Discovery of New Companions to High Proper Motion Stars from the VVV Survey. *

Valentin D. Ivanov1, Dante Minniti2,3,4,5, Maren Hempel2,5, Radostin Kurtev6, Ignacio Toledo2,7, Roberto K. Saito2,5,6,8, Javier Alonso-García2,5, Juan Carlos Beamín2,5,9, Jura Borissova2,6, Márcio Catelan2,5, André-Nicolas Chene6,10,11, Jim Emerson12, Oskar A. González1, Phillip W. Lucas13, Eduardo L. Martín14, Marina Rejkuba15, and Mariusz Gromadzki6

1 European Southern Observatory, Ave. Alonso de Córdova 3107, Vitacura, Santiago, Chile
2 Instituto de Astrofísica, Facultad de Física, Pontificia Universidad Católica de Chile, Casilla 306, Santiago 22, Chile
3 Departamento de Ciencia Físicas, Universidad Andrés Bello, Santiago, Chile
4 Vatican Observatory, V00120 Vatican City State, Italy
5 The Milky Way Millennium Nucleus, Av. Viciña Mackennan 4860, 782-0436, Macul, Santiago, Chile
6 Departamento de Física y Astronomía, Facultad de Ciencias, Universidad de Valparaíso, Av. Gran Bretana 1111, Playa Ancha, Casilla 5030, Valparaíso, Chile
7 ALMA Santiago Central Offices, Alonso de Córdova 3107, Vitacura, Casilla 763 0355, Santiago, Chile
8 Universidade Federal de Sergipe, Departamento de Física, Av. Marechal Rondon s/n. 49100-000, São Cristóvão, SE, Brazil
9 Instituto de Astrofísica, Facultad de Física, Pontificia Universidad Católica de Chile, Avda. Viciña Mackenna 4860, 782-0436 Macul, Santiago, Chile
10 Departamento de Astronomía, Universidad de Concepción, Bio-Bío 160-C, Concepcion, Chile
11 Gemini Observatory, Northern Operations Center, 670 North A'ohoku Place, Hilo, HI 96720, USA
12 Astronomy Unit, School of Physics & Astronomy, Queen Mary University of London, Mile End Road, London, E1 4NS, UK
13 Centre for Astrophysics Research, University of Hertfordshire, College Lane, Hatfield AL10 9AB, UK
14 Centro de Astrobiología (INTA-CSIC), Carretera de Ajalvir, km 4, E-28850 Torrejón de Ardoz, Madrid, Spain
15 European Southern Observatory, Karl-Schwarschild-Str. 2, D-85748 Garching bei Muenchen, Germany

Received 2 November 1002 / Accepted 7 January 3003

ABSTRACT

Context. The severe crowding in the direction of the inner Milky Way suggests that the census of stars within a few tens of parsecs in that direction may not be complete.

Aims. We search for new nearby objects companions of known high proper motion (HPM) stars located towards the densest regions of the Southern Milky Way where the background contamination presented a major problem to previous works.

Methods. The common proper motion (PM) method was used–we inspected the area around 167 known HPM (≥200 mas yr−1) stars: 67 in the disk and 100 in the bulge. Multi-epoch images were provided by the Two Micron All Sky Survey (2MASS) and the VISTA Variables in Via Lactea (VVV). The VVV is a new on-going 3YJKS survey of ~562 deg2 of Milky Way’s bulge and inner Southern disk.

Results. Seven new co-moving companions were discovered around known HPM stars (L 149-77, LHS 2881, L 200-41, LHS 3188, LP 487-4, LHS 3333, and LP 922-16); six known co-moving pairs were recovered (LTT 5140 A + LTT 5140 B, L 412-3 + L 412-4, LP 920−25 + LP 920−26, LTT 6990 A + LTT 6990 B, M 124.22158.2900 + M 124.22158.2910, and GI 2136 A + GI 2136 B); a pair of stars that was thought to be co-moving was found to have different proper motions (LTT 7318, LTT 7319); published HPMs of eight stars were not confirmed (C* 1925, C* 1930, C* 1936, CD−604613, LP 866−17, OGLE BUL−SC20 625107, OGLE BUL−SC21 298351, and OGLE BUL−SC32 388121); last but not least, spectral types ranging from G8V to M5V were derived from new infrared spectroscopy for seventeen stars, members of the co-moving pairs.

Conclusions. The seven newly discovered stars constitute ~4% of the nearby HPM star list but this is not a firm limit on the HPM star incompleteness because our starting point–the HPM list assembled from the literature–is incomplete itself, missing many nearby HPM M and L type objects, and it is contaminated with non-HPM stars. We have demonstrated, that the superior sub-arcsec spatial resolution, with respect to previous surveys, allows the VVV to examine further the binary nature nature of known HPM stars. The ≥5 yr span of VVV will provide sufficient baseline for finding new HPM stars from VVV data alone.

Key words. astrometry – proper motions – stars:general – stars:binaries:general – Galaxy:solar neighborhood

1. Introduction

The direction toward the inner Milky Way presents a formidable challenge for proper motions (PM) studies because of the crowding and confusion (for previous attempts see [Lépine et al. 2002b] Lépine 2008). VISTA Variables in the Via Lactea (VVV) is a new ESO Public survey (Minniti et al. 2010) that may help to alleviate these problems. The VVV is carried out with the Visible and Infrared Survey Telescope for Astronomy (VISTA; [Dalton et al. 2006] Emerson et al. 2006) at Paranal.
Observatory, and will obtain ZYJHK$_S$ coverage and multi-epoch (up to 100 for some pointings) $K_S$ observations of $\sim562$ deg$^2$ in the Milky Way’s bulge and inner disk, at sub-arcsec seeing. After two years of operation, we already demonstrated, that VVV is producing new, interesting results: discovery of new star clusters (Minniti et al. 2011a; Borissova et al. 2011)Moni Bidin et al. 2011), investigation of the structure and stellar populations content of the Milky Way (Minniti et al. 2011b; Gonzalez et al. 2011a; Gonzalez et al. 2011b; Gonzalez et al. 2012; Saito et al. 2012c), study of variable stars and transients (Catelan et al. 2011; Saito et al. 2012b), and others. One of the main goals is to obtain 3-dimensional tomographic map of the Milky Way bulge based on Red Clump giants, RR Lyr and Cepheid variables.

However, some corollary science objectives are also considered, including a PM study, taking advantage of the projected $\geq5$ yr survey duration. Early PM science with VVV is possible if it is used as a second epoch to a previous infrared survey, e.g. the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006). The 2MASS observations provide $\geq10$ yr baseline.

