Further deep imaging of HR 7329 A (η Tel A) and its brown dwarf companion B

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ABSTRACT

About 4 arcsec south of the young A0-type star HR 7329, a faint companion candidate was found by Lowrance et al. Its spectral type of M7-8 is consistent with a young brown dwarf companion. Here we report 10 new astrometric imaging observations of the pair HR 7329 A and B, obtained with the Hubble Space Telescope and the Very Large Telescope, aimed at showing a common proper motion with high significance and possible orbital motion of B around A. With 11 yr of epoch difference between the first and our last image, we can reject the possibility by more than 21σ that B would be a non-moving background object unrelated to A. We detect no change in position angle and small or no change in separation (2.91 ± 2.41 mas yr⁻¹), so that the orbit of HR 7329 B around A is inclined and/or eccentric and/or the orbital motion is currently only in the radial direction. If HR 7329 B is responsible for the outer radius of the debris disc around HR 7329 A being 24 au, and if HR 7329 B currently is at its apastron at 200 au (4.2 arcsec at 47.7 pc), we determine its pericentre distance to be 71 au, its semimajor axis to be 136 au, and its eccentricity to be e = 0.47. From the magnitude differences between HR 7329 A and B and the 2MASS magnitudes for the HR 7329 A+B system, we can estimate the magnitudes of HR 7329 B (J = 12.06 ± 0.19, H = 11.75 ± 0.10, Ks = 11.6 ± 0.1, L = 11.1 ± 0.2 mag) and then, with a few otherwise known parameters, its luminosity and mass (20–50 Jupiter masses). In the deepest images available, we did not detect any additional companion candidates up to ≤9 arcsec, but we determined the upper limits in the planetary mass regime.

Key words: astrometry – binaries: visual – brown dwarfs – stars: formation – stars: individual: HR 7329.

1 INTRODUCTION

The A0-type star HR 7329 (also called η Tel or HD 181296, distance 47.7 ± 1.5 pc at position α = 19h22m51s and δ = −54° 25′ 26″ for J2000.0 according to Perryman et al. (1997), V = 5.0 mag according to SIMBAD) is a member of the β Pic moving group (Zuckerman et al. 2001) with a probability of 95 per cent (Torres et al. 2006) to 100 per cent (Torres et al. 2008); it has an age of ~12 Myr (Zuckerman et al. 2001; Ortega et al. 2002, 2004; Song, Zuckerman & Bessell 2003); see Torres et al. (2008) for a review about this association.

Lowrance et al. (2000, henceforth L00) discovered a 6-mag fainter companion candidate ~4 arcsec south of HR 7329 with coronagraphic images using NICMOS at the Hubble Space Telescope (HST) and also obtained a spectral type of M7-8; if bound to HR 7329 A, it would be a brown dwarf companion (L00).

Guenther et al. 2001 (henceforth G01) confirmed the spectral type with an infrared (IR) H-band spectrum obtained with the Infrared Spectrograph and Array Camera (ISAAC) at the European Southern Observatory (ESO) 8.2-m Very Large Telescope (VLT) Antu (Unit Telescope 1, UT 1), in 2000 April. Using the acquisition image, they measured the separation and position angle (PA) between HR 7329 A and B, trying to show common proper motion, but the significance did not exceed ~1σ (G01).

HR 7329 is one of the youngest stars known to have both a substellar companion candidate and a debris disc (Backman & Paresce 1993; Smith et al. 2009). HR 7329 also has a wide stellar companion (~7 arcmin separation), namely the F6-type star HD 181327 with common proper motion and significant lithium abundance (Torres et al. 2006), which also has a spatially resolved debris disc seen in scattered light (Schneider et al. 2006).
2 MOTIVATION FOR NEW DEEP IMAGING

Torres et al. (2008) wrote in their β Pic review about the brown dwarf companion to be studied here (HR 7329 B = HD 181296 B): ‘Only one of the proposed members, the brown dwarf HD 181296 B, has no kinematical data published and its membership cannot be determined.’ Such kinematic data can be obtained by new deep high angular resolution imaging.

