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Characterization of the long-period companions of the exoplanet host stars: HD 196885, HD 1237 and HD 27442⋆

VLT/NACO and SINFONI near-infrared, follow-up imaging and spectroscopy

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ABSTRACT

Aims. We present the results of near-infrared, follow-up imaging and spectroscopic observations at VLT, aimed at characterizing the long-period companions of the exoplanet host stars HD 196885, HD 1237 and HD 27442. The three companions were previously discovered in the course of our CFHT and VLT coronographic imaging survey dedicated to the search for faint companions of exoplanet host stars.

Methods. We used the NACO near-infrared adaptive optics instrument to obtain astrometric follow-up observations of HD 196885 A and B. The long-slit spectroscopic mode of NACO and the integral field spectrograph SINFONI were used to carry out a low-resolution spectral characterization of the three companions HD 196885 B, HD 1237 B and HD 27442 B between 1.4 and 2.5 μm.

Results. We can now confirm that the companion HD 196885 B is comoving with its primary exoplanet host star, as previously shown for HD 1237 B and HD 27442 B. We find that both companions HD 196885 B and HD 1237 B are low-mass stars of spectral type M1 ± 1V and M4 ± 1V respectively. HD 196885 AB is one of the closer (∼23 AU) resolved binaries known to host an exoplanet. This system is then ideal for carrying out a combined radial velocity and astrometric investigation of the possible impact of the binary companion on the planetary system formation and evolution. Finally, we confirm via spectroscopy that HD 27442 B is a white dwarf companion, the third one to be discovered orbiting an exoplanet host star, following HD 147513 and Gliese 86. The detection of the broad Brγ line of hydrogen indicates a white dwarf atmosphere dominated by hydrogen.

Key words. instrumentation: high angular resolution – stars: binaries: close – stars: low-mass, brown dwarfs – stars: planetary systems

1. Introduction

The radial velocity (RV) technique is without contest nowadays the most successful method for detecting and characterizing the properties of exo-planetary systems. Since the discovery of 51 Peg (Mayor & Queloz 1995), more than 200 exo-planets have been identified featuring a broad range of physical (mass) and orbital (P, e) characteristics (Udry et al. 2003). Major progress has been made in improving detection performance and data analysis and has enabled us to explore the mass regime down to neptunian and telluric masses (Santos et al. 2004; McArthur et al. 2004). Hitherto, most surveys have been focused on solar-type stars because these stars show more and thinner lines than their more massive counterparts and less activity than their less massive ones, which ensures in both cases comparatively higher RV precision. Only recently have been planet-search programs devoted to late-type stars with the use of high precision spectrograph and repeated measurements (Delfosse et al. 1998; Endl et al. 2003; Wright et al. 2004; Bonfils et al. 2005) as well as to early-type stars with the development of new methods for RV measurements (Chelli 2000; Galland et al. 2005).

Despite the success of this technique, the time span explored limits the study to the close (≤4–5 AU) circumstellar environment. To understand the way exo-planetary systems form and evolve, it is therefore clearly worthwhile using complementary techniques such as pulsar timing, micro-lensing, photometric transit or direct imaging to fill out our knowledge. For solar analogs, the current deep-imaging capability is limited to the detection of massive brown dwarf (BD) companions. Typical separations larger than 50–100 mas (i.e. ≥3–5 AU from a star at 50 pc) can be explored in the stellar regime and 0.5–1″ (i.e. ≥30–50 AU from a star at 50 pc) in the substellar regime. The recent discovery of a T7 dwarf companion at 480 AU from the exoplanet host star HD 3651 (Mugrauer et al. 2006) illustrates the scope of deep, near-infrared imaging for resolving ultra-cool companions at large separations. Recent efforts have been also devoted to systematic search for stellar companions to nearby stars with and without planets, aimed at studying the impact of stellar duplicity on planet formation and evolution (Eggenberger et al. 2007).

Since 2003, we have conducted a deep-coronographic imaging survey of 26 exoplanet host stars, using PUEO-KIR at CFHT, and NACO at VLT (Chauvin et al. 2006). Three probable companions were detected around the stars HD 196885, HD 1237 and HD 27442 (see Tables 1 and 2). Follow-up observations

⋆ Based on ESO observing programs 075.C-0825(A), 275.B-5057A and 077.C-0444(A).

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Table 1. Characteristics of the observed exoplanet host stars HD 196885 A, HD 1237 A and HD 27442 A.

