10-2002

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Recommended Citation

Elliott P. Horch et al 2002 AJ 124 2245 <https://doi.org/10.1086/342543>

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SPECKLE OBSERVATIONS OF BINARY STARS WITH THE WIYN TELESCOPE. III. A PARTIAL SURVEY OF A, F, AND G DWARFS¹

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Received 2002 May 13; accepted 2002 June 25

ABSTRACT

Two hundred thirty nearby main-sequence stars with spectral types in the range of A to G have been observed by way of speckle interferometry using the WIYN 3.5 m telescope at Kitt Peak, Arizona. The stars had no previous mention of duplicity in the literature. Of those observed, 14 showed clear evidence of a companion, and 63 were classified as suspected nonsingle based on a power spectrum analysis. The remaining stars discussed show no evidence of duplicity to the limit of the detection system in high-quality observations.

Key words: astrometry — binaries: visual — techniques: interferometric

1. INTRODUCTION

Although a speckle survey has been completed on a large sample of bright ($5.0 < V < 6.5$) stars (McAlister et al. 1987, 1989, 1993), field stars in the magnitude range 6.5–9 have not been uniformly surveyed for duplicity yet are prime targets for speckle interferometry. Several surveys of specialized groups of stars have been completed, however, such as high-velocity stars (Lu et al. 1987), open cluster stars (Mason et al. 1993a, 1993b; Patience et al. 1998, 2002), Be stars (Mason et al. 1997), star-forming regions (Ghez, Neugebauer, & Matthews 1993; Leinert et al. 1993), white dwarfs (McAlister et al. 1996), O stars (Mason et al. 1998), Wolf-Rayet stars (Hartkopf et al. 1999), and λ Bootis stars (Marchetti, Faraggiana, & Bonifacio 2001). Together, these surveys have provided important information on binary statistics, as well as binary formation and evolution issues.

With the publication of the final *Hipparcos* Catalogue (ESA 1997), improved distances now exist to nearby stars. If a set of solar-type *Hipparcos* stars were to be identified as true binaries, they would probably have reasonably short periods, allowing for precise orbit determination within the next couple of decades. This information could then be used to refine the empirical mass-luminosity relation (MLR), for example, which is in need of improvement, especially in the mass range of 1.0 – $0.2 M_{\odot}$ (Henry & McCarthy 1993; Henry et al. 1999). This is due to the fact that many stars contributing to this region of the MLR are visual and speckle binaries, whose mass estimates are dominated by parallax

uncertainty, even post-*Hipparcos*. However, in view of further improvements in the distances to these systems that are likely from missions such as the *Space Interferometry Mission* (SIM) and the *Global Astrometric Interferometer for Astrophysics*, the promise for substantial improvements in the MLR in the next two decades is high.

Nearby solar-type stars were considered for the makeup of the astrometric grid for the SIM, although it now appears that most grid stars will be giants that are much farther away (nominally 1 kpc). Nonetheless, duplicity surveys of nearby stars have some utility with regard to SIM in yielding information of the binary statistics of the types of stars that are the progenitors of the giants like those to be used in the grid, as well as providing a sample of secondary candidate grid stars, which could contribute to the performance of the satellite pointing at some level. Another potential use of the objects unresolved in our study would be as science targets for planet searches with SIM or future NASA missions such as the planned *Terrestrial Planet Finder*.

Horch et al. (1999, hereafter Paper I; 2002, hereafter Paper II) demonstrated the basic capabilities of a fast read-out CCD camera used as a speckle imaging device at the WIYN telescope. In this paper, we report results of speckle observations of a sample of stars in the distance range of 150–250 pc and in the spectral range A to G, none of which had previous indications of close (i.e., subarcsecond) companions in the literature.

2. OBSERVATIONS AND DATA REDUCTION

Observations were carried out at the WIYN 3.5 m telescope at Kitt Peak, Arizona. As discussed in Papers I and II, the speckle camera consists of a front-illuminated Photometrics CCD camera with a 2033×2044 Kodak KAF-4200 chip and a speckle optics package on loan from J. G. Timothy of Nightsen, Inc. The readout electronics for this system operates at a rate of $500 \text{ kpixel s}^{-1}$, and the method of obtaining small-format (128×90 pixels) speckle frames

¹ The WIYN Observatory is a joint facility of the University of Wisconsin–Madison, Indiana University, Yale University, and the National Optical Astronomy Observatory.

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with the device was the strip method of Horch, Ninkov, & Slawson (1997). A typical observation for the survey described here was a sequence of 700 frames, stored as a stack of approximately 70 strips, with each strip containing eight to 12 images. The strips were then further separated into 128×90 pixel images, each containing one speckle pattern. The observations were obtained during several runs spanning the time frame 1998 December to 2000 October, and the large majority were obtained in subarcsecond seeing conditions.

Analysis of the individual speckle images was carried out as described in Paper I. The technique is based on a study of the spatial frequency power spectrum for each object deconvolved with that of a point source observed close in time and near to the target on the sky. Such calibration point sources are selected from the *Bright Star Catalogue* (Hoffleit & Jaschek 1982). In the case of a binary star, the deconvolved power spectrum will exhibit a fringe pattern where the spacing and orientation of the fringes is related to the separation and position angle of the two stars on the image plane. In the case of an unresolved star, no such pattern is found, and the deconvolved power spectrum should, in principle, be flat out to the diffraction limit of the power spectrum. Rudimentary reconstructed images were also made using two near-axis subplanes of the image bispectrum and studied for all objects discussed here. These images were useful in confirming the power spectrum result and resolving the quadrant ambiguity inherent in the power-spectrum approach for discovered components.

