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ADAPTIVE OPTICS OBSERVATIONS OF THE BINARY STAR HD 43587[1]

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ABSTRACT

We present adaptive optics observations of HD 43587, one of the primary targets of the *COROT* (Convection, Rotation, and Planetary Transits) asteroseismology and planet-finding space mission and a star that was previously detected as a spectroscopic binary by Vogt and coworkers. We resolve a close companion, which is responsible for the radial velocity variations of the primary. Our observations over a 3 year interval measure the orbital displacement of the companion. Combining these measurements with the radial velocity data of Vogt and coworkers, we solve for the three-dimensional orbit of the system and derive individual masses for HD 43587 and its companion. This is particularly interesting in the perspective of the upcoming *COROT* mission. These observations were part of a preparatory program for *COROT*, in which we observed all *COROT* potential primary targets and some of its secondary targets with adaptive optics. The majority of these stars have potential companions in a 30″ field. Most of these are probably background objects, but some are found within a few arcseconds of the *COROT* targets and are likely to be true physical companions.

Key words: binaries: visual — stars: oscillations — techniques: high angular resolution — techniques: photometric

Online material: machine-readable table

1. INTRODUCTION

HD 43587 is one of the primary targets of the asteroseismology program of the *COROT* (Convection, Rotation, and Planetary Transits) space mission, to be launched in 2006 October. *COROT* is a Centre National d'Etudes Spatiales–led high-precision long-duration photometric space mission with the dual goals of studying stellar interiors by asteroseismology and searching for extrasolar planetary transits (Baglin et al. 2002). The asteroseismology program involves the monitoring of a few primary bright targets, as well as several dozens of fainter stars in the same 1.3×2.6 deg^2 fields.

Unrecognized fainter sources in the vicinity of *COROT* targets can interfere with the extraction of the photometric signal, while known neighbors can be taken into account by the analysis software and do not appreciably degrade the data quality. Physical companions also provide additional information on their primary, as illustrated below for HD 43587. As part of the *COROT* preparation, we therefore obtained high angular resolution images with adaptive optics for the fields of all primary targets and some secondary targets.

HD 43587 (also Gl 231.1A) is a bright solar-type star (F9 V, $d = 19.3$ pc, $V = 5.71$), and as such it has been included in the samples of radial velocity searches for extrasolar planets (Vogt et al. 2002; M. Mayor & S. Udry 2004, private communication). Shortly after our initial adaptive optics observations, we found out that Vogt et al. (2002) monitored the star's radial velocity from 1997 to 2001 and discovered that it is a highly eccentric spectroscopic binary. The radial velocity curve indicates a minimum secondary mass of 0.34 $M_\odot$, with a period of 33.7 yr. The orbital solution of Vogt et al. (2002) predicts a minimum semimajor axis of 11.6 AU, corresponding to about 0″.6 at the distance of HD 43587. Even for its minimum mass the secondary would only be ~5.5 mag fainter than the primary at V, and only ~3.5 mag fainter in the near-infrared. These parameters are within easy reach of adaptive optics observations in good weather.

In this paper we indeed report the adaptive optics detection of the companion of HD 43587 that causes its radial velocity variations. Observations at three epochs during a 3 yr interval reveal a large orbital motion for the system. Combined with the published radial velocity measurement, they fully determine its three-dimensional orbit.

In § 2 we present the observations and data-reduction procedure. Section 3 presents the derivation of the orbital elements and discusses the results. The Appendix summarizes the other adaptive optics observations performed for the *COROT* preparation program, and reports the detection of several close companions to *COROT* primary targets.

2. OBSERVATIONS AND DATA REDUCTION

We used the Pueo adaptive optics bonnette of the Canada-France-Hawaii Telescope (CFHT; Rigaut et al. 1998), equipped

[1] Based on observations obtained at the Canada-France-Hawaii Telescope, which is operated by the National Research Council of Canada, the Institut National des Science de l'Univers of the Centre National de la Recherche Scientifique of France, and the University of Hawaii.

TABLE 1
CHARACTERISTICS OF THE FILTERS USED FOR THESE OBSERVATIONS

Filter	Central Wavelength (μm)	FWHM (μm)
K'	2.12	0.34
H	1.635	0.29
J	1.25	0.16
$H_2(1-0)$	2.122	0.021
[Fe II]	1.644	0.016
[O II]	1.237	0.012

TABLE 2
LOG OF THE CFHT AOB OBSERVATIONS OF HD 43587

Date and UT	t_{exp} (s)	Filter	n	N
2002 Jan 24, 08:06:41	1.5	H_2	13	4
2004 Sep 28, 15:37:07	3.0	H_2	7	5
2004 Sep 28, 15:49:53	2.0	[Fe II]	7	5
2005 Jan 28, 09:41:45	0.8	[Fe II]	7	5

with the 1024 × 1024 near-infrared detector KIR (Doyon et al. 1998). This configuration provides a pixel size of 0″.0348 in a field of view of about 35″. We used a set of both wideband and narrowband filters, whose characteristics are given in Table 1. The program was spread over four observing runs: one night in 2002 January, two nights in 2002 June, one night in 2004 September, and one night in 2005 January.

