Infrared spectroscopy of free-floating planet candidates in Upper Scorpius and Ophiuchus

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ABSTRACT

Context. A rich population of low-mass brown dwarfs and isolated planetary mass objects has been reported in the Upper Scorpius and Ophiuchus star-forming complex.

Aims. We investigate the membership, nature, and properties of 17 of these isolated planetary mass candidates using low-resolution near-infrared spectra.

Methods. We investigated the membership by looking for evidence of their youth using four diagnostics: the slope of the continuum between the J and Ks band, the H_cont, and the TLI-g gravity-sensitive indices. In addition, we compared the spectra to young and field (old) M and L-dwarf standards.

Results. All the targets but one are confirmed as young ultracool objects, with spectral types between L0 and L6 and masses in the range 0.004–0.013 M⊙. Only one possible contaminant has been identified among the 17 targets, suggesting that the contamination level of the original sample must be low (≤6%).

Conclusions. Only one possible contaminant has been identified among the 17 targets, suggesting that the contamination level of the original sample must be low (≤6%).

Key words. brown dwarfs – stars: late-type – stars: pre-main sequence – planets and satellites: formation

1. Introduction

Free-floating planets are planetary-mass objects that do not orbit a star, but roam the galaxy in isolation instead. Apart from micro-lensing detections, only a few tens of directly imaged free-floating planet candidates are known to date (e.g., Tamura et al. 1998; Lucas & Roche 2000; Zapatero Osorio et al. 2000; Luhman et al. 2003; Peña Ramírez et al. 2012; Suárez et al. 2019; Lodieu et al. 2018; Luhman & Hapich 2020, and references therein) and only a small fraction have been confirmed so far. Because of the degeneracy in the mass–luminosity relationship for these ultracool objects, it is indeed impossible to distinguish a low-mass brown dwarf from a planetary mass object when the age and distance are unknown. This deadlock can be overcome by studying free-floating planets members of young associations where the age and distance are precisely known. In the context of the COSMIC-DANCE project (Miret-Roig et al. 2022) obtained deep optical and near-infrared photometry and measured accurate proper motions 5 mag beyond Gaia’s limit in the nearby Upper Scorpius OB association (USco) and ρ-Ophiuchus (Oph) molecular clouds. They identified over 3500 members, including between 70 and 170 planetary mass objects, depending on the age assumed.

* Full Table B.4 is only available at the CDS via anonymous ftp to cdsarc.u-strasbg.fr (130.79.128.5) or via http://cdsarc.u-strasbg.fr/viz-bin/cat/J/A+A/664/A111

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This large number of planetary mass object candidates in a young association has important implications for the theories and models of star, brown dwarf, and planet formation. In order to confirm this important discovery, we performed follow-up spectroscopic observations of 18 free-floating planet candidates to confirm their nature and membership to the association and validate Miret-Roig et al. (2022) analysis. In the following, we describe the observations and the processing of the data obtained at the Grantecan and Subaru telescopes. We discuss the membership to the association by looking for spectral features characteristic of young ultracool objects. Finally, we estimate the spectral types of the objects and derive effective temperatures, as well as a contamination rate in Miret-Roig et al. (2022) sample.

2. Observations

2.1. Targets

We selected 18 targets within Miret-Roig et al. (2022) sample, after discarding objects already observed spectroscopically in the literature (e.g., Lodieu et al. 2018; Luhan & Esplin 2022). A total of 18 objects were randomly selected in the range between 17.3 < J < 19.2 mag, corresponding to masses between 7 ≤ M ≤ 10 M_{Jup} and effective temperatures between 1500 ≤ T_{eff} ≤ 1900 K, according to Baraffe et al. (2002) evolutionary models for an age of 5 Myr and a distance of 145 pc. One brighter target (DANCe J16064553−2121595 = 3355, J = 16.19 mag) was added during the course of the observations as clouds were degrading the sensitivity and preventing us from observing our original targets. Figure 1 shows a (M_J, J − K_s) color-magnitude diagram of the sample and Fig. 2 shows the location of the targets in Upper Scorpius and Ophiuchus. Two sources (3213 and 3214) are separated by only 120″.

