

ICCD SPECKLE OBSERVATIONS OF BINARY STARS. I. A SURVEY FOR DUPLICITY AMONG THE BRIGHT STARS

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Received 11 April 1986; revised 21 May 1986

ABSTRACT

A survey of a sample of 672 stars from the Yale *Bright Star Catalogue* has been carried out using speckle interferometry on the 3.6 m Canada-France-Hawaii Telescope in order to establish the binary star frequency within the sample. This effort was motivated by the need for a more observationally determined basis for predicting the frequency of failure of the *Hubble Space Telescope* (HST) fine-guidance sensors to achieve guide-star lock due to duplicity. This survey of 426 dwarfs and 246 evolved stars yielded measurements of 52 newly discovered binaries and 60 previously known binary systems. While the implications for HST operations are described elsewhere, we show that the frequency of close visual binaries in the separation range 0".04–0".25 is 11%, or nearly three-and-one-half times that previously known.

I. INTRODUCTION

The frequency of binary and multiple stars has wide-ranging implications within astrophysics, and even relates to the question of the frequency of life in the universe. The observational limitations of the various techniques for discovering binary stars give rise to selection effects which, if well understood, permit reasonable estimates of the number of overlooked binary stars within a specific sample. For visual binaries, these selection effects are tied to the apparent magnitude of the binary star, the angular separation of the system, and the magnitude difference within the system. In their analysis of the *Index Catalogue of Visual Double Stars* (IDS) (Jeffers, van den Bos, and Greeby 1963), Poveda, Allen, and Parrao (1982) find that after eliminating more than one-fourth of the IDS entries as either optical or spurious pairs, it can be concluded that practically every field star is a potential visual binary. Most of these pairs remain to be discovered.

Speckle interferometry undertaken at the largest telescopes provides an extension of the methods of visual binary star astrometry routinely down to below 0".04 in angular resolution and to magnitude difference as large as 1.5–2.0 mag. Concerted efforts can increase the Δm sensitivity significantly. The accomplishments of binary star speckle interferometry prior to 1984 have been cataloged by McAlister and Hartkopf (1984). These accomplishments include the first direct resolution of some 120 bright binary stars and the accurate measurement of many previously known systems at separations difficult or impossible for other techniques. Although speckle observations have tremendous potential for discovering new pairs, no extensive survey programs exploiting this potential have been undertaken. This has been due to the limited amount of time available on large telescopes to speckle observers and to the obvious priority given to the resolution of known spectroscopic and close visual binaries for stellar mass and luminosity determinations. We report here the first systematic attempt to carry out a speckle inter-

ferometric survey for duplicity among a large sample of stars. This survey was motivated by the need for a more directly established estimate of the binary star frequency in the range of separations (0".018–0".20) for which the *Hubble Space Telescope* (HST) fine-guidance sensors would fail to achieve lock. This frequency distribution could potentially lead to significant dead time for HST when all guide-star pairs for a given field contain resolved binaries. The implications of this survey for the HST are discussed elsewhere (Shara *et al.* 1987) and we will restrict our consideration here to the purely astronomical results derived from the observations.

II. SURVEY SAMPLE AND OBSERVATIONAL RESULTS

All of the speckle measurements published prior to this paper as a result of the Georgia State University program have been based upon a photographic speckle camera employing analog techniques for data processing (McAlister 1977). The data for our new survey were obtained using the GSU ICCD speckle camera (McAlister *et al.* 1982, 1987; Hartkopf and McAlister 1986) in which speckle pictures are initially processed digitally with a hardwired vector-autocorrelator and then finally reduced and measured with a VAX 11/750-based image-processing system. The speckle camera has been used regularly at the 4 m KPNO telescope and 1.8 m Perkins telescope at the Lowell Observatory since late 1981. Approximately 2700 measurements of one thousand binary stars, including some 60 newly resolved systems, have been reduced from the data gathered to date, and a detailed discussion of these collected results is to be presented in Paper II of this series. The ICCD data gathered at KPNO between July 1982 and January 1985 were recorded on videocassette tapes and post-processed through the hardwired vector-autocorrelator. The desirability of producing vector-autocorrelograms in real time, and thereby eliminating the effects of tape noise, compressed dynamic range, etc., was realized early on in our experience with the new camera, and provision was made for this in time for the HST-related observations discussed here.

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Following experiments with potential HST guide stars (most with $V = 12\text{--}14$) at the 2.5 m Hooker telescope of Mount Wilson and Las Campanas Observatories and the 3.0 m Shane telescope of the Lick Observatory in early 1985, we decided to restrict further speckle observations to bright stars from which we could statistically extrapolate the binary frequency to HST guide stars. Experience to date has shown that speckle observations can resolve systems with combined magnitudes as faint as $V = +15$, but these have invariably been for objects which have *a priori* evidence for duplicity. The speckle measurements of the Pluto-Charon system as recently summarized by Tholen (1985) are a case of particular interest and clearly demonstrate the method's ability to measure faint double objects. Autocorrelograms or power spectra produced from speckle data for faint objects are unavoidably of lower signal-to-noise than those for bright objects and are far more subject to the interpretation of noise fluctuations as features indicative of duplicity. In principle, long integration times and subsequent confirming observations can increase the confidence of a discovery, but both require a significant increase in the investment of telescope time. The reliability of speckle interferometry in discovering faint binary stars thus remains to be established, although we believe that great potential exists in this area. On the other hand, speckle interferometry has now provided the first direct resolution of nearly 200 binary stars (McAlister and Hartkopf 1984; McAlister *et al.* 1987), most of which have been confirmed by subsequent observation. Only a few spurious cases of resolution are indicated by lack of confirmation, and most of these might be the result of closure below resolution limits at the epochs of subsequent observations rather than outright errors in interpreting speckle autocorrelograms.

