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The nearest cool white dwarf ($d \sim 4$ pc), the coolest M-type subdwarf (sdM9.5), and other high proper motion discoveries⋆,⋆⋆

R.-D. Scholz[1], I. Lehmann[2], I. Matute[2], and H. Zinnecker[1]

[1] Astrophysikalisches Institut Potsdam, An der Sternwarte 16, 14482 Potsdam, Germany
e-mail: [rdscholz;hzinnecker]@aip.de
[2] Max-Planck-Institut für extraterrestrische Physik, Postfach 1312, 85741 Garching, Germany
e-mail: [ile;matute]@mpe.mpg.de

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Abstract. We report the discovery of seven high proper motion stars with proper motions between about 0.7 and 2.2 arcsec/yr, all at relatively low Galactic latitudes ($13° < |b| < 35°$) and located in the southern sky. They were detected in a high proper motion search using multi-epoch positions in the optical SuperCOSMOS Sky Surveys and in the near-infrared sky surveys 2MASS and DENIS. Classification spectroscopy carried out for six of the objects reveals them to represent three different classes of cool objects in the solar neighbourhood: M dwarfs, M subdwarfs and cool white dwarfs. The star with the largest proper motion, SSSPM J1138–7722, is classified as a very nearby ($d \sim 8$ pc) M 5.5 dwarf with Galactic thin disk kinematics. A second star with ∼2 arcsec/yr proper motion, SSSPM J1358–3938, is still lacking spectroscopic confirmation but can be classified from photometry as a thick disk ∼M 3.5 dwarf. Three objects turn out to be cool subdwarf members of the Galactic thick disk or halo, including the first sdM9.5 object, SSSPM J1013–1356, which represents the currently coolest known M subdwarf, another ultra-cool subdwarf, SSSPM J1930–4311, of spectral type sdM7.0 as well as an earlier type (sdM1.5) star. The latter, SSSPM J1530–8146, has an extremely large space velocity with clear halo kinematics (heliocentric $(U, V, W) = (-534 \pm 78, -239 \pm 74, +188 \pm 23)$ km s^{-1}). Two objects show featureless spectra classifying them as cool white dwarfs with $T_{\rm eff} < 4500$ K. One of them, SSSPM J1549–3544, is an extremely nearby ($d \sim 4$ pc) thin disk object, the other one, SSSPM J1148–7458, has thick disk kinematics. SSSPM J1549–3544 is likely to be the nearest cool white dwarf and may be even the nearest isolated white dwarf, i.e. closer than van Maanen 2.

Key words. astrometry – surveys – stars: kinematics – stars: low-mass, brown dwarfs – stars: subdwarfs – stars: white dwarfs

1. Introduction

A large stellar proper motion, of e.g. >0.18 arcsec/yr, which is the lower limit in the New Luyten Two Tenths (NLTT) catalogue of about 60 000 stars (Luyten 1979–80), may be an indication of a small distance and/or an intrinsic high velocity of a star. Practically, all known stars in the immediate solar neighbourhood ($d < 10$ pc) exhibit proper motions larger than the NLTT limit (see http://www.chara.gsu.edu/RECONS/). However, a high proper motion (hereafter HPM) sample does not reflect the real number densities of Galactic thin disk, thick disk and halo populations in the solar neighbourhood (see e.g. Digby et al. 2003) but is strongly biased towards thick disk and halo members. The larger the lower proper motion limit in such a sample, the more exotic thick disk and halo objects can be expected.

Therefore, it is not surprising that recent discoveries of new extreme HPM objects (with proper motion larger than ∼2 arcsec/yr; only 77 NLTT stars are above that limit) include only a few very nearby ($d < 4$ pc) disk M dwarfs (Teegarden et al. 2003) and T-type brown dwarfs (Scholz et al. 2003; McCaughrean et al. 2004). On the other hand, there are more still relatively nearby ($d < 25$ pc), halo M dwarfs (Lépine et al. 2002) and L subdwarfs (Burgasser et al. 2003) as well as thick disk or halo cool white dwarfs (Ibata et al. 2000; Scholz et al. 2002a) being discovered.

Here we present two new discoveries matching the limit of ∼2 arcsec/yr together with five other new HPM stars with $0.7 < \mu < 1.7$ arcsec/yr, identified as a result of an ongoing HPM survey of the southern sky briefly described in Sect. 2. For six of these objects, which are all located at low Galactic latitudes, as well as for a previously known NLTT star apparently moving in front of a dark cloud close to the direction to the Galactic centre we have carried out optical classification spectroscopy (Sects. 3.1 and 3.2). For five objects we have measured radial velocities (Sect. 3.3). Section 4 deals with distance estimates on the basis of the available data, which were

⋆ Based on the systematic search in archival data from the SuperCOSMOS Sky Surveys, 2MASS and DENIS, and on spectroscopic observations with the ESO NTT.
⋆⋆ Figure 1 is only available in electronic form at http://www.edpsciences.org

Fig. 1. (in electronic form only) 3 × 3 arcmin^2 SSS images (*left*: B_J; *centre*: R; *right*: I) for (*from top to bottom*): SSSPM J1013–1356, SSSPM J1138–7722, SSSPM J1148–7458, SSSPM J1358–3938, SSSPM J1530–8146, SSSPM J1549–3544, T3 and SSSPM J1930–4311, (east is left, north is up).

combined to determine space velocities and Galactic population memberships of the objects. In Sect. 5 we draw conclusions and propose some future work.

2. High proper motion survey and photometry

The digitised archival data from the SuperCOSMOS Sky Surveys (SSS) provide multi-epoch data in three optical (B_J, R, I) passbands (Hambly et al. 2001a,b,c) for the entire southern hemisphere. These data, combined with the recently completed near-infrared survey 2MASS (Two Micron All Sky Survey, Cutri et al. 2003) are perfectly suited to the search for hitherto unknown HPM objects in the southern sky. Different search methods using SSS and 2MASS are possible.