2.2. SWIMS at Subaru

A total of six objects were observed with the Simultaneous-color Wide-field Infrared Multi-object Spectrograph (SWIMS, Motohara et al. 2014, 2016; Konishi et al. 2018, 2020) mounted on the Subaru Telescope in May 2021 (Program S21A-047, PI: M. Tamura). SWIMS was used in long-slit mode with its simultaneous J (700 < R < 1200) and HK (600 < R < 1000) grisms. The 300 s individual exposures were acquired following a standard ABBA procedure to efficiently remove the sky emission. The seeing was generally very good (between 0′′3 and 0′′6) but clouds were hindering the observations at times. A slit of 0′′5 or 0′′8 was used depending on the seeing. Table 1 gives the list of targets observed with SWIMS and the corresponding number of exposures and individual exposure times. Three B stars of the Upper Scorpius associations were observed (HIP81145, HIP82133 and HIP78702) to be used as telluric standards.

The raw data were processed following standard procedures for infrared spectroscopy using a combination of custom made Python code using the astropy and specutils libraries (Astropy Collaboration 2018; Earl et al. 2022) and IRAF/PyRAF’s apall package for the spectra extraction and telluric correction. The closest-in-time B stars spectrum was used to remove the telluric contamination in each of our targets spectra. Because the B stars belong to Upper Scorpius as well, the typical airmass differences with the target were less than 0.2 ~ 0.3.

2.3. EMIR at GTC

A total of 13 objects were observed with Espectrógrafo Multi-objeto Infra-Rojo (EMIR, Garzón et al. 2014) mounted on the Grantecan telescope (Program GTC2-21A, PI: D. Barrado) in May 2021. EMIR was used in long-slit mode with its HK grism and a slit of 1′′2 chosen to match the ambient seeing during the observations, and leading to an effective resolution of R ~ 500. The weather was mostly clear during the observations. Table 1 gives the list of targets observed with EMIR and the corresponding number of exposures and exposure times. The 200 s individual exposures were acquired following a standard ABBA procedure to efficiently remove the sky emission.

The data were reduced using RedEmIR, a new GTC pipeline written in Python; RedEmIR eliminates the contribution of the
sky background in the near infrared using the consecutive A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum. The telluric correction is achieved using A–B pairs. The sky-subtracted images are subsequently flat-fielded, calibrated in wavelength and average combined to obtain the final spectrum.

Gravity-sensitive absorption lines: Collision-induced pressure broadening depends on both the temperature and gravity through the ultracool dwarf atmosphere. For a given effective temperature, an older ultracool dwarf with a higher gravity will therefore have more prominent absorption lines than a younger (lower gravity) counterpart (Martin et al. 1996; Gorlova et al. 2003; Allers & Liu 2013). At the resolution of our observations, the 1.244 and 1.253 μm K1 lines are the most gravity sensitive lines detectable in the SWIMS spectra. Unfortunately, the relatively low signal-to-noise ratio (S/N) of our SWIMS spectra in the J-band results in large uncertainties and inconclusive values of the KIg index of Allers & Liu (2013).

TLI-g gravity sensitive index: Taking advantage of the growing number of near-infrared spectra available in the literature and in various databases, Almendros-Abad et al. (2022) recently used machine learning techniques to define a new gravity sensitive index. Their TLI-g index is designed to separate young objects from older field objects with a performance superior to other indices from the literature. It seems to be particularly less sensitive to the presence of dust in the upper layer of the atmosphere, but it is, however, sensitive to extinction.

In the following, we discuss the J – Ks color, Hcon and TLI-g indices of our targets and compare their spectra to young and field M and L-dwarf standards.

3.1. J – Ks colours

Figure 1 shows that all our targets have J – Ks colors redder than older field counterparts from the literature and similar to known young low-gravity ultracool dwarfs. Both the multiplicity and extinction can shift objects in this diagram and mimic the effect of youth. The presence of an unresolved companion can indeed shift the position mostly vertically in a colour–magnitude diagram (Houk et al. 1996; Gorlova et al. 2003; Allers & Liu 2013). At the resolution of our observations, the 1.244 and 1.253 μm K1 lines are the most gravity sensitive lines detectable in the SWIMS spectra. Unfortunately, the relatively low signal-to-noise ratio (S/N) of our SWIMS spectra in the J-band results in large uncertainties and inconclusive values of the KIg index of Allers & Liu (2013).