The sample of stars used in defining the survey was obtained by selecting all stars from the Yale *Bright Star Catalogue* (BSC) (Hoffleit 1982) with equatorial coordinates ranging from 15^{h} to 23^{h} in right ascension and -20° to $+60^{\circ}$ in declination along with a visual-magnitude constraint such that $5.0 < V < 6.5$ (BSC limit). The positional constraints ensured that all objects observed would be within 40° of the zenith of Mauna Kea during the scheduled observing. Complete compensation for atmospheric dispersion using the Risley prisms in the GSU speckle camera requires zenith angles no larger than approximately 60° . The survey-sample results are thus free of dispersion effects that might otherwise mimic duplicity. These criteria resulted in 1191 stars, or 13% of the BSC, as candidate objects for the survey. No selection criteria involving prior knowledge of duplicity were imposed, and all data were reduced blindly with respect to existing visual micrometer or speckle results for any of the visual binary stars that happened to be observed. As will be discussed in Sec. III, we emphasized the observations of dwarf over giant stars in this candidate sample in order to have a distribution of luminosity classes more closely related to that expected for faint HST guide stars.

Speckle observations were obtained on the four nights of 7–10 July 1985 UT using the GSU ICCD speckle camera at the Cassegrain focus of the 3.6 m Canada-France-Hawaii telescope on Mauna Kea. Seeing conditions were generally excellent with FWHM seeing disks estimated to be typically less than $0''.7$, occasionally less than $0''.5$, and only $2''.0$ under the worst seeing conditions encountered during part of the night of 8 July 1985 UT when occasional cirrus clouds appeared. Of particular interest is the atmospheric redistribu-

tion or correlation time, found to be comparable to that we have experienced on many nights over the years on Kitt Peak. There was certainly no indication of the very "fast seeing" that is occasionally mentioned for Mauna Kea. Although four nights are certainly insufficient for site comparison, we can unequivocally state that the seeing conditions encountered at the CFH telescope on these four nights were the best we have ever seen anywhere in nearly ten years of speckle observing.

A total of 763 separate objects were observed at the CFH telescope. Seventy-two of these objects were previously known visual or occultation binaries included in the final sample for calibration purposes, as well as a variety of objects in miscellaneous categories. In 13 cases, the primary and secondary components of wide binaries that could not be observed together in our field of $2''.4$ square were observed separately to search for close companions. Data for six objects were not included in the final analysis because of instrumental effects or other peculiarities in the autocorrelograms which could not be removed. We thus obtained observations of 672 of the 1191 survey candidates. This represents an inspection of 7.4% of all BSC members for duplicity at a resolution limit of $0''.038$, corresponding to the Rayleigh limit of a 3.6 m aperture telescope. All observations consisted of 60 s of video data (equivalent to 1800 individual speckle pictures) taken through a Strömgen y filter and with 10 ms exposure times. Integrated vector-autocorrelograms were stored on floppy disks for subsequent reduction and analysis at GSU in Atlanta. Calibration for scale and position-angle origin was obtained from the measurements of nine visual binaries that have been routinely observed in our program at the KPNO 4 m telescope and were in fact observed on Kitt Peak with the same equipment during a run that ended just five days before the Mauna Kea observing run began. The effect of orbital motion on this calibration is therefore totally insignificant. The spatial calibration procedure employed at KPNO continues to utilize a double-slit mask in the pupil plane as described by McAlister (1977). This method provides a truly external calibration procedure independent of any standard or reference binaries. The scale on the detector for the CFHT data was thus indirectly determined to be $0''.00951$ per pixel with an uncertainty indicated by the scatter for the nine calibration stars of approximately $\pm 0.5\%$. The observational results of this survey are presented in Tables I–III.

Table I contains measurements of 52 newly resolved binary stars. The measured angular separation ranged from $0''.040$, just above the CFHT diffraction limit, to $0''.965$. The mean separation for this sample is $0''.162$, reducing to $0''.140$ when the two systems with separations exceeding $0''.50$ are excluded. Since autocorrelated speckle data cannot discern the true quadrant in which the secondary star lies, position angles inherently have a 180° ambiguity. In Table I we adopt $\theta < 180^{\circ}$. Some of these new binaries have already been confirmed by speckle observations obtained at the KPNO 4 m telescope during November 1985. These confirmed objects are indicated by an asterisk preceding the HR number in Table I. Lack of confirmation at the present time is by no means an indication of decreased confidence in Table I, as only a minority of the new binaries were reobserved in November 1985. The conservative approach we have continued to apply in the inspection of autocorrelograms for duplicity gives us a very high confidence in the reliability of the results in Table I.

TABLE I. Newly resolved systems.

