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MEETING THE COOL NEIGHBORS. IV. 2MASS 1835+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 unrecognized late-type M dwarf within 6 pc of the Sun. Identified based analysis of 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 it 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.

Key words: Galaxy: stellar content — stars: low-mass, brown dwarfs — stars: luminosity function, mass function

On-line material: color figure

1. INTRODUCTION

A reliable census of the stellar constituents of the solar neighborhood 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 pc of the Sun. Our initial studies centered on proper-motion stars from Luyten's NLTT catalog (Reid & Cruz 2002); more recently, we have concentrated on candidates identified directly from the 2MASS database (Cruz et al. 2003). In follow-up observations of the latter sample, we have identified a previously unrecognized M8.5 dwarf within 6 pc of the Sun. This short paper presents the details of that discovery and discusses the implications.

2. OBSERVATIONS

2.1. *Identification*

2MASSI J1835379+325954 (hereafter 2M1835+32) was selected in early 2001 as a candidate nearby dwarf by K. L. C. in the course of analysis of the 2MASS Second Incremental Data Release, and, as described below, was observed as part of our follow-up spectroscopic survey. Almost contemporaneously, S. P. L. identified the star as likely to be a particularly close neighbor 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 Digitized Sky Survey (Fig. 1). Using those images and his own CCD observations, S. P. L. derived a preliminary estimate of $\sim$0."75 yr^{-1}.

Until recently, 2M1835+32 was not included in proper-motion catalogs. Lépine, Shara, & Rich (2002), however, recently made an independent identification of this star (designated as LSR 1835+3259: $\mu = 0.''747$ yr^{-1}, $\theta = 185.^\circ8$) in a survey for high proper motion stars near the Galactic plane. With Galactic coordinates of ($l \sim +61^\circ$, $b \sim +17^\circ$), 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 Ritchey-Chrétien spectrograph on the Kitt Peak Mayall 4 m on 2001 July 22. We used the BL181 grating in first order to give a dispersion of 2.8 Å pixel^{-1} and wavelength coverage from 6000 Å to beyond 1 μm. This setup has a resolution of 5.6 Å (2 pixels) with the 1."0 slit

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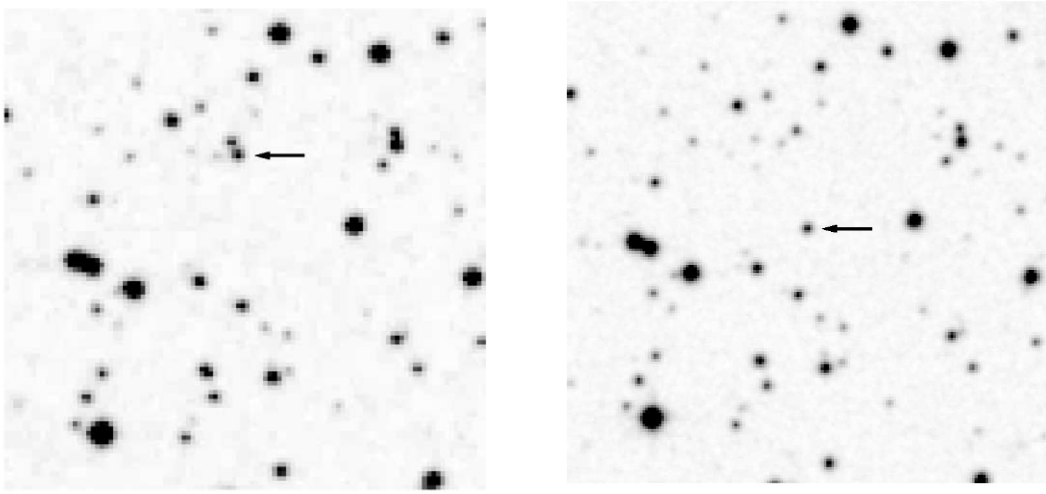

FIG. 1.—The $5' \times 5'$ regions centered on the 2MASS-determined position of 2M1835+32 from the POSS I E plate (*left*) and POSS II F plate (*right*). The images are oriented with north at the top and east on the left. The object 2M1835+32 lies $\sim 6''$ north of center on the latter plate, taken on 1993 June 27, and is clearly visible $\sim 32''$ further north on the first epoch plate, from 1951 July 5.

used for these observations. Conditions were moderately good, with 1\".5 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 $\pm$ 0.5.