As stated earlier, the target list is a subset of potential *SIM* astrometric grid candidates. At the time of selection, it was unclear if *SIM* would use faint, distant grid stars or nearby, bright ones. The bright grid stars would allow a variety of techniques to be used to uncover duplicity, including speckle interferometry, long baseline optical interferometry, CMOS observations (see, e.g., Winter 2000), Fourier transform spectroscopy (FTS), and the utilization of historical observations (Mason et al. 1999). Each works best on brighter objects; this drove the magnitude selection criterion to $6.5 < V < 8.5$, where the lower bound (bright end) was set by the *SIM* program and the upper bound would allow enough stars for a uniform grid of about 7000 objects. One technique (the FTS) works best if there are many spectral lines, so early-type stars were avoided. The final selection criteria were A5–K5 class V with variability less than 0.1 mag and no historical data indicating duplicity. A spatially uniform list was made with priority given to those stars already having at least one large aperture speckle or optical interferometric observation. The WIYN list originally consisted of stars of any allowable spectral classification with a magnitude fainter than 8.25. However, as the *SIM* project evolved to place a higher emphasis on G dwarfs, the magnitude restriction was dropped but a G dwarf spectral type restriction was put in place. The final WIYN target list was composed of main-sequence stars with spectral types in the range of A5–G2 and within approximately 250 pc from the Sun. The very great majority of the stars observed fit these criteria. A more detailed explanation of the construction of the full target list and an overview of the observing programs was discussed by Urban et al. (1999).

For the part of the project discussed here, a total of over 500 observations were divided into four basic groups in the analysis phase: (1) single to the detection limit (unresolved), if the object showed no evidence of duplicity in a high-

quality observation as defined below; (2) suspected non-single, if the object showed evidence of power spectrum irregularities, that is, features potentially consistent with duplicity but inconclusive in nature; (3) double, if the object showed clear evidence of binary fringes; and (4) no result claimed, if the observation was not high enough in quality to make a definitive statement to the detection limit. We desired the results reported here to be of the highest possible quality, so a signal-to-noise ratio of 3 at half the Nyquist frequency was required for inclusion in the “unresolved” category. This limit is intentionally conservative so as to provide a list of stars with the highest chance of being single and limits the observations reported here to approximately half of the total taken. Of course, even this criterion does not guarantee that a star is single, because detection capabilities impose limitations on the magnitude difference and total magnitude that can be successfully measured as discussed below, and because it is possible for the orbital geometry to be such that even an easily resolved system may be below the diffraction limit during the epoch of observation.

3. RESULTS

Of the stars observed, 153 were high enough in quality to be classified as unresolved, and 63 were classified as suspected nonsingle. Of these, five objects observed twice had one observation resulting in a determination of “unresolved” and one resulting in a determination of “suspected nonsingle.” Fourteen stars were classified as double. The remainder fell into category 4 described above and therefore are not reported. The results for the other three categories are displayed in Tables 1–3. Table 1 shows observations of stars in category 1 (unresolved), for which the column headings are (1) the Durchmusterung number (BD in all cases here); (2) the HD number; (3) the *Hipparcos* or Tycho Catalogue number; (4) the right ascension and declination in J2000.0 coordinates; (5) the *V* magnitude of the target; (6) the observation date in fraction of the Besselian year; (7) the center wavelength of the filter used to make the observation, in nanometers; and (8) the full width at half maximum of the filter passband, also in nanometers. Table 2 shows the suspected nonsingle stars, for which the column headings are identical to Table 1. Five objects observed twice have one entry in Table 1 and the other in Table 2. While a lower quality observation could produce a spurious “suspected nonsingle” result, it is also possible that orbital motion of a companion with separation below the diffraction limit might cause a “suspected nonsingle” result during the portion of the orbit with relatively large separation and a “single” result during the portion of relatively small separation. We suggest that the overall conclusion for these objects at the moment must therefore be that they are suspected nonsingle pending future observations.

Table 3 shows the 14 objects resolved as doubles in our survey; the discoverer designation of Yale-RIT (YR) 19 through 32 is given here. In this case, the column headings are (1) the Durchmusterung number (BD in all cases); (2) the discoverer designation; (3) the HD number; (4) the *Hipparcos* or Tycho Catalogue number; (5) the right ascension and declination in J2000.0 coordinates, (6) the system *V* magnitude; (7) the observation date in fraction of the Besselian year; (8) the observed position angle (θ), in degrees, with north through east defining the positive sense of θ ; (9) the observed separation (ρ) in arcseconds; (10) the