HD 43587 was only observed during the 2002 January, 2004 September, and 2005 January runs in the H_2 and the [Fe II] filters. The star was observed either four or five times with a given filter, with an offset of a few arcseconds applied to the telescope between successive exposures in both right ascension and declination. This dithering procedure, which is classical in this kind of observation (see, e.g., ten Brummelaar et al. 2000), allows us to subtract the sky background and to detect nearby faint stars around bright targets with a high confidence level. It also provides a conservative estimate of the error bars on the relative astrometric and photometric measurements.

Each observation consists of a series of 5–10 elementary exposures separated by reference frames. Reference frames (offsets) are systematically subtracted from the elementary exposures before being written to the output FITS file. We then average subexposures contained in the FITS data cube files and subsequently work only on these averaged images. Because of the variable atmospheric conditions during the observations, some elementary frames have a few saturated pixels at the location of our bright central targets. We identify these frames and simply discard them.

Table 2 gives the log of the HD 43587 observations. In this table, n is the number of elementary exposures with exposure time t_{exp}, while N is the number of telescope pointings in the dithering procedure. The 2002 January run was interrupted within a few hours by bad weather, but the seeing and transparency conditions were good before the interruption. The star was observed only in the H_2 narrowband filter, no time being available to observe in the other filters. The 2004 September run was also plagued by bad weather, and only a few hours were available in fair but variable conditions. Finally, the 2005 January observations were obtained in reasonably good conditions. Because the seeing conditions and therefore the Strehl ratios were different from one run to another, we were led to choose different elementary exposure times, as seen in Table 2.

All images obtained in the dithering procedure described above were analyzed using the *find* algorithm of the DAOPHOT package (Stetson 1987), available in the *IDL astron* library. The *find* algorithm detects all stars present in the image and determines their positions and fluxes above a local image background. A 3 σ lower threshold was applied for this source detection.

3. RESULTS

We detected the companion of HD 43587 at all three epochs and in both filters, with the flux in the image of the companion being more than 3000 times the noise level. The relative position and magnitude of the companion with respect to the primary were measured independently in all images. These results are presented in Table 3, in which the separation in right ascension $\Delta\alpha$ is given in seconds of hours, while that in declination $\Delta\delta$ and angular separation ρ are given in arcseconds. Errors represent 1 σ uncertainties, estimated using the dispersion of individual measurements on all images used in the dithering procedure. Figure 1 shows images of HD 43587 and its companion in the H_2 filter in 2002 January and 2004 September.

The relative position of the companion with respect to the primary has clearly changed between the 2002 and 2004/2005 observations. These measurements, combined with the radial velocity measurements published by Vogt et al. (2002), allow us to derive the elements of the orbit. We used the ORBIT package, fully described in Forveille et al. (1999), which performs a least-squares fitting of both spectroscopic and visual observations to search for the orbit solution. We find the following results:

$P = 28.8 \pm 1.1$ yr.
$T_0 = 1998.0494 \pm 0.0024$ (Besselian year).
$e = 0.78 \pm 0.006$.
$i = 35.^\circ4 \pm 2.^\circ5$.
$M_1 = 0.96 \pm 0.18\ M_\odot$.
$M_2 = 0.67 \pm 0.04\ M_\odot$.
$\Omega = 166.^\circ8 \pm 1.^\circ3$.
$\omega = 75.^\circ0 \pm 0.^\circ3$.
$a = 0.^\circ621 \pm 0.''019$.

The mass of the primary agrees well with its atmospheric parameters, $T_{\rm eff} = 5870$ K, $\log g = 4.3$, and $[{\rm Fe/H}] = -0.09$ (Bruntt et al. 2004), and with its absolute magnitude $M_V = 4.28$ derived from the *Hipparcos* parallax. Using the evolutionary models of Lejeune & Schaerer (2001), we indeed find that the location of HD 43587 in the H-R diagram places it at a mass of 1.1 $M_\odot$ and an age of 5 Gyr.

It is worth noting that the orbital elements calculated above indicate an angular separation between primary and secondary components of 0″.72 in 1991, when the star was observed by the *Hipparcos* satellite, which did not detect the companion at that time. We believe this is due to the large magnitude difference in the *Hp* filter of *Hipparcos*, which is fairly blue.