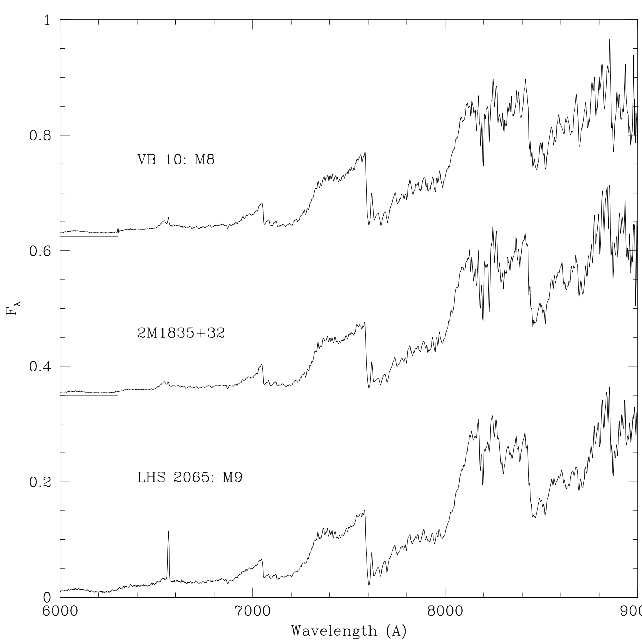

FIG. 2.—Far-red optical spectrum of 2M1835+32 compared with similar resolution observations of the M8 standard VB 10 and the M9 standard LHS 2065.

2.3. *Photometry and Astrometry*

Following our spectroscopic confirmation, 2M1835+32 was added to the US Naval Observatory (USNO) parallax program. Eighty-one CCD images with the USNO 61 inch (1.5 m) reflector were obtained between 2001 July 23 and 2002 July 13. 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 $\pm$ 0\".0005. Correcting for the reference frame gives an absolute value of 0\".1765 $\pm$ 0\".0005, corresponding to a distance of 5.67 $\pm$ 0.02 pc. This is slightly closer than VB 8 and the Wolf 629/630 system (6.45 $\pm$ 0.02 pc) and currently places 2M1835+32 as the 59th nearest system to the Sun.[2] The proper motion calculated from the CCD images, 0\".7590 $\pm$ 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

[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 better than 20 mas (T. Henry 2002, private communication).

TABLE 1
BASIC DATA FOR 2M1835+32

Parameter	Value	Source
V	18.27 $\pm$ 0.03	USNO
I	13.46 $\pm$ 0.02	USNO
z	12.63 $\pm$ 0.02	USNO
J	10.27 $\pm$ 0.03	2MASS
H	9.58 $\pm$ 0.05	2MASS
K_s	9.15 $\pm$ 0.04	2MASS
π_{rel} (mas)	175.4 $\pm$ 0.5	USNO
π_{abs} (mas)	176.5 $\pm$ 0.5	USNO
μ (mas yr^{-1})	759.0 $\pm$ 1.1	USNO
θ (deg)	186.1 $\pm$ 0.1	USNO