Name	SpT	d (pc)	Age[a] (Gyr)	$M_2\sin i^b$ ($M_{\rm Jup}$)	P^b (days)	e^b
HD 196885 A	F8IV	33.0	0.5	1.84	386.0	0.30
HD 1237 A	G6V	17.6	0.8	1.94	311.29	0.24
HD 27442 A	K2IV	18.2	10	1.28	423.84	0.07

[a] Age references: Naef et al. (2001); Randich et al. (1999); Lambert et al. (2004).
[b] Radial velocity references: Naef et al. (2001); Butler et al. (2001); `http://exoplanets.org/esp/hd196885/hd196885.shtml`

Table 2. Characteristics of the long-period companions to the exoplanet host stars HD 196885 A, HD 1237 A and HD 27442 A. Date, separation and reference of the first observation are reported. The contrast values in K_s come from Chauvin et al. (2006).

Name	UT Date	Δ (arcsec)	Δ (AU)	ΔK_s (mag)	Ref.
HD 196885 B	01/08/2005	0.714	25	3.1	(1)
HD 1237 B	03/06/2003	3.857	68	5.0	(1)
HD 27442 B	1930	~13.7	240	10.7	(2)

(1): Chauvin et al. (2006).
(2): Worley & Douglass (1997).

were obtained for HD 1237 B and HD 27442 B, confirming their companionship (Chauvin et al. 2006; Raghavan et al. 2006). Based on their photometry, HD 196885B and HD 1237 B are likely to be low-mass stars and HD 27442 B is probably the third white dwarf companion known to date orbiting an exoplanet host star. In this paper, we report new imaging and spectroscopic observations of these three companions, using NACO and SINFONI at VLT. In Sect. 2, the instrument set-up and the data analysis are described. In Sect. 3, we discuss the astrometric and spectroscopic results that confirm and refine their previous suggested nature.

2. Observations and data reduction

2.1. NACO imaging of HD 196885 AB

The NACO adaptive optics (AO) instrument is installed at the Nasmyth B focus of VLT/UT4 and provides diffraction-limited images in the near-infrared (1–5 μm) range. On 26 August 2006, we used NACO to carry out a second-epoch observation of HD 196885 A and B and confirm that both systems were co-moving. The atmospheric conditions were stable although not optimal (airmass of 1.3, seeing of $\omega = 0.9''$ and correlation time of $\tau_0 = 3.0$ ms). A set of five jittered images was obtained using the K_s filter and the S27 camera CONICA, leading to a total exposure time of ~2 min on source. To calibrate the plate scale and the detector orientation, we observed at each epoch the astrometric field of θ Ori 1 C (McCaughrean & Stauffer 1994). After cosmetic reductions using *eclipse* (Devillard 1997), we used the deconvolution algorithm of Véran & Rigaut (1998) to obtain the position of HD 196885 B relative to A at each epoch. Single stars of similar brightness observed the same night were used for point spread function (PSF) estimation. The results are reported in Table 3 and the relative positions plotted in Fig. 1.

2.2. NACO spectroscopy of HD 196885 B and HD 1237 B

NACO also provides AO-assisted, long-slit, near-infrared spectroscopy. We used the low-resolution ($R_\lambda = 550$) grism with the SHK (1.40–2.50 μm) filter and the 86 mas slit to characterize HD 196885 B on August 27 2006 and HD 1237 B on July 7 2005. A standard ABBA nodding sequence in and out the slit was conducted to properly remove the background contribution. The telluric standard stars HIP 104320 (B3V) and HIP 007873 (B2V) were observed for HD 196885 B and HD 1237 B respectively. After substracting the sky and dividing by a flat field using *eclipse*, the science and reference spectra were extracted and calibrated in wavelength using the REDSPEC[1] software.

The system HD 1237 was observed at high airmass (1.8) and under poor atmospheric conditions (seeing $\omega = 1.0''$ and correlation time of $\tau_0 = 2.5$ ms) resulting in a poor and unstable AO correction. These unstable conditions have a critical effect on the continuum slope of the observed spectra when long-slit spectroscopy is coupled to AO (see Goto et al. 2002; Chauvin et al. 2005). To determine the spectral type of HD 1237 B, we then decided to use a limited spectral range between 2.3 and 2.4 μm where the obvious temperature-sensitive features of the CO molecular bands are present. The continuum slope of each spectrum was fitted between 2.20 and 2.45 μm and divided. The result is shown in Fig. 3. In the case of HD 196885 A and B, the atmospheric conditions were stable (airmass of 1.2, seeing of $\omega = 0.8''$ and correlation time of $\tau_0 = 3.5$ ms). As the flux ratio between both components was relatively small, we placed both objects into the 86 mas slit. The reduced spectra in H and K-band are shown in Fig. 2.

