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Meeting the Cool Neighbours, IV: 2M1835+32, a newly-discovered M8.5 dwarf within 6 parsecs of the Sun

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ABSTRACT

We present observations of 2MASSI J1835379+325954, a previously unrecognised late-type M dwarf within 6 parsecs of the Sun. Identified based analysis of

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the Two-Micron All Sky Survey, optical spectroscopy and photometry indicate a spectral type of M8.5. The star has a proper motion of 0.759 $''$ yr^{-1} and is clearly visible on both POSS I and POSS II photographic plate material, but may have escaped detection in previous surveys through its proximity to the Galactic Plane. We discuss potential implications for the completeness of the local stellar census.

Subject headings: stars: low-mass, brown dwarfs; stars: luminosity function, mass function; Galaxy: stellar content

1. Introduction

A reliable census of the stellar constituents of the Solar Neighbourhood is a vital ingredient in the determination of such fundamental parameters as the luminosity function, the mass function, multiplicity, kinematics and the abundance distribution. We are currently engaged in a large-scale analysis of data from the Two-Micron All Sky Survey (2MASS; Skrutskie *et al.*, 1997) with the primary goal of identifying all M and L dwarfs within 20 parsecs of the Sun. Our initial studies centred on proper motion stars from Luyten's NLTT catalogue (Reid *et al.*, 2002); more recently, we have concentrated on candidates identified directly from the 2MASS database (Cruz *et al.*, in prep.). In follow-up observations of the latter sample, we have identified a previously-unrecognised M8.5 dwarf within 6 parsecs of the Sun. This short paper presents the details of that discovery and discusses the implications.

2. Observations

2.1. Identification

2MASSI J1835379+325954 (hereinafter 2M1835+32) was selected in early 2001 as a candidate nearby dwarf by K. Cruz in the course of analysis of the Second Incremental 2MASS data release, and, as described below, was observed as part of our follow-up spectroscopic survey. Almost contemporaneously, S Laurie identified the star as likely to be a particularly close neighbour based on his own search of the 2MASS database. Most red 2MASS sources at these bright magnitudes are giants, but 2M1835+32 has significant proper motion, evident from simple inspection of the POSS I and POSS II images in the Digitised Sky Survey (Figure 1). Using those images and his own CCD observations, S. Laurie derived a preliminary estimate of $\sim 0.75''$ yr^{-1} .

Until recently, 2M1835+32 was not included in proper motion catalogues. Lépine *et al.* (2002), however, recently made an independent identification of this star (designated as LSR1835+3259: $\mu = 0.747''$ yr^{-1} , $\theta = 185.8^o$) in a survey for high proper motion stars near the Galactic Plane. With Galactic co-ordinates of ($l \sim +61^o, b \sim +17^o$), the background star density is moderately high, and this presumably accounts for it having escaped attention in Luyten's Palomar surveys.

2.2. Spectroscopy

We obtained optical spectroscopy of 2M1835+32 with the R-C spectrograph on the Kitt Peak Mayall 4-metre on July 22 2001. We used the BL181 grating in first order to give a dispersion of 2.8 Å/pixel and wavelength coverage from 6000Å to beyond 1μm. This setup has a resolution of 5.6Å (2 pixels) with the 1.0 arcsecond slit used for these observations. Conditions were moderately good, with 1.5 arcsecond seeing and some cloud, precluding absolute spectrophotometry.

The data were bias-subtracted and flat-fielded (with dome flats) using the CCDRED routine in the IRAF package, and the spectrum extracted, wavelength calibrated and flux calibrated using standard techniques. The results are plotted in Figure 2, where we compare against similar-resolution observations of VB 10 (M8) and LHS 2065 (M9). It is clear that 2M1835+32 is confirmed as a late-type dwarf, with an estimated spectral type of M8.5±0.5.