L00 estimate the probability for a foreground main-sequence (MS) M7.5-type object with \( H = 11.9 \pm 0.1 \) mag (like the substellar companion candidate now known as HR 7329 B) to lie within 4 arcsec of the primary star to be \( \sim 10^{-7} \) (L00). This is the probability to find one such faint object within that separation around one target. Since they (PI Becklin, HST programme 7226) observed 45 stars (Lowrance et al. 2005), the probability to find one such faint object (as MS foreground star) within that separation around any one of the 45 stars is then \( \sim 45 \times 10^{-7} \).

In 2MASS, there are 4307-497 sources between \( K = 11.5 \) and 11.7 mag (i.e. as faint as HR 7329 B), so that the probability to find one such faint object in a circle with 4 arcsec radius (the separation between HR 7329 A and B) around any one of the 45 stars is \( \sim 1.8 \) per cent.

Given that HR 7329 A is a member of the β Pic moving group, there can be many young stellar and substellar objects in this area of the sky, all showing a similar proper motion as members of the moving group. Hence, the two objects HR 7329 A and the companion candidate, even though with spectral type M7-8 and located within \( \sim 4 \) arcsec, can in principle be two independent members of the β Pic moving group, which are not orbiting each other, but have distances different by a few or more pc. In the β Pic group the dispersion in space velocities is 2.0, 1.2 and 1.5 km s\(^{-1}\) in \( U, V \) and \( W \) velocities, respectively, from 36 member stars (Zuckerman et al. 2001; Song et al. 2003; Moor et al. 2006; Rice, Faherty & Cruz 2010; Kiss et al. 2011), i.e. quite typical of a young stellar association (Jones & Herbig 1979).

There are a total of 69 stellar members known in the β Pic moving group, with multiple stars counted multiple, down to spectral type M8.5 (Zuckerman et al. 2001; Song et al. 2003; Moor et al. 2006; da Silva et al. 2009; Lepine et al. 2009; Rice et al. 2010; Schlieder, Lepine & Simon 2010; Kiss et al. 2011) – counted without the three substellar companions. These members are spread over an area of \( \sim 2 \times 10^4 \) deg\(^2\), i.e. almost half the sky. Even if we assume that there are three times more members when including all the late M-type stars, brown dwarfs and other as yet unknown members,\(^1\) i.e. in total 207 members, then the probability to find one member within 4 arcsec (the separation between HR 7329 A and B) of any of the 206 other members is \( \sim 4 \times 10^{-6} \), i.e. small.

G01 wrote about the brown dwarf HR 7329 B that it is consistent with a comoving companion of HR 7329, but they present only \( \sim 1\sigma \) evidence, i.e. not convincing. Chauvin et al. (2003) wrote that they confirmed the known binary system HR 7329 AB, but did not give any details, values or significance about the observation on HR 7329; their data obtained with the ESO 3.6-m telescope with the ADONIS/SHARPII AO system are not available in the ESO archive. Data on separation and/or position angle would be useful for future attempts to fit the orbit of B around A, e.g. in order to measure the mass of B.

Given that a small separation together with a large magnitude difference (as in HR 7329 A+B) does not prove companionship,\(^2\) even if the probability for chance alignment would be negligibly small, we obtained a new deep imaging (i) to confirm companionship in Section 3 (as can be expected), (ii) to provide data points for future attempts to fit the orbit (Table 1), (iii) to search for orbital motion of B around A in Section 4, and (iv) to search for additional fainter and/or closer companions in Section 5.

3 OBSERVATIONS AND DATA REDUCTION

We observed HR 7329 A and B on 2009 July 1 utr 5:19–5:45 h in service mode using the Adaptive Optics camera NACO (for Naos-Conica for Nasmyth Adaptive optics system with the COude near-infrared imager and spectrograph, Rouset et al. 2003) located in the VLT UT4 (Yepun) Nasmyth focus using the 2.17-μm narrow-band filter and the S13 optics with the smallest pixels available. We obtained 22 images, each consisting of 120 0.3454-s co-added (jittered) exposures. Darks and flats were also obtained in the same night.

We obtained the median of the darks in the same exposure times as the flats and the science frames, then subtracted the corresponding median dark from the flat and science frames, then normalized the dark-subtracted flats, and then divided the science frames by those flats. Finally, we shifted and co-added the images. The data reduction was done with ESO eclipse.

