A&A 462, L61–L64 (2007)
DOI: 10.1051/0004-6361:20066814
© ESO 2007

Astronomy & Astrophysics

LETTER TO THE EDITOR

The widest ultracool binary*

J. A. Caballero[1,**]

Max-Planck-Institut für Astronomie, Königstuhl 17, 69117 Heidelberg, Germany
e-mail: `caballero@mpia.de`

Received 24 November 2006 / Accepted 12 December 2006

ABSTRACT

Aims. I test the ejection scenario for the formation of brown dwarfs and low-mass stars through the detection of a very wide ultracool binary.

Methods. LEHPM 494 (M6.0 ± 1.0 V) and DENIS-P J0021.0–4244 (M9.5 ± 0.5 V) are separated by 1.3 arcmin and are high proper motion co-moving ultracool stars. I have used six astrometric epochs spaced by 22 years to confirm their common tangential velocity.

Results. The angular separation between both low-mass stars remains constant with an uncertainty of less than 0.1%. I have also derived their most probable heliocentric distance (23 ± 2 pc), age interval (2–10 Ga) and masses (0.103 ± 0.006 and 0.079 ± 0.004 $M_\odot$). The pair, with a projected physical separation of 1800 ± 170 AU, is by far the widest ultracool binary yet found in the field.

Conclusions. This serendipitous and simple detection is inconsistent with ultra low-mass formation ejection scenarios and complements current searches for low-mass tight binaries.

Key words. stars: low-mass, brown dwarfs – stars: binaries: general – stars: individual: DENIS-P J0021.0–4244 – stars: formation – stars: individual: LEHPM 494 – stars: binaries: visual

1. Introduction

DENIS-P J0021.0–4244 (hereafter DE0021–42), with a spectral type ≥M9 V, was, at the end of the previous decade, one of the coolest known isolated field dwarfs (Tinney et al. 1998; Delfosse et al. 1999). At that time, only a few benchmark cooler objects had been identified as companions to more massive bodies (Becklin & Zuckerman 1988; Nakajima et al. 1995; Rebolo et al. 1998) or free floating ones (Ruiz et al. 1997; Kirkpatrick et al. 1997). Since then, hundreds of stars and brown dwarfs with very late M, L and T spectral types have been discovered in direct imaging (see a full list at `DwarfArchives.org`). Many of them are faint companions to stars at separations of between 15 and ~3600 AU (with mass ratios $q \equiv \frac{M_2}{M_1} < 0.5$; Kirpatrick 2005; Burgasser et al. 2005, and references therein) or form tight binary systems with separations smaller than ~20 AU (with mass ratios $q > 0.5$; Bouy et al. 2005; Burgasser et al. 2006). The masses and effective temperatures of late M-, L- and T-type objects are below ~0.15 $M_\odot$ and ~3000 K, respectively, which leads to a classification as "ultracool" objects. I will call a dwarf ultracool if it is M6 or later.

There are only three known *relatively wide* ultracool binary systems *in the field* with separations of the order of 30–40 AU and total masses below ~0.2 $M_\odot$ (Harrington et al. 1974; Phan-Bao et al. 2005; Burgasser & McElwain 2006). Only very recently, a very wide low-mass binary, with a physical separation significatively larger than the rest, has been discovered ($r \approx 220$ AU, $M_1 \approx 0.090\ M_\odot$, $M_2 \approx 0.075\ M_\odot$; Billères et al. 2005). Wide very low-mass binaries like this are unexpected in the embryo-ejection scenario models, which also under-predict the observed frequency of tight low-mass binaries (Bate et al. 2002; Sterzik & Durisen 2003; Delgado Donate et al. 2004; Umbreit et al. 2005).