2.3. Photometry and astrometry

Following our spectroscopic confirmation, 2M1835+32 was added to the US Naval Observatory parallax program. Eighty-one CCD images with the USNO 61-inch reflector were obtained between 23 July 2001 and 13 July 2002. Following standard policy, the observations were taken close to meridian passage, and the measurements reduced using the methods described by Dahn *et al.*(2002). The derived relative parallax is 0.1754±0.0005 arcseconds. Correcting for the reference frame gives an absolute value of 0.1765±0.0005 arcsecond, corresponding to a distance of 5.67±0.02 parsecs. This is slightly closer than VB8 and the Wolf 629/630 system (6.45 ± 0.02 parsecs), and currently places 2M1835+32 as the fifty-ninth nearest system to the Sun[2]. The proper motion calculated from the CCD images,

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[2]See the RECONS site, *http://www.chara.gsu.edu/ thenry/RECONS/*. Note that this list, and the Henry *et al.* (1997) calculations, include only systems with trigonometric parallaxes determined to an accuracy of

0.7590 ± 0.0011 $''$ yr^{-1} (Table 1), is in good agreement with the initial estimate derived from POSS I/II plate material.

Photometric observations at V, I (Cousins) and z (on the preliminary SDSS system) were obtained with the USNO 40-inch telescope on 18 May 2002, 19 May 2002 and 9 June 2002. These measurements were reduced using standard techniques (Dahn *et al.*, 2002), and the averaged results are listed in Table 1. The dispersion in the individual measurements about the mean magnitude in each passband is larger than expected based on observations of other late-type dwarfs, suggesting possible intrinsic variations at the ~ 0.05 magnitude level.

Figure 3 shows the location of 2M1835+32 in the (M_V, (V-I)) and (M_J, (J-K)) diagrams. At visual magnitudes, 2M1835+32 is 0.3 magnitudes fainter than LHS 2065 and 0.1 magnitudes fainter than LHS 2924, both classed as spectral type M9 by Kirkpatrick *et al.* (1995). The new discovery is 0.06 magnitudes and 0.17 magnitudes brighter than the two M9 standards at M_J. These results are consistent with the spectral type of M8.5 derived from our spectroscopic observations.

3. Discussion

2M1835+32 is the third late-type M dwarf added to the local stellar census within the last two years. DENIS-P J104814.7-395606.1 was identified by Delfosse *et al.* (2001) as an M9 dwarf at a distance of $\sim 5.2^{+1.2}_{-0.8}$ parsecs (Deacon & Hambly, 2001), while Scholz *et al.* (2001) estimate a distance of 6 ± 1 parsecs for the M6.5 dwarf, LHS 2090. A number of recent studies, notably by Henry *et al.* (1997) and Delfosse *et al.* (1999) have argued that there is substantial incompleteness in the census of stellar systems within even the immediate Solar Neighbourhood. These new discoveries clearly refocus attention on that issue.

The degree of incompleteness inferred for a given nearby-star sample depends on the reference dataset adopted. In their analysis, Henry *et al.* (1997) set the baseline using the all-sky 5-parsec sample, 59 stars and one brown dwarf (LP 944-20) in 45 systems (considering α Cen AB and Proxima as a single system). On this basis, they find a shortfall of $\sim$30% in the current 8-parsec sample (128 systems identified, all-sky, versus 184 predicted) and nearly 40% in the 10-parsec sample (360 systems predicted versus 229 catalogued). Approximately half of the deficit lies in late-type M dwarfs, $M_V > 15$. These predictions, however, make no allowance for the statistical uncertainties inherent in the 5-parsec sample, an issue we

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better than 20 milliarcseconds (Henry, priv. comm.)

consider here.

In calculating the expected numbers of stellar systems within 8 and 10 parsecs, Henry *et al.* are extrapolating the measured space density within 5 parsecs; the associated uncertainty is given by the Poisson statistics for the 5-parsec sample. Table 2 and Figure 4 present luminosity function data for 5-parsec and 8-parsec samples. We limit analysis to northern systems, adding LHS 2090 and 2M1835+32 to the compilation given in Reid *et al.* (1999). We also include the Sun in these calculations.

