The Astrophysical Journal, 646:523–542, 2006 July 20

TWO SUNS IN THE SKY: STELLAR MULTIPLICITY IN EXOPLANET SYSTEMS

Deepak Raghavan and Todd J. Henry
Center for High Angular Resolution Astronomy and Department of Physics and Astronomy, Georgia State University, P.O. Box 4106, Atlanta, GA 30302-4106; raghavan@chara.gsu.edu

Brian D. Mason
US Naval Observatory, 3450 Massachusetts Avenue NW, Washington, DC 20392-5420

John P. Subasavage, Wei-Chun Jao, and Thom D. Beaulieu
Center for High Angular Resolution Astronomy and Department of Physics and Astronomy, Georgia State University, P.O. Box 4106, Atlanta, GA 30302-4106

and

Nigel C. Hambly
Institute for Astronomy, School of Physics, University of Edinburgh, Royal Observatory, Blackford Hill, Edinburgh EH9 3HJ, Scotland, UK
Received 2005 November 4; accepted 2006 March 29

ABSTRACT

We present results of a reconnaissance for stellar companions to all 131 radial velocity–detected candidate extrasolar planetary systems known as of 2005 July 1. Common proper-motion companions were investigated using the multiepoch STScI Digitized Sky Surveys and confirmed by matching the trigonometric parallax distances of the primaries to companion distances estimated photometrically. We also attempt to confirm or refute companions listed in the Washington Double Star Catalog, in the Catalogs of Nearby Stars Series by Gliese and Jahreiß, in *Hipparcos* results, and in Duquennoy & Mayor's radial velocity survey. Our findings indicate that a lower limit of 30 (23%) of the 131 exoplanet systems have stellar companions. We report new stellar companions to HD 38529 and HD 188015 and a new candidate companion to HD 169830. We confirm many previously reported stellar companions, including six stars in five systems, that are recognized for the first time as companions to exoplanet hosts. We have found evidence that 20 entries in the Washington Double Star Catalog are not gravitationally bound companions. At least three (HD 178911, 16 Cyg B, and HD 219449), and possibly five (including HD 41004 and HD 38529), of the exoplanet systems reside in triple-star systems. Three exoplanet systems (GJ 86, HD 41004, and γ Cep) have potentially close-in stellar companions, with planets at roughly Mercury–Mars distances from the host star and stellar companions at projected separations of $\sim$20 AU, similar to the Sun–Uranus distance. Finally, two of the exoplanet systems contain white dwarf companions. This comprehensive assessment of exoplanet systems indicates that solar systems are found in a variety of stellar multiplicity environments—singles, binaries, and triples—and that planets survive the post–main-sequence evolution of companion stars.

Subject headings: binaries: general — planetary systems — surveys

Online material: machine-readable tables

1. INTRODUCTION

The hunt for planets outside our solar system has revealed 161 candidate planets in 137 stellar systems as of 2005 July 1, with 18 of these systems containing multiple planets. After the initial flurry of "hot jupiter" discoveries—primarily a selection effect due to the fact that (1) the nascent effort was biased toward discovery of short-period systems and (2) massive planets induce more readily detected radial velocity variations—it is now believed that the more massive planets preferentially lie farther away from the primary (Udry et al. 2004; Marcy et al. 2005a), perhaps leaving the space closer to the star for the harder to detect terrestrial planets. Through these discoveries, we are now poised to gain a better understanding of the environments of exoplanet systems and compare them to our solar system.

Our effort in this paper is focused on a key parameter of planetary systems: the stellar multiplicity status of exoplanet hosts. We address questions such as the following: (1) Do planets preferentially occur in single-star systems (like ours), or do they commonly occur in multiple-star systems as well? (2) For planets residing in multiple-star systems, how are the planetary orbits related to stellar separations? (3) What observational limits can we place on disk truncations or orbit disruptions in multistar planetary systems? This study contributes to the broader subjects of planetary system formation, evolution, and stability through a better understanding of the environments of exoplanet systems.

Stellar multiplicity among exoplanet systems was first studied by Patience et al. (2002), who looked at the first 11 exoplanet systems discovered and reported two binaries and one triple system. Luhman & Jayawardhana (2002) conducted an adaptive optics (AO) survey looking for stellar and substellar companions to 25 exoplanet hosts and reported null results. More recently, Eggenberger et al. (2004) and Udry et al. (2004) reported 15 exoplanet systems with stellar companions in a comprehensive assessment, and additional companions have been reported for several specific systems (Mugrauer et al. 2004a, 2004b, 2005). Our effort confirms many of these previously reported systems, reports two new companions, identifies an additional candidate, and recognizes, for the first time, one triple and four binary exoplanet systems (these are known stellar

TABLE 1

Exoplanet Systems Searched for Companions

Name (1)	Proper Motion (arcsec yr^{-1}) (2)	Proper Motion (deg) (3)	DSS Images		Total μ (arcsec) (6)	μ Observable? (7)	Companions	
			Epoch 1 (4)	Epoch 2 (5)			CPM (8)	Other (9)
BD −10 3166	0.183	268.5	1983.29	1992.04	1.602	Yes	. . .	. . .
GJ 436	1.211	132.2	1955.28	1996.38	49.770	Yes	. . .	. . .
GJ 876	1.174	125.1	1983.76	1989.83	7.116	Yes	. . .	. . .
HD 000142	0.577	94.0	1982.87	1996.62	7.933	Yes	. . .	B
HD 001237	0.438	97.6	1977.77	1997.58	8.676	Yes	. . .	. . .
HD 002039	0.080	79.0	1978.82	1997.61	1.503	No	. . .	. . .
HD 002638	0.248	205.5	1983.53	1993.85	2.560	Yes	. . .	. . .
HD 003651	0.592	231.2	1953.91	1987.65	19.972	Yes	. . .	. . .
HD 004203	0.176	134.7	1954.00	1987.65	5.922	Yes	. . .	. . .
HD 004208	0.348	64.4	1980.63	1989.74	3.171	No	. . .	. . .
HD 006434	0.554	197.8	1976.89	1990.73	7.666	Yes	. . .	. . .
HD 008574	0.298	122.1	1949.98	1991.76	12.453	Yes	. . .	. . .
HD 008673	0.250	109.8	1954.67	1991.76	9.273	Yes	. . .	B?
HD 009826	0.418	204.4	1953.71	1989.77	15.073	Yes	B	B
HD 010647	0.198	122.6	1977.92	1997.61	3.898	Yes	. . .	. . .
HD 010697	0.115	203.1	1954.89	1986.69	3.657	Yes	. . .	. . .
HD 011964	0.441	236.6	1982.63	1991.70	4.003	Yes	B	B
HD 011977	0.105	46.1	1976.67	1987.72	1.160	No	. . .	. . .
HD 012661	0.206	211.6	1953.87	1990.87	7.622	No	. . .	. . .
HD 013189	0.006	13.3	1954.76	1989.83	0.210	No	. . .	. . .
HD 013445	2.193	72.6	1975.85	1988.91	28.646	Yes	. . .	B
HD 016141	0.464	199.7	1982.79	1997.74	6.937	Yes	. . .	B?
HD 017051	0.399	56.7	1977.78	1997.81	7.995	Yes	. . .	. . .
HD 019994	0.205	109.7	1951.69	1997.84	9.463	Yes	. . .	B
HD 020367	0.118	241.2	1953.77	1993.72	4.714	Yes	. . .	. . .
HD 022049	0.977	277.1	1982.79	1998.97	15.806	Yes	. . .	. . .
HD 023079	0.214	244.6	1978.82	1993.96	3.241	Yes	. . .	. . .
HD 023596	0.058	68.5	1953.03	1989.76	2.130	No	. . .	. . .
HD 027442	0.175	196.0	1983.04	1997.74	2.573	Yes	. . .	B
HD 027894	0.328	33.8	1983.04	1997.74	4.823	Yes	. . .	. . .
HD 028185	0.101	126.7	1982.82	1985.96	0.317	No	. . .	. . .
HD 030177	0.067	100.3	1983.04	1997.74	0.985	No	. . .	. . .
HD 033636	0.227	127.2	1954.85	1990.81	8.164	Yes	. . .	. . .
HD 034445	0.149	184.4	1954.85	1990.82	5.360	Yes	. . .	. . .
HD 037124	0.427	190.8	1951.91	1991.80	17.032	Yes	. . .	. . .
HD 037605	0.252	167.5	1955.90	1992.06	9.114	Yes	. . .	. . .
HD 038529	0.163	209.4	1951.91	1990.87	6.350	Yes	B	. . .
HD 039091	1.096	16.5	1978.03	1989.99	13.116	Yes	. . .	. . .
HD 040979	0.179	148.0	1953.12	1989.83	6.570	Yes	B	B
HD 041004	0.078	327.0	1978.03	1993.96	1.243	Yes	. . .	B, C
HD 045350	0.069	219.3	1953.19	1986.91	2.326	No	. . .	. . .
HD 046375	0.150	130.3	1953.94	1998.88	6.740	Yes	. . .	B
HD 047536	0.126	59.5	1979.00	1992.99	1.763	Mar	. . .	. . .
HD 049674	0.128	164.1	1953.19	1989.86	4.694	Yes	. . .	. . .
HD 050499	0.097	314.8	1976.89	1994.21	1.679	No	. . .	. . .
HD 050554	0.103	201.2	1956.27	1994.03	3.889	Yes	. . .	. . .
HD 052265	0.141	304.8	1983.04	1989.18	0.864	No	. . .	. . .
HD 059686	0.087	150.5	1953.02	1989.08	3.137	Mar	. . .	. . .
HD 063454	0.045	207.5	1975.94	1992.99	0.767	No	. . .	. . .
HD 065216	0.190	320.1	1976.25	1991.13	2.827	No	. . .	. . .
HD 068988	0.132	76.1	1954.01	1989.98	4.747	Yes	. . .	. . .
HD 070642	0.303	318.1	1976.97	1991.10	4.283	No	. . .	. . .
HD 072659	0.150	229.2	1954.97	1992.03	5.559	Yes	. . .	. . .
HD 073256	0.192	290.0	1977.22	1991.26	2.697	Mar	. . .	. . .
HD 073526	0.173	339.5	1977.06	1991.27	2.459	Mar	. . .	. . .
HD 074156	0.202	172.9	1953.02	1991.10	7.692	Yes	. . .	. . .
HD 075289	0.229	185.1	1977.06	1991.27	3.255	Yes	. . .	B
HD 075732	0.539	244.2	1953.94	1998.30	23.908	Yes	B	B
HD 076700	0.308	293.2	1976.26	1991.05	4.558	Yes	. . .	. . .
HD 080606	0.047	81.6	1953.13	1995.25	1.979	Yes	B	B
HD 082943	0.174	179.2	1983.36	1987.32	0.689	No	. . .	. . .
HD 083443	0.123	169.5	1980.06	1995.09	1.849	No	. . .	. . .

TABLE 1—*Continued*

Name (1)	Proper Motion (arcsec yr^{-1}) (2)	Proper Motion (deg) (3)	DSS Images Epoch 1 (4)	DSS Images Epoch 2 (5)	Total μ (arcsec) (6)	μ Observable? (7)	Companions CPM (8)	Companions Other (9)
HD 088133	0.264	182.8	1955.23	1998.99	11.555	Yes	...	...
HD 089307	0.276	261.8	1950.29	1987.32	10.219	Yes	...	...
HD 089744	0.183	220.9	1953.21	1990.23	6.773	No	...	B
HD 092788	0.223	183.2	1982.37	1991.21	1.971	Yes	...	...
HD 093083	0.177	211.6	1980.21	1995.10	2.636	Yes	...	...
HD 095128	0.321	279.9	1955.22	1998.38	13.855	Yes	...	...
HD 099492	0.755	284.7	1955.29	1996.28	30.944	Yes	A	A
HD 101930	0.348	2.5	1987.20	1992.24	1.754	No	...	...
HD 102117	0.094	222.1	1987.20	1992.24	0.474	No	...	...
HD 104985	0.174	122.1	1955.17	1997.11	7.299	Yes	...	...
HD 106252	0.280	175.1	1955.29	1991.27	10.076	Yes	...	...
HD 108147	0.192	251.5	1987.26	1996.30	1.735	No	...	...
HD 108874	0.157	124.7	1955.39	1991.07	5.602	Yes	...	...
HD 111232	0.116	13.9	1987.08	1996.29	1.067	No	...	B?
HD 114386	0.353	203.0	1975.41	1992.25	5.943	Yes	...	...
HD 114729	0.369	213.2	1978.13	1991.21	4.826	Yes	...	B
HD 114762	0.583	269.8	1950.30	1996.30	26.822	Yes	...	B
HD 114783	0.138	274.0	1956.27	1996.23	5.514	Yes	...	...
HD 117176	0.622	202.2	1955.38	1997.35	26.110	Yes	...	...
HD 117207	0.217	250.7	1975.27	1991.21	3.458	Mar	...	...
HD 117618	0.127	168.6	1975.19	1991.23	2.037	No	...	...
HD 120136	0.483	276.4	1954.25	1992.20	18.328	Yes	...	B
HD 121504	0.264	251.5	1987.26	1994.19	1.828	No	...	...
HD 128311	0.323	140.5	1950.28	1989.25	12.588	Yes	...	...
HD 130322	0.191	222.6	1980.22	1996.37	3.085	Yes	...	...
HD 134987	0.400	86.1	1976.42	1991.50	6.034	Yes	...	...
HD 136118	0.126	280.7	1955.30	1992.41	4.676	Yes	...	...
HD 137759	0.019	334.5	1953.46	1995.15	0.792	No	...	...
HD 141937	0.100	76.1	1976.41	1991.61	1.520	No	...	...
HD 142022	0.339	264.7	1977.63	1996.30	6.329	Yes	B	B
HD 142415	0.153	228.1	1988.30	1992.58	0.654	No	...	...
HD 143761[a]	0.798	194.3	1950.28	1994.37	35.182	Yes	...	...
HD 145675	0.326	156.1	1955.23	1991.43	11.802	Yes	...	...
HD 147513	0.073	87.3	1987.39	1993.25	0.428	No	...	B
HD 149026	0.094	304.7	1954.49	1993.33	3.651	Yes	...	...
HD 150706	0.130	132.6	1955.39	1996.54	5.350	Yes	...	B?
HD 154857	0.103	122.4	1987.30	1993.32	0.621	No	...	...
HD 160691	0.192	184.5	1987.70	1992.58	0.938	No	...	...
HD 162020	0.033	140.2	1987.71	1991.68	0.131	No	...	...
HD 168443	0.242	202.3	1978.65	1988.59	2.406	No	...	...
HD 168746	0.073	197.7	1978.65	1988.59	0.726	No	...	...
HD 169830	0.015	356.8	1987.38	1992.41	0.075	No	...	B?
HD 177830	0.066	218.1	1950.46	1992.42	2.770	No	...	...
HD 178911B	0.203	18.6	1955.39	1992.44	7.523	Yes	A	A, C
HD 179949	0.153	131.6	1987.42	1991.62	0.643	No	...	...
HD 183263	0.038	208.2	1950.61	1992.59	1.595	No	...	...
HD 186427	0.212	219.6	1951.53	1991.53	8.679	Yes	A	A, C
HD 187123	0.189	130.7	1952.54	1992.67	7.583	Yes	...	...
HD 188015	0.106	149.4	1953.53	1992.49	4.130	Yes	B	...
HD 190228	0.126	123.7	1953.53	1992.49	4.910	Yes	...	...
HD 190360	0.861	127.5	1953.53	1992.49	33.549	Yes	B	B
HD 192263	0.270	346.4	1951.58	1988.67	10.013	Yes	...	...
HD 195019	0.354	99.2	1951.52	1990.71	13.874	Yes	...	B
HD 196050	0.201	251.4	1977.61	1991.75	2.842	Mar	...	B
HD 196885	0.096	29.7	1953.68	1987.50	3.246	Yes	...	...
HD 202206	0.126	197.7	1977.55	1991.74	1.788	No	...	...
HD 208487	0.156	139.3	1980.55	1995.63	2.353	Mar	...	...
HD 209458	0.034	122.4	1950.54	1990.73	1.366	No	...	...
HD 210277	0.458	169.2	1979.72	1987.79	3.693	Yes	...	...
HD 213240	0.236	214.9	1980.77	1995.65	3.510	Yes	B	B
HD 216435	0.232	110.6	1980.54	1996.62	3.730	No	...	...
HD 216437	0.085	329.5	1978.82	1996.79	1.527	No	...	...
HD 216770	0.290	127.9	1980.78	1995.79	4.354	Yes	...	...