In young star forming regions (1–120 Ma), some fragile systems with extremely low binding energies (i.e. with ultra-low masses and/or very large separations) have been reported (e.g. Martín et al. 1998; Luhman 2004, 2005; López Martí et al. 2004, 2005; Bouy et al. 2006; Jayawardhana & Ivanov 2006). One of the least bound systems known is the SE 70 + S Ori 68 pair in the 3 Ma-old σ Orionis cluster ($r \approx 1700$ AU, $M_1 \approx 0.045\ M_\odot$, $M_2 \approx 0.005\ M_\odot$; Caballero et al. 2006). Unlike systems in the field, the "confirmation" of multiplicity in systems in young clusters does not come from proper-motion measurements, but from statistical considerations on the separation from background sources and the rest of the (candidate) cluster members. It is expected that most of these systems, that may have formed in the same way as low mass stars and not in a protoplanetary disc, will not survive the tidal disruption within the cluster. Nevertheless, they are still a problem in the ejection scenario because it predicts that low-mass wide systems are torn apart at ages much less than 3 Ma.

In this Letter I present the least bound binary system in the field with common proper-motion confirmation.

2. Analysis and results

DE0021–42, which has been now classified as a normal M9.5V field dwarf (Basri et al. 2000; Mohanty & Basri 2003), is located at ~1.3 arcmin to the northwest of the faint high proper motion star LEHPM 494 (see finding chart in Fig. A.1). The latter was discovered in the Liverpool-Edinburgh survey by Pokorny et al. (2003), and has gone unnoticed until now. Their only known physical parameters were the proper motion and photographic B_J- and I-band magnitudes.

---

[*] Appendix (Fig. A.1) is only available in electronic form at `http://www.aanda.org`

[**] Alexander von Humboldt Fellow at the MPIA.

Article published by EDP Sciences and available at http://www.aanda.org or http://dx.doi.org/10.1051/0004-6361:20066814

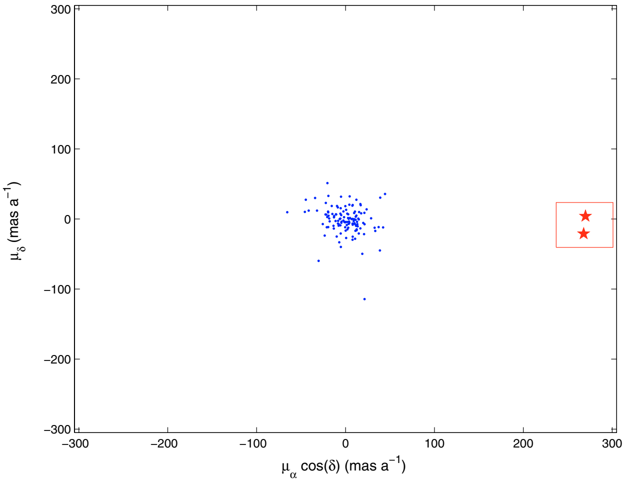

Fig. 1. Proper motions from SSA of all the sources in a 5-arcmin radius centred in Kö 1A with errors less than 30 mas a^{-1}. Background sources are plotted with small dots. Kö 1A and Kö 1B are shown with filled stars. The box indicates the 2σ uncertainty on the average proper motion of the binary.

A routine visual inspection of the tangential velocities tabulated by USNO-B1/NOMAD1 serendipitiously showed that the proper motions of DE0021–42 and LEHPM 494 are very similar and very different from those of background objects. USNO-B1/NOMAD1 proper-motion uncertainties are in general understimated (e.g. Caballero et al. 2006), so I also studied the tangential velocities tabulated by the SuperCOSMOS Science Archive (SSA). Figure 1 illustrates the high proper motion, apparently common, of DE0021–42 and LEHPM 494. In the upper part of Table 1, I provide the catalogued coordinates, tangential velocities and magnitudes of both objects. From now on, I will call the pair Koenigstuhl 1 (LEHPM 494 ≡ Koenigstuhl 1 A, Kö 1A; DE0021–42 ≡ Koenigstuhl 1 B, Kö 1B; new wide low-mass binaries detected in an on-going survey will have the same designation – Caballero in prep.).