We also observed the binary HIP 6445 A and B as astrometric reference with the same set-up in the same night from UT 7:40 to 7:46 h [five images with 86 short (0.3454 s) exposures co-added each, also jittering]. HIP 6445 A and B have a separation of 8.360 ± 0.0155 arcsec at PA = 220.9 ± 0.1 (measured from north over east and south) at the epoch 1991.25 (Fabricius et al. 2002). We reduced these data in the same way. The separation and PA between HIP 6445 A and B yield the pixel scale of the S13 optics for that night. In the error budget, we include the maximum possible orbital motion between HIP 6445 A and B between the central Hipparcos epoch and our observation: HIP 6445 A and B have a distance of 120 ± 15 pc and spectral types F4.5V and K1V, hence a total mass of \( \sim 1.8 M_\odot \), so that the maximum possible orbital motion (for a circular orbit) in a 18.25-yr epoch difference results in a change of 25.9 mas (milliarcsecond) in separation and 0.28 in PA.

The measurement of the separation between HIP 6445 A and B in the NACO images gives 629.88 ± 0.14 pixels. Compared to the Hipparcos data, and taking into account the errors from

\(^1\) Tetzlaff, Neuhäuser & Hohle (2011) catalogued young Hipparcos runaway star candidates. They investigated not only the magnitude of the velocities, but also the velocity vectors for each star compared to neighbouring stars and surrounding associations including the β Pictoris moving group (β Pic-Cap). In the Tetzlaff et al. catalogue, there are 112 stars for which the 3D velocity deviates from the mean motion vector of β Pic-Cap and 123 stars for which the 2D velocity vector does so (59 stars in both samples). Since β Pic-Cap is large (radius \( \sim 56 \) pc), the number of stars with different kinematics that are inside the nominal boundaries of the group just by chance is probably large. It is thus more conservative to choose those candidates that are also classified as runaway star candidates owing to their large peculiar spatial velocity (runaway star probability larger than 50 per cent). A total of 35 stars are then currently found inside the β Pic-Cap boundaries and also show large peculiar space velocities and might be considered potential (former) members of the moving group.

\(^2\) There are counterexamples known such as TWA 6 and TWA 7 with faint nearby companion candidates (Lowrance et al. 2001; Neuhäuser et al. 2000, respectively) later found to be background (Macintosh et al. 2001; Neuhäuser et al. 2002, respectively).
orbital motion in HIP 6445 A+B, the NACO pixel scale is 13.272 ± 0.049 mas pixel$^{-1}$ (half the error budget from possible orbital motion in HIP 6445 A and B) and the detector orientation for those images of 0.31 ± 0.30, which have to be added to all PA measurements on uncorrected images (two-thirds of the error budget from possible orbital motion in HIP 6445 A and B). With this pixel scale, we can convert the separation measured between HR 7329 A and B on the detector to 4199 ± 31 mas and obtain a true, corrected PA between A and B of 166.99 ± 0.30.

We retrieved all archival \textit{HST} and ESO data and reduced them in a similar way as above. In cases, where the object HR 7329 B was located within the point spread function (PSF) of HR 7329 A, we first subtracted the PSF of HR 7329 A, before we measured the position and magnitude of HR 7329 B (and hence the separation between A and B) after subtraction of the PSF of HR 7329 A from the image, which was not done in G01. The position and magnitude of HR 7329 B, the NACO pixel scale is 13.272 ± 0.049 mas pixel$^{-1}$, both for NACO S13, so that our choice here of the NIC2 detector is slightly tilted towards its -axis.

