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Reaching the boundary between stellar kinematic groups and very wide binaries

The Washington double stars with the widest angular separations[⋆]

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ABSTRACT

Aims. I look for and characterise very wide binaries and multiple systems with projected physical separations larger than $s = 0.1$ pc, which is generally believed to be a sharp upper limit to the distribution of wide binary semimajor axes.

Methods. I investigated in detail 30 Washington double stars with angular separations of $\rho > 1000$ arcsec. I discarded 23 of them as probably unbound systems based on discordant astrometry, photometry, spectral types, and radial velocities. The remaining seven systems were subject to a comprehensive data compilation and derivation (multi-wavelength photometry, heliocentric distance, multiplicity, age, mass, metallicity, membership in a young kinematic group).

Results. Of the seven very wide systems, six have projected physical separations greater than the hypothetical cutoff at $s = 0.1$ pc and four have separations $s > 0.2$ pc. Although there are two systems in young kinematic groups (namely HD 136654 and BD+32 2572 in the Hyades Supercluster, and AU Mic and AT Mic AB in the β Pictoris moving group), there is no clear prevalence of young systems ($\tau < 1$ Ga) among these very wide binaries. Finally, I compare the binding energies of the seven systems with those of other weakly bound systems in the field.

Key words. astronomical data bases: miscellaneous – binaries: general – binaries: visual – stars: kinematics

1. Introduction

Binaries can be classified by physical separation into *close* and *wide* binaries. Close binaries include spectroscopic, astrometric, interferometric, eclipsing, cataclysmic, and semi-detached binaries, which have quite differentiated astrophysical properties. However there is subjectiveness in the determination of the boundary between close and wide binaries. While for some authors a wide binary is a detached pair with a physical separation of a few tens solar radii, enough to avoid Roche lobe filling and mass transfer after the main sequence, for others the stars in a wide binary must be separated by at least 10^3–10^4 AU (0.005–0.05 pc)[1], depending on the total mass of the system.

It remains an open question whether the definition of wide binaries must be "stretched a little" to include common proper motion pairs (pairs of stars traveling together through space without any discernible relative orbital motion; Batten 1973). For example, just in the very closest solar neighbourhood, the gravitational binding between Proxima Centauri (M5.5Ve) and α Cen A and B (G2V+K2IV), a celebrated common proper motion "pair" (Innes 1915) with a physical separation $r = 12\,000 \pm 600$ AU (0.058 ± 0.003 pc) and a long-expected orbital period ($P \gtrsim 0.9$ Ma), has been repeatedly questioned (Voûte 1917; Wertheimer & Laughlin 2006, and references therein).

Some authors have proposed that α Cen A and B are the brightest members in a stellar kinematic group that includes Proxima Centauri (e.g. Anosova & Orlov 1991). Stars in a stellar kinematic group share a common origin and Galactic spatial velocities (UVW) and are typically young, with Hyades-like or younger ages ($\tau \lesssim 600$ Ma – Soderblom & Mayor 1993; Montes et al. 2001; Zuckerman & Song 2004). Youth may partly explain the existence of some *very wide* binaries (or *very wide* common proper motion pairs), with physical separations of more than 0.1 pc. The younger a wide (or very wide) binary in the Galactic disc, the less time it has had to encounter individual stars and giant molecular clouds, whose gravity will eventually tear them apart (e.g. Bahcall & Soneira 1981; Retterer & King 1982; Weinberg et al. 1987; Saarinen & Gilmore 1989; Poveda & Allen 2004). For instance, the common proper motion "pair" AU Mic and AT Mic A and B has one of the widest projected physical separations ever measured, $s \sim 0.23$ pc, and belongs to one of the youngest stellar kinematic groups, the β Pictoris moving group ($\tau \sim 12$ Ma – Zuckerman et al. 2001; Ortega et al. 2004).

Another way for a very wide binary to avoid encounters in the Galactic disc is to belong to the Galactic halo stellar population. Because of the large inclination of their orbits, halo stars spend most of their lives far from the Galactic plane, where the probability of encountering stars and molecular clouds is at a minimum. As another example, the system HD 149414 AB and BD–03 3968B was the widest metal-poor "binary" in the imaging search by Zapatero Osorio & Martín (2004). The projected physical separation between both components is $s \sim 0.27$ pc. Low metallicities, such as measured in the primary of the system (the F8 subdwarf HD 149414 AB has [Fe/H] ~ -1.4), are

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[⋆] Appendix A is only available in electronic form at `http://www.aanda.org`

[1] 1 pc ≈ 206 264.806 AU.

typical of halo population II stars. The three systems (α Cen, AU Mic, and HD 149414 AB) are discussed next.

There is a sharp cutoff in the number of very wide binaries with physical separations greater than 0.1 pc, possibly dictated by dynamical evolution, as stated in classical (Tolbert 1964; Kraicheva et al. 1985; Abt 1988; Weinberg & Wasserman 1988; Weis 1988; Close et al. 1990; Latham et al. 1991; Wasserman & Weinberg 1991 and references above) and modern works (Allen et al. 2000; Palasi 2000; Chanamé & Gould 2004; Lépine & Bongiorno 2007; Makarov et al. 2008). My aim is to characterise and look for very wide binaries and multiple systems with projected physical separations larger than $s = 0.1$ pc (2×10^4 AU). Some of these systems will be among the least bound ones and might help trace the boundaries between very wide binaries, common proper motion pairs, and stellar kinematic groups on the point of being disrupted.

In this paper, I start a programme of identifying and investigating the widest common proper motion pairs with a detailed analysis of the binary and multiple system candidates with angular separations over 1000 arcsec in the Washington Double Star Catalog (WDS; Mason et al. 2001). It is expected that these large angular separations translate into large physical separations, of the order of a tenth of a parsec. However, the membership in a proper motion pair of many doubles has not been confirmed since their discovery dates (as early as the 19th century in some cases) and most of them were last characterised in the pre-*Hipparcos* era (i.e. no accurate projected physical separations could be measured).

2. Analysis and results

2.1. Data retrieval

First, I compiled the angular separations, ρ, position angles, θ, coordinates, visual magnitudes, and identifiers of 104 312 WDS pairs (as in 2009 May). As can be seen in Fig. 1, the cumulative number of pairs approximately increases with a power law in the interval $\rho \sim 0.2$ to 20 arcsec. The distribution of angular separations is the Öpik law (which formally applies to the distribution of physical separations – Öpik 1924; Poveda & Allen 2004) folded with the distribution of observed systems with heliocentric distance. The number of pairs increases at a more moderate rate from $\rho \sim 20$ to 200 arcsec and practically becomes constant at larger separations. Only 1% [0.1%] of the WDS pairs have angular separations $\rho > 200$ arcsec [500 arcsec]. There are 36 WDS pairs with tabulated separations $\rho > 1000$ arcsec (actually, the WDS catalogue lists them as $\rho \equiv 999$ arcsec). I have carefully investigated all 36 of them, mainly using the Aladin sky atlas (Bonnarel et al. 2000).

Of the 36 WDS binaries, I was not able to identify five binary candidates:

- WDS 05463+5627 (LDS 3673; W. J. Luyten, proper motion catalogues).
- WDS 04022+2808 (STF 481AD; F. G. W. Struve). The primary in the system in the G8II triple star system HD 25296 ABC.
- WDS 09510+0105 (GRV 1149; J. Greaves, private communication). The system might consist of the faint white dwarfs WD 0948+013 and 2QZ J095234.0+011046, but I could not confirm it.
- WDS 18382+2543 (BUP 185AC; S. W. Burnham, proper motion stars). Coordinates have large uncertainties.
- WDS 21435+2721 (A 299DE; R. G. Aitken). Bright star BD+26 4249 is likely the primary in the system.

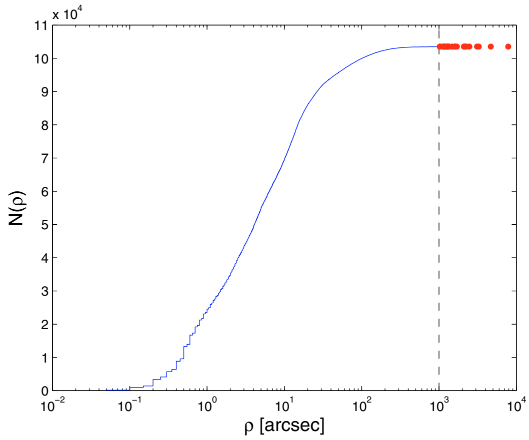

Fig. 1. Cumulative number of WDS pairs as a function of the angular separation, ρ. Data points with $\rho > 1000$ arcsec (to the right of the vertical dashed line) are for the 30 WDS binary candidates investigated here.

