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New neighbours: II. An M9 dwarf at $d \sim 4$ pc, DENIS-P J104814.7−395606.1*

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Abstract. We present the discovery of a previously unknown member of the immediate solar neighbourhood, DENIS-P J104814.7−395606.1 (hereafter DENIS 1048−39), identified while mining the DENIS database for new nearby stars. A HIRES echelle spectrum obtained with the 10-m Keck telescope shows that it is an M9 dwarf. DENIS 1048−39 has a very bright apparent magnitude ($I = 12.67$) for its spectral type and colour ($I - J = 3.07$), and is therefore very nearby. If it is single its distance is only 4.1 ± 0.6 pc, ranking it as between our 12th and 40th closest neighbour. It is also the closest star or brown dwarf with a spectral type later than M7V. Its proper motion was determined through comparison of Sky atlas Schmidt plates, scanned by the MAMA microdensitometer, with the DENIS images. At $1.52'' \mathrm{yr}^{-1}$ it primarily attests the closeness of DENIS 1048−39 and hence its dwarf status. These characteristics make it an obvious target for further detailed studies.

Key words. astronomical data base: surveys – astrometry and celestial mechanism: astrometry – stars: low mass, brown dwarfs – stars: late-type

1. Introduction

Much of our understanding of stellar astronomy rests upon the nearest stars. As individual objects they are the brightest and hence best studied examples of their spectral type, and they have distances that can usually be measured directly from an accurate trigonometric parallax. These stars are also the source of some of the most accurate stellar masses: for nearer multiple systems the same physical separation translates into a wider angular separation, and hence into a better characterized orbit. As a population, the solar neighbourhood sample therefore provides deep insight into the nature of our Galaxy's components, through studies of its stellar luminosities and mass functions, its kinematics, its chemical composition, and its multiplicity statistics.

For the moderately bright ($M_V < 7$) G and K dwarfs, our current census of the solar neigbourhood is complete out to at least 25 pc (Jahreiss 1994). Intrinsically fainter stars however dominate the galactic population budget, and represent a large fraction of its mass budget: M dwarfs account for at least 70% of all stars, and about 50% of the mass of the galactic disk. For this fainter population our present census unfortunately becomes incomplete at a rather small distance: from a comparison of observed star densities within 5 and 10 pc, Henry et al. (1997) demonstrate that over 100 systems are missing in the larger volume, even under the purposedly optimistic assumption that the current inventory is complete for the 5 pc sphere. In addition to these systems which are altogether missing, a further source of incompleteness is that some of the identified nearby stellar systems have unrecognized components, as illustrated by the sustained discovery rate of

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* Based on observations made at the European Southern Observatory, and at the W. M. Keck Observatory, which is operated jointly by the University of California and the Californian Institute of Technology. Also based on plates scanned with the MAMA microdensitometer (`http://dsmama.obspm.fr`) developed and operated by INSU/CNRS/Observatoire de Paris.

Table 1. Basic parameters of DENIS 1048−39. The photometry is extracted from the DENIS catalog for the I, J and K_s bands and from the sky atlas Schmidt plates for the B and R bands. The J2000.0 position of the object is for epoch 1999.11 (date of the DENIS observations)

		Photometry		
$B = 19.0$	$R = 15.7$	$I = 12.67$	$J = 9.59$	$K_s = 8.58$
±0.3	±0.2	±0.05	±0.05	±0.05
		Astrometry		
α (2000.0)	δ (2000.0)	$\mu\ \alpha$ ($''$ yr^{-1})	$\mu\ \delta$ ($''$ yr^{-1})	
10:48:14.68	−39:56:06.1	−1.147±0.008	−0.992±0.009	

new companions to nearby M dwarfs (e.g. Henry et al. 1999; Delfosse et al. 1999a; Beuzit et al. in preparation).

To address both of these incompleteness sources, some of us are conducting a systematic search for companions to nearby M dwarfs (Delfosse et al. 1999a, for a presentation of that programme), and we use the DENIS near infrared sky survey to complete the identification of the southern solar neighbourhood M dwarfs. Here we present an initial result of that second programme, the discovery and initial characterization of a previously unknown very nearby ($d \sim 4$ pc) M9 dwarf.

2. Observational data

The DEep Near-Infrared Survey (DENIS) is a southern sky survey (Epchtein 1997), which will provide full coverage of the southern hemisphere in two near-infrared bands (J and K_s) and one optical band (I). DENIS observations are carried out on the ESO 1 m telescope at La Silla. Dichroic beam splitters separate the three channels, and focal reducing optics provide scales of 3$''$ per pixel on the 256×256 NICMOS3 arrays used for the two infrared channels and 1$''$ per pixel on the 1024×1024 Tektronix CCD detector of the I channel. The sky is scanned in a step and stare mode, along 30 degrees strips at constant right ascension.