The VVV footprint on the sky is relatively small: $\sim20\text{deg}\times15\text{deg}$ centered on the bulge, and $\sim55\text{deg}\times4.5\text{deg}$ along the adjacent Southern disk, or just above $1\%$ of the total sky, but it encompasses the regions with the highest stellar surface density in the Galaxy. This study is based on the available multi-filter imaging that was taken during the first VVV observing season, covering $\sim500$ deg$^2$. The typical image quality is 0.8-1.0 arcsec, and the pixel scale is $\sim0.34$ arcsec pix$^{-1}$, which compare favorably to other Galactic surveys. The final VVV data products will be ZYJHK$_S$ atlas and a catalog of $\sim10^8$ sources, $\sim10^6$ of which are variable$^1$.

We embarked on a project to improve the Solar neighborhood census by searching for common PM companions to known nearby HPM stars. Our effort has the potential to improve the local stellar multiplicity fraction estimate—a key constraint to star formation theories, with implications for the stellar population modeling of unresolved stellar systems. We were driven by the argument that relatively bright new solar neighborhood stars could be found only in a survey covering the densest regions of the Milky Way, like VVV, because such stars far away from the Galactic plane were easy to discover with the previous generation of surveys. We build upon the success of the RECONS PM and parallax measurements project (Finch et al. 2007; Henry et al. 2003; Jao et al. 2009; Subasavage et al. 2009), the work of Lépine and collaborators (Lépine et al. 2002a; Lépine & Bongiorno 2007), Raghavan et al. (2010), Faherty et al. (2010), Allen et al. (2012), and others, with the advantage that VVV has better spatial resolution and higher sensitivity to low mass red objects, with respect to the previous surveys.

The selection is dominated by nearby dwarfs (SIMBAD lists: 8 F, 19 G, 24 K, and 22 M-types). The distances to the few stars with parallaxes range from $\sim1.3$ to $\sim136$ pc, with a median of $\sim44$ pc.

3. Analysis

We visually searched around known HPM stars on false-3-color images, generated combining the reddest available POSSII band, and $J$-bands from 2MASS and VVV (Fig. 1). Three field sizes were used, to provide different levels of “zoom” into the vicinity of program stars: 0.9, 1.8, and 3.6 arcmin, centered on each candidate. Inspecting larger images was found impractical.

For each object in our sample we performed the following steps: first, we identified the known HPM star from its coordinates and the apparent change of position between the epochs of the surveys used to create the false-3-color images. The large PMs relative in nature, because the 2MASS reference stars that were used to derive the astrometric solution for the VVV have the potential of program stars: 0.9, 1.8, and 3.6 arcmin, centered on each candidate. Inspecting larger images was found impractical. The astrometric calibration of VVV data is based on hundreds of 2MASS stars that fall onto each tile (Irwin et al. 2004; Minniti et al. 2010). This procedure removes the systematic bulk motion of the “unmoving” background stars between the VVV and the 2MASS epochs. Therefore, we directly compared 2MASS and VVV coordinates, to measure PMs. This makes our PMs relative in nature, because the 2MASS reference stars that were used to derive the astrometric solution for the VVV have some average common motion than remains unaccounted for.

For fainter co-moving companions because the motions of the “doughnuts” with burned out cores are still discernible.

The VVV survey plan for the first year envisioned separate visits of each point of the survey area for ZY and JHK$_S$ observations, and up to six visits in $K_S$, on separate nights, for variability studies. At the time we carried this study, 144 out of 152 disk tiles and 188 out of 196 bulge tiles were completed, covering $\sim216$ and $\sim282$ deg$^2$, respectively.

We arrived at a target list of 167 objects: 67 in the disk and 100 in the bulge, for which the VVV can provide a new epoch of observations (Table 1). The stars come from the catalogs of LHS (Luyten 1979a), LTT (Luyten 1957, Luyten 1961, Luyten 1962), MACHO (Alcock et al. 2001), OGLE (Sumi et al. 2004), and number of other works: Finch et al. (2007) Lépine (2005), Rattenbury & Mao (2008), Subasavage et al. (2005), Terzan et al. (1980).

We visually searched around known HPM stars on false-3-color images, generated combining the reddest available POSSII band, and $J$-bands from 2MASS and VVV (Fig. 1). Three field sizes were used, to provide different levels of “zoom” into the vicinity of program stars: 0.9, 1.8, and 3.6 arcmin, centered on each candidate. Inspecting larger images was found impractical.

For each object in our sample we performed the following steps: first, we identified the known HPM star from its coordinates and the apparent change of position between the epochs of the surveys used to create the false-3-color images. The large PMs relative in nature, because the 2MASS reference stars that were used to derive the astrometric solution for the VVV have the potential of program stars: 0.9, 1.8, and 3.6 arcmin, centered on each candidate. Inspecting larger images was found impractical. The astrometric calibration of VVV data is based on hundreds of 2MASS stars that fall onto each tile (Irwin et al. 2004; Minniti et al. 2010). This procedure removes the systematic bulk motion of the “unmoving” background stars between the VVV and the 2MASS epochs. Therefore, we directly compared 2MASS and VVV coordinates, to measure PMs. This makes our PMs relative in nature, because the 2MASS reference stars that were used to derive the astrometric solution for the VVV have some average common motion than remains unaccounted for.

1 For further details see the VVV web page at: [http://vvvsurvey.org](http://vvvsurvey.org)
We measured PMs only for the new co-moving HPM candidates, for their hosts from the known HPM star list, and for the stars from the HPM list that appeared to move with much slower PM than the one given in the literature (Tables 2 and 3). We calculated the stellar positions as unweighted centroids. The cores of the bright stars ($K_s \leq 12$ mag) are saturated, and to investigate the effect of the saturation we set to zero the central pixels that are above 60% of the saturation limit, for 50 stars below the saturation limit. The result was much stronger than the typical saturation effect for the stars in our sample. The differences of the coordinates with and without “saturation” was 0.03 arcsec, e.g. the wings of the images are sufficient to measure the stellar positions accurately.

The final PMs are simple arithmetic averages of the PMs determined between 2MASS and various VVV observations, and the error are the r.m.s. of the measurements, if more than three are available (Tables 4 and 5). Adding older photographic epochs usually worsens the fit because of crowding and contamination. The 2MASS sets the faint magnitude limit of our new HPM candidates, and the minimum primary–companion separations from Table 3. Typically (Skrutskie et al. 2006), the maximum separation was determined by the size of the cut outs.