These non-idenfications left only 31 WDS pairs to be investigated. In Table A.1, I list their WDS identifier, discovery designation, Simbad name, equatorial coordinates, proper motions, heliocentric distance, V, J, and K_s magnitudes, spectral type, angular separation, and position angle. Coordinates and J and K_s magnitudes were homogeneously retrieved from the Two Micron All Sky Survey (2MASS; Skrutskie et al. 2006), except for the two faint white dwarfs in the system WDS 02255-0904 (GRV 1148), whose coordinates were taken from the sixth data release of the Sloan Digital Sky Survey (SDSS DR6; Adelman-McCarthy et al. 2008). Proper motions were generally taken from the Tycho-2 catalogue (Høg et al. 2000), Salim & Gould (2003), Lépine & Shara (2005 – without tabulated error bars), and Röser et al. (2008), but in some particular cases (e.g. faint white dwarfs), the proper motions were borrowed from other sources in the literature (e.g. Farihi et al. 2005). Some of these values may be affected by observational errors. I retrieved parallaxes from the *Hipparcos* catalogue (van Leeuwen 2007), except for the white dwarf G 1–45 AB in the system WDS 01024+0504, for which I got it from van Altena et al. (1995)[2]. In hierarchical systems, I used the parallax of the brightest component (e.g. α Cen A for the primary in the system WDS 14396–6050). The V-band magnitudes of the brightest stars were taken from the original *Hipparcos* catalogue (Perryman et al. 1997). For the faintest stars, if not available in other works (e.g. Weis 1984; Ryan 1992), I estimated the V-band magnitudes from four epochs of photographic B_J and R_F magnitudes in the USNO-B1 catalogue (Monet et al. 2003) or from SDSS g and r magnitudes. These estimations agreed with others (e.g. Lépine & Shara 2005). Finally, I tabulated spectral types as given by Simbad except for a few cases, for which I found more accurate determinations in the literature (e.g. Joy & Abt 1974). Besides this, I compiled radial velocities from a number of works (Evans 1967; Strassmeier et al. 2000; Latham et al. 2002; Nordström et al. 2004; Torres et al. 2006). Given the low fraction of stars with this measurement, I did not list them in Table A.1.

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[2] The value of d_π of G 1–45 AB tabulated in the fourth edition of the general catalogue of trigonometric parallaxes of van Altena et al. (1995) has a lower uncertainty than the one in Harrington & Dahn (1980), which is 22.2 ± 2.0 pc.

Table 1. Rejected wide binary candidates^a.

WDS identifier	μ	$d_{\rm phot}$	$d_{\rm spec}$	d_π	$V_{\rm r}$
00152+2454	No:	No	...	...	...
00400–1533	No:	No	...	...	...
00435+3351	No	No:	No	...	...
00520+2035	No	No	...	...	...
01163–3217	No:	No	...	...	...
03442–6448	No	No	No	No	No
07590–6338	No	No:	...	...	...
11125+3549	No	No	No	...	...
13410+6808	No:	No	No	...	...
13599+2520	No	No	No	...	...
20084+1503	No:	No	...	...	...
20302+2651	No	No	No	...	...

^{a} Coordinates are provided in Table A.1. The colon after "No" indicates that the corresponding parameters of stars in binary system candidates might be comparable if accounting for generous error bars.

The stars in the system WDS 03330+0306 (G 80–8 and NLTT 11184) are actually separated by *less* than 1000 arcsec ($\rho \approx 429.5$ arcsec), so I did not keep it in the next analysis.

2.2. Rejected binary candidates

I classified the 30 WDS identified binaries with true angular separations $\rho > 1000$ arcsec into confirmed and unconfirmed physical systems based on their basic properties in Table A.1. First, I made a preliminary filtering by rejecting 12 binary candidates whose membership in a physically bound system is impractical because of their different proper motions (μ), heliocentric distances (photometric $d_{\rm phot}$, spectroscopic $d_{\rm spec}$, or parallactic d_π), and/or radial velocities ($V_{\rm r}$), as summarised in Table 1.

WDS 03442–6448. The binary candidate formed by β Ret AB, a K2III spectroscopic binary, and HD 24293, a G3V star, was proposed by Luyten in the mid-20th century based on their similar proper motions. They are bright stars and have accurate *Hipparcos* distance determinations. The distances and true proper motions do not match, nor do their radial velocities, as noted by Gliese & Jahreiss (1988; precise radial velocities are $V_{\rm r,K2III} = +50.8 \pm 0.9$ km s^{-1}, $V_{\rm r,G3V} = +20.8 \pm 0.3$ km s^{-1}).

WDS 00435+3351, WDS 00520+2035, WDS 07590–6338, WDS 11125+3549, WDS 13599+2520, WDS 20302+2651, and WDS 23228+2208. The components in the seven binary candidates have different proper motions. These differences range between $\Delta\mu \approx 44$ mas a^{-1} for Giclas' WDS 00520+2035 and over 400 mas a^{-1} for Weisse's WDS 00435+3351, and cannot be explained by the different location in the sky or by multiplicity of one of the components (see the case of α Cen AB and Proxima in Table A.1). There is spectral type determination for the two components in four systems, and the secondaries have earlier spectral types than the primaries (i.e. the secondaries are located further away).

WDS 00152+2454, WDS 00400–1533, WDS 01163–3217, and WDS 13410+6808. The secondaries of the four binary candidates are fainter and bluer than their corresponding primaries. For example, secondary G 57–17 in Giclas' WDS 11452+1821 is $\Delta J \approx 3.70$ mag fainter, but $\Delta(V - J) \approx 1.90$ mag bluer, than primary G 57–15. From magnitudes, the secondaries seem to be normal dwarfs or subdwarfs with earlier spectral types than the primaries. In the case of Luyten's WDS 13410+6808, there is spectral type determination for the two stars (Lee 1984): the primary G 238–50 is an M2 dwarf at $d = 40 \pm 3$ pc, while the secondary LP 40–200 is a K3 dwarf at $d \sim 100$ pc. Besides, proper motions of primaries and secondaries in the four systems are different at the 3–5σ level.

2.3. Dedicated astro-photometric follow-up

Next, I performed an astro-photometric follow-up and investigated the possible physical bounding of the remaining 18 binary candidates. Of them, five have hypothetical primaries and secondaries with reliable published common proper motions and parallaxes from the *Hipparcos* catalogue. The hypothetical secondary in a sixth system, WDS 13090+3353, in contrast to the primary, does not have a *Hipparcos* measurement, but its proper motion is tabulated in the accurate Tycho-2 catalogue. In all six cases, the similarity between proper motions (and parallaxes) of primaries and secondaries indicate that they are probably bound wide systems (Sect. 2.4).

The other 12 binary candidates were the subject of a detailed proper motion study. For each of them, I collected precise coordinates of secondaries (and primaries, if not too bright) at different astrometric epochs from SuperCOSMOS (Hambly et al. 2001) digitisations of the Palomar Observatory Sky Survey (POSS-I Red, POSS-II Red, POSS-II Blue, POSS-II Infrared) and the 2MASS and CMC14 (Carlsberg Meridian Catalogue; Evans et al. 2002) catalogues. In a couple of cases, I was also able to use SDSS and Guide Star Catalog data. With at least six astrometric epochs covering more than 45 a, I could measure new proper motions of 16 stars (12 secondaries, three primaries, one tertiary) with unprecendented accuracy ($\delta\mu/\mu \lesssim 1\%$).

I display the proper motions of the components in the 12 followed-up systems in Table 2. Primaries and secondaries in nine of them have very different measured proper motions ($\Delta\mu \sim 25$–90 mas a^{-1}), and are likely not to form physically bound systems. There is accurate SDSS photometry for at least one of them (WDS 11452+1821) that supports this assumption (the $K_{\rm s}$ magnitudes and $g - K_{\rm s}$ colours of the hypothetical primary and secondary are 8.260 ± 0.016 and 6.071 ± 0.016, and 12.097 ± 0.023 mag and 3.589 ± 0.023 mag, respectively). There are only three discarded candidate systems, WDS 10197+1928, WDS 11455+4740, and WDS 18111+3241, with the (incorrect) WDS note about binarity "*V*" ("proper motion or other technique indicates that this pair is physical").

The proper motions of the faint white dwarfs WD 0223–092 and WD 0221–095 in the WDS 02255–0904 system differ by about 14 mas a^{-1}, which translates into a relative difference of about 17%. Given the relatively low absolute value of the proper motions (the same order of magnitude as those of typical background thick disc and halo stars and white dwarfs), the very large expected projected physical separation ($s \sim 0.6$ pc for a minimum heliocentric distance of $d = 100$ pc), and the low mass of the objects ($M_{\rm A} \sim M_{\rm B} \lesssim 1\ M_\odot$), asserting that the system may be gravitationally bound is rather speculative.