HR	MK	V	Epoch	θ	ρ	d^\dagger (pc)	a^\dagger (au)	P^\dagger (yr)
5612	F6IV	6.65	1985.5171	85.4	0.166	100	17	94
5715	A4V	5.66	1985.5172	155.4	0.217	85	19	78
5818	A2V	5.74R	1985.5172	14.9	0.514	120	61	420
5858	A0V	6.14	1985.5198	98.9	0.130	180	24	91
5895	A3Vn	5.11	1985.5199	25.3	0.126	75	9	26
6123	A5V	5.52R	1985.5200	174.3	0.195	75	15	56
6194	A3IV	6.93	1985.5146	96.3	0.145	250	36	198
6213	F2III	5.92	1985.5173	95.7	0.126	125	16	72
6286	K2III	6.00	1985.5173	121.1	0.292	215	63	360
6317	A7V	6.59	1985.5201	100.6	0.128	100	14	48
6383	A1V	6.46	1985.5173	72.3	0.168	185	32	150
6412	A2V	6.17	1985.5201	70.1	0.136	135	18	72
6571	A2Vn	5.62R	1985.5220	74.0	0.080	105	9	24
6641	A2Vs	6.43	1985.5228	109.0	0.142	160	23	95
6656	A2V	5.02	1985.5228	112.8	0.120	80	9	26
6781	A3V	5.86	1985.5228	173.8	0.106	100	11	32
*6851	B5V	6.30	1985.5231	46.2	0.054	430	24	65
6906	B9V	6.37	1985.5148	100.0	0.118	225	27	110
*6928	B8III-IV	5.73	1985.5148	131.2	0.078	200	16	30
*6941	B2V	6.69	1985.5148	172.8	0.149	1240	186	1165
6956	A4V	6.37	1985.5149	41.4	0.040	125	5	11
*6977	A0Vn	5.78R	1985.5146	31.5	0.151	145	23	85
*6984	B5Vne	6.10	1985.5229	75.8	0.241	395	95	540
6987	F3V	5.45	1985.5148	97.0	0.141	45	7	19
7053	A8Vn	5.14H	1985.5176	66.6	0.184	50	9	30
7091	A1V	6.59R	1985.5175	124.2	0.219	185	41	215
*7109	B8Vnn	6.14	1985.5231	99.3	0.104	250	26	95
7110	A7Vn	6.34	1985.5231	89.6	0.178	90	16	68
7263	F3V	6.23	1985.5233	63.8	0.177	60	11	45
*7272	G1V	6.74	1985.5232	173.0	0.089	40	3	10
7307	B9.5V	5.63	1985.5204	56.2	0.051	145	8	16
7386	F7V	6.19	1985.5233	71.5	0.181	45	8	31
*7436	A3Vn	6.61	1985.5233	173.8	0.137	160	21	95
7480	A3IV	5.67	1985.5149	41.4	0.084	120	10	30
*7554	B2.5IVe	6.51	1985.5149	82.9	0.057	1300	75	300
*7571	A0V+F8IV	6.48	1985.5150	8.9	0.291	200	59	370
*7677	A5Vn	6.45R	1985.5177	55.6	0.050	110	6	12
7684	A2IV	6.01R	1985.5178	23.4	0.340	180	61	420
7752	A1V	6.27	1985.5177	57.1	0.176	165	29	130
*7755	A2Vn	6.31R	1985.5178	13.5	0.176	140	25	110
7767	O9V	5.84	1985.5177	7.7	0.047	1720	80	240
7994	G1V	6.38	1985.5205	2.3	0.169	35	6	20
8246	A0V	5.75	1985.5179	64.2	0.043	145	7	13
8257	F0IV	6.31	1985.5178	110.4	0.184	100	19	90
8274	G9III	6.16	1985.5178	20.2	0.099	200	19	145
8507	F3V	6.39	1985.5208	108.5	0.104	70	7	24
8553	B2V	6.14	1985.5208	60.3	0.185	940	175	1060
8574	B9.5V	5.63	1985.5208	64.1	0.155	140	21	85
8581	F7V	6.14	1985.5151	84.8	0.094	40	3	10
8603	B2Ve	5.73	1985.5182	127.0	0.042	780	33	85
*8617	G2III+A4V	6.40R	1985.5181	115.5	0.113	180	20	85
8690	B3IV:e	5.92	1985.5154	124.0	0.965	650	630	7800

*Confirmed Nov 85 at KPNO 4-m telescope.

†Modeled, not observed, parameter.

Table II contains 76 measurements of 74 previously known binary stars. Fourteen of these measurements, indicated by an asterisk preceding the system identification, are for binaries observed for calibration purposes and are not systems that were part of the survey sample. All stars in the survey sample were checked against the Washington Double Star Catalog (WDS) maintained by C. E. Worley at the U.S. Naval Observatory. Three of the survey stars turned out to be binaries previously first resolved by speckle interferometry (HR 6469, 8059, 8704), and three were discovered either by W. S. Finsen or R. H. Wilson using visual interferometry (HR 6676, 7441, 8355). The remaining 66 systems in Table II were all resolved with visual micrometer methods by a variety of observers. The mean separation for the known binaries among the survey sample is $0''.504$, increasing to $0''.562$ when the six interferometric pairs are excluded. When compared with the mean separation for the measurements in Table I, the anticipated gain from the increased sensitivity of speckle interferometry to small angular resolutions is clearly

seen. As might be expected from our conservative approach to interpreting autocorrelograms, it is mainly the increased resolution rather than a gain in magnitude-difference sensitivity that is responsible for the new binaries in Table I.

Table III contains the HR numbers of 560 stars that were observed in the survey and for which no convincing evidence of duplicity was detected in the autocorrelograms. The effective field of view was determined by the size of the autocorrelator address window and was limited to a rectangle with dimensions $1''.22 \times 2''.44$ centered on the primary star and with the long dimension parallel to a position angle of approximately 30° on the sky. Thus the upper limit to any angular separation that would be detected in the survey was between $0''.61$ and $1''.36$ depending upon position angle. A search of the WDS for known binaries in Table III having separations falling within this window was made, and a list of such systems is presented in Table IV. From the comments accompanying Table IV, we can conclude that there is every indication that this survey has completely detected

TABLE II. Measures of previously known systems.