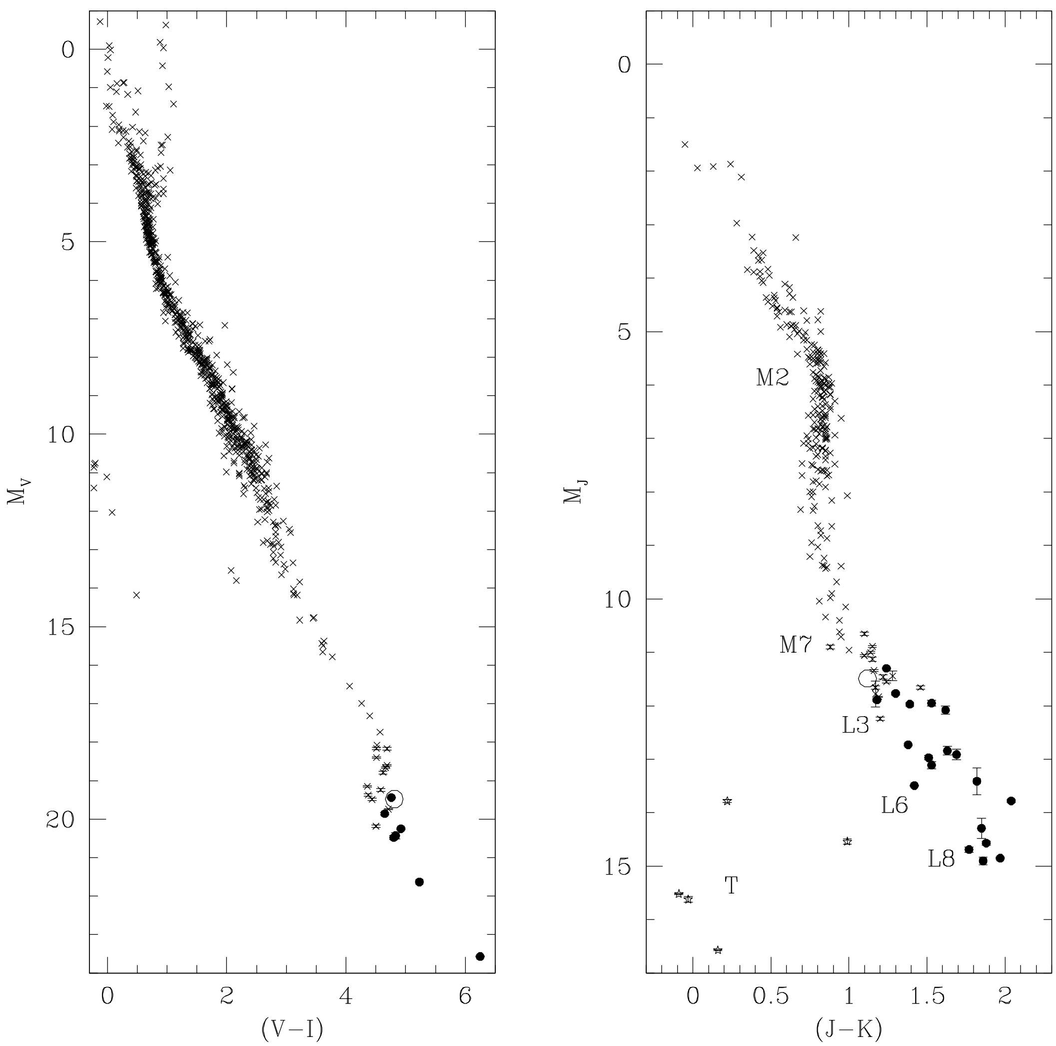

FIG. 3.—Open circle marks the location occupied by 2M1835+32 in the (M_V, $V-I$) and (M_J, $J-K$) planes. Data for nearby stars are plotted as crosses (photometry by Bessell 1990 and Leggett 1992), ultracool M dwarfs (sp. type greater than M7.5) are plotted as crosses with error bars, L dwarfs are plotted as filled circles, and five-point stars mark T dwarfs. Data for the last three subsets are all from Dahn et al. (2002).

USNO 40 inch (1 m) telescope on 2002 May 18, May 19, and June 9. 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 mag 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 mag fainter than LHS 2065 and 0.1 mag fainter than LHS 2924, both classed as spectral type M9 by Kirkpatrick, Henry, & Simons (1995). The new discovery is 0.06 and 0.17 mag 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

The object 2M1835+32 is the third late-type M dwarf added to the local stellar census within the last 2 years. DENISP J104814.7−395606.1 was identified by Delfosse et al. (2001) as an M9 dwarf at a distance of $\sim 5.2^{+1.2}_{-0.8}$ pc (Deacon & Hambly 2001), while Scholz, Meusinger, & Jahreiss (2001) estimate a distance of 6 ± 1 pc 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 neighborhood. These new discoveries clearly refocus attention on that issue.

The degree of incompleteness inferred for a given nearby-star sample depends on the reference data set adopted. In their analysis, Henry et al. (1997) set the baseline using the all-sky 5 pc 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 ∼30% in the current 8 pc sample (128 systems identified, all-sky, vs. 184 predicted) and nearly 40% in the 10 pc sample (360 systems predicted vs. 229 cataloged). 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 pc sample, an issue we consider here.

TABLE 2
NEARBY STAR STATISTICS

M_V (1)	N_{sys}(8 pc) (2)	N_{sys}(5 pc) (3)	Δ_{sys}(5−8) (4)	Δ_{sys}/σ (5)	$N*$(8 pc) (6)	$N*$(5 pc) (7)	$\Delta*$(5−8) (8)	$\Delta*/\sigma$ (9)
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

NOTES.—Col. (2): the number of systems within 8 pc of the Sun, segregated based on the absolute magnitude of the brightest component; col. (3): the number of systems within 5 pc; col. (4): $\Delta_{sys}(5-8)$, the difference between the expected number of systems within 8 pc, extrapolated from N_{sys}(5 pc.), and the observed numbers; col. (5): scales that difference based on the Poisson uncertainties of the respective samples; and cols. (6)–(9): the same data, but on a star-by-star basis (that is, including fainter components in binary and multiple systems).