I have used six imaging epochs, with a time baseline of 22 years, to measure the variation of the angular separation, ρ, and orientation or parallactic angle, θ, between Kö 1A and Kö 1B. The epochs used were (in parenthesis, the passband(s) and the epoch of observation): UK Schmidt blue survey (B_J, J1977.626), ESO Schmidt (R_1, J1984.878), DENIS (IJK, J1996.520), UK Schmidt red survey (R_2, J1996.617), UK Schmidt near-infrared survey (I_N, J1999.603) and 2MASS ($JHK_{\rm s}$, J1999.643). I used the coordinates provided by the DENIS and 2MASS catalogues to compute ρ and θ at their respective epochs. For the other epochs, I downloaded 10 arcmin-wide images centred on Kö 1A from the SuperCOSMOS Science Archive[1], and performed standard astrometric measurements within IRAF. I used relatively bright USNO-B1 sources in the field of view with null proper motion to compute the scale and orientation of the plates. In Fig. 2, I show the variation of ρ and θ with time. They remain constant with uncertainties as low as 0.09% (see Table 2). The average projected angular separation between Kö 1A and Kö 1B is ρ = 1.296 ± 0.012 arcmin. The modulus of the mean proper motion of the system, μ = 258 mas a^{-1}, is 14 times larger than the median of the tangential velocities of the background sources tabulated by SSA in a region of a radius of 5 arcmin centred in Kö 1A. After 22 years, the pair has travelled 5.7 arcsec, which is ~80 times larger than the uncertainty of the average ρ. The probability of two field objects being separated by ~1.3 arcmin, sharing the same tangential velocity and *not* being gravitationally bound is insignificant. Therefore, Kö 1A and Kö 1B are a common proper motion pair.

Table 1. Data of Koenigstuhl 1 A and Koenigstuhl 1 B.

	Kö 1A	Kö 1B	Unit	Ref.[a]
Name	LEHPM 494	DE0021.0–42		1, 2
α (J2000)	00 21 10.42	00 21 05.74		3
δ (J2000)	–42 45 40.0	–42 44 43.3		3
$\mu_\alpha \cos\delta$	+268 ± 10	+270 ± 11	mas a^{-1}	3
$\mu_\alpha \cos\delta$	+246 ± 15	+250 ± 9	mas a^{-1}	4
μ_δ	–21 ± 8	+4 ± 10	mas a^{-1}	3
μ_δ	–48 ± 18	+18 ± 15	mas a^{-1}	4
B_J	18.562	22.694	mag	3
R_1	16.033	19.633	mag	3
R_2	16.181	19.784	mag	3
I_N	13.599	16.697	mag	5
I	13.92 ± 0.03	16.79 ± 0.10	mag	6
J	12.00 ± 0.02	13.52 ± 0.02	mag	6
H	11.37 ± 0.03	12.81 ± 0.02	mag	6
$K_{\rm s}$	11.05 ± 0.03	12.30 ± 0.02	mag	6
Sp. type	M6.0 ± 1.0 V	M9.5 ± 0.5 V		7, 8
$\log \frac{L_{\rm H\alpha}}{L_{\rm bol}}$	–	–5.62		7
$v \sin i$	–	17.5 ± 2.5	km s^{-1}	7
M_J	10.2 ± 0.2	11.7 ± 0.2	mag	8
Mass	0.103 ± 0.006	0.079 ± 0.004	$M_\odot$	8
$T_{\rm eff}$	2850 ± 100	2250 ± 100	K	8

[a] References: 1: Pokorny et al. (2003); 2: Tinney et al. (1998); 3: SSA (Hambly et al. 2001); 4: USNO-B1/NOMAD1 (Monet et al. 2003; Zacharias et al. 2004); 5: DENIS (Epchtein et al. 1997); 6: 2MASS (Cutri et al. 2003); 7: Basri et al. (2000), Mohanty & Basri (2003); 8: this work.

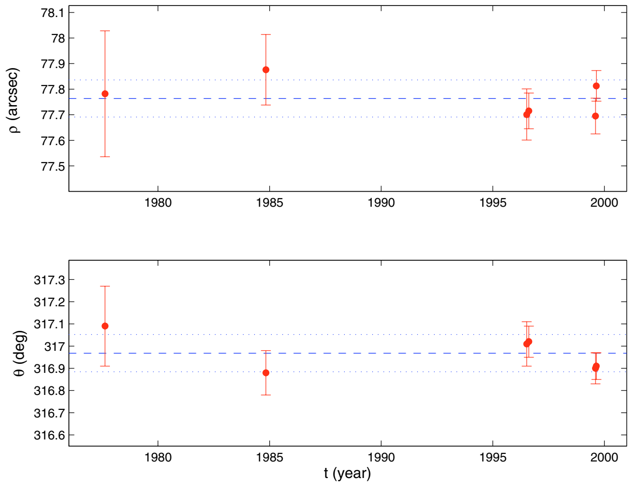

Fig. 2. Projected angular separations, ρ, and parallatic angles, θ, for the six epochs. Baseline covers 22 years from 1977 to 1999. Dashed and dotted lines indicate the average and $\pm 1\sigma$ values, respectively.

