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Search for Pleiades T dwarfs

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Abstract. We present our on-going project aimed at identifying Pleiades T-type planetary-mass members. An area of 0.82 deg^2 was explored photometric and astrometrically with deep images taken in the J and H filters and separated by 9 yr. The survey limiting magnitude is $J, H = 21$ mag. The long time baseline allowed us to measure proper motions, since the cluster motion is quite distinctive. For a small fraction of our survey, methane images in the H-band are also available. To select our candidates we imposed the following criteria: $H \geq 18$ mag, $J - H \leq 0.3$ mag, and proper motions compatible with that of the cluster at the 1.5-σ level. According to substellar evolutionary models, our exploration is sensitive to T-type Pleiads with masses in the interval 9-15 $M_{\rm Jup}$. These observations will lead to the study of the planetary mass function in the Pleiades cluster. Confirmed Pleiades T-type dwarfs will have a well-defined age (120 Myr) and solar metallicity; they will thus become benchmark objects for our understanding of the ultracool dwarf population (both single and orbiting stars, including massive planets) of the solar vicinity.

Key words. Galaxy: open clusters and associations: individual: Pleiades – Stars: brown dwarfs, low-mass – Techniques: photometric proper motions

1. Introduction

For its relatively youth (∼120 Myr), nearby distance (∼120 pc), solar metallicity, and negligible internal extinction (except for the Merope cloud), the Pleiades star cluster offers an excellent opportunity to study the brown dwarf (75-13 $M_{\rm Jup}$) and planetary-mass ($\leq$13 $M_{\rm Jup}$) populations of intermediate age. Furthermore, the Pleiades mass function and the cluster members usually become benchmark objects for

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the understanding of the properties of field sources with similar temperature and metal composition. To date, the smallest and coolest Pleiades members that are astrometric, photometric and spectroscopically confirmed have $\sim 25\,M_{\rm Jup}$ and mid-L spectral type (Bihain et al. 2010).

The present-day low-mass function of the Pleiades across the star-brown dwarf boundary and down to $\sim 25\,M_{\rm Jup}$ can be represented by a rising power-law model, $dN/dM \sim M^{-\alpha}$. Various works found values for α in the range 0.4–1.0 (e.g. Zapatero Osorio et al. 1997; Jameson et al. 2002; Lodieu et al. 2007). More recently, Casewell et al. (2010) presented two T-type Pleiades candidates, implying that the cluster mass function likely extends down to the deuterium burning mass limit at $\sim 13\,M_{\rm Jup}$.

To properly understand the ultracool, brown dwarf population of the solar neighborhood (spectral types L and T or $T_{\rm eff}$ = 2000–700 K), it becomes necessary to characterise the Pleiades population of similar surface temperature, but of much smaller mass given the young age of the cluster. Our survey consists of deep J- and H-band images collected with 9 yr separation and posterior CH_4 images.

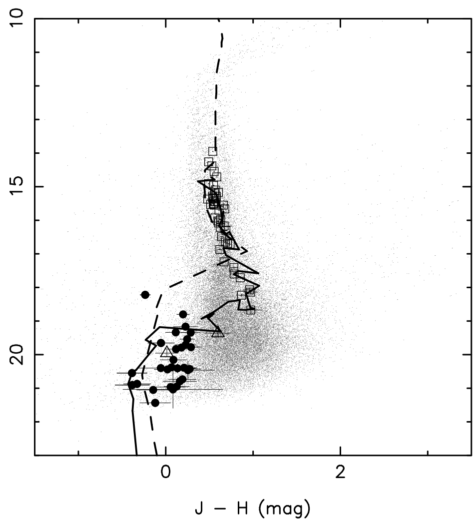

Fig. 1. Color-magnitude diagram resulting from the combination of the J and H data. Dots stand for the JH candidates, which have $J-H \leq 0.3$ mag and proper motion compatible with the cluster. The known Pleiades sequence of mid-Ms through mid-Ls is shown with the squares (Bihain et al. 2010). The field spectroscopic sequence (Dupuy & Liu 2012) is plotted as continuous solid line; it is normalised to the M9 dwarfs of the Pleiades. The two T-type candidates of Casewell et al. (2010) are shown with triangles. The 120 Myr Lyon model at the distance of the cluster is also included with the dashed line.

2. Observations

We performed three different observations obtaining a total explored area of 0.82 deg^2.