TABLE 1
STARS SHOWING NO EVIDENCE OF DUPLICITY IN HIGH-QUALITY OBSERVATIONS

DM (1)	HD (2)	HIP or TYC (3)	α, δ (J2000.0) (4)	V (5)	Date (6)	λ (nm) (7)	$\Delta\lambda$ (nm) (8)
BD +43°4627.....	72	474	00057+4428	8.36	1999.8854	503	40
BD +54°1.....	299	641	00079+5535	7.82	2000.7591	648	41
BD +47°17.....	652	889	00109+4807	8.41	1999.8854	503	40
BD +43°28.....	949	1125	00140+4431	8.40	1999.8854	503	40
BD +56°78.....	2907	2591	00329+5711	8.22	1999.0174	648	41
BD +49°123.....	2931	2602	00331+5030	8.38	1999.0174	648	41
BD +54°120.....	3410	2955	00375+5514	7.60	2000.7591	648	41
BD +45°199.....	4406	3662	00469+4622	7.48	2000.7619	503	40 ^a
BD +51°149.....	4535	3742	00480+5217	8.48	1999.0174	648	41
BD +39°198.....	5065	4127	00529+4015	6.76	2000.7619	503	40
BD +41°163.....	5285	4307	00552+4215	8.25	1999.0173	648	41
BD +51°188.....	5372	4393	00563+5229	7.53	2000.7646	503	40
BD +53°211.....	6250	5016	01043+5412	6.84	2000.7646	503	40
BD +44°252.....	6873	5466	01100+4545	8.45	1999.5686	648	41
BD +25°197.....	7352	5777	01141+2550	8.35	2000.7674	648	41
BD +11°169.....	8068	6251	01202+1147	8.43	1999.0118	648	41
BD −1°219.....	9958	7549	01373+0021	7.08	2000.7649	648	41
BD −7°268.....	10008	7576	01376−0646	7.66	2000.7648	648	41
BD +45°404.....	10086	7734	01396+4553	6.60	2000.6200	503	40
BD +16°204.....	10995	8399	01483+1701	7.35	2000.6173	503	40
BD +21°242.....	11014	8418	01486+2224	8.30	1999.0146	648	41
BD +5°249.....	11271	8587	01509+0632	8.45	2000.7649	648	41
BD −2°311.....	11505	8798	01531−0120	7.43	2000.7649	648	41
BD +21°250.....	11465	8802	01531+2159	8.21	1999.0146	648	41
BD +20°314.....	11974	9159	01579+2122	8.30	1999.0119	648	41
BD +17°291.....	12019	9193	01584+1816	8.36	1999.8830	648	41
BD +21°267.....	12355	9454	02016+2238	8.45	1999.8830	648	41
BD +23°285.....	12846	9829	02065+2420	6.89	2000.7593	503	40
BD +22°312.....	13364	10201	02112+2313	8.33	1998.9246	648	41
					1999.0119	648	41
BD +32°417.....	14275	10823	02193+3336	8.21	1999.0093	648	41 ^a
BD +40°513.....	14983	11344	02259+4054	8.37	1999.8856	648	41
BD +42°546.....	15753	11873	02332+4254	7.15	2000.6201	503	40
					2000.7621	648	41
BD +3°359.....	16086	12034	02352+0407	8.15	2000.7649	648	41
BD −4°426.....	16141	12048	02353−0334	6.83	2000.7649	648	41
BD +41°496.....	16175	12191	02370+4204	7.28	2000.6201	503	40
					2000.7621	648	41
BD +7°411.....	16707	12505	02409+0814	8.44	1999.0120	648	41
BD +39°634.....	17248	2849 00943 1	02474+3955	8.42	1999.8856	648	41
BD +35°583.....	17841	13438	02530+3538	8.38	1999.8885	648	41
BD +49°836.....	18916	14300	03044+5002	7.99	2000.6201	503	40
					2000.7594	503	40
BD +31°534.....	19103	14370	03054+3206	8.06	2000.7676	503	40
BD +59°708.....	23074	17540	03454+6021	8.02	2000.7595	648	41
BD +54°713.....	23674	17901	03497+5443	8.21	1999.0175	648	41
BD +0°675.....	24552	18261	03544+0116	7.97	2000.7623	648	41
BD +24°605.....	25065	1817 00439 1	03599+2441	8.29	1999.6289	648	41
BD +7°667.....	28993	21304	04344+0811	8.32	1999.0122	648	41
BD +52°861.....	29192	3732 00471 1	04385+5245	8.28	1999.8859	648	41
BD +6°728.....	29462	21629	04386+0652	8.32	1999.0122	648	41
BD +51°987.....	30723	22695	04528+5133	7.87	2000.7651	503	40
BD +72°242.....	30388	22788	04541+7303	8.20	1999.0176	648	41
BD +5°765.....	31354	22889	04554+0538	8.36	1999.0122	648	41
BD +76°188.....	31814	23885	05079+7638	8.34	1999.0176	648	41
BD +69°315.....	34409	25156	05230+6924	8.44	1999.0176	648	41
BD +9°921.....	37685	26729	05408+0916	7.96	2000.1454	648	41
BD +2°1039.....	37945	0119 00390 1	05423+0236	8.28	1999.8833	648	41
BD +15°1007.....	40396	28323	05590+1519	8.16	2000.1454	648	41
					2000.7625	853	39
BD +29°1075.....	40653	1876 00470 1	06014+2935	8.43	1999.8834	648	41
BD +25°1105.....	41221	28791	06047+2511	8.46	1999.8834	648	41
BD +35°1362.....	42558	29504	06130+3521	8.24	2000.1455	648	41