Of the other two systems, the identical parallactic distances and similar proper motions and isochronal ages of binary star HD 6101 AB and white dwarf G 1–45 AB in system WDS 01024+0504 support a true physical connection (see below). However, HD 101 and LP 404–21 in system WDS 00059+1805, although having similar proper motions, are *not* physically connected. WDS 00059+1805 is a hierarchical triple system at $d = 37.1 \pm 0.8$ pc. The non-tabulated system

Table 2. New proper motions of components in wide binary candidates.

WDS identifier	Name	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	$\Delta\mu$ [mas a^{-1}]
00059+1805	HD 101[a]	–152.2 ± 1.1	–148.1 ± 1.4	9.1 ± 1.7
	LP 404–21	–146.6 ± 0.4	–140.9 ± 0.4	
01024+0504	HD 6101 AB[a]	+323.3 ± 1.2	+226.0 ± 1.2	6 ± 2
	G 1–45 AB	+329.3 ± 0.5	+223.7 ± 1.0	
02255–0904	WD 0223–092	+82.0 ± 1.5	+11.3 ± 1.0	14 ± 3
	WD 0221–095	+82.8 ± 1.9	–2.9 ± 1.7	
02310+0823	G 73–63[a]	+376.1 ± 1.9	–85.4 ± 1.6	50 ± 3
	G 73–59	+344.7 ± 0.9	–124.2 ± 1.5	
03162+5810	GJ 130.1 A[a]	+445.6 ± 3.9	–340.3 ± 4.1	92 ± 6
	G 246–30	+479.4 ± 0.7	–255.1 ± 1.0	
10197+1928	40 Leo[a]	–230.2 ± 0.6	–214.6 ± 0.4	25 ± 2
	LP 371–59 A[b]	–223.5 ± 1.3	–238.2 ± 1.6	
11452+1821	G 57–17	–297.1 ± 1.9	–291.3 ± 1.2	50 ± 3
	G 57–15	–258.0 ± 1.4	–260.9 ± 0.7	
11455+1821	HD 102158[a]	–591.6 ± 0.7	–290.7 ± 0.5	91.6 ± 1.5
	G 122–46	–581.2 ± 1.0	–199.7 ± 0.7	
16348–0412	HD 149414 AB[a]	–133.7 ± 1.4	–701.2 ± 1.4	61 ± 2
	BD–03 3968B[c]	–191.2 ± 0.7	–680.0 ± 1.0	
18111+3241	BD+32 3065[a]	–134.7 ± 1.2	+322.1 ± 1.3	28 ± 2
	G 206–16	–161.1 ± 0.8	+326.8 ± 1.3	6 ± 2[d]
	NLTT 46103	–156.7 ± 0.5	+322.4 ± 1.6	
22175+2335	G 127–13	–93.1 ± 1.1	–383.7 ± 0.4	36.4 ± 1.5
	G 127–14	–115.7 ± 0.7	–412.2 ± 0.5	
23228+2208	BD+21 4923[a]	+198.3 ± 1.2	–69.8 ± 1.2	94 ± 3
	G 68–7	+276.1 ± 1.8	–122.1 ± 1.3	

[a] Proper motions of bright primaries are from Röser et al. (2008); [b] LP 371–59 A is the primary in a close binary system (see text); [c] Bakos et al. (2002) tabulated "revised proper motions" for BD–03 3968B that were wrong by almost 1000 mas a^{-1}; [d] $\Delta\mu$ between G 206–16 and NLTT 46103.

members are HD 113 A and B (HIP 495), which is a K0+K0 binary ($\rho = 3.445 \pm 0.004$ arcsec, $\Delta H_P = 0.29 \pm 0.02$ mag) at about 9.4 arcmin to the south of the F8 primary HD 101. The hypothetical fourth component, LP 404–21, is 7.7 mag fainter in the J band than the primary. This magnitude difference would imply that LP 404–21 is an M5–6 dwarf with a colour $V - J \sim 5.5$ mag if it were located at the same heliocentric distance to HD 101 (assuming a typical age of 0.5–5 Ga). However, its actual $V - J$ colour is only about 2.5 mag and LP 404–21 is thus a late-K- or early-M-type dwarf or subdwarf at a larger heliocentric distance. Lépine & Bongiorno (2007) also suggest its subdwarf nature.

2.4. Probable bound systems

From previous section, only seven systems remain (six with reliable common proper motions from *Hipparcos* or Tycho-2 catalogues, plus the HD 6101 AB + G 1–45 AB system) with a high probability of being physically connected, as discussed in detail just below.

2.4.1. WDS 01024+0504 (HD 6101 AB and G 1–45 AB)

This is a hierarchical quadruple system. HD 6101 AB is a relatively bright (V = 8.16 mag) close binary star of combined spectral type K3V and low activity ($\log R'_{\rm HK} = -4.661$; Gray et al. 2003). It was first resolved by the *Hipparcos* mission ($\rho = 0.711 \pm 0.011$ arcsec, $\Delta H_P = 1.87 \pm 0.04$ mag). Afterwards, it has been astrometrically followed up by several authors (Mason et al. 1999; Balega et al. 2002, 2004, 2007; Richichi et al. 2007). Using mostly speckle interferometric observations, Balega et al. (2006) present new orbital parameters for HD 6101 AB, from where they derive a period $P = 29.0 \pm 0.6$ a, a semi-major axis $a = 9.8 \pm 0.3$ AU, and a total mass $\mathcal{M}_{\rm A} + \mathcal{M}_{\rm B} = 1.17 \pm 0.14\,M_\odot$. Accounting for the magnitude difference in the optical ($\Delta V \approx$ 1.7 mag), the Siess et al. (2000) grid of tracks for low- and intermediate-mass stars of 1–5 Ga and the Balega et al. (2006) total mass, one may derive that the secondary must have a spectral type between K7V and M2V.

At 1276 arcsec to the east of HD 6101 AB, it is located the binary white dwarf G 1–45 AB (WD 0101+048). It was discovered in the Lowell proper motion survey of Giclas et al. (1959), who assigned it a DAs spectral type (currently, it is determined at DA5). Because of its relative brightness (V = 14.10 mag), G 1–45 AB has been investigated and catalogued on numerous occasions (Shipman 1979; Green et al. 1986; Liebert et al. 1988; McCook & Sion 1999; Bergeron et al. 2001; Zuckerman et al. 2003; Farihi et al. 2005; Mullally et al. 2007). The white dwarf is a double degenerate, as it shows radial velocity variations with an uncertain period of 0.7–6.5 d (Saffer et al. 1998; Maxted et al. 2000). The spectroscopic (total) mass of 0.77 $M_\odot$ provided by Lajoie & Bergeron (2007) is consistent with the parallactic distance of G 1–45 AB measured by van Altena et al. (1995) and of HD 6101 AB measured by *Hipparcos* (however, many papers list photometric distances at about 13.5 pc, which do *not* fit white dwarf theoretical models).

Proper motions of both binary objects differ by only 6 ± 3 mas a^{-1} (Sect. 2.3). Because of the similarity in parallactic distance and proper motion, the WDS note "V" about the wide binarity of HD 6101 AB and G 1–45 AB ("[...] this pair is physical") may be correct.

2.4.2. WDS 13090+3353 (LP 268–35 and LP 268–33)

The system LEP 62AC is proposed by Lépine & Bongiorno (2007). It is, therefore, one of the very wide binary candidates in this work that have been identified more recently. It is also the faintest system in this section (only the primary is listed in the *Hipparcos* catalogue). As a result, both stars have been poorly investigated. The most remarkable fact in the literature is that Ryan (1992) classified the primary, LP 268–35, as a normal dwarf based on *UBVRI* photometry (i.e., it is not a subdwarf of the Galactic halo). Previously, it had been proposed in one of the Luyten proper motion catalogues that the primary forms a closer pair with a star located at about 3 arcmin to the southwest (LP 268–34). The USNO-B1 proper motion of this hypothetical companion, "WDS 13090+3353 B", is ($\mu_\alpha \cos\delta$, μ_δ) ≈ (–218, –38) mas a^{-1}, consistent with an accurate measurement by Lépine & Shara (2005), but different from those of LP 268–35 and LP 268–33 by more than 70 mas a^{-1} (i.e., LP 268-34 is not part of the proper motion system).

In Table 3, I compile SDSS and 2MASS photometry of both LP 268–35 and LP 268–33. There is good agreement between the observed magnitudes and those expected for K7–M1V and M4–5V stars at the *Hipparcos* distance of the primary, d = 66 ± 12 pc. For the comparison, I used the colours and absolute magnitudes as functions of late spectral type as tabulated by Bochanski et al. (2007), West et al. (2008), and Caballero et al. (2008). While the fit of the colours from $rizJHK_{\rm s}$-band magnitudes of LP 268–33 to an M4.5 ± 0.5V template is excellent, the dwarf displays an obvious blueing in the u and g bands. This is not unforeseen, since roughly 50% of M4–5V stars display activity, which is associated to an excess of flux in the blue optical (West et al. 2008). Activity lifetimes of M4–5V stars vary

Table 3. Photometry of system WDS 13090+3353.