Here we applied a search technique similar to that of Scholz et al. (2003), i.e. starting from SSS I-band data and looking for bright ($I < 17$) objects with no counterparts in the R- and B_J-bands (with an initial search radius of 3 arcsec) which could be identified with an other I-band measurement on a different plate. The 6° × 6° UK Schmidt Telescope (UKST) survey plates overlap by about half a degree on each side so that roughly one third of the southern sky is covered by overlapping UKST plates. The I-band observations were made starting in the early 80 s with most plates taken in the 90 s, whereas the majority of the UKST B_J and ESO R plates (also included in the SSS) were taken in the 70 s and early 80 s. The UKST R plates were typically observed in the late 80 s and 90 s. Therefore, a search based on the I-band data is sensitive to both HPM and red objects.

The completeness of our HPM survey is difficult to estimate due to the variation of epoch differences in different bands over the sky. Hambly et al. (2004) have recently published the first results of their most complex HPM search using the complete SSS data base. From their five new objects with proper motions larger than 1 arcsec/yr in the declination zone south of −57.5°, we were able to detect two, including SSSPM J1138–7722.

Altogether seven objects with the largest newly detected proper motions in the all southern sky HPM survey were selected for this study taking into account their visibility during the spectroscopic observing run. One of the objects (SSSPM J1358–3938 = 2MASS 13580529–3937545) was first identified as a potential HPM candidate among bright 2MASS objects without optical counterparts in the 2MASS data base.

All new HPM candidates were checked on SSS finding charts (see e.g. Fig. 1) in all passbands with a search radius of up to a few arcminutes. For a more accurate proper motion determination we then used all identified SSS positions on overlapping plates, including those from the SuperCOSMOS H_α survey (SHS) (Parker & Phillips 1998) in the Galactic plane, together with that from 2MASS, and in some cases from the second release of DENIS (DEep Near-Infrared Survey, Epchtein et al. 1997) data (`http://vizier.u-strasbg.fr/viz-bin/Cat?B/denis`). The astrometric and photometric data of the extreme HPM objects, which were selected for the spectroscopic follow-up observations of this study, are listed in Table 1. The SSS magnitudes in the table are averaged values from several plate measurements. The proper motions were determined from fitting the available multi-epoch positions. The errors are relatively small, since for all objects, except for SSSPM J1930–4311, there were overlapping plate measurements.

The standard SSS R and I magnitudes are corrected in such a way that the SSS $B_J - R$ and $R - I$ colours are anchored at the same median value across the entire survey (see `http://www-wfau.roe.ac.uk/sss/`). We also extracted the uncorrected magnitudes (given in brackets in the second line after each object in Table 1), since the correction may be wrong for HPM (foreground) stars in fields close to the Galactic plane. In some cases, additional I band magnitudes from DENIS were available (see the notes to Table 1). At higher Galactic latitudes, we usually mentioned good agreement between the (corrected) SSS and DENIS I magnitudes for the majority of HPM objects detected in our survey. Here, at relatively low Galactic latitudes, we found more than 1 mag differences for some of the new HPM stars (see e.g. the large deviation for SSSPM J1358–3938). The uncorrected SSS I magnitudes do, however, agree well with the DENIS I magnitudes.

One known NLTT star, which showed up with an extreme optical-to-infrared colour in a cross-correlation of NLTT and 2MASS, was also included in the target list of our observations. This star, originally detected by Terzan et al. (1980) and listed in Luyten's NLTT catalogue as T3, is located close to the Galactic centre ($l = 357°, b = +6°$) and seems to move in the foreground of a dark cloud (see images in Fig. 1). We selected this object with a proper motion of about 0.25 arcsec/yr, i.e. well above the NLTT limit of 0.18 arcsec/yr, as a nearby brown dwarf candidate for our spectroscopic observations. Compared to the large colour indices $I - J = +4.7$ and $J - K_s = +1.69$, the optical SSS colours were rather blue: $B_J - R = +1.5$ and $R - I = +1.2$. From the uncorrected magnitudes we got the alternative colours: $B_J - R = +2.5, R - I = +1.7$ and $I - J = +3.2$, which were more consistent with a brown dwarf candidate.

3. Spectroscopy

3.1. Observations

Spectroscopic observations of seven HPM stars were carried out with the 3.5 m New Technology Telescope (NTT) at ESO La Silla between May 2th and 4th, 2003 using the EMMI instrument equipped with the new 2048 × 4096 MIT/LL CCDs. The relatively bright objects were observed at the beginning and end of the nights as test and supplement targets for the original programme (ESO N 071.A-0444), dealing with the identification of optically faint type-2 quasars candidates selected from XMM-Newton XID fields (see Page et al. 2004). Optical low-resolution spectra were obtained using a 360 line/mm grism in the RILD mode and a 1 arcsec wide

Table 1. Astrometry and photometry from SSS and 2MASS.

Name	α, δ	Epoch	$\mu_\alpha \cos\delta$	μ_δ	B_J	R^i	I^i	J	H	K_s
SSSPM J..	(J2000)		mas/yr			(SSS)			(2MASS)	
1013–1356[a]	10 13 07.34 − 13 56 20.4	1999.099	+66 ± 07	−1026 ± 04	21.931	18.687	16.077	14.621	14.382	14.398
						(18.752)	(16.406)			
1138–7722[b]	11 38 16.71 − 77 21 48.4	2000.068	−2063 ± 05	+620 ± 07	16.280	13.897	11.290	9.399	8.890	8.521
						(13.276)	(11.646)			
1148–7458[c]	11 47 34.44 − 74 57 59.2	2000.068	−1078 ± 07	+1350 ± 07	18.646	17.421	16.904	15.580	15.572	15.217
						(16.796)	(16.276)			
1358–3938[d]	13 58 05.29 − 39 37 54.5	1999.290	+1738 ± 04	−889 ± 03	15.138	12.559	10.299	9.720	9.226	8.948
						(12.724)	(11.218)			
1530–8146[e]	15 30 28.67 − 81 45 37.5	2000.216	−594 ± 07	−287 ± 03	18.511	16.636	15.715	14.154	13.601	13.404
						(16.164)	(15.286)			
1549–3544[f]	15 48 40.23 − 35 44 25.4	1998.625	−591 ± 08	−538 ± 05	15.994	14.765	14.285	12.340	11.765	11.620
						(13.776)	(13.500)			
1930–4311[g]	19 29 40.99 − 43 10 36.8	2000.633	−19 ± 11	−865 ± 08	21.077	18.423	16.311	14.794	14.230	14.091
						(18.411)	(16.359)			
T3[h] (NLTT)	17 15 11.91 − 27 33 01.1	1998.529	−123 ± 05	−220 ± 03	19.904	18.408	17.210	12.514	11.318	10.827
						(17.364)	(15.685)			

