kinematic associations. However, the lack of parallax or radial velocity measurements for those objects prevents us from directly assessing their kinematics, which makes the identification of BD members to nearby young associations very hard. Identifying such BDs of known age would provide benchmarks to study the atmospheres of very low-mass stars and BDs, most of them having spectral types later than L0. A few other SIMP discoveries have been highlighted in Artigau et al. (2006) and Artigau et al. (2007). Among those, we have identified SIMP J2154−1055, an L4β brown dwarf identified in the SIMP survey that displays signs of low gravity, by obtaining a second $J$-band epoch for 30% of the sky (mostly in the Southern Hemisphere), 5–8 yr after the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) survey. This was achieved by using the CPAPIR camera (Artigau et al. 2004) on both the CTIO 1.5m telescope and the Observatoire du Mont-Méjantique 1.6 m telescope. The SIMP survey typically reached an astrometric precision of $0.’15$ and a photometric depth of $J = 17$. Any source in the SIMP survey that satisfied at least one of three filters based on proper motion ($\mu$) and $I−J$ color was selected for a spectroscopic follow-up: (1) $\mu > 100$ mas yr$^{-1}$ and detected in $I$ with $I−J > 3.5$; (2) $\mu > 100$ mas yr$^{-1}$ and not detected in $I$ such that $I−J > 3$; or (3) $\mu > 200$ mas yr$^{-1}$ and not detected in $I$. Magnitudes were selected either from the SuperCOSMOS Sky Survey (Hambly et al. 2001), the Sloan Digital Sky Survey (York et al. 2000), or the Catalina Sky Survey (CSS; Larson et al. 1998), as available and in this order of preference. These criteria were designed to reject close-by M-type dwarfs as well as distant objects. A large number of new BD candidates have been identified this way, from which more than a hundred have been followed with NIR spectroscopy and confirmed as new M5–T3 very low-mass stars and BDs, most of them having spectral types later than L0. Among those, we have identified SIMP J2154−1055, an L4β BD displaying signs of low-gravity. A few other SIMP discoveries have been highlighted in Artigau et al. (2006) and Artigau et al. (2011), whereas remaining discoveries will be presented in an upcoming paper (J. Robert et al., in preparation).

2. THE SIMP SURVEY

The SIMP survey (Artigau et al. 2009) has been initiated in 2006 to identify new nearby BDs from their red optical-to-NIR colors and high proper motions, by obtaining a second $J$-band epoch for 30% of the sky (mostly in the Southern Hemisphere), 5–8 yr after the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006) survey. This was achieved by using the CPAPIR camera (Artigau et al. 2004) on both the CTIO 1.5m telescope and the Observatoire du Mont-Méjantique 1.6 m telescope. The SIMP survey typically reached an astrometric precision of $0.’15$ and a photometric depth of $J = 17$. Any source in the SIMP survey that satisfied at least one of three filters based on proper motion ($\mu$) and $I−J$ color was selected for a spectroscopic follow-up: (1) $\mu > 100$ mas yr$^{-1}$ and detected in $I$ with $I−J > 3.5$; (2) $\mu > 100$ mas yr$^{-1}$ and not detected in $I$ such that $I−J > 3$; or (3) $\mu > 200$ mas yr$^{-1}$ and not detected in $I$. Magnitudes were selected either from the SuperCOSMOS Sky Survey (Hambly et al. 2001), the Sloan Digital Sky Survey (York et al. 2000), or the Catalina Sky Survey (CSS; Larson et al. 1998), as available and in this order of preference. These criteria were designed to reject close-by M-type dwarfs as well as distant objects. A large number of new BD candidates have been identified this way, from which more than a hundred have been followed with NIR spectroscopy and confirmed as new M5–T3 very low-mass stars and BDs, most of them having spectral types later than L0. Among those, we have identified SIMP J2154−1055, an L4β BD displaying signs of low-gravity. A few other SIMP discoveries have been highlighted in Artigau et al. (2006) and Artigau et al. (2011), whereas remaining discoveries will be presented in an upcoming paper (J. Robert et al., in preparation).