TABLE 1—*Continued*

Name (1)	Proper Motion (arcsec yr^{-1}) (2)	Proper Motion (deg) (3)	DSS Images Epoch 1 (4)	DSS Images Epoch 2 (5)	Total μ (arcsec) (6)	μ Observable? (7)	Companions CPM (8)	Companions Other (9)
HD 217014	0.217	73.7	1954.59	1990.79	7.856	Yes	. . .	. . .
HD 217107	0.017	200.7	1982.80	1991.68	0.151	No	. . .	B?
HD 219449	0.369	92.6	1983.82	1991.76	2.931	Yes	B	B, C
HD 222404	0.136	339.0	1954.73	1992.76	5.172	Yes	. . .	B
HD 222582	0.183	232.6	1983.54	1989.83	1.152	Yes	B	B
HD 330075	0.254	248.2	1988.45	1995.25	1.725	No	. . .	. . .

Note.—Table 1 is also available in machine-readable form in the electronic edition of the *Astrophysical Journal*.
[a] We conclude that this system (ρ CrB) has either a planetary or a stellar companion, but not both. See § 2.3 for more details.

companions, but previously not noted to reside in exoplanet systems).

2. SAMPLE AND COMPANION SEARCH METHODOLOGY

Our sample includes all known exoplanet systems detected by radial velocity techniques as of 2005 July 1. We primarily used the Extrasolar Planets Catalog,[1] maintained by Jean Schneider at the Paris Observatory, to build our sample list for analyses. To ensure completeness, we cross-checked this list with the California & Carnegie Planet Search Catalog.[2] Our sample excludes planets discovered via transits and gravitational lensing, as these systems are very distant, with poor or no parallax and magnitude information for the primaries. In addition, these systems cannot be observed for stellar companions in any meaningful way. We also exclude a radial velocity–detected system, HD 219542, identified by Eggenberger et al. (2004) as an exoplanet system with multiple stars but since confirmed as a false planet detection by its discoverers (Desidera et al. 2004). The final sample comprises 155 planets in 131 systems. This list is included in Table 1 along with companion detection information, as described below.

Several efforts were carried out to gather information on stellar companions to exoplanet stars. To identify known or claimed companions, we checked available sources listing stellar companions: the Washington Double Star Catalog (WDS), the *Hipparcos* Catalog (Perryman et al. 1997), the Catalog of Nearby Stars (CNS; Gliese 1969; Gliese & Jahreiss 1979, 1991), and Duquennoy & Mayor (1991). We also visually inspected the STScI Digitized Sky Survey (DSS) multiepoch frames for the sky around each exoplanet system to investigate reported companions and to identify new common proper-motion (CPM) companion candidates. We then confirmed or refuted many candidates through photometric distance estimates using plate magnitudes from SuperCOSMOS, optical CCD magnitudes from the Cerro Tololo Inter-American Observatory (CTIO) 0.9 and 1.0 m telescopes, and infrared magnitudes from the Two Micron All Sky Survey (2MASS). The origin and status of each companion are summarized in Table 2 and described in § 5.1.

Table 1 lists each target star in our sample, sequenced alphabetically by name, and identifies all known and new companions. Column (1) is the exoplanet host star's name (HD when available, otherwise BD or GJ name). Columns (2) and (3) give the proper-motion magnitude (in arcsec yr^{-1}) and direction (in deg) of the star, mostly from *Hipparcos*. Columns (4) and (5) specify the observational epochs of the DSS images blinked to identify CPM companion candidates. Column (6) lists the total proper motion (in arcsec) of the exoplanet host during the time interval between the two observational epochs of the DSS plates. Column (7) identifies whether the proper motion of the star was detectable in the DSS frames, allowing the identification of CPM candidates. The entries "Yes" and "No" are self-explanatory, and "Mar" identifies that the proper motion was marginally detectable. Systems with very little proper motion or a brief separation between plate epochs could not be searched effectively (see § 2.1). Column (8) specifies companions identified via CPM, and column (9) specifies companions listed in the sources mentioned above or in other refereed papers. A question mark following the companion ID indicates that the source remains a candidate and could not be confirmed or refuted with confidence. The absence of a question mark indicates that the companion is confirmed.

Each reference we used for the companion search is described in the subsections below.

2.1. *STScI Digitized Sky Survey*

We downloaded multiepoch images of the sky around each exoplanet primary from the STScI Digitized Sky Survey (DSS).[3] The images of these surveys are based on photographic data obtained using the Oschin Schmidt Telescope on Palomar Mountain and the UK Schmidt Telescope in Australia. We typically extracted 10$'$ square images at two epochs centered on an exoplanet host star. The range of time interval between the epochs for a given target is 3.1–46.2 yr. Figure 1 shows a histogram of the number of systems per time interval bin for our sample.

We identified CPM companion candidates by eye, by blinking the two epoch frames. In general, primaries with a total proper motion of $\geq 3''$ were effectively searched, while those with a total proper motion in the range of $2''$–$3''$ were marginally searched, and stars with $\leq 2''$ total proper motion could not be searched for companions using this method. Exceptions to these ranges exist and are due to poorly matched astrometric fields caused by specific issues with the plate images, such as saturation around the primary, distribution of background stars in the frames, brightness of the companion and its proximity to the primary, and the relative rotation between the frames. The $3''$ detection limit corresponds to a proper-motion range of $0\farcs1$–$1\farcs0$ yr^{-1} with a median value of $0\farcs2$ yr^{-1} for the time intervals sampled. In addition, this method favors the detection of wide companions because bright primaries saturate the surrounding region out to many arcseconds and prevent companion detection within a $\sim 15''$–$30''$ radius, depending on source brightness. At the median distance

[1] See http://vo.obspm.fr/exoplanetes/encyclo/catalog.php.
[2] See http://exoplanets.org.
[3] See http://stdatu.stsci.edu/cgi-bin/dss_form.

TABLE 2

Exoplanet Systems with Stellar Companions

Sequence (1)	HD Name (2)	Other Name (3)	Component (4)	R.A. (J2000.0) (5)	Decl. (J2000.0) (6)	π (arcsec) (7)	Distance (pc) (8)	Basis (9)	Spectral Type (10)	Angular Separation (arcsec) (11)	P.A. (deg) (12)	Projected Separation (AU) (13)	$M \sin i$ (M_J) (14)	$a \sin i$ (AU) (15)	e (16)	Sources (17)	References (18)
1................	000142	GJ 4.2	A	00 06 19.18	−49 04 30.7	0.03900	25.6	T	G1 IV	...	...	...	...	...	...	...	
	000142	...	b	...	...	...	...	...	...	...	...	...	1	0.98	0.38	...	
	000142	...	B	...	...	...	...	...	...	5.4	177	138	...	...	...	WC	1, 2
2................	009826	υ And	A	01 36 47.84	+41 24 19.7	0.07425	13.5	T	F8.0 V	...	...	...	...	...	...	...	
	009826	...	b	...	...	...	...	...	...	...	...	...	0.69	0.059	0.012	...	
	009826	...	c	...	...	...	...	...	...	...	...	...	1.89	0.829	0.28	...	
	009826	...	d	...	...	...	...	...	...	...	...	...	3.75	2.53	0.27	...	
	009826	...	B	01 36 50.40	+41 23 32.1	...	...	...	M4.5 V	52	150	702	...	...	...	P	2, 3, 4
3................	011964	GJ 81.1	A	01 57 09.61	−10 14 32.7	0.02943	34.0	T	G5	...	...	...	...	...	...	...	
	011964	...	b	...	...	...	...	...	...	...	...	...	0.11	0.229	0.15	...	
	011964	...	c	...	...	...	...	...	...	...	...	...	0.7	3.167	0.3	...	
	011964	...	B[a]	01 57 11.07	−10 14 53.2	...	...	...	...	29.7	133	1010	...	...	...	PWC	5, 6
4................	013445	GJ 86	A	02 10 25.93	−50 49 25.4	0.09163	10.9	T	K1 V	...	...	...	...	...	...	...	
	013445	...	b	...	...	...	...	...	...	...	...	...	4.01	0.11	0.046	...	
	013445	...	B	...	...	...	...	...	WD	1.93	119	21	...	...	...	O	7, 8, 9
5................	019994	GJ 128	A	03 12 46.44	−01 11 46.0	0.04469	22.4	T	F8.5 V	...	...	...	...	...	...	...	
	019994	...	b	...	...	...	...	...	...	...	...	...	2	1.3	0.2	...	
	019994	...	B	...	...	...	...	...	M	2.5	213	56	...	...	...	WCD	10, 11, 12, 13
6................	027442	ϵ Ret	A	04 16 29.03	−59 18 07.8	0.05484	18.2	T	K2 IVa	...	...	...	...	...	...	...	
	027442	...	b	...	...	...	...	...	...	...	...	...	1.28	1.18	0.07	...	
	027442	...	B[a]	...	...	...	...	...	...	13.8	36	251	...	...	...	WCI	14, 15
7................	038529	HIP 27253	A	05 46 34.91	+01 10 05.5	0.02357	42.4	T	G4 V	...	...	...	...	...	...	...	16
	038529	...	b	...	...	...	...	...	...	...	...	...	0.78	0.129	0.29	...	
	038529	...	c	...	...	...	...	...	...	...	...	...	12.7	3.68	0.36	...	
	038529	...	B[b]	05 46 19.38	+01 12 47.2	...	28.7	C	M3.0 V	284	305	12042	...	...	...	P	
8................	041004	HIP 28393	A	05 59 49.65	−48 14 22.9	0.02324	43.0	T	K1 V	...	...	...	...	...	...	...	
	041004	...	b	...	...	...	...	...	...	...	...	...	2.3	1.31	0.39	...	
	041004	...	B	05 59 43.81	−48 12 11.9	...	...	...	M2.5 V	0.5	176	22	...	...	...	WH	4, 17, 18, 19
	041004	...	C	...	...	...	...	...	...	...	...	...	18.4	0.016	0.08	...	18, 19
9................	040979	BD +44 1353	A	06 04 29.95	+44 15 37.6	0.03000	33.3	T	F8	...	...	...	...	...	...	...	
	040979	...	b	...	...	...	...	...	...	...	...	...	3.32	0.811	0.23	...	
	040979	BD +44 1351	B	06 04 13.02	+44 16 41.1	...	15.2	P	K5	192	290	6394	...	...	...	P	4, 16, 20, 21
10..............	046375	HIP 31246	A	06 33 12.62	+05 27 46.5	0.02993	33.4	T	K0 V	...	...	...	...	...	...	...	
	046375		b	...	...	...	...	...	...	...	...	...	0.249	0.041	0.04	...	
	046375		B[a]	06 33 12.10	+05 27 53.2	...	26.4	C	...	9.4	308	314	...	...	...	WI	22, 23
11..............	075289	HIP 43177	A	08 47 40.39	−41 44 12.5	0.03455	28.9	T	G0 V	...	...	...	...	...	...	...	
	075289	...	b	...	...	...	...	...	...	...	...	...	0.42	0.046	0.054	...	
	075289	...	B	08 47 42.26	−41 44 07.6	...	...	...	...	21.5	78	621	...	...	...	O	24
12..............	075732	55 Cnc	A	08 52 35.81	+28 19 50.9	0.07980	12.5	T	K0 IV−V	...	...	...	...	...	...	...	
	075732	...	e	...	...	...	...	...	...	...	...	...	0.045	0.038	0.174	...	
	075732	...	b	...	...	...	...	...	...	...	...	...	0.784	0.115	0.020	...	
	075732	...	c	...	...	...	...	...	...	...	...	...	0.217	0.24	0.44	...	
	075732	...	d	...	...	...	...	...	...	...	...	...	3.92	5.257	0.327	...	
	075732	...	B	08 52 40.85	+28 18 59.0	...	8.7	C	M4	84	130	1050	...	...	...	PWCD	4, 12, 25, 26, 27
13..............	080606	HIP 45982	A	09 22 37.57	+50 36 13.4	0.01713	58.4	T	G5	...	...	...	...	...	...	...	
	080606	...	b	...	...	...	...	...	...	...	...	...	3.41	0.439	0.927	...	
	080607	HIP 45983	B	09 22 39.73	+50 36 13.9	...	...	...	G5	20.6	269	1203	...	...	...	PWH	4, 28

TABLE 2—*Continued*

Sequence (1)	HD Name (2)	Other Name (3)	Component (4)	R.A. (J2000.0) (5)	Decl. (J2000.0) (6)	π (arcsec) (7)	Distance (pc) (8)	Basis (9)	Spectral Type (10)	Angular Separation (arcsec) (11)	P.A. (deg) (12)	Projected Separation (AU) (13)	$M \sin i$ (M_J) (14)	$a \sin i$ (AU) (15)	e (16)	Sources (17)	References (18)
14..............	089744	HIP 50786	A	10 22 10.56	+41 13 46.3	0.02565	39.0	T	F8 IV	...	...	...	...	...	...	...	
	089744	...	b	...	...	...	...	...	...	...	...	...	7.99	0.89	0.67	...	
	089744	...	B	10 22 14.87	+41 14 26.4	...	...	...	L0 V	63.0	48	2456	...	...	...	O	29, 30
15..............	099492	GJ 429B	B	11 26 46.28	+03 00 22.8	0.05559	18.0	T	K2 V	...	...	...	...	...	...	...	
	099492	...	b	...	...	...	...	...	...	...	...	...	0.122	0.119	0.05	...	
	099491	GJ 429A	A	11 26 45.32	+03 00 47.2	0.05659	17.7	T	K0 IV	28.6	150	515	...	...	...	PWHC	31
16..............	114729	HIP 64459	A	13 12 44.26	−31 52 24.1	0.02857	35.0	T	G3 V	...	...	...	...	...	...	...	
	114729	...	b	...	...	...	...	...	...	...	...	...	0.82	2.08	0.31	...	
	114729	...	B	13 12 43.97	−31 52 17.0	...	...	...	...	8.05	333	282	...	...	...	O	32
17..............	114762	HIP 64426	A	13 12 19.74	+17 31 01.6	0.02465	40.6	T	F9 V	...	...	...	...	...	...	...	
	114762	...	b	...	...	...	...	...	...	...	...	...	11.02	0.3	0.25	...	
	114762	...	B	...	...	...	...	...	...	3.26	30	132	...	...	...	O	3, 4
18..............	120136	τ Boo	A	13 47 15.74	+17 27 24.9	0.06412	15.6	T	F6 IV	...	...	...	...	...	...	...	
	120136	...	b	...	...	...	...	...	...	...	...	...	4.13	0.05	0.01	...	
	120136	...	B	...	...	...	...	...	...	2.87	31	45	...	...	...	WCD	3, 4, 12
19..............	142022	GJ 606.1	A	16 10 15.02	−84 13 53.8	0.02788	38.9	T	G8/K0 V	...	...	...	...	...	...	...	
	142022	...	b	...	...	...	...	...	...	...	...	...	4.4	2.8	0.57	...	
	142022	...	B	16 10 25.34	−84 14 06.7	...	...	...	K7 V	20.4	130	794	...	...	...	PWC	33, 34
20..............	147513	GJ 620.1	A	16 24 01.29	−39 11 34.7	0.07769	12.9	T	G5 V	...	...	...	...	...	...	...	
	147513	...	b	...	...	...	...	...	...	...	...	...	1	1.26	0.52	...	
	147513	...	B	16 23 33.83	−39 13 46.1	0.07804	12.8	T	WD	345	245	4451	...	...	...	C	13, 35
21..............	178911B	HIP 94076B	B	19 09 03.10	+34 35 59.5	0.02140	46.7	T	G5	...	...	...	...	...	...	...	
	178911B	...	b	...	...	...	...	...	...	...	...	...	6.292	0.32	0.124	...	
	178911	HIP 94076	A	19 09 04.38	+34 36 01.6	0.02042	49.0	T	G1 V J	16.1	82	789	...	...	...	PWH	4, 36, 37, 38, 39
	178911	...	C[c]	...	...	...	...	...	...	0.1	21	4.9	...	...	...	W	
22..............	186427	16 Cyg B	B	19 41 51.97	+50 31 03.1	0.04670	...	...	G3 V	...	...	...	...	...	...	...	
	186427	...	b	...	...	...	...	...	...	...	...	...	1.69	1.67	0.67	...	
	186408	16 Cyg A	A	19 41 48.95	+50 31 30.2	0.04625	21.6	T	G1.5 V J	39.8	313	860	...	...	...	PWC	2, 3, 4, 40, 41
	186408	...	C[c]	...	...	...	...	...	...	3.4	209	73	...	...	...	W	
23..............	188015	HIP 97769	A	19 52 04.54	+28 06 01.4	0.01900	52.6	T	G5 IV	...	...	...	...	...	...	...	
	188015	...	b	...	...	...	...	...	...	...	...	...	1.26	1.19	0.15	...	
	188015	...	B[b]	19 52 05.51	+28 06 03.7	...	46.9	C	...	13	85	684	...	...	...	P	
24..............	190360	GJ 777	A	20 03 37.41	+29 53 48.5	0.06292	15.9	T	G7 IV–V	...	...	...	...	...	...	...	
	190360	...	c	...	...	...	...	...	...	...	...	...	0.057	0.128	0.01	...	
	190360	...	b	...	...	...	...	...	...	...	...	...	1.502	3.92	0.36	...	
	190360	...	B	20 03 26.58	+29 51 59.5	...	18.5	P	M4.5 V	179	234	2846	...	...	...	PWC	4, 5, 16, 42
25..............	195019	HIP 100970	A	20 28 18.64	+18 46 10.2	0.02677	37.3	T	G3 IV–V	...	...	...	...	...	...	...	
	195019	...	b	...	...	...	...	...	...	...	...	...	3.43	0.14	0.05	...	
	195019	...	B	...	...	...	...	...	...	3.5	330	131	...	...	...	W	4, 5, 43, 44
26..............	196050	HIP 101806	A	20 37 51.71	−60 38 04.1	0.02131	46.9	T	G3 V	...	...	...	...	...	...	...	
	196050	...	b	...	...	...	...	...	...	...	...	...	3	2.5	0.28	...	
	196050	...	B	20 37 51.85	−60 38 14.9	...	...	...	...	10.9	175	510	...	...	...	O	32
27..............	213240	HIP 111143	A	22 31 00.37	−49 25 59.8	0.02454	40.8	T	G0/G1 V	...	...	...	...	...	...	...	
	213240	...	b	...	...	...	...	...	...	...	...	...	4.5	2.03	0.45	...	
	213240	...	B	22 31 08.26	−49 26 56.7	...	41.8	C	M5.0 V	95.8	127	3909	...	...	...	P	32