The infrared magnitudes and colors of the companion can only be determined by comparison with those of the primary, because the atmospheric conditions were not photometric during our adaptive optics observations. Unfortunately, the infrared magnitudes of HD 43587 are not well known: because it is a very bright source, the magnitudes in the Two Micron All Sky Survey (2MASS) catalog are provided with a very low quality factor and very large error bars. On the other hand, the effective temperature and absolute visual magnitude are well constrained, and we expect negligible interstellar reddening for this very nearby system. We can therefore rely on atmospheric models to estimate the infrared colors of HD 43587, and then those of its companion using the

TABLE 3

Relative Positions of the Detected Companion to HD 43587

Date (Besselian Year)	$\Delta\alpha$ (sec)	$\Delta\delta$ (arcsec)	ρ (arcsec)	θ (deg)	Filter	Δm
2002.06384	0.0104 ± 0.00014	0.547 ± 0.0028	0.569 ± 0.0025	15.86 ± 0.28	H_2	2.44 ± 0.02
2004.74243	0.0221 ± 0.00023	0.638 ± 0.0042	0.720 ± 0.0052	27.36 ± 0.40	H_2	2.49 ± 0.04
2004.74243	0.0221 ± 0.00023	0.635 ± 0.0034	0.717 ± 0.0036	27.47 ± 0.37	[Fe II]	2.69 ± 0.09
2005.07568	0.0233 ± 0.00034	0.638 ± 0.0042	0.728 ± 0.0043	28.62 ± 0.51	[Fe II]	2.70 ± 0.07

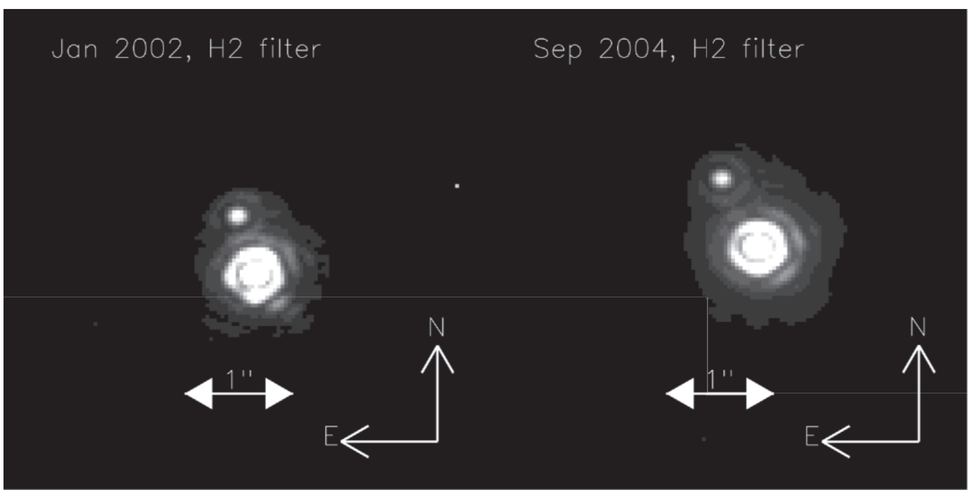

Fig. 1.—Adaptive optics images of the HD 43587 field.

TABLE 4

Estimated Characteristics of HD 43587 and Its Companion

Component	V	$V-K$	$H-K$	M_V	M_K	M_H	$T_{\rm eff}$ (K)	Mass ($M_\odot$)
HD 43587A	5.71 ± 0.01	1.44 ± 0.03	0.04 ± 0.007	4.28 ± 0.08	2.84 ± 0.11	2.88 ± 0.12	5870 ± 60	1.10 ± 0.10
HD 43587B	...	...	0.23 ± 0.13	...	5.30 ± 0.15	5.57 ± 0.21	3820 ± 100	0.54 ± 0.05

Note.—The mass in the last column is derived from comparison with theoretical evolutionary tracks.