### Table 1. Astrometry of HR 7329 A and B.

| Epoch year | Telescope, instrument | Band, camera | Exposure time (s) | FWHM (mas) | Separation (mas) | PA\(^a\) | \(\Delta \text{mag}\) Ref.\(^b\) |
|------------|-----------------------|--------------|------------------|-------------|------------------|--------|-----------------|
| 1998.4931507 | \textit{HST} Nicmos | F 160W NIC 2 | 5 \times 143.9 | 150 \times 4170 \pm 50 | 166.80 \pm 0.2 | 6.9 \pm 0.1 | L00 |
| 2000.3060109 | VLT ISAAC | NB in K\(^c\) | 3 \times 1.7726 | 500 \times 4097 \pm 48 | 166.90 \pm 0.42 | 5.7 \pm 0.1 | G01 |
| 2000.3808219 | NTT SofI | H SF\(^d\) | 10 \times 46 \times 1.3 | 1200 \times 4310 \pm 270 | 165.8 \pm 6.7 | 6.8 \pm 0.1 | G01 |
| 2004.3315068 | VLT NACO | H S13 | 5 \times 90 \times 0.7 | 108 \times 4189 \pm 20 | 167.32 \pm 0.22 | 6.8 \pm 0.1 | |
| 2004.3315068 | VLT NACO | K, S13 | 5 \times 120 \times 0.7 | 93 \times 4200 \pm 17 | 166.85 \pm 0.22 | 6.7 \pm 0.1 | |
| 2004.3424658 | VLT NACO | K, S13 | 5 \times 180 \times 0.35 | 78 \times 4199 \pm 36 | 167.02 \pm 0.22 | 6.7 \pm 0.1 | |
| 2004.3424658 | VLT NACO | K, S13 | 5 \times 120 \times 0.7 | 76 \times 4195 \pm 17 | 166.97 \pm 0.22 | 6.5 \pm 0.1 | |
| 2006.4328767 | VLT Visir | S IV | 22 \times 48 \times 0.04 | 880 \times 4170 \pm 110 | 167.2 \pm 1.4 | 6.2 \pm 0.2 | G08 |
| 2007.7534246 | \textit{HST} Nicmos | F 110W NIC 2 | 17 \times 160 | 155 \times 4212 \pm 33 | 167.42 \pm 0.35 | 7.6 \pm 0.1 | |
| 2008.3114754 | VLT NACO | L S27 | 40 \times 150 \times 0.2 | 165 \times 4214 \pm 17 | 166.81 \pm 0.22 | 6.2 \pm 0.2 | |
| 2008.5983607 | VLT NACO | H S13 | 3 \times 25 \times 0.36 | 70 \times 4195 \pm 17 | 166.87 \pm 0.29 | 7 \pm 0.1 | |
| 2008.5983607 | VLT NACO | H S13 | 27 \times 2 \times 25 | 109 \times 4194 \pm 16 | 166.20 \pm 0.29 | 7 \pm 0.1 | |
| 2009.3506849 | NTT SofI | K, L\(f\) | 10 \times 50 \times 12 | 1193 \times 4239 \pm 104 | 168.5 \pm 1.3 | 7 \pm 0.1 | |
| 2009.4958908 | VLT NACO | NB in K S13\(^g\) | 22 \times 21 \times 0.345 | 86 \times 4199 \pm 31 | 166.99 \pm 0.30 | 6.28 \pm 0.02 |

Remarks: \(^a\)Position angle (PA) measured from north over east and south. \(^b\)References: L00 for Lowrance et al. (2000); G01 for Guenther et al. (2001); and G08 for Geissler, Chauvin & Sterzik (2008). \(^c\)Narrow-band (NB) filter inside the K band. \(^d\)Separation slightly larger than in G01, because we measured the PSF centre of HR 7329 B (and hence the separation between A and B) after subtraction of the PSF of HR 7329 A from the image, which was not done in G01. \(^e\)Re-reduced by us. \(^f\)With SofI Small Field (SF) 147 mas pixel$^{-1}$, or SofI Large Field (LF) 288 mas pixel$^{-1}$. \(^g\)HR 7329 B too faint and/or not resolved well from HR 7329 A, or HR 7329 A is saturated, hence no useful magnitude difference obtainable. \(^h\)Obtained from public archive and reduced by us. \(^i\)Obtained and reduced by us.
of HR 7329 B, and hence the separation and PA between HR 7329 A and B, we subtracted the PSF of HR 7329 A with idl.

All observations used here are listed in Table 1.

4 INTERPRETATION OF ASTROMETRY

To check for common proper motion and orbital motion, we use the astrometric data from *Hipparcos*: proper motion $\mu_\alpha \times \cos(\delta) = 25.57 \pm 0.21$ mas yr$^{-1}$ and $\mu_\delta = -82.71 \pm 0.14$ mas yr$^{-1}$, distance $47.7 \pm 1.5$ pc, both for HR 7329 A, data from Perryman et al. (1997) and van Leeuwen (2007), whose values differ slightly from each other, but are compatible within the error bars.