The image data were processed with the standard pipeline software (Borsenberger 1997; Borsenberger et al. in preparation) at the Paris Data Analysis Center (PDAC). The instrumental and sky background are derived from a local clipped mean along the strip. Flat-field corrections are derived from observation of the sunrise sky. Source extraction and photometry is performed at PDAC, using a space-varying kernel (Alard 2000) algorithm. The astrometry of the individual DENIS frames is referenced to the USNO-A2.0 catalog, whose ∼1$''$ accuracy therefore determines the absolute precision of the DENIS positions.

With typical 3-σ limits of $I \sim 19.0$, $J \sim 16.0$ and $K_s \sim 13.5$, the DENIS survey is very sensitive to very late M and L dwarfs (Delfosse et al. 1999b; Martín et al. 1999). We are extracting large statistical sample of such very low mass stars and brown dwarfs, by selecting sources with $I - J \geq 3.00$ (later than M8) and $|l_{II}| \geq 20°$ (Delfosse et al. in preparation). A set of morphological parameters is used to reject artefacts.

While analysing the first 3000 square degrees processed by PDAC, we have identified a bright and previously unknown red object ($I - J = 3.07$), DENIS-P J104814.7−395606.1 (hereafter DENIS 1048−39). Its DENIS photometry (Table 1) is most consistent with a very close M8-M9 dwarf, and somewhat less compatible with a cool giant at halo-like distances.

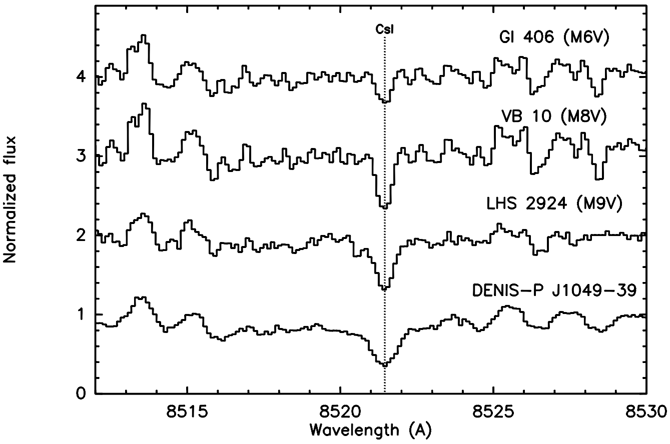

Fig. 1. 8521 Å CsI line of very late M dwarf templates and DENIS 1048−39

DENIS 1048−39 was observed with the HIRES echelle spectrograph (Vogt et al. 1994) on the 10 m Keck I telescope (Mauna Kea, Hawaii), on the nights of May 30th and 31st 2000, to obtain a high-resolution spectrum ($R = 31\,000$). Gl 406, VB10 and LHS2924 were observed with the same instrumental configuration, for use as late M-type spectral templates.

Figure 1 shows the spectrum of DENIS 1048−39 (and the spectral templates) around the 8521 Å CsI resonance doublet. The detection of a strong CsI line immediately demonstrates that DENIS 1048−39 is a dwarf, as this feature disappears at the lower gravity of a giant's atmosphere. Basri et al. (2000) have demonstrated that alkali resonance doublets are excellent effective temperature diagnosis. We therefore use the equivalent width of the CsI line (Table 2) to determine a spectral type of M9V for DENIS 1048−39, through comparison with the spectral templates. This determination coincides with the result of an eyeball comparison of the spectra, and we estimate that it is accurate to better than 0.5 subclass.

We note that H_α emission is variable. On the first night we did not detect H_α. We set an upper limit to the equivalent width of 0.11 Å. However, on the second night we detected H_α emission with equivalent width of 1.1 Å.

Table 2. Equivalent width of CsI line (8521 Å) for the very late M dwarf templates and for DENIS 1048−39. (a) The spectral type of the DENIS object is determined from the present observations. (b) Value from Basri et al. 2000

Object	Spectral Type	EW(CsI)
Gl 406	dM6	0.21 ± 0.02
VB10	dM8	0.38 ± 0.03
LHS2924	dM9	0.42 ± 0.04
DENIS 1048−39	dM9[a]	0.65 ± 0.06
LP944−20	bdM9	0.60[b]