2.3. SINFONI spectroscopy of HD 27442 B

SINFONI is a near-infrared integral field spectrograph fed by an AO module, currently installed at the Cassegrain focus of the VLT/UT4. To characterize the companion HD 27442 B, we used the medium resolution ($R_\lambda = 1500$) grating with the H+K (1.45–2.45 μm) filter, coupled to the 25 mas objective (providing a field of view of $0.8'' \times 0.8''$). In comparison with NACO, the great advantage of SINFONI is that the instrument is relatively insensitive to differential chromatical effects as the whole PSF is dispersed. The observations were obtained on October 18 2005. The telluric standard star HIP 39483 (B3V) was successively observed. The SINFONI pipeline and the QFitsView[2] software were used to properly reduce the observations (sky subtraction, flat-fielding, wavelength calibration and extraction) and the reduced spectrum of HD 27442 B is shown in Fig. 2.

3. Results

3.1. HD 196885 B, a close M1V dwarf companion

The exoplanet host star HD 196885 A was first observed on August 1st 2005 and a relatively bright companion candidate (here after HD 196885 B) was resolved at 0.7″. By reimaging this system at a second epoch, our goal was to show that HD 196885 B shares a common proper motion with A. Fig. 1 displays, in a ($\Delta\alpha$, $\Delta\delta$) diagram, the offset positions of HD 196885 B from A, observed with NACO on August 1st 2005 and August 26 2006. The expected evolution of the relative A-B positions, under the assumption that B is a stationary background object, is indicated for August 26 2006. Based on the

[1] `http://www2.keck.hawaii.edu/inst/nirspec/redspec/`
[2] `http://www.mpe.mpg.de/ ott/QFitsView/`

Table 3. Offset positions of HD 196885 B relative to A measured with NACO at VLT.

UT Date	Δ (mas)	PA (deg)	Plate scale (mas)	Detector Orien. (deg)
01/08/2005	714 ± 3	67.5 ± 0.3	27.01 ± 0.05	−0.05 ± 0.20
26/08/2006	713 ± 3	65.7 ± 0.3	27.01 ± 0.05	−0.12 ± 0.19

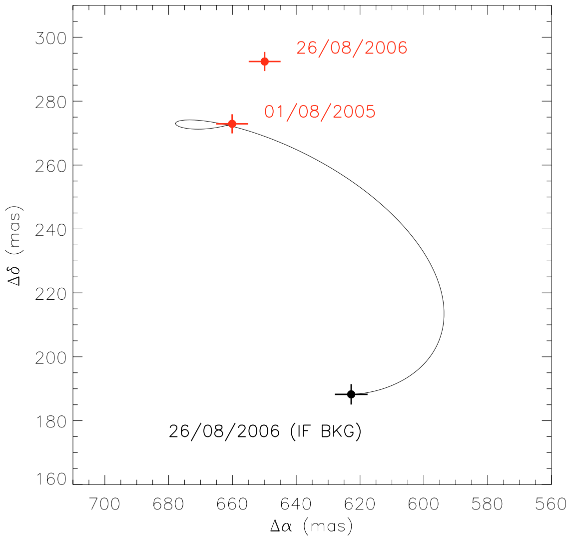

Fig. 1. VLT/NACO measurements with uncertainties in the offset positions of HD 196885 B relative to A, obtained on August 1st 2005 and August 26 2006. The expected variation of offset positions, if B is a background stationary object, is shown (*solid line*), based on a distance of 33 ± 1 pc, a proper motion of $(\mu_\alpha, \mu_\delta) = (47.5 \pm 0.9, 83.1 \pm 0.5)$ mas/yr for A and the initial offset position of B from A. The corresponding expected offset positions of a background object on August 26 2006 is also given with total uncertainties, which are the quadratic sum of individual uncertainties (distance, proper motion of A and initial position of B from A).

relative positions of B from A at both epochs (see Table 3), the 33 ± 1 pc distance of A and its proper motion of $(\mu_\alpha, \mu_\delta) = (47.5 \pm 0.9, 83.1 \pm 0.5)$ mas/yr, we find that the χ^2 probability that HD 196885 B is a background stationary object is less than $1e^{-9}$. HD 196885 B is then likely to be comoving with A.