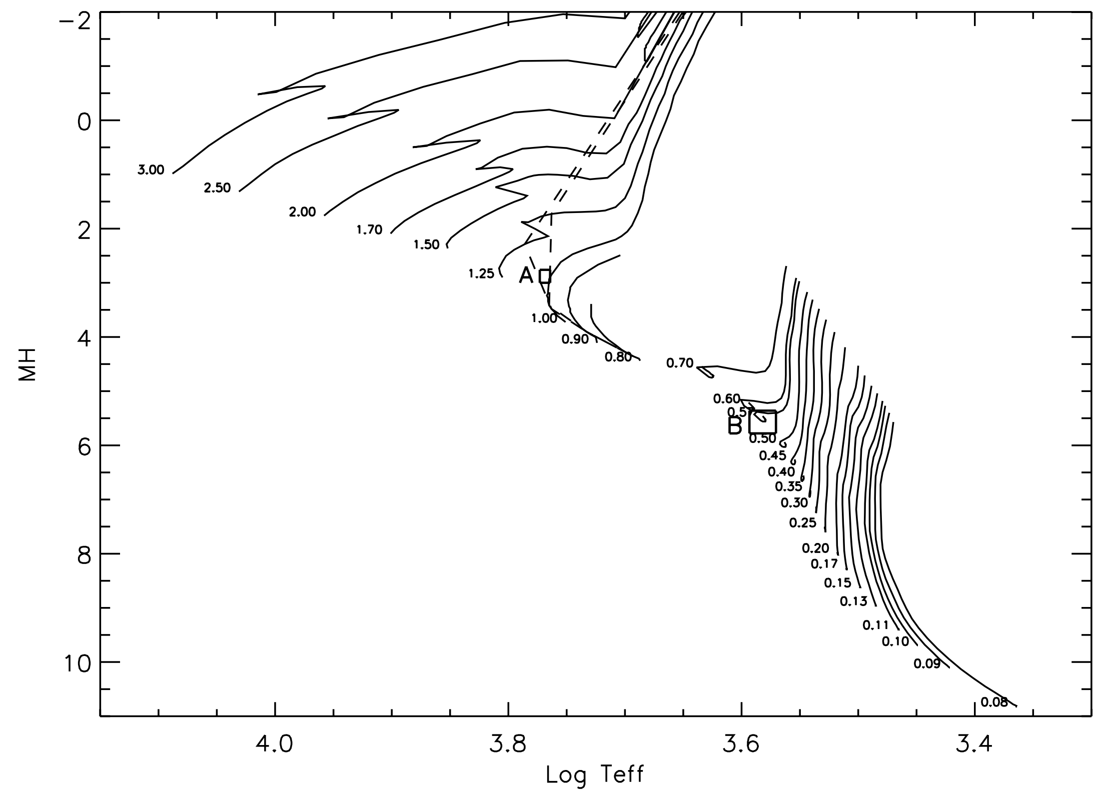

FIG. 2.—Location of HD 43587 (A) and its companion (B) in the H-R diagram. Uncertainties are represented by squares. Evolutionary tracks are shown as solid lines and labeled by their mass in solar masses, and isochrones for 4 and 5 Gyr are indicated by dashed lines.

observed magnitude differences. We used the atmospheric models of Bessell et al. (1998) to determine $V - K$ and $H - K$ from the parameters of HD 43587, then combined them with the Vabsolute magnitude to determine its H and K absolute magnitudes. We subsequently computed the H and K magnitudes of the companion using our observations in the [Fe II] and H_2 filters as proxies for the H and K bands, respectively.

We then used the low-mass star evolutionary tracks of Baraffe et al. (1998) and the age estimate of 5 Gyr for the HD 43587 system to evaluate the effective temperature and mass of the companion. The H and K absolute magnitudes give consistent results, which Table 4 summarizes.

Figure 2 shows the location of HD 43587 and its lower mass companion in the H-R diagram, with the evolutionary tracks of Lejeune & Schaerer (2001) and Baraffe et al. (1998), as well as isochrones for 4 and 5 Gyr. We note that the mass of HD 43587 estimated using the infrared magnitudes is in fair agreement with that inferred from the orbital elements.

4. CONCLUSION AND FUTURE WORK

We have resolved with adaptive optics images the companion of the F9 V star HD 43587, which Vogt et al. (2002) discovered using radial velocity monitoring. Observations at three epochs allow us to derive the elements of the binary orbit and to calculate the mass of each component.

These measurements, and most importantly, the masses of the two components of this system, can have a significant impact on the scientific return of the asteroseismology space mission *COROT*, for which HD 43587 is one of the primary targets. Continued monitoring of this star, in both radial velocity and adaptive optics imagery, is of utmost importance to improve the precision of the mass determination.

We thank the staff of the Canada-France-Hawaii 3.6 m telescope for their efficient assistance during the observations. We are grateful to the anonymous referee for useful comments. This research has made use of the SIMBAD database and of the VizieR service, operated at CDS, Strasbourg, France.

APPENDIX

ADDITIONAL ADAPTIVE OPTICS OBSERVATIONS OF THE FIELDS AROUND *COROT* POTENTIAL TARGETS

In addition to HD 43587, many other *COROT* potential targets were observed with the same instrumental configuration. We detected neighboring faint sources around most of them.

Table 5 gives the list and characteristics of the detected faint neighboring sources to our target stars. In this table, $\Delta\alpha$ is given in seconds of hours, while $\Delta\delta$ and angular separations ρ are given in arcseconds. Errors given with a $\pm$ represent 1 σ errors estimated using the variance of the measurements for different telescope pointings.

Many of these neighboring sources are either background sources or newly reported physical companions to our target stars, but some of them are identified as second components of known double stars using the Catalog of Components of Double and Multiple Stars (CCDM; Dommanget & Nys 2000, 2002). For these targets, the column labeled ΔV in Table 5 contains the visual magnitude difference between the companion and the target star.

