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Proper motion Pleiades candidate L-type brown dwarfs

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Abstract. We present results of an optical and near-infrared (IR) 1.8 deg^2 survey in the Pleiades open cluster to search for substellar objects. From optical I-band images from the CFHT and J-band images from the 3.5 m CAHA Telescope, we identify 18 faint and very red L brown dwarf candidates, with $I > 20.9$ and $I - J > 3.2$. The follow-up observations of nine objects in the H- and $K_{\rm s}$-bands confirm that eight belong to the IR sequence of the cluster and the proper motion measurements of seven candidates confirm that they are Pleiades members. A preliminary estimation of the substellar mass spectrum dN/dM in the form of a power law $M^{-\alpha}$ provides α=+0.57±0.14. We extrapolate this function to estimate the number of very low-mass brown dwarfs and planetary mass objects that could be present in the cluster down to 1 M$_{{\rm J}up}$. Sensitive searches combining far red and near infrared observations may unveal these objects in a near future.

Key words: (Galaxy:) open clusters and associations: individual (Pleiades) – stars: low-mass, brown dwarfs – astrometry

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1. Introduction

After the first discoveries of free-floating brown dwarfs in the (∼120 Myr, ∼130 pc) Pleiades open cluster (e.g. Rebolo, Zapatero Osorio & Martín 1995), fainter objects were found, with spectral types down to late M (Zapatero Osorio, Rebolo & Martín 1997; Bouvier et al. 1998). Several were confirmed as Pleiades brown dwarfs by lithium detection (e.g. Stauffer et al. 1998) or by proper motion (Moraux, Bouvier & Stauffer 2001). Then an L0 dwarf, Roque 25 (Martín et al. 1998), and some fainter objects with red near-infrared (IR) colors were identified, but they still lack a proper motion or lithium confirmation (Dobbie et al. 2002; Nagashima et al. 2003). Here we present some Pleiades candidate L-type brown dwarfs (color $I - J > 3.2$) that we confirmed by proper motion (see Bihain et al. 2005 for more details). Finding L-dwarfs of well defined ages is necessary to constrain models of stellar and substellar evolution.

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2. Proper motion candidates

Using near-IR J-band images obtained in 1998 with the 3.5 m Telescope/Ω' (Calar Alto Obs.) and optical RI-band images from Bouvier et al. (1998) covering 1.8 deg^2 of the Pleiades open cluster, we found 18 L-type low-mass brown dwarf candidates with magnitudes $I > 20.9$ and $J > 17.4$, and colors $I - J > 3.2$. The errors in these magnitudes were $\sigma_I \sim 0.1$ and $\sigma_J < 0.1$, respectively. The data reduction, the photometry and the coordinates of our candidates are provided in Bihain et al. (2005). Follow-up $K_{\rm s}$ imaging of eight candidates with the 1.5 m TCS/CAIN-2 (Teide Obs.) during winter 2004–2005 allowed us to confirm that seven belong to the expected near-IR photometric sequence of the cluster, with colors $1.2 < J - K_{\rm s} < 2.0$. We obtained also subarcsecond H- and $K_{\rm s}$ -band images for seven objects and the brown dwarf Teide 1, with the 4.2 m WHT/LIRIS (Roque de los Muchachos Obs.) and the 3.5 m Telescope/Ω2000 (Calar Alto Obs.) during 2005 January–March. Comparing the pixel positions of the objects in the first-epoch I-band images with those in the $HK_{\rm s}$-band images, we confirmed that they are indeed Pleiades proper motion members. In the vector point diagram (Fig. 1), they all lie at less than 3σ (where σ stands for the standard deviation (8.5 mas/yr) of the proper motion sample

from Moraux et al. 2001) from the cluster peculiar motion, ($\mu_\alpha cos\delta$, μ_δ)=(+19.15±0.23, −45.72±0.18) mas/yr (Robichon et al. 1999). We thus confirm that Teide 1 is a Pleiades brown dwarf. Observations of this object and the brightest brown dwarf candidate with the two telescopes allowed us to obtain double-check measurements (see linked symbols). These are in agreement within $\sim 1\,\sigma$.