I have collected an extensive sample of field M- and L-type dwarfs with spectral type and parallax determinations and homogeneous 2MASS photometry. The distance measurements come from Perryman et al. (1997) (in the case of companions to *Hipparcos* stars), Dahn et al. (2002), Vrba et al. (2004) and the List of the Nearest 100 Stellar Systems of the Research Consortium on Nearby Stars (`www.chara.gsu.edu/RECONS`;

---

[1] The pixel size of the SuperCOSMOS Sky Surveys is smaller than the Digital Sky Surveys DSS-I and DSS-II.

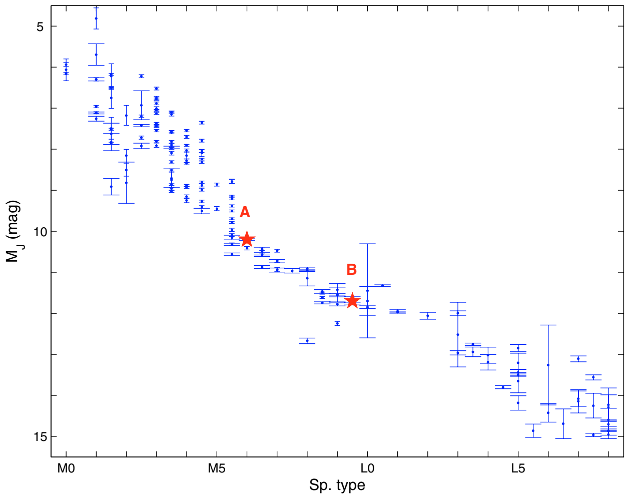

Fig. 3. M_J vs. spectral type diagram. Ultracool dwarfs with parallax determination and J-band magnitude from 2MASS are shown with small dots with errorbars. Expected positions of Kö 1A and Kö 1B for their most probables M_J and spectral types (measured from optical spectra in the case of Kö 1B) are indicated with filled stars. The cubic polynomial fit is not shown for clarity.

maintained by T. J. Henry). I have fitted the relation between absolute J-band magnitude, $M_J = J + 5 - 5 \log d$, and spectral type in the interval M0–L9 to a cubic polynomial (Fig. 3). I have computed the heliocentric distance to Kö 1B at 23 ± 2 pc from the fit using its J-band magnitude and its spectral type (M9.5 ± 0.5 V; Basri et al. 2000). I have also derived the M_J and the most probable spectral type of Kö 1A (M6.0 ± 1.0 V) from its J-band magnitude and the distance deduced for Kö 1B. Uncertainties come from the error in the fit. Kö 1A displays colours from SSA, DENIS and 2MASS photometry that are very similar to other standard M5.5–6.5 field dwarfs (Proxima Centauri, DX Cancri), which supports the derived spectral type. The same occurs in Kö 1B when compared to other M9.0–9.5 field dwarfs (GJ 3517, DY Piscium). The projected physical separation of Koenigstuhl 1 is 1800 ± 170 AU, the widest found among ultracool binaries.