3. SPECTROSCOPIC FOLLOW-UP

The NIR spectrum of SIMP J2154−1055 presented here was obtained on 2008 September 16 at the IRTF (program number 2008B054), using SpeX in the prism mode with the 0’5 slit ($R \sim 150$), covering the 0.8–2.5 $\mu$m range. The source was moved along the slit in an ABBA pattern, with a total of 10 exposures of 180 s to achieve a signal-to-noise ratio of $\sim 180$ per resolution element. Raw exposures were reduced and combined using the SpeXtool package (Cushing et al. 2004), and telluric corrections were applied in a standard way (Vacca et al. 2003), using the A-type star HD 202990 observed immediately before the target and at a similar airmass.
4. SIGNS OF LOW-GRAVITY

The NIR spectrum of SIMP J2154−1055 was visually compared with various NIR spectral templates to assign it a spectral type and identify peculiar features, following the method of K. Cruz et al. (in preparation; see also Cruz & Núñez 2007). Field templates were built for all spectral types in the M5–T8 range by median-combining high-quality spectra that showed no peculiarities nor signs of unresolved binarity in the DwarfArchives.3 Low-gravity templates were built from known L0γ−L4γ BDs that were classified as low-gravity objects in the optical or the NIR (Cruz et al. 2009; Allers & Liu 2013; K. Cruz et al., in preparation). This comparison showed that SIMP J2154−1055 matches the L4 templates better than any other spectral types. Furthermore, the L4γ template is a better match than the field L4. The key spectral regions that differentiate between those two templates are: (1) the depth of the $K\beta$ feature at $\sim1.25$ $\mu$m; (2) the level of the red end of the $J$ band ($\sim1.3$ $\mu$m); (3) the triangular shape of the $H$ band (1.5–1.8 $\mu$m); and (4) the slope of the $K$ band plateau (2.15–2.3 $\mu$m). We show a comparison of SIMP J2154−1055 with the L4 and L4γ templates in Figure 1, with those four regions identified. The L4 and L4γ templates were built using five and two distinct spectra respectively.

Allers & Liu (2013) developed an NIR classification scheme to determine spectral types in a way that should not be sensitive to surface gravity, using visual classification supplemented by the $H_2O$ indices, and then determined a gravity class using various spectroscopic indices sensitive to surface gravity. Objects for which most low-gravity indices are strong are classified as very low-gravity (VL-G) objects, and those having only a few indices as intermediate-gravity (INT-G) objects. Those without significant signs of youth are classified as field gravity. We have used this scheme to classify SIMP J2154−1055, with the exception that we used solely visual classification to determine its spectral type. Results are presented in Table 1, as well as in Figure 2. We find it is classified as an INT-G BD. Allers & Liu (2013) indicate that their INT-G and VL-G classifications respectively correspond to the $\beta$ and $\gamma$ classifications defined for optical spectra by Cruz et al. (2009). For this reason, we adopt $L4\beta$ as the NIR spectral type of SIMP J2154−1055. Obtaining a higher-resolution NIR spectrum for this object would be useful in verifying that its alkali line equivalent widths are effectively weaker than normal. SIMP J2154−1055 is detected

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3 http://dwarfarchives.org

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Figure 2. Panels (a)–(c): Gravity-sensitive spectroscopic indices for SIMP J2154−1055 (black star) compared with the field dwarf sequence (dark blue line) and its associated scatter (pink shaded region delimited by dashed pale blue lines). The dashed dark blue line delimits the intermediate-gravity and very low-gravity regimes. All objects classified as INT-G and VL-G in Allers & Liu (2013) are also displayed as green and purple dots, respectively. Panel (d): 2MASS $J - K_S$ colors of SIMP J2154−1055 (black star) compared with the median values and standard deviation for field dwarfs (pink shaded region delimited by dashed pale blue lines; constructed from field BDs in the Dwarf Archives), young field BDs (red dots; see Gagné et al. 2014b for the extensive list), and moderately young BD candidates (open purple symbols; Bannister & Jameson 2005; Bihain et al. 2010; Casewell et al. 2014; Jameson et al. 2008); circles for the Pleiades ($\sim$125 Myr), downside triangles for Ursa Major ($\sim$400 Myr), right triangles for Coma Berenices ($\sim$500 Myr) and left triangles for the Hyades ($\sim$625 Myr). The colors of SIMP J2154−1055 are consistent with its probable membership in Argus (Section 5).