TABLE 1—*Continued*

DM (1)	HD (2)	HIP or TYC (3)	α, δ (J2000.0) (4)	V (5)	Date (6)	λ (nm) (7)	$\Delta\lambda$ (nm) (8)
BD +27° 1019.....	42634	29510	06130+2726	8.39	1999.0152	648	41
BD +26° 1204.....	44452	30346	06230+2560	8.30	1999.0152	648	41
BD +52° 1085.....	45561	3765 00864 1	06312+5248	8.46	1999.8835	648	41
BD +52° 1112.....	47309	31965	06408+5159	7.60	2000.7680	503	40
BD +28° 1247.....	49365	32700	06493+2833	8.26	1999.0124	648	41
BD +60° 1001.....	48893	32725	06496+6010	8.39	1999.8835	648	41
BD +59° 1034.....	50690	3779 01189 1	06579+5913	8.37	1999.8835	648	41
BD +23° 1617.....	54294	1896 01878 1	07093+2338	8.41	1999.8835	648	41
BD +53° 1121.....	55155	35027	07147+5335	8.36	1999.0153	648	41
BD +28° 1356.....	56387	35336	07180+2829	8.40	1999.8835	648	41
BD −1° 1644.....	56652	4820 00764 1	07179−0159	8.28	1999.8836	648	41
BD +25° 1677.....	58779	36268	07281+2502	8.47	1999.8835	648	41
BD +40° 1864.....	58595	36285	07282+4039	7.39	2000.1456	503	40
BD +40° 1892.....	60234	36906	07353+4030	7.68	2000.1457	503	40
BD +49° 1645.....	60253	36975	07370+4860	8.47	1999.0153	780	31
BD +57° 1086.....	60272	37061	07370+5733	7.97	2000.1457	648	41
BD +56° 1235.....	62095	37828	07454+5608	8.42	1999.0154	780	31
BD +16° 1585.....	64628	1363 00254 1	07554+1630	8.49	1999.8836	648	41
BD +45° 1516.....	65137	39044	07593+4451	8.44	1999.0180	648	41
BD +9° 1860.....	66573	39506	08045+0916	7.26	2000.1416	648	41
BD +24° 1843.....	66485	39528	08047+2420	8.43	1999.0126	648	41
BD +37° 1831.....	67661	40026	08105+3721	8.27	1999.0154	780	31
BD +15° 1783.....	68438	0806 00208 1	08130+1436	8.43	1999.8836	648	41
BD −0° 2024.....	72760	42074	08345+0044	7.32	2000.1457	648	41
BD +5° 2035.....	74156	42723	08424+0435	7.61	2000.1416	648	41
BD +33° 1776.....	75898	43674	08538+3303	8.03	2000.1458	648	41
BD +63° 806.....	75576	43696	08540+6235	8.27	1999.0180	648	41
BD +61° 1134.....	82703	47117	09361+6115	8.35	1999.0183	648	41
BD +53° 1356.....	83905	47670	09432+5307	8.49	1999.0128	648	41
BD +59° 1260.....	84142	47840	09451+5826	8.45	1999.0128	648	41
BD +58° 1220.....	85472	48537	09540+5741	7.45	2000.1461	503	40
BD +45° 1802.....	87679	49632	10078+4508	8.29	1999.0128	648	41
BD +57° 1259.....	88828	50314	10164+5646	8.47	1999.0128	648	41
BD +52° 1473.....	89251	50513	10190+5124	6.81	2000.1461	503	40
BD +35° 2146.....	90681	51312	10289+3453	7.83	2000.1405	503	40
BD +68° 611.....	91255	51729	10342+6731	8.36	1999.0157	648	41
BD +60° 1279.....	92320	52278	10409+5921	8.38	1999.0157	648	41
BD +48° 1889.....	92786	52470	10436+4813	8.02	2000.1461	503	40
BD +64° 814.....	94176	53256	10535+6333	8.01	2000.1461	503	40
BD +60° 1299.....	94880	53634	10584+5917	8.16	2000.1462	503	40
BD +57° 1307.....	96232	54312	11067+5703	8.41	1999.0157	648	41
BD +54° 1421.....	96689	54501	11090+5409	8.10	2000.1462	503	40
BD +19° 2426.....	97227	54683	11117+1842	8.24	1999.0129	648	41
BD +59° 1353.....	97140	54687	11117+5854	7.35	2000.1462	503	40
BD +54° 1450.....	100667	56526	11354+5334	8.05	2000.1462	503	40
BD +15° 2352.....	100809	56597	11362+1442	8.26	1999.0158	648	41
BD +48° 1964.....	102158	57349	11455+4740	8.06	2000.1462	503	40
BD +25° 2445.....	104076	58454	11592+2438	8.39	2000.1462	503	40
BD +43° 2186.....	105247	59092	12071+4240	8.46	1999.0158	648	41
BD +47° 1935.....	106056	59493	12120+4636	8.31	1999.0158	648	41
BD +31° 2343.....	106366	59666	12141+3049	8.25	1999.0158	648	41
BD +28° 2095.....	106678	59824	12160+2803	8.28	1999.0103	648	41
					1999.0184	648	41
BD +53° 1547.....	108271	60678	12261+5241	8.31	1999.0185	648	41
BD +27° 2150.....	109415	61355	12344+2617	8.31	1999.0103	648	41
BD +23° 2492.....	111154	62384	12471+2237	8.38	1999.0103	648	41
					1999.0185	648	41
BD +7° 2588.....	112099	62942	12539+0646	8.24	1999.0104	648	41
BD +33° 2296.....	113319	63636	13026+3226	7.51	2000.1463	648	41
BD +36° 2354.....	115349	64747	13162+3553	8.29	2000.1463	648	41
BD +36° 2382.....	117858	66051	13325+3602	7.96	2000.1463	648	41
BD +33° 2349.....	118051	66175	13338+3220	7.81	2000.1464	648	41
BD +44° 2312.....	121825	68134	13569+4417	7.65	2000.1464	648	41
BD +34° 3708.....	187123	97336	19470+3425	7.83	2000.7667	648	41