The JHK photometry of HD 196885 B is compatible with that expected for an M0V to M1V dwarf (see Chauvin et al. 2006; Leggett et al. 1996). The NACO H-band and K-band spectra of HD 196885 B feature neutral atomic lines for MgI (1.50 and 1.71 μm), AlI (1.68 μm), NaI (2.20 and 2.33 μm) and CaI (2.26 μm) as well as weak molecular lines for CO and H_2O, typical of early-M dwarfs. Using the template spectra of Pickles et al. (1998) and Leggett et al. (2001), the best fit to the H- and K-band spectra of HD 196885 B is obtained using the M1V dwarf LHS386 spectrum. Therefore, photometry and spectroscopy confirm a spectral type M1 ± 1V for HD 196885 B. Using Baraffe et al. (1998) model predictions for an age of 0.5 Gyr, we derive a mass of 0.5–0.6 $M_\odot$, which gives a period of several decades. It is therefore not surprising that our two epoch measurements already resolve the orbital motion of B relative to A (see Fig. 1).

With a physical projected separation of 23 AU, this system is among the closer binaries known to host a planetary system. Like Gliese 86 (Lagrange et al. 2006), HD 41004 (Zucker et al. 2004) and γ Cet (Neuhäuser et al. 2007), HD 196885 is an ideal system for carrying out combined astrometric and RV observations to constrain the binary dynamic properties and the possible impact of a close binary companion on planet formation and evolution.

3.2. HD 1237 B, an M4V dwarf

HD 1237 B is located at a projected angular separation of 3.8″ (i.e a projected physical separation of 68 AU) from the exoplanet host star HD 1237 A. Previous NACO follow-up observations showed that HD 1237 B is comoving with A and revealed the orbital motion of B relative to A (Chauvin et al. 2006). The near-infrared photometry of HD 1237 B is compatible with that expected for an M4V to M6V field dwarfs according to the evolutionary model predictions of Baraffe et al. (1998).

Based on the near-infrared spectroscopy, the HD 1237 B spectrum can be compared to the template spectra of M dwarfs (Leggett et al. 2001; Cushing et al. 2005; see Fig. 3). Using the CO index that measure the strength of the ^{12}CO 2–0 band head at 2.29 μm (McLean et al. 2003), we find a value of 0.945 which excludes spectral types later than M6V according to Cushing et al. (2005). Using a minimum χ^2 adjustment to find the best spectra matching the CO bands of our HD 1237 B spectrum, we derive a spectral type M4 ± 1V for HD 1237 B. Additional neutral atomic lines typical of M dwarfs are also present such as MgI (1.50 μm) NaI (2.20 and 2.33 μm) and CaI (2.26 μm). This result is also in agreement with the spectral type estimation independently obtained by Mugrauer et al. (2007) using ISAAC at the VLT.

For a system age of 0.8 Gyr, the predictions of the Baraffe et al. (1998) model give a mass of ~0.13 $M_\odot$. The maximum radial velocity drift that B should produce on A is about 4 m s^{-1} yr^{-1} (assuming a circular orbit). The chromospheric activity of HD 1237 A induces a RV residual of 18 m s^{-1} (Naef et al. 2001), which excludes a short-term study combining RV with astrometric measurements to dynamically characterize this system.

3.3. HD 27442 B, a DA white dwarf

On November 17 2003, the faint companion HD 27442 B was detected at ∼13″ (i.e. 240 AU in projected physical distance) from the subgiant exoplanet host star HD 27442 A. Follow-up observations confirmed that HD 27442 A and B are comoving (Raghavan et al. 2006, Chauvin et al. 2006). The combined use of NACO JK photometry and V-band observations from the Washington Visual Double Star Catalog (WDS, Worley & Douglass 1997) revealed that HD 27442 B is not a main sequence star or a brown dwarf, but more probably a white dwarf companion. The SINFONI near-infrared spectrum for HD 27442 B spectral range confirms unambiguously this assumption (see Fig. 2). The H and K-band spectra do not present any H_2O or CO molecular bands typical of cool stellar or substellar atmospheres. The continuum slope follows the Rayleigh-Jeans domain typical of warm, early-type star atmospheres. The lack of helium lines and the detection of a broad Brγ (2.166 μm) hydrogen feature indicates a white-dwarf atmosphere dominated by hydrogen (DA). The broad Brγ line profile results from pressure and Doppler broadening and is a well-known characteristic of white dwarfs' dense atmospheres. While writing this paper, a similar analysis was obtained by Mugrauer et al. (2007) using ISAAC at the VLT who independently confirm the hydrogen-rich white dwarf status of HD 27442 B.