HR/HD/BD	ADS/Disc.	MK	V	Epoch	θ	ρ
*HD 2880	ADS 450 AB	K0V	8.89	1985.5236	149.6	0.125
*HR 142	ADS 490 AB	F8V	5.20	1985.5236	286.9	0.264
*HR 5472	McA 40	G0V	6.05R	1985.5226	79.9	0.061
*HR 5477-8	ADS 9343 AB	A2III	3.86	1985.5145	304.0	0.965
*HR 5504	Fin 309	F7V	6.40	1985.5145	292.0	0.238
*HD 130669	ADS 9397	K2V	8.6	1985.5226	152.2	0.148
HR 5654	Cou 189	M4IIIab	5.89	1985.5171	143.2	0.454
HR 5728	ADS 9617	G3V	6.08H	1985.5171	9.7	0.827
HR 5774	ADS 9688 AB	A5V	5.02	1985.5172	169.2	0.040
HR 5915	ADS 9834	B5V	5.94	1985.5199	122.0	0.556
HR 6255	ADS 10230	A2Vs	5.51	1985.5146	341.6	0.235
HR 6329	ADS 10312 A	A4V	6.33	1985.5201	186.8	1.246
HR 6367	ADS 10355	A1V+F3V	6.06	1985.5201	12.8	0.444
*HR 6377	ADS 10360 AB	A5m	5.39	1985.5228	122.6	0.127
HR 6469	McA 47	F9Vn:	5.51	1985.5228	228.8	0.045
HR 6488	ADS 10531 AB	F8IV	6.49	1985.5228	289.8	0.069
HR 6516	ADS 10598	G9IV-V	5.31	1985.5203	156.9	0.932
HR 6560	Mlr 571	A5V+G5III	6.17	1985.5228	349.0	0.140
*+27 2853	Kui 83 AB	dMOp	9.2	1985.5228	305.0	0.225
HR 6627	ADS 10795	A1V	5.72R	1985.5203	266.4	0.552
HR 6676	Fin 381	F5Vn	6.38	1985.5203	279.3	0.102
*HD 163640	McA 49	A0III	7.4	1985.5229	67.9	0.083
HR 6689	ADS 10912	A3V	5.97	1985.5203	92.7	0.313
HR 6733-4	ADS 11005 AB	F5V	4.78	1985.5204	278.2	1.831
HR 6795	ADS 11111 AB	F2V	5.73	1985.5204	320.2	0.369
HR 6798	ADS 11127	A4V	6.36	1985.5204	193.9	1.261
HR 6803	ADS 11123 AB	B9V+F7III	6.09R	1985.5231	221.8	1.166
HR 6814	ADS 11149 AB	A3V	5.88R	1985.5229	64.1	0.098
HR 6898	ADS 11324	A9III+F6III	6.15	1985.5148	355.2	0.836
HR 6904	ADS 11334 AB	A0V+A4V	6.24R	1985.5229	128.5	0.639
HR 6981	ADS 11483 AB	G2V+G2V	6.21	1985.5148	160.5	1.697
HR 6999	ADS 11520 AB	F9IV	6.49	1985.5149	349.0	0.141
HR 7002	ADS 11524	K1III+M6IIIe	6.4 H	1985.5148	135.9	0.453
HR 7017	Cou 1607	B9V	6.25	1985.5229	115.1	0.175
HR 7033	ADS 11593 Aa	B5V	6.47	1985.5175	303.3	0.145
HR 7048 A	ADS 11640 Aa	A1V+A1V	5.83	1985.5231	129.9	0.141
HR 7048 B	ADS 11640 Bb	A1V+A1V	5.83	1985.5231	139.6	0.137
HR 7090	Hei 72	A1V	6.40R	1985.5176	215.8	0.489
HR 7305	ADS 12239 AB	B8V	6.54	1985.5233	158.1	0.863
*HR 7362	Fin 327	Am	5.03	1985.5231	84.5	0.081
HR 7441	Wrh	A0V+F8III	5.38	1985.5233	266.2	0.053
HR 7486	Kui 93	B5V	6.01	1985.5149	309.1	0.178
HR 7546	ADS 12973 AB	A3V	5.00	1985.5149	177.6	0.180
HR 7599	ADS 13104 AB	F2V	6.51	1985.5149	296.0	0.173
HR 7637	Ho 276	F8V	5.88	1985.5150	295.6	0.233
HR 7657	ADS 13277	F2III	5.22	1985.5177	120.5	0.851
HR 7737	ADS 13572 AB	B9IV-V	6.71	1985.5177	169.7	0.908
HR 7784	ADS 13728 AB	A1V	6.23	1985.5234	108.9	0.329
*HD 195481	ADS 13944 AB	A3V	6.85	1985.5232	213.4	0.058
HR 7840 A	ADS 13946 Aa	B8V	7.11	1985.5205	126.8	0.341
HR 7840 B	ADS 13946 Bb	B8V	7.11	1985.5205	295.2	0.108
*HR 7889	ADS 14099 AB	B6III	5.22	1985.5232	111.7	0.345
HR 7958	Kui 101	A3V	6.30	1985.5234	109.6	0.374
*HR 7963	ADS 14296 AB	B5Ve	4.53	1985.5232	15.7	0.793
HR 7982	ADS 14360 AB	F5V+F7V	5.99	1985.5205	12.9	0.982
HR 8038	Kui 102	F1Vp	5.99	1985.5151	52.1	0.296
HR 8056	ADS 14573 AB	F5V	6.25	1985.5151	125.3	1.344
HR 8059	McA 66 Aa	G4III	5.89H	1985.5208	232.6	0.045
HR 8116	ADS 14761	A7Vn	6.27	1985.5150	58.8	0.090
*HR 8123	ADS 14773 AB	F5V+GOV	4.49	1985.5234	13.8	0.202
HR 8258	ADS 15115	A4V	6.11	1985.5178	298.4	0.295
HR 8355	Fin 358	B9V	6.59	1985.5208	91.2	0.093
HR 8355	Fin 358	B9V	6.59	1985.5234	92.7	0.090
HR 8407	ADS 15578 AB	A0IV	5.60	1985.5179	3.4	0.939
HR 8532	ADS 15896 AB	F7V	6.04R	1985.5208	4.1	0.296
HR 8533	ADS 15902 AB	A0V	5.78	1985.5151	217.7	0.121
HR 8545	ADS 15934 AB	G1V	6.35H	1985.5153	340.8	2.495
HR 8612	ADS 16130	G0III+FOV	6.23	1985.5151	136.9	0.136
HR 8629	Kui 114	F6V	6.31	1985.5153	124.9	0.184
HR 8631	ADS 16173 AB	G3V+G8V	5.71	1985.5153	97.7	0.216
HR 8652	ADS 16214 AB	A1V+G:	6.39	1985.5154	306.2	0.492
HR 8704	McA 73	B9III	5.80	1985.5153	284.3	0.073
HR 8704	McA 73	B9III	5.80	1985.5234	283.3	0.074
HR 8708	ADS 16345 AB	A3m+F6V	5.81	1985.5154	210.8	0.910
HR 8737	ADS 16417 AB	G2V+G4V	6.43	1985.5153	345.7	0.290
HR 8739	ADS 16428	A8V+F6V	5.75	1985.5153	306.2	0.563

* indicates those binaries observed but not on survey list

TABLE III. Negative results for bright stars.