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field sequence. Extinction is unlikely to have shifted the objects given that the cumulative line-of-sight reddening towards our objects is low in most cases (see Table 1) and still places them on the redder low-gravity sequence even in the worst cases of 3293 and 3144. While it is not a conclusive proof, the very red \( J-K_s \) color certainly adds to the list of evidence indicating youth and, hence, membership to USco or Oph.

### 3.2. Comparison with young and old M and L standards

To further assess the youth of our targets and at the same time derive their spectral type, we performed an empirical comparison with spectra of young and old ultracool objects from the literature. The comparison was made using The SpeX Prism Library Analysis Toolkit (SPLAT, Burgasser & Splat Development Team 2017). A number of spectral libraries of young ultracool dwarfs have been presented in the literature and we chose to use the very-low gravity spectral standards included in SPLAT (see Table B.2 and Burgasser & Splat Development Team 2017). The field-gravity (older) standards chosen for the comparison are presented in Table B.3.

The degeneracy between extinction and spectral type can affect and compromise the comparison (see e.g., Luhman et al. 2017). To partially lift this degeneracy and explore the effect of extinction on the results of our analysis, we performed the comparison after dereddening our spectra by the cumulative extinction in the line of sight of each target up to 250 pc reported in the 3D extinction map of Green et al. (2019). Assuming that all our targets belong to USco, this should represent a worst-case scenario in terms of reddening and provide an estimate of the lower limit on the spectral type. USco is indeed located at approximately 145 pc and Oph at 125 pc, although possibly extending up to \( \sim 200 \) pc (Damiani et al. 2019). The value of 250 pc was therefore chosen to be conservative and be sure to include the entire depth of the clouds associated with these two regions.

SPLAT was first used to scale the instrumental fluxes to physical units using the target \( H \)-band photometry reported in Miret-Roig et al. (2022) as reference. The closest match in each of the two libraries of standards is found using a standard \( \chi^2 \)-minimization. Figures A.1–A.3 show the results, with the original spectra on the left and the dereddened spectra on the right. As expected the spectral types obtained using the high-gravity (older) field standards are systematically later than those obtained with the low-gravity (young) standards.

Figures A.1–A.3 show that 3210, 3200, 3314, 3091, 3326, 3214, 3355, 3144, 3299, and 3345 are clearly better matched by a young spectral standard than by an old spectral standard than by an old spectral standard.

### 3.3. Sharp H-band continuum

As mentioned earlier in this paper, the shape of the \( H \)-band continuum varies from a typical triangular shape at young ages to a flatter continuum at more advanced ages as gravity increases. The \( H_{\text{cont}} \) index is defined by Allers & Liu (2013) as commonly used to quantify the sharpness of the \( H \)-band continuum and look for evidence of youth.

We measured the \( H_{\text{cont}} \) index in all our spectra, as well as in the 891 spectra from the SPEX Ultracool dwarfs library with a good level of quality (QUALITY_FLAG=OK and \( \text{MEDIAN}_\text{SNR} \geq 50 \)) and a resolution of \( R \geq 120 \). The uncertainty was estimated by simply propagating the standard errors of the means used in the \( H_{\text{cont}} \) index formula. We derived near-infrared spectral types for each spectrum from the SPEX Ultracool dwarfs library based on the Kirkpatrick et al. (2010) \( L \)-dwarf classification scheme and a gravity classification between very-low (VL-G), intermediate (INT-G) and field (FLD-G) gravity using Allers & Liu (2013) classification scheme. Figure 3 shows the results in the form of a violin graph, using the spectral types presented in Sect. 4 for our targets. The index measurement, spectral type, and gravity classification for the 891 spectra are available in electronic form in Table B.4.