Holberg et al. (2002) found that 70% of the nearby ($d \leq$ 20 pc) white dwarfs are hydrogen-rich and 25% are part of multiple systems, which does not mean that the HD 27442

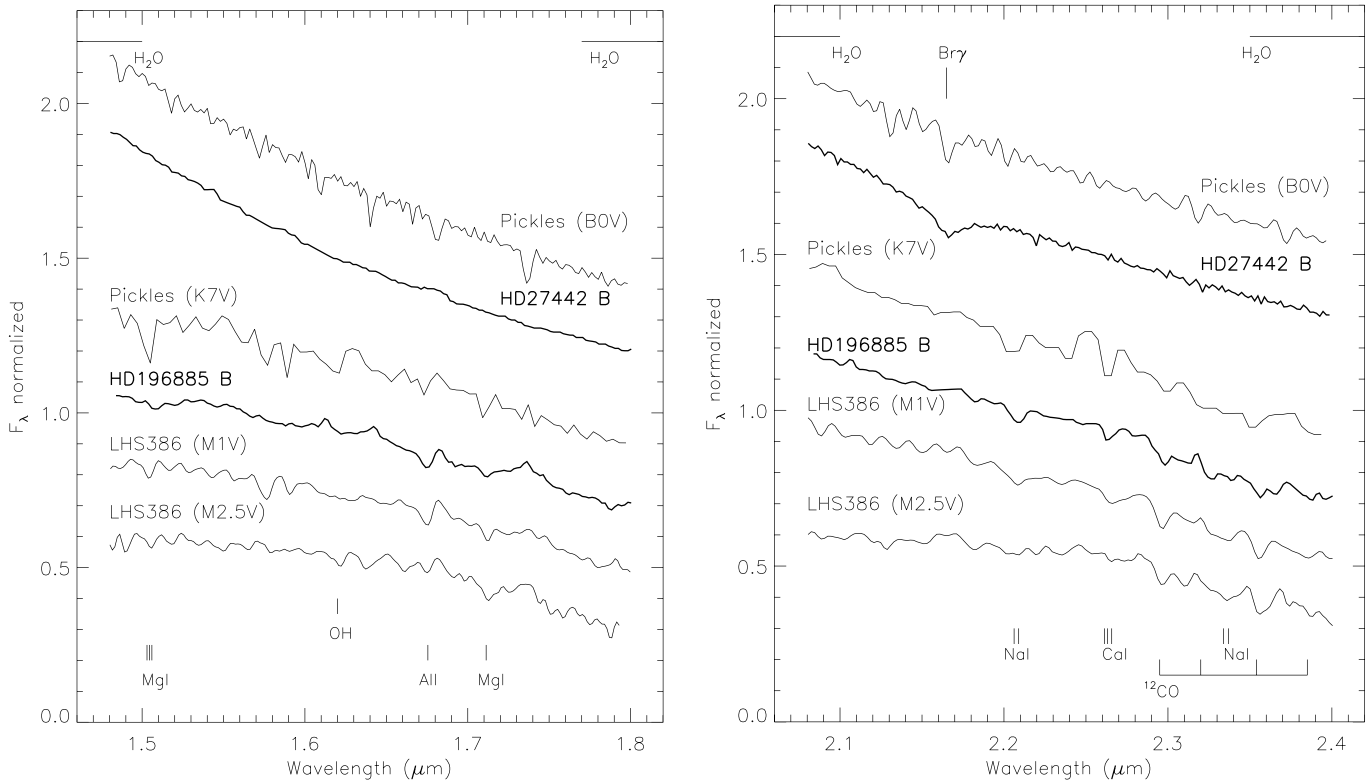

Fig. 2. VLT/NACO and SINFONI spectroscopy for HD 27442 B and HD 196885 B over the spectral range (1.4–1.9 μm, *left*) and (2.0–2.5 μm, *right*). Template spectra of Pickles et al. (1998) and Leggett et al. (2001) are shown for direct comparison.