We show in Figs 1 and 2 the astrometric data from Table 1, which reject the hypothesis that HR 7329 B would have been a non-moving background object with $\geq 21\sigma$, so that we can continue to regard HR 7329 A and B as common proper motion pair. We also show the expected maximal orbital motion for a circular orbit of HR 7329 B around A, being $\pm 8.84$ mas yr$^{-1}$ change in separation for an edge-on orbit (Fig. 1) and $\leq 0.189$ yr$^{-1}$ change in PA for a pole-on orbit (Fig. 2). We do not see any change in PA (Fig. 2) and conclude that the (2D) orbit (on sky) is not pole-on at all. The non-reduced $\chi^2$ for the separation fit (Fig. 1) is lower than for the PA fit (Fig. 2) – possibly indicating that the separation errors are overestimated, while PA errors are not overestimated. This could be due to radial NACO detector distortions, which are negligible for PA values. Since the separation of the astrometric calibrator is higher than that of the HR 7329 system, increased errors are introduced into the radial error budget (separation errors) by jittering, which has to be done in order to remove the background in the IR in both cases. The possibly detected change in separation due to orbital motion ($2.91 \pm 2.41$ mas yr$^{-1}$) is much smaller than the expected maximum orbital motion for a circular edge-on orbit (Fig. 1), so that we conclude that the (2D) orbit (on sky) is not a circular edge-on orbit, but inclined and/or eccentric with HR 7329 B currently near the apastron, hence the small motion on sky. The orbital plane of HR 7329 B could be in the line of sight (edge-on like the debris disc around HR 7329 A), with HR 7329 B currently near the largest angular separation from HR 7329 A, but with orbital motion mostly in the radial direction; such orbital motion could be detectable with a high-resolution spectrum.

The possible detection of a change in the separation can also be interpreted as evidence for a slightly different proper motion between HR 7329 A and companion candidate, namely a difference of $0.66 \pm 0.57$ km s$^{-1}$ (namely $2.91 \pm 2.41$ mas yr$^{-1}$ in $47.7 \pm 1.5$ pc). This value is comparable to the typical velocity dispersion in $\beta$ Pic and other young associations (see Section 2), so that one can still not exclude the possibility that the two objects called HR 7329 A and B are two independent members of the $\beta$ Pic association. The probability for this possibility is very low. Orbital motion with curvature is not yet detected.

The most precise measurement of the separation between A and B is the long 22.5-min exposure in 2008 August with NACO (4194 ± 16 mas), even though HR 7329 A is saturated; the position of A was determined with MIDAS centre/moment, the position of B

$\chi^2 = 12.8$ with 13 data points, i.e. no change in PA detected.

Figure 1. Separation versus observing epoch for data listed in Table 1 (except for the first SofI data point due to its large error bar). The short-dashed lines indicate maximum possible separation change due to orbital motion for a circular edge-on orbit. The wobbled dot-dashed line is for the background hypothesis, i.e. if HR 7329 A had moved according to its known parallactic and proper motion, while the fainter southern object would be a non-moving object (error cone from parallax and proper motion errors); the data points are inconsistent with the background hypothesis by many $\sigma$ (only the last six data points together yield a significance of 5$\sigma$ against the background hypothesis; the first data point alone gives a significance of 21$\sigma$). All data points are fully consistent with common proper motion (within long-dashed lines). The formal best fit for linear orbital motion yields an increase in separation of $2.91 \pm 2.41$ mas yr$^{-1}$ (linear dot-dashed line) with (non-reduced) $\chi^2 = 3.4$ with 13 data points, i.e. a possible (but not yet significant) marginal detection.

Figure 2. Position angle versus observing epoch for data listed in Table 1 (except for the first SofI data point due to its large error bar). The short-dashed lines indicate maximum PA change due to orbital motion for a circular pole-on orbit. The wobbled line is for the background hypothesis, which has already been rejected in the previous figure (without an error cone for clarity). All the data points are fully consistent with common proper motion (within long-dashed lines). The formal best fit for orbital motion as linear change in PA gives only $-0.0252 \pm 0.0282$ yr$^{-1}$ with (non-reduced) $\chi^2 = 12.8$ with 13 data points, i.e. no change in PA detected.