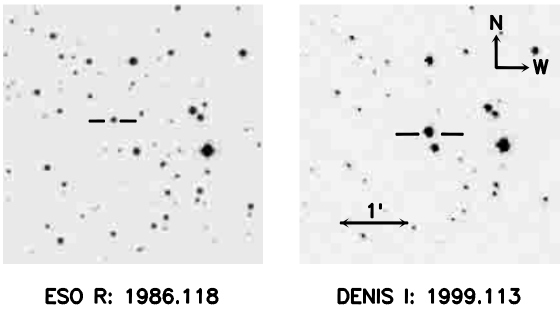

Fig. 2. The position of DENIS 1048−39 in the ESO-R and DENIS-I image

This is a low level of H_α emission for an M9 dwarf (Gizis et al. 2000). We do not detect the lithium resonance feature at 670.8 nm, with an upper limit to its equivalent width of 0.12 Å. This implies substantial lithium depletion with respect to the nearby M9 brown dwarf LP 944−20, for which Tinney (1998) measured $EW(\mathrm{LiI}) = 0.53$ Å. Thus, DENIS 1048−39 is more massive and older than LP 944−20. It will be interesting to compare gravity sensitive spectral features in the two objects. We have also measured the heliocentric radial velocity and rotational broadening of DENIS 1048−39. The results are $V_R = -10.1 \pm 0.5$ km s^{-1} and $v \sin(i) = 27 \pm 5$ km s^{-1}. Both measurements were derived by cross-correlation with the spectrum of VB 10 obtained on the same night and with the same instrumental configuration. We adopted a radial velocity of 34.4 km s^{-1} for VB 10 (Tinney & Reid 1998).

A very bright M9 dwarf such as DENIS 1048−39 has to be very close, and it must therefore have a large proper motion, unless its tangential velocity serendipitously happens to be very small.

The DENIS object is easily seen on archival plates (field 318) from the POSS I (1964.209), the SRC-J atlas (epoch 1975.364), the ESO-R atlas (epoch 1986.118) and the SRC-R atlas (epoch: 1993.463). Figure 2 shows the motion of DENIS 1048−39 over the last 13 years. We used the MAMA microdensitometer (Berger et al. 1991) to digitize the ESO-R and SRC-J survey plates. The astrometry and the photometry were respectively referenced to the ACT (Astrographic Catalogue + Tycho; Urban et al. 1998) and to the GSPC-2 (Postman et al. 1997). The position on the SRC-R survey plate was taken from the APM catalog, and for the POSS I plates it was measured with SeXtractor from an image obtained from the DSS scan server, and referenced to several surrounding stars. From the five available epochs (including the DENIS position at epoch 1999.113), we determine a total proper motion of $1.52''$ yr^{-1} (Table 1) with an accuracy of $0.009''$ yr^{-1} on each axis. Such a proper motion would easily have qualified DENIS 1048−39 for inclusion in the LHS catalogue (Luyten 1979). The absence of this relatively bright star ($B = 19.0$, $R = 15.7$, $I = 12.7$) again illustrates the acknowledged incompleteness of that catalog below −33°, the declination limit of the Palomar Sky Surveys. It also confirms the dwarf status of DENIS 1048−39.

3. Discussion

Only five M9 dwarfs have published trigonometric parallaxes (Kirkpatrick et al. 2000 for a review). Of those, LP944−20 is a young brown dwarfs and its absolute magnitudes and colours are slightly different from the others. Using the four stellar M9 dwarfs, we determine mean absolute magnitudes of $M_I = 14.77 \pm 0.2$, $M_J = 11.53 \pm 0.2$ and $M_K = 10.30 \pm 0.2$. If DENIS 1048−39 is a single star, its I, J and K magnitudes therefore translate into distances of respectively $d_I = 3.8 \pm 0.35$ pc, $d_J = 4.1 \pm 0.35$ pc and $d_K = 4.5 \pm 0.35$pc. The slight inconsistency between the three distances may be due in part to our comparing the photometry of DENIS 1048−39 in the DENIS system with absolute magnitudes referenced to the Cousins-CIT system. A preliminary comparison of the two photometric systems for very late M dwarfs (Delfosse 1997) shows ∼0.1 mag differences in the J and K bands. Any difference in the I band on the other hand is below 0.05 mag, and the distance determined from the I mag should thus be the most precise. For the time being, we nonetheless prefer to consider the issue as incompletely resolved and we conservatively adopt $d = 4.1 \pm 0.6$ pc. If DENIS 1048−39 is actually an unresolved double star it is slightly more distant, with the maximum distance of $d \sim 5.8$ pc reached for an equal mass binary.

The single-star distance would make DENIS 1048−39 our 12th to 37th nearest neighbour system, while the larger distance for an equal mass binary would place it around the 60th place. If single it is also the closest dwarf later than M7V (Table 3), and whatever its multiplicity status it is the brightest very late M dwarf. As such DENIS 1048−39 is clearly destined to become an observational benchmark. At $I = 12.7$ it is in particular bright enough for very high signal to noise high resolution spectroscopy.

The UVW heliocentric space motions, calculated from the above proper motion, radial velocity, and distance are $U = 11$, $V = 0$ and $W = -29$ km s^{-1} (with U defined as positive away from the Galactic Center). They are typical of the young disk dynamical population.