(K2IV + DA) binary system is anything odd. The main particularity is that the primary is a subgiant exoplanet host star and is in that sense a more evolved system than HD 147513 (G5V + DA, Porto de Mello & da Silva 1997; Mayor et al. 2004) and Gliese 86 AB (K1V + WD; Queloz et al. 2000; Els et al. 2001; Jahreiss 2001), which were the first two systems of this kind to be discovered.

Using visible and near-infrared photometry on HD 27442 B compared to predictions from the evolutionary model of Bergeron et al. (2001) for white dwarfs with hydrogen-rich atmospheres, the mass of HD 27442 B ranges from 0.3 to 1.2 $M_{\odot}$ and the effective temperature from 9000 to 17000 K. The next step would be to carry out a detailed photometric and spectroscopic analysis in optical and near-infrared wavelengths to determine the effective temperature and the surface gravity of HD 27442 B. Such an analysis can be done based on the comparison of hydrogen Balmer lines or combined optical BVRI and infrared JHK photometry with model predictions for pure hydrogen atmospheres (Bergeron et al. 1992, 1997). As the trigonometric parallax of the system is known thanks to HD 27442 A, the radius of HD 27442 B and hence its mass could be determined through the theoretical mass-radius relation for white dwarfs.

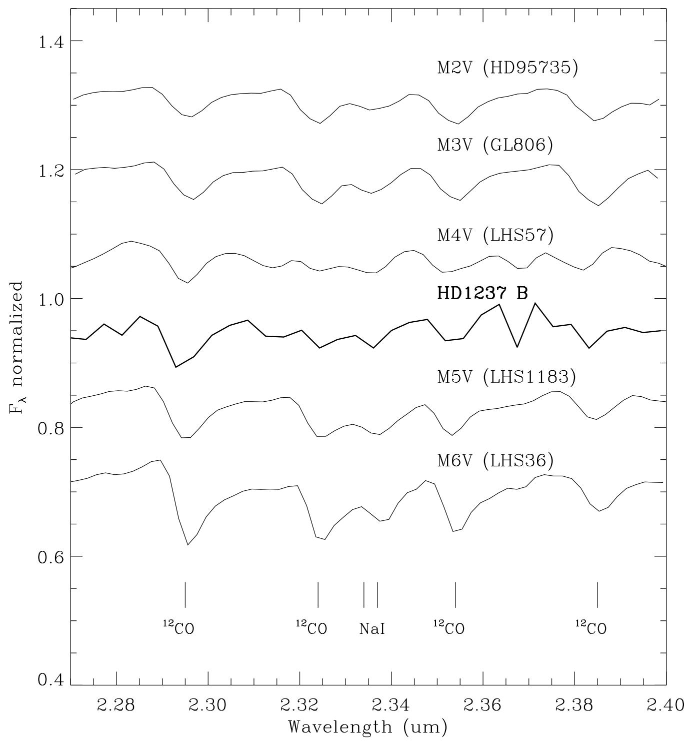

Fig. 3. VLT/NACO near-infrared spectrum of HD 1237 B obtained with the low resolution (R_{λ} = 550) grism, the SHK (1.40–2.50 μm) filter and the 86 mas slit. The limited spectral range between 2.27 and 2.40 μm is shown. For spectral type determination, the obvious temperature sensitive features of the CO molecular bands were compared to the template spectra of M dwarfs (Leggett et al. 2001, Cushing et al. 2005), smoothed to the same spectral resolution. This comparison confirms a spectral type M4 ± 1V for HD 1237 B.

4. Conclusions

We present the follow-up imaging and spectroscopic characterization of three long-period companions to the exoplanet host stars HD 196885, HD 1237 and HD 27442. The three objects were discovered during a previous deep-imaging survey carried out at CFHT and at VLT. Our new observations confirm their companionship unamiguously as well as their nature, which had previously been inferred from their photometry. Whereas

HD 196885 and HD 1237 are two stellar companions of spectral type M1 ± 1V and M4 ± 1V respectively, HD 27442 is the second confirmed white dwarf companion of an exoplanet host star. The detection of the broad Brγ hydrogen line indicates a white dwarf atmosphere dominated by hydrogen.