TABLE 1—*Continued*

DM (1)	HD (2)	HIP or TYC (3)	α, δ (J2000.0) (4)	V (5)	Date (6)	λ (nm) (7)	$\Delta\lambda$ (nm) (8)
BD +23°3847.....	189067	98206	19573+2405	7.19	2000.7641	503	40
BD +15°4026.....	190067	98677	20026+1536	7.15	2000.6167	503	40
					2000.7640	503	40
BD +16°4149.....	191066	99128	20075+1701	7.62	2000.7641	503	40 ^a
BD +50°2989.....	191649	99241	20087+5035	7.40	2000.6167	648	41
					2000.7669	503	40
BD +35°4179.....	196361	101614	20356+3629	8.24	2000.7641	503	40
BD +35°4311.....	199100	103131	20537+3608	7.78	2000.7641	503	40
BD +34°4383.....	203246	105335	21202+3536	8.22	2000.7641	503	40
BD -2°5561.....	204951	106325	21321-0133	8.26	1999.8851	648	41
BD +28°4161.....	206332	107040	21407+2845	7.41	2000.7644	503	40 ^a
BD +26°4237.....	206374	107070	21411+2645	7.45	2000.7644	503	40
BD +40°4658.....	207954	107918	21519+4139	8.37	2000.7643	503	40
BD +9°4939.....	208669	108408	21577+1026	7.30	2000.7672	503	40
BD +23°4433.....	208729	2203 02113 1	21578+2343	8.45	1999.6394	503	40
BD +43°4116.....	209393	108774	22021+4421	7.96	2000.7644	503	40
BD +24°4537.....	210120	109224	22076+2501	8.32	1999.8852	648	41
BD +20°5106.....	211180	109858	22150+2117	8.24	2000.7644	503	40
BD +39°4792.....	211275	109881	22153+3947	7.59	2000.7616	648	41 ^a
BD +19°4922.....	...	110771	22265+2018	8.43	1999.6395	503	40
BD +20°5174.....	213423	111130	22308+2101	8.30	1999.6395	503	40
BD +18°5023.....	214808	111935	22404+1928	8.42	1999.6395	503	40
BD +41°4624.....	216240	112810	22507+4200	8.36	1999.8826	648	41
BD +43°4325.....	216450	112937	22524+4417	8.33	1999.8826	648	41
BD +39°4959.....	216574	3219 03139 1	22535+4016	8.37	1999.8826	648	41
BD +48°3879.....	216783	113177	22551+4928	7.87	2000.7672	648	41
BD +39°4995.....	217800	113804	23028+3953	8.36	1999.8826	648	41
BD +38°4956.....	219170	114657	23136+3915	8.35	1999.8826	648	41
BD +40°5057.....	220285	115375	23223+4119	8.37	1999.8827	503	40
BD -2°5951.....	220554	115572	23246-0144	7.54	2000.7645	648	41
BD +35°5028.....	220845	115734	23268+3606	8.44	2000.7673	648	41
BD -1°4443.....	221146	115951	23295-0102	6.88	2000.7645	648	41
BD +53°3193.....	221712	4000 00151 1	23342+5404	8.34	1999.5685	648	41
BD +29°4971.....	222033	116542	23371+3041	7.21	2000.7673	648	41
BD +40°5119.....	222219	116668	23386+4058	8.37	1999.8854	503	40
BD +2°4718.....	223374	117463	23490+0311	8.38	2000.7645	648	41
BD +42°4777.....	223635	117620	23513+4330	8.33	1999.8854	503	40
BD +36°5126.....	223848	117762	23529+3657	6.52	2000.7591	648	41
BD +40°5179.....	224141	3237 00608 1	23554+4105	8.49	1999.8854	503	40
BD +49°4291.....	224465	118162	23581+5027	6.72	2000.6171	503	40

^a Another observation of this object is reported in Table 2.

center wavelength of the filter used to make the observation, in nanometers; and (11) the full width at half-maximum of the filter passband, also in nanometers. The position angles have not been corrected for precession and are appropriate for the epoch of observation shown. Position angles and separations are shown without uncertainties, but a reasonable uncertainty estimate for any measure shown may be obtained from the discussion in Paper II on measurement precision. In general, position angle measurements with our system are made with a precision of approximately 1° and separation measures with a precision of 3 mas, although these figures will vary depending on magnitude, separation, and other factors, as explained in Paper II. Because of the large format of the CCD used and the details of the strip method of acquiring speckle data, there is a small possibility that a large separation component that lands on the chip but outside the strip could be aliased to a subarcsecond separation. However, no such companions were noted while examining short full-frame exposures of the targets during

the observations, and the closest companions to any of the systems in Table 3 listed in the SIMBAD database are approximately $2''$ away from the targets here. These wide components would therefore be safely off the CCD active area. The speckle instrument has a field of view of approximately $30'' \times 60''$; half of the active area is masked off for speckle observations.