HR	MK	V	HR	MK	V
5610	FOV	6.50	6140	G2-6III	5.68
5613	G8III-IV	6.59	6158	B9.5III	5.63
5627	A1V	5.57	6162	A4Vn	5.65
5630	F8V	6.35	6169	A2V	6.41
5635	G7.5IIICN-0.5Fe-1	5.25	6171	K2V	5.75
5640	K1III	5.81	6181	F5IV	6.26R
5648	KOIII	6.39	6184	B9.5Vn	5.53
5656	A3Vn	6.08	6185	B9V	5.56H
5659	G5V	6.68	6186	A1Vnn	6.58H
5665	A2V	6.30	6189	F3V	6.35
5676	A2V	5.26	6195	A1V	5.77
5677	M2IIIIa	6.13	6201	A7III	6.24
5679	A4V	5.63	6202	F4IV-III	5.57
5692	G8IIIIaBa0.3	5.70	6203	A3Vn	6.08
5706	KOV	6.35	6205	F2-4III-IV	5.74
5709	KOIII	5.51	6222	F2-3III-IV	5.99
5716	F3-4IVs	6.19	6224	B9.5III	6.03
5717	AOV	6.28	6227	M3IIIIab	5.56
5718	B9Vn	5.37	6228	K5III	5.15
5721	FOV	6.12	6230	K4III	6.05
5732	K2III	6.01	6232	A3V	6.10
5734	G1V	6.50	6235	AOVn	6.03
5740	G0IV-V	6.27	6239	G5III	6.35
5741	K4III	5.46	6240	A5V	6.08
5748	A2IV	6.45	6246	A1V	5.91
5752	AmA3-FOV:	6.15	6248	F1III-IV	6.32
5758	F4Vw	6.57	6256	KOIV	6.13
5760	A4IV	6.46	6258	M1IIIIa	5.72
5763	K5III	5.02	6259	KOIII	6.13
5764	B2Vn	5.50	6270	K0.5IIIIaCa0.5	5.04
5769	F6III	6.38	6277	FOV	6.25
5770	B9V	6.22	6278	A2IV	6.57
5779	F7V	6.51	6279	F0-2V	5.32
5800	M2IIIIab	5.11	6280	K2III	5.25
5804	F3V	5.93	6284	KOIV	6.37
5813	F5V:	6.51R	6287	G8III	5.41
5815	F6IV-V	6.50	6292	G5III	6.08
5816	F6V	6.48	6293	K4III	5.35
5817	F4IIIp	6.74	6294	B6V+B7V	6.27
5823	G8III-IV	5.24	6296	G8-KOIII-IV	6.19
5830	F2V	5.75	6301	KOV	6.37
5833	B9V	6.00H	6302	F3IV	6.59
5834	B7V	5.07H	6306	M2IIIIab	6.62R
5835	G8III	5.84	6307	KOIII	6.32
5841	K1III	6.45	6313	K3III	6.34
5853	G5V	5.88	6332	A3IV	5.25
5859	AOV	5.58	6341	A1V	5.93
5870	A3V	5.71	6346	M4IIIIab	6.69R
5919	A7Vn	6.29	6349	F8.5IV-V	6.01
5924	M0III	5.44	6351	A5V	6.04R
5927	F7V:	6.37	6361	A9V	6.38
5932	M3IIIIaBa0.3	5.37	6362	A3IV	6.43
5936	F0IV	5.45	6363	K1III	6.09
5949	AOV	6.31	6372	G5-BIV-V	6.36
5954	F8V	5.47	6376	A2IV	6.28R
5959	A0Vs	5.55	6391	A8V	6.19
5964	F0IV	6.05	6395	B9V	6.29
5968	G2V	5.41	6399	A5III	6.04R
6002	B9.5Vnn	5.78	6406	M5Ib-II	3.48H
6004	A7V	5.63	6407	G5III+F2V	5.39H
6012	F4V	6.47	6414	B5Vnn+B5V	5.88
6013	A0Vnn	6.14	6419	K2III	5.96
6026	B8V+B9VpSi	6.30	6432	A1V	6.00
6033	A4V	5.43	6434	F0-2IV-Vn	6.51
6035	AOV	6.08	6435	A2Vnn	6.02
6036	A1V	6.33R	6443	KOIII	5.65
6041	A1V	6.25	6457	A2V	5.12
6050	K4II+F6-8V	5.87	6458	G0V	5.39
6052	F3V	6.50	6467	F4V	6.43
6060	G2Va	5.50	6473	B9Vn	6.21
6061	AOV	6.09	6481	A3V	5.71
6063	GOVCaIIe	5.64	6482	B9V	6.35
6064	G1V	5.66H	6484	A0Vn	5.47H
6067	A9Vn	6.18	6489	F3V	6.44
6074	A3V	5.78	6496	F7V	6.21
6091	F3IV-V	5.49R	6497	B9.5V+GOV	6.06
6096	B9V	6.23	6502	B5V	5.54
6110	A4Vn	6.40	6506	AOV	5.94
6121	G8III	6.11	6507	A8V	5.44
6124	G8III	6.07	6509	A4V	5.80R
6128	M2.5III	5.23	6514	A4V	6.51
6136	K4IIIp	5.39	6533	A1V	5.62R
6137	F2V	6.48	6534	A5V	5.62

TABLE III. (continued)