Within the relatively large error bars, a number of our targets seem to have an \( H_{\text{cont}} \) favoring low or intermediate gravity and hence a young age. These include 3210, 3200, 3314, 3091, 3326, 3214, 3355, 3144, 3299, and 3345. Two objects have \( H_{\text{cont}} \) values more consistent with high-gravity older objects: 3404 and 3293; however, the broad uncertainties also make them consistent with intermediate gravity objects. Objects 3244, 3421, and 3231 have \( H_{\text{cont}} \) values that are consistent with intermediate or low gravity, while 3378 and 3213 have inconclusive \( H_{\text{cont}} \) indices compatible within the uncertainties either with high or intermediate gravity objects.

### 3.4. TLI-g index

The TLI-g index was invented recently by Almendros-Abad et al. (2022) using machine learning techniques to specifically distinguish low and field gravity ultracool objects. We measured the TLI-g index in all our spectra, as well as in the 891 spectra from the SPEX library mentioned in the previous section (see Table B.4). Figure 4 shows the results in the form of a violin graph.

Within the error bars we can see that all our targets have a TLI-g index favoring low or intermediate gravity and hence a young age except in the case of:

- 3144 with a TLI-g index favoring a field gravity and hence an older age;
- 3378 and 3404 have such large uncertainties that the TLI-g index is inconclusive.

Although Almendros-Abad et al. (2022) defined the TLI-g index using a sample of M0–L3 ultracool dwarfs, we can see in Fig. 4 that it seems to work equally well on the L4 and L6 dwarfs of our sample.

### 3.5. Final youth status

Table 2 gives a summary of the four youth diagnostics as well as the final status for each target. Among the 17 targets, there are 9 that have the four diagnostics indicating a young age, and are

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*Note: The above text is a natural representation of the document. For a more accurate understanding, please refer to the original document.*
Fig. 3. $H_{\text{cont}}$ gravity index from Allers & Liu (2013) for our targets (red dots) over-plotted over a violin graph of the distributions for ultracool dwarfs with very-low gravity (red), intermediate gravity (blue) and field-gravity (cyan) from the SPEX library of ultracool dwarfs. Our targets are shifted randomly horizontally for clarity.

Fig. 4. TLI-g gravity index from Almendros-Abad et al. (2022) for our targets (red dots) over-plotted over a violin graph of the distributions for ultracool dwarfs with very-low gravity (red), intermediate gravity (blue) and field-gravity (cyan) from the SPEX library of ultracool dwarfs. Our targets are shifted randomly horizontally for clarity.

therefore firmly confirmed as young ultracool dwarfs members of the USco and Oph associations. Another 5 have inconclusive $H_{\text{cont}}$ indices within the broad uncertainties or an inconclusive comparison with standards – however, all of them have other diagnostics indicating low-gravity and are therefore confirmed as young ultracool dwarfs with a high level of confidence as well.

The remaining cases are discussed here:

- 3144 is classified as young from the $J-K_s$ color, the comparison with spectral standards, and the $H_{\text{cont}}$ index, but as old from the TLI-g index. Extinction can affect the TLI-g measurement, but would move the object down in the diagram and make it look younger. Instead, we find that 3144 has a higher TLI-g value. Its value is still consistent with intermediate gravity object within the uncertainties and given that all the other diagnostics favor a young age, we classified 3144 as a young ultracool dwarf as well;
- 3404 is classified as young using two diagnostics and is only classified as possibly old using the $H_{\text{cont}}$ index, while the TLI-g index is inconclusive because of the large uncertainties. Given that the large uncertainties on the $H_{\text{cont}}$ index make it fully compatible with intermediate and low gravity objects as well, we classified 3404 as young as well;
- 3293 has a marginally better fit with an old standard and has a $H_{\text{cont}}$ index clearly favoring a high-gravity older object. But
that reddening does not affect the spectrum of the targets. We adopted the integrated line-of-sight extinction at 250 pc is relatively small (\(A_V = 2.99\) mag) and its influence (see Table 1). The match is significantly better without extinction in the cases of 3213 (L2), 3314 (L0), 3210 (L0), and 3421 (L1–L4). We note that the integrated line-of-sight extinction at 250 pc, we can partially break the degeneracy between extinction, which the target eventually lies at the far edge of the association.