Magnitude	LP 268–35	LP 268–33
u [mag]	15.480 ± 0.007	19.860 ± 0.038
g [mag]	12.588 ± 0.001	17.175 ± 0.007
r [mag]	11.126 ± 0.001	15.727 ± 0.006
i [mag]	10.720 ± 0.001	14.135 ± 0.006
z [mag]	10.887 ± 0.002[a]	13.265 ± 0.007
J [mag]	9.296 ± 0.019	11.685 ± 0.021
H [mag]	8.740 ± 0.018	11.052 ± 0.021
K_s [mag]	8.623 ± 0.018	10.769 ± 0.019

[a] The z-band measurement of LP 268–35 is probably affected by non-linearity of the detector.

between 4.0 and 7.5 Ga, which may be understood as an upper (conservative) limit for the age of LP 268–33.

The difference in proper motion between LP 268–35 and LP 268–33, $(\Delta\mu_\alpha \cos\delta, \Delta\mu_\delta) = (1\pm6, 11\pm6)$ mas/a, is null within 1–2σ. Given the resemblance between proper motions and parallactic and photometric distances of the two of them, I will assume that they *travel together* through the Galaxy. No radial velocity measurements exist for the two dwarfs, from where one could confirm the common space velocity or identify membership in a young moving group.

Using the 2MASS J-band magnitudes in Table 3, the hypothetical common distance $d = 66 \pm 15$ pc, a solar age, and the theoretical models of Baraffe et al. (1998), I derive masses $\mathcal{M}_{\rm A} = 0.71 \pm 0.08\,M_\odot$ and $\mathcal{M}_{\rm B} = 0.32 \pm 0.09\,M_\odot$ for LP 268–35 and LP 268–33 (at late spectral types, the near-infrared J band works better for comparison with the Lyon theoretical models than optical ones – e.g. V).

2.4.3. WDS 14396–6050 (α Cen AB and Proxima)

The α Cen system has been the subject of intensive and extensive studies in the literature (Gasteyer 1966; Kamper & Wesselink 1978; Matthews & Gilmore 1993; Wertheimer & Laughlin 2006). As already mentioned in Sect. 1, Anosova & Orlov (1991) proposed that α Cen AB and Proxima are stars in the "moving group of α Cen". The other stars in the moving group would be the binary HD 21209 AB (K3.5V + K8Vk:) and the triple system V1089 Her and V1090 Her AB (K5.0V + [K5.0V + M1.0V]; Reid et al. 2004). Anosova et al. (1994) went on the discussion[3], and enlarged the list of "satellites of α Cen". However, in spite of the chromospheric activity of Proxima (with flares and strong Mg II h+k λ280 nm in emission), the α Cen triple system is accepted to be relatively old, with an age at about 5–6 Ga. Since I do not present new data that help answering the original question in Voûte (1917), that if "they [α Cen AB and Proxima] are physically connected or members of the same drift", I follow Ludwig Wittgenstein's proposition of "passing over in silence" and will follow the general agreement that they *are* gravitationally bound.

The masses compiled by Wertheimer & Laughlin (2006) for α Cen AB and Proxima were $2.039 \pm 0.009\,M_\odot$ (combined) and $0.11 \pm 0.02\,M_\odot$, respectively.

2.4.4. WDS 15208+3129 (HD 136654 and BD+32 2572)

This system, formed by an F5V and a K0V star, was also proposed by Lépine & Bongiorno (2007). However, in contrast to system WDS 13090+3353, there exist *Hipparcos* parallax measurements for both HD 136654 and BD+32 2572. From the new data reduction by van Leeuween (2007), the differences between proper motions and parallactic distances are $(\Delta\mu_\alpha \cos\delta, \Delta\mu_\delta) = (1.3 \pm 0.7, 0.6 \pm 1.1)$ mas/a and $\Delta d = 1 \pm 2$ pc. The difference between radial velocities is also very small and probably not significant: $\Delta V_{\rm r} = 0.7 \pm 0.5$ km s^{-1} (Montes et al. 2001; Nordström et al. 2004). As a result, they seem to form a real common proper motion pair.

The primary in the system, HD 136654, is a single (Mason et al. 2001), non-variable (McMillan et al. 1976), high metallicity (Fischer & Valenti 2005; Robinson et al. 2006) star. The secondary, BD+32 2572, has not been investigated so well: Strassmeier et al. (2000) found Ca II H+K in emission and Violat-Bordonau & Violat-Martín (2006) measured a low amplitude of photometric variability ($\Delta V \approx 0.18$ mag) with a period near 9.24 d. However, the most important fact is that BD+32 2572 is a probable member in the Hyades Supercluster ("Kapteyn's stream I"; Montes et al. 2001), which automatically puts HD 136654 in as well. Indeed, the HD 136654 high metallicity and space velocities from Nordström et al. (2004) and Karataş et al. (2004) agree well with such a membership and, thus, an Hyades-like age. At $\tau \sim 600$ Ma, theoretical masses of HD 136654 and BD+32 2572 are $\mathcal{M}_{\rm A} \sim 1.2$–$1.3\,M_\odot$ and $\mathcal{M}_{\rm B} \sim 0.9$–$1.0\,M_\odot$ (Baraffe et al. 1998; Siess et al. 2000).

2.4.5. WDS 20124–1237 (ξ^{02} Cap and LP 754–50)

The primary star, ξ^{02} Cap, is a single (McAlister et al. 1987; Lagrange et al. 2009), F7V-type star that has been subject of numerous analyses. Some basic stellar parameters are $T_{\rm eff} \approx 6330$ K, [Fe/H] $\approx$ –0.27, $\mathcal{M} \approx 1.10\,M_\odot$, $\log \epsilon_{\rm Li} \approx 2.79$, $\tau \approx 4.78$ Ga (Chen et al. 2001; Lambert & Reddy 2004). Its solar age is consistent with a relatively large modulus of vertical heliocentric space velocity component, $W = -42$ km s^{-1} (Nordström et al. 2004).

The secondary star, LP 754–50, has been referred to a few times in the literature. It is a Luyten star whose astrometry was improved by Salim & Gould (2003) and whose spectral type was determined at M0Vk by Gray et al. (2006). The latter authors also measured $\log R'_{\rm HK} = -4.699$, which is at the active-inactive boundary (but with redder $B - V$ colour). The star was tabulated in the *Hipparcos* catalogue. Its parallactic distance in the new reduction by van Leeuwen (2007), $d = 23.6 \pm 1.6$ pc, differs from the one in the original catalogue by Perryman et al. (1997), $d = 26.4 \pm 1.9$ pc, and from those of ξ^{02} Cap ($d = 27.7 \pm 0.3$ and 28.1 ± 0.7 pc, respectively). In general, the new reduction by van Leeuwen (2007) provided better accuracy, by up to a factor four, than in the original *Hipparcos* catalogue. However, it was not infallible. For example, Caballero & Dinis (2008) show some stars whose astrometric solution got worse with the new reduction. If LP 754–50 were located at the distance to ξ^{02} Cap, it would have an absolute J-band magnitude $M_J = 6.27 \pm 0.03$ mag, which translates into a theoretical mass $\mathcal{M} \sim 0.55\,M_\odot$ and an effective temperature typical of an early M dwarf of solar age (Baraffe et al. 1998). Using the original *Hipparcos* astrometry (parallaxes, proper motions), there are grounds for considering WDS 20124–1237 a physical pair.

2.4.6. WDS 20452–3120 (AU Mic and AT Mic AB)

It is a late-type, hierarchical triple system in the very young β Pictoris moving group ($\tau \sim 12$ Ma). The secondary,

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[3] A critical reading is needed: Anosova et al. (1994) assumed a mass of $0.020\,M_\odot$ for Proxima, close to the brown dwarf-planet boundary, which is about five times lower than currently assumed.

Table 4. Probable bound wide systems.

WDS identifier	Primary	Secondary	s [10^3 AU]	$\mathcal{M}_1$ [$M_\odot$]	$\mathcal{M}_2$ [$M_\odot$]	P^* [Ma]	U_g^* [10^{33} J]
01024+0504	HD 6101 AB	G 1–45 AB	26.9 ± 0.6	1.17	0.77	3.2	–59.1
13090+3353	LP 268–35	LP 268–33	84 ± 15	~0.7	~0.3	24	–4.4
14396–6050	α Cen AB	Proxima	12.0 ± 0.6[a]	2.039	0.11	0.90[a]	–32.1[a]
15208+3129	HD 136654	BD+32 2572	68.8 ± 1.7	~1.2	~0.9	12	–28
20124–1237	ξ^{02} Cap	LP 754–50	28.3 ± 0.3	1.10	0.55	3.7	–37.8
20452–3120	AU Mic	AT Mic AB	46.4 ± 0.5	0.45	0.52	10	–7.7
20599+4016	HD 200077 AE–D	G 210–44 AB	49.7 ± 1.1	~2.9	~1.2	5.5	–120

[a] True physical separation, orbital period, and gravitational energy accounting for the different heliocentric distances.