Although the measures in Table 3 do not include estimates of the magnitude difference of each system, it is possible to derive these from the power spectrum analysis in addition to the astrometry. For the systems described here, the raw magnitude differences spanned a range from 0.0 to 3.7 mag. Because of the opportunity to better characterize the photometric precision with a large sample of observations, magnitude differences for these 14 systems will be presented in a future publication devoted to speckle photometry at WIYN (Horch, Meyer, & van Altena 2002). Observations that led to an ambiguous quadrant determination for the secondary are noted in Table 3. Generally, these

TABLE 2
SUSPECTED NONSINGLE STARS

DM (1)	HD (2)	HIP or TYC (3)	α, δ (J2000.0) (4)	V (5)	Date (6)	λ (nm) (7)	$\Delta\lambda$ (nm) (8)
BD +16°3.....	483	759	00093+1732	7.07	2000.6144	648	41
					2000.7646	503	40
BD +45°199.....	4406	3662	00469+4622	7.48	2000.6144	648	41 ^a
BD +37°259.....	8100	6309	01211+3802	7.83	2000.6200	503	40
BD +3°215.....	9537	7281	01338+0346	8.26	1999.8883	648	41
BD +11°207.....	9986	7585	01377+1205	6.77	2000.6173	503	40
BD +55°434.....	11417	3688 01817 1	01539+5611	8.39	1999.8911	648	41
BD +22°287.....	11850	9073	01568+2303	7.85	2000.7593	503	40
BD -3°300.....	12356	9423	02011-0230	7.84	2000.7649	648	41
BD +48°635.....	13759	10519	02155+4913	8.36	2000.7621	648	41
BD +11°309.....	13997	10599	02165+1223	7.99	2000.7676	503	40
BD -4°374.....	14264	10746	02183-0406	8.46	1999.8830	648	41
BD +32°417.....	14275	10823	02193+3336	8.21	1998.9246	648	41 ^a
BD +63°330.....	14719	11281	02253+6434	8.37	1999.8856	648	41
BD +19°355.....	15028	11329	02258+2017	7.85	2000.7649	648	41
BD +69°158.....	15460	11874	02332+7013	8.29	1999.8856	648	41
BD +6°405.....	16466	12323	02387+0657	8.44	1999.8830	648	41
BD +14°454.....	17009	12763	02440+1535	8.49	1999.0120	648	41
BD +10°379.....	17821	13364	0251*+1118	8.38	1999.0120	648	41
BD +24°419.....	18594	13994	03002+2515	8.48	1999.8831	648	41
BD +31°595.....	21086	15937	03252+3223	8.44	1999.6399	503	40
BD +17°638.....	24040	17960	03504+1729	7.50	2000.1453	503	40
					2000.7650	648	41
BD +32°679.....	24322	18189	03535+3307	8.30	1999.0094	648	41
BD +18°562.....	24778	1257 00562 1	03570+1850	8.49	1999.6290	648	41
BD +14°633.....	24961	18576	03586+1505	8.41	1999.6289	648	41
BD +22°626.....	25532	18995	04042+2324	8.20	1999.0094	648	41
BD +36°842.....	26396	2383 01387 1	04120+3646	8.33	1999.8913	648	41
BD +59°811.....	28578	21260	04337+5929	8.28	1999.8859	648	41
BD +56°969.....	29893	3741 00230 1	04459+5712	8.25	1999.8859	648	41
BD +15°790.....	34811	24958	05207+1538	8.24	1999.0176	648	41
BD +4°1147.....	42300	29262	06102+0443	8.45	1999.0152	648	41
BD +52°1112.....	47309	31965	06408+5159	7.60	2000.1456	503	40
BD +50°1405.....	54983	34927	07137+5034	8.29	1999.0153	648	41
BD +43°1697.....	58986	36446	07300+4333	8.45	2000.1457	503	40
BD +15°1761.....	67403	39837	08084+1451	8.26	1999.8836	648	41
BD +39°2065.....	67827	40093	08114+3844	6.61	2000.1416	648	41
BD +53°1226.....	69011	40602	08174+5256	8.43	1999.0180	648	41
BD +71°459.....	71222	41808	08314+7101	8.22	1999.0180	853	39
BD +36°1888.....	76218	43852	08559+3612	7.69	2000.1458	648	41
BD +28°1723.....	79595	1957 01400 1	09159+2753	8.49	1999.8864	648	41
BD +42°1990.....	79890	2987 01045 1	09181+4204	8.35	1999.8891	648	41
BD +23°2163.....	86312	48874	09581+2240	8.28	1999.0101	648	41
BD +41°2109.....	92075	52088	10386+4019	8.40	1998.9255	648	41
BD +17°2289.....	94291	53225	10532+1659	8.39	1999.0102	648	41
BD +52°1545.....	97178	54696	11119+5206	8.47	1999.0157	648	41
BD +49°2066.....	100485	56424	11341+4834	7.95	2000.1462	503	40
BD +25°2411.....	102161	57351	11455+2507	8.40	1999.0184	648	41
BD +22°2430.....	104452	58661	12017+2206	6.57	2000.1462	503	40
BD +25°2450.....	104603	58731	12028+2450	8.28	2000.1462	503	40
BD +47°1928.....	105237	59083	12070+4709	8.48	2000.1462	503	40
BD +19°2552.....	107087	60039	12188+1910	8.04	2000.1462	503	40
BD +14°2863.....	136618	75140	15213+1331	7.99	2000.1465	503	40
BD +40°3458.....	173024	91658	18415+4029	8.37	1999.5654	503	40
BD +16°4149.....	191066	99128	20075+1701	7.62	2000.6167	503	40 ^a
BD +51°2932.....	197666	102240	20430+5218	7.75	2000.7669	503	40
BD +7°4689.....	204173	1106 01193 1	21266+0753	8.29	1999.6391	648	41
BD +28°4161.....	206332	107040	21407+2845	7.41	2000.6196	648	41 ^a
BD +21°4663.....	209060	108618	22002+2202	8.42	1999.6395	503	40
BD +18°4913.....	209346	108793	22024+1850	8.32	1999.6395	503	40
BD +39°4792.....	211275	109881	22153+3947	7.59	2000.6170	648	41 ^a
BD +34°4645.....	211526	110017	22170+3522	8.13	2000.6170	648	41
BD +16°4906.....	219948	115185	23198+1741	8.37	1999.8907	648	41
BD +24°4777.....	220899	115787	23274+2528	7.93	2000.7645	648	41
BD +44°4475.....	222717	116983	23429+4454	8.34	1998.9270	648	41