HR	MK	V	HR	MK	V
6538	G5V	6.56	7057	F0IVv	5.73
6541	F6V	5.64	7059	A2Vm	5.90
6544	B8Vn	5.55	7060	A2IV	6.11R
6548	A2V	5.81	7071	G5III	6.23
6551	A8Vn	6.40R	7073	B6V	6.04
6570	A5V	5.76R	7079	F8V	6.15
6589	A1V	6.34	7080	A2IV	6.52
6592	K1III+F4V	6.36	7081	B3IVp	6.06
6594	F4Vw	5.52	7084	B2.5Ve	5.88
6600	F0V	6.39	7085	A1V	6.25
6601	B1.5V	6.30	7086	A1V	5.88
6609	A1IV-V	6.17	7096	A7III	6.13
6610	A0V	6.56	7098	A0Vs	6.64
6618	A2V	5.75	7100	B3IV	5.91
6626	K3III+F7V	6.68	7102	A3V	5.25
6633	B9.5V	6.22	7115	B6IV	6.09
6642	A1V	6.12	7123	G9IVa	5.51
6655	A9V	5.98R	7126	F4V	5.79
6670	F3-5IV-V	5.77	7131	B2.5V	5.58
6679	A4V	6.52	7132	K4III	5.62
6681	A1V	5.89	7140	G8III+A2	6.02
6684	B2IV-V	5.82	7154	F3III	5.77
6696	A1V	6.36	7162	F9V	5.22
6697	G2V	6.30	7171	B7III-IV	6.50
6720	B8Vne	6.50	7172	F8V	5.23
6732	B9V	6.76	7173	B2Vp	6.75
6741	B3Vn	6.21	7174	B7IV	5.89
6744	A0V	6.50R	7179	B3V	6.22
6753	A2V	6.21	7181	K2III	5.27
6754	F0IV-V	6.34	7183	M3.5IIIab	6.29
6764	F7V	6.52	7185	B5IV	6.41
6775	F7V	5.04	7196	G8III	6.30
6776	A2Vn	6.63	7200	B2IV-V	6.69
6782	A3V	5.90	7202	B5V	5.69
6792	A2V	6.32R	7207	A4V	6.40R
6797	F5V	5.69	7209	A1V	5.42
6806	K2V	6.40	7214	A4V	5.83
6830	A4V	6.36	7215	A7V	5.01
6831	F8V	6.56	7231	F1V	6.53
6843	A8V	6.31	7251	A0Vn	5.38
6844	F2V	6.63	7258	B3V	6.49
6847	G2V	6.29	7260	G5V	6.07
6849	F1V	6.37	7261	F0V	5.23
6852	B9V	5.99R	7267	F5IV-V	6.48
6873	B3Ve	6.13	7269	B5Vn	6.34
6877	A7V	5.12	7279	B3V	5.34
6878	B9.5V	6.33	7284	A3V	6.18
6881	B8IV-Ve	5.73	7286	A2Vn	5.93R
6883	A2V	6.00R	7288	A3V	6.49
6885	K3III	5.25	7293	G4V	6.75
6890	F6III-IV	6.38	7294	G4V	6.57
6900	B9V	6.74	7301	A4V	5.64
6902	G8III-IV+AOV	5.65	7313	A1Vn	6.19
6918	G0III+A6V	5.21	7324	A3V	6.68
6919	B8V	6.20	7332	A2V	6.02
6924	B3V	6.53	7345	G8V	6.31
6925	K3III	6.07	7346	B9V	6.31
6935	K0III	5.39	7351	A1V	6.26
6944	A0Vn	5.14	7364	B9.5V	6.40
6946	B2V	5.72	7368	G8V	6.37
6955	A2V	5.77	7384	A0V	6.31
6957	A4III	5.94	7390	A0V	5.63
6962	A2V	5.76	7403	B3Ve	6.34
6967	B8IIIpSiSr:	6.42	7457	B8Vne	6.05
6970	G8III	5.14	7466	B5V	6.43
6971	B4Ve	6.59	7476	K2III+F8V	6.2
6974	B9.5V	6.56	7516	B3III	6.48
6975	A3V	6.46R	7519	A3IV	5.91
6976	A1V	6.40R	7541	K5III	6.04
6985	F5III	5.39	7553	F0V	5.39
6992	B9V	6.42R	7559	K5III	6.13
6995	G8IV	6.29	7569	G0V	6.13
7000	F1IV-V	6.66	7572	B7V	6.54
7003	F0V	6.26R	7580	B9.5Vn	6.53
7010	G8III	6.28	7593	B7Vn	5.71
7030	B8V	6.41	7594	B8V	6.49
7034	F7V	6.31	7596	A0III	5.61
7040	B9V	5.02	7598	A2V	6.15
7044	F1III-IV	5.70	7610	A1IV	5.28
7047	F6V	6.31	7622	B9III	5.33
7051	A4V	5.06H	7636	G8III	6.17
7052	F1V	6.02H	7649	A3V	5.71
7054	F0Vn	5.37H	7655	K0III	6.20

TABLE III. (continued)