TABLE 2—*Continued*

Sequence (1)	HD Name (2)	Other Name (3)	Component (4)	R.A. (J2000.0) (5)	Decl. (J2000.0) (6)	π (arcsec) (7)	Distance (pc) (8)	Basis (9)	Spectral Type (10)	Angular Separation (arcsec) (11)	P.A. (deg) (12)	Projected Separation (AU) (13)	$M \sin i$ (M_J) (14)	$a \sin i$ (AU) (15)	e (16)	Sources (17)	References (18)
28.............	219449	GJ 893.2	A	23 15 53.49	−09 05 15.9	0.02197	45.5	T	K0 III	...	...	...	...	...	...	...	
	219449	...	b	...	...	...	...	...	...	...	...	...	2.9	0.3	–	...	
	219430	...	B[a]	23 15 51.00	−09 04 42.7	...	42.4[d]	C	K8 V J	49.4	313	2248	...	...	...	PWC	6, 45
	219430	...	C[a,e]	...	...	...	42.4[d]	C	...	0.4	101	18	...	...	...	W	
29.............	222404	γ Cephei	A	23 39 20.85	+77 37 56.2	0.07250	13.8	T	K1 III	...	...	...	...	...	...	...	
	222404	...	b	...	...	...	...	...	...	...	...	...	1.59	2.03	0.2	...	
	222404	...	B	...	...	...	...	...	...	...	...	...	...	20.3	0.39	H	4, 46, 47, 48, 49
30.............	222582	HIP 116906	A	23 41 51.53	−05 59 08.7	0.02384	42.0	T	G5	...	...	...	...	...	...	...	
	222582	...	b	...	...	...	...	...	...	...	...	...	5.11	1.35	0.76	...	
	222582	...	B[a]	23 41 45.14	−05 58 14.8	...	32.1	C	M3.5 V	113	302	4746	...	...	...	PW	6
Candidate (Unconfirmed) Stellar Companions																	
31.............	008673	HIP 6702	A	01 26 08.78	+34 34 46.9	0.02614	38.3	T	F7 V	...	...	...	...	...	...	...	
	008673	...	b	...	...	...	...	...	...	...	...	...	14	1.58	–	...	
	008673	...	B	...	...	...	...	...	...	0.1	78	3.8	...	...	...	W	
32.............	016141	HIP 12048	A	02 35 19.93	−03 33 38.2	0.02785	35.9	T	G5 IV	...	...	...	...	...	...	...	
	016141	...	b	...	...	...	...	...	...	...	...	...	0.23	0.35	0.21	...	
	016141	...	B	02 35 19.88	−03 33 43.9	...	...	...	...	6.2	188	222	...	...	...	O	32
33.............	111232	HIP 62534	A	12 48 51.75	−68 25 30.5	0.03463	28.9	T	G8 V	...	...	...	...	...	...	...	
	111232	...	b	...	...	...	...	...	...	...	...	...	6.8	1.97	0.2	...	
	111232	...	B	...	...	...	...	...	...	...	...	...	...	...	...	H	13
34.............	150706	GJ 632	A	16 31 17.59	+79 47 23.2	0.03673	27.2	T	G0	...	...	...	...	...	...	...	
	150706	...	b	...	...	...	...	...	...	...	...	...	1	0.82	0.38	...	
	150706	...	B	...	...	...	...	...	...	...	...	...	...	...	...	H	50
35.............	169830	HIP 90485	A	18 27 49.48	−29 49 00.7	0.02753	36.3	T	F9 V	...	...	...	...	...	...	...	
	169830	...	b	...	...	...	...	...	...	...	...	...	2.88	0.81	0.31	...	
	169830	...	c	...	...	...	...	...	...	...	...	...	4.04	3.6	0.33	...	
	169830	...	B[f]	18 27 48.65	−29 49 01.6	...	...	...	...	11	270	399	...	...	...	...	
36.............	217107	HIP 113421	A	22 58 15.54	−02 23 43.4	0.05071	19.7	T	G8 IV–V	...	...	...	...	...	...	...	
	217107	...	b	...	...	...	...	...	...	...	...	...	1.37	0.074	0.13	...	
	217107	...	c	...	...	...	...	...	...	...	...	...	2.1	4.3	0.55	...	
	217107	...	B	...	...	...	...	...	...	0.3	156	6	...	...	...	W	51, 52

Notes.—Planet data are from the Exoplanet Encyclopedia Web site, http://vo.obspm.fr/exoplanetes/encyclo/catalog.php. Table 2 is also available in machine-readable form in the electronic edition of the *Astrophysical Journal*.

[a] Known companion, but first identification of the star as a companion to an exoplanet host.

[b] New stellar companion reported by this work.

[c] Separation and position angle are listed with respect to component A. A and C have been referred to as Aa and Ab, respectively, in other publications, but we follow a consistent naming convention, using uppercase letters to represent stars and lowercase letters to denote planets.

[d] Photometry obtained is for the BC pair. Distance estimate assumes identical binary components.

[e] Separation and position angle are listed with respect to component B.

[f] New candidate companion reported by this work, via Kevin Apps.

References.—(1) Bailey 1900; (2) Lowrance et al. 2002; (3) Patience et al. 2002; (4) Eggenberger et al. 2004; (5) Allen et al. 2000; (6) Zacharias et al. 2004; (7) Els et al. 2001; (8) Mugrauer & Neuhäuser 2005; (9) Queloz et al. 2000; (10) Smyth 1844; (11) Hale 1994; (12) Duquennoy & Mayor 1991; (13) Mayor et al. 2004; (14) Jessup 1955; (15) Holden 1966; (16) Lepine & Shara 2005; (17) See 1897; (18) Zucker et al. 2003; (19) Zucker et al. 2004; (20) Hog et al. 1998; (21) Halbwachs 1986; (22) Soulie 1985; (23) Urban et al. 1998; (24) Mugrauer et al. 2004a; (25) van Altena et al. 1995; (26) Dahn et al. 1988; (27) Marcy et al. 2002; (28) Naef et al. 2001; (29) Wilson et al. 2001; (30) Mugrauer et al. 2004b; (31) Marcy et al. 2005b; (32) Mugrauer et al. 2005; (33) Luyten 1979; (34) Eggenberger et al. 2006; (35) Wegner 1973; (36) McAlister et al. 1987b; (37) Balega et al. 2004; (38) Hartkopf et al. 2000; (39) Zucker et al. 2002; (40) Turner et al. 2001; (41) Cochran et al. 1997; (42) Naef et al. 2003; (43) Hough 1887; (44) Fischer et al. 1999; (45) Wilson 1953; (46) Mason et al. 2001; (47) Campbell et al. 1988; (48) Griffin et al. 2002; (49) Hatzes et al. 2003; (50) Halbwachs et al. 2003; (51) McAlister et al. 1987a; (52) Mason et al. 1999.

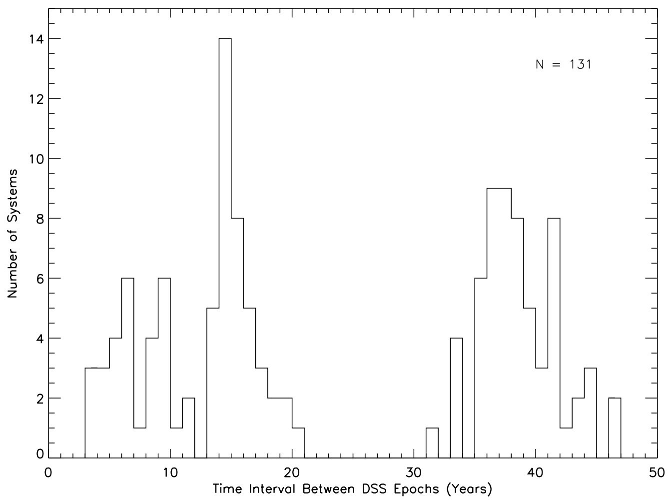

FIG. 1.—Histogram of time intervals between DSS epochs for the exoplanet sample.

of 35.6 pc for our sample, this translates to a minimum projected distance of ∼500–1000 AU. However, some bright companions can be picked up much closer, due to twin diffraction spikes or an anomalous point-spread function (PSF) compared to other stars in the field. For an outer limit, the 10′ image gives us a radius of 5′, which translates to a projected distance of ∼10,000 AU for the median distance of the exoplanet sample. This is of the order of magnitude of the canonical limit for gravitational binding, although Poveda et al. (1994) listed several companions with separations larger than this.

Of the 131 systems, 82 had easily detectable proper motions and hence were searched effectively for CPM companions, 7 had marginal proper motions, and 42 systems had no detectable proper motions. Of the 82 systems searched effectively, 15 definite CPM companions were confirmed (one per system), and 67 had no CPM companions detected within the search region outlined above. However, in 12 (plus 3 candidates) of these 67 systems, close companions were identified by other sources. In 3 (plus 3 candidates) of the 49 marginal or unsearched systems, companions were reported by other sources. These additional companions could not be detected by our method due to saturation around the primary and/or a short time baseline between the DSS image pair.

2.2. *Washington Double Star Catalog* (*WDS*)

The WDS catalog[4] is the world's most comprehensive database of multiple stars. However, it is a catalog of doubles, not binaries, so it explicitly contains an unknown number of nonphysical chance alignments. Table 3 lists 20 WDS entries that are not gravitationally bound to the exoplanet host, but rather are field stars, listed in WDS ID sequence (col. [1]). Column (2) is the HD identifier of the star. Column (3) is the component suffix

[4] See http://ad.usno.navy.mil/wds.

TABLE 3
WDS ENTRIES THAT ARE NOT GRAVITATIONALLY BOUND COMPANIONS

WDS ID (1)	HD Name (2)	Component (3)	θ (deg) (4)	ρ (arcsec) (5)	Epoch (6)	Number (7)	Notes (8)
00394+2115	003651	...	80	167.6	1997	9	1
01368+4124	009826	AB	128	114.0	1909	1	1
01368+4124	009826	AC	289	273.6	1991	7	1
03329−0927	022049	...	143	0.0	1975	1	2
11268+0301	099492	AC	187	90.5	1937	3	1
13284+1347	117176	AB	127	268.6	2002	13	1
13284+1347	117176	AC	263	325.5	1923	1	1
13573−5602	121504	...	55	36.2	1999	32	3
15249+5858	137759	...	50	254.8	2002	12	4
16010+3318	143761	...	49	135.3	2002	22	1
19091+3436	178911	Aa-C	130	60.0	1944	1	1
20140−0052	192263	A-BC	102	73.1	2003	19	1
20140−0052	192263	AD	244	71.3	1921	1	1
20140−0052	192263	BC-D	65	23.5	1998	8	1
20283+1846	195019	AC	72	70.9	1998	11	1
20283+1846	195019	AD	97	84.5	1998	2	1
20399+1115	196885	...	6	182.9	2000	13	1
22310−4926	213240	...	359	21.9	1999	7	1
23159−0905	219449	AD	274	80.4	1924	6	1
23159−0905	219449	BC-E	341	19.7	1924	6	1

NOTES.—Cols. (1), (3), and (7) are listed here exactly as in the WDS catalog. Cols. (4), (5), and (6) correspond to the most recent observation. All data are as of 2005 June 20. Certain pairs of multiple systems omitted from this table are confirmed to be gravitationally bound companions (01368+4124AD, 11268+0301AB, 19091+3436Aa and Aa-B, 20283+1846AB, and 23159−0905A-BC and BC). One omitted pair (20140−0052BC) has several speckle observations (Jonckheere 1911, 1917, 1944; Vanderdonck 1911; Van Biesbroeck 1960) and several failed attempts (van den Bos 1949, 1960, 1963; Couteau 1954; Baize 1957) and is hence inconclusive. Col. (8) notes: (1) DSS multiepoch plates do not show CPM for WDS entry. In fact, proper motion of the primary star causes change in separation and position angle, indicating that the "companion" is a background star. (2) Primary star is ϵ Eri, the well-studied exoplanet system. WDS listing is based on a single speckle measure by Blazit et al. (1977). This system has been observed 13 other times and no companion was resolved (McAlister 1978; Hartkopf & McAlister 1984; Oppenheimer et al. 2001). (3) Primary's $\mu = 0\farcs264$ yr^{-1} at 251° from *Hipparcos* is not detectable in DSS plates. For the WDS companion, SuperCOSMOS lists $\mu = 0\farcs013$ yr^{-1} at 91°, clearly not matching the primary's. (4) Primary does not show detectable proper motion in DSS plates. Planet discovery paper, Frink et al. (2002), refuted the WDS entry based on distance estimate to WDS entry and proper-motion comparisons.