^a Another observation of this object is reported in Table 1.

TABLE 3
SPECKLE RELATIVE ASTROMETRY MEASURES FOR NEWLY RESOLVED PAIRS

DM	Discoverer Designation	HD	HIP or TYC	α, δ (J2000.0)	V	Date	θ (deg)	ρ (arcsec)	λ (nm)	$\Delta\lambda$ (nm)
BD +43°165.....	YR 19	4901	2810 00748 1	00516+4412	8.32	1999.5686	100.7	0.071	648	41 ^a
						1999.8882	101.5	0.077	648	41
BD +40°248.....	YR 20	7205	5684	01131+4139	7.24	2000.6200	263.8	1.267	503	40
BD -4°189.....	YR 21	8234	6360	01217-0326	8.46	1999.0119	229.5	0.118	648	41
						2000.7648	51.0	0.127	648	41 ^b
BD +33°482.....	YR 22	16510	2332 01378 1	02399+3403	8.38	1999.8856	289.0	0.550	648	41
BD -02°726.....	YR 23	24031	17895	03496-0220	7.22	2000.7623	10.0	0.283	648	41
BD +14°1220.....	YR 24	43209	0743 00600 1	06156+1409	8.40	1999.8915	86.1	0.421	648	41
BD +41°1737.....	YR 25	63749	38415	07522+4109	8.30	1999.0154	354.3	0.113	780	31
BD +40°2363.....	YR 26	92903	52510	10442+3955	8.31	1999.0128	175.4	0.593	648	41
BD +14°4413.....	YR 27	197896	1634 01293 1	20462+1520	8.36	1999.6392	240.5	0.880	601	42
BD +18°4612.....	YR 28	197976	1642 01243 1	20467+1846	8.37	1999.6392	333.3	0.126	601	42 ^a
BD +48°3346.....	YR 29	203284	105290	21196+4913	7.70	2000.7641	143.1	0.268	648	41
BD +20°4977.....	YR 30	205897	106804	21379+2102	8.17	2000.7644	333.9	0.137	503	40 ^a
BD +7°4971.....	YR 31	218055	113974	23049+0753	8.40	1999.5657	41.8	0.169	648	41
BD +41°4906.....	YR 32	224416	3241 01549 1	23577+4209	8.29	1999.8854	245.5	0.185	503	40

^a Quadrant ambiguous.

^b Quadrant ambiguous and evidently inconsistent with the previous observation.

objects have smaller separations, smaller magnitude differences, or both. Signal-to-noise ratio is another factor that can lead to a lack of a definitive quadrant determination from bispectral analysis.

Figure 1 shows two examples of our rudimentary reconstructed images obtained for resolved doubles. It should be emphasized that these images are presented as an illustration of data quality only and not as meaningful irradiance maps. Only two subplanes of the image bispectrum were used in the construction of phase map in the Fourier plane, and we started with the “zero phase” assumption and iter-

ated from that point. This has the tendency of often leaving a “ghost peak” in the reconstructed image in the opposite quadrant from the true secondary location. In most cases, the amplitude of this peak is low enough that no confusion exists in the determination of the true secondary location, but it renders the photometric information suspect. The resolution of the images is also typically not diffraction-limited; we filter the reconstructed Fourier transform of the object with a low-pass Gaussian filter in order to attenuate noise. These features are in contrast to the reconstructed images that were presented in Paper II; in that work, we used many

FIG. 1.—Examples of rudimentary reconstructed images made in the process of the data analysis for two resolved double stars: (a) YR 29 (=HD 203284) and (b) YR 32 (=HD 224416). In both plots, solid contours are drawn at 0.02, 0.04, 0.06, 0.1, 0.3, and 0.5 of the maximum value in the array, and dotted contours are drawn at -0.02 and -0.01. A low “ghost peak” in the opposite quadrant from the secondary is present in both images because of the zero-phase input assumption of the reconstruction technique. The YR 29 image is one of the higher quality images obtained from the 14 resolved systems, and the YR 31 image is closer to average quality.