AT Mic AB, is a binary resolved by *Hipparcos* (ρ = 3.349 ± 0.007 arcsec, $\Delta H_P = 0.09 \pm 0.06$ mag). Numerous investigations and reviews have targeted the *three* stars, which are among the youngest pre-main sequence stars in the solar neighbourhood. They display X-ray emission, flaring activity, flux excess in the infrared due to a circumstellar disc (AU Mic), photometric variability (of BY Dra type), active coronae, Ca ii H+K in emission, and other properties typical of young stars (Linsky et al. 1982; Kundu et al. 1987; Pallavicini et al. 1990; Batalha et al. 1996; Barrado y Navascués et al. 1999; Katsova et al. 1999; Zuckerman et al. 2001; Kalas et al. 2004). There is a difference between *Hipparcos* heliocentric distances of 0.8 ± 0.4 pc, which could be real (as in the case of α Cen AB and Proxima) or stem from a poor accuracy in the parallax measurement (e.g. as in the case of WDS 13090+3353 and WDS 20124–1237).

Using the parallactic distances by van Leeuwen (2007), the 2MASS JHK_s-band magnitudes, an estimated age $\tau = 12^{+8}_{-4}$ Ma, and the NextGen models from Baraffe et al. (1998), and assuming that the difference of magnitudes in the near infrared between AT Mic A and AT Mic B are $\Delta(JHK_s) \lesssim \Delta H_P$, I derive masses of 0.45 ± 0.10, $0.27^{+0.04}_{-0.09}$, and $0.25^{+0.04}_{-0.09}$ $M_\odot$ for AU Mic (M1Ve), AT Mic A (M4.5Ve), and AT Mic B (M5:).

Although the stars in the β Pictoris moving group are spread over a space region with a size of only about 74 pc (Ortega et al. 2002), the short separation between AU Mic and AT Mic AB (projected physical separation s = 0.226 ± 0.002 pc) is remarkable and may indicate a common origin within the birthplace.

2.4.7. WDS 20599+4016 (HD 200077 AE–D and G 210–44 AB)

It is a hierarchical quintuple system of complicated nomenclature and structure. On the one hand, HD 200077 is a triple star of combined F8V spectral type. In the year 1908, Burnham proposed that two stars of $V \sim 6-10$ mag at $\rho \sim$ 2–3 arcmin to the southeast and southwest of HD 200077, labelled "B" and "C", were common proper motion companions. They are, however, background stars of lower proper motion. Almost a century later, the *Hipparcos* mission resolved HD 200077 into a close binary with ρ = 1.949 ± 0.027 arcsec, ΔH_P = 4.07 ± 0.10 mag; the faintest component receives the label "D". The brightest one is, in its turn, a double-lined spectroscopic binary discovered by Latham et al. (1988) and confirmed by Goldberg et al. (2002); the low-mass spectroscopic companion is labelled "E". Mazeh et al. (2003) tabulated $P_{\rm AE} = 112.55 \pm 0.04$ d, $q_{\rm AE} = 0.85 \pm 0.02$, and $[{\rm Fe/H}]_{\rm AE} = -0.40$. These authors used the estimated mass $\mathcal{M}_{\rm A} \sim 0.84$ $M_\odot$ for the primary from Carney et al. (1994), which is inconsistent with the F8V spectral type and several effective temperature determinations of components A and E (e.g. Goldberg et al. 2002). These determinations favour masses $\mathcal{M}_{\rm A} \sim 1.1-1.3$ $M_\odot$ and $\mathcal{M}_{\rm E} \sim$ 0.9–1.0 $M_\odot$ (and spectral types G1V and G6–9V, respectively). The component D, given its magnitude difference with respect to AE, may be a late K-type dwarf with a mass $\mathcal{M}_{\rm D} \sim 0.7$ $M_\odot$. The triple system as a whole does not display X-ray activity (Ottmann et al. 1997).

On the other hand, G 210–44 AB, of combined spectral type M1V, is another close binary first resolved by *Hipparcos* (ρ = 0.334 ± 0.023 arcsec, ΔH_P = 1.30 ± 0.27 mag – see also Balega et al. 2004, 2007). Using the theoretical models of Baraffe et al. (1998), G 210–44 AB matches the scenario of an 0.65 $M_\odot$- and an 0.55 $M_\odot$-mass pair at d = 41.0 ± 0.9 pc moving in the same direction as HD 200077 AE–D.

3. Discussion

3.1. The 0.1 pc "cutoff", young moving groups, orbital periods, and missing binaries

Parallax, proper motion, and photometry measurements are all consistent with the seven systems being physical pairs. Six of them have projected physical separations $s > 0.1$ pc ($s > 2 \times 10^4$ AU; fourth column in Table 4). The exception is the α Cen system. Even accounting for the different heliocentric distances, the true physical separation between α Cen AB and Proxima, r = 0.058 ± 0.003 pc ($r > s$), is shorter than the tenth of a parsec. However, the existence of six systems with $s > 0.1$ pc, if really bound, shows that there are deviations to the hypothetical cutoff in binary frequency at this value, as proposed originally by Bahcall & Soneira (1981) and Retterer & King (1982).

The widest systems are WDS 13090+3353 (LP 268–35; s = 0.41 ± 0.07 pc) and WDS 15208+3129 (HD 136654; s = 0.334 ± 0.008 pc), which is a probable member in the Hyades Supercluster ($\tau \sim 600$ Ma). Systems WDS 20599+4016 (HD 200077) and AU Mic in the β Pictoris group ($\tau \sim 12$ Ma) also have projected physical separations larger than 0.2 pc. Three of the latter four systems were first proposed by Lépine & Bongiorno (2007) as faint companions of *Hipparcos* stars. This is an indication of how much we still must learn of wide binarity in the solar neighbourhood.

Remarkably, two of the seven systems belong to young kinematic groups (HD 136654 and AU Mic). This agrees with the simple idea that young wide binary systems have had less time to be perturbed and disrupted by Galactic material of all types. However, a few of the remaining systems have relatively well-determined ages at about the Solar value, such as WDS 01024+0504 (HD 6101, which has a relatively cool binary white dwarf companion that had to leave the main sequence several 10^8 a ago), α Cen, and WDS 20124–1237 (ξ^{02} Cap). The absence of X-ray emission from HD 200077 probably indicates that its system is older than 1 Ga as well. It only leaves the LP 268–35 system (the widest one) as a suitable target for investigating its membership in a young kinematic group.

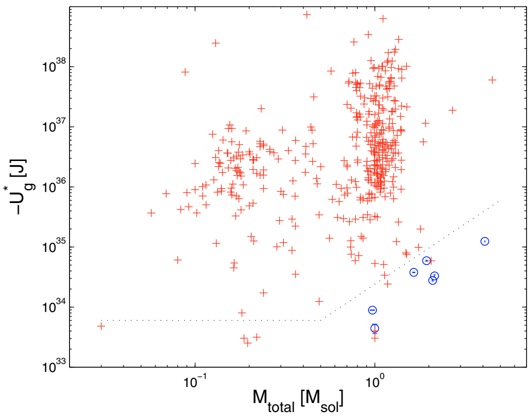

Fig. 2. Binding energy-total mass diagram. Open (blue) circles with error bars are for the seven systems in Sect. 2.4 and (red) crosses are for the ensemble of systems with very low-mass components presented in the text. The dotted line indicates a boundary for the selection of multiple systems in the solar neighbourhood with at least one low-mass component ($\mathcal{M} < 0.15\ M_\odot$) and the lowest binding energies for their total masses.

The minimum orbital periods P^* (Table 4) range between less than 1 Ma for α Cen and 24 Ma for LP 268–35. I computed P^* using the Kepler's Third Law and the projected physical separation between components in system, s, assuming that they are located at the distance of the primary (i.e. s instead of r or a). With an age not older than $\tau \sim 20$ Ma, the AU Mic system in the β Pictoris moving group has only completed at most two orbital periods since its formation. However, although it is also young and has a long orbital period of about 12 Ma, the HD 136654 system in the Hyades Supercluster ($\tau \sim 600$ Ma) has revolved roughly 50 times about a common centre of mass. The rest of the wide systems have had enough time to complete several hundred orbits.