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![Figure 1: Separation versus observing epoch for data listed in Table 1 (except for the first SofI data point due to its large error bar).](https://example.com/figure1)

![Figure 2: Position angle versus observing epoch for data listed in Table 1 (except for the first SofI data point due to its large error bar).](https://example.com/figure2)

$\chi^2$ is the reduced chi-squared statistic, which is a measure of how well the data fit the model. A value of 1 indicates a good fit, while values significantly greater than 1 indicate a poor fit.

$H$-band S13 image from 2004 [not saturated, full width at half-maximum (FWHM) 108 mas] with the long-exposure NACO $H$-band S13 image from 2008 (saturated, FWHM 109 mas) shows that the precision is similar, i.e. that mild saturation does not matter much (see Table 1).
after subtraction of the PSF of A with MIDAS centre/Gauss; with a distance of 47.7 ± 1.5 pc, the projected physical separation between HR 7329 A and B is then 200 ± 16 au, the semimajor axis for a pole-on circular orbit; for a uniform eccentricity distribution (e = 0 to 1) and a random viewing angle, we correct this value by a factor of 1.10±0.031 (Torres 1999; Allers et al. 2009) and obtain 220±21 au. We use 2.2 ± 0.1 M⊙ as the mass of the A0-type star HR 7329 (Tetzlaff et al. 2011) and as the total mass of HR 7329 A+B. For this system mass, the orbital period would then be ~1900 yr for a semimajor axis of 200 au (2200 yr for 220 au, 345–6100 yr for 64–434 au).

Smith et al. (2009) directly detected the debris disc around HR 7329 A with an outer radius being 24 au. From the very existence (and, hence, stability) of this debris disc (and its outer radius), we can constrain the eccentricity of HR 7329 B even further: its eccentricity cannot be too large, otherwise it would fly through the disc. Our deep imaging (Fig. 3 below) shows that there is no additional companion outside of 24 au (or between 24 and 200 au) with a mass larger than ~20 Mjup. If we further assume that HR 7329 B is responsible for shaping the debris disc and thereby fixing its outer radius, we can constrain the eccentricity as follows: following Pichardo, Spake & Aguilar (2005), for the masses given here for HR 7329 A and B, and assuming that HR 7329 B has its apocentre at 200 au (see above) and is responsible for the outer disc radius at 24 au, we determine the pericentre distance of HR 7329 B to be 71 au, its semimajor axis to be 136 au, and, hence, its eccentricity to be e = 0.47. Then, the orbital period would be ~10³ yr.

5 DEEP IMAGING AND LIMITS ON FURTHER COMPANIONS

In the three deepest images (1998 HST NICMOS, 2009 VLT NACO and 2008 VLT NACO H band), no additional companion candidates were detected up to ≲9 arcsec separation. Companions with 12–Myr of age with 13 Jup (or 1 Jup) of masses, would have a luminosity of log(L/L⊙) ≳ −4 (or −5.9) (Burrows et al. 1997), hence a magnitude difference of ~10 mag (or 14.7 mag) to HR 7329 A, they would just be detectable at ≥1 arcsec (or ≥3 arcsec, respectively) with NICMOS and NACO (Fig. 3). At ~10-arcsec separation (~500 au), two companion candidates are detected in the HST images with J = 21 and H = 17.5 mag, which would be in the planetary mass regime, but probably are background; they are outside the NACO S13 field (~9-arcsec radius around HR 7329 A), too faint and/or blue for the NACO L-band L27 field (ΔL ≲ 10 mag), and too close and/or faint for the ISAAC and SofI images, and are, hence, detected only once.

We determined the dynamic range for all images by measuring the 3σ level4 above the background noise for any pixel (or group of three or nine or 49 pixels) in all co-added images and compared this background flux to the flux of the central star HR 7329 A. The flux ratio between background and HR 7329 A is plotted in Fig. 3 for the images with the best dynamic ranges, i.e. where the closest and the faintest companions could be detected.