In order to identify physical companions, we have estimated, for each detected neighboring source, the probability of finding a background source of the observed magnitude at the observed distance from the target star. In the absence of information about

TABLE 5

Characteristics of Faint Neighbors to the Target Stars

Source (HD)	Date (Besselian Year)	$\Delta\alpha$ (sec)	$\Delta\delta$ (arcsec)	ρ (arcsec)	P.A. (deg)	Filter	Δm	ΔV	P	T_p (K)	T_c (K)
43318	2002.06384					H_2					
43587B	2002.06384	0.0104 ± 0.0001	0.547 ± 0.003	0.569 ± 0.003	15.86 ± 0.28	H_2	2.44 ± 0.02		1.0e−6	5870	3820
43587B	2004.74243	0.0221 ± 0.0002	0.635 ± 0.003	0.717 ± 0.004	27.47 ± 0.37	[Fe II]	2.69 ± 0.09				
43587B	2004.74243	0.0221 ± 0.0002	0.638 ± 0.004	0.720 ± 0.005	27.36 ± 0.40	H_2	2.49 ± 0.04				
43587B	2005.07568	0.0233 ± 0.0003	0.638 ± 0.004	0.728 ± 0.004	28.62 ± 0.51	[Fe II]	2.70 ± 0.07				
44195B	2002.06409	0.0624 ± 0.0001	0.253 ± 0.001	0.969 ± 0.001	74.86 ± 0.08	H_2	2.83 ± 0.09		2.0e−5	7270	4000
44333B	2002.06421	−0.0162 ± 0.0005	−0.170 ± 0.020	0.297 ± 0.020	235.15 ± 3.99	H_2	0.78 ± 0.07		0	7680	6350
44947	2002.06421					H_2					
45067	2002.06384					H_2					
46304B	2002.06396	0.3032 ± 0.0002	0.011 ± 0.003	4.571 ± 0.003	89.86 ± 0.04	H_2	3.71 ± 0.06	7.7	5.2e−3	7460	3500
46558B	2004.74231	−0.2052 ± 0.0004	23.952 ± 0.003	24.149 ± 0.003		H_2	3.95 ± 0.08				
49434	2002.06396					H_2					
49933B	2002.06409	0.1456 ± 0.0002	6.118 ± 0.003	6.496 ± 0.003	19.64 ± 0.03	H_2	3.25 ± 0.05	5.5	2.5e−3	6470	4100
49933B	2004.74231	0.1435 ± 0.0002	6.146 ± 0.013	6.512 ± 0.212	19.30 ± 0.06	[Fe II]	3.53 ± 0.21				
49933B	2004.74231	0.1437 ± 0.0003	6.147 ± 0.015	6.514 ± 0.015	19.32 ± 0.08	H_2	3.45 ± 0.09				
52265B	2004.74231	0.5307 ± 0.0007	1.441 ± 0.016	8.090 ± 0.016		H_2	7.88 ± 0.19				
55057	2002.06409					H_2					
57006	2002.06409					H_2					
169842B	2002.47498	0.7373 ± 0.0009	5.127 ± 0.016	12.191 ± 0.019		K'	5.05 ± 0.10				
169842B	2004.74133	0.7375 ± 0.0025	5.182 ± 0.083	12.216 ± 0.084		H	7.61 ± 0.52				
169912B	2004.74146	−0.0064 ± 0.0003	−0.072 ± 0.007	0.120 ± 0.007	233.15 ± 3.96	J	0.43 ± 0.16	1.1	2.4e−5	7760	6760