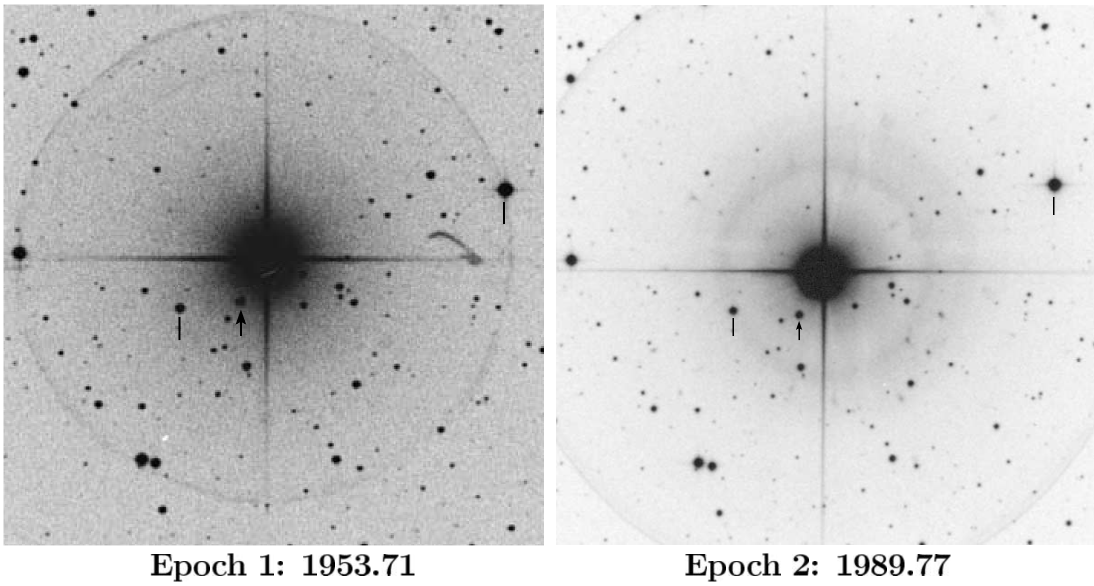

FIG. 2.—DSS images from two epochs for HD 9826. The 10′ square images have north up and east to the left. WDS lists components B and C (marked by lines), which are background stars. WDS component D (marked by an arrow), however, is a CPM companion. The primary's $\mu = 0\farcs42\ \mathrm{yr}^{-1}$ at 204°.

of the pair, as it appears in the WDS catalog, for which position angle, separation, and epoch of the most recent observation are listed in columns (4), (5), and (6). Column (7) is the number of observations listed in the WDS. Note that a few of these "companions" have many observations, but they are not true companions. Column (8) identifies the specific method used to refute the WDS entry.

Figure 2 shows an example for HD 9826. The lines mark two WDS entries that do not share the primary's high proper motion and hence are background stars. On the other hand, the known CPM companion (marked by an arrow) is easily identifiable in these images.

2.3. *Hipparcos Catalog*

As most of the exoplanet systems are close to the Sun (128 of the 131 are within 100 pc), the *Hipparcos* Catalog[5] provides fairly reliable distances and some photometric data for these systems. The catalog also notes some stellar companions, identified by field H59 as component solutions ("C" flag), accelerated proper motions ("G" flag), or orbital solutions ("O" flag). In total, *Hipparcos* identified stellar companions in nine exoplanet systems, four each with C and G flags, and one with the O flag. Five of the nine *Hipparcos* companions were independently confirmed, one (HD 38529c) is a close brown dwarf, and two (both G flags) remain as candidates. The ρ CrB system (HD 143761) has an O flag and contains a companion that is a planet (Noyes et al. 1997; Zucker & Mazeh 2001) or a star (Gatewood et al. 2001; Pourbaix & Arenou 2001; Halbwachs et al. 2003), but not both.

2.4. *Catalog of Nearby Stars*

Among our sample of 131 stars, 39 are listed in the CNS. We reviewed the earlier versions of the catalog (Gliese 1969; Gliese & Jahreiss 1979, 1991), as well as the consolidated information on the Web.[6] The catalog identifies any known companions and lists separation, position angle, and references in the notes section. Twelve stars from our sample have companions listed in the CNS, and every one of them was confirmed by other sources to be a true companion.

2.5. *Duquennoy & Mayor*

The Duquennoy & Mayor (1991) G Dwarf Survey specifically looked at multiplicity among solar-type stars in the solar neighborhood using radial velocity techniques. This is an ideal reference for our sample because searches for exoplanet systems have focused on such systems. Duquennoy & Mayor (1991) identified target stars as single-line, double-line, or line width spectroscopic binaries, or spectroscopic binaries with orbits. Only three stars from our sample have companions listed in this reference, and each of these was confirmed by other sources to be a true companion.

3. PHOTOMETRIC DISTANCE ESTIMATES FOR COMPANION CANDIDATES

In addition to the proper-motion investigation, we collected archival 2MASS and SuperCOSMOS photometry and new CCD photometry that allowed us to compute distance estimates to companion candidates, as described below. Table 4 summarizes the photometry data, as well as the distance estimates computed. Column (1) is the star's name, and column (2) contains the spectral type identified as part of this work (see § 4). Columns (3), (4), and (5) are the *BRI* plate magnitudes from SuperCOSMOS, followed by the *VRI* CCD magnitudes observed by us at the CTIO 0.9 and 1.0 m telescopes in columns (6), (7), and (8). Column (9) gives the number of observations available for the *VRI* photometry. This is followed by 2MASS JHK_s photometry in columns (10), (11), and (12). Columns (13), (14), and (15) are the estimated plate photometric distance, total error of this estimate, and the number of color relations used in computing this estimate. Columns (16), (17), and (18) similarly list the CCD distance estimate, total error, and the number of color relations used.

3.1. *2MASS Coordinates and Photometry*

We used the 2MASS Web database, accessed via the Aladin interactive sky atlas[7] (Bonnarel et al. 2000), to obtain equinox

[5] See http://www.rssd.esa.int/Hipparcos/HIPcatalogueSearch.html.
[6] See http://www.ari.uni-heidelberg.de/aricns.
[7] See http://aladin.u-strasbg.fr/aladin.gml.

TABLE 4
OBSERVATIONS AND COMPUTED DISTANCES

Name (1)	Spectral Type (2)	Plate Magnitudes B (3)	Plate Magnitudes R (4)	Plate Magnitudes I (5)	CCD Magnitudes V (6)	CCD Magnitudes R (7)	CCD Magnitudes I (8)	Number of Observations (9)	Infrared Magnitudes J (10)	Infrared Magnitudes H (11)	Infrared Magnitudes K_s (12)	D_{plt} (pc) (13)	Error (pc) (14)	Number of Relations (15)	D_{CCD} (pc) (16)	Error (pc) (17)	Number of Relations (18)
Exoplanet Host Without Parallax																	
BD −10 3166	...	9.90	8.80	8.08	10.03	9.59	9.19	1	8.61	8.30	8.12	33.8	8.8	1	66.8	10.0	1
Confirmed Companions																	
HD 038529B	M3.0 V	13.81	11.84	10.05	13.35	12.29	10.98	3	9.72	9.04	8.80	31.8	9.0	11	28.7	4.8	12
HD 040979B	...	9.92	8.72	...	...	...	...	...	7.27	6.79	6.69	15.2	4.0	3	...	...	...
HD 046375B	...	...	...	...	11.80	11.01	9.80	3	8.70	8.08	7.84	...	...	...	26.4	6.0	12
HD 075732B	...	13.14	11.53	...	13.26	11.91	10.24	2	8.56	7.93	7.67	14.5	4.6	6	8.7	1.4	12
HD 188015B	...	...	...	...	...	15.54	13.91	1	12.09	11.59	11.34	...	...	...	46.9	9.5	7
HD 190360B	...	15.30	12.35	...	...	...	...	...	9.55	9.03	8.71	18.5	6.2	6	...	...	...
HD 213240B	M5.0 V	...	...	...	17.40	15.96	14.13	1	12.36	11.74	11.47	...	...	...	41.8	6.5	12
HD 219449BC	Early K	...	...	...	9.17	8.57	8.05	1	7.31	6.84	6.69	...	...	...	29.9	4.7	6
HD 222582B	M3.5 V	15.25	13.16	11.41	14.49	13.33	11.83	1	10.39	9.81	9.58	35.1	9.3	11	32.1	5.0	12
Candidate Companions																	
HD 169830B	...	...	...	...	14.35	13.62	12.39	1	10.16	9.50	9.35	...	...	...	29.2	23.4	12
Refuted Candidate Companions																	
BD −10 3166 #1	M5.0 V	14.71	13.36	11.78	14.43	13.03	11.22	1	9.51	8.97	8.64	16.4	10.1	11	12.5	2.0	12
HD 033636 #1	M1.0 V	20.56	18.17	...	19.31	18.43	17.37	1	16.26	15.63	15.16	608.5	162.9	6	738.9	162.3	12
HD 041004 #1	M0.5 V–VI	18.90	16.87	15.76	17.89	16.91	16.05	1	15.06	14.50	14.16	414.0	119.1	11	557.4	103.3	9
HD 072659 #1	M3.0 V	20.21	18.05	16.43	18.91	18.02	16.53	1	15.31	14.67	14.30	293.0	82.5	11	368.6	99.2	12
HD 114783 #1	Early K	10.60	9.32	8.92	9.78	9.31	8.90	2	8.32	7.90	7.79	20.2	5.4	3	54.0	9.3	2

J2000.0 coordinates for the companion candidates, the epoch of observation, and J, H, and K_s photometry. The errors in JHK_s were almost always less than 0.05 mag and were typically 0.02–0.03 mag. Notable exceptions are three distant and faint refuted candidates listed in Table 4, HD 33636 #1 (errors of 0.14, 0.15, null at JHK_s, respectively), HD 41004 #1 (0.05, 0.06, and 0.07 mag), and HD 72659 #1 (0.05, 0.06, and 0.07 mag).

3.2. *SuperCOSMOS Plate Photometry and Distance Estimates*

We obtained optical plate photometry in B_J, R_{59F}, and I_{IVN} bands (hereafter *BRI*) from the SuperCOSMOS Sky Survey (SSS) scans of Schmidt survey plates (Hambly et al. 2001b). The SSS plate photometry is calibrated by means of a network of secondary standard-star sequences across the entire sky, with the calibration being propagated into fields without standards by means of the ample overlap regions between adjacent survey fields. The external accuracy of the calibrations is ±0.3 mag in individual passbands (Hambly et al. 2001a); however, the internal accuracy in colors (e.g., $B - R$, $R - I$) is much better, being typically 0.1 mag for well-exposed, uncrowded images. We used point-source photometric measures in all cases.

Photometric distance estimates were then derived using these SSS plate magnitudes, combined with 2MASS JHK_s by fitting various colors to M_{K_s}-color relations from Hambly et al. (2004). Results for 11 companion candidates are given in Table 4. Errors quoted from this procedure include internal and external errors. Internal errors represent the standard deviation of distance estimates from the suite of M_{K_s}-color relations. External errors represent a measure of the reliability of the relations for stars of known distance, which is estimated to be 26% in Hambly et al. (2004).

3.3. *CCD Photometry Observations and Distance Estimates*

Because of the relatively large photometric distance errors associated with photographic plate photometry, we obtained optical CCD photometry for one exoplanet host and 13 companion candidates (given in Table 4) in the $V_J R_{KC} I_{KC}$ bands (hereafter *VRI*) using the CTIO 0.9 and 1.0 m telescopes during observing runs in 2003 December, 2004 June, September, and December, 2005 August and December, and 2006 March as part of the SMARTS (Small and Moderate Aperture Research Telescope System) Consortium. For the 0.9 m telescope, the central quarter of the 2048 × 2046 Tektronix CCD camera was used with the Tek 2 *VRI* filter set. For the 1.0 m telescope, the Y4KCam CCD camera was used with the Harris 1 4mts *VR* and kc 1 4mts *I* filter set. Standard stars from Graham (1982), Bessel (1990), and Landolt (1992) were observed through a range of air masses each night to place measured fluxes on the Johnson-Kron-Cousins *VRI* system and to calculate extinction corrections.

Data were reduced using IRAF via typical bias subtraction and dome flat-fielding, using calibration frames taken at the beginning of each night. In general, a circular aperture 14″ in diameter was used to determine stellar fluxes in order to match apertures used by Landolt (1992) for the standard stars. In cases of crowded fields, an appropriate aperture 2″–12″ in diameter was used to eliminate stray light from close sources and aperture corrections were applied. For one target (HD 169830B), we used Gaussian fitting via an IDL program to the PSF tail of a bright nearby source to eliminate its effects and completed the photometry on the target using the IDL APER routine. The same approach was performed on two of our standard stars to correct for zero-point difference between IDL and IRAF magnitudes. As discussed in Henry et al. (2004), photometric errors are typically ±0.03 mag or less, which includes both internal and external errors. The only exceptions with larger errors were distant and faint refuted candidates HD 33636 #1 (errors of 0.06, 0.04, and 0.04 mag at V, R, and I, respectively) and HD 72659 #1 (0.10, 0.05, and 0.03 mag), new companion HD 188015B (0.05 and 0.04 mag at R and I, respectively), and new candidate HD 169830B (0.12, 0.09, and 0.13 mag). The errors for HD 188015B and HD 169830B are high due to the uncertainties introduced by the large-aperture corrections and, for HD 169830B, PSF fitting as well.

Photometric distances were obtained using the *VRI* magnitudes along with 2MASS JHK_s and fitting various colors to M_{K_s}-color relations from Henry et al. (2004). The results for these companion candidates are given in columns (16)–(18) of Table 4. Errors quoted from this procedure include internal and external errors. Internal errors represent the standard deviation of distance estimates from the suite of M_{K_s}-color relations. External errors represent a measure of the reliability of the relations for stars of known distance, which is estimated to be 15% in Henry et al. (2004).

4. SPECTROSCOPIC OBSERVATIONS

New spectra of nine companion candidates were obtained during observing runs in 2003 October and December, 2004 March and September, and 2005 January at the CTIO 1.5 m telescope as part of the SMARTS Consortium. The Ritchey-Chrétien spectrograph and Loral 1200 × 800 CCD detector were used with grating 32 in our red setup and grating 09 in our blue setup, which provided 8.6 Å resolution and wavelength coverage over 6000–9500 Å in the red and 3800–6800 Å in the blue. Data reduction consisted of background subtraction, spectrum extraction, and wavelength and flux calibrations in IRAF after standard bias subtraction, flat-fielding, and illumination corrections were applied. Standard dome flats were used for flat-fielding and calibration frames were taken at the beginning of each night. Fringing at wavelengths longer than 7000 Å is common in data from this spectrograph; however, it is typically removed fully by flat-fielding, and no further steps were needed to remove the fringes. Spectral types for stars observed in the red wavelength regime, listed in Table 4, were assigned using the ALLSTAR program as described in Henry et al. (2002). RECONS types have been assigned using a set of standard comparison stars from the RECONS database, a library of ~500 M0.0 V–M9.0 V spectra. Only rough spectral types were assigned based on our blue spectra by comparing features in our spectra with standard stars in Jacoby et al. (1984).

5. RESULTS

Table 2 is a compendium of the 30 exoplanet systems confirmed to have two or more stellar components, listed in coordinate sequence. At the end of the table, six additional systems are listed that may be stellar multiples, although these have not yet been confirmed. Column (1) lists a sequence number of the exoplanet system matching the value plotted in Figure 5, and columns (2) and (3) list the HD name and an alternate name of the exoplanet host and companion stars. Column (4) lists stellar (A, B, C, . . .) or planetary components (b, c, d, . . .). Columns (5) and (6) list the right ascension and declination of stars at epoch 2000.0, equinox J2000.0. For stars listed in *Hipparcos* (all primaries and a few companions), we used the *Hipparcos* 1991.25 epoch coordinates and proper motions to compute the coordinates listed. For fainter stars not observed by *Hipparcos*, we used 2MASS coordinates at the epoch of observation and converted the coordinates to epoch 2000.0 using proper motions from SuperCOSMOS or NLTT (Luyten 1979),[8] if available.

[8] Also available via the VizieR Online Data Catalog I/98A.