In conclusion, 16 of the 17 targets have multiple pieces of evidence to support their youth and one (3293) is inconclusive. In total we therefore firmly confirm the youth of 16 candidates out of 17 as young L-dwarf members of the USco and Oph associations, or 94%.

4. Spectral types, effective temperature and masses

We then use Figs. A.1–A.3 to estimate the spectral types of the 16 targets with evidence of youth identified in the previous section. With the question of their youth settled, we are left to decide whether extinction affects the spectrum of the targets. By using the integrated line-of-sight extinction towards each target until 250 pc, we can partially break the degeneracy between spectral type and reddening and check the worst-case scenario in which the target eventually lies at the far edge of the association.

Figures A.1–A.3 show that extinction does not affect the result of the comparison for 3091, 3200, 3231, 3244, 3299, 3324, 3326, 3421, and 3345. All indeed have fairly small integrated extinction (see Table 1). The match is significantly better without extinction in the cases of 3213 (L2), 3314 (L0), 3210 (L0), and 3421 (L4–L3), especially in the K-band. Finally, the match is equally good with or without reddening for 3404 (L3–L4), 3378 (L2–L4), 3355 (L1–L3), 3241 (L2–L4). We note that the difference is always smaller than two subclasses and we adopted the corresponding ranges as final spectral type. These results show that reddening does not affect our target substantially, which is in agreement with the integrated line-of-sight extinction at 250 pc and confirm that they are most likely not reddened background contaminants.

These spectral types are translated into effective temperatures using the empirical relationship for young L-dwarfs reported in Faherty et al. (2016), which in turn are translated into masses using the Saumon & Marley (2008) models for 3, 6, and 10 Myr. Given their location in the Scorpius OB2 complex, most of our targets are expected to belong to Upper Scorpius and have ages in the range of 6–10 Myr. Three of them (3421, 3293, 3144; see Fig. 2) are nevertheless located on top of the \(p\)-Ophiuchus molecular clouds and probably belong to the young (1–3 Myr) association. Uncertainties on the spectral types (1 to 2 subclasses) translate into uncertainties of the order of 300 K for the effective temperatures and 0.002 \(M_\odot\) for the masses at a given age. Table 3 gives the results and shows that all the candidates seem to have masses in the planetary domain, the least massive having a mass of only 0.004–0.006 \(M_\odot\) depending on the age. These objects will cool steadily over time, dissolve in the galactic field population and become field T and Y-dwarfs within the next 50–100 Myr, as illustrated in Fig. 5.

Table 2. Diagnostics of youth.

| ID   | J−KS    | Comparison with standard | \(H_{\text{cont}}\) | TLI-g | Young? |
|------|---------|--------------------------|---------------------|-------|-------|
| 3091 | Young   | Young                    | Young               | Young | Young |
| 3144 | Young   | Young                    | Old                 | Young | Young |
| 3200 | Young   | Young                    | Young               | Young | Young |
| 3210 | Young   | Young                    | Young               | Young | Young |
| 3213 | Young   | ?                        | Young               | Young | Young |
| 3214 | Young   | Young                    | Young               | Young | Young |
| 3231 | Young   | ?                        | Young               | Young | Young |
| 3244 | Young   | ?                        | Young               | Young | Young |
| 3299 | Young   | Old?                     | ?                   | Young | Young |
| 3314 | Young   | Young                    | Young               | Young | Young |
| 3326 | Young   | Young                    | Young               | Young | Young |
| 3345 | Young   | Young                    | Young               | Young | Young |
| 3355 | Young   | Young                    | Young               | Young | Young |
| 3378 | Young   | ?                        | Young               | Young | Young |
| 3387 | Young   | ?                        | Young               | Young | Young |
| 3404 | Young   | Old?                     | ?                   | Young | Young |
| 3421 | Young   | Int?                     | Young               | Young | Young |

The J−KS color and TLI-g index are favoring a young object. The integrated line-of-sight extinction at 250 pc is relatively large (\(A_V = 2.99\) mag) and its J−KS color and TLI-g index might therefore be affected by reddening. With the current data it is difficult to draw any conclusions about the youth of 3293.