After inspecting the 167 objects in our sample (67 in the disk and 100 in the bulge), we found:

(1) seven new co-moving companions to bright ($J < 16$ mag) HPM stars with PM ≤ 200 mas yr$^{-1}$: L 149-77, LHS 2881, L 200-41, LHS 3188, LP 487-4, LHS 5333, and LP 922-16. Particularly notable is the discovery of a low-mass M5V companion to LHS 3188, at ~21 pc from the Sun;

(2) six known co-moving binaries were recovered: LTT 5140 A + LTT 5140 B, L 412-3 + L 412-4, LTT 6990 A + LTT 6990 B, GJ 2136 A + GJ 2136 B, LP 920-25 + LP 920-26, and MACHO 124.22158.2900 + MACHO 124.22158.2910;

(3) LTT 7318 and LTT 7319 that were considered co-moving stars, appeared not to be;

(4) we measured the PMs of all co-moving pairs of HPM stars in our sample (Table 4), and of the stars with previously overestimated PMs (Table 5);

(5) the spectral types of seventeen members of the co-moving pairs were determined from new near-infrared spectroscopy (Table 6). They range from G8V to M5V;

(6) HPMs of eight stars (C* 1925, C* 1930, C* 1936, CD-604613, LP 866-17, OGLE BUL–SC20 625107, OGLE BUL–SC21 298351, and OGLE BUL–SC32 388121) reported in at least some previous works appear to have been grossly overestimated.

4. Follow-up Spectroscopic Observations

Near-infrared spectra of co-moving pairs were obtained to determine their spectral types at the ESO NTT with SofI (Son of ISAAC: Moorwood et al. 1998) in two low-resolution modes, with blue ($\lambda = 0.95 - 1.64$ μm) and red ($\lambda = 1.53 - 2.52$ μm) grisms to cover the entire near-infrared spectral range. The slit was 1 arcsec wide during the Apr 2011 run, and 0.6 arcsec during the May 2012 run, delivering an average resolution of R ~ 600 and ~1000, respectively. It was aligned along the axis connecting the two candidate companions, except if their apparent magnitudes were too different—in which case they were observed separately. Typically, four (six in the case of the relatively faint MACHO 124.22158.2900–MACHO 124.22158.2910 binary candidate) images were obtained, into a two-nodding ABBA or ABBAAB sequences, with nodding of 30-60 arcsec.

Each image constituted 48–1050 sec of integration, averaged over 3–12 individual detector integrations to ensure the peak values are well below the non-linearity limit of the detector (Table 6). The atmospheric conditions varied during the observations but most often they were mediocre, with a seeing above 1.5 arcsec, thin to thick cirrus—because these targets were poor weather fillers which accounts for somewhat longer than usual integration times.

The data reduction steps were: sky/dark/bias removal by subtracting from each other the two complementary images in a nodding pair; flat fielding with dome flats; extraction of 1-dimensional (1-D) spectra from each star, on each individual image, by tracing the stellar continuum, with 6-8 pixel (1 pixel ~ 0.29 arcsec) wide apertures, with the IRAF task apall; wavelength calibration of each 1-D stellar spectrum with 1-D Xenon lamp spectrum, extracted from Xenon lamp images with the same trace as each target spectrum; combination of the four or six 1-D spectra of each star in wavelength space with the IRAF task scombine, with appropriate masking or rejection of remaining detector artifacts and cosmic ray affected regions; telluric correction with spectra of near-solar analogs (G1V-G3V), observed just before or after the science target, at similar airmass, and reduced the same way; recovery of the original spectral shape and removal of the artificial emission lines (Maiolino et al. 1996) by multiplying with spectra of corresponding spectral type star from the flux-calibrated IRTF library (Cushing et al. 2005; Rayner et al. 2009). The signal-to-noise of the final spectra varies significantly with the target’s brightness and with wavelength, but the areas clear from telluric absorption have S/N ~ 10–30. The final spectra are plotted in Fig. 2.

The spectral typing was performed comparing the overall shape of the SofI spectra with spectra from the IRTF library (Fig. 3) and the results are listed in Table 6. The typical uncertainty, estimated from a comparison with template stars of neighboring sub-types (Fig. 3), is one sub-type. It was determined by comparing our targets with IRTF spectra of stars with nearby subtypes, and comparing stars with multiple IRTF observations. Finally, we corrected for telluric absorption the telluric standard HIP 084636 with HIP 098813, and re-determined its spectral type obtaining a best match with G2V star, to be compared with G3V reported by Gray et al. (2006).

5. Discussion and Summary

Why have the new HPM stars not been detected before? Some of them appear on old photographic surveys but the contamination from nearby stars, aggravated by the poor spatial resolution of those surveys, makes the identification of the stars as HPM objects difficult. The extreme differences between optical and infrared brightness of stars that is often found in the Galactic plane often led to misidentifications and some spurious HPM detections while true HPM stars were missed. Even with the high-quality of the VVV data we cannot consider the position of the stars reliable because of the uneven background. Multiple measurements are needed, separated by some years, to let the stars move by at least 2-3 arcsec, so they lay on a completely different background, averaging out the contamination effects.

The PM errors in Table 2 are the r.m.s. for 3-4 measurements (Table 2), and they only include statistical uncertainties. A comparison with the measurements in the literature suggest that the real uncertainties are larger. Excluding the obvious errors which

2 IRAF is distributed by the NOAO, which is operated by the AURA under cooperative agreement with NSF.
yield differences exceeding 100 mas yr\(^{-1}\), e.g. due to misidentification, we find an average difference of 2 mas yr\(^{-1}\), with an r.m.s of 17 mas yr\(^{-1}\), and suggest that the reader uses the latter number as the real error of our PMs that includes both internal and external uncertainties. The scatter gives an upper limit to the unaccounted bulk PM of the filed stars used for the astrometric calibration of the VVV data, and these are indeed small. More accurate measurements will become available in the future, as the VVV survey progresses. The planned survey duration of 5 yrs is likely to be extended to \(\sim 7\) yrs.

Some of the objects with overestimated PMs are very red. Interestingly, three of them were considered HPM objects despite being classified as Carbon stars, suggesting that they were giants. Probably, unaccounted astrometric color terms, combined with the extreme colors, have led to the erroneous classification.