Notes:
[a] – α, δ from 2MASS; proper motion from 1 2MASS and 7 SSS positions.
[b] – α, δ from 2MASS; proper motion from 1 2MASS and 10 SSS positions; first discovered by Hambly et al. (2004) as SCR 1138–7721.
[c] – α, δ from 2MASS; proper motion from 1 2MASS and 7 SSS positions; DENIS I = 16.290, J = 15.855.
[d] – α, δ from 2MASS; proper motion from 1 2MASS, 1 DENIS and 4 SSS positions; DENIS I = 11.161, J = 9.651, K = 8.929.
[e] – α, δ from 2MASS; proper motion from 1 2MASS, 4 DENIS and 8 SSS positions; DENIS mean magnitudes: I = 15.243, J = 14.156, K = 13.397.
[f] – α, δ from 2MASS; proper motion from 1 2MASS and 6 SSS positions.
[g] – α, δ from DENIS; proper motion from 1 2MASS and 4 SSS positions; DENIS I = 16.267, J = 14.717, K = 13.906.
[h] – α, δ from 2MASS; proper motion from 1 2MASS, 1 DENIS, 8 SSS and 2 SHS positions; DENIS I = 15.156, J = 12.660, K = 10.886.
[i] – standard SSS magnitudes are corrected to bring $B_J - R$ and $R - I$ colours to same median across the sky; uncorrected magnitudes given in brackets.

slit. The grism efficiency is 77% at the blaze wavelength of 4600 Å. Without an order blocking filter the wavelength coverage ranges from 3850–9100 Å. Second order overlap occurs beyond 8000 Å. The spectral dispersion is 2.3 Å/pix and the resolution is ∼5 Å. The seeing was between 0.7 arcsec and 1.4 arcsec. The exposure times ranged from 60 s for the brightest object, SSSPM J1138–7722, to 300–500 s for the other objects.

The reduction of the raw spectra was carried out using the standard routines under the NOAO/onedspec package available in IRAF. Raw data were sky-subtracted and corrected for pixel-to-pixel variations by division with a suitably normalised exposure spectrum of a continuum lamp. Prior to the extraction and calibration of the spectra, the two-dimensional data were corrected for geometric distorsion, induced by the spectrograph optics, by fitting the Ne-Ar lamp lines with two-dimensional cubic splines along the chip of the CCD. Wavelength calibration was done by comparison with exposures of Ar and Ne lamps, while relative flux calibration was carried out by observations of spectrophotometric standards stars (Hamuy 1992, 1994). The 5577 Å sky line was used to correct for small shifts of the location of the spectra during the night caused by telescope flexure (generally <1 pixel).

3.2. Spectroscopic classification

The spectra shown in Fig. 2 can be roughly divided into three different groups: the lower two spectra (of SSSPM J1148–7458 and SSSPM J1549–3544) do not show any features except for telluric absorption bands; the upper spectrum (of T3) has a very smooth red continuum with sharp absorption lines resembling reddened earlier-type (<K) background stars; and the remaining four spectra (of SSSPM J1138–7722, SSSPM J1013–1356, SSSPM J1930–4311 and SSSPM J1530–8146) are dominated by broad absorption bands of TiO and CaH, typical of M dwarfs and subdwarfs.

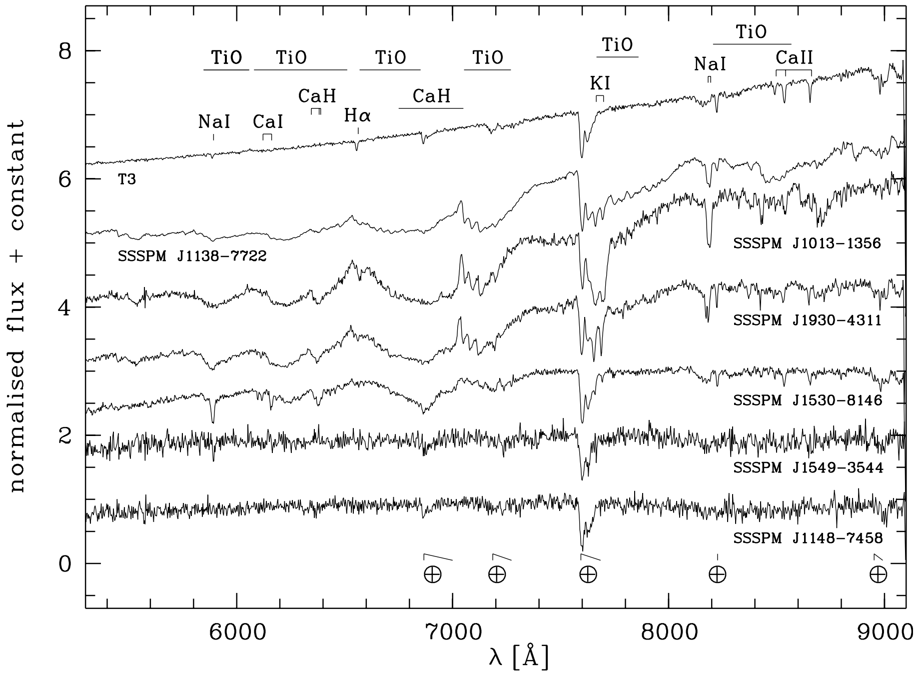

Fig. 2. Spectra of seven objects observed with the ESO NTT. The spectra are flux calibrated, normalised at 7500 Å and vertically shifted by integer constants. The positions of the main absorption lines are marked at the top, whereas telluric absorption bands and lines are marked at the bottom.