When the proper motion of a companion was not available, we used the primary's *Hipparcos* proper motion. In some instances, 2MASS coordinates were not available for the companions, and in these instances, the coordinates of the companions are not listed. However, in all but three of these cases, the separation and position angle of the companion from the primary are listed in columns (11) and (12). The three exceptional cases (one confirmed and two candidates), where neither coordinates nor separations from the primaries are known, are all *Hipparcos* G flags and hence close astrometric binaries. Column (7) lists the trigonometric parallax from *Hipparcos*, in arcseconds. Columns (8) and (9) list the distance, in pc, and its basis on either trigonometric parallax, if available (coded as "T"), calculated CCD photometric distance using relations from Henry et al. (2004) (coded as "C"), or calculated plate magnitude distance from SuperCOSMOS using relations from Hambly et al. (2004) (coded as "P"). If both plate and CCD distance estimates are available, only the more reliable CCD distance is listed. Column (10) lists the spectral type from Gray et al. (2003), the planet discovery paper, or other references for the primary and from our spectroscopic observations or other references for the companion. Columns (11) and (12) list the angular separation (in arcsec) and position angle (in deg) of stellar companions with respect to the exoplanet host. For companions listed in WDS, these are typically the most recent entry in WDS; otherwise, they are the values listed in the companion discovery paper. For new companions, these astrometry values are our measurements from our CTIO or the DSS images. Column (13) lists the projected spatial separation (and is therefore a lower limit at the epoch of plate observation) of companion stars with respect to their primaries, in AU. Column (14) gives the $M \sin i$ in Jupiter masses for planets. Columns (15) and (16) list the $a \sin i$ (in AU) and eccentricity of the orbits. Column (17) specifies the sources used to detect the companion stars. The codes are as follows: "P" represents a CPM detection using the multiepoch DSS images; "W" represents a companion listing in the WDS catalog; "H" represents a *Hipparcos* catalog companion identification; "C" represents a companion identification in the CNS catalog; "D" represents a companion identification in Duquennoy & Mayor (1991); "I" represents confirmation via our recent *VRI* images taken to verify CPM; and "O" represents that the companion was not found by any of the above means but reported in one or more refereed papers. Finally, column (18) lists relevant references relating to stellar companions. We have chosen not to list the individual planet discovery papers as references, unless they identify a stellar companion.

5.1. *Notes for Each Multiple System*

5.1.1. *New, Known, or Confirmed Companion Systems*

HD 142.—This close binary (separation 5″4) is listed in WDS and CNS. While this pair was first resolved at Harvard College Observatory in 1894 (Bailey 1900), the separation and $\Delta m \simeq 5$ make this a difficult object. It was found at approximately the same position six times from 1894 to 1928. It then remained unmeasured for 72 yr until it became evident in 2MASS in 2000 at approximately the same position angle. Given the primary's $\mu = 0\farcs58\ \mathrm{yr}^{-1}$ due east and the long time lapse between the 1928 WDS observation and our image of 2004, a background star would easily have been detected, but we found a blank field at its expected position. This system was mentioned in Lowrance et al. (2002) as a single planet in a multiple-star system.

HD 9826.—This CPM pair is clearly identified in DSS images but not listed in any of the other sources checked. Lowrance et al. (2002) identified this as the first system discovered with multiple planets and multiple stars. It was also mentioned in Patience et al. (2002) and Eggenberger et al. (2004) as an exoplanet primary having a stellar companion.

HD 11964.—This CPM pair is clearly identified in DSS images and listed in WDS and CNS. Allen et al. (2000) listed this as a wide binary system in a catalog of 122 binaries identified via CPM from a sample of 1200 high-velocity, metal-poor stars. The primary's $\mu = 0\farcs441\ \mathrm{yr}^{-1}$ at 237° from *Hipparcos*, and the companion's $\mu = 0\farcs444\ \mathrm{yr}^{-1}$ at 236° (Zacharias et al. 2004), a good match. Our work is the first identification of this as a stellar companion to a planetary system.

HD 13445.—Els et al. (2001) reported the discovery of this close companion ($1\farcs72 \pm 0\farcs2$ separation) via AO imaging, incorrectly identifying the companion as a T dwarf based on its colors. The recent publication of Mugrauer & Neuhäuser (2005) identified this companion as a cool white dwarf based on its spectrum, claiming the first white dwarf discovery in a planetary system. However, HD 147513 was in fact the first white dwarf discovery in a planetary system, reported by Mayor et al. (2004). There are now two known systems with evidence of planets surviving the post–main-sequence evolution of a stellar companion, with this one being the closest known white dwarf companion to an exoplanet host (at a projected separation of just 21 AU, similar to the Sun–Uranus distance).

HD 19994.—WDS lists 14 observations for this companion. This pair was first resolved by Admiral Smyth in 1836 with a 6 inch refractor (Smyth 1844). It has been resolved 15 times since then, most recently by Hale (1994), who also calculated a 1420 yr orbit for this pair. While there is some hint of curvilinear motion in the data, the orbit is certainly preliminary. This companion is also listed in CNS and Duquennoy & Mayor (1991). Several references have identified this as a stellar companion to a planetary system (Lowrance et al. 2002; Mayor et al. 2004; Eggenberger et al. 2004; Udry et al. 2004).

HD 27442.—WDS and CNS list this companion at 13″8 separation at 36°. It was first resolved in 1930 by Jessup (1955) and measured again by Holden (1966) almost 35 years later at approximately the same position. Our short-exposure *VRI* images taken at CTIO in 2004 September identified a source about 13″ away at 34°, consistent with the observations of almost 75 years ago. Given the primary's $\mu = 0\farcs175\ \mathrm{yr}^{-1}$, this can be confirmed as a companion. Our work is the first identification of this as a stellar companion to a planetary system.

HD 38529.—This CPM pair was discovered by us using DSS images. The primary's $\mu = 0\farcs163\ \mathrm{yr}^{-1}$ at 209° from *Hipparcos*, and the companion's $\mu = 0\farcs162\ \mathrm{yr}^{-1}$ at 204° from Lepine & Shara (2005)[9] and $0\farcs158\ \mathrm{yr}^{-1}$ at 208° from SuperCOSMOS. Figure 3 includes two DSS images showing the primary and the companion. Our CCD photometric distance estimate of 28.7 ± 4.8 pc is consistent with our spectral identification of M3.0 V and matches the primary's distance of 42 pc within 3 σ. At our request, spectroscopic observations of the companion were obtained by G. Fritz Benedict in 2004 February using the McDonald Observatory 2.1 m telescope and Sandiford Cassegrain echelle spectrograph (McCarthy et al. 1993). The data were reduced and one-dimensional spectra were extracted using the standard IRAF `echelle` package tools. The radial velocity was determined by cross-correlating the spectra of the star with that of an M2 dwarf (GJ 623) template using the IRAF task `fxcor`. The adopted radial velocity for the GJ 623 primary (it is a binary) was $-29.2\ \mathrm{km\ s}^{-1}$, given the orbital phase at which the template was secured and a

[9] Also available via the VizieR Online Data Catalog I/298.

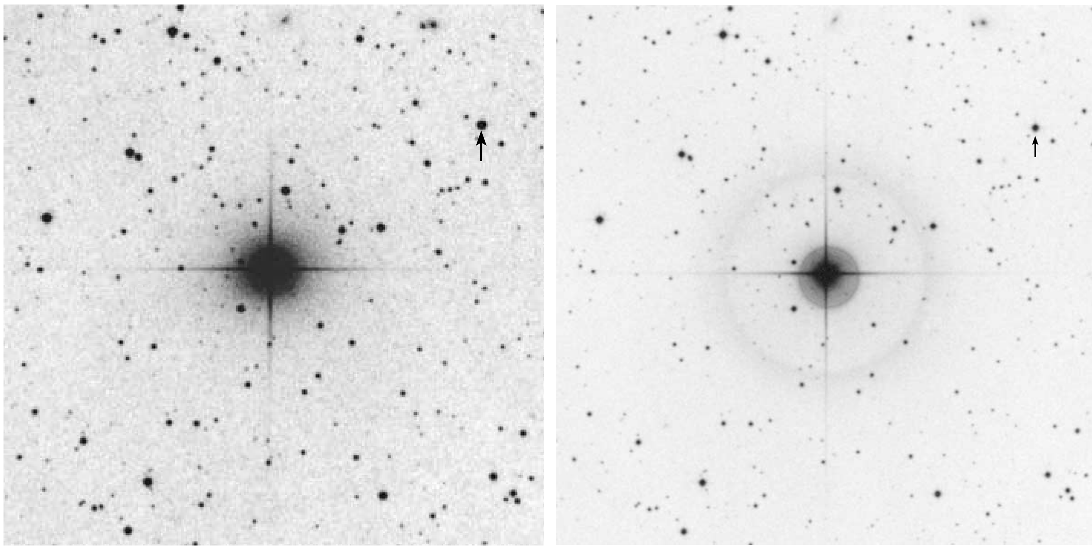

Fig. 3.—New stellar companion to exoplanet host HD 38529. The 10′ square DSS images have north up and east to the left. The companion, marked by arrows, is at an angular separation of 284″ at 305° from the primary, which is at the center of the images.

systemic velocity of −27.5 km s^{-1}, from Marcy & Moore (1989). HD 38529B's radial velocity was measured to be 26.26 ± 0.10 km s^{-1}. This is roughly consistent with the primary's radial velocity of 30.21 km s^{-1} (Nidever et al. 2002), and the odds of two unassociated stars having such similar velocities are low. However, discrepancies in radial velocities and photometric distances could indicate that the new companion is a double. The projected separation of the primary to the new companion(s) is ∼12,000 AU, which is extreme for a gravitationally bound system, although Poveda et al. (1994) listed a few wide binaries with even greater separations. This primary also has a *Hipparcos* G flag listing, which was recently used by Reffert & Quirrenbach (2006) to conclude that the substellar companion "c" is actually a brown dwarf of mass $37^{+36}_{-19}\,M_{\rm J}$.

HD 41004.—A companion is listed in WDS and annotated in *Hipparcos* with a C flag, indicating a linear relative motion of components, implying either an orbital period that is several times the length of the *Hipparcos* observing interval (3.3 yr) or stars that are not physically linked. At a separation of 0″.5 and a $\Delta m = 3.67$ (from *Hipparcos*), the identification of a close companion is difficult, but there are other such *Hipparcos* observations (similar separation and Δm) that were independently confirmed. For example, T. J. J. See measured a close large Δm pair, known as SEE 510 (HIP 86228), with the Lowell 24 inch (0.61 m) telescope in 1896 (See 1897). This pair, lost for nearly 100 yr, was recovered by *Hipparcos* at about the same position (0″.2, $\Delta m = 1.8$). While SEE 510 is not morphologically identical to HD 41004, we believe that it is comparably difficult, and so we accept the *Hipparcos* identification of a companion to HD 41004. This system was mentioned in Eggenberger et al. (2004) as a stellar companion in an exoplanet system. Further, Zucker et al. (2003) listed the radial velocity for the primary as 42.5 ± 0.01 km s^{-1} and found the companion to be a double, with a velocity range of 34–48 km s^{-1} (±0.56 km s^{-1}) over 103 observations. They derived an orbital solution for the BC pair, concluding that the orbit is nearly circular with $a \sin i = 0.016$ AU and that the low-mass companion has a minimum mass of $18.4 M_{\rm J}$. Zucker et al. (2004) derived orbital elements of the possible M dwarf–brown dwarf pair and concluded that this is a unique system with each stellar component of a visual binary having a low-mass companion in orbit around it: one a planet, and the other a possible brown dwarf. Note that the projected separation between A and B is just 22 AU, similar to the separation of the Sun and Uranus.

HD 40979.—This CPM pair is clearly identified in DSS images. The primary is 33 pc away with $\mu = 0''.179$ yr^{-1} at 148° (from *Hipparcos*). The companion, BD +44 1351, has a very similar $\mu = 0''.179$ yr^{-1} at 148° from Lepine & Shara (2005) and 0″.180 yr^{-1} at 148° from Hog et al. (1998). Halbwachs (1986) identified this CPM pair, listing the companion as a K5 star. Eggenberger et al. (2004) identified this as a stellar companion to a planetary system, noting that physical association of this pair has been confirmed via radial velocity measurements. However, our plate photometric distance estimate to the companion is 15.2 ± 4.0 pc (based on only three colors), not a very good match with the primary, although the error is large. This discrepancy could be due to the poor quality of the photometric distance estimate (due to the blue colors of the companion) or perhaps because the companion is an unresolved double.

HD 46375.—WDS lists this 9″.4 separation companion at 308°. We took short exposure frames at CTIO in 2004 September, which identified a companion at a separation of 10″ at 310°, consistent with the WDS observation. The first published resolution of this pair made by Soulie (1985) in 1984 has also been confirmed by 2MASS images. Reanalysis of Astrographic Catalogue data (Urban et al. 1998) has added an observation at about the same secondary position in 1932, thereby confirming that it has the same proper motion. Our CCD photometric distance estimate of 26.4 ± 6.0 pc is within 2 σ of the primary's distance of 33.4 pc from *Hipparcos*. We therefore conclude that this is a physical pair. This work is the first identification of this as a stellar companion to a planetary system.

HD 75289.—This CPM candidate was detected by Mugrauer et al. (2004a) and confirmed by their photometry and spectroscopy. While the companion is seen in the epoch 2 DSS image, CPM could not be established by our method due to saturation of the region around the primary in the epoch 1 image.

HD 75732.—This CPM pair is easily identified in DSS images and matches entries in WDS, CNS, and Duquennoy &

Mayor (1991). The primary has $\mu = 0\farcs539$ yr^{-1} at 244° and $\pi = 0\farcs07980 \pm 0\farcs00084$, from *Hipparcos*. Our CCD photometric distance estimate to the companion is 8.7 ± 1.4 pc, a match within 3 σ. The companion's $\mu = 0\farcs540$ yr^{-1} at 244° and $\pi = 0\farcs0768 \pm 0\farcs0024$ from the Yale Parallax Catalog (van Altena et al. 1995) and $0\farcs0757 \pm 0\farcs0027$ from Dahn et al. (1988) are all consistent with the primary's. This system is listed in Eggenberger et al. (2004) as a stellar companion to a planetary system. The primary star, more commonly known as 55 Cnc, has four reported planets, so this system is the most extensive solar system with a stellar companion, which is at a projected distance of more than 1000 AU. The discrepancy in photometric distance could hint that the companion is an unresolved double.

HD 80606.—This CPM pair is easily identified in DSS images and matches entries in WDS and *Hipparcos*. The primary's $\mu = 0\farcs047$ yr^{-1} at 82° and $\pi = 0\farcs01713 \pm 0\farcs00577$, from *Hipparcos*. The parallax has a large error due to the close companion. The companion is HD 80607, spectral type G5, $\mu = 0\farcs043$ yr^{-1} at 79°, and *Hipparcos* lists an identical parallax. This companion was listed by Eggenberger et al. (2004) as a stellar companion to a planetary system.

HD 89744.—This companion was reported as a candidate by Wilson et al. (2001) based on spectroscopic observations, and they identified it as a massive brown dwarf of spectral type L0 V. Companionship was subsequently confirmed astrometrically by Mugrauer et al. (2004b). This faint companion is not seen in the DSS images.

HD 99492.—This CPM pair is easily identified in DSS images and matches entries in WDS, *Hipparcos*, and CNS. Component B (the exoplanet host) has $\mu = 0\farcs755$ yr^{-1} at 285° and $\pi = 0\farcs05559 \pm 0\farcs00331$, from *Hipparcos*. Component A is HD 99491 with spectral type K0 IV, $\mu = 0\farcs749$ yr^{-1} at 284°, and $\pi = 0\farcs05659 \pm 0\farcs00140$, from *Hipparcos*. These match HD 99492's values well and confirm the pair as physical.

HD 114729.—This CPM candidate was detected recently by Mugrauer et al. (2005) and confirmed by their photometry and spectroscopy. It could not be detected using DSS frames due to saturation of the region around the primary.