(A color version and supplemental data of this figure are available in the online journal.)

in the ALLWISE (Kirkpatrick et al. 2014) W3 channel, but does not display signs of infrared excess. We also show that it displays the reddest $J - K_S$ NIR color of all currently known L4 dwarfs (Figure 3), an effect likely attributed to thicker clouds in its photosphere. It is suspected that low gravity (youth) can cause such thicker clouds (Burgasser et al. 2008b).

5. ARGUS MEMBERSHIP

We used the BANYAN II tool (Gagné et al. 2014b) to verify if SIMP J2154−1055 is a candidate member of nearby young associations. We used the 2MASS and ALLWISE astrometry, as well as data from DENIS (Epchtein 1988) and measurements obtained with CPAPIR through the SIMP survey to calculate its proper motion (Table 1). We find that SIMP J2154−1055 has a 83.8% probability of being a member of the Argus association (30–50 Myr; Torres et al. 2008). The Argus association of stars was first identified by Makarov & Urban (2000), which proposed that the open cluster IC 2391 was a part of it. Torres et al. (2003) used the method of convergent point proper motion to show that both associations shared common kinematics, thus confirming this hypothesis. This association currently has 11 known A0–M5 bona fide members (Malo et al. 2013), from which the latest-type is the nearby star AP Col (Riedel et al. 2011). Gagné et al. (2014b) also proposed three low-gravity L-type BDs as candidate members to this association. Since the probability for the Argus membership of SIMP J2154−1055 is derived from a naive Bayesian classifier, it is expected to be biased when using...
dependent measurements as input observables (such as is the case here, see detail in Gagné et al. 2014b). Hence, we used the Monte Carlo contamination analysis presented in Gagné et al. (2014b) to obtain a probability of 20.5% that SIMP J2154−1055 is a young false-positive from the field. In the present case, the contamination and membership probabilities are almost exactly complementary, but this is not true in general.

In Figure 4, we show the proper motion of SIMP J2154−1055 compared with those of known bona fide members in Argus. Since members are spread across a large portion of the sky, the direction of their proper motion can be different, however it is expected that the great circles corresponding to the motion of all members of a given moving group will pass close to the group’s apex and antapex. The proper motion of SIMP J2154−1055 thus seems consistent with a membership to Argus, since its great circle is closer to the apex than 6/11 bona fide members. Its very red $J-K_S$ colors (Figures 2 and 3) are also consistent with this interpretation. The BANYAN II tool allows us to predict that this object should have a distance of $22.1^{+2.8}_{-2.4}$ pc and a radial velocity of $-13.0 \pm 1.4$ km s$^{-1}$ if it is a member of Argus, or a distance of $23.7^{+5.4}_{-5.2}$ pc and a radial velocity of $-8.9 \pm 9.1$ km s$^{-1}$ if it is a field object. Using its 2MASS and ALLWISE apparent magnitudes, statistical distance, AMESCOND isochrones (Baraffe et al. 2003) and CIFIST2011 BT-SETTL atmosphere models (Allard et al. 2013) we determined that, at the age of Argus (30–50 Myr; Torres et al. 2008), SIMP J2154−1055 has a predicted mass of $10 \pm 0.5$ $M_{\text{Jup}}$, in the planetary-mass regime. Adding measurements of radial velocity and parallax will be needed to assert its membership.

6. CONCLUSIONS

We present the discovery of a new young L4$\beta$ BD, identified as part of the SIMP survey. We classify it as intermediate-gravity BD following the NIR gravity classification scheme of Allers & Liu (2013). We determine that it has an 84% probability of being an Argus member. We estimate that if it is a member of the Argus association with an adopted age of 30–50 Myr, its mass would be $10 \pm 0.5$ $M_{\text{Jup}}$, in the planetary-mass regime. Adding
this object to the currently known late-type low-mass stars and BDs will help shape our understanding of the properties of low-gravity, low-pressure atmospheres reminiscent of those of giant, gaseous exoplanets. The data presented in this Letter can be downloaded at our group’s Web site.4

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