4. Spectral types, effective temperature and masses

We then use Figs. A.1–A.3 to estimate the spectral types of the 16 targets with evidence of youth identified in the previous section. With the question of their youth settled, we are left to decide whether extinction affects the spectrum of the targets. By using the integrated line-of-sight extinction towards each target until 250 pc, we can partially break the degeneracy between spectral type and reddening and check the worst-case scenario in which the target eventually lies at the far edge of the association.

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5. Objects of interest

In the following we discuss a couple of objects of interest: the coolest of our targets and an ultra-wide pair of planetary mass objects.

5.1. The coolest target: DANCe J16081299−2304316 (3345)

In this section and in Figs. 6 and 7, we compare the spectrum of the coolest of our targets, the L6 DANCe J16081299−2304316 (3345) with the spectra of exoplanets and free-floating planets with similar ages and spectral types from the literature.

The $H$-band is generally well matched by all these young exoplanet and free-floating planet spectra, but the overall slope of DANCe J16081299−2304316 is shallower than that of all these objects and the higher $J$-band flux must be due to the slightly earlier spectral type. The 2.3 $\mu$m CO overtone is well matched in most free-floating planet spectra but is not as pronounced in the exoplanet spectra. On the other hand the drop observed in DANCe J16081299−2304316 at wavelengths greater than 2.3 $\mu$m is observed in HR8799c.
spectrum only, making it a good free-floating analog of this directly imaged young gas-giant planet. Overall, the spectrum of DANCe J16081299−2304316 appears most similar to that of HR8799c, and both objects have near-infrared spectral types of L6.

5.2. DANCe J16135217−2443562 and DANCe J16134589−2442310: a possible ultra-wide pair

DANCe J16135217−2443562 (3213) and DANCe J16134589−2442310 (3214) form a wide visual pair with a separation on 120′′ corresponding to a projected separation of ~17 400 AU at a distance of 145 pc (as shown in Fig. 8). Such a wide separation for such low-mass objects suggests that it is probably a coincidence rather than a bound physical pair; on the other hand, the very low spatial density of free-floating planets reported in Miret-Roig et al. (2022), of between 0.4 and 1 FPF per square degree, suggests that such a coincidence is highly unlikely and calls for follow-up observations of this intriguing pair. Improved proper motions measurements, along with parallaxes and radial velocities, would help us understand and eventually confirm their common origin. Such a pair could indeed also be a remnant of an extreme case of ultra-wide multiple system such as the ones reported in Taurus (Joncour & Bressert 2017) or the result of a simultaneous dynamical ejection of two planets in a planetary system.

6. Conclusions

We obtained near-infrared spectra of 18 ultracool candidate members of Upper Scorpius and Ophiuchus discovered by Miret-Roig et al. (2022) using SWIMS at the Subaru telescope and EMIR at the Granatecan telescope. One of the spectra was affected by the poor ambient conditions (clouds) and we discarded it in the analysis.

The spectra allow us to confirm the low gravity and, hence, youth, using four diagnostics: (i) the shape of their H-band continuum measured by the $H_{cont}$ index; (ii) their $J - Ks$ color redder than field counterparts; (iii) by comparison with near-infrared spectra of young L-dwarf standards; (iv) using the TLI-g gravity sensitive index. Among the 17 targets, 16 have multiple pieces of evidence supporting their youth and one (3293) is inconclusive. In total we therefore firmly confirm the youth of 16 candidates out of 17 as young L-dwarfs members of the USco or Ophiuchus association, corresponding to a contamination rate of only $\lesssim 6\%$ and indicating that the methodology devised by Bouy et al. (2013) and Sarro et al. (2014) and used by Miret-Roig et al. (2022) is very reliable.

The spectral types of the targets are estimated via comparisons with young L-dwarf standards, ranging between L0 and L6. Using the Faherty et al. (2016) empirical relationship for young L-dwarfs, we transformed these spectral types into effective temperatures and found that the objects have temperatures in the range between 1220 and 2060 K, corresponding to masses in the range 0.004–0.013 $M_\odot$, according to the models of Saumon & Marley (2008) for ages between 3 and 10 Myr, consistent with the Miret-Roig et al. (2022) estimate that is based on the photometry only. Interestingly, even the brightest target (DANCe J16064553−2121595 = 3355) is an early L-dwarf, suggesting that many objects fainter than $M_J \gtrsim 10.5$ mag must indeed have masses in the planetary mass domain.

