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An L0 dwarf companion in the brown dwarf desert, at 30 AU*

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Abstract. We present the discovery of an L0 companion to the nearby M1.5 dwarf G 239-25, at a projected distance of 31 AU. It is the faintest companion discovered so far in our adaptive optics survey of all known M dwarfs within 12 pc, and it lies at the stellar/substellar limit. Given the assumed age of the primary star, the companion is likely an extremely low mass star. The long orbital period of G 239-25 AB (≈100 years) precludes a direct mass determination, but the relatively wide angular separation will allow detailed analyses of its near infrared and visible spectra.

Key words. very low mass stars – brown dwarfs – binary stars

1. Introduction

Radial velocity surveys find that about 5% of solar-type stars have planets within 4 AU with $M \sin(i) = 0.25$–$13\ M_J$ (e.g. Marcy et al. 2000). The same surveys demonstrate, in contrast, that fewer than 1% of these stars have more massive substellar companions ($M \sin(i) = 13$–$80\ M_J$). This "brown dwarf desert" for close companions actually extends to the lowest mass stellar companions, up to $\approx 100\ M_J$, in keeping with the expectation that star formation does not care about the substellar limit. The frequency of more massive stellar companions in the same separation range is ≈10% (Duquennoy & Mayor 1991; Halbwachs et al. 2003), and this clear dichotomy of the mass distribution supports the idea that the stellar and planetary companions to solar-type stars form through distinct channels.
This "desert" stands in contrast to the relative abundance of free-floating brown dwarfs in the field (e.g. Delfosse et al. 1999; Chabrier 2003), and in young clusters down to very low masses (e.g. Bouvier et al. 1998; Zapatero Osorio et al. 2000; Luhman et al. 2000). One open question is how far the brown dwarf desert extends beyond the current 0–4 AU sensitivity range of the radial velocity surveys. The prototype L and T dwarfs, GD 165B and Gl 229B, have been found as companions to stars with initial masses within a factor of 2 of the Sun (Zuckerman & Becklin 1992; Oppenheimer et al. 1995), and the limited statistics to date suggests that the brown dwarf desert may not exist beyond 250 AU from solar-type stars (Gizis et al. 2001) and that 1 ± 1% have companions in the 75–250 AU range (McCarthy & Zuckerman 2004). There is also good evidence that brown dwarfs are fairly common as close companions to other brown dwarfs and to very low mass stars (e.g. Bouy et al. 2003; Close et al. 2003; Martín et al. 2003). The situation at intermediate separations or intermediate mass ratios is less clear, with probable brown dwarf found within 14 AU and 47 AU of two solar analogs (Liu et al. 2002; Potter et al. 2002) and within 5 and 45 AU of two early M dwarfs (Oppenheimer et al. 1995; Beuzit et al. 2004).

In this letter we present a new companion in this intermediate range around a nearby M1.5 dwarf, G 239-25. Section 2 discusses the observations and their analysis, while in Sect. 3 we examine the physical parameters of the binary system. We then briefly discuss the population of L dwarfs companions orbiting M dwarfs.

2. Observations and data analysis

We observed G 239-25 in August 2001 with the 3.6-meter Canada-France-Hawaii-Telescope (CFHT), using the PUE'O adaptive optics (Rigaut et al. 1998) and the KIR infrared camera, with observing and analysis procedures documented in

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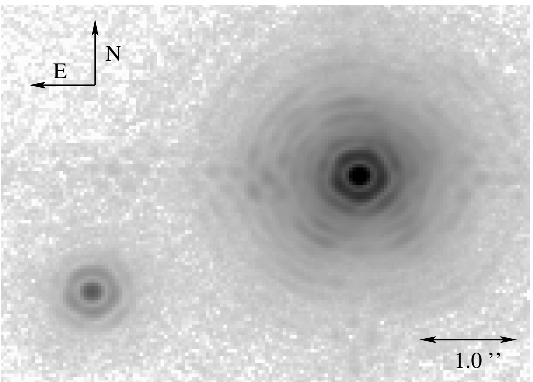

Fig. 1. Adaptive optics image of the G 239-25 AB system in Br_γ in August 2001.

Table 1. Adaptive optics and HST measurements of G 239-25. Plate scale and orientation error from HST have not been taken into account.