The northern ($\delta > -30^o$) 8-parsec sample encompasses 107 systems, including 142 main-sequence stars, three brown dwarfs (Gl 229B and Gl 570D, both with $M_V > 20$, and LP 944-20) and eight white dwarfs (four isolated, four companions). Thirty-three systems, including 44 main-sequence stars and three white dwarfs (Sirius B, Procyon B and vMa 2), fall within the 5-parsec distance limit. Table 2 gives the statistics for the main-sequence stars, both for systems (binned by the absolute magnitude of the brightest member) and on a star-by-star basis. The parameter Δ lists the numerical difference between the observed number of systems/stars in the 8-parsec sample and the predicted numbers, in the sense predicted-observed, and $\frac{\Delta}{\sigma}$ normalises that difference in terms of the Poisson statistics associated with the two samples[3].

Table 2 shows that, in most cases, the difference between the observed and predicted numbers is less than 1σ. Notable exceptions are the $M_V = 9.5$ and 12.5 bins, where every star lies beyond 5 parsecs. Considered as a whole, the net difference between the 8-parsec sample and the 5-parsec predictions is 29 systems and 38 stars, corresponding to deficits of only 1.2σ and 1.3σ respectively. Subdividing the sample more coarsely into three absolute magnitude intervals, $M_V < 10$, $10 \leq M_V < 14$, and $M_V > 14$, $\Delta_{sys} = -5.3$ at the brightest absolute magnitudes, corresponding to an excess of 18% (0.4σ) in the 8-parsec sample. At intermediate magnitudes, the net deficit in the 8-parsec sample is $\sim$ 8 systems, or -15% (0.5σ). Not unexpectedly, Δ_{sys} rises to -26 in the faintest bin, or -58% (1.5σ). We note that most luminosity and mass function analyses, including our own (Reid *et al.*, 1999), adopt a 5-parsec limit at the latter absolute magnitudes.

Given these statistics, it seems optimistic to assign all of the discrepancy between the two samples to incompleteness in the 8-parsec dataset. We suspect that the shortfalls in the current 8-parsec and 10-parsec samples are likely to be less dramatic than proposed by Henry *et al.* 'Missing' systems in the $10 \leq M_V < 14$ range should have apparent magnitudes brighter than V=13.5, sufficiently bright for most stars to be detectable on early twentieth

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[3]Note that the statistical uncertainties for the 5-parsec sample are given by the number of actual systems/stars in each bin, not the predicted numbers listed in Table 2.

century photographic surveys, such as the Bruce proper motion survey. The bright limiting magnitudes of those survey ($m_{pg} \sim 15.5$) leads to less crowding in high star density regions, and therefore favours detection of nearby stars close to the Galactic Plane, as indicated by the (α, δ) distribution of bright NLTT stars (illustrated in Reid *et al.*, 2001, Figure 1).

In contrast, most of the intrinsically faintest stars in the 8-parsec sample were identified only from Luyten's surveys with the Palomar 48-inch Schmidt, where the higher sensitivity ($m_r(lim) > 19.5$) leads to greater confusion at low Galactic latitudes. Incompleteness in the current 8- and 10-parsec catalogues is much more likely at those magnitudes, particularly at low Galactic latitudes. and all three recent additions fall in this régime, although LHS 2090 was, of course, first identified by Luyten.

The new proper motion stars identified by Lépine *et al.* (2002) have characteristics consistent with this hypothesis. All of the sample have R> 13, corresponding to V> 14.5 for late-type dwarfs. Fifty-seven of the 141 stars lie within the region covered by the 2MASS Second Incremental Release, and several, notably LSR0602+3910, LSR0510+2712 and LSR0539+4038, are clearly late-M or L dwarfs within 10 parsecs of the Sun. The majority, however, are either cool white dwarfs or halo subdwarfs.