6 CONCLUSIONS

By several new images of HR 7329 A and B obtained with HST/NICMOS and VLT/NACO with 11 yr of epoch difference, we could reject (≥2σ) the background hypothesis that HR 7329 B would have been a non-moving background object unrelated to HR 7329 A. Hence, HR 7329 A and B form a common proper motion pair. The possible detection of a small linear change in separation (but no change in PA) is consistent with an on-sky 2D orbit of B around A, which is eccentric and/or inclined. Curvature in orbital motion as either acceleration or deceleration would be a final proof of it being gravitationally bound, but it is not yet detected, similarly to all other substellar companions detected by direct imaging, except PZ Tel B (Mugrauer et al. 2010).

The magnitude difference between HR 7329 A and B is ΔH = 6.75 ± 0.10 mag and ΔKs = 6.6 ± 0.1 mag (Table 1), with K = 5.008 ± 0.033 mag for HR 7329 A+B (2MASS), we get Ks = 11.6 ± 0.1 mag for HR 7329 B; we obtain L = 11.1 ± 0.2 mag for HR 7329 B (from Table 1, with L = 5.0 mag for HR 7329 as A0-type star with J = H = K = L = 5.0 mag); from the magnitude difference between HR 7329 A and B in the HST F110W filter (Table 1); we get J = 12.06 ± 0.19 mag for HR 7329 B, calibrated with the M9.5 dwarf BRI B0021 − 02 from Persson et al. (1998) and the NIC web site. Those JHK colours are consistent with spectral type M7-8 for HR 7329 B. With a bolometric correction of B.C.K = 3.10 ± 0.05 mag (for M7-8, Golimowski et al. 2004), and the distance towards HR 7329 A, we get a luminosity of log(L/L⊙) = −2.627 ± 0.087 for HR 7329 B.

For T age = 2500–2800 K (for M7-8, Golimowski et al. 2004 and Luhmann 1999, intermediate scale) at ~12 Myr, we then derive the mass of HR 7329 B from evolutionary tracks to be 20–50 Jup masses (Burrows et al. 1997; Chabrier et al. 2000; Baraffe et al. 2002).

4 Choice confirmed by inserting and retrieving simulated companions at this contrast level (Haase 2009).
Hence, HR 7329 B is indeed a brown dwarf. No additional companion candidates were detected up to $\leq 9$ arcsec. The HR 7329/HD 181327 system is therefore a triple system with two stars with debris discs (HR 7329 and its wide companion HD 181327; Backman & Paresce 1993; Schneider et al. 2006; Smith et al. 2009) plus one brown dwarf (HR 7329 B). With $\beta$ Pic (Smith & Terrile 1984; Lagrange et al. 2010) and PZ Tel (Smith et al. 2009; Biller et al. 2010; Mugrauer et al. 2010) there are two more members of the $\beta$ Pic moving group, which have both a debris disc and a substellar companion, indicating quite a large fraction and motivating further searches.