There can be missing binaries in the WDS catalogue with angular separations $\rho < 1000$ arcsec but projected physical separations $s > 10^5$ AU (i.e. at larger heliocentric distances than the systems studied here and, therefore, more difficult to follow up in general) or even not listed in the WDS catalogue. For example, the system Fomalhaut + TW PsA in the young Castor moving group was proposed by Gliese (1969) and does not appear in the catalogue as a possible wide binary ($\rho \approx 7100$ arcsec, $r = 0.28 \pm 0.03$ pc, $\Delta\mu = 6.1 \pm 0.8$ mas a^{-1}). The halo system HD 149414 (Sect. 1) is neither in the WDS. The search for such missing wide binaries will be carried out in another work.

3.2. A comparison of binding energies

Wide binarity is synonymous with multiplicity of systems with very low (absolute values of) gravitational potential energies, $U_g = -GM_1\ M_2/r$. In the last column of Table 4, I show the gravitational potential (binding) energy, U^*_g, using $r \sim s$ (except for α Cen), and the corresponding combined masses (e.g. at a large separation, Proxima feels the gravitational attraction of α Cen AB as if it were a single, more massive star). The asterisk in U^*_g indicates that the absolute values of the "true" potential energies U_g using the physical separation r must be lower than in Table 4.

In Fig. 2, I show a $-U^*_g$ vs. $M_1 + M_2$ diagram for the seven systems in Sect. 2.4 (circles) and a collection of 399 multiple systems including mostly:

- the Sun and the four giant planets in the Solar System (Jupiter, Saturn, Uranus, and Neptune);
- transit and radial-velocity exoplanets and candidates from the Extrasolar Planet Encyclopaedia;
- "classic" late-M-type binaries of the Solar neighbourhood with mass ratios $q > 0.5$, such us EZ Aqr AB, EI Cnc AB, QY Aur AB, and GJ 1005 AB;
- field late-M-, L-, and T-type binaries in systems with $q > 0.5$ (e.g. Lane et al. 2001; Bouy et al. 2003; Siegler et al. 2005; Forveille et al. 2005; Burgasser & McElwain 2006; Caballero 2007a – see also Bouy et al. 2005 and Burgasser et al. 2007 for compilations);
- "classic" systems in the Solar neighbourhood with late-M-type companions and $q < 0.5$, such us V1054 Oph + GJ 643 + vB 8, GX And + GQ And, EQ Peg AB, V1428 Aql + vB 10, and o^2 Eri AC;
- field stellar systems with late-M-, L-, and T-type companions and $q < 0.5$ (e.g. Rebolo et al. 1998; Goldman et al. 1999; Burgasser et al. 2000; Kirkpatrick et al. 2001; Gizis et al. 2001; Scholz et al. 2003; Seifahrt et al. 2005).

This sample was used by Caballero (2007b) for comparison purposes and was quite complete for systems with at least one planet, brown dwarf, or low-mass star with $M_2 \lesssim 0.15\ M_\odot$ (i.e. with low $M_1 M_2$ product or, inversely, small expected $|U^*_g|$). Afterwards, it has been updated with new discoveries (e.g. Radigan et al. 2009).

The seven systems in Sect. 2.4 are among the multiple systems in the solar neighbourhood with the lowest binding energies for their total masses. Of the collection of 399 multiple systems, only eight (not counting α Cen) have comparably low values of $|U^*_g|$ (Table 5; they are the systems below the dotted line in Fig. 2). Two of them are not resolved multiple stellar systems, but planetary systems: the Sun and Uranus, and the Sun and Neptune.

The brown dwarf-exoplanet pair 2M1207–39 AB (Chauvin et al. 2004, 2005), because of its high mass ratio ($q \sim 0.2$) and young age ($\tau \sim 8$ Ma; it is a member of the TW Hydrae Association) if compared to those of the rest of exoplanetary systems, resembles a recently-born, low-mass, substellar binary more than an exo-planetary system (Chauvin, priv. comm.). Other similar systems, some of them with wider projected physical separations but without common proper-motion confirmation, have also been discovered in the Orion OB1 association (Caballero et al. 2006; Barrado y Navascués et al. 2007), Upper Scorpius (Kraus & Hillenbrand 2007; Béjar et al. 2008), and highly extinguished star-forming regions in the Southern Hemisphere, such as Chamaeleon and Lupus (López Martí et al. 2004, 2005; Luhman 2004).

Five proper-motion-confirmed, low binding-energy systems remain, of which three have total masses $M_1 + M_2 \ll 1\ M_\odot$. They are the only representatives of the rare class of very wide ($s > 1000$ AU), very low-mass ($M_1 + M_2 \lesssim 0.2\ M_\odot$), equal-mass ($q \sim 1$) binaries: Koenigstuhl 1, 2M0126–50, and 2M1258+40. The other two systems with total masses $M_1 + M_2 \sim 1 - 2\ M_\odot$ have L-type companions at 3600 (η CrB) and 11 900 AU (Koenigstuhl 3) to bright stars.

Because of the relatively high value of $|U^*_g|$, typical of binaries in the solar neighbourhood, the quintuple system HD 200077 in Table 4 is likely bound. The same can be applied to HD 6101, α Cen, HD 136654, and ξ^{02} Cap, with values $|U^*_g| > 25 \times 10^{33}$ J. However, both LP 268–35 and AU Mic systems have very low absolute values of potential energy, similar to those of the most weakly bound known binaries, which are the Chauvin et al. (2004) substellar pair and the three binaries of very low-mass stars or brown dwarfs separated by more than

Table 5. Multiple systems in the solar neighbourhood with at least one low-mass component ($\mathcal{M} < 0.15\ M_\odot$) and the lowest binding energies for their total masses.

WDS identifier	Primary	Secondary	s [10^3 AU]	$\mathcal{M}_1$ [$M_\odot$]	$\mathcal{M}_2$ [$M_\odot$]	U_g^* [10^{33} J]	Discovery reference
00212–4246[a]	Kö 1 A	Kö 1 B	1.8	0.103	0.079	–8.0	Caballero (2007a)
01269–5023	2M0126–50 A	2M0126–50 B	5.1	0.095	0.092	–3.0	Artigau et al. (2007)
12076–3933	2M1207–39 A	2M1207–39 B	0.046	0.025	0.005	–4.8	Chauvin et al. (2004)
...[b]	2M1258+40 A	2M1258+40 B	6.7	0.105	0.091	–2.5	Radigan et al. (2009)
15232+3017[c]	η CrB AB	η CrB C	3.6	2.000	0.060	–59	Kirkpatrick et al. (2001)
23315–0405[d]	Kö 3 A	Kö 3 BC	11.9	1.02	0.160	–24	Caballero 2007b)
...	Sun	Uranus	0.019191	1.000	4.367×10^{-5}	–4.0	Herschel 1783[e]
...	Sun	Neptune	0.030069	1.000	5.151×10^{-5}	–3.0	Le Verrier (1847)[f]

[a] The (abridged) names of the components in the Koenigstuhl 1 system are LEHPM 494 (Kö 1 A) and DE0021–42 (Kö 1 B); [b] the system 2M1258+40 AB awaits a WDS numbering; [c] Kirkpatrick et al. (2001) used the name "Gl 584C" for the brown dwarf companion η CrB C. The primary η CrB AB is a spectroscopic binary with individual masses 1.003 and 0.997 $M_\odot$; [d] the (abridged) names of the components in the Koenigstuhl 3 system are HD 221356 (Kö 3 A) and 2M2331–04 AB (Kö 3 BC). The secondary is, in its turn, an M8.0V + L3.0V close binary with individual masses 0.088 and 0.072 $M_\odot$ (Gizis et al. 2000, 2003; Caballero 2007b); [e] actually, Uranus was pointed out by William Herschel in March 1781; [f] there is a consensus that Urbain Le Verrier, John Couch Adams, and Johann Galle jointly deserve credit for discovering Neptune.

1000 AU. LP 268–35 and AU Mic, with projected physical separations between two and three orders of magnitude larger, must be very fragile and will be soon torn apart by third bodies, if they are not already in the process of disruption.

4. Summary

Of the 104 312 pairs in the Washington Double Star Catalog (as in 2009 May), I selected for follow-up the 36 pairs with tabulated angular separations $\rho > 1000$ arcsec. Of them, I was not able to identify five, and a sixth pair had an actual angular separation under 1000 arcsec. I rejected 12 of the remaining 30 pairs as binary candidates based on discordant published proper motions, heliocentric distances, and radial velocities. After a careful astro-photometric examination, with several astrometric epochs covering at least 45 a and proper-motion accuracies of 0.4–1.9 mas a^{-1}, only seven of the other 18 systems remained as probable bound systems. They were:

- WDS 01024+0504: a quadruple system containing HD 6101 AB, a K3V close binary, and G 1–45 AB, a spectroscopic white dwarf binary.
- WDS 13090+3353: LP 268–35 and LP 268–33, two poorly-know, late-type dwarfs separated by about 84 000 AU. It is the widest (and most fragile) system in my sample. The hypothetical secondary displays flux excess in the blue optical (SDSS u and g) that can be ascribed to activity.
- WDS 14396–6050: the celebrated system α Cen AB and Proxima.
- WDS 15208+3129: a pair of F5V and K0V stars in the Hyades Supercluster. I first assign membership of the primary, HD 136654, in this moving group.
- WDS 20124–1237: the bright star ξ^{02} Cap and the M0Vk high-proper motion star LP 754–50.
- WDS 20452–3120: the very young stars AU Mic and AT Mic AB in the β Pictoris moving group. They have completed two orbital periods at most since their birth.
- WDS 20599+4016: a hierarchical quintuple system around an F8V star. With a total mass of about 4.1 $M_\odot$, it is the most massive system in my sample.