HD 196885 AB is one of the closer resolved binaries known to host an exoplanet. The presence of this long-period companion may have played a key-role in the formation and the evolution of the inner planetary system, but how? The two main mechanisms of planetary formation, core accretion and disk instability, do not lead to the same predictions while the impact of a binary companion, depending on the separation and the mass ratio, is still debated. A complete dynamic characterization of nearby, tight binaries with planets and a dedicated imaging survey to study the multiplicity among stars with and without planets are clearly required to throw new light on the mechanisms of planetary formation and evolution.

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References

Baraffe, I., Chabrier, G., Allard, F., & P. H. Hauschildt 1998, A&A, 337, 403
Bergeron, P., Saffer, R. A., & Liebert, J. 1992, ApJ, 394, 228
Bergeron, P., Ruiz, M. T., & Leggett, S. K. 1997, ApJS, 108, 339
Bergeron, P., Leggett, S. K., & Ruiz, M. T. 2001, ApJS, 133, 413
Bonfils, X., Forveille, T., Delfosse, X., et al. 2005, A&A, 443, L15
Butler, R. P., Tinney, C. G., Marcy, G. W., et al. 2001, ApJ., 555, 410
Chauvin, G., Lagrange, A. M., Lacombe, F., et al. 2005, A&A, 430, 1027
Chauvin, G., Lagrange, A. M., Udry, S., et al. 2006, A&A, 456, 1165
Chelli, A. 2000, A&A, 358, L59
Cushing, M. C., Rayner, J. T., & Vacca, W. D. 2005 ApJ, 623, 1115
Delfosse, X., Forveille, T., Mayor, M., et al. 1998, A&A, 338, L67
Devillard, N. 1997, The messenger, 87
Eggenberger, A., Udry, S., Chauvin, G., et al. 2007, A&A, submitted
Endl, M., Cochran, W. D., Tull, R. G., et al. 2003, AJ, 126, 3099
Galland, F., Lagrange, A.-M., Udry, S., et al. 2005, A&A, 443, 337
Goto, M., Kobayashi, N., Terada, H., et al. 2002, ApJ, 567, L59
Holberg, J. B., Oswalt, T. D., & Sion, E. M. 2002, ApJ, 571, 512
Jahreiss, H. 2001, Astron. Ges. Abstr. Ser., 18, 190
Lagrange, A.-M., Beust, H., Udry, S., et al. 2006, A&A, 459, 955
Leggett, S. K., Allard, F., Geballe, T. R., Hauschildt, P. H., & Schweitzer, A. 2001, ApJ, 548, 908
Luhman, K., & Jayawardhana, R. 2002, ApJ, 566, 1132
Mayor, M., & Queloz, D. 1995, Nature, 378, 355
Mayor, M., Udry, S., Naef, D., et al. 2004, A&A, 415, 391
McArthur, B. E., Endl, M., Cochran, W. D., et al. 2004, ApJ, 614, 81
McCaughrean, M. J., & Stauffer, J. R. 1994, AJ, 108, 1382
McLean, I. S., McGovern, M. R., Burgasser, A. J., et al. 2003, ApJ, 596, 561
Mugrauer, M., & Neuhäuser, R. 2005, MNRAS, 361, 15
Mugrauer, M., Seifahrt, Neuhäuser, R., & Mazeh, T. 2006, MNRAS, 373, 31
Mugrauer, M., Neuhäuser, R., Mazeh, T., & Guenther, E. 2007, A&A, 469, 755
Naef, D., Mayor, M., Pepe, F., et al. 2001, A&A, 375, 205
Neuhäuser, R., Mugrauer, M., Fukagawa, M., et al. 2007, A&A, 462, 777
Oppenheimer, B. R., Golimowski, D. A., Kulkarni, S. R., et al. 2001, AJ, 121, 2189
Pickles, A. J. 1998, PASP, 110, 863
Porto de Mello, G. F., & da Silva, L. 1997, ApJ, 476, 89
Queloz, D., Mayor, M., Weber, L., et al. 2000, A&A, 354, 99
Raghavan, D., Henry, T. J., Mason, B. D., et al. 2006, ApJ, 646, 523
Santos, N. C., Bouchy, F., Mayor, M., et al. 2004, A&A, 426, L19
Udry, S., Mayor, M., Clausen, J. V., et al. 2003, A&A, 407, 369
Worley, C. E., & Douglass, G. G. 1997, A&AS, 125, 123
Wright, J. T., Marcy, G. W., Butler, R. P., et al. 2004, ApJS, 152, 261
Zucker, S., Mazeh, T., Santos, N., Udry, S., & Mayor, M. 2004, A&A, 426, 695