Based on these arguments, we estimate that the deficit in the current northern 8-parsec sample amounts to no more than 15 systems, with most (perhaps all) of the missing systems fainter than $M_V \sim 14$ and lying within 20 degrees of the Galactic Plane. This corresponds to ∼15% incompleteness, rather than the higher value favoured by Henry *et al.* (1997). Similarly, we estimate that the current 10-parsec sample is ∼ 75% complete. The level of incompleteness may be somewhat higher in the southernmost skies, not included in our statistical comparison. In any case, further analysis of the 2MASS database, particularly at low Galactic latitudes, will provide definitive answers on these issues.

4. Summary and conclusions

We have presented spectroscopic, photometric and astrometric observations of 2MASSI J1835379+325954, an M8.5 dwarf within 6 parsecs of the Sun. We estimate that up to 15 additional late-type M dwarfs with distances of less than 8 parsec may remain undetected within the area of the celestial sphere covered by our analysis.

Despite a substantial proper motion, 2M1835+32 eluded detection until the availability of a digitised sky survey (2MASS) equipped with appropriate tools for searching the resultant database (IRSA). There is considerable current interest in establishing a National Virtual Observatory, providing ready access to, and cross-referencing between, substantial astronomical datasets. The independent discovery of 2M1835+32 by a knowledgeable non-professional astronomer, using publicly-available survey data and analysis tools, emphasises the benefits of providing wide access to such resources.

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Table 1. Basic data for 2M1835+32

Parameter	Value	Source
V	18.27±0.03	USNO
I	13.46±0.02	USNO
z	12.63±0.02	USNO
J	10.27±0.03	2MASS
H	9.58±0.05	2MASS
K_S	9.15±0.04	2MASS
π_{rel}	175.4 ± 0.5 mas	USNO
π_{abs}	176.5 ± 0.5 mas	USNO
μ	759.0 ± 1.1 mas. yr^{-1}	USNO
θ	186.1 ± 0.1 degrees	USNO

Table 2. Nearby star statistics

M_V	N_{sys}(8 pc.)	N_{sys}(5 pc.)	$\Delta_{sys}(5-8)$	$\frac{\Delta_{sys}}{\sigma}$	N_*(8 pc.)	N_*(5 pc.)	$\Delta_*(5-8)$	$\frac{\Delta_*}{\sigma}$
0.5	1	0	-1.0	-1.00	1	0	-1.0	-1.00
1.5	2	1	2.1	0.48	2	1	2.1	0.48
2.5	2	1	2.1	0.48	2	1	2.1	0.48
3.5	0	0	0.0	0.00	0	0	0.0	0.00
4.5	2	1	2.1	0.48	2	1	2.1	0.48
5.5	7	1	-2.9	-0.60	7	1	-2.9	-0.60
6.5	6	1	-1.9	-0.40	7	1	-2.9	-0.60
7.5	2	1	2.1	0.48	4	1	0.1	0.02
8.5	4	1	0.1	0.02	7	2	1.2	0.19
9.5	8	0	-8.0	-2.83	9	0	-9.0	-3.00
10.5	11	5	9.5	0.97	11	5	9.5	0.97
11.5	14	5	6.5	0.65	21	6	3.6	0.32
12.5	16	0	-16.0	-4.00	21	0	-21.0	-4.58
13.5	8	4	8.4	0.97	13	6	11.6	1.09
14.5	7	4	9.4	1.09	8	4	8.4	0.97
15.5	7	4	9.4	1.09	16	10	25.0	1.84
16.5	2	2	6.2	1.04	4	3	8.3	1.12
17.5	2	1	2.1	0.49	3	1	1.1	0.48
18.5	1	0	-1.0	-1.00	4	1	0.1	0.02
Totals	102	32	29.1	1.19	142	44	38.2	1.32

Note. — Column 2 lists the number of systems within 8 parsecs of the Sun, segregated based on the absolute magnitude of the brightest component;

Column 3 gives the number of systems within 5 parsecs.

Column 4 lists $\Delta_{sys}(5-8)$, the difference between the expected number of systems within 8 parsecs, extrapolated from N_{sys}(5 pc.), and the observed numbers;

Column 5 scales that difference based on the Poisson uncertainties of the respective samples.