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Table 3. M, L and T dwarfs of spectral type later than M7 and closer than 7 pc. Note that spectral type of DENIS-P J0255−4700 is in the Martín et al. (1999) system. The references are: (a) Kirkpatrick et al. (1999); (b) Tinney (1996); (c) Martín et al. (1999); (d) Kirkpatrick et al. (2000); (e) Kirkpatrick et al. (1995); (f) ESA (1997) (Hipparcos catalog); (g) Nakajima et al. (1995); (h) Van Altena et al. (1995); (i) Burgasser et al. (2000a); (j) Burgasser et al. (2000b); (k) Ianna (1993)

Objects	Spect. type	Dist. (in pc)	Method
DENIS 1048−39	M9	4.1	spect. par.
LP944−20	M9[a]	4.96[b]	trigo. par.
DENIS-P J0255−4700	L6[c]	5.0[d]	spect. par.
Gl 644D (VB8)	M7[e]	5.74[f]	trigo. par.
Gl 229B	T[g]	5.77[f]	trigo. par.
Gl 752B (VB10)	M8[e]	5.83[h]	trigo. par.
Gl 570D	T[i]	5.91[f]	trigo. par.
2MASSI J0559191−140448	T[j]	6.0[d]	spect. par.
GJ 3877 (LHS 3003)	M7[e]	6.36[k]	trigo. par.

It is clearly essential to measure the trigonometric parallax of this new nearby star. This can be achieved with useful precision even within a single observing season, since this parallax will range between 300 and 200 milliarcseconds, depending on the actual multiplicity of the system. Whether it is multiple however may be resolved even before its parallax can be determined, since it is easily bright enough ($I = 12.7$) for adaptive optics imaging.

The discovery of this very close M9 dwarf shows again, if need there be, that our inventory of the immediate solar neighbourhood is incomplete and misses isolated very low mass objects, in addition to unrecognised members of identified systems. Table 3 lists the 9 objects with a spectral type later than M7 that are known within 7 pc. One can note that 4 of these have been discovered during the past years, by either the 2MASS (Gl 570D and 2MASSI J0559191−140448) or the DENIS (DENIS 1048−39 and DENIS-P J0255−4700) surveys. The approaching completion of these surveys, and their subsequent full analysis, will bring us much closer to a full census of our neighbourhood.

Specifically, we are now deriving photometric parallaxes from the I and J mag of all DENIS sources at high galactic latitude. From this we assemble a sample of candidate members of the solar neighbourhood. That sample still contains some contamination by giants, which from the DENIS I–J/J–K colour-colour diagram alone can be reduced significantly but not excised with 100% completeness and reliability (Fig. 3). As an initial step towards rejecting giants, we determine the proper motion of the candidates from a comparison of the DENIS position with archival Schmidt plates digitized on the MAMA microdensitometer. Our eventual goal however is to obtain spectra of all candidates, independently of their proper motions, to produce a complete inventory of the solar neighbourhood for the high galactic latitude southern sky that has no kinematic bias. In a second stage, we plan to extend the search to include the low galactic latitudes, where contamination by giant or dust-reddened stars is much more severe and precludes obtaining spectra all photometric candidates. We will there resort to proper motion selection amongst these candidates, and will use the high galactic latitude sample to measure the resulting kinematic bias.

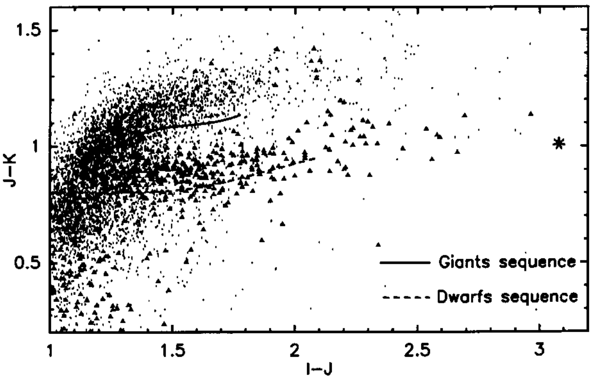

Fig. 3. All DENIS sources detected in the first 3000 squares degrees processed by PDAC with a photometric parallax ≤ 25 pc, galactic latitude ≥ 30° and $I - J$ in the 1.0–3.0 range (corresponding to the M spectral class). The photometric parallaxes were obtained from an $M_I(I - J)$ relation apropriate for dwarfs. The dots represent the object which have a counterpart in the USNO A2 catalog, while the triangles have no counterpart (and include all high proper motion stars). The asterisk represents DENIS-P J1048−39. The solid and dashed lines respectively represent the giant and dwarf sequences of Bessel & Brett (1988), for slightly different filters

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