3.2.1. Featureless and reddened spectra

Lépine et al. (2003a) found 11 cool white dwarfs among their sample of 104 HPM stars. Half of their spectra are completely featureless (DC white dwarfs) and half show weak H_α absorption (DA white dwarfs). Our two objects, SSSPM J1148–7458 and SSSPM J1549–3544, can be classified as DC white dwarfs due to the absence of any lines, although higher signal-to-noise spectra are required to be sure. Their effective temperatures can be estimated to be lower than 4500 K, since both spectra have a redder continuum than all the cool white dwarfs in Lépine et al. (2003a). We assign a preliminary spectral type of >DC11 to each object.

The very red and smooth spectrum on top of Fig. 2 looks like that of a reddened early-type star and was not expected for this relatively faint HPM object, T3. The spectrum was found to be most similar to that of a reddened G-type star, since there are no Paschen lines at the red end of the spectrum, typical of earlier-type stars, and there are no TiO bands indicative of later spectral types. Compared to K stars, NaI is only weak and CaI almost absent, whereas the H_α absorption line is relatively strong (see Fig. 6 in Torres-Dodgen & Weaver 1993). We can also exclude the possibility of T3 being a more distant giant, since there is no CN at 7878–8068 Å and also no 6497 Å blend (BaII, FeI, CaI) left of H_α, which are clearly seen in G5IIIa and G5Ib stars (see Fig. 20 in Torres-Dodgen & Weaver 1993). The G2V, G5V and G8V are difficult to distinguish (as mentioned by Torres-Dodgen & Weaver 1993) so that we adopt a spectral type of G5V with an uncertainty of a few subclasses.

3.2.2. M (sub)dwarf spectra

A classification scheme for M dwarfs has been developed by Reid et al. (1995) by measuring the bandstrengths of TiO and CaH. This scheme was later extended to cool subdwarf stars (K and M) by Gizis (1997) using the spectral indices TiO5, CaH1, CaH2, CaH3 defined by Reid et al. (1995) of observed HPM stars mainly from the Luyten Half second (LHS) catalogue (Luyten 1979), i.e. stars with proper motions exceeding 0.5 arcsec/yr. Our NTT spectra have nearly the same resolution as the spectra used by Reid et al. (1995) and Gizis (1997) so that the classification by the spectral indices can be applied.

We have computed these indices (see Table 2) and used them to classify the M (sub)dwarfs. Three of them, namely SSSPM J1013–1356, SSSPM J1930–4311 and SSSPM J1530–8146, show very strong CaH (e.g. at ~6350 Å) in comparison to the TiO band strengths, giving a strong hint on their probable subdwarf nature. Following the three-step classification procedure of Gizis (1997), we classify these objects as normal subdwarfs (sd) with spectral types sdM1.5 (SSSPM J1530–8146), sdM7.0 (SSSPM J1930–4311) and sdM9.5 (SSSPM J1013–1356). The latter, extremely late-type M subdwarf, with its extremely small spectral indices (TiO5 = 0.208, CaH1 = 0.174, CaH2 = 0.116, CaH3 = 0.200), falls outside the frame of the CaH1/TiO5 and CaH2/TiO5 plots and is on the edge of the CaH3/TiO5 plot in Fig. 1 of Gizis (1997)!

In order to allow direct comparison with other recently discovered ultra-cool subdwarfs, we show the CaH2+ CaH3/TiO5 diagram (Fig. 4), also used by Lépine et al. (2003b, 2004), with normal dwarfs (M), normal subdwarfs (sdM) and

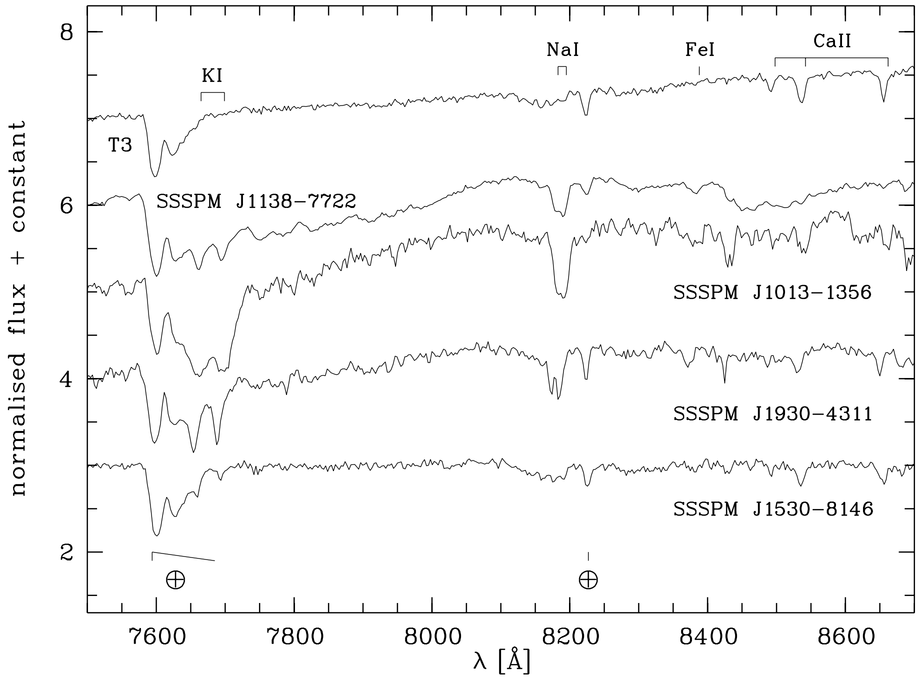

Fig. 3. Red spectral region used for radial velocity measurements. Shown are the locations of the KI, NaI, FeI and CaII lines which were measured with respect to telluric absorption lines marked at the bottom.

extreme subdwarfs (esdM) occupying different parts of the diagram. Late K (sub)dwarfs are also included in the upper right part of this diagram. The spectral indices of SSSPM J1930–4311 are similar to those of LHS 377, which was the latest-type (sdM7.0) normal subdwarf in Gizis (1997). Two recently discovered objects, LSR J2036+5059 (sdM7.5, Lépine et al. 2003a) and LSR J1425+7102 (sdM8.0, Lépine et al. 2003b) are somewhat cooler according to their CaH2+CaH3 of about 0.5. Our newly discovered object, SSSPM J1013–1356 (sdM9.5) is with its extremely small CaH2+CaH3 $\sim$ 0.3 clearly located below all other objects shown in the diagram, including the coolest extreme subdwarf, APMPM J0559–2903 (esdM7.0, Schweitzer et al. 1999), and is therefore the coolest currently known M-type subdwarf.