In calculating the expected numbers of stellar systems within 8 and 10 pc, Henry et al. are extrapolating the measured space density within 5 pc; the associated uncertainty is given by the Poisson statistics for the 5 pc sample. Table 2 and Figure 4 present luminosity function data for 5 pc and 8 pc 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.

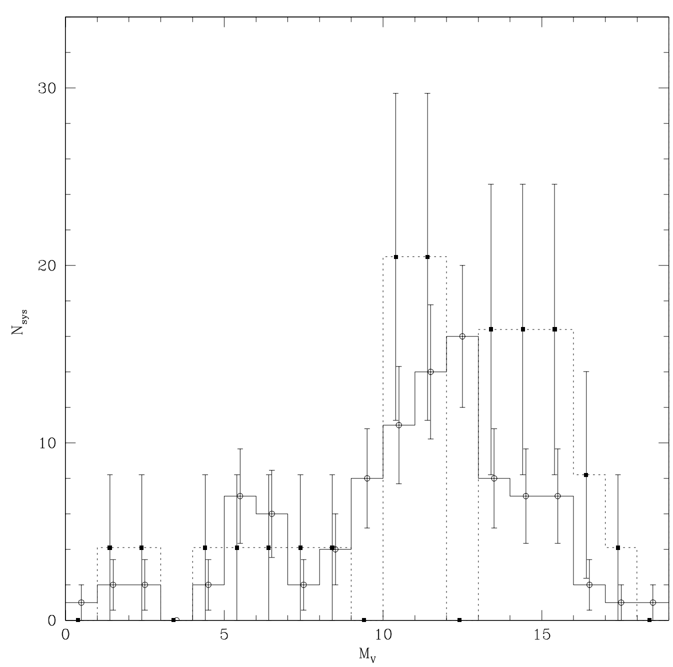

FIG. 4.—Luminosity functions for the 5 pc (*dotted line*) and 8 pc (*solid line*) stellar system . The error bars indicate 1 σ counting uncertainties, with the 5 pc data points scaled to match the 8 pc sampling volume and slightly offset (in M_V) for clarity.

The northern ($\delta > -30°$) 8 pc 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 pc 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 pc sample and the predicted numbers, in the sense predicted minus observed, and Δ/σ normalizes 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 1 σ. Notable exceptions are the $M_V = 9.5$ and 12.5 bins, where every star lies beyond 5 pc. Considered as a whole, the net difference between the 8 pc sample and the 5 pc predictions is 29 systems and 38 stars, corresponding to deficits of only 1.2 σ and 1.3 σ, respectively. Subdividing the sample more coarsely into three absolute magnitude intervals, $M_V < 10$, $10 \le M_V < 14$, and $M_V > 14$, $\Delta_{sys} = -5.3$ at the brightest absolute magnitudes, corresponding to an excess of 18% (0.4 σ) in the 8 pc sample. At intermediate magnitudes, the

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

net deficit in the 8 pc sample is approximately eight systems, or -15% ($0.5\ \sigma$). Not unexpectedly, Δ_{sys} rises to -26 in the faintest bin, or -58% ($1.5\ \sigma$). We note that most luminosity and mass function analyses, including our own (Reid et al. 1999), adopt a 5 pc 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 pc data set. We suspect that the shortfalls in the current 8 and 10 pc 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 century photographic surveys, such as the Bruce proper motion survey. The bright limiting magnitudes of those surveys ($m_{pg} \sim 15.5$) leads to less crowding in high star density regions and therefore favors detection of nearby stars close to the Galactic plane, as indicated by the (α, δ) distribution of bright NLTT stars (illustrated in Reid & Cruz 2002, Fig. 1).

In contrast, most of the intrinsically faintest stars in the 8 pc sample were identified only from Luyten's surveys with the Palomar 48 inch (1.2 m) 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 pc catalogs 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 LSR 0602+3910, LSR 0510+2712, and LSR 0539+4038, are clearly late-M or L dwarfs within 10 pc 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 pc 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° of the Galactic plane. This corresponds to $\sim$15% incompleteness, rather than the higher value favored by Henry et al. (1997). Similarly, we estimate that the current 10 pc sample is $\sim$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 pc of the Sun. We estimate that up to 15 additional late-type M dwarfs with distances of less than 8 pc 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 digitized sky survey (2MASS) equipped with appropriate tools for searching the resultant database (Infrared Science Archive). There is considerable current interest in establishing a National Virtual Observatory, providing ready access to, and cross-referencing between, substantial astronomical data sets. The independent discovery of 2M1835+32 by a knowledgeable nonprofessional astronomer, using publicly available survey data and analysis tools, emphasizes the benefits of providing wide access to such resources.

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