HD 114762.—This close companion was discovered using high-resolution imaging (Patience et al. 2002). It was also mentioned by Eggenberger et al. (2004) as a stellar companion to a planetary system. The "planet," with $M \sin i = 11.0 M_J$, may in fact be a star in a low-inclination orbit (Cochran et al. 1991; Fischer & Valenti 2005).

HD 120136.—This close companion is listed in WDS (53 observations), CNS, and Duquennoy & Mayor (1991). The primary's $\mu = 0\farcs483$ yr^{-1} at 276° from *Hipparcos*. CNS lists the companion as GJ 527B, and SIMBAD gives its $\mu = 0\farcs480$ yr^{-1} at 274°, a good match to the primary's. This system has been recognized as a stellar companion to an exoplanet system (Patience et al. 2002; Eggenberger et al. 2004).

HD 142022.—This CPM pair (GJ 606.1AB) is easily identified in DSS images and matches entries in WDS and CNS. The companion's spectral type is K7 V. The NLTT catalog lists identical μ for both components, $\mu = 0\farcs320$ yr^{-1} at 269° (Luyten 1979).

HD 147513.—This companion is listed in CNS and was the first white dwarf found in an exoplanet system (Mayor et al. 2004). The primary's $\mu = 0\farcs073$ yr^{-1} at 87° and $\pi = 0\farcs07769 \pm 0\farcs00086$, from *Hipparcos*. The companion is HIP 80300, type DA2 (Wegner 1973), with matching *Hipparcos* values of $\mu = 0\farcs076$ yr^{-1} at 90° and $\pi = 0\farcs07804 \pm 0\farcs00240$.

HD 178911.—This is a triple-star system with one known planet. The wide CPM pair (AC-B) is clearly seen in DSS images. The $6.3 M_J$ planet orbits HD 178911B, while HD 178911AC is a close binary, first resolved by McAlister et al. (1987b) with the Canada-France-Hawaii Telescope (CFHT). This pair has since been resolved 10 more times, most recently with the 6 m telescope of the Special Astrophysical Observatory in Zelenchuk in 1999 (Balega et al. 2004). Hartkopf et al. (2000) present an orbital solution with a 3.5 yr period based on speckle observations, and Tokovinin et al. (2000) present a full orbital solution using spectroscopic and interferometric data. The multiplicity of this system has been previously identified (Zucker et al. 2002; Eggenberger et al. 2004). From *Hipparcos*, HD 178911AC's $\mu = 0\farcs200$ yr^{-1} at 14° and $\pi = 0\farcs02042 \pm 0\farcs00157$ and the companion's $\mu = 0\farcs203$ yr^{-1} at 19° and $\pi = 0\farcs02140 \pm 0\farcs00495$, a match within the errors, confirming a physical association.

HD 186427.—This is a triple-star system with one known planet. The wide CPM pair (AC-B) is clearly seen in DSS images. The planet orbits 16 Cyg B (HD 186427), while 16 Cyg A (HD 186408) is a close binary, first resolved by Turner et al. (2001) with the AO system on the Hooker 100″ telescope and independently confirmed by IR imaging by Patience et al. (2002) with the Keck 10 m and Lick 3 m. In the five total observations, the position of the secondary has not changed much. However, they span less than 2 yr of time and little motion would be expected at a projected separation of 73 AU. The multiplicity of this system has been previously identified (Patience et al. 2002; Lowrance et al. 2002; Eggenberger et al. 2004). From *Hipparcos*, 16 Cyg A's $\mu = 0\farcs217$ yr^{-1} at 223° and $\pi = 0\farcs04625 \pm 0\farcs00050$ and the planet host's $\mu = 0\farcs212$ yr^{-1} at 220° and $\pi = 0\farcs04670 \pm 0\farcs00052$, a match within the errors, confirming a physical association.

HD 188015.—This new companion was detected by us as a CPM candidate and confirmed via CCD photometry. The primary's $\pi = 0\farcs01900 \pm 0\farcs00095$ and $\mu = 0\farcs106$ yr^{-1} at 149°, from *Hipparcos*. The companion, 13″ away from the primary at 85°, does not have proper motion listed in SuperCOSMOS or NLTT, but our CCD photometric distance of 46.9 ± 9.5 pc matches the primary's distance within 1 σ and hence confirms this as a companion. Figure 4 includes two DSS images showing the primary and the companion.

HD 190360.—This CPM pair is easily identified in DSS images and matches entries in WDS and CNS. The primary is GJ 777A with spectral type G7 IV–V and $\mu = 0\farcs861$ yr^{-1} at 127° from *Hipparcos*. The companion is GJ 777B with spectral type M4.5 V and $\mu = 0\farcs860$ yr^{-1} at 127° (Lepine & Shara 2005). Our plate photometric distance estimate of 18.5 ± 6.2 pc is a good match with the primary's trigonometric parallax distance of 15.9 pc. This system has been recognized as a binary and as an exoplanet primary with a stellar companion (Allen et al. 2000; Naef et al. 2003; Eggenberger et al. 2004).

HD 195019.—WDS is the only source listing this close binary at a separation of $3\farcs5$ at 330°. The close pair, first resolved by Hough (1887) with an 18 inch refractor, has moved 7° in position angle and closed in from $4\farcs5$ to $3\farcs5$ in separation in 12 observations over 107 yr. This transition has not been smooth, no doubt due to $\Delta m = 4$, making observations a challenge. The typical measurement errors of micrometry, coupled with slow motion, make characterization difficult. It was identified as a binary in Allen et al. (2000) and recognized as a stellar companion to an exoplanet system in Eggenberger et al. (2004).

HD 196050.—This CPM candidate was detected recently by Mugrauer et al. (2005) and confirmed by their photometry and spectroscopy. It could not be detected using DSS frames due to saturation of the region around the primary.

HD 213240.—This CPM pair was identified by us using DSS images. The primary's $\mu = 0\farcs236$ yr^{-1} at 215° and $\pi = 0\farcs02454 \pm 0\farcs00081$, from *Hipparcos*. The companion's

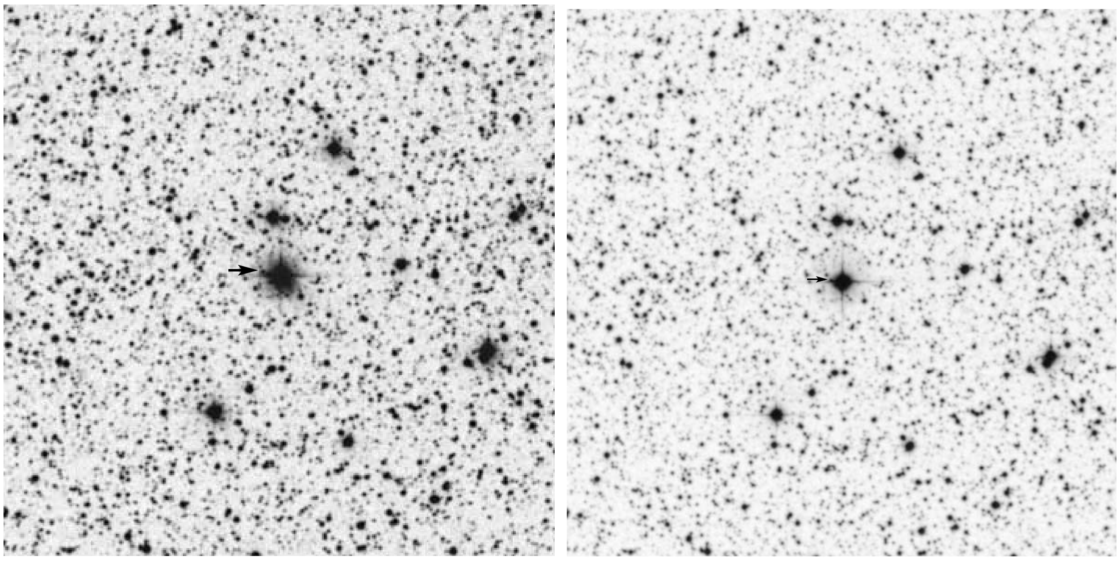

FIG. 4.—New stellar companion to exoplanet host HD 188015. The 10′ square DSS images have north up and east to the left. The companion, marked by arrows, is at an angular separation of 13″ at 85° from the primary, which is the bright source at the center of the images.

$\mu = 0''.229$ yr^{-1} at 214° from SuperCOSMOS is a good match. Our CCD photometric distance of 41.8 ± 6.5 pc is consistent with our spectral type identification of M5.0 V and is a good match to the primary's trigonometric parallax distance of 40.8 pc. This new companion identification in an exoplanet system was recently reported by Mugrauer et al. (2005) during the writing of this paper.

HD 219449.—A CPM companion is easily detected in the DSS images and is matched by WDS and CNS entries. WDS lists the secondary as a tight binary (0″.4 separation at 101°). The primary's $\mu = 0''.369$ yr^{-1} at 93° and $\pi = 0''.02197 \pm 0''.00089$, from *Hipparcos*. The companion binary has $\mu = 0''.377$ yr^{-1} at 91° from NLTT and 0″.385 yr^{-1} at 96° from Zacharias et al. (2004), both good matches to the primary. NLTT also lists the companion's spectral type as K8 V. Our CCD photometric distance of 29.9 ± 4.7 pc is for the BC pair, and we predict an actual distance of 42.4 pc (assuming identical spectral types), which is a good match to the primary (45.5 pc). Radial velocities from Wilson (1953) are −26.4 ± 0.9 km s^{-1} for the primary and −25 ± 5 km s^{-1} for the secondary, also a match within the errors. Our approximate spectral identification as an early K type is consistent with the photometric distances. This work recognizes, for the fist time, that this exoplanet system resides in a triple-star system.

HD 222404.—This companion is listed in *Hipparcos* with a G flag, indicating a close astrometric binary. While some speckle searches have failed to detect a companion (e.g., Mason et al. 2001), the companion has been detected via radial velocity efforts and identified as a stellar companion in an exoplanet system (Campbell et al. 1988; Griffin et al. 2002; Eggenberger et al. 2004). The semimajor axes of the planet and stellar companions with respect to the primary place them at Sun–Mars and Sun–Uranus separations, respectively.

HD 222582.—This CPM pair is easily seen in DSS images and is listed in the WDS. The primary's $\mu = 0''.183$ yr^{-1} at 233° and $\pi = 0''.02384 \pm 0''.00111$, from *Hipparcos*. The secondary's $\mu = 0''.180$ yr^{-1} at 231° from NLTT, 0″.186 yr^{-1} at 230° from SuperCOSMOS, and 0″.187 yr^{-1} at 232° from Zacharias et al. (2004) are all good matches to the primary. Our CCD photometric distance of 32.1 ± 5.0 pc matches the primary's distance of 42.0 pc within 2 σ. Our spectral type of M3.5 V is consistent with the photometric distance estimates. This pair, resolved by Luyten in 1960, was noted to have a common proper motion. This work confirms the gravitational relationship via CPM, photometry, and spectroscopy and is the first identification of this stellar companion to an exoplanet system.

5.1.2. *Candidate Companion Systems*

HD 8673.—WDS is the only source listing a close companion, at 0″.1 separation. Resolved by Brian Mason in 2001 as part of a survey of nearby G dwarfs for duplicity, this unpublished observation has yet to be confirmed. The projected stellar separation of 3.8 AU is just over twice the planet/brown dwarf projected separation of 1.6 AU and dynamical instability is likely. Alternatively, given the large $M \sin i = 14M_{\rm J}$ for the "planet," it is possible that it is actually a star in a near face-on orbit ($i \leq 10°$) and that the radial velocity and speckle observations are of the same object.

HD 16141.—This CPM candidate was recently detected by Mugrauer et al. (2005) at a separation of 6″.2, and they plan follow-up observations to confirm it. We could not detect the companion using DSS frames due to saturation of the region around the primary.

HD 111232.—This companion is mentioned only in *Hipparcos* and is listed with a G flag, indicating that the proper motion was best fitted with higher order terms. Mason et al. (1998) conducted a specific search for a companion using optical speckle but did not find any. Their effort should have picked up companions with $\Delta V \lesssim 3$ and separations 0″.035–1″.08.

HD 150706.—This companion is mentioned only in *Hipparcos* and is listed with a G flag, indicating that the proper motion was best fitted with higher order terms. Halbwachs et al. (2003) reported this as a single star based on two CORAVEL radial velocity surveys that yielded statistical properties of main-sequence binaries with spectral types F7–K and with periods up to 10 yr.

HD 169830.—A candidate companion was detected by Kevin Apps as a close 2MASS source with 11″ separation at 265° (K. Apps 2005, private communication). Our CCD photometric distance estimate for the companion is 29 ± 23 pc, consistent with the primary's distance of 36 pc, but the large error in our estimate prevents confirmation. The large error is likely due to the uncertainty in our and 2MASS photometry, caused by the close, bright primary and the proximity of the companion to the primary's diffraction spike. While 2MASS lists errors of 0.04 mag for JHK_s, it notes that the photometry is contaminated by a nearby bright source. Also, the J magnitude from DENIS is 0.36 mag brighter than the 2MASS value, indicating a larger uncertainty. The low proper motion (0$''$.015 yr^{-1}) of the primary prevents confirmation via CPM. While we believe that the evidence strongly indicates that this is a true companion, we cannot confirm it until we obtain a spectrum or other conclusive evidence.

HD 217107.—Only WDS lists this close companion with 0$''$.3 separation at 156°. Proper motion of the primary is not detectable in DSS images. This pair has been resolved only twice (McAlister et al. 1987a; Mason et al. 1999) 15 yr apart, and the lack of additional resolutions of this bright pair seems to indicate that a large magnitude difference may be preventing additional detections. Given the two reported planets with $a \sin i = 0.1$ and 4.3 AU, this companion at a projected separation of just 6 AU would likely induce dynamical instability. Explanations for this include the possibility that this is an unrelated star with a chance alignment and/or that the wider "planet" is actually a stellar companion with a face-on orbit.

5.2. *Refuted Candidates: CPM Alone Does Not Confirm Companionship*

As CPM is often used to detect gravitationally bound companions, we list here five exceptions that, upon follow-up analyses, turned out to be unrelated field stars rather than true companions. In three of these instances (HD 33636, HD 41004, and HD 72659) we found proper motions in DSS plates to be an acceptable match by eye, but photometric distances indicated that each candidate was a distant field star. In the cases of BD −10 3166 and HD 114783, photometric distances did not provide a conclusive answer, but plotting these on an M_V versus $B - V$ curve of a sample of *Hipparcos* stars allowed us to refute them.

BD −10 3166 is the only exoplanet primary without a *Hipparcos* parallax. We derived a CCD photometric distance of 66.8$\pm$ 10.0 pc, but that is based on just one color because the object is on the blue end of the M_{K_s}-color relations described in Henry et al. (2004). The companion candidate, LP 731-076, is 17$''$ from the primary at 217° (in the DSS1, epoch 1983.29 image) and appears to have a matching proper motion. The two stars were identified by Luyten (1978) as a CPM pair and recently recovered in SuperCOSMOS data by R. Jaworski (2005, private communication). In SuperCOSMOS, the primary's $\mu = 0''.189$ yr^{-1} at 252° and the candidate's $\mu = 0''.202$ yr^{-1} at 242°. The candidate has a published photometric distance of 11.6 $\pm$ 0.8 pc (Reid et al. 2002), which is consistent with our photometric distance estimate of 12.5 $\pm$ 2.0 pc and our spectral type listed in Table 4. In order to get a better distance estimate to the primary, we plotted 285 stars from *Hipparcos* on an M_V versus $B - V$ diagram. The stars were selected based on distance (parallax greater than 0$''$.05), quality of parallax (error less than 10%), luminosity class (main sequence only), and $B - V$ value of greater than 0.5. Fitting the primary's $B - V$ of 0.84 from Ryan (1992) to the least-squares fit curve through the *Hipparcos* data yields a distance estimate of 68 pc, consistent with our photometric distance estimate and too large to be associated with the candidate companion. This is an interesting example of a close (17$''$ separation) CPM pair for which distance estimates to both components are of the same order of magnitude, but the components seem to be unrelated.