Notes on some individual objects:
- LHS 2881 B is \(-8.1\) arcsec away from a HPM object listed in Monet et al. (2003) with \(\mu_{\text{RA}}=198.38\) and \(\mu_{\text{Dec}}=848.319\) arcsec yr\(^{-1}\) which is absent on our data and it is likely a result of a misidentification or a spurious entry in the USNOB1.0. Interestingly, the LHS 2881 pair has similar PM to that of LHS 2871: \(\mu_{\text{RA}}=-461.01\pm 1.67\) and \(\mu_{\text{Dec}}=-645.32\pm 31.31\) arcsec yr\(^{-1}\) as reported by van Leeuwen (2007). The wide separation of \(-44\) arcmin makes it unlikely that they are bound but may indicate a common origin.
- LP 487-4 is projected on the sky close to the open cluster NGC 6475 (M7) but it is not a physical member because the cluster has \(\mu_{\text{RA}}=2.58\) and \(\mu_{\text{Dec}}=-5.44\) arcsec yr\(^{-1}\) (Loktin & Beshenov 2003). Furthermore, the optical spectroscopy of James et al. (2000) yields a radial velocity \(v_{\text{rad}}=78.6\pm 0.2\) km s\(^{-1}\), inconsistent with \(v_{\text{rad}}=-14.21\pm 1.39\) km s\(^{-1}\) of NGC 6475 (Kharchenko et al. 2005).
- LTT 5140 A parameters were derived from optical spectroscopy and Strömgren photometry by Nordström et al. (2004); \(log T_{\text{eff}}=3.785\), \([\text{Fe/H}]=0.04\), \(M_v=3.67\) mag, \(Age=3.3\) Gyr \(v_{\text{rad}}=15.9\pm 0.2\) km/s. Later, Holmberg et al. (2009) updated them to \(log T_{\text{eff}}=3.774\), \([\text{Fe/H}]=0.06\), and \(M_v=3.63\) mag to reflect the revised HIPPARCOS parallaxes. Desidera et al. (2006) estimated from chromospheric activity \(log age=9.82\) and \(9.58\) for the primary and the secondary, respectively.
- LTT 7318 and LTT 7319 were considered a binary by Dommanget (1983) but later measurement by Salim & Gould (2003), and van Leeuwen (2007) indicate that the two stars are not physically connected. Our data support this conclusion.
- Some objects were included in our sample just because one source, namely Monet et al. (2003) reported HPM for them, despite the fact that other works have estimated low PM. For example, \(\ast=1925\), \(\ast=1930\), \(\ast=1936\), which are known carbon stars, i.e. distant giants, as reported by Alksnis et al. (2001).
- \(CD=60\) 4613 was considered a HPM star by Turon et al. (1992) but it was probably misidentified with the nearby LTT 5126 because of the large error in the NLT coordinates of the latter star, identified by Salim & Gould (2003). Indeed, van Leeuwen (2007) reported correct position and low PM for this star in the revised HIPPARCOS catalog under HIP 65056.
- the HPMs for OGLE-BUL−SC20 625107, OGLE-BUL−SC21 298351, OGLE-BUL−SC32 388121 are subject to various sources of systematics: blending, contamination from variable sources, and seeing variations, aggravated by the crowded OGLE fields (see for details Sec. 7 in Simi et al. 2004).

HPM stars are nearby objects, and finding seven of them implies an incompleteness of \(-4\%\) (over 167 HPM stars) in the Solar neighborhood census. However, this is not a firm limit because: (i) it refers only to the bright stars considered here, (ii) the starting list of 167 stars is likely incomplete itself, and (iii) it is contaminated by non-moving stars, as we showed. Therefore, we refrain from making statements on the completeness of the Solar neighborhood census; we only demonstrated that the HPM census is lacking stars, and that high angular resolution surveys help for addressing this issue in the most crowded regions of the Galaxy.

The new generation of near-infrared surveys of the Milky Way will produce enormous amounts of data, allowing the possibility of many discoveries. This work allows us to refine the strategy for future surveys and HPM star searches in the densest regions of the Southern Milky Way disk and the Bulge. We expect that many more HPM stars and companions to them—including brown dwarfs and even planetary mass objects—will be discovered by these surveys when the baseline of observations reaches a few years, contributing to complete the census of faint nearby stars, and their multiplicity.

Acknowledgements. We acknowledge support by the FONDAP Center for Astrophysics 15100003; BASAL CATA Center for Astrophysics and Associated Technologies PFB-06; the Ministry for the Economy, Development, and Tourism’s Programa Iniciativa Científica Milenio through grant P07-021-F, awarded to The Milky Way Millennium Nucleus; FONDECYT grants No. 1090213 and 1110326 from CONICYT; and the European Southern Observatory. JICF acknowledges support from a Ph.D. Fellowship from CONICYT. MG is financed by the GEMINI-CONICYT Fund, allocated to the project 32110014. RR acknowledges partial support from FONDECYT through grant 1130410. ELM acknowledges support from grant AyA2011-30147-C03-03. JB acknowledges support from FONDECYT No. 1120601; ANC acknowledges support from GEMINI-CONICYT No. 32110005 and from Comité Mixto ESO-GOBIERNO DE CHILE. JAG acknowledge support from Proyecto Fondecyt Postdoctoral 3130552, Fondecyt Regular 1110326, and Anillos ACT-86. We gratefully acknowledge use of data from the ESO VISTA telescope, and data products from the Cambridge Astronomical Survey Unit. We have also made extensive use of the SIMBAD Database at CDS Strasbourg, of the 2MASS, which is a joint project of the University of Massachusetts and IPAC/Caltech, funded by NASA and NSF, and of the VizieR catalogue access tool, CDS, Strasbourg, France. Last but not least, we thank the anonymous referee for the thoughtful and helpful comments that greatly improved the paper.

References
Alcock, C., Allsman, R.A., Alves, D.R. et al. 2001, ApJ, 562, 337
Alksnis, A., Balklavs, A., Dzerzitis, U., Eglitis, I., Paupers, O., & Pundure, I. 2010, Balt. A., 10, 1
Allen, P.R., Burgasser, A.J., Faherty, J.K., & Kirkpatrick, J.D. 2012, AJ, 144, 62
Ammons S.M., Robinson S.E., Strader J., Laughlin G., Fischer D., Wolf A. 2006, ApJ, 638, 1004
Bakos, Gáspár A., Sahu, K.C., & Németh, P. 2002, ApJS, 141, 187
Bastian U., Röser S. 1993, Catalogue of Positions and Proper Motions - South, Astronomisches Rechen-Institut, Heidelberg
Bidelman, W.P. 1985, ApJS, 59, 197
Borisssova, J., Bonatto, C., Kurtev, R., et al. 2011, A&A, 532, 131
Catelan, M., Minniti, D., Lucas, P.W., et al. 2011, Carnegie Observatories Astrophysics Series, Volume 5 Garching: 1119
Cushing, M.C., Rayner, J.T., & Vacca, W.D., 2005, ApJ, 623, 1115
Dalton, G.B., Caldwell, M., Ward, A. K., et al. 2006, SPIE, 6269, 30
Desidera, S., Gratton, R.G., Lucatello, S., et al. 2006, A&A, 454, 553
Dommanget, J. 1983, Bulletin d’Information du Centre de Donnees Stellaires, 24, 83
Dunham D.W. 1986, Combined Lick Voyage Reference Star Catalogue
Emerson, J., McPherson, A., & Sutherland, W. 2006, The Messenger, 126, 41
Faherty, J.K., Burgasser, A.J., West, A.A., et al. 2010, AJ, 139, 176
Finch, C.T., Henry, T.J., Subasavage, J.P., Jao, W.-C., & Hambly, N.C. 2007, AJ, 133, 2898
Fresneau A., Vaughan A.E., & Argyle R.W. 2007, A&A, 469, 1221
Gonzalez, O.A., Rejkuba, M., Minniti, D., Zoccali, M., Valenti, E., & Saito, R.K. 2011a, A&A, 534, L14
Gonzalez, O.A., Rejkuba, M., Zoccali, M., Valenti, E., & Minniti, D. 2011b, A&A, 534, 3
Gonzalez, O.A., Rejkuba, M., Zoccali, M., et al. 2012, A&A, 543, 13
Fig. 1. Examples for the co-moving companion search. North is up and East is left. The red images are 2MASS $K_S$, and the blue images are VVV $K_S$. The objects of interest are circled. From left to right: LP922-16 A and B ($\sim 2 \times 2$ arcmin), LHS 3188 A and B ($\sim 1.5 \times 1.5$ arcmin), and C* 1936 ($\sim 1 \times 1$ arcmin).
Fig. 2. Near-infrared spectra of our targets. The spectral areas with poor atmospheric transmission are omitted. The spectra were normalized to 0.5 in the overlapping region (bracketed with dotted lines) and shifted vertically by 0.5 for clarity. M124A and M124B indicate MACHO 124.22158.2900 and MACHO 124.22158.2910, respectively. L 412−3 B is an alternative notation of HD 322416 and LP 920−26 B is the same for LP 920−26. The spectrum of the telluric HIP 084636 shown here was corrected for the atmospheric absorption with HIP 098813.
Fig. 3. Spectral classification example. Solid lines show our spectra, and dotted lines—the template spectra from the IRTF library (Cushing et al. 2005; Rayner et al. 2009).
Table 1. HPM stars in the VVV area.