Columns 6 to 9 present the same data, but on a star-by-star basis (that is, including fainter components in binary and multiple systems).

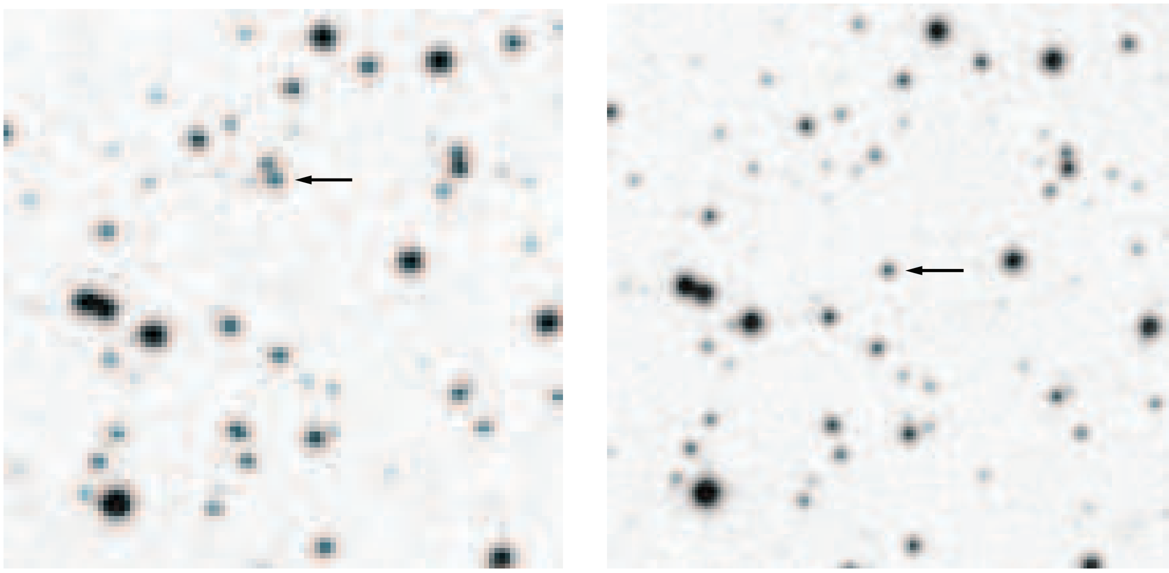
Figure captions

Fig. 1.— 5×5 arcminute regions centred on the 2MASS-determined position of 2M1835+32 from the POSS I E plate (left) and POSS II F plate (right). The images are orient with North at the top and East on the left. 2M1835+32 lies $\sim$ 6 arcseconds North of centre on the latter plate, taken on 27 June 1993, and is clearly visible $\sim$ 32 arcseconds further north on the first epoch plate, from July 5 1951.

Fig. 2.— The far-red optical spectrum of 2M1835+32 compared to similar resolution observations of the M8 standard VB 10 and the M9 standard LHS 2065.

Fig. 3.— The open circle marks the location occupied by 2M1835+32 in the (M_V, (V-I)) and (M_J, (J-K) planes. Data for nearby stars are plotted as crosses (photometry by Bessell, 1990, and Leggett, 1992); ultracool M dwarfs (sp. type >M7.5) are plotted as crosses with errorbars; L dwarfs are plotted as solid points; and five-point stars mark T dwarfs. Data for the last three subsets are all from Dahn *et al.* (2002).

Fig. 4.— The 5-parsec (dotted line) and 8-parsec (solid line) stellar system luminosity functions. The error bars indicate 1σ counting uncertainties, with the 5-parsec datapoints scaled to match the 8-parsec sampling volume and slightly offset (in M_V) for clarity.