HD 33636 has $\mu = 0''.227$ yr^{-1} at 127° and $\pi = 0''.03485 \pm 0''.00133$ (29 pc) from *Hipparcos*. The faint CPM candidate at a separation of 220$''$ at 250° (in the DSS POSS2/UKSTURed, epoch 1990.81 image) was refuted by us after obtaining a CCD photometric distance of 739 $\pm$ 162 pc. Our spectrum, although noisy, allows us to estimate the spectral type to be M1.0 V, which indicates a large distance consistent with the photometric estimate.

HD 41004 has $\mu = 0''.078$ yr^{-1} at 327° and $\pi = 0''.02324 \pm 0''.00102$ (43 pc), from *Hipparcos*. The faint CPM candidate at a separation of 145$''$ at 335° (in the DSS POSS2/UKSTURed, epoch 1993.96 image) was refuted by us after obtaining a CCD photometric distance of 557 $\pm$ 103 pc. We estimate the spectral type to be M0.5, although the luminosity class is uncertain: it could be a dwarf or a subdwarf. The candidate's $\mu = 0''.046$ yr^{-1} at 6° from SuperCOSMOS is not a good match to the primary.

HD 72659 has $\mu = 0''.150$ yr^{-1} at 229° and $\pi = 0''.01947 \pm 0''.00103$ (51 pc), from *Hipparcos*. The candidate, at a separation of 195$''$ at 165° (in the DSS POSS2/UKSTURed, epoch 1992.03 image), was refuted by us after obtaining a CCD photometric distance of 369 $\pm$ 99 pc. Our spectral identification as M3.0 V is consistent with this photometric distance. SuperCOSMOS lists the CPM candidate's $\mu = 0''.066$ yr^{-1} at 199°, showing that proper motion is not a good match.

HD 114783 is another CPM pair that looks like it may be physical but is not. From *Hipparcos*, the primary has $\mu = 0''.138$ yr^{-1} at 274° and from SuperCOSMOS, the candidate companion (at a separation of 240$''$ at 47° in the DSS POSS2/UKSTURed, epoch 1996.23 image) has $\mu = 0''.184$ yr^{-1} at 281°. The primary's distance from the *Hipparcos* parallax is 20.4 pc. Our plate photometric distance estimate for the companion is 20.2 $\pm$ 5.2 pc based on only three colors. However, using CCD photometry, we get a distance of 54.0 $\pm$ 9.3 pc, based on only two colors. The candidate companion is CCDM J13129−0213AB, a binary (listed in the WDS with a separation of 2$''$.0 at 28°), and hence its actual distance is greater than photometrically indicated. We plotted the primary on the M_V versus $B - V$ diagram using *Hipparcos* data as described above, and it falls close to the main-sequence fit, indicating that it is likely a single star. The candidate companion, based on its $B - V$ of 1.10, yields a distance of 36 pc, using the *Hipparcos* plot, but its actual distance will be greater because it is a binary. Our spectra for the two stars show very similar absorption lines, although the continuum seems to indicate that the candidate companion is slightly redder. Given that the spectral types are close and that the candidate companion is a binary while the primary appears to be single, we can only explain the large ΔV (primary $V = 7.56$, and candidate companion $V = 9.78$) by adopting significantly different distances to the two stars. Hence, we conclude that this is not a gravitationally bound pair, despite the compelling proper-motion match.

6. DISCUSSION

Our findings indicate that 30 (23%) of the 131 exoplanet systems have confirmed stellar companions and 6 more (5%) have candidate companions. Given the constraints of our search (any new companions we detected had to be widely separated from primaries with high proper motion), these numbers should be regarded as lower limits. This point is confirmed by a recent paper, Mugrauer et al. (2005), which reported four new companions in exoplanet systems, of which we had independently identified only one (HD 213240B). Several interesting properties are revealed by this comprehensive assessment.

Three of the exoplanet systems (HD 178911, 16 Cyg B, and HD 219449) are stellar triples and are arranged similarly: a

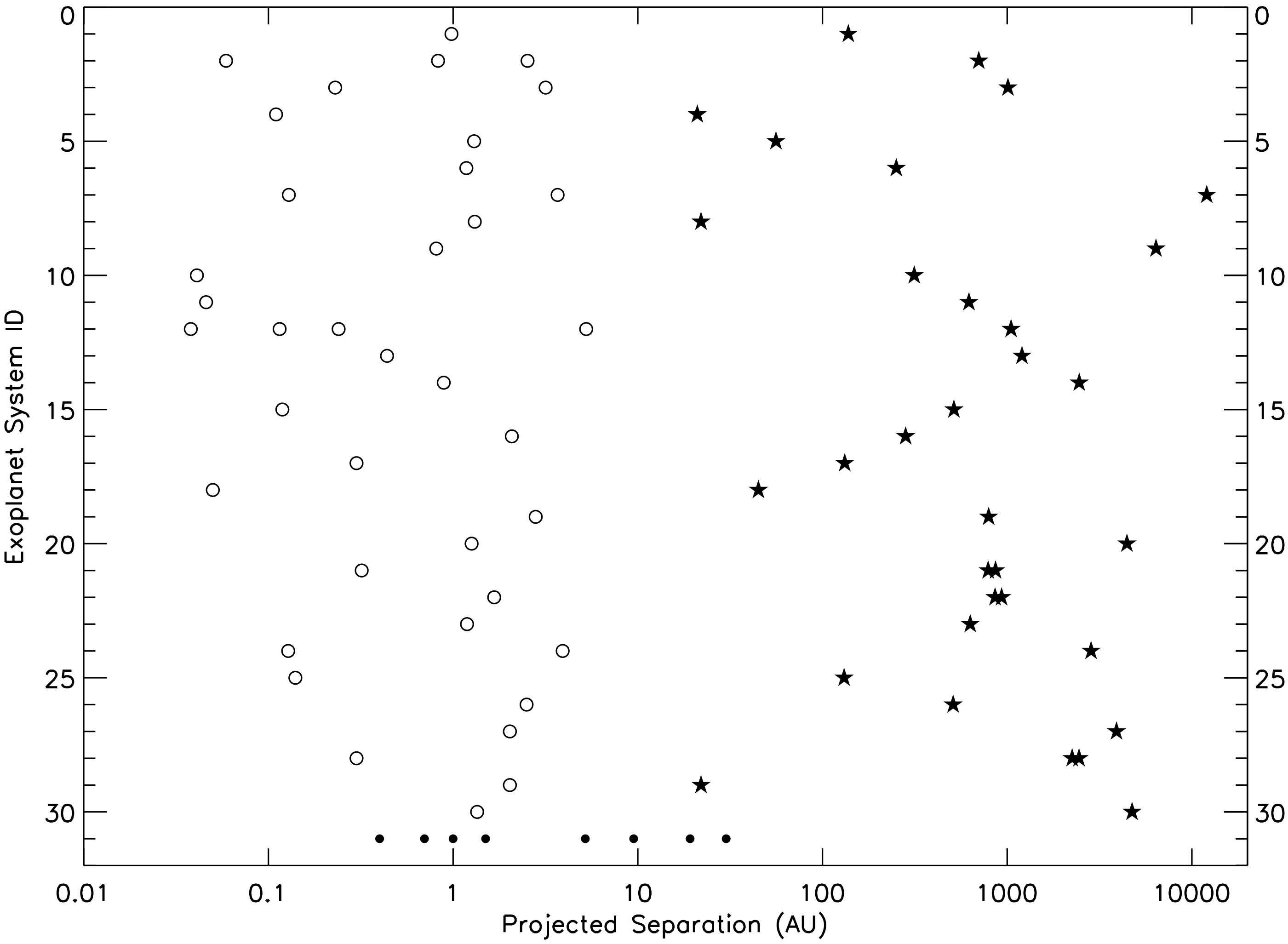

Fig. 5.—Orbits of planets and stars in exoplanet systems with stellar companions. The exoplanet host stars are at a position of 0 AU. Open circles represent planets, and stars represent stars. Points will tend to move right because of orbital inclination and projection effects. Separations between the components of the three binary companions are exaggerated to be able to distinguish the binary components on the plot. For comparison, the positions of the eight planets of our solar system are shown at the bottom as filled circles.

single planet orbits close to one star and there is a distant, tight binary. In each system, the three stars are all of the same spectral class (G for HD 178911 and 16 Cyg, and K for HD 219449). We find it curious that all three triple systems contain stars of comparable mass (i.e., systems such as a G dwarf exoplanet host with an M dwarf binary are not seen). Could this be due to a selection effect (i.e., faint companions are not as well studied for multiplicity), or does this say something about the angular momentum distribution in star-forming regions? Only a comprehensive survey of all companions for duplicity can lead us to an answer.

It is interesting to note that recent exoplanet discoveries are predominantly found in single-star systems. Of the first 102 radial velocity–detected exoplanet systems, 26 (26%) have confirmed stellar companions. In contrast, only 4 (14%) of the latest 29 systems have confirmed stellar companions. Even though we are dealing with small number statistics, we believe that this change is significant and worthy of further examination. Our first inclination was that recent planet detections are at larger projected semimajor axes and hence favor single systems because stellar companions would have to be even farther out to provide the uncorrupted "single" systems sought by radial velocity programs. However, we found no correlation between the timing of exoplanet reporting and its projected semimajor axis. Thus, we are not able to explain this curiosity at this point and simply identify it for further examination.

Exoplanet hosts are deficient in having stellar companions when compared to a sample of field stars. Our updated results for stellar counts in the exoplanet sample yield a single : double : triple : quadruple percentage of 79:21:2:0 for confirmed systems, and 72:24:4:0 considering candidates. While these are lower limits for multiplicity, they are significantly lower than the Duquennoy & Mayor (1991) results of 57 : 38 : 4 : 1 for multiples with orbits, and 51 : 40 : 7 : 2 considering candidates. This is certainly due in part to the fact that planet searches specifically exclude known close binaries from their samples (e.g., Vogt et al. 2000) and further eliminate any new binaries detected via radial velocity. We currently do not have enough detailed information about the exoplanet search target selection process to say whether the different multiplicity ratios are entirely due to selection effects or are indicative of planetary disk instability and reduced planet formation in binary-star systems.

6.1. *Planetary and Stellar Orbits in Multiple-Star Systems*

Figure 5 shows the $a \sin i$ of planetary companions and projected separations of the stellar companions for the 30 confirmed exoplanets that reside in multiple-star systems. The *Y*-axis shows

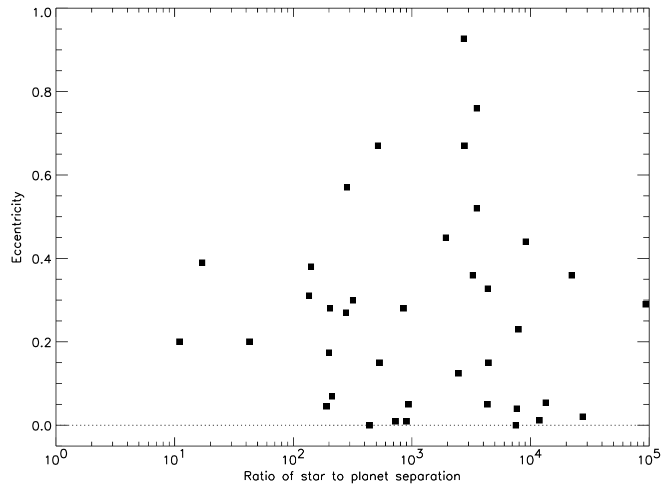

FIG. 6.—Eccentricity of planetary orbits as a function of proximity of the stellar companion. The ratio is computed using projected stellar separation and $a \sin i$ of the planetary orbit.

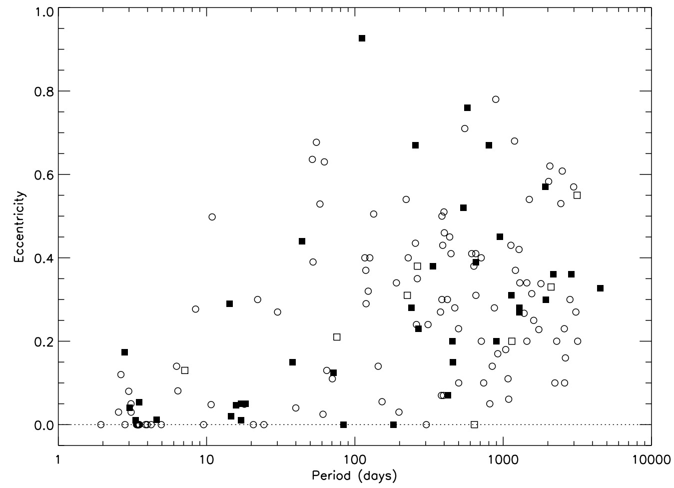

FIG. 7.—Period-eccentricity diagram for planets orbiting single stars (*open circles*) and planets in systems with more than one star (*open squares*: candidate multiplicity; *filled squares*: confirmed multiplicity).

the sequence number of the exoplanet system as listed in column (1) of Table 2. The figure clearly indicates the presence of separate planetary and stellar orbit regimes for the data currently available. All planets are within 6 AU, and all stars are at a projected separation of greater than 20 AU from the exoplanet host. Note that all points in the figure can potentially move right because (1) planets are plotted at a separation of $a \sin i$ and (2) stars are plotted based on their projected separations (although a few could move left if they have been caught near apastron in their orbits). The continued search for wider orbit planets will answer the question of whether this is simply due to selection effects or if this says something significant about planetary disk truncation in multiple-star systems.

55 Cnc (HD 75732), an extensive extrasolar system with four reported planets, has the widest projected planetary orbit with an $a \sin i$ of 5.3 AU. It is noteworthy that such an extensive exoplanet system also has a stellar companion, at a projected separation of 1050 AU. This provides direct evidence of the stability of protoplanetary disks in multiple-star systems such as to allow formation and sustenance of multiple planets, at least as long as the separation between the stars is sufficiently large. This system can also provide an observational constraint for evaluating theoretical models of disk stability and solar system evolution.

The smallest projected separation for a stellar companion is 21 AU for GJ 86, closely followed by 22 AU for HD 41004 and γ Cep. Each system has only one reported planet, with $a \sin i$ of 0.1, 1.3, and 2.0 AU, respectively. This may be evidence that a sufficiently close stellar companion will disrupt the protoplanetary disk, truncating planet formation at a few AU from the primary.

Several studies have investigated the theoretical stability of planetary orbits in multiple-star systems (e.g., Holman & Wiegert 1999; Benest & Gonczi 2003), deriving ratios of orbital semimajor axes of the planet and stellar companions for various values of mass ratio and eccentricity of the stellar orbits. Our work provides observational constraints based on all known exoplanets in multiple-star systems. Of the 30 confirmed exoplanets in multiple-star systems, only 3 have a ratio of stellar to planetary projected separation of less than 100. The lowest ratio is 11, for γ Cep (HD 222404). Although numerical simulations demonstrate the stability of orbits for much smaller separation ratios [e.g., for $m_2/(m_1 + m_2) = 0.5$ and $e = 0.1$, the minimum ratio of stellar and planetary orbital semimajor axes is about 4 from Holman & Wiegert 1999], no planets have yet been observed in this regime. This could be attributed to the selection effect of close binaries being excluded from planet searches, as described above. However, this could also provide evidence for protoplanetary disk truncation by a close stellar companion, preventing planet formation in systems with separation ratios close to the limits permitted by numerical simulations.

Every exoplanet system so far discovered in a multiple-star system has an S-type (satellite-type) orbit, where the planet orbits one of the stars. This is not surprising because current radial velocity searches for exoplanets exclude close binaries (e.g., Vogt et al. 2000). While the formation and stability of planets in P-type (planet-type) orbits, where a planet orbits the center of mass of a binary- or multiple-star system, have been theoretically demonstrated (Holman & Wiegert 1999; Boss 2005; Musielak et al. 2005), they have not yet been observationally supported. However, Correia et al. (2005) have raised the interesting possibility that the $2.4M_J$ outer planet around HD 202206 may in fact have formed in a circumbinary disk around the primary and the closer $17M_J$ minimum-mass object.