| Star ID | VVV Tiles | Star ID | VVV Tiles | Star ID | VVV Tiles | Star ID | VVV Tiles |
|---------|-----------|---------|-----------|---------|-----------|---------|-----------|
| LTT 18269 | d007 | NLTT 37871 | d053 | L 200−41 | d095 | SCR J1440−5745 | d130 |
| LTT 5140 | d008 | HR 5459 | d053 | LSR J15292−5620 | d096 | L 199−84 | d131 |
| L 149−77 | d012 | HR 5460 | d053 | L 263−307 | d097 | SCR J1448−5735 | d131 |
| V* V645 Cen | d014 | LSR J14570−5943 | d055 | LHS 401 | d098 | L 263−307 | d135 |
| LSR J14382−6231 | d014 | LSR J14585−5916 | d055 | L 339−20 | d101 | L 264−83 | d137 |
| L 6019 | d017 | LTT 5981 | d055 | LTT 6467 | d102 | L 264−78 | d138 |
| L 200−104 | d019 | L 200−52 | d059 | LHS 3185 | d104 | LHS 3182 | d142 |
| LHS 3223 | d029 | LTT 6763 | d071 | LTT 6714 | d109 | L 265−6 | d140 |
| LTT 413−57 | d036 | LTT 6830 | d073 | LTT 6709 | d109 | LTT 6612 | d144 |
| C* 1925 | d039 | GJ 662A | d075 | LP 485−113 | d113 | L 339−20 | d144 |
| C* 1936 | d040, d078 | SCR J1637−4703 | d068, d106 | L HS 3233 | d107 | LHS 3188 | d143 |
| LTT 7182 | b232 | MACHO 116.24513.110 | d265 | LTT 7072 | d304 | LP 920−26 | d345 |
| LP 487−35 | b232, b246 | LP 922−14 | d266 | LTT 7073 | d304 | N LTT 45088 | b346 |
| LHS 3372 | b235 | LTT 7259 | d266 | LP 866−12 | d309 | LP 865−14 | b348 |
| NLTT 46160 | b235 | OGLE BUL−SC29 39202 | b273 | LP 866−13 | d310 | N LTT 7150 | b352 |
| LTT 7233 | b235 | LPS 559−192 | b274, b288 | LHS 5333 | b311 | G 154−40 | b354 |
| LP 922−20 | b237 | LP 487−4 | b274 | NLTT 45321 | b318 | N LTT 45477 | b359 |
| LTT 7318 | b238 | LHS 3335 | b275 | LP 921−21 | b319 | LP 920−55 | b359 |
| LTT 7319 | b238 | LP 559−120 | b276 | LP 921−20 | b319 | LHS 3310 | b362 |
| LHS 5337a | b239 | LP 921−23 | b277 | LP 921−15 | b320 | N LTT 45440 | b365 |
| LP 922−17 | b239 | LP 921−26 | b277 | LP 921−16 | b321 | LP 864−17 | b376 |
| LHS 3337 | b244 | LTT 6990 | b285 | LTT 7183 | b324 | G 154−29 | b381 |
| LP 414−1 | b243 | LHS 3330 | b289 | LP 558−60 | b330 | LP 808−23 | b382, b396 |
| LP 487−37 | b246 | LP 921−28 | b291 | N LTT 45128 | b331 | N LTT 45450 | b386 |
| LP 922−18 | b250 | OGLE BUL−SC20 625107 | b292 | N LTT 45014 | b331 | [TFB80] 10b | b387 |
| LP 866−17 | b253 | HD 316899 | b292 | N LTT 45163 | b332 | [TFB80] 10a | b387 |
| LP 922−15 | b253 | OGLE BUL−SC21 298351 | b292 | LP 921−11 | b333 | N LTT 44888 | b387 |
| LP 922−16 | b253 | OGLE BUL−SC32 388121 | b293 | LP 921−13 | b334 | LTT 6900 | b387 |
| LP 866−19 | b254 | OGLE BUL−SC02 783242 | b293 | LP 865−20 | b336 | LTT 6890 | b387 |
| GJ 2136 A | b255 | LTT 7186 | b294, b308 | LTT 6873 | b341 | LP 864−16 | b389 |
| GJ 2136 B | b255 | LP 921−18 | b294 | LTT 6869 | b341 | LP 864−14 | b390 |
| LP 559−37 | b264 | NLTT 45948 | b294 | HD 156384 | b342 | LTT 7022 | b392 |
Table 2. Multi-epoch observations of target stars. Typical positional uncertainties: ~0.1 arcsec for 2MASS, and ~0.05 arcsec for VVV.