HR	MK	V	HR	MK	V
7656	B4V	5.88	8166	G8IV	5.68
7670	G6IV+M6V	5.71	8169	A1V	6.04
7672	G1V	5.80	8170	F8V	6.40
7675	A1Vn	6.55	8178	A3V	5.16
7683	G5IV	6.17	8182	K1III	6.05
7687	M1IIIa	6.14	8186	A1V	6.63
7688	B3V	5.07	8187	F1V	5.49
7689	K0IV	5.36	8190	F1IV	5.71
7693	F3V	6.43	8194	A2V	6.15
7697	F5V	5.85	8197	K0III	6.32
7700	B3V	6.31	8198	A8III	5.68
7705	F5IV	6.48	8205	F5V	6.13
7709	B1V	6.49	8212	F3V	6.61
7711	A3III	5.52	8215	B3V	5.31
7715	F7V	5.85	8217	A1V	5.41
7719	B7Ve	5.92	8220	F0V	5.80
7721	B7V	6.92	8222	F0V	6.57
7731	A7IVn	5.18	8231	B9.5V	6.08
7733	K4III	6.14	8250	F7V	6.47
7734	A0V	6.45	8261	G8III-IV	6.36R
7743	K0III	5.66	8263	A2V	6.25
7746	K1III	6.13	8265	A2V	6.18
7753	G8III	5.32	8266	A5V	5.01
7756	F5V:	5.91	8267	F1IV	5.45
7757	B6III	6.48	8270	A9IV-Vn	5.67
7760	G9III	6.22	8272	A7III	6.20
7769	A2V	5.58	8276	F2V	5.85
7777	B2V	6.45	8283	G1V+GOV	5.18
7782	A0III	6.57	8302	F0V	5.99
7793	F8V	6.17	8307	A0V	5.65R
7803	B9V	6.15	8310	G2V	6.08H
7807	B2Ven	5.90	8314	GOV	5.94
7821	B9V	6.13	8319	A1V	5.58
7829	A7V	6.74	8328	A1V	5.64
7830	A3Vn	5.94	8330	F3V	6.21
7855	F6V	6.13	8332	A7V	6.17
7857	A2Vnn	6.56	8338	B8V	6.12
7865	A7V	6.19	8341	B2V	6.29
7880	B9V	5.59	8343	A1Vs	5.04
7883	A2V	5.43	8354	F6IV-Vvw	5.53
7887	F0V	6.49	8356	B3Ve	5.08
7899	B3V	5.96R	8358	A0Vs	5.68
7914	G5V	6.45	8372	K5V	6.38
7917	A2V	6.08R	8373	A2Vnn	5.54
7927	B2IV-Ve	6.66	8382	K2V	6.22
7947	F7V	5.14	8391	F5III	6.40R
7953	A0V	5.58	8396	A2V+K0III	6.37
7954	A0Vn	6.40	8403	B5III	5.78
7973	F5V	5.98	8404	B9.5V	5.80
7974	A1Vs	6.33	8406	O9V	5.56
7981	A1Vs	6.52R	8415	K2III	5.78
7983	B4Ve	6.33	8419	B9Vn	5.63R
8004	A1V	6.66	8421	M4IIab	6.13
8006	A9Vn	6.55	8422	A0V	6.44
8009	B8Vnne	6.70	8424	K5III	5.14
8012	A4V	5.58R	8427	B2V	6.27
8014	B8Vn	6.57	8429	A3V	6.19
8023	O6Ve	5.96	8434	A0III	6.39
8041	G1V	6.21	8438	B7Vne	5.78
8044	M3IIIab	5.65	8441	F1IV	6.11
8054	B6V	6.50	8442	G6III	6.32
8057	M1III	6.31	8445	K5III	6.42R
8058	A3V	7.31H	8448	G2IV+K0III	6.11
8066	K5III	5.61	8451	A1Vnn	6.27
8077	F8V	5.94	8455	GOV	6.18
8083	A0V	6.17	8459	A3III	6.46
8085	K5V	5.21	8460	A8IV	6.32
8086	K7V	6.03	8462	F2V	6.03
8088	K2IV	6.42R	8463	A5V	5.40
8090	K5III	6.15	8467	F7V	6.39
8094	B9V	5.59	8472	F8V	5.24
8095	F5IV	6.45	8476	K0III	6.30
8098	A2Vs	6.07	8482	K2III	5.89
8101	A1V	6.68	8487	A0III	5.53
8105	B1Vp	6.54	8489	A2Vnn	5.68R
8121	M1III	6.38	8491	A1Vn	6.21
8134	A2V	6.40	8495	A5Vn	6.15
8139	F2V	7.05	8503	G9III	6.37
8141	B5V	5.82	8506	G8III	5.88
8144	B7Vn	6.19	8510	A9IIIp	6.17
8149	K5III	5.96	8512	B8IIIpMn+Hg:	5.37
8158	B6IV	6.29	8513	B5V	5.37
8165	K1III	5.57	8514	F6V	6.17

TABLE III. (continued)

HR	MK	V	HR	MK	V
8520	B2IV-Ve	5.01	8654	K5III+K2III	5.95
8528	B5V	6.41	8656	K0III	5.08
8530	G6IIIBaII	5.93	8666	F0III-IV	5.76
8534	G6.5III	5.76	8670	G7III	5.26
8535	B8III-IV	6.16	8673	A0V	5.66
8548	F7V	5.75	8676	A9III-IV	6.19
8549	B2V	6.46	8677	B9.5IV	6.36
8554	B5III	6.57	8681	F0IV-V	6.54
8562	K5IIIa	5.58	8682	B5Vne	6.12
8565	F3IV	6.40	8688	K1III	5.43
8567	B8Vs	6.37	8697	F7IV	5.16
8569	A2V	6.56	8705	B8V	6.46
8575	K2III	6.40	8706	B7III-IV	6.34
8583	A8III	6.38	8710	K3III	6.19
8586	F1V	6.24R	8711	K2.5IIIb	5.56
8588	A6V	5.79R	8712	K0III	5.81
8589	G8III	6.35R	8715	A7III	6.11
8594	G8III-IV	5.71	8716	K0III-IV	5.72
8605	A1III	6.40	8723	B7III	5.74
8606	B3V	6.29	8724	A3Vs	6.51
8607	A3V	6.38	8725	B2IV	5.59
8610	K2III	5.03	8727	G9III	6.31
8621	M4III	5.21R	8729	G2.5IVa	5.49
8624	A2V	6.21R	8730	K1III	6.28
8633	K0III	5.93	8731	B4IIIep	5.43
8640	B2III	5.25	8733	B2IV-V	6.18
8643	G9III	5.94R	8734	G8IV	6.16
8645	A5V	6.45	8735	F0-2V	6.37
8647	A0Vn	6.41	8738	A1V	6.33
8651	B1V	6.43	8741	K5III	6.07
8653	G8IV	6.51	8745	B9III	6.43

those previously known visual binaries having geometries and magnitude differences falling within the survey window of resolution. Previously known systems that were missed by the survey can be invariably excused on the basis of their currently exhibiting unresolvable separations and/or possessing very large magnitude differences.

III. DISCUSSION

The limiting resolution of speckle interferometry when carried out at 4 m class telescopes permits the detection of

binary star systems that would otherwise be overlooked by traditional visual micrometry surveys using large refractors or even by attempts to detect variable radial velocity. Although the direct resolution of spectroscopic binaries continues to be a major justification for binary star speckle interferometry, the great majority of radial-velocity amplitudes that have and can be measured lead to semimajor axes too small to encourage direct resolution. This situation could be improved substantially if precision radial-velocity methods, such as those summarized by Campbell and Walker (1985),

TABLE IV. Known visual binaries not resolved in survey.