6.2. *Stellar Companions Might Influence Eccentricity of Planetary Orbits*

Eccentricities of exoplanet orbits are significantly higher than those of planets in our solar system (Marcy et al. 2005a). Takeda & Rasio (2005) investigated whether the Kozai mechanism can explain this entirely and concluded that other effects are also at play. We investigated the potential impact of close stellar companions on the eccentricity of planetary orbits, as these would have a greater gravitational influence on the planet's orbit and potentially reduce the period of Kozai cycles. Figure 6 shows the eccentricity of the planetary orbits as a function of the ratio of projected stellar separations to the $a \sin i$ of planetary orbits and does not conclusively demonstrate any relationship. However, even though three data points do not provide conclusive evidence, it is interesting to note that the systems with ratios under 100 have a minimum eccentricity of 0.2, while larger ratio systems have lower eccentricities.

We also looked at the relationship between period and eccentricity of planetary orbits in systems with and without stellar companions. Figure 7 shows the eccentricity of planetary orbits versus the orbital period. Planet orbits in systems with confirmed stellar companions are represented by filled squares, orbits with candidate stellar companions are represented by open squares, and orbits in single-star systems are denoted by open circles. Udry et al. (2004) and Eggenberger et al. (2004) presented similar plots and concluded that all of the planets with a period $P \lesssim 40$ days orbiting in multiple-star systems have an eccentricity smaller than 0.05, whereas longer period planets found in multiple-star systems can have larger eccentricities. Our updated results show that this conclusion is no longer strictly true. The latest planet reported around 55 Cnc, designated with suffix e, has a period of 2.81 days and an eccentricity of 0.17. Also, we report HD 38529 as a multiple-star system, which was assumed to be a single-star system in Udry et al. (2004). Planet HD 38529b has a period of 14.31 days and an eccentricity of 0.29. It appears that single-star and multiple-star planetary systems have similar period-eccentricity relationships.

7. CONCLUSIONS

Our comprehensive investigation of 131 exoplanet systems reveals that 30 (23%) of these have stellar companions, an increase from 15 reported in previous such comprehensive efforts (Eggenberger et al. 2004; Udry et al. 2004). We report new stellar companions to HD 38529 and HD 188015 and identify a candidate companion to HD 169830. Our synthesis effort, bringing together disparate databases, recognizes, for the first time, five additional stellar companions to exoplanet hosts, including one triple system. A by-product of our CPM investigation is the determination that 20 of the WDS entries for exoplanet hosts are not gravitationally bound to their "primaries" but are chance alignments in the sky. Some interesting examples in the inventory of multiple-star exoplanet systems include the following: (1) at least three and possibly five exoplanet systems are stellar triples (see § 6); (2) three systems (GJ 86, HD 41004, and γ Cep) have planets at roughly Mercury–Mars distances and potentially close-in stellar companions at projected separations similar to the distance between the Sun and Uranus ($\sim$20 AU); and (3) two systems (GJ 86 and HD 147513) have white dwarf companions. These results show that planets form and survive in a variety of stellar multiplicity environments. We hope that this compendium of stellar multiples in exoplanet systems will provide a valuable benchmark for future companion searches and exoplanet system analyses.

We wish to thank Charlie Finch and Jennifer Winters for their supporting work in this effort. We also thank G. Fritz Benedict and Jacob Bean for obtaining and reducing the radial velocity data for HD 38529B. We are grateful to Geoff Marcy and Kevin Apps for reviewing our draft and providing useful suggestions and to the anonymous referee, who provided detailed comments based on a thorough review. The photometric and spectroscopic observations reported here were carried out under the auspices of the SMARTS (Small and Moderate Aperture Research Telescope System) Consortium, which operates several small telescopes at CTIO, including the 0.9, 1.0, and 1.5 m. T. J. H.'s Space Interferometry Mission grant supported some of the work carried out here. This effort used multiepoch images from the Digitized Sky Survey, which was produced at the Space Telescope Science Institute under US Government grant NAG W-2166. This work also used data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. In addition, this work used data from the SuperCOSMOS Sky Survey, the *Hipparcos* catalog, and SIMBAD databases.

REFERENCES

Allen, C., Poveda, A., & Herrera, M. A. 2000, A&A, 356, 529
Bailey, S. I. 1900, Harvard Ann., 32, 296
Baize, P. 1957, J. des Obs., 40, 165
Balega, I., Balega, Y. Y., Maksimov, A. F., Pluzhnik, E. A., Schertl, D., Shkhagosheva, Z. U., & Weigelt, G. 2004, A&A, 422, 627
Benest, D., & Gonczi, R. 2003, Earth Moon Planets, 93, 175
Bessel, M. S. 1990, A&AS, 83, 357
Blazit, A., Bonneau, D., Koechlin, L., & Labeyrie, A. 1977, ApJ, 214, L79
Bonnarel, F., et al. 2000, A&AS, 143, 33
Boss, A. P. 2005, BAAS, 207, 84.03
Campbell, B., Walker, G. A. H., & Yang, S. 1988, ApJ, 331, 902
Cochran, W. D., Hatzes, A. P., Butler, R. P., & Marcy, G. W. 1997, ApJ, 483, 457
Cochran, W. D., Hatzes, A. P., & Hancock, T. J. 1991, ApJ, 380, L35
Correia, A. C. M., Udry, S., Mayor, M., Laskar, J., Naef, D., Pepe, F., Queloz, D., & Santos, N. C. 2005, A&A, 440, 751
Couteau, P. 1954, J. des Obs., 37, 37
Dahn, C. C., et al. 1988, AJ, 95, 237
Desidera, S., Gratton, R. G., Endl, M., Claudi, R. U., & Cosentino, R. 2004, A&A, 420, L27
Duquennoy, A., & Mayor, M. 1991, A&A, 248, 485
Eggenberger, A., Mayor, M., Naef, D., Pepe, F., Queloz, D., Santos, N. C., Udry, S., & Lovis, C. 2006, A&A, 447, 1159
Eggenberger, A., Udry, S., & Mayor, M. 2004, A&A, 417, 353
Els, S. G., Sterzik, M. F., Marchis, F., Pantin, E., Endl, M., & Kürster, M. 2001, A&A, 370, L1
Fischer, D. A., Marcy, G. W., Butler, R. P., Vogt, S. S., & Apps, K. 1999, PASP, 111, 50
Fischer, D. A., & Valenti, J. 2005, ApJ, 622, 1102
Frink, S., Mitchell, D. S., Quirrenbach, A., Fischer, D. A., Marcy, G. W., & Butler, R. P. 2002, ApJ, 576, 478
Gatewood, G., Han, I., & Black, D. C. 2001, ApJ, 548, L61
Gliese, W. 1969, Veröff. Astron. Rech.-Inst. Heidelberg, 22, 1
Gliese, W., & Jahreiss, H. 1979, Bull. Cent. Donnees Stellaires, 16, 92
———. 1991, The Astronomical Data Center CD-ROM: Selected Astronomical Catalogs, Vol. 1, ed. L. E. Brotzmann & S. E. Gesser (Greenbelt: NASA GSFC)
Graham, J. A. 1982, PASP, 94, 244
Gray, R. O., Corbally, C. J., Garrison, R. F., McFadden, M. T., & Robinson, P. E. 2003, AJ, 126, 2048
Griffin, R. F., Carquillat, J.-M., & Ginestet, N. 2002, Observatory, 122, 90
Halbwachs, J. L. 1986, A&AS, 66, 131
Halbwachs, J. L., Mayor, M., Udry, S., & Arenou, F. 2003, A&A, 397, 159
Hale, A. 1994, AJ, 107, 306
Hambly, N. C., Henry, T. J., Subasavage, J. P., Brown, M. A., & Jao, W. 2004, AJ, 128, 437
Hambly, N. C., Irwin, M. J., & MacGillivray, H. T. 2001a, MNRAS, 326, 1295
Hambly, N. C., et al. 2001b, MNRAS, 326, 1279
Hartkopf, W. I., & McAlister, H. A. 1984, PASP, 96, 105
Hartkopf, W. I., et al. 2000, AJ, 119, 3084
Hatzes, A. P., Cochran, W. D., Endl, M., McArthur, B., Paulson, D. B., Walker, G. A. H., Campbell, B., & Yang, S. 2003, ApJ, 599, 1383
Henry, T. J., Subasavage, J. P., Brown, M. A., Beaulieu, T. D., Jao, W., & Hambly, N. C. 2004, AJ, 128, 2460
Henry, T. J., Walkowicz, L. M., Barto, T. C., & Golimowski, D. A. 2002, AJ, 123, 2002
Hog, E., Kuzmin, A., Bastian, U., Fabricius, C., Kuimov, K., Lindegren, L., Makarov, V. V., & Roeser, S. 1998, A&A, 335, L65
Holden, F. 1966, Publ. Univ. Michigan Obs., 9, 185
Holman, M. J., & Wiegert, P. A. 1999, AJ, 117, 621
Hough, G. W. 1887, Astron. Nachr., 116, 273
Jacoby, G. H., Hunter, D. A., & Christian, C. A. 1984, ApJS, 56, 257
Jessup, M. K. 1955, Publ. Univ. Michigan Obs., 11, 1
Jonckheere, R. 1911, MNRAS, 72, 45
———. 1917, MmRAS, 61, 1
———. 1944, J. des Obs., 27, 11

Landolt, A. U. 1992, AJ, 104, 340
Lepine, S., & Shara, M. M. 2005, AJ, 129, 1483
Lowrance, P. J., Kirkpatrick, J. D., & Beichman, C. A. 2002, ApJ, 572, L79
Luhman, K. L., & Jayawardhana, R. 2002, ApJ, 566, 1132
Luyten, W. J. 1978, Univ. Minnesota Proper Motion Survey 50
———. 1979, New Luyten Catalogue of Stars with Proper Motions Larger than Two Tenths of an Arcsecond (NLTT) (Minneapolis: Univ. Minnesota)
Marcy, G., Butler, R. P., Fischer, D., Vogt, S., Wright, J. T., Tinney, C. G., & Jones, H. R. A. 2005a, Prog. Theor. Phys. Suppl., 158, 24
Marcy, G. W., Butler, R. P., Fischer, D. A., Laughlin, G., Vogt, S. S., Henry, G. W., & Pourbaix, D. 2002, ApJ, 581, 1375
Marcy, G. W., Butler, R. P., Vogt, S. S., Fischer, D. A., Henry, G. W., Laughlin, G., Wright, J. T., & Johnson, J. A. 2005b, ApJ, 619, 570
Marcy, G. W., & Moore, D. 1989, ApJ, 341, 961
Mason, B. D., Hartkopf, W. I., Holdenried, E. R., & Rafferty, T. J. 2001, AJ, 121, 3224
Mason, B. D., Henry, T. J., Hartkopf, W. I., Ten Brummelaar, T., & Soderblom, D. R. 1998, AJ, 116, 2975
Mason, B. D., et al. 1999, AJ, 117, 1890
Mayor, M., Udry, S., Naef, D., Pepe, F., Queloz, D., Santos, N. C., & Burnet, M. 2004, A&A, 415, 391
McAlister, H. A. 1978, PASP, 90, 288
McAlister, H. A., Hartkopf, W. I., Hutter, D. J., & Franz, O. G. 1987a, AJ, 93, 688
McAlister, H. A., Hartkopf, W. I., Hutter, D. J., Shara, M. M., & Franz, O. G. 1987b, AJ, 93, 183
McCarthy, J. K., Sandiford, B. A., Boyd, D., & Booth, J. 1993, PASP, 105, 881
Mugrauer, M., & Neuhäuser, R. 2005, MNRAS, 361, L15
Mugrauer, M., Neuhäuser, R., Mazeh, T., Alves, J., & Guenther, E. 2004a, A&A, 425, 249
Mugrauer, M., Neuhäuser, R., Mazeh, T., Guenther, E., & Fernández, M. 2004b, Astron. Nachr., 325, 718
Mugrauer, M., Neuhäuser, R., Seifahrt, A., Mazeh, T., & Guenther, E. 2005, A&A, 440, 1051
Musielak, Z. E., Cuntz, M., Marshall, E. A., & Stuit, T. D. 2005, A&A, 434, 355
Naef, D., et al. 2001, A&A, 375, L27
———. 2003, A&A, 410, 1051
Nidever, D. L., Marcy, G. W., Butler, R. P., Fischer, D. A., & Vogt, S. S. 2002, ApJS, 141, 503
Noyes, R. W., Jha, S., Korzennik, S. G., Krockenberger, M., Nisenson, P., Brown, T. M., Kennelly, E. J., & Horner, S. D. 1997, ApJ, 487, L195
Oppenheimer, B. R., Golimowski, D. A., Kulkarni, S. R., Matthews, K., Nakajima, T., Creech-Eakman, M., & Durrance, S. T. 2001, AJ, 121, 2189
Patience, J., et al. 2002, ApJ, 581, 654
Perryman, M. A. C., et al. 1997, The *Hipparcos* and Tycho Catalogues (ESA SP-1200; Noordwijk: ESA)
Pourbaix, D., & Arenou, F. 2001, A&A, 372, 935
Poveda, A., Herrera, M. A., Allen, C., Cordero, G., & Lavalley, C. 1994, Rev. Mex. AA, 28, 43
Queloz, D., et al. 2000, A&A, 354, 99
Reffert, S., & Quirrenbach, A. 2006, A&A, 449, 699
Reid, I. N., Kilkenny, D., & Cruz, K. L. 2002, AJ, 123, 2822
Ryan, S. G. 1992, AJ, 104, 1144
See, T. J. J. 1897, Astron. Nachr., 142, 43
Smyth, W. H. 1844, Cycle of Celestial Objects (London: J. W. Parker)
Soulie, G. 1985, A&AS, 61, 17
Takeda, G., & Rasio, F. A. 2005, ApJ, 627, 1001
Tokovinin, A. A., Griffin, R. F., Balega, Y. Y., Pluzhnik, E. A., & Udry, S. 2000, Astron. Lett., 26, 116
Turner, N. H., Brummelaar, T. A. t., McAlister, H. A., Mason, B. D., Hartkopf, W. I., & Roberts, L. C. 2001, AJ, 121, 3254
Udry, S., Eggenberger, A., Mayor, M., Mazeh, T., & Zucker, S. 2004, Rev. Mex. AA Conf. Ser., 21, 207
Urban, S. E., Corbin, T. E., Wycoff, G. L., Martin, J. C., Jackson, E. S., Zacharias, M. I., & Hall, D. M. 1998, AJ, 115, 1212
van Altena, W. F., Lee, J. T., & Hoffleit, E. D. 1995, Yale Trigonometric Parallaxes (4th ed.; New Haven: Yale Univ. Obs.)
Van Biesbroeck, G. 1960, Publ. Yerkes Obs., 9, Pt. 2, 1960
van den Bos, W. H. 1949, Union Obs. Circ., 5, 312
———. 1960, Publ. Yerkes Obs., 9, Pt. 1, 1960
———. 1963, AJ, 68, 582
Vanderdonck, J. 1911, MNRAS, 72, 45
Vogt, S. S., Marcy, G. W., Butler, R. P., & Apps, K. 2000, ApJ, 536, 902
Wegner, G. 1973, MNRAS, 163, 381
Wilson, J. C., Kirkpatrick, J. D., Gizis, J. E., Skrutskie, M. F., Monet, D. G., & Houck, J. R. 2001, AJ, 122, 1989
Wilson, R. E. 1953, General Catalogue of Stellar Radial Velocities (Washington, DC: Carnegie Inst. Washington)
Zacharias, N., Urban, S. E., Zacharias, M. I., Wycoff, G. L., Hall, D. M., Monet, D. G., & Rafferty, T. J. 2004, AJ, 127, 3043
Zucker, S., & Mazeh, T. 2001, ApJ, 562, 549
Zucker, S., Mazeh, T., Santos, N. C., Udry, S., & Mayor, M. 2003, A&A, 404, 775
———. 2004, A&A, 426, 695
Zucker, S., et al. 2002, ApJ, 568, 363