| Image Source | Primary RA Dec (J2000) | Secondary RA Dec (J2000) | Epoch, UT | 2MASS, separation | VVV, separation |
|--------------|------------------------|--------------------------|-----------|-------------------|----------------|
| 2MASS        | 13 21 23.211           | -64 02 59.08             | 2000 04 27 02 57 44 |
| VVV K_e      | 13 21 22.873           | -64 02 59.51             | 2000 02 19 08 02 07 |
| VVV K_e      | 13 21 22.882           | -64 02 59.58             | 2000 03 17 06 27 32 |
| VVV J        | 13 22 28.677           | -64 02 56.56             | 2000 03 17 06 36 38 |
| VVV K_e      | 14 12 28.089           | -62 56 14.90             | 2000 02 21 08 08 07 |
| VVV K_e      | 14 12 28.351           | -62 56 12.84             | 2000 03 05 07 28 16 |
| VVV K_e      | 14 12 28.313           | -62 56 12.97             | 2000 03 19 05 07 05 |
| VVV J        | 14 12 28.329           | -62 56 12.91             | 2000 03 19 05 15 03 |
| VVV K_e      | 14 12 28.323           | -62 56 12.98             | 2000 03 28 06 20 19 |
| LHS 2881 A   | 15 18 40.449           | -56 27 55.70             | 2000 09 07 05 21 16 |
| VVV J        | 15 18 40.240           | -56 27 57.17             | 2000 09 04 07 27 33 |
| LHS 3188 A   | 17 31 40.047           | -30 40 56.51             | 1998 08 10 03 19 18 |
| VVV K_e      | 17 31 39.894           | -30 40 58.87             | 2000 04 15 08 56 31 |
| VVV K_e      | 17 31 39.884           | -30 40 59.05             | 2000 08 03 18 06 06 |
| VVV K_e      | 17 31 39.887           | -30 40 58.97             | 2000 08 03 18 06 06 |
| VVV J        | 17 35 08.353           | -38 37 27.94             | 2000 07 05 00 38 29 |
| VVV K_e      | 17 35 08.087           | -38 37 30.51             | 2000 08 31 02 58 30 |
| VVV J        | 17 35 08.080           | -38 37 30.49             | 2000 08 31 02 58 30 |
| VVV J        | 17 35 08.072           | -38 37 30.70             | 2011 07 27 04 43 36 |
| LHS 5333 A   | 18 09 17.677           | -22 54 30.03             | 1999 07 07 01 49 09 |
| VVV J        | 18 09 17.713           | -22 54 35.12             | 2000 04 21 06 10 06 |
| VVV J        | 18 09 17.708           | -22 54 35.23             | 2000 04 21 06 13 16 |
| VVV J        | 18 09 17.713           | -22 54 35.24             | 2000 10 06 01 38 42 |
| LHS 5333 A   | 18 23 51.140           | -27 46 18.21             | 1998 07 19 02 56 37 |
| VVV J        | 18 23 51.029           | -27 46 20.65             | 2000 04 08 07 35 20 |
| VVV K_e      | 18 23 51.029           | -27 46 20.72             | 2000 04 08 07 35 20 |
| VVV K_e      | 18 23 51.026           | -27 46 20.81             | 2000 10 26 23 57 33 |
| LTT 7318 A   | 18 24 26.943           | -29 32 39.75             | 1998 07 19 03 10 49 |
| VVV K_e      | 18 24 27.119           | -29 32 41.40             | 2000 10 05 12 17 24 |
| VVV J        | 18 24 27.124           | -29 32 41.24             | 2000 10 05 12 17 24 |
| VVV K_e      | 18 24 27.135           | -29 32 41.40             | 2000 10 05 12 17 24 |

LTT 5140 A – LTT 5140 B, separation ~5 arcsec
2MASS 18 27 18.623 – 25 04 23.59 18 27 18.432 – 25 04 02.55 1998 07 19 03 46 39
2MASS 18 27 18.623 – 25 04 23.59 18 27 18.432 – 25 04 02.55 1998 07 19 03 46 39
2MASS 18 27 18.623 – 25 04 23.59 18 27 18.432 – 25 04 02.55 1998 07 19 03 46 39
2MASS 18 27 18.623 – 25 04 23.59 18 27 18.432 – 25 04 02.55 1998 07 19 03 46 39
2MASS 18 27 18.623 – 25 04 23.59 18 27 18.432 – 25 04 02.55 1998 07 19 03 46 39
Table 3. Multi-epoch observations of stars with over-estimated PMs. Typical positional uncertainties: ~0.1 arcsec for 2MASS, and ~0.05 arcsec for VVV.

| Image  | Coordinates       | Epoch, UT          |
|--------|-------------------|--------------------|
|        | RA Dec (J2000)    | yyyy mm dd hh ss  |
|        |                   | C* 1925            |
| 2MASS  | 11 52 11.709      | 2000 02 14 04 28   |
| VVV K  | 11 52 11.700      | 2010 03 15 03      |
| VVV J  | 11 52 11.686      | 2010 03 15 03 42   |
| VVV K  | 11 52 11.721      | 2011 07 24 23 25   |
|        |                   | C* 1930            |
| 2MASS  | 11 54 49.404      | 2000 02 14 04 43   |
| VVV K  | 11 54 49.405      | 2010 03 14 03 29   |
| VVV J  | 11 54 49.509      | 2010 03 14 03 36   |
| VVV K  | 11 54 49.518      | 2011 06 12 02 44   |
|        |                   | C* 1936            |
| 2MASS  | 11 56 55.808      | 2000 02 14 05 13   |
| VVV K  | 11 56 55.798      | 2010 03 15 03 56   |
| VVV J  | 11 56 55.818      | 2010 03 15 04 03   |
| VVV K  | 11 56 55.808      | 2011 05 20 23 45   |
|        |                   | CD–604613          |
| 2MASS  | 13 20 07.358      | 2000 04 17 02 41   |
| VVV K  | 13 20 07.367      | 2010 03 09 01 48   |
| VVV J  | 13 20 07.347      | 2010 03 09 08 40   |
| VVV K  | 13 20 07.331      | 2011 06 14 03 38   |
|        |                   | LP 866–17          |
| 2MASS  | 18 20 55.854      | 1998 07 19 02 14   |
| VVV K  | 18 20 55.851      | 2010 04 08 07 32   |
| VVV J  | 18 20 55.851      | 2010 04 08 07 35   |
| VVV K  | 18 20 55.849      | 2010 10 26 23 57   |
|        |                   | OGLE BUL–SC20 625107|
| 2MASS  | 17 59 35.685      | 1998 07 16 05 34   |
| VVV K  | 17 59 35.526      | 2011 05 09 05 22   |
| VVV J  | 17 59 35.523      | 2011 05 09 05 26   |
| VVV K  | 17 59 35.521      | 2011 05 18 07 44   |
|        |                   | OGLE BUL–SC21 298351|
| 2MASS  | 18 00 12.122      | 2000 07 05 03 48   |
| VVV K  | 18 00 12.120      | 2011 05 09 05 22   |
| VVV J  | 18 00 12.118      | 2011 05 09 05 26   |
| VVV K  | 18 00 12.116      | 2011 05 18 07 44   |
|        |                   | OGLE BUL–SC32 388121|
| 2MASS  | 18 03 11.721      | 1998 03 19 09 21   |
| VVV K  | 18 03 11.733      | 2011 05 09 05 51   |
| VVV J  | 18 03 11.729      | 2011 05 09 05 55   |
Table 4. Measured PMs for new, known, and rejected co-moving pairs of stars. The letter M in the star ID column stands for MACHO. PMs, parallaxes and spectral types from the literature are also listed.