169912B	2004.74146	−0.0065 ± 0.0003	−0.072 ± 0.005	0.121 ± 0.007	233.15 ± 3.94	H	0.59 ± 0.24				
169912B	2004.74146	-0.0069 ± 0.0007	−0.082 ± 0.004	0.133 ± 0.008	231.75 ± 4.18	K'	0.61 ± 0.18				
169912C	2004.74146	0.9311 ± 0.0001	0.871 ± 0.025	13.994 ± 0.025		K'	6.34 ± 0.12				
169912C	2004.74146	0.9330 ± 0.0005	0.880 ± 0.023	14.023 ± 0.023		J	6.90 ± 0.08				
169912C	2004.74146	0.9334 ± 0.0009	0.882 ± 0.016	14.029 ± 0.016		H	7.36 ± 0.23				
169912D	2004.74146	−0.9343 ± 0.0010	8.771 ± 0.018	16.533 ± 0.018		K'	7.19 ± 0.16				
169912D	2004.74146	−0.9344 ± 0.0006	8.778 ± 0.030	16.538 ± 0.030		H	7.98 ± 0.22				
169912D	2004.74146	−0.9395 ± 0.0046	8.779 ± 0.003	16.603 ± 0.059		J	8.24 ± 0.64				
169912E	2004.74146	−0.3417 ± 0.0006	−12.868 ± 0.023	13.851 ± 0.023		J	6.59 ± 0.29				
169912E	2004.74146	−0.3421 ± 0.0004	−12.864 ± 0.023	13.850 ± 0.023		K’	6.47 ± 0.26				
169912E	2004.74146	−0.3421 ± 0.0013	−12.875 ± 0.043	13.860 ± 0.047		H	7.41 ± 0.38				
169912F	2004.74146	−1.1804 ± 0.0004	−5.285 ± 0.020	18.478 ± 0.020		K’	7.12 ± 0.30				
169912F	2004.74146	−1.1815 ± 0.0007	−5.289 ± 0.030	18.494 ± 0.030		J	7.29 ± 0.45				
169912F	2004.74146	−1.1848 ± 0.0067	−5.333 ± 0.039	18.555 ± 0.086		H	7.91 ± 0.11				
169958	2002.47192					K'					
169959B	2002.47229	0.0351 ± 0.0001	−1.775 ± 0.002	1.862 ± 0.002	162.42 ± 0.03	H	1.15 ± 0.09	1.6	3.0e−5	12000	7890
169959B	2002.47192	0.0352 ± 0.0002	−1.772 ± 0.001	1.849 ± 0.002	163.41 ± 0.08	K'	0.98 ± 0.11				
169959B	2002.47229	0.0353 ± 0.0002	−1.775 ± 0.001	1.852 ± 0.002	163.42 ± 0.08	J	1.06 ± 0.08				
169959C	2002.47229	0.0649 ± 0.0006	−0.940 ± 0.003	1.353 ± 0.007	134.01 ± 0.17	H	5.76 ± 0.05		8.7e−4	12000	3700
169959C	2002.47229	0.0656 ± 0.0002	−0.933 ± 0.001	1.356 ± 0.003	133.48 ± 0.06	J	5.57 ± 0.07				
169959C	2002.47192	0.0658 ± 0.0003	−0.927 ± 0.007	1.354 ± 0.007	133.21 ± 0.09	K'	5.51 ± 0.08				
169959D	2002.47192	0.7116 ± 0.0012	1.487 ± 0.013	10.777 ± 0.016		K'	4.94 ± 0.69				
169959D	2002.47229	0.7131 ± 0.0004	1.483 ± 0.013	10.799 ± 0.013		J	5.46 ± 0.06				
169959D	2002.47229	0.7133 ± 0.0009	1.484 ± 0.016	10.801 ± 0.016		H	5.91 ± 0.16				
169959E	2002.47192	0.1097 ± 0.0028	6.866 ± 0.110	7.061 ± 0.117		K'	7.23 ± 0.58				