Six of the seven hypothetical very wide systems have projected physical separations greater than the cutoff at $s = 0.1$ pc stated in many classical works, such as Bahcall & Soneira (1981), Retterer & King (1982), or Weinberg et al. (1987). Actually, there are four [two] systems with projected physical separations larger than 0.2 pc [0.3 pc]. In order words, the cutoff at $s = 0.1$ pc is not an absolute limit: there are systems with wider projected physical separations, although they are extremely rare.

Only two wide systems belong to young moving groups (Hyades Supercluster and β Pictoris), which indicates that the origin of such wide separations resides not only in the binary formation process, but also in the subsequent dynamical evolution (e.g. by interaction with another stars in the Galactic disc or with the interstellar medium).

All the systems except AU Mic + AT Mic AB and LP 268–35 + LP 268–33 are consistent with being physical doubles. To ascertain that, I computed the minimum absolute values of binding energies, $|U_g^*(s)|$ of the seven systems, and compared them with those of a large ensemble of systems containing at least one component less massive than 0.15 $M_\odot$.

Bound systems that are wider than 10^5 AU may exist if they have enough gravitational energy (i.e. total mass $M_1 + M_2 \gtrsim 6\ M_\odot$), but they are likely to be young systems on the point of disruption by dynamical encounters in the Galactic disc.

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Appendix A: Washington double stars with $\rho > 1000$ arcsec

Table A.1. Basic data from the literature of Washington double stars with tabulated angular separations $\rho > 1000$ arcsec.

WDS identifier	Discovery designation[a]	Simbad name	α (J2000)	δ (J2000)	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	d_π [pc]	V^b [mag]	J [mag]	K_s [mag]	Sp. type	ρ [arcsec]	θ [deg]
00059+1805	LEP 1AE	HD 101	00 05 54.74	+18 14 05.8	–152.2 ± 1.1	–148.1 ± 1.4	37.1 ± 0.8	7.46	6.332 ± 0.019	6.034 ± 0.024	F8	1606.8	245.9
		LP 404–21	00 04 11.81	+18 03 10.7	–146	–146	...	16.3	14.068 ± 0.030	13.339 ± 0.029	...		
00152+2454	GIC 4	G 131–46	00 16 53.59	+24 20 48.7	–136 ± 11	–204 ± 10	...	13.6	9.944 ± 0.020	9.067 ± 0.017	K	2469.8	145.8
		G 130–59	00 15 11.85	+24 54 52.1	–105 ± 11	–215 ± 11	...	14.5	12.600 ± 0.022	11.951 ± 0.022	...		
00400–1533	LDS 5286	LP 765–52	00 37 29.44	–15 45 52.3	+173 ± 5	–19 ± 5	...	15.5 *	11.890 ± 0.021	11.038 ± 0.023	...	2274.9	71.5
		LP 765–57	00 39 59.21	–15 34 07.9	+169 ± 5	–34 ± 5	...	15.2 *	13.317 ± 0.026	12.746 ± 0.035	...		
00435+3351	WEI 46AC	GJ 30	00 43 32.90	+33 50 41.3	–204.0 ± 0.8	–357.2 ± 0.6	20.6 ± 0.4	8.73	6.592 ± 0.018	5.938 ± 0.016	K8	1295.0	266.8
		BD+33 96	00 41 49.11	+33 51 54.8	+8.3 ± 1.2	+1.8 ± 1.2	...	8.63	6.639 ± 0.021	5.966 ± 0.018	K0		
00520+2035	GIC 16	G 69–27	00 52 00.03	+20 34 58.6	+176.5 ± 1.8	–107.4 ± 1.5	32 ± 3	11.40	8.490 ± 0.019	7.628 ± 0.020	...	1614.0	56.1
		G 69–29	00 53 35.48	+20 49 59.4	+213 ± 11	–132 ± 11	...	13.9 *	10.095 ± 0.021	9.248 ± 0.015	...		
01024+0504	WNO 50AC	HD 6101 AB	01 02 24.60	+05 03 41.4	+323.3 ± 1.2	+226.0 ± 1.2	21.1 ± 0.5	8.16	6.199 ± 0.019	5.510 ± 0.020	K2+...	1276.0	87.8
		G 1–45 AB	01 03 49.94	+05 04 30.7	+317 ± 8	+227 ± 8	21.3 ± 1.7	14.10	13.504 ± 0.024	13.418 ± 0.034	DA5		
01163–3217	LDS 1091	LP 883–336	01 16 21.75	–31 58 12.2	+408 ± 5	–1 ± 5	...	17.9 *	11.899 ± 0.022	11.001 ± 0.023	...	1151.0	186.0
		LP 883–337	01 16 12.35	–32 17 17.0	+388 ± 5	+17 ± 5	...	18.0 *	13.884 ± 0.026	13.132 ± 0.034	...		
02255–0904	GRV 1148	WD 0223–092	02 25 30.96	–09 04 14.9	+81 ± 5	–2 ± 5	...	19.5 *	...	...	DA4.6	1272.1	228.2
		WD 0221–095	02 24 26.96	–09 18 23.5	+85 ± 4	–0 ± 4	...	19.8 *	...	...	DA5.8		
02310+0823	GIC 32	G 73–63	02 31 03.28	+08 22 55.1	+376.1 ± 1.9	–85.4 ± 1.6	33 ± 3	10.90	8.356 ± 0.023	7.554 ± 0.023	K4–7V:	3094.6	277.9
		G 73–59	02 27 36.68	+08 29 58.8	+350	–63	...	16.1 *	11.271 ± 0.026	10.455 ± 0.021	...		
03162+5810	LEP 13AC	GJ 130.1 A	03 16 13.82	+58 10 02.4	+445.6 ± 3.9	–340.3 ± 4.1	14.4 ± 0.7	10.53	7.344 ± 0.020	6.566 ± 0.024	M2	1164.1	197.6
		G 246–30	03 15 29.44	+57 51 33.0	+467	–237	...	15.5 *	11.121 ± 0.024	10.271 ± 0.019	M:		
03330+0306	LDS 3504	G 80–8	03 32 59.02	+03 06 08.0	+294.8	–80.9	...	13.1 *	10.102 ± 0.023	9.281 ± 0.023	...	429.5	266.4
		NLTT 11184	03 32 30.40	+03 05 40.8	+286	–77	...	17.0 *	12.491 ± 0.026	11.750 ± 0.029	...		
03442–6448	LDS 104	β Ret AB	03 44 11.96	–64 48 24.9	+310.1 ± 0.7	+83.2 ± 0.6	29.9 ± 0.5	3.84	1.937 ± 0.310	1.279 ± 0.270	K2III SB	1466.3	94.2
		HD 24293	03 48 01.12	–64 50 11.7	+334.0 ± 1.0	+99.0 ± 1.1	40.5 ± 1.3	7.85	6.630 ± 0.029	6.241 ± 0.024	G3V		
07590–6338	LDS 199	CD–63 370	07 58 57.36	–63 37 45.5	–143.0 ± 1.7	+262.5 ± 1.8	...	9.90	8.826 ± 0.034	8.502 ± 0.023	F8	1033.4	195.8
		L 137–85	07 58 14.99	–63 54 19.6	–178 ± 10	+384 ± 10	...	11.2 *	9.791 ± 0.024	9.175 ± 0.023	...		
10197+1928	WNO 53	40 Leo	10 19 44.20	+19 28 15.8	–230.0 ± 0.9	–214.7 ± 0.5	21.37 ± 0.11	4.78	4.037 ± 0.292	4.020 ± 0.314	F6IV	5231.4	308.3
		LP 371–59 A	10 14 53.94	+20 22 18.9	–225	–198	...	15.3 *	10.815 ± 0.026	9.99 ± 0.023	M5		
11125+3549	STTA 108BD	HD 97371	11 12 44.28	+35 49 48.4	–60.1 ± 0.7	–7.8 ± 0.7	141 ± 13	7.20	5.423 ± 0.019	4.805 ± 0.018	K0	2100.8	88.5
		HD 97832	11 15 36.98	+35 50 44.7	+0.1 ± 1.2	–2.2±1.3	...	8.20	6.668 ± 0.021	6.194 ± 0.018	G5		
11452+1821	GIC 101	G 57–17	11 45 11.92	+18 20 58.7	–296 ± 8	–296 ± 8	...	13.27	9.162 ± 0.022	8.260 ± 0.016	M4	1341.3	280.2
		G 57–15	11 43 39.18	+18 24 56.9	–259	–267	...	15.07	12.863 ± 0.026	12.097 ± 0.021	...		