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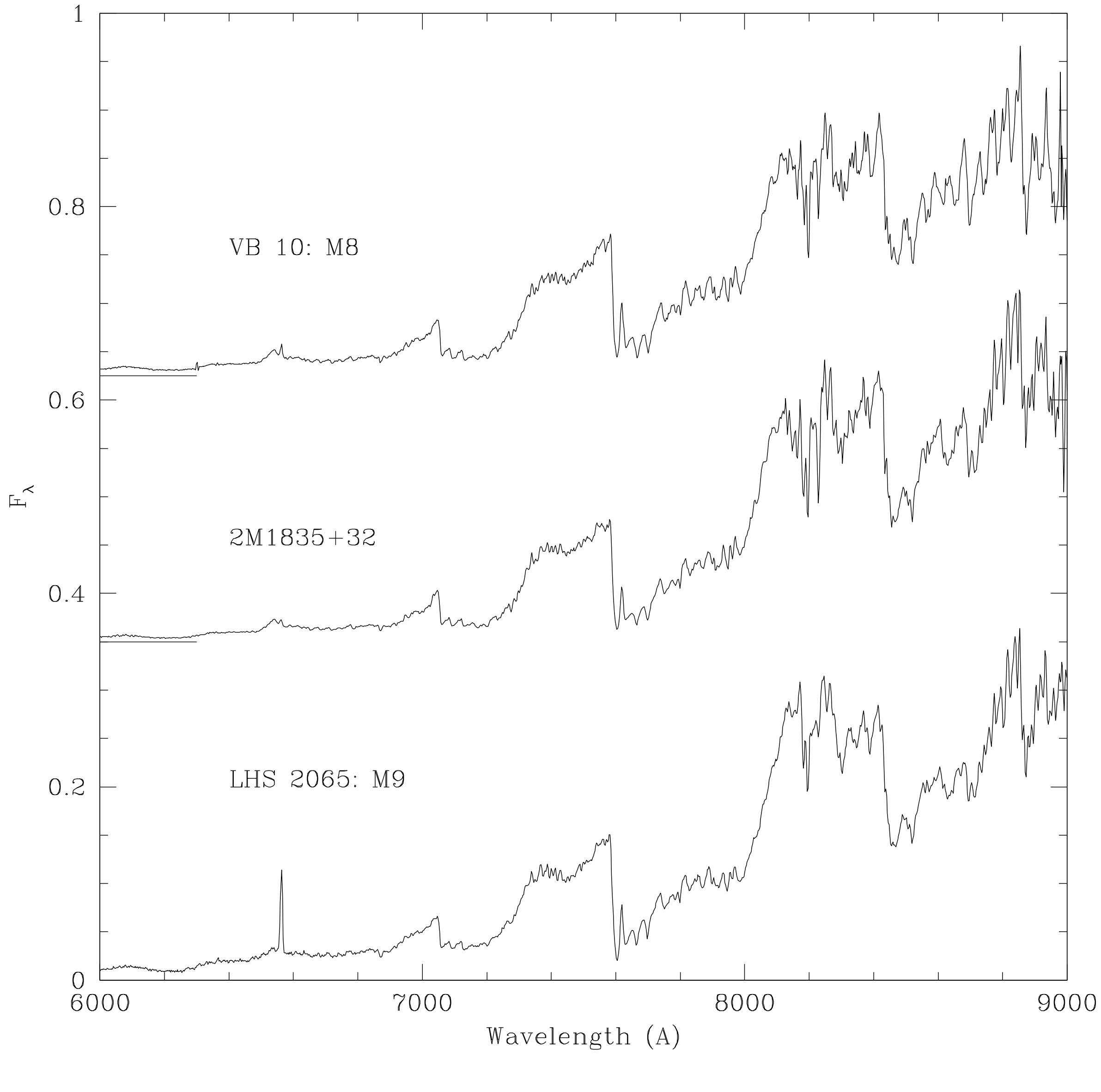