| Star ID  | RA (2MASS) | Dec | PM(RA,Dec) [mas yr$^{-1}$], this work | PM(RA,Dec) [mas yr$^{-1}$], literature | Ref. | Parallax [mas] | Ref. | Sp. Type | Ref. |
|----------|------------|-----|----------------------------------------|-----------------------------------------|------|----------------|------|-----------|------|
| L 149-77 A | 14 12 28.089 | −62 56 14.90 | 162.5±11.9 | 196.3±6.7 | 154.8±4.5 | 184.3±4.1 | (4) | 25.6±12.8 | (17) | K7V | (17)/(18) |
| L 149-77 B | 14 12 28.829 | −62 56 27.86 | 171.2±0.4 | 192.6±1.2 | 141.3±10.0 | 163.0±10.0 | (20) | 14.17±1.56 | (20) |            |     |
| LHS 2881 A | 14 13 32.369 | −62 07 33.37 | −541.1±1.5 | −551.7±7.9 | −496±19 | −588±33 | (21) | 548.3±8.0 | −511.7±8.0 | (22) |
| LHS 2881 B | 14 13 30.335 | −62 07 45.70 | −545.8±1.0 | −545.3±1.1 |                     |                 |       |            |      |      |
| L 200-41 A | 15 18 40.449 | −56 27 55.70 | −162.7±7.5 | −134.5±6.5 | −174.2±3.4 | −142.8±3.2 | (4) | 24.47±11.9 | (20) |            |     |
| L 200-41 B | 15 18 39.953 | −56 28 12.94 | −159.8±4.9 | −138.3±7.6 | −180±22 | −126±36 | (21) | 548.3±8.0 | −511.7±8.0 | (22) |
| LHS 3188 A | 16 24 21.178 | −46 44 01.78 | −491.3±1.4 | −774.1±15.3 | −511.6 | −741.6 | (12) | 48±12 | (10) | K5 | (11) |
| LHS 3188 B | 16 24 21.202 | −46 44 05.78 | −478.9±3.7 | −658.5±5.1 |                     |                 |       |            |      |      |
| LP 487-4 A | 17 51 22.238 | −35 05 58.39 | −165.8±3.9 | −120.8±0.8 | −157.9±4.4 | −146.0±4.4 | (1) | 158.3±2.7 | −136.3±2.7 | (16) |
| LP 487-4 B | 17 51 23.322 | −35 05 25.88 | −150.5±3.9 | −117.7±1.2 |                     |                 |       |            |      |      |
| LHS 5333 A | 18 09 17.677 | −22 54 30.03 | 61.6±4.8 | −473.3±9.5 | 40.0±0.91 | −459.5±0.59 | (2) | 31.54±0.93 | (2) | K1IV | (13) |
| LHS 5333 B | 18 09 18.212 | −22 55 12.06 | 52.5±6.5 | −452.9±1.5 |                     |                 |       |            |      |      |
| LP 922-16 A | 23 12 15.140 | −27 46 18.21 | −117.0±1.6 | −212.1±3.3 | −124.8±3.06 | −205.7±1.89 | (2) | 10.93±2.29 | (2) |            |     |
| LP 922-16 B | 23 12 52.896 | −27 47 50.87 | −130.7±3.4 | −205.4±1.3 | −132.3±9.0 | −197.4±9.0 | (15) | 160±48 | −134±57 | (21) | −154.8±9.5 | −143.4±9.5 | (23) |
Table 4. Continued.

| Star ID | RA (2MASS) | Dec | PM (RA,Dec) [mas yr\(^{-1}\), this work] | PM (RA,Dec) [mas yr\(^{-1}\), literature] | Ref. | Parallax [mas] | Ref. | Sp. Type | Ref. |
|---------|------------|-----|---------------------------------|---------------------------------|------|----------------|------|-----------|------|
| LTT 5140 A | 13 21 23.965 | −64 02 59.68 | −223.4±6.3 | −48.3±3.0 | −233.7±0.6 | −44.0±0.8 | (2) 17.8±0.98 | (2) G0V | (6) |
| LTT 5140 B | 13 21 23.211 | −64 02 59.08 | −207.1±8.1 | −49.2±6.2 | −223.0±3.1 | −47.6±2.3 | (4) | | |
| L412-3 | 16 58 45.218 | −40 13 03.85 | −135.1±7.1 | −121.2±7.5 | −174.7±5.4 | −136.0±5.4 | (1) | | |
| L412-4 | 16 58 43.324 | −40 13 18.64 | −150.4±7.3 | −121.8±7.0 | −145.1±5.5 | −129.0±4.5 | (1) | | |
| LTT 5140 A | 17 31 40.047 | −30 40 56.51 | −164.3±2.2 | −206.5±5.0 | −181.7±2.0 | −197.0±2.0 | (1) | | |
| LTT 6990 A | 13 35 08.353 | −38 37 28.15 | −295.7±8.6 | −250.9±1.8 | −311.7±1.7 | −228.8±1.08 | (2) 30.40±1.36 | (2) K0V | (13) |
| LTT 6990 B | 13 35 08.644 | −38 37 29.89 | −317.4±4.3 | −230.6±7.8 | | | | |
| M124.22158–2900 | 18 07 57.462 | −30 54 55.50 | −148.6±7.1 | −244.7±7.5 | −119.7±5.0 | −249.8±5.0 | (5) | | |
| M124.22158–2910 | 18 07 57.313 | −30 54 58.14 | −140.8±2.7 | −245.9±7.0 | −115.8±5.0 | −242.8±5.0 | (5) | | |
| GJ 2136 A | 18 27 18.623 | −25 04 23.59 | −79.8±8.2 | −179.2±6.3 | −84.4±3.2 | −198.1±3.0 | (1) 30.86±4.57 | (7) M0/M0.5 (14)/(7) |
| GJ 2136 B | 18 27 18.432 | −25 04 02.55 | −77.1±3.7 | −184.7±5.3 | −88.0±25.0 | −168.0±25.0 | (8) | | |

Not co-moving:

| Star ID | RA (2MASS) | Dec | PM (RA,Dec) [mas yr\(^{-1}\), this work] | PM (RA,Dec) [mas yr\(^{-1}\), literature] | Ref. | Parallax [mas] | Ref. | Sp. Type | Ref. |
|---------|------------|-----|---------------------------------|---------------------------------|------|----------------|------|-----------|------|
| LTT 7318 | 18 24 26.943 | −29 32 39.75 | 184.7±12.1 | −132.1±7.6 | 194.4±2.0 | −120.8±1.8 | (1) 21.3±0.18 | (2) F8V | (6) |
| LTT 7319 | 18 24 26.559 | −29 31 54.53 | 0.0±7.9 | −207.4±2.6 | 0.5±1.5 | −197.8±2.0 | (1) 21.38±0.92 | (2) K3/K4III+ | (6) |