TABLE 5—*Continued*

Source (HD)	Date (Besselian Year)	$\Delta\alpha$ (sec)	$\Delta\delta$ (arcsec)	ρ (arcsec)	P.A. (deg)	Filter	Δm	ΔV	P	T_p (K)	T_c (K)
169959E	2002.47229	0.1111 ± 0.0005	6.944 ± 0.012	7.141 ± 0.013		J	7.45 ± 0.11				
169959E	2002.47229	0.1166 ± 0.0096	6.989 ± 0.085	7.205 ± 0.118		H	8.19 ± 0.44				
169959F	2002.47229	0.1974 ± 0.0011	10.572 ± 0.016	10.978 ± 0.016		H	8.10 ± 0.16				
169959F	2002.47229	0.1979 ± 0.0002	10.573 ± 0.007	10.982 ± 0.007		J	7.62 ± 0.15				
169959F	2002.47192	0.1979 ± 0.0011	10.553 ± 0.013	10.963 ± 0.013		K'	7.50 ± 0.14				
169959G	2002.47192	0.4362 ± 0.0062	11.562 ± 0.077	13.285 ± 0.080		K'	7.52 ± 0.47				
169959G	2002.47229	0.4389 ± 0.0007	11.540 ± 0.044	13.287 ± 0.034		H	7.93 ± 0.24				
169959G	2002.47229	0.4396 ± 0.0003	11.535 ± 0.016	13.286 ± 0.016		J	7.61 ± 0.25				
170011B	2004.74146	−1.3017 ± 0.0101	9.467 ± 0.130	21.700 ± 0.178		H	8.58 ± 0.26				
170011B	2004.74146	−1.3082 ± 0.0067	9.520 ± 0.197	21.810 ± 0.176		J	8.46 ± 0.24				
170030B	2004.74158	0.5723 ± 0.0020	−2.807 ± 0.008	9.031 ± 0.031		H	7.75 ± 0.40				
170030C	2004.74158	0.0814 ± 0.0005	−4.690 ± 0.017	4.846 ± 0.018		H	7.51 ± 0.29				
170030D	2002.47510	1.2933 ± 0.0001	−1.742 ± 0.002	19.478 ± 0.002		K'	5.53 ± 0.08				
170030D	2004.74158	1.2936 ± 0.0006	−1.696 ± 0.034	19.478 ± 0.035		H	7.59 ± 0.11				
170079	2002.47510					K'					
170094B	2002.47522	−0.9017 ± 0.0007	13.348 ± 0.033	19.003 ± 0.033		K'	2.99 ± 0.02				
170114B	2002.47522	0.0697 ± 0.0002	−0.235 ± 0.007	1.071 ± 0.007	102.67 ± 0.33	K'	1.17 ± 0.03	1.0	3.1e−5	7020	
170135	2002.47205					K'					
170158B	2002.47522	1.1891 ± 0.0007	−7.408 ± 0.024	19.313 ± 0.019		K'	3.87 ± 0.20				
170271	2002.47522					K'					
170293B	2002.47522	−0.1199 ± 0.0003	7.306 ± 0.005	7.524 ± 0.006		K'	3.76 ± 0.06		1.1e−2	7070	
170346B	2002.47534	−0.4865 ± 0.0008	−2.604 ± 0.015	7.748 ± 0.015		K'	6.03 ± 0.19				
170346C	2002.47534	0.0779 ± 0.0003	4.966 ± 0.010	5.102 ± 0.010		K'	6.39 ± 0.18		6.6e−2	7400	
170563B	2002.47192	0.0787 ± 0.0008	−6.339 ± 0.014	6.448 ± 0.015		K'	6.99 ± 0.13				
170563B	2002.47229	0.0797 ± 0.0005	−6.360 ± 0.009	6.471 ± 0.010		J	7.10 ± 0.12				
170563B	2002.47449	0.0793 ± 0.0005	−6.358 ± 0.011	6.468 ± 0.011		J	7.50 ± 0.23				
170563C	2002.47192	−0.3865 ± 0.0008	−7.737 ± 0.020	9.668 ± 0.020		K'	7.52 ± 0.11				
170563C	2002.47229	−0.3874 ± 0.0007	−7.745 ± 0.020	9.683 ± 0.022		J	7.93 ± 0.19				
170563C	2002.47449	−0.3956 ± 0.0070	−7.640 ± 0.120	9.674 ± 0.059		J	8.41 ± 0.39				
170563D	2002.47192	0.0704 ± 0.0005	−10.214 ± 0.011	10.269 ± 0.012		K'	7.13 ± 0.17				
170563D	2002.47229	0.0708 ± 0.0005	−10.233 ± 0.014	10.288 ± 0.014		J	7.35 ± 0.17				
170580B	2004.74121	0.3360 ± 0.0003	−19.461 ± 0.005	20.103 ± 0.005	165.48 ± 0.01	H_2	4.44 ± 0.03	5.3		18200	8100
170699	2002.47180					H_2					
170782	2002.47217					K'					
170881B	2002.47205	0.1838 ± 0.0003	3.235 ± 0.007	4.251 ± 0.007	40.45 ± 0.11	K'	1.00 ± 0.09	1.3	1.5e−4	10500	8450
170881B	2002.47241	0.1842 ± 0.0005	3.242 ± 0.007	4.260 ± 0.007		J	1.16 ± 0.10				
170881B	2002.47461	0.1839 ± 0.0004	3.241 ± 0.005	4.256 ± 0.005		H	1.14 ± 0.10				
170881B	2002.47449	0.1841 ± 0.0003	3.237 ± 0.004	4.255 ± 0.004		J	1.16 ± 0.06				
171234B	2002.47217	0.6475 ± 0.0003	−15.048 ± 0.020	17.910 ± 0.020		K'	3.55 ± 0.05		1.6e−2	7650	
171234B	2002.47498	0.6508 ± 0.0040	−15.071 ± 0.029	17.957 ± 0.020		H	4.13 ± 0.15				
171234C	2002.47217	−0.1080 ± 0.0136	−18.142 ± 0.105	18.215 ± 0.120		K'	5.27 ± 0.32				
171834B	2002.47229	−0.4789 ± 0.0005	0.450 ± 0.008	7.198 ± 0.010		[Fe II]	6.63 ± 0.14		3.6e−2	6880	
171834B	2002.47180	−0.4789 ± 0.0005	0.456 ± 0.009	7.199 ± 0.009		H_2	6.55 ± 0.16				
171834B	2002.47217	−0.4812 ± 0.0002	0.456 ± 0.011	7.233 ± 0.012		[O II]	7.21 ± 0.25				
174866B	2002.47205	0.3163 ± 0.0003	2.215 ± 0.010	5.236 ± 0.010		H_2	7.00 ± 0.15		6.7e−2	7680	
174866B	2002.47461	0.3169 ± 0.0007	2.220 ± 0.006	5.247 ± 0.010		J	7.44 ± 0.18				
174866C	2002.47205	0.5409 ± 0.0003	13.590 ± 0.020	15.827 ± 0.020		H_2	6.46 ± 0.10				
175726B	2004.74133	0.4894 ± 0.0001	15.529 ± 0.025	17.177 ± 0.025		H_2	7.92 ± 0.52				