Included in Fig. 4 are all known subdwarfs with classification as "sd" or "esd" and with published TiO5, CaH2 and CaH3 indices, which we found in the literature (Gizis 1997; Gizis & Reid 1997, 1999; Gizis et al. 1997; Schweitzer et al. 1999; Jahreiß et al. 2001; Cruz & Reid 2002; Lépine et al. 2003a,b,c, 2004). Also shown are normal M dwarfs from Gizis (1997), Gizis & Reid (1997), Lépine et al. (2003a), and a large number of M dwarfs ($\sim$1850) selected from the sample of nearly 2000 stars from Reid et al. (1995) and Hawley et al. (1995) according to the criteria of Gizis (1997), i.e. his Eqs. (4)–(6).

SSSPM J1138–7722, the star with the largest proper motion in our small sample, is also plotted in Fig. 4, where it falls into the region of normal M dwarfs. A spectral type of M 5.5 was assigned to SSSPM J1138–7722 according to its TiO5 index and from comparison of the spectrum with those of known mid-M dwarfs (LHS 168 = M 5.0, LHS 546 = M 5.5, LHS 1326 = M 6.0) also observed with the ESO NTT with similar resolution (Reylé et al. 2004). The direct comparison of the spectra includes more information than the spectral indices can provide, but may be affected by flux calibration errors. We have used the wavelength interval from 5400 Å to 8000 Å, where flux calibration errors as well as second order spectral overlap are small, and found the spectrum of SSSPM J1138–7722 to be in perfect agreement with that of the M 5.5 star LHS 546. The other two comparison star spectra were also confirming the spectral sequence. Therefore, we adopted the spectral type of M 5.5 with an uncertainty of less than 0.5 spectral subtypes.

SSSPM J1013–1356 has a strong red continuum, clearly redder than that of all other objects in Fig. 2, including that of the only normal M dwarf in that plot, SSSPM J1138–7722. On the other hand, we mention that SSSPM J1013–1356 is rather blue in the near infrared with the smallest $J - K \sim 0.2$ in Table 1.

3.3. Radial velocity measurements

We were not able to see any lines (e.g. H_α) in the two cool white dwarf spectra with their relatively low signal-to-noise (see Fig. 2). Therefore, we could not measure their radial velocities. For the other five stars, we investigated the red spectral region shown in Fig. 3, which includes both strong stellar absorption lines as well as some sharp telluric absorption lines, for rough radial velocity estimates. The stellar lines used (with different weights according to the line strengths) were those of potassium (7665 Å and 7699 Å), sodium (8183 Å, 8195 Å), iron (8388 Å) and calcium (8498 Å, 8542 Å, 8662 Å). These lines are usually found in M dwarfs and subdwarfs (see Kirkpatrick et al. 1991), whereas the spectrum of the reddened G-type star, T3, shows only a very strong calcium triplet and a weak sodium doublet in that red spectral region. The telluric H_2O line (8227 Å) and the sharp absorption feature in the atmospheric A band of telluric O_2 (at about 7601 Å), which were

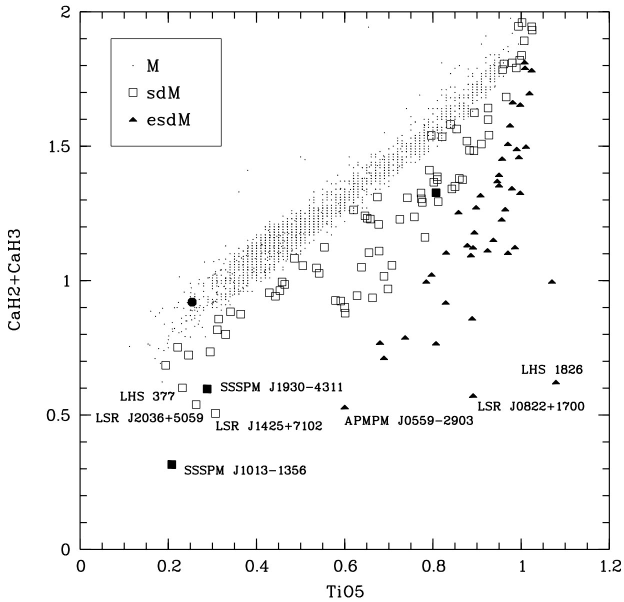

Fig. 4. New version of the CaH2+CaH3 versus TiO5 diagram, used by Lépine et al. (2003b,c) to discriminate between three different object classes (M, sdM, esdM) according to the classification scheme of Gizis (1997). Included are all known subdwarfs, with the coolest (smallest CaH2+CaH3) labeled by their names. The three new subdwarfs are marked as filled squares. The new nearby M 5.5 dwarf is marked by a filled circle. For more details on the samples and individual objects shown in this plot, see text.

also used by Scholz et al. (2002b), served as reference wavelengths and for placing the red parts of all seven spectra on the same internal system.

The accuracy of the radial velocity measurements is dominated by the zero-point calibration error with the telluric lines and is estimated to be about ±25 km s^{-1}. The measured radial velocities have been corrected to a heliocentric system and are listed in Table 2.

4. Distances, space velocities, population memberships

Lépine et al. (2003a) have shown for their larger HPM sample (including 104 northern stars with proper motions between 0.5 arcsec/yr and 1.5 arcsec/yr) the different space velocity distributions of the M dwarfs, subdwarfs and cool white dwarfs compared to the velocity distributions of Galactic disk and halo stars from Chiba & Beers (2000). For the individual objects in our small sample we refer to these data (Figs. 15 to 18 in Lépine et al. 2003a) for comparison. Based on the best available measurements (spectroscopic classification, 2MASS photometry, proper motions) we have evaluated the distances to the objects, combined them with the radial velocity measurements (or assumptions) and computed heliocentric space velocities (Table 2) following Johnson & Soderblom (1987). These first estimates of the kinematics allowed us to identify the new HPM objects as members of different Galactic populations (thin disk, thick disk and halo).