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REFERENCES

Allers K. N. et al., 2009, ApJ, 697, 824
Backman D. E., Paresce F., 1993, in Levy E. H., Lunine J. I., eds, Protostars and Planets III. Arizona Univ. Press, Tucson, p. 1253
Baraffe I., Chabrier G., Allard F., Hauschildt P. H., 2002, A&A, 382, 563
Biller B. A. et al., 2010, ApJ, 720, L82
Burrows A. et al., 1997, ApJ, 491, 856
Chabrier G., Baraffe I., Allard F., Hauschildt P. H., 2000, ApJ, 542, 464
Chauvin G. et al., 2003, A&A, 404, 157
da Silva L., Torres C. A. O., de la Reza R., Quast G. R., Melo C. H. F., Sterzik M. F., 2009, A&A, 508, 833
Eggenberger A., Udry S., Chauvin G., Beuzit J. L., Lagrange A. M., Segransan D., Mayor M., 2007, A&A, 474, 273
Fabricius C., Hog E., Makarov V. Y., Mason B. D., Wycoff G. L., Urban S. E., 2002, A&A, 384, 180
Geissler K., Chauvin G., Sterzik M. F., 2008, A&A, 480, 193 (G08)
Golimowski D. A. et al., 2004, ApJ, 127, 3516
Guenther E. W., Neuhäuser R., Huelamo N., Brandner W., Alves J., 2001, A&A, 365, 514 (G01)
Haase D., 2009, Report about Student Research Project, Univ. Jena
Jones B. F., Herbig G. H., 1979, AJ, 84, 1872
Kiss L. L. et al., 2011, MNRAS, 411, 117
Lagrange A. et al., 2010, Sci, 329, 57
Lepine S., Thorstensen J. R., Shara M. M., Rich R. M., 2009, AJ, 137, 4109
Lowrance P. J. et al., 2000, ApJ, 541, 390 (L00)
Lowrance P. J. et al., 2001, in Jayawardhana R., Greene T., eds, ASP Conf. Ser. 244, Young Stars Near Earth: Progress and Prospects. Astron. Soc. Pac., San Francisco, p. 289
Lowrance P. J. et al., 2005, AJ, 130, 1845
Luhmann J. K., 1997, ApJ, 525, 466
Macintosh B. et al., 2001, in Jayawardhana R., Greene T., eds, ASP Conf. Ser. Vol. 244, Young Stars Near Earth: Progress and Prospects. Astron. Soc. Pac., San Francisco, p. 309
Moor A., Abraham P., Derekas A., Kiss C., Kiss L. L., Apai D., Grady C., Henning T., 2006, ApJ, 644, 525
Mugrauer M., Vogt N., Neuhäuser R., Schmidt T. O. B., 2010, A&A, 532, L1
Neuhäuser R., Brandner W., Eckart A., Guenther E., Alves J., Ott T., Huelamo N., Fernandez M., 2000, A&A, 354, L9
Neuhäuser R., Guenther E. W., Brandner W., Huelamo N., Ott T., Alves J., Comerón Cuby J.-G., Eckart A., 2002, in Alves J., McCaughrean M., eds, The Origins of Stars and Planets: The VLT View. Springer, Berlin, p. 383
Neuhäuser R., Guenther E. W., Wuchterl G., Mugrauer M., Bedalov A., Hauschildt P., 2005, A&A, 435, L13
Neuhäuser R., Mugrauer M., Seifahrt A., Schmidt T. O. B., Vogt N., 2008, A&A, 484, 281
Ortega V. G., de la Reza R., Jilinski E., Buzzabekka B., 2002, ApJ, 575, L75
Ortega V. G., de la Reza R., Jilinski E., Buzzabekka B., 2004, ApJ, 609, 243
Perryman M. A. C. et al., 1997, A&A, 323, L23
Persson S. E., Murphy D. C., Krzeminski W., Roth M., Rieke J. M., 1998, AJ, 116, 2475
Pichardo B., Sparke L. S., Aguilar L. A., 2005, MNRAS, 359, 521
Rice E. L., Faherty J. K., Cruz K. L., 2010, ApJ, 715, L165
Rouset G. et al., 2003, in Wizinowich P. L., Bonaccini D., eds, Proc. SPIE Vol.4839, Adaptive Optical Systems Technologies II. SPIE, Bellingham, p. 140.
Schliefder J., Lepine S., Simon M., 2010, AJ, 140, 119
Schneider G. et al., 2006, ApJ, 650, 414
Smith B. A., Terrile R. J., 1984, Sci, 226, 1421
Smith R., Churcher L. J., Wyatt M. C., Moerchen M. M., Telesco C. N., 2009, A&A, 493, 299
Song I., Zuckerman B., Bessell M. S., 2003, ApJ, 599, 342
Tetzlaff N., Neuhäuser R., Hohle M. M., 2011, MNRAS, 410, 190
Torres G., 1999, PASP, 111, 169
Torres C. A. O., Quast G. R., da Silva L., de La Reza R., Melo C. H. F., Sterzik M., 2006, A&A, 460, 695
Torres C. A. O., Quast G. R., Melo C. H. F., Sterzik M. F., 2008, in Reipurth B., ed., Young Nearby Loose Associations. Handbook of Low Mass Star Forming Regions. Astron. Soc. Pac., San Francisco, p. 757
van Leeuwen F., 2007, A&A, 474, 653
Zuckerman B., Song I., Bessell M. S., Webb R. A., 2001, ApJ, 562, L87

Further deep imaging of HR 7329 A+B

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