FIG. 2.—Binary detection capabilities of the speckle system at the WIYN telescope in terms of magnitude difference and separation of the companion. In both plots, the open circles are known binaries observed at WIYN over the same time period as the survey objects and successfully reduced. (Astrometry for these systems appears in Paper II, and in nearly all cases the Δm coordinate shown here is that appearing in the *Hipparcos* Catalogue.) The filled circles are the locations of the 14 newly discovered doubles in Table 3 (where the separation coordinate is that appearing in Table 3, and the magnitude difference is the preliminary result from the speckle analysis). (a) Objects in the V magnitude range 6.5–7.5. (b) Objects in the V magnitude range 7.5–8.5.

more subplanes in order to make a more robust phase estimate and did not use the zero-phase starting point.

Paper II also discussed detection limits of the speckle system at WIYN (particularly Fig. 7 and its description), finding that systems with magnitude differences of up to four and system magnitudes of as faint as 10 can normally be detected and reduced successfully in high-quality observations. The sample of target stars in this survey have total magnitudes in the range 6.5–8.5, well within the system magnitude limit. In Figure 2, we show the separation and magnitude difference coordinates for all known binaries resolved at WIYN over the same time frame as the survey project described here. Two magnitude bins are shown; in Figure 2a, stars with system magnitudes between 6.5 and 7.5 are shown, while in Figure 2b, stars with system magnitudes between 7.5 and 8.5 are shown. Using column (5) in Tables 1 and 2, one can easily estimate the detection limits for any object presented here. These plots no doubt contain a bias in the WIYN binary target list toward smaller magnitude differences at small separation, since there are fewer large Δm , small separation systems listed in the Washington Double Star Catalog. Nonetheless, the envelope of these points represents a conservative lower limit of detectability for companions for each magnitude bin. All stars in Table 1, if binary or multiple, would therefore have an expected separation and/or magnitude difference outside of the envelope. Similarly, any object in Table 2 that is truly binary or multiple would have an expected position near the edge of the envelope. The locations of the 16 observations listed in Table 3 are also plotted in the figures. As their locations indicate, these are detections within the limits expected for the system, with most systems near the envelope boundary.

4. DISCUSSION

These results can be compared with the earlier survey of McAlister et al. (1987, 1989, 1993), where those authors observed over 2000 objects from the Bright Star Catalogue in an attempt to determine the duplicity fraction, as well as

new candidate systems for astrophysical studies. In that work, a binary fraction of approximately 15% was seen for dwarfs regardless of spectral type, including binaries known from previous observing techniques. In the first of the three mentioned references, 39 of 426 dwarfs (i.e., luminosity class V only) were resolved for the first time via speckle, but in the third reference, some of these discoveries were then determined to be spurious. Removing these from the list, 26 dwarf doubles remain, and therefore the fraction of stars determined to be double from speckle observations was approximately 6.1%. Using the figures in our survey, we obtain the same “speckle” discovery rate of $14/230 = 6.1\%$.

Due to the selection criteria discussed in § 2, we may view the current survey as a collection of similar, albeit fainter, stars. While the range of distances was larger in the McAlister et al. sample, the average is comparable to that of the systems here, and the difference in brightness is largely due to a shift toward later spectral types in our survey. Since McAlister et al. found little variation in the binary fraction with spectral type for dwarfs, we therefore expect a similar binary fraction if the detection efficiencies are similar. The speckle camera used by those authors at the time had a limiting magnitude of approximately 8.5 at the Kitt Peak 4 m telescope, whereas the system used here has a limiting magnitude of at least 10 at WIYN and is sensitive to somewhat larger magnitude differences. In both studies, the objects in the survey were therefore 2–3 mag brighter than the detection limit, and any objects resolved because of the greater sensitivity to larger magnitude differences at WIYN may well be offset by the larger diffraction limit of the slightly smaller telescope aperture and redder filter used for many of our observations. Overall, we conclude that a similarity of discovery rate is plausible from instrumental, as well as astrophysical, considerations. If the detection efficiency is, in fact, comparable between the two studies, it may also suggest that few of the suspected nonsingle stars reported here are actually resolvable at WIYN, although more observations are needed to confirm this hypothesis.

5. CONCLUSIONS

We have reported the results of speckle observations of 230 field stars with spectral types ranging from A to G examined using CCD-based speckle interferometry at the WIYN 3.5 m telescope. Of these stars, 153 were found to have no evidence of duplicity in high-quality observations, 63 showed signatures in the power spectrum that indicated a difference from a single star power spectrum and are reported as suspected nonsingle, and 14 stars were resolved for the first time and found to be double. The remaining stars observed in the survey did not meet the quality criteria for inclusion in the group of high-quality nondetections. The discovery rate is consistent with an earlier survey on bright stars by McAlister et al.

We are grateful to J. Gethyn Timothy for continued use of the speckle optics package and to Charles Corson, David Sawyer, Wendy Shook, Gillian Rosenstein, and Eugene McDougall at Kitt Peak for their excellent assistance with the telescope, as well as the referee. This work was funded by JPL subcontract 1201846 from the Preparatory Science Program for the *Space Interferometry Mission*, and a Theodore Dunham, Jr. Grant from the Fund for Astrophysical Research. It also made use of the Washington Double Star Catalog, maintained at the US Naval Observatory, and the SIMBAD database, operated at CDS, Strasbourg, France.

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