Date	Filter / λ_c (μm)	ρ (arcsec)	PA (degree)	Δmag
07 Nov. 1998	*F110W* /1.128	3.028 ± 0.010	114.13 ± 0.18	4.40 ± 0.13
07 Nov. 1998	*F180M* /1.797	3.024 ± 0.001	114.15 ± 0.03	4.10 ± 0.02
07 Nov. 1998	*F207M* /2.082	3.025 ± 0.001	114.17 ± 0.02	3.94 ± 0.01
07 Nov. 1998	*F222M* /2.218	3.023 ± 0.001	114.22 ± 0.02	3.76 ± 0.01
06 Aug. 2001	J_{cont} /1.207	2.922 ± 0.006	111.0 ± 0.2	4.21 ± 0.04
06 Aug. 2001	Brγ /2.166 eps	2.906 ± 0.006	111.0 ± 0.2	3.83 ± 0.04
28 Apr. 2002	Brγ /2.166	2.89 ± 0.01	110.1 ±0.2	3.85 ± 0.07
25 Jun. 2002	H2 /2.122	2.87 ± 0.01	110.2 ± 0.2	3.91 ± 0.05
05 Apr. 2004	H2 /2.122	2.810 ± 0.008	108.4 ± 0.3	3.83 ± 0.04

Beuzit et al. (2004). A possible companion to G 239-25 was easily seen in real time (Fig. 1), but we needed follow-up observations to confirm its physical association.

The probability of observing a background star within a few arcseconds of any given target is quite small at the +47deg galactic latitude of G 239-25, but we have observed a sufficiently large parent sample that we could not a priori reject this possibility with extremely high confidence. The two-band photometry from the J_{cont} and Brackett γ (Br_γ) filters was also not strongly conclusive: the near-IR colours of very low mass stars and brown dwarfs are only moderately distinctive, as opposed to their optical-to-IR color index; this general difficulty was compounded here by observations through narrow-band filters for which we do not have accurate colour transformations to standard photometric bands.

Like most nearby stars G 239-25 fortunately has a high proper motion ($\mu_\alpha = -310.62$ mas/yr, $\mu_\delta = -59.23$ mas/yr), and it moves relative to background stars by 9 pixel/yr. Common proper motion is thus easily tested after just a few months, and we have now reobserved G 239-25 on several occasions. We also found from the *HST* archive that G 239-25 was observed in November 1998 with NICMOS, which doubles the time span of the observations. For each PUE'O observing run, we determine the detector scale and orientation by observing either the inner part of the Orion Trapezium or some wide and distant HIPPARCOS binaries. We typically achieve a pixel scale accuracy of 0.01 mas/pixel and determine the orientation of the detector with 0.08 deg precision. Table 1 displays the parameters of the binary system at each observed epoch.

The relative displacement of the two components over 6 years is $\Delta_\alpha = -0.097''$ and $\Delta\delta = +0.351''$, 5 times smaller than the proper motion and in a different direction. It is, on the other hand, consistent with the expected keplerian motion of the system and shows incipient curvature (see Fig. 3 for a tentative orbit).

Due the intrinsic dispersion of spectral type vs. colour or absolute magnitude (e.g. Knapp et al. 2004), compounded here by non-standard filters, our photometry constrains the spectral class of the companion rather loosely, to an M9–L3 interval (see Fig. 2). We therefore obtained infrared spectra of both components of G 239-25 during the commissioning of LIRIS, the new near-infrared spectrograph of the William Herschel Telescope (Manchado et al. 2000; Acosta Pulido et al. 2003). The spectra have a resolution of $R \approx 700$ and cover the 1 to 2.4 μm wavelength range. A spectral index analysis of the G 239-25 B spectrum gives a spectral type of L0±1 based on the depth of the CO absorbtion band. Figure 4 demonstrates that it is visually very similar to our L0 template. We will present a detailed quantitative analysis of this spectrum in a forthcoming paper.