Table A.1. continued.

WDS identifier	Discovery name[a]	Simbad name	α (J2000)	δ (J2000)	$\mu_\alpha \cos\delta$ [mas a^{-1}]	μ_δ [mas a^{-1}]	d_π [pc]	V^b [mag]	J [mag]	K_s [mag]	Sp. type	ρ [arcsec]	θ [deg]
11455+4740	LEP 45	HD 102158	11 45 30.58	+47 40 01.1	–591.6 ± 0.7	–290.7 ± 0.5	49.3 ± 1.7	8.06	6.860 ± 0.026	6.509 ± 0.026	G2V	1176.1	72.4
		G 122–46	11 47 21.66	+47 45 56.7	–585	–200	...	14.16	10.586 ± 0.020	9.846 ± 0.020	M:		
13090+3353	LEP 62AC	LP 268–35	13 08 58.26	+33 53 10.0	–209.7 ± 2.3	–111.8 ± 1.7	66 ± 12	11.56	9.296 ± 0.019	8.623 ± 0.018	...	1273.8	192.3
		LP 268–33	13 08 36.42	+33 32 25.7	–208.8 ± 5.5	–101.2 ± 5.5	...	16.3 *	11.685 ± 0.021	10.769 ± 0.019	...		
13410+6808	LDS 5788	G 238–50	13 44 29.36	+68 27 50.3	–269.9 ± 1.5	+43.5 ± 1.8	40 ± 3	11.17	8.845 ± 0.021	8.023 ± 0.015	M2	1696.8	44.5
		LP 40–200	13 40 54.27	+68 07 43.8	–265.5 ± 1.8	+32.8 ± 1.8	...	11.83	9.837 ± 0.019	9.138 ± 0.020	K3		
13599+2520	BUP 156	BD+26 2517 AB	14 01 11.60	+25 21 36.2	+5.5 ± 1.4	+36.2 ± 1.3	...	9.51	8.337 ± 0.023	8.060 ± 0.018	G0	1033.9	83.2
		BD+26 2513	13 59 55.87	+25 19 33.7	+20.5 ± 1.2	–55.9 ± 1.2	...	10.41	9.433 ± 0.021	9.145 ± 0.019	F8		
14396–6050[c]	LDS 494AC	α Cen AB	14 39 35.93	–60 50 07.0	–3633.7 ± 0.7	+702.3 ± 0.6	1.325 ± 0.007	1.35	–1.454 ± 0.133	–2.008 ± 0.260	G2V+K1V	7860.1	236.9
		Proxima	14 29 42.91	–62 40 46.5	–3775.8 ± 1.6	+766 ± 2	1.296 ± 0.004	11.01	5.357 ± 0.023	4.384 ± 0.033	M5.5Ve		
15208+3129	LEP 74	HD 136654	15 20 50.07	+31 28 48.5	–180.0 ± 0.4	+139.0 ± 0.5	43.5 ± 1.1	6.90	5.982 ± 0.020	5.742 ± 0.027	F5V	1580.6	325.6
		BD+32 2572	15 19 40.15	+31 50 32.9	–181.2 ± 0.6	+140.2 ± 0.8	42 ± 2	9.03	7.569 ± 0.021	7.115 ± 0.020	K0V		
16348–0412	GIC 144AB	HD 149414 AB	16 34 42.36	–04 13 44.1	–133.7 ± 1.4	–701.2 ± 1.4	45 ± 3	9.60	8.055 ± 0.024	7.517 ± 0.024	G5Ve SB$_1$	1176.5	36.4
		BD–03 3968B	16 35 29.03	–03 57 57.2	–162	–685	...	13.86	11.086 ± 0.022	10.541 ± 0.022	M:		
18111+3241	LEP 87	BD+32 3065	18 11 06.22	+32 41 00.3	–134.7 ± 1.2	+322.1 ± 1.3	46 ± 3	10.52	8.590 ± 0.039	7.931 ± 0.020	K5	1106.0	148.3
		G 206–16	18 11 52.28	+32 25 20.0	–143	+318	...	15.6 *	10.885 ± 0.021	10.024 ± 0.017	...		
20084+1503	LDS 1033AF	G 143–33	20 08 21.93	+15 02 36.6	–159.1 ± 1.7	–180.7 ± 1.7	...	11.56	9.408 ± 0.028	8.409 ± 0.024	...	2186.6	269.0
		G 143–27	20 05 51.01	+15 01 59.2	–156	–210	...	12.88	11.626 ± 0.022	11.245 ± 0.020	...		
20124–1237	TDT 2085AC	ξ^{02} Cap	20 12 25.86	–12 37 02.5	+193.4 ± 0.4	–196.0 ± 0.5	27.7 ± 0.3	5.84	4.971 ± 0.020	4.634 ± 0.017	F7V	1021.3	193.6
		LP 754–50	20 12 09.44	–12 53 35.1	+195.3 ± 2.0	–194.8 ± 1.8	23.6 ± 1.4	11.30	8.485 ± 0.023	7.625 ± 0.021	M0Vk		
20302+2651	BUP 213AE	HD 340345 AB	20 30 10.67	+26 50 34.5	–145.9 ± 2.7	–141.9 ± 2.7	23.8 ± 1.8	9.69	7.133 ± 0.021	6.347 ± 0.020	M1V+	1338.7	93.2
		HD 340459	20 31 50.53	+26 49 19.3	–8.1 ± 1.4	–5.5 ± 1.4	...	10.15	8.235 ± 0.023	7.647 ± 0.016	G5		
20452–3120	LDS 720AB	AU Mic	20 45 09.49	–31 20 26.7	+279.6 ± 1.2	–360.3 ± 0.8	9.92 ± 0.10	8.81	5.436 ± 0.017	4.529 ± 0.020	M1Ve	4680.9	212.8
		AT Mic AB	20 41 51.12	–32 26 07.3	+261.3 ± 3.6	–344.8 ± 3.9	10.7 ± 0.4	10.27	5.807 ± 0.026	4.944 ± 0.042	M4Ve+M5:		
20599+4016	LEP 98AD	HD 200077 AE–D	20 59 55.24	+40 15 31.4	+230.5 ± 01.1	+211.2 ± 1.3	41.0 ± 0.9	6.58	5.450 ± 0.021	5.119 ± 0.024	F8+	1212.8	258.5
		G 210–44 AB	20 58 11.48	+40 11 29.0	+229.7 ± 1.2	+202.9 ± 1.2	46 ± 4	10.75	8.142 ± 0.030	7.339 ± 0.018	M1		
22175+2335	GIC 179	G 127–13	22 17 25.87	+23 35 04.7	–104 ± 12	–388 ± 11	...	14.1 *	9.890 ± 0.019	9.057 ± 0.023	...	2107.7	12.7
		G 127–14	22 17 59.56	+24 09 21.1	–124 ± 10	–416 ± 10	...	14.2 *	10.276 ± 0.021	9.49 ± 0.018	...		
23228+2208	GIC 191	BD+21 4923	23 22 48.81	+22 07 59.4	+198.3 ± 1.2	–69.8 ± 1.2	71 ± 9	9.71	8.293 ± 0.020	7.851 ± 0.016	F5	3265.3	253.9
		G 68–7	23 19 03.21	+21 52 54.5	+310 ± 11	–101 ± 11	...	14.7 *	11.589 ± 0.020	10.784 ± 0.018	...		

[a] References of discovery names – BUP: Burnham, S. W. proper motion stars (from additional "DD" list): GIC: Giclas et al. (1961); GRV: Greaves, J. private communication (from data in Eisenstein et al. 2006); LEP: Lépine & Bongiorno (2007); LDS: Luyten, W. J. proper motion catalogues (e.g. Luyten 1941); STF: Struve, F. J. W. (several citations by e.g.: Herschel 1833; Bessel 1833); STTA: Struve, O. "DD" (Appendix list); TDT: Tycho Double Star (from additional "DD" list); WNO: Washington Observations; WEI: Weisse, M. (cited in, e.g., Burnham Double Star Catalogue 1906).

[b] V-band magnitudes marked with an asterisk are estimated from four epochs of photographic B_J and R_F magnitudes or from Sloan g and r magnitudes. Remaining V-band magnitudes are from the literature (see main text).

[c] The proper motion of the primary in the system corresponds to α Cen A. The apparent difference with respect Proxima (of up to 292 ± 4 mas a^{-1} in μ_δ) is due to the strong dynamical effect on α Cen A by its close companion, α Cen B.