References. (1) Salim & Gould (2003); (2) van Leeuwen (2007); (3) Nesterov et al. (1995); (4) Hog et al. (2000); (5) Alcock et al. (2001); (6) as given in SIMBAD, the original reference is unknown; (7) Reid et al. (2004); (8) Luyten (1963); (9) Bakos et al. (2002); (10) Jenkins (1993); (11) Bidelman (1985); (12) Luyten (1979); (13) Gray et al. (2006); (14) Stephenson & Sanduleak (1975); (15) Zacharias et al. (2004); (16) Röser et al. (2008); (17) Ammons et al. (2006); (18) Schmidt-Kaler (1982); (19) Pickles & Depagne (2010); (20) Fresno et al. (2004); (21) Monet et al. (2003); (22) Zacharias et al. (1980) – possibly, a wrong sign for the RA PM of LHS 2881 A; (23) Röser et al. (2010); (24) Stauffer et al. (2010); (25) Hog & von der Heide (1979); (26) Dunham (1986); (27) Smithsonian Astrophysical Observatory Star Catalog; (28) Schlesinger & Barney (1943); (29) Bastian & Röser (1993); (30) Perryman et al. (1997); (31) Urban et al. (1997); (32) Röser et al. (1994).

Table 5. List of stars with overestimated PMs. The first literature PM is the one listed in SIMBAD at the time of the sample preparation.

| Star ID | PM(RA,Dec) [mas yr\(^{-1}\), this work] | PM(RA,Dec) [mas yr\(^{-1}\), literature] | Ref. | Sp. Type | Ref. |
|---------|---------------------------------|---------------------------------|------|-----------|------|
| C* 1925 | −1.3±12.0 | 25.2±10.6 | 256±110 | 342±40 | (1) Carbon star (2) |
| C* 1930 | 10.6±7.1 | −10.3±3.3 | 18±91 | 278±46 | (1) Carbon star (2) |
| C* 1936 | 5.9±7.6 | −6.5±11.6 | 146±44 | 226±7 | (1) Carbon star (2) |
| CD−604613 | −3.7±13.6 | −8.2±6.7 | −8.6±6.9 | −8.27±6.40 | (4) |
| | | | −7.2±2.2 | −0.35±2.2 | (5) |
| | | | −7.38±10.7 | −1.76±1.04 | (9) |
| LP 866−17 | −8.2±0.2 | −3.4±3.4 | −7.4±5.5 | −216.9±5.5 | (6) |
| | | | −16.1±4.4 | −19.1±4.3 | (5) |
| OGLE BUL−SC20 625107 | −162.0±4.2 | −117.5±2.6 | −42.56±9.6 | −330.93±32.81 | (7) |
| OGLE BUL−SC21 298351 | 8.1±1.5 | −10.4±1.5 | 29.48±13.9 | −262.32±28.43 | (7) |
| | | | 0.2±4.4 | −0.2±4.4 | (5) |
| | | | −5.9±12.3 | −8.1±12.2 | (8) |
| OGLE BUL−SC32 388121 | 11.1±7.4 | 5.0±6.8 | −78.63±6.88 | −183.12±6.66 | (7) |
| | | | −116±2 | −574±112 | (1) |
| | | | −114.6±9.5 | −579.6±9.5 | (5) |
| | | | 24.9±7.4 | −18.7±11.6 | (8) |

References. (1) Monet et al. (2003); (2) Westerlund (1971); (3) Turon et al. (1992); (4) Perryman (1997); (5) Röser et al. (2010); (6) Salim & Gould (2003); (7) Sumi et al. (2004); (8) Zacharias et al. (2013); (9) van Leeuwen (2007).
Table 6. Details of the IR spectroscopic observations and derived spectral types. Median airmasses are given. The target IDs are the same as in Fig. 2. A+B means that both the primary and the secondary were observed, B means that only the secondary was observed.

| Target ID | NDIT \times DIT sec \ z | NDIT \times DIT sec \ z | Primary + Secondary | Date | Telluric | Blue grism | Red grism | Derived Sp. Types | mm- | Science Target | Blue grism | Red grism | Sp. Ref. |
|-----------|--------------------------|--------------------------|---------------------|------|-----------|------------|-----------|------------------|-----|--------------|------------|-----------|----------|
| L 412-3 A+B | 4 \times 30 s 1.42 | 6 \times 30 s 1.36 | K2V + K5V | 05-2012 | HIP 084636 | 4 \times 1.2 s 1.46 | 6 \times 1.2 s 1.44 | G3V (1) |
| LHS 2881 A+B | 25 \times 25 s 1.22 | 7 \times 100 s 1.34 | K3V + M4V | 04-2011 | HIP 064574 | 5 \times 10 s 1.28 | 5 \times 10 s 1.39 | G1V (1) |
| LHS 3188 B | 7 \times 150 s 1.10 | 7 \times 150 s 1.05 | n.a. + M5V | 04-2011 | HIP 090446 | 5 \times 6 s 1.12 | 3 \times 6 s 1.07 | G0V (2) |
| LHS 5333 A+B | 12 \times 2 s 1.14 | 12 \times 4 s 1.16 | K0V + M3V | 05-2012 | HIP 092515 | 6 \times 10 s 1.12 | 6 \times 15 s 1.14 | G2V (1) |
| LTT 6990 A+B | 6 \times 10 s 1.02 | 12 \times 10 s 1.02 | K0V + K4V | 05-2012 | HIP 084636 | 5 \times 2 s 1.04 | 10 \times 2 s 1.04 | G3V (1) |
| LP 487-4 A+B | 2 \times 120 s 1.01 | 3 \times 120 s 1.01 | G8V + K5V | 05-2012 | HIP 084636 | 5 \times 2 s 1.04 | 10 \times 2 s 1.04 | G3V (1) |
| LP 920-25 A+B | 6 \times 30 s 1.39 | 8 \times 30 s 1.32 | M1.5V + M1.5V | 05-2012 | HIP 084636 | 4 \times 1.2 s 1.46 | 6 \times 1.2 s 1.44 | G3V (1) |
| LP 922-16 A+B | 3 \times 20 s 1.21 | 4 \times 30 s 1.23 | K1IV + M1.5V | 05-2012 | HIP 092515 | 6 \times 10 s 1.12 | 6 \times 15 s 1.14 | G2V (1) |
| M 124... A+B | 2 \times 120 s 1.01 | 3 \times 120 s 1.01 | M0V + M1.5V | 05-2012 | HIP 098813 | 10 \times 2 s 1.01 | 20 \times 2 s 1.01 | G1V (3,4) |

References. (1) Houk & Smith-Moore (1988); (2) Houk & Cowley (1975); (3) Houk (1982); (4) Gray et al. (2006).