3. Physical parameters

G 239-25 A is an M 1.5 dwarf with $V = 10.83$ and $K = 6.49$ (Hawley et al. 2002). It belongs to the immediate solar neighborhood, at a distance of only 10.8 pc ($\pi = 92.62 \pm 1.52$ mas, Table 2). Visible spectra taken at Observatoire de Haute Provence with the ELODIE Echelle spectrograph (Baranne et al. 1996) show no signs of chromospheric activity (H_α, H_β, or CaII H and K emission), and they put a low upper limits of $v \sin(i) < 3$ km s^{-1} to the projected rotational velocity. It is thus not very young, but its kinematics ($(U, V, W) = (22, 32, 14)$ km s^{-1}) suggest that G 239-25 belongs to the young disk and is not an old star either. The ROSAT detection of X-ray emission and flares on G 239-25 (Hünsch et al. 1999; Fuhrmeister & Schmitt 2003) further supports a moderately young age for that system. We tentatively adopt an age of 1 to 3 Gyr for G 239-25.

The 2MASS infrared photometry (Cutri et al. 2003) and the parallax result in absolute magnitudes of $M_J = 7.14$, $M_H = 6.57$, $M_K = 6.32$ for G 239-25 A. Theoretical and empirical mass-luminosity relations (Baraffe et al. 1998; Delfosse et al. 2000) both lead to a 0.4 $M_\odot$ mass for the primary, for any age between 200 Myr and 15 Gyrs (Baraffe et al. 1998). The mass derived for the companion is, unsurprisingly, very sensitive to the age. The absolute K band magnitude from the evolutionary models make G239-25 B a brown dwarf if it is younger than 500 Myr (Chabrier et al. 2000), so for the adopted age range it would be stellar. The uncertainties in the models, the photometry, and most seriously the age, are however easily sufficient to make it a brown dwarf.

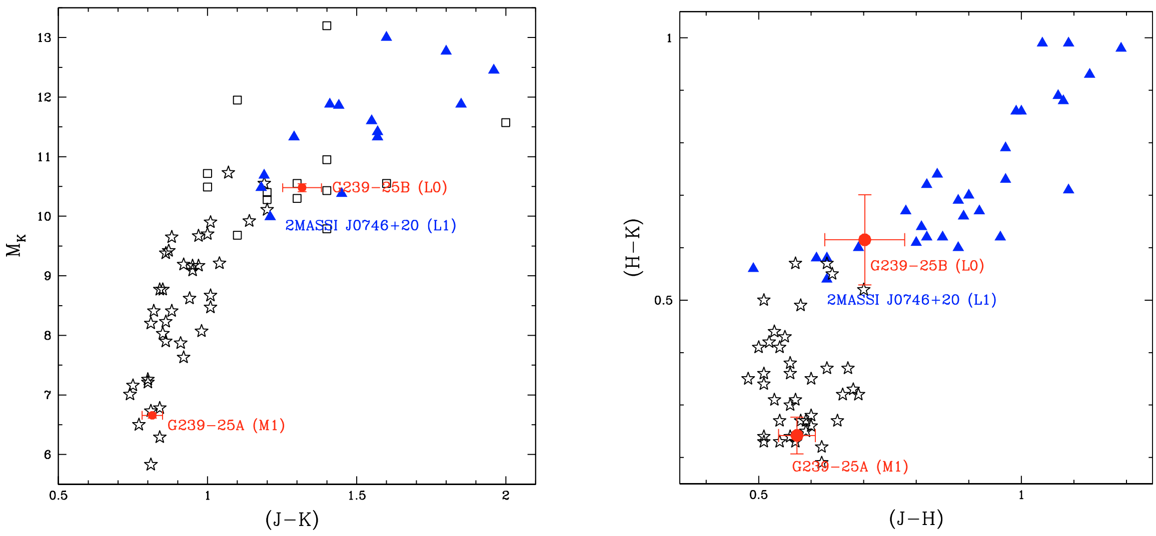

Fig. 2. Absolute K magnitude vs. $J-K$ (*left*) and color–color diagram of $H-K$ vs. $J-H$ (*right*) for M and L dwarfs. *Stars* correspond to M dwarfs (Leggett et al. 2000, 2002) while *filled triangles* (Leggett et al. 2002) and *open squares* (Kendall et al. 2004) correspond to L dwarfs. G 239-25 A and B are represented by *filled circles* with error bars.