3. Discussion

The proper motion candidate L-type brown dwarfs are shown in the $J-K_{\rm s}$,$I-J$ diagram of Fig 1. The DUSTY isochrone from Chabrier et al. (2000) is also represented (solid line), for a cluster age of 120 Myr and a distance of 133.8 pc (Percival, Salaris & Groenewegen 2005). Most of the L-type candidates appear bluer in $I-J$ than the model prediction which takes into account the dust in the brown dwarf atmospheres. This is possibly due to an underestimation of the I-band far red flux respect to the near-IR flux.

The masses of all our survey candidates were obtained by comparing their empirical bolometric luminosities (derived from the sum of their absolute J-band magnitude and a bolometric correction depending of $I-J$) with those from the DUSTY model. For the L candidates, we obtained masses between 0.040 and 0.020 $M_\odot$. We corrected the number of candidates for the expected number of foreground and background late-type dwarf contaminants towards the Pleiades. To compare our results with previous determinations of the stellar content of the Pleiades, we scaled the resulting number to the whole cluster using an integrated King profile for a tidal radius 5.54° (Pinfield, Jameson & Hodgkin 1998) and core radii 1.6 and 3.0° for stars and brown dwarfs, respectively (Moraux et al. 2003). Fitting a power law $M^{-\alpha}$ to our mass spectrum $\mathrm{d}N/\mathrm{d}M$ data points (where $\mathrm{d}N$ stands for the number of objects in the mass range $\mathrm{d}M$) and those from Deacon & Hambly (2004), and over a mass range from 0.5 $M_\odot$ to the survey completeness at 0.025 $M_\odot$, we obtained α=+0.57±0.14.

A smooth extrapolation of the power law leads to ∼100 and ∼70 planetary-mass objects with masses 5–15 and 1–4 M_{Jup}, respectively, in the whole cluster. Using the COND models, the corresponding effective temperatures are estimated to be in the range ∼600–1300 K and ∼300–550 K, respectively. Objects in the first group are expected to exhibit T dwarf spectral types, and $I-J$, $J-K_{\rm s}$ colours as illustrated in Fig 1. The J-band magnitudes of Pleiades T dwarfs will be in the range 20–21. Most likely, the second lower mass group will be conformed by fainter and cooler objects requiring a new spectral classification (Y type?). A combination of deep I-band imaging (completeness limit ∼26) and near/mid IR observations with the Spitzer Space Telescope would be an efficient way to detect these challenging extremely low-mass Pleiads in the substellar realm.

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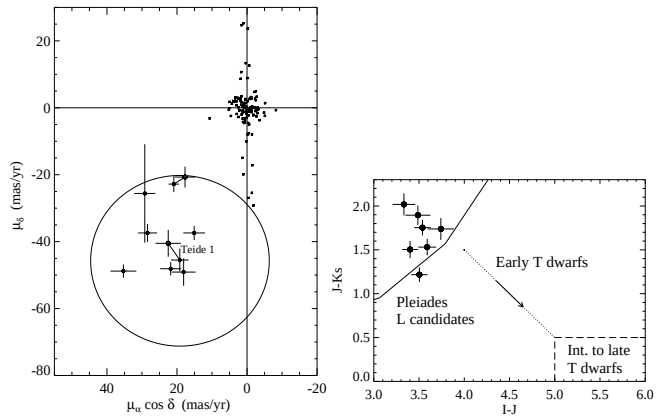

Fig. 1. Left: Vector point diagram for the Pleiades candidate L brown dwarfs (dots with error bars) and the reference objects (asterisks) used for the astrometric measurements. Right: J-$K_{\rm s}$, I-J diagram for the Pleiades L candidates. The solid line represents the Dusty model isochrone. The regions for the early and the intermediate- to late T dwarfs are indicated.

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