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Fig. 8. Three-color image (r, Y, Ks as blue, green, red) of the field around DANCe J16135217−2443562 and DANCe J16134589−2442310. Both are indicated by a square.
Fig. A.1. Comparison of our targets spectra (black) with very-low gravity standards (red) and field-gravity standards (blue). The left panels show the original spectrum, and the right panels show the spectrum dereddened by the cumulative line-of-sight extinction indicated in the plot title and in Table 1.
Fig. A.2. Comparison of our targets spectra (black) with very-low gravity standards (red) and field-gravity standards (blue). The left panels show the original spectrum, and the right panels show the spectrum dereddened by the cumulative line-of-sight extinction indicated in the plot title and in Table 1.
Fig. A.3. Comparison of our targets spectra (black) with very-low gravity standards (red) and field-gravity standards (blue). The left panels show the original spectrum, and the right panels show the spectrum dereddened by the cumulative line-of-sight extinction indicated in the plot title and in Table 1.
## Appendix B: Tables

### Table B.1. Gravity sensitive indices.

| Object | $H_{cont}$ | TLI-g |
|--------|-----------|-------|
| 3091   | 0.97 ± 0.05 | 0.84 ± 0.05 |
| 3144   | 0.99 ± 0.07 | 1.03 ± 0.07 |
| 3200   | 1.01 ± 0.03 | 0.95 ± 0.04 |
| 3210   | 0.99 ± 0.03 | 0.97 ± 0.03 |
| 3213   | 0.92 ± 0.05 | 0.85 ± 0.05 |
| 3214   | 0.96 ± 0.09 | 0.97 ± 0.07 |
| 3231   | 0.93 ± 0.03 | 0.92 ± 0.03 |
| 3244   | 0.94 ± 0.03 | 0.90 ± 0.02 |
| 3293   | 0.93 ± 0.03 | 0.95 ± 0.03 |
| 3299   | 0.94 ± 0.03 | 0.91 ± 0.03 |
| 3314   | 0.99 ± 0.02 | 0.93 ± 0.02 |
| 3324   | 0.96 ± 0.02 | 0.98 ± 0.02 |
| 3326   | 0.99 ± 0.04 | 0.92 ± 0.04 |
| 3345   | 0.99 ± 0.05 | 0.86 ± 0.05 |
| 3355   | 0.96 ± 0.04 | 0.90 ± 0.05 |
| 3378   | 0.91 ± 0.12 | 0.93 ± 0.14 |
| 3404   | 0.84 ± 0.10 | 0.96 ± 0.15 |
| 3421   | 0.93 ± 0.03 | 0.94 ± 0.03 |

### Table B.2. SPEX library of very-low gravity ultracool standards.

| Name | RA (J2000) | Dec (J2000) | SpT | Ref. |
|------|------------|-------------|-----|------|
| 2MASS J1207334-393254A | 181.8959 | -39.548443 | M8 | (1) |
| TWA 26 | 174.96304 | -31.989279 | M9 | (1) |
| 2MASS J01415823-4633574 | 25.492626 | -46.56945 | L0y | (2) |
| 2MASS J05184616-2756457 | 79.692337 | -27.946028 | L1y | (3) |
| 2MASS J05361998-1920396 | 84.083244 | -19.344334 | L2y | (3) |
| 2MASSW J2208136+292121 | 332.05679 | 29.355972 | L3y | (2) |
| 2MASS J05012406-0010452 | 341.13196 | 20.728695 | L7y | (4) |

References. (1) Gizis (2002) ; (2) Cruz et al. (2009) ; (3) Bardalez Gagliuffi et al. (2014) ; (4) Kirkpatrick et al. (2008).