Through comparison of M_J to theoretical models of the Lyon group (Baraffe et al. 1998; Chabrier et al. 2000), I have estimated the masses of Kö 1A and Kö 1B at 0.103 ± 0.006 and 0.079 ± 0.004 $M_\odot$. Both NextGen98 and Cond00 models provide similar results. The total mass and mass ratio of the system are 0.182 ± 0.007 $M_\odot$ and q = 0.77 ± 0.06, comparable to those derived for tight low-mass binary systems. The long orbital period of ~0.2 Ma will prevent any astrometric mass measurement. I have used a most probable age of the system in the interval between 2 and 10 Ga for several reasons: (*i*) the absence of Li I λ6707.8 Å in absorption in the optical spectrum of Kö 1B (M9.5-type stars or brown dwarfs younger than ~1 Ga are expected to display lithium in absorption); (*ii*) the low activity of Kö 1B based on its Hα emission (pEW(Hα) = +0.5 Å; Mohanty & Basri 2003); and (*iii*) Koenigstuhl 1 does not share the motion of any young stellar kinematic group (the Galactic space-velocity components UVW have been computed from the average tangential velocity and the radial velocity of Kö 1B from Mohanty & Basri 2003, V_r = +2 ± 1 km s^{-1}). If younger than 1 Ga, then Kö 1B would be a brown dwarf. Tables 1 and 2 summarise the data of the binary system and their components. The gravitational potential energy of Kö 1AB, U_g, is similar to those of the very young low-mass systems found by Chauvin et al. (2004), Luhman (2004) and Jayawardhana & Ivanov (2006).

Table 2. Data of the Koenigstuhl 1 AB binary system.

Quantity	Value	Unit
$\mu_\alpha \cos\delta$	+258 ± 12^a	mas a^{-1}
μ_δ	–12 ± 29^a	mas a^{-1}
ρ	77.76 ± 0.07	arcsec
θ	316.97 ± 0.08	deg
d	23 ± 2	pc
r	1800 ± 170	AU
U_g	–8.0 ± 1.0	10^{33} J
P	~2 × 10^5	a
U	–23 ± 3	km s^{-1}
V	–15 ± 3	km s^{-1}
W	–4.9 ± 1.3	km s^{-1}
Age	2–10	Ga

[a] Average of the tangential velocities of Kö 1A and Kö 1B tabulated by SSA and USNO-B1/NOMAD1.

Basri & Reiners (2006) recently claimed a marginal (3σ) detection of spectroscopic binarity in Kö 1B, which would make Koenigstuhl 1 a hierarchical triple system. In the case of Kö 1B being an equal-mass binary, then Koenigstuhl 1 ABab would be located at about 33 pc and be formed by an 0.11 $M_\odot$-mass primary separated by 2500 AU from an 0.08 + 0.08 $M_\odot$-mass binary. The hypothetical ABab triple system would have roughly the same binding energy as the simple AB binary ($U_g = -1.2 \times 10^{33}$ J). If confirmed, Kö 1ABab would be a low-mass analog to the system G 124–62 ABab ($M_{\rm total} \approx 0.73~M_\odot$, $r \approx$ 1500 AU; Seifahrt et al. 2005). Wide triples like Kö 1ABab, G 124–62 ABab, GJ 1001 ABab, ϵ Ind ABab and GJ 417 ABab may be more prevalent than wide binaries.

3. Conclusions

Assuming Kö 1B is a single object, then Koenigstuhl 1 AB is eight times wider than the Billères et al. (2005) system, about 50 times wider than other relatively wide ultra low-mass binaries in the field, and three orders of magnitude wider than the widest "normal" tight ultracool binary. It is 40 times wider than the maximum projected separation of low-mass binaries scaled with the total mass found by Burgasser et al. (2003). Koenigstuhl 1 AB is also much wider than the binaries found in young clusters. Its projected physical separation is only comparable to those of the Hn 12 A + B (López Martí et al. 2005) and SE 70 + S Ori 68 (Caballero et al. 2006) very young systems. The separation could be even larger if Kö 1B were a tight binary.

There are excellent discussions on how wide low-mass binaries challenge current hydrodynamical and N-body simulations of the fragmentation in molecular clouds (see references in Sect. 1, especially Billères et al. 2005). This confrontation is even harder to explain in the case of the relatively old Koenigstuhl 1 AB system, which is by far the least bound binary in the field. Very probably, there are similar systems, waiting to be discovered. Were their original physical separations so wide? Or have they been perturbed by encounters with massive objects as they traveled in the Galaxy? The answer may come from the measurement of the variation of the frequency of wide ultracool binaries in the solar neighbourhood as a function of the separation from tens to thousands of AU. This project is achievable with already-available astronomical databases and is complementary to the study of tight low-mass binaries, which in contrast requires expensive high spatial resolution imaging facilities. If Galactic perturbation has not played an important rôle, then Koenigstuhl 1 AB should be seriously taken into account for further low-mass star-forming scenarios.