Data reductions were carried out using the standard reduction procedures in the IRAF CCDRED and DAOPHOT packages: bias subtraction, flat field correction, selection of objects with stellar point spread function and aperture and PSF photometry.

***J*-band images of 1998:** J-band images were acquired with the OmegaPrime wide field near-infrared camera mounted on the 3.5 m telescope of the Calar Alto Observatory in October 1998. The total explored area is 0.82 deg^2. This is about 5% of the cluster extension. The limiting magnitude in this filter is 21 mag.

***H*-band images of 2007:** H-band images were acquired with the Omega2000 near-infrared wide field camera mounted on the 3.5 m telescope of the Calar Alto Observatory in October 2007. The total explored area is overlapping with J-band survey. The limiting magnitude in this filter is 21 mag.

CH_4-band images of 2011: CH_4-band images were acquired with HAWK-I on the ESO Very Large Telescope in December 2011. The total explored area in methane is very small: only 0.15 deg^2 (∼18% of the J and H total coverage), but overlaps completely with J- and H-band images. The limiting magnitudes in this filter are 18 and 20 mag.

3. Analysis

***J*- and *H*-band search:** We calibrate the J- and H-band photometry and astrometry with UKIDSS and 2MASS (to a precision of 0.3 arcsec). We cross-matched the images using a radius of 2 arcsec.

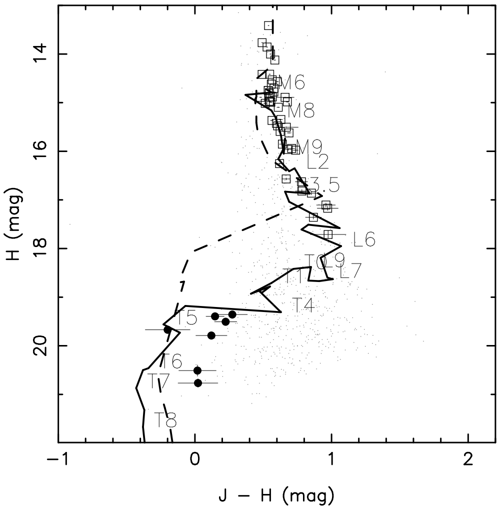

Fig. 2. Photometric candidates found in the CH_4 survey (dots). Only one is common to the JH search shown in Fig. 1. Description as in Fig. 1, where spectral types are indicated for the field spectroscopic sequence.

With the cross-match, we selected all targets with H = 18–21.5 mag, $J - H \leq$ 0.3 mag, and proper motion compatible with the Pleiades motion at the 1.5-σ level. Proper motions were estimated by direct comparison of the H and J equatorial coordinates normalised to the time baseline of 9 yr. A total of 27 candidates were found (Fig. 1).

Methane search: Methane imaging is a very useful tool for discriminating whether a brown dwarf is a T dwarf if a spectrum is not available (Tinney al. 2005). Methane filter is centered at 1.575 μm, i.e., at the blue side of the H-band methane absorption. As discussed in Peña Ramírez et al. (2011), the $H - CH_4$ colour can easily discriminate ≥T3 dwarfs ($H - CH_4 \geq 0.1$ mag) from warmer dwarfs. Late-Ls and early-Ts have bluer methane colours and cannot be distinguished photometrically from other sources in the field. We artificially calibrated the methane observations against the H-band data by imposing $H - CH_4 = 0$ mag on the bulk of bright field stars. We found seven objects with redder $H - CH_4$ colour, implying a methane absorption. Similarly to Fig. 1, Fig. 2 plots H vs. J - H for methane candidates. From the 27 candidates obtained in the JH cross-match, we could observe nine of them in the methane images and only one presented methane absorption.

4. Summary

With deep JH images we found a total of 27 candidates that would need further confirmation through photometry and proper motion, and, using the $H - CH_4$ colour, we found seven objects that may present methane absorption. Only one candidate successfully passes the J, H, CH_4 and proper motion criteria. Ideally, these data must be complemented with optical photometry for a better discrimination of the T candidates.

The confirmation of Pleiades T-type candidates is crucial to extend for the first time the cluster mass function down to the planet frontier at 13 M_{Jup}, and to provide benchmark ~120 Myr, ultracool substellar objects that are useful references to "calibrate" the new findings (including the Y dwarfs, Kirkpatrick et al. 2012) in the solar vicinity and the massive planets discovered around stars (e.g, HR 8799; Marois et al. 2008; Janson et al. 2010).

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