4.1. Cool white dwarfs

Photometric distances of the newly discovered cool white dwarfs can be estimated by using the relation

$$M_{B_J} = 12.73 + 2.58\,(B_J - R), \qquad (1)$$

which was derived by Oppenheimer et al. (2001). This relation is valid for SSS magnitudes so that we can use the values given in Table 1. However, we have again the choice between the corrected (standard) SSS R magnitudes and the uncorrected ones, whereas the B_J magnitudes remain the same. The corresponding distance estimates are shown in Table 2 (notes ^{d} and ^{e}), where the formal errors correspond to 0.3 mag uncertainties in the absolute B_J magnitudes. There is a large difference between the distances derived from using corrected and uncorrected SSS R magnitudes. In any case, as can be seen from the computed possible space velocities of the cool white dwarfs based on assumptions on their radial velocities (Table 2), SSSPM J1549–3544 is clearly a very nearby (d = 3...10 pc !) object of the Galactic thin disk population, whereas SSSPM J1148–7458 represents more likely a high velocity object of the Galactic thick disk (if d = 17 pc) or halo (if d = 36 pc).

Not many cool white dwarfs are bright enough to show up in 2MASS data. This fact alone is already an indication of the probable proximity of SSSPM J1549–3544 and SSSPM J1148–7458. For comparison, among the 11 cool white dwarfs identified in Lépine et al. (2003a) there are only 4 with measured 2MASS K_s magnitudes, all being comparable to that of SSSPM J1148–7458 ($K_s \sim 15.2$) but more than 3 mag fainter than that of SSSPM J1549–3544 ($K_s \sim 11.6$). The 2MASS magnitudes are more accurate than the photographic SSS magnitudes and can be used for an independent distance estimate provided there are suitable comparison objects. SSSPM J2231–7514 and SSSPM J2231–7415, a wide pair of cool white dwarfs of comparable low effective temperature ($T_{\rm eff}$ < 4000 K) discovered recently by Scholz et al. (2002a) with an estimated distance of about 14 pc, have 2MASS magnitudes J, H, K_s of 14.662,14.658,14.436 and 14.858,14.824,14.723, respectively. Using these values for comparison yields distances of $d = 4 \pm 1$ pc and $d = 20 \pm 2$ pc, respectively, for SSSPM J1549–3544 and SSSPM J1148–7458. These estimates are in good agreement with those obtained when using the uncorrected SSS magnitudes in Eq. (1).

Bergeron et al. (1997) list only one cool white dwarf within 10 pc and with comparable temperature ($T_{\rm eff}$ = 4590 K), LP 701-29 = LHS 69, with a trigonometric parallax of 123.7 ± 4.3 mas, for which we find from 2MASS: J, H, K_s = 14.013,13.685,13.546. Using this object as distance calibrator, we get d_J = 3.7 pc, d_H = 3.3 pc, d_{K_s} = 3.3 pc and d_J = 16.6 pc, d_H = 19.3 pc, d_{K_s} = 17.4 pc, for SSSPM J1549–3544 and SSSPM J1148–7458, respectively.

From the above comparisons and preferring the use of uncorrected SSS magnitudes in Eq. (1), we get a good agreement of the distance estimates and adopt $d = 4 \pm 1$ pc for SSSPM J1549–3544 and $d = 18 \pm 3$ pc for SSSPM J1148–7458. Although trigonometric parallax measurement is required for confirmation, SSSPM J1549–3544 is

Table 2. Spectral indices and types, distance estimates and kinematics.

Name SSSPM J..	TiO5	CaH1	CaH2	CaH3	Sp.Type	$d_{\rm spec}$ [pc]	v_t [km s^{-1}]	v_r [km s^{-1}]	U [km s^{-1}]	V [km s^{-1}]	W [km s^{-1}]
1013–1356	0.208	0.174	0.116	0.200	sdM9.5	50 ± 15	245	+6[a]	+145 ± 63	−140 ± 62	−137 ± 62
1138–7722	0.254	0.729	0.305	0.615	M5.5	8±1	82	−50[a]	−95 ± 16	+2 ± 22	+14 ± 07
1148–7458					>DC11[c]	36 ± 5[d]	296	0[g]	−185 ± 39	−148 ± 36	+175 ± 35
								−50[g]	−209 ± 39	−106 ± 36	+186 ± 35
								+50[g]	−162 ± 39	−191 ± 36	+164 ± 35
						17 ± 2[e]	140	0[g]	−88 ± 17	−70 ± 23	+83 ± 12
								−50[g]	−111 ± 17	−27 ± 23	+94 ± 12
								+50[g]	−64 ± 17	−113 ± 23	+71 ± 12
						18 ± 3[f]	148	0[g]	−93 ± 22	−74 ± 26	+87 ± 18
								−50[g]	−116 ± 22	−32 ± 26	+99 ± 18
								+50[g]	−69 ± 22	−117 ± 26	+76 ± 18
1358–3938					~M3.5[b]	23^{+11}_{-6}	214	0[g]	+144 ± 53	+78 ± 32	−137 ± 49
								−50[g]	+109 ± 53	+109 ± 32	−155 ± 49
								+50[g]	+178 ± 53	+46 ± 32	−119 ± 49
1530–8146	0.807	0.651	0.572	0.755	sdM1.5	185 ± 29	581	−205[a]	−534 ± 78	−239 ± 74	+188 ± 23
1549–3544					>DC11[c]	10 ± 2[d]	38	0[g]	−13 ± 23	−36 ± 12	−1 ± 07
								−50[g]	−58 ± 23	−20 ± 12	−14 ± 07
								+50[g]	+33 ± 23	−52 ± 12	+12 ± 07
						3 ± 1[e]	11	0[g]	−4 ± 23	−11 ± 09	−0 ± 07
								−50[g]	−49 ± 23	+6 ± 09	−13 ± 07
								+50[g]	+42 ± 23	−27 ± 09	+13 ± 07
						4 ± 1[f]	15	0[g]	−5 ± 23	−14 ± 10	−0 ± 07
								−50[g]	−51 ± 23	+2 ± 10	−13 ± 07
								+50[g]	+40 ± 23	−31 ± 10	+13 ± 07
1930–4311	0.288	0.354	0.210	0.387	sdM7.0	73 ± 12	301	−262[a]	−288 ± 25	−270 ± 57	+50 ± 17
T3					dG5	(70^{+50}_{-20})[h]	84	−64[a]	−66 ± 25	−81 ± 35	−15 ± 05
						370 ± 80[i]	444	−64[a]	−76 ± 25	−438 ± 122	−51 ± 15