TABLE 5—*Continued*

Source (HD)	Date (Besselian Year)	$\Delta\alpha$ (sec)	$\Delta\delta$ (arcsec)	ρ (arcsec)	P.A. (deg)	Filter	Δm	ΔV	P	T_p (K)	T_c (K)
175726C	2004.74133	-0.3952 ± 0.0009	-2.479 ± 0.018	6.425 ± 0.018		H_2	8.01 ± 0.04				
175726D	2004.74133	-0.5018 ± 0.0006	20.948 ± 0.012	22.259 ± 0.012		H_2	8.05 ± 0.40				
177552B	2004.74121	0.0871 ± 0.0003	2.183 ± 0.004	2.544 ± 0.005	30.90 ± 0.13	H_2	6.53 ± 0.08		6.4e−3	7040	2900
180642B	2004.74133	-0.4057 ± 0.0005	5.244 ± 0.012	8.033 ± 0.012		K'	5.07 ± 0.35		6.4e−2	26500	
181555	2004.74121					H_2					
183324	2002.47217					H_2					
184663	2002.47180					H_2					

Note.—Table 5 is also available in machine-readable form in the electronic edition of the *Astronomical Journal*.

the colors of the detected neighboring sources, their R magnitudes were roughly approximated using the known R magnitude of the target star and the highest magnitude difference found in the various filters used in this analysis, including as well the V-magnitude difference whenever it was known from other catalogs. Although definitely not rigorous, because we combine R magnitudes with IR magnitudes in the J, H, and K bands or in narrow bands within them, we believe that this procedure provides a reasonable first guess for the probability we are looking for. We then used the USNO-B1.0 catalog (Monet et al. 2003) to estimate the star density down to the approximate R magnitude of the detected neighboring sources in that particular region of the sky and derived the probability of finding a star brighter than the observed magnitude in a circular area with a radius equal to the distance from the target star to the neighboring source. The resulting probabilities that the detected neighboring sources are background sources are indicated in Table 5 in the column labeled P whenever they are smaller than 10%.

We consider that all detected neighbors with a probability of being a background source lower than 0.01 are physical companions of our targets. We have found 11 such companions, six of which can be identified as the secondary components of already known double stars. For these 11 physical companions to our target stars, we have indicated the position angle of the secondary in the column of Table 5 labeled P.A.

The infrared magnitudes of the central stars of the observed fields are not known with sufficient reliability, because they are usually too bright for the Deep Near Infrared Survey of the Southern Sky and 2MASS. We therefore cannot directly use the observations in the J, H, and K bands to constrain the colors of the detected companions.

On the other hand, the physical companions can be considered as coeval to our target stars. Since they are fainter, and since all of our target stars are on the main sequence or only slightly evolved, we conclude that all detected companions must be less massive stars on the main sequence. It is thus possible to derive a rough approximation of their effective temperature by comparison of their infrared magnitudes with those of the main targets. We used the method described in § 3, replacing the evolutionary tracks of Baraffe et al. (1998) with those of Lejeune & Schaerer (2001) for effective temperatures above 4000 K. We used the CFHT K' or H_2 magnitudes as proxies of the K magnitudes.

For companions that are already known as secondary components of double stars and for which V magnitudes are available, we used the effective temperature of the bright target to estimate its $V - K$ color using the models by Bessell et al. (1998), then computed the $V - K$ color of the companion, again using the CFHT K' or H_2 magnitudes as proxies of the K magnitudes. The effective temperatures of the companions were finally derived from these $V - K$ colors. For these stars, we generally find a reasonable agreement between both methods.

One noticeable exception is HD 170114, for which the detected companion has a measured ΔK larger than the ΔV found in the CCDM (Dommanget & Nys 2000, 2002). This is impossible if the companion is indeed physically associated and coeval with the primary component, since it is fainter and therefore in principle redder. We may have erroneously identified our detected companion with that in the CCDM. Also, because the 2002 June 23 observations were obtained in poor weather and seeing conditions, our ΔK measurement for this star may be overestimated.

In Table 5, T_p is the effective temperature of the primary, taken from the COROTSKY database (*COROT* observation preparation, S. Charpinet 2006, private communication), and T_c is a rough estimate of the effective temperature of the companion, as described above.

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