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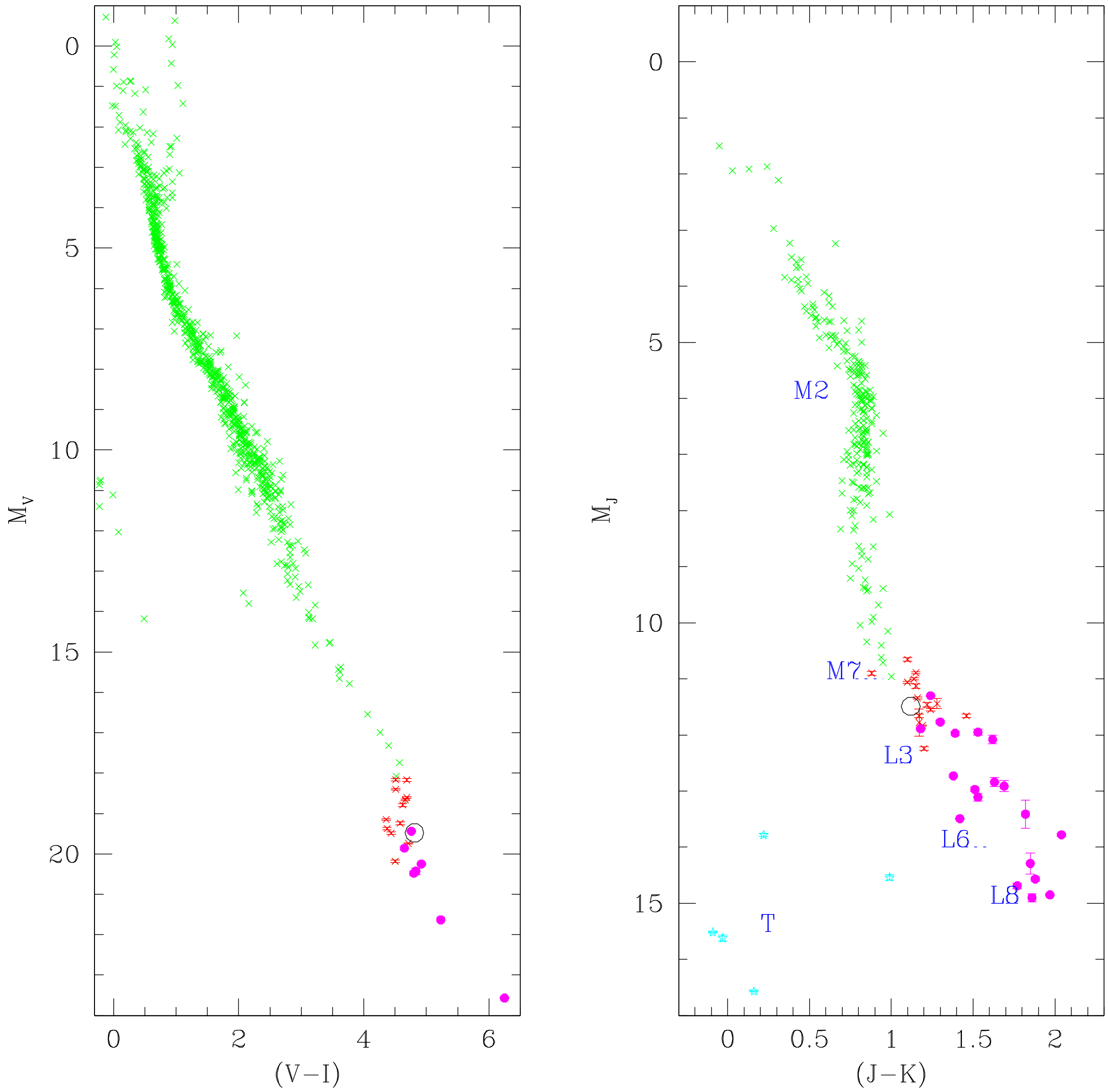
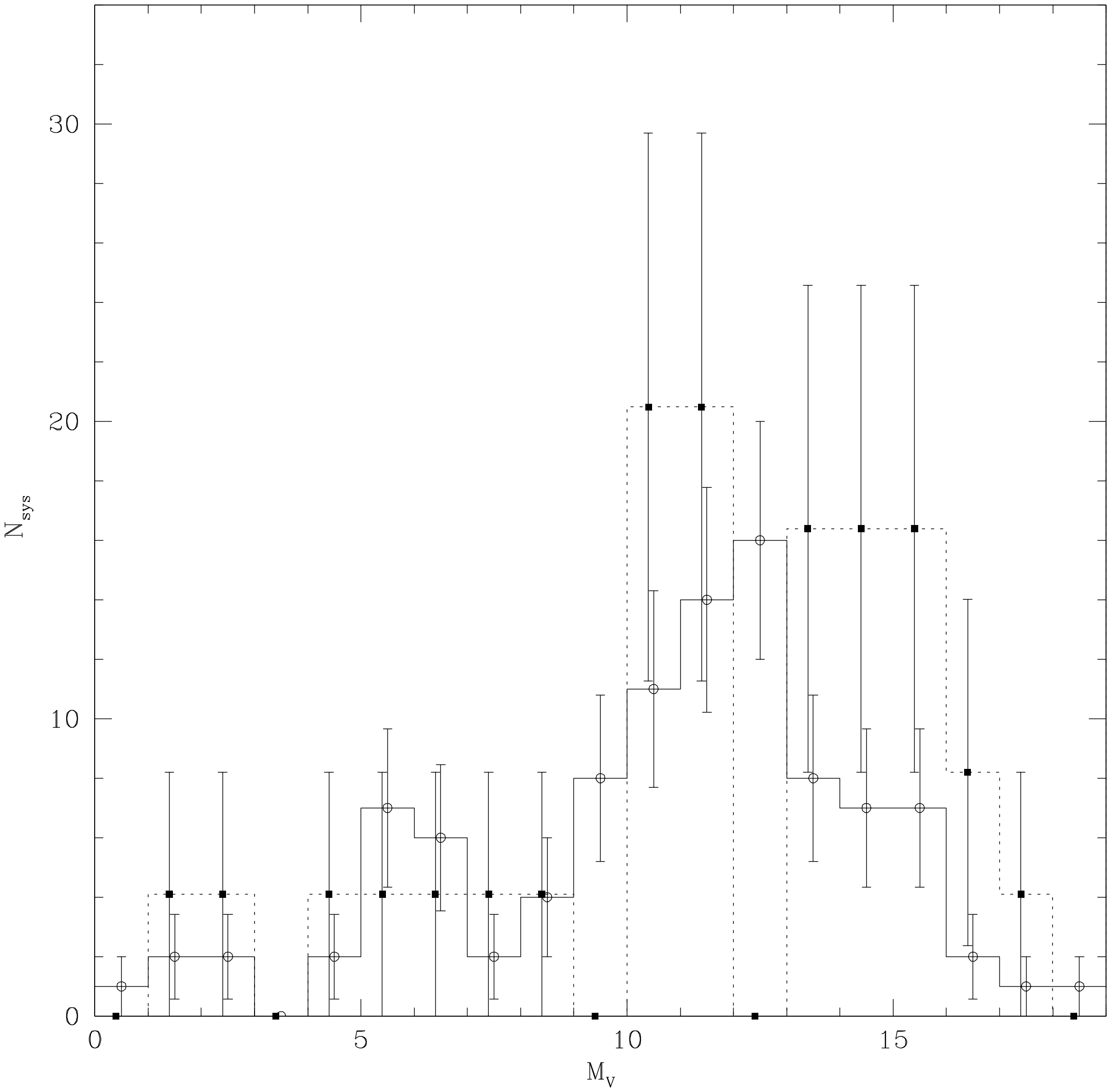


Fig. 3.— The open circle marks the location occupied by 2M1835+32 in the (M_V, (V-I)) and (M_J, (J-K)) planes. Nearby stars from the pCNS3 (photometry by Bessell, 1989, and Leggett, 1992) are plotted as crosses; ultracool M dwarfs are plotted as crosses with errorbars; L dwarfs are plotted as solid points; and five-point stars mark T dwarfs. Data for the last three subsets are all from Dahn *et al.* (2002).



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