Notes:
[a] – Measured radial velocities, errors are about ±25 km s^{-1}.
[b] – Spectral type estimate from colours (see text and Table 1).
[c] – Preliminary, conservative spectral type estimate.
[d] – Photometric distance estimate from Eq. (1) using (standard) corrected SSS magnitudes (see Table 1).
[e] – Photometric distance estimate from Eq. (1) using uncorrected SSS magnitudes (see Table 1).
[f] – Adopted distance estimate from 2MASS photometry of comparison objects and preferred use of uncorrected SSS magnitudes in Eq. (1).
[g] – Assumed radial velocity values with assumed errors ±25 km s^{-1}.
[h] – Assumed distance based on Hipparcos parallax measurements of other G-type main sequence stars with similar proper motions.
[i] – Assumed distance based on zero extinction in $K_{\rm s}$ band.

probably the nearest cool white dwarf and may be even closer than van Maanen 2 = LHS 7, the nearest isolated white dwarf listed in Bergeron et al. (1997) with $T_{\rm eff}$ = 6750 K and a trigonometric parallax of 232.5 ± 1.9 mas.

4.2. M dwarfs

In order to estimate the distance to SSSPM J1138–7722, we have compared the observed 2MASS magnitudes with absolute magnitudes of M 5.5 dwarfs. Since there are no M 5.5 dwarf data given in Kirkpatrick & McCarthy (1991), we used five single M 5.5 dwarfs with measured trigonometric parallaxes (LHS 2, LHS 39, LHS 549, LHS 1565, LHS 3339) with the following mean absolute magnitudes $M_J = 9.87, M_H = 9.31, M_{K{\rm s}} = 8.97$ (Jahreiß 2004), which yielded distances of 8.05 pc, 8.24 pc and 8.13 pc, respectively. Assuming an uncertainty in the absolute magnitudes of ±0.3 mag, we adopted a spectroscopic distance of 8 ± 1 pc.

For the second object with a proper motion of about 2 arcsec/yr in our sample, SSSPM J1358–3938, we do not yet have a spectrum, but we can estimate its spectral type from its $I - J$ = 1.44 computed from DENIS and 2MASS data (see Table 1). This $I - J$ colour is typical of M 3.5 dwarfs (Kirkpatrick & McCarthy 1991 give $I-J$ = 1.32 for M 3, $I-J$ = 1.47 for M 3.5 and $I-J$ = 1.52 for M 4). Assuming a spectral type of M 3.5 for SSSPM J1358–3938, we can derive its distance from the comparison of the 2MASS magnitudes with corresponding absolute magnitudes of M 3.5 dwarfs given in Kirkpatrick & McCarthy (1991) to be about 23^{+11}_{-6} pc, taking into account a larger uncertainty in the absolute magnitudes of ±0.8 mag (corresponding to 0.5 spectral subclasses).

Considering the computed *UVW* velocities (Table 2), SSSPM J1138–7722 can be identified as a thin disk object. SSSPM J1358–3938 seems to be a thick disk object with higher space velocity according to our distance estimate and independent of the assumed moderate (−50... + 50 $\mathrm{km\,s^{-1}}$) radial velocities.

4.3. M subdwarfs

For the distance determination of the three subdwarfs we have used comparison stars from among the LHS subdwarfs with measured trigonometric distances listed in Gizis (1997) and extracted their 2MASS photometry. The following absolute magnitudes M_J, M_H, M_{K_s} were obtained: 7.801,7.316,7.082 (sdM1.5), 10.461,10.000,9.746 (sdM7) and 11.5,11.0,10.7 (sdM9.5). These values rely on the sdM1.5 stars LHS 178 and LHS 482, the sdM7.0 star LHS 337 and on extrapolating the data from the sdM4.5 star LHS 3409 via those of LHS 337 (sdM7.0) to get approximate absolute magnitudes of sdM9.5 objects, respectively.

Assuming for 0.3 mag uncertainties in the absolute magnitudes of sdM1.5 and sdM7.0 and somewhat larger uncertainty (0.4 mag) for sdM9.5 objects, we got distance estimates of 185 ± 29 pc for SSSPM J1530–8146 (sdM1.5), 73 ± 12 pc for SSSPM J1930–4311 (sdM7.0) and 50 ± 15 pc for SSSPM J1013–1356 (sdM9.5).

All three newly discovered cool subdwarfs described in this paper are remarkable in different aspects. SSSPM J1013–1356 is clearly the coolest M-type subdwarf known so far, as can be seen from its separate location in Fig. 4, well below all other objects. The other late-type (sdM7.0) subdwarf, SSSPM J1930–4311, was found to be member of an extremely wide common proper motion pair, which will be further investigated in a separate paper (Scholz et al., in preparation). The third subdwarf, SSSPM J1530–8146 (sdM1.5), is not as cool as the other two but has the largest space motion of all three (see Table 2) and thus is clearly a Galactic halo representative, whereas the other two may be members of the thick disk or halo component.