### Table B.3. Library of field ultracool standards.

| Name | RA (J2000) | Dec (J2000) | SpT | Ref. |
|------|------------|-------------|-----|------|
| VB 10 | 289.2400917 | 5.1506056 | M8 | (2) |
| LP 944-20 | 54.89675 | -35.4289139 | L0 | (1) |
| GJ 1048B | 38.9997083 | -23.5223611 | L1 | (1) |
| 2MASSI J2057540-025230 | 314.4753917 | -2.8750722 | L2 | (2) |
| 2MASSW J1506544+132106 | 226.7267125 | 13.3516889 | L3 | (3) |
| 2MASSW J0036159+182110 | 9.0674 | 18.3529083 | L4 | (1) |
| SDSSp J144600.60+002452.0 | 221.5025833 | 0.4144444 | L5 | (4) |
| 2MASSI J1010148-040649 | 152.561958 | -4.113894 | L6 | (5) |
| 2MASSI J1526140+204341 | 231.5585417 | 20.7281833 | L7 | (2) |

References. (1) Burgasser et al. (2008) ; (2) Burgasser et al. (2004) ; (3) Burgasser (2007) ; (4) Bardalez Gagliuffi et al. (2014) ; (5) Reid et al. (2006).
Table B.4. Gravity sensitive indices measured in 891 spectra of the SPEX library.

| Name                  | RA (J2000)   | Dec (J2000)  | SpT | SPEX_CLASS | H<br>cont | e_H<br>cont | TLI-g | e_TLI-g |
|-----------------------|--------------|--------------|-----|------------|-----------|------------|-------|---------|
| 2MASS J0000286-124515 | 0.11945834   | -12.75425    | M9.0| FLD-G      | 0.947     | 0.003      | 1.015 | 0.01    |
| 2MASS J00013044+1010146 | 0.37683335  | 10.170723    | M6.0| VL-G       | 0.988     | 0.006      | 1.009 | 0.023   |
| LHS 102B              | 1.1451666    | -40.734943   | L4.0| FLD-G      | 0.855     | 0.002      | 1.011 | 0.008   |
| LEHPM 1-162           | 1.4486667    | -21.954889   | M8.0| FLD-G      | 0.963     | 0.002      | 0.994 | 0.009   |
| 2MASSI J0006205-172051 | 1.5854167    | -17.347389   | L2.0| FLD-G      | 0.897     | 0.006      | 0.998 | 0.006   |
| 2MASS J000632.60+140606.4 | 1.6358334  | 14.101778    | L1.0| FLD-G      | 0.931     | 0.009      | 0.989 | 0.017   |
| 2MASS J000649.16-085246.3 | 1.7048334 | -8.879528    | M8.0| FLD-G      | 0.921     | 0.004      | 1.035 | 0.008   |
| 2MASS J0007078-245804 | 1.7827917    | -24.967834   | M8.0| INT-G      | 0.987     | 0.003      | 1.008 | 0.017   |
| 2MASS J00085931+2911521 | 2.2471251   | 29.197805    | M8.0| INT-G      | 0.967     | 0.002      | 1.013 | 0.007   |
| 2MASS J01010009-2031122 | 2.500375    | -20.520056   | M8.0| FLD-G      | 0.933     | 0.003      | 1.049 | 0.003   |
| 2MASSI J013578-223520 | 3.4907918    | -22.58889    | L5.0| FLD-G      | 0.859     | 0.01       | 0.992 | 0.01    |
| WISE J01450.14-083823.1 | 3.7089167   | -8.6397219   | M7.0| FLD-G      | 0.945     | 0.008      | 1.042 | 0.016   |
| 2MASS J0145575-4844171 | 3.7322917   | -48.738083   | L3.0| FLD-G      | 0.883     | 0.006      | 1.022 | 0.013   |
| 2MASSI J015447+351603 | 3.9364998    | 35.267387    | L2.0| INT-G      | 0.9       | 0.003      | 1.025 | 0.006   |
| SDSS J01608.44-004302.3 | 4.0351253   | -0.71722221  | L3.0| INT-G      | 0.898     | 0.008      | 0.961 | 0.023   |
| 2MASS J0163761+3448368 | 4.1567087   | 34.810223    | M8.0| FLD-G      | 0.939     | 0.004      | 1.016 | 0.013   |

Notes. The entire table is available electronically at the CDS.