Table 2. Photometry and color of G 239-25 using: [a] Reid & Cruz (2002); [b] Cutri et al. (2003); [c] this paper, CFHT data; [d] this paper, HST data; [e] the parallax value for G 239-25 is from a note to the on-line HIPPARCOS catalog and supersedes the printed parallax.

Name	π (mas)	μ_α (mas/yr)	μ_β (mas/yr)	Spectral type	V	I	J	H	K	$J-K$
G 239-25 A	92.62 ± 1.52^e	-302.09 ± 1.58	-33.35 ± 1.86	M1.5	10.83^a	8.59^a	7.306 ± 0.024^b	6.733 ± 0.026^b	6.491 ± 0.024^b	0.815^b
G 239-25 B	92.62 ± 1.52^e	–	–	L0 ± 1	–	–	$11.51 \pm 0.03c$	10.83 ± 0.03^d	$10.33 \pm 0.07^{c,d}$	$1.175^{c,d}$

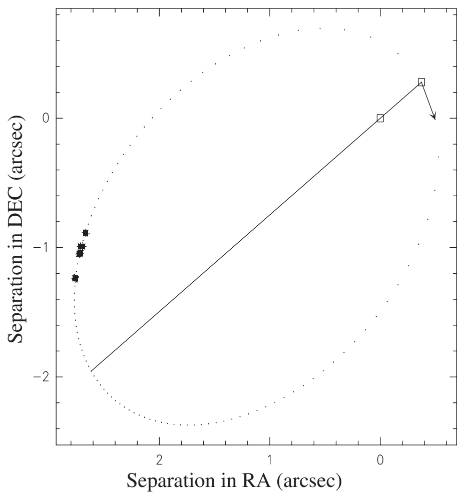

Fig. 3. Tentative visual orbit of the G239-25 pair (North is up and East is left). The orbit is highly indeterminate, and should not be relied upon for more than observation planning over hte next few years. The predicted separations and positions angle on January 1st are (2.76, 107.0) for 2005, (2.71, 105.7) for 2006, (2.66, 104.4) for 2007 and (2.59, 102.9) for 2008.

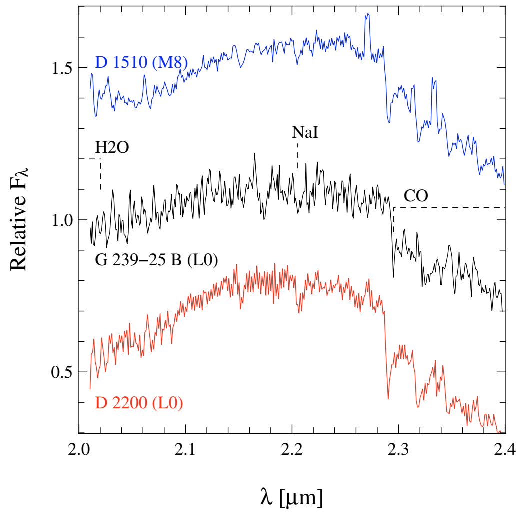

Fig. 4. Near infrared spectrum of G 239-25 B (March 2004) compared to Denis 1510 (M8) and to Denis 2200 (L0), Kendall et al. (2004). The estimation of the spectral type of G239-25 B is based on the depth of the CO absorbtion band which is very similar to Denis 2200.

4. Discussion

The new L dwarf was discovered while observing a volume-limited sample, and is amenable to a crude statistical analysis of the frequency of brown dwarf companions around early M dwarfs. The parent sample of the observing program (Beuzit et al. 2004) comprises the ≈450 M dwarfs within 12 pc, of which ≈300 are M4.5 and earlier. To date we have observed about 250 of those, and we would have easily detected G 239-25 B in every case. Our only other detection of a faint companion beyond 10 AU of its primary is Gl 229B (Oppenheimer et al. 1995), the prototype of the T dwarf spectral class. Its projected distance from its M1.5 primary is 44 AU, quite similar to G 239-25 B. The two detections in a sample of 250 suggest that ≈1% of early M dwarfs have L and T dwarf companions orbiting between 10 and 50 AU.

Note added in proofs: An independant discovery of G 239-25 B has been announced by Golimowski et al. (AJ in press, [arXiv:astro-ph0406664]) during the refereeing of the present letter. Their conclusions are consistent with the photometric part of our analysis.

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