5. Conclusions and outlook

Combining optical (SSS) and near-infrared (2MASS, DENIS) archival data has allowed us to discover some extreme HPM stars close to the Galactic plane. From the analysis of low-resolution spectra and from the available photometry/astrometry we conclude that among these objects there are:

- two featureless cool white dwarfs, including the probably closest ($d \sim 4$ pc) white dwarf with $T_{\mathrm{eff}} < 4500$ K, which may also be the closest isolated white dwarf
- two nearby M dwarfs with proper motions of ~2 arcsec/yr, one M 5.5 dwarf at 8 pc and one probably within 25 pc (still to be confirmed spectroscopically)
- three M subdwarfs, including the currently coolest known M subdwarf, for which we assigned a spectral type of sdM9.5

The NLTT star T3 was rejected as a foreground brown dwarf candidate but instead classified as a reddened G-type star, possibly associated with a dark cloud. It deserves further attention, since the dark cloud may be located relatively nearby. Alternatively, the star could move with a large space velocity. Special high resolution spectroscopy in the region of interstellar absorption features (see e.g. Hearty et al. 2004) could help to estimate the distance to the cloud and to separate fore- and background objects.

All the new HPM stars are certainly worth investigating further by more detailed follow-up observations. In particular, higher-resolution spectroscopic observations will yield more accurate radial velocities for the M (sub)dwarfs and could also help to confirm the kinematics and hence the Galactic halo or disk membership of the cool white dwarfs, if any lines can be detected in their spectra.

The nearby cool white dwarfs, SSSPM J1549–3544 and SSSPM J1148–7458, and M dwarf (candidates), SSSPM J1138–7722 (and SSSPM J1358–3938), obviously present promising targets for ongoing trigonometric parallax programmes aimed at filling the census of the nearby stars sample and at the search of low-mass companions. The nearest objects are also excellent targets for extra-solar planet search programmes.

Trigonometric distance estimates, although more difficult to obtain, would also be important for the cool subdwarfs, again in order to constrain their kinematics, in particular to check the extremely large space velocity of the sdM1.5 object SSSPM J1530–8146, which is dominated by the tangential velocity, derived from the accurate proper motion and the rather uncertain distance estimate.

The sdM9.5 object, SSSPM J1013–1356, is of special interest, since it could belong to the still poorly investigated class of substellar subdwarfs. Until now, there is only one clearly substellar L-type subdwarf, discovered by Burgasser et al. (2003), for which however the classification scheme of Gizis (1997) could not be applied. Another object, LSR 1610–0040, according to its spectral indices is only a sdM6.0, but was classified by Lépine et al. (2003c) as an early L subdwarf on the basis of its very red continuum and two prominent atomic lines of Rb I, normally seen only in L dwarfs. Thus, the classification scheme of very late-type subdwarfs (including an extension to sdL) has not yet been developed.

Among the coolest sdM and esdM objects (marked in Fig. 4) there are only two LHS stars but six recently discovered new HPM objects. This underlines the importance and the potential of new HPM surveys for completing our knowledge of ultra-cool subdwarfs.

Note added in proof. Burgasser (2004) reported that SSSPM J1013–1356 was among the T dwarf candidates in his thesis (Burgasser 2001), where it is listed as a proper motion star without follow-up.

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Online Material

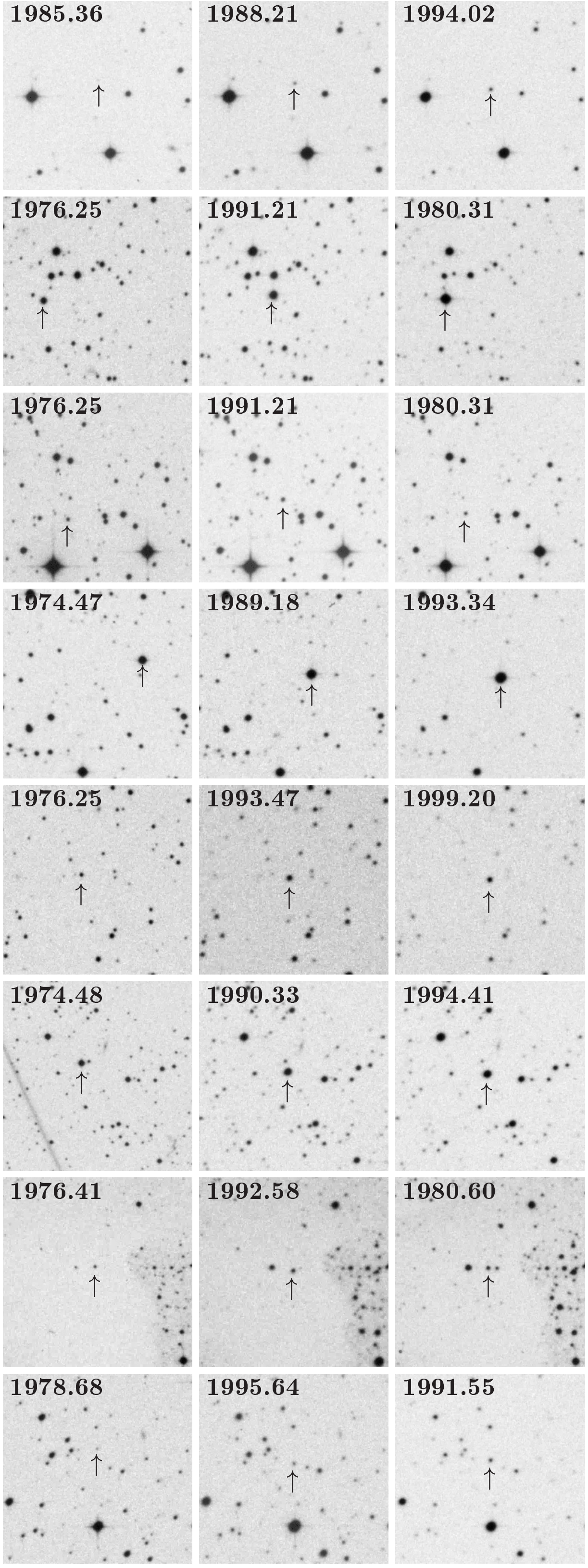

Fig. 1. (in electronic form only) 3×3 arcmin^2 SSS images (*left*: B_J; *centre*: R; *right*: I) for (*from top to bottom*): SSSPM J1013–1356, SSSPM J1138–7722, SSSPM J1148–7458, SSSPM J1358–3938, SSSPM J1530–8146, SSSPM J1549–3544, T3 and SSSPM J1930–4311, (east is left, north is up).