Acknowledgements. I thank A. Burgasser for his fast and efficient refereeing and to the A&A Editorial Office. I also thank B. Goldman, J. Maldonado and R. Mundt for providing me helpful comments and UVW data. I have used IRAF, the M, L, and T dwarf compendium housed at `DwarfArchives.org`, the List of the Nearest 100 Stellar Systems, the Two-Micron All Sky Survey, the Deep Near Infrared Survey of the Southern Sky, the USNO-B1 and NOMAD catalogues, the SuperCOSMOS Science Archive and the SIMBAD database. Partial financial support was provided by the Spanish Ministerio de Ciencia y Tecnología project AYA2004–00253 of the Plan Nacional de Astronomía y Astrofísica.

References

Baraffe, I., Chabrier, G., Allard, F., & Hauschildt, P. H. 1998, A&A, 337, 403
Basri, G., & Reiners, A. 2006, AJ, 132, 663
Basri, G., Mohanty, S., Allard, F., et al. 2000, ApJ, 538, 363
Bate, M. R., Bonnell, I. A., & Bromm, V. 2002, MNRAS, 332, L65
Becklin, E. E., & Zuckerman, B. 1988, Nature, 336, 556
Billères, M., Delfosse, X., Beuzit, J.-L., et al. 2005, A&A, 440, L55
Bouy, H., Martín, E. L., Brandner, W., & Bouvier, J. 2005, AN, 326, 969
Bouy, H., Martín, E. L., Brandner, W., et al. 2006, A&A, 451, 177
Burgasser, A. J., & McElwain, M. W. 2006, AJ, 131, 1007
Burgasser, A. J., Kirkpatrick, J. D., Reid, I. N., et al. 2003, ApJ, 586, 512
Burgasser, A. J., Kirkpatrick, J. D., & Lowrance, P. J. 2005, AJ, 129, 2849
Burgasser, A. J., Reid, I. N., Siegler, N., et al. 2006 `[arXiv:astro-ph/0602122]`
Caballero, J. A., Martín, E. L., Dobbie, P. D., & Barrado y Navascués, D. 2006, A&A, 460, 635
Chabrier, G., Baraffe, I., Allard, F., & Hauschildt, P. 2000, ApJ, 542, 464
Chauvin, G., Lagrange, A.-M., Dumas, C., et al. 2004, A&A, 425, L29
Cutri, R. M., Skrutskie, M. F., van Dyk, S., et al. 2003, The IRSA 2MASS All-Sky Point Source Catalog, NASA/IPAC Infrared Science Archive
Dahn, C. C., Harris, H. C., Vrba, F. J., et al. 2002, AJ, 124, 1170
Delfosse, X., Tinney, C. G., Forveille, T., et al. 1999, A&AS, 135, 41
Delgado-Donate, E. J., Clarke, C. J., & Bate, M. R. 2004, MNRAS, 347, 759
Epchtein, N., de Batz, B., Capoani, L., et al. 1997, Msngr, 87, 27
Hambly, N. C., MacGillivray, H. T., Read, M. A., et al. 2001, MNRAS, 326, 1279
Harrington, R. S., Dahn, C. C., & Guetter, H. H. 1974, ApJ, 194, L87
Kirkpatrick, J. D. 2005, ARA&A, 43, 195
Kirkpatrick, J. D., Beichman, C. A., & Skrutskie, M. F. 1997, ApJ, 476, 311
Jayawardhana, R., & Ivanov, V. D. 2006, Science, 313, 1279
López Martí, B., Eislöffel, J., Scholz, A., & Mundt, R. 2004, A&A, 416, 555
López Martí, B., Eislöffel, J., & Mundt, R. 2005, A&A, 440, 139
Luhman, K. L. 2004, ApJ, 614, 398
Luhman, K. L. 2005, ApJ, 633, L41
Martín, E. L., Basri, G., Brandner, W., et al. 1998, ApJ, 509, L113
Mohanty, S., & Basri, G. 2003, ApJ, 583, 451
Monet, D. G., Levine, S. E., Casian, B., et al. 2003, AJ, 125, 984
Nakajima, T., Oppenheimer, B. R., Kulkarni, S. R., et al. 1995, Nature, 378, 463
Phan-Bao, N., Martín, E. L., Reylé, C., Forveille, T., & Lim, J. 2005, A&A, 439, L19
Perryman, M. A. C., Lindegren, L., Kovalevsky, J., et al. 1997, A&A, 323, L49
Pokorny, R. S., Jones, H. R. A., & Hambly, N. C. 2003, A&A, 397, 575
Rebolo, R., Zapatero Osorio, M. R., Madruga, S., et al. 1998, Science, 282, 1309
Ruiz, M. T., Leggett, S. K., & Allard, F. 1997, ApJ, 491, L107
Seifahrt, A., Guenther, E., & Neuhäuser, R. 2005, A&A, 440, 967
Sterzik, M. F., & Durisen, R. H. 2003, A&A, 400, 1031
Tinney, C. G., Delfosse, X., Forveille, T., & Allard, F. 1998, A&A, 338, 1066
Umbreit, S., Burkert, A., Henning, T., Mikkola, S., & Spurzem, R. 2005, ApJ, 623, 940
Vrba, F. J., Henden, A. A., Luginbuhl, C. B., et al. 2004, AJ, 127, 2948
Zacharias, N., Monet, D. G., Levine, S. E., et al. 2004, A&AS, 205, 4815

Online Material

Appendix A: Finding chart

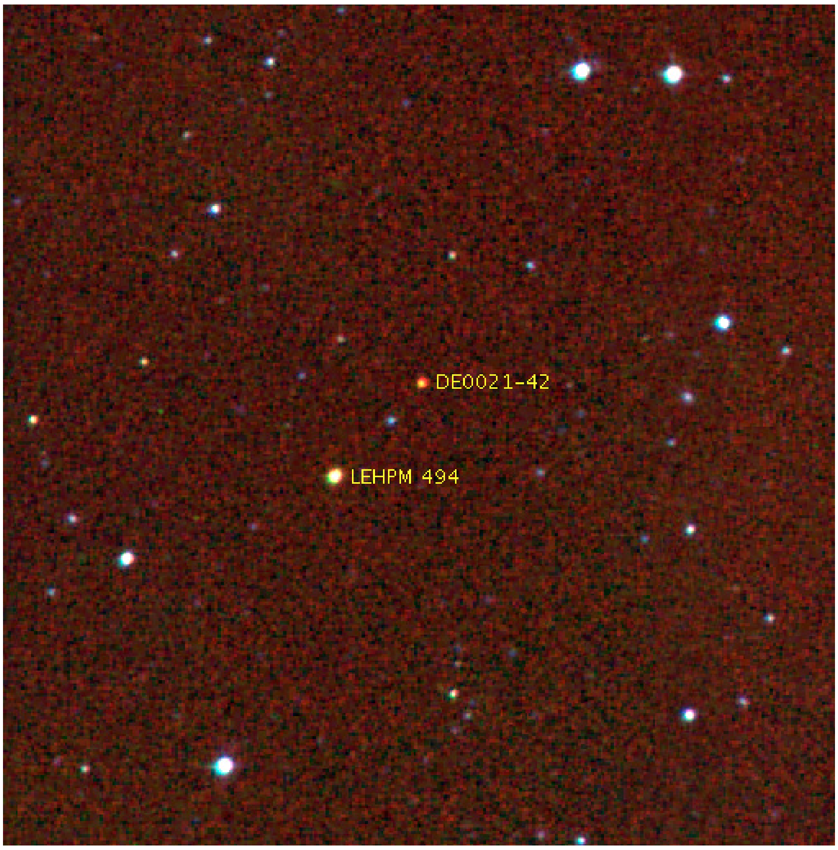

Fig. A.1. False-colour finding chart, 10 × 10 arcmin^2 wide, showing the Koenigstuhl 1 binary system. Both components are labelled (LEHPM 494 ≡ Kö 1A, DE0021–42 ≡ Kö 1B). Red is for *H*, green is for *I* and blue is for *R*.