HR	ADS	Disc.	Epoch	Comment*
6388	-	McA	1985.5174	1
6484	10526	McA Ap	1985.5227	2
6697	-	McA	1985.5228	3
6918	11353	Stf 2316 Ap	1985.5148	4
7059	11667	McA Ap	1985.5231	5
7209	-	A 3105	1985.5204	6
7466	12696	WRH 23 Ap	1985.5234	7
7953	14293	Bu 65	1985.5206	8

*Comments - Unreferenced dates of speckle observations refer to the catalog of McAlister and Hartkopf (1984):

1. Unresolved at 10 epochs between 1977.49 and 1981.47 with separation of 0".039 on 1980.48.
2. A companion with a separation of 0".29 seen only on 1981.47; unresolved on 1985.25 by Bonneau et al (1985)
3. Rapidly moving pair closing from 0".114 to 0".065 between 1981.5 and 1984.3.
4. A companion with a separation of 0".25 seen only on 1976.61; unresolved at four other epochs between 1976.3 and 1979.5.
5. A companion with a separation of 0".13 seen only on 1980.48; unresolved on 1976.30.
6. Consistently unresolved at five epochs between 1977.48 and 1981.47.
7. Consistently unresolved at eight epochs between 1976.45 and 1981.70.
8. This system with an estimated Δm of 3.6 magnitudes is probably also showing a separation just outside the survey window.

were routinely applied to long-period binary systems. Thus speckle interferometry using large reflectors can realistically be considered as a technique that begins to bridge the gap between classical visual and spectroscopic detection of binary stars and provides important overlaps into the regimes of these two complementary methods. Among the 52 newly resolved binaries in Table I, there are 13 which are designated as spectroscopic binaries by the BSC. The longest spectroscopic orbital period in this subgroup is just over 13 days, and it can be concluded that none of the newly resolved systems can be associated with previously known spectroscopic orbits. There are ten stars in Table I for which the BSC designates the radial velocity as being variable and nine additional stars with suspected variable velocities. Whether or not these velocity variations can be attributed to the speckle companions remains to be established. Two of the stars in Table I show composite spectra: HR 7571, A0 V + F8 IV, and HR 8617, G2 III + A4 V, and it is likely that these spectral types correspond to the individual components now resolved by speckle interferometry. It is also interesting to note that we have discovered a new close companion to component C of the famous visual multiple system ϵ Lyrae (HR 7053).

A few of the stars we have observed have been included in other surveys for the purpose of estimating duplicity frequencies. In their study of solar-type dwarfs, Abt and Levy (1976) found a constant radial velocity for HR 6987, a star which we find to be double with a separation of 0".141. We estimate that HR 6987 would have a period of the order of 15 yr, with a maximum possible radial-velocity variation of approximately 10 km/s, a value that would be decreased according to the actual orbital inclination. The long period and likely small velocity amplitude are not inconsistent with the conclusion of Abt and Levy (1976). Three stars for which we failed to detect companions but for which Abt and Levy (1976) determined spectroscopic orbits are HR 5954 ($P = 3100$ days), HR 7261 ($P = 49.1$ days) and HR 8283 ($P = 13.2$ days). In the case of HR 5954, the 8.4 yr period system could conceivably be resolvable by speckle interferometry at maximum angular separation, provided that the magnitude difference is not too large for this single-lined system. The shorter periods for HR 7261 and HR 8283 give no hope for direct resolution by single-aperture interferometric techniques. In nine other cases (HR 5968, 6091, 6458, 6594, 6775, 7172, 7947, 8472, 8697), Abt and Levy (1976) found constant velocities for stars which we also see as single while they suspect variable velocity for HR 6985, a star that is unresolved to us. The only star we have in common with the study of B type dwarfs by Abt and Levy (1978) is HR 8520, an object for which neither spectroscopic nor speckle analysis find evidence of duplicity. The observational selection effects of spectroscopic methods and speckle methods do overlap some in their sensitivity to binary star discoveries, but in the case of bright-star duplicity surveys the two approaches serve primarily as complementary rather than redundant means for discovery.

The complementary nature of speckle interferometry with spectroscopic and visual surveys for duplicity is exemplified in the case of the B stars. Abt (1983) discusses the duplicity frequency for a sample of 114 B2–B5 dwarfs, pointing out an absence of such binaries with periods between approximately 1/3 yr and 270 yr. Our Table I includes two stars in this spectral range that have estimated periods of less than 100 yr and three more stars with periods less than 1000 yr. Even these few binaries in this period range would significantly

alter the depression in the frequency distribution for B stars shown in Fig. 2 of Abt (1983).

Heintz (1978) defines an index $C = 0.22\Delta m - \log \rho$ as a "measure of difficulty" for visual detections based upon magnitude difference and angular separation. He states that for stars brighter than magnitude 9.5 binaries for which $C < 0.5$ have been completely detected by surveys, while those for which $C > 1.0$ are "virtually unknown." In the separation range of 0".038 to 0".25, in which 47 of the 52 newly resolved binaries fall, the value of C ranges from 1.4 to 0.6 if we assume that the average Δm within this sample is approximately 0.5 mag. The majority of these new binaries thus have very small likelihood of ever contributing to duplicity surveys employing visual methods.

We can conclude that the great majority of the binaries newly resolved in this survey fall into an orbital-period regime not generally detectable by other methods and have thus not contributed to previous studies of the stellar duplicity frequency. Furthermore, these systems would not be discovered if this same sample were to be surveyed by classical spectroscopic and visual methods. If we estimate that the 47 new systems in Table I with separation less than 0".25 are uniquely discoverable by speckle interferometry at large telescopes, then we can conclude that duplicity surveys in the past have typically overlooked at least approximately 7% of the actual binaries because they fall into the selection regime between spectroscopic and visual methods. This addition to the overall frequency of binary stars must be considered a minimum value to the true increase because speckle interferometry does not completely bridge the gap between spectroscopy and micrometry. Although this survey is not intended to provide the means for independently modifying across all spectral types the binary frequencies that have been summarized by Abt (1983), the breakdown in frequency as shown in Table V offers comparisons supportive of the high frequency of duplicity and its variation with spectral type.

Our sample of 672 bright stars is not generally representative of the luminosity-class makeup of the BSC because this observed sample includes 424 dwarfs and 246 stars of luminosity class IV or brighter as indicated in Table V. Two stars,

TABLE V. Summary of duplicity results by primary spectral type (no. of stars observed/no. of stars resolved/% resolved).

Spectral Type	Luminosity Class			
	V	IV	III	II
O	3/ 1/33	-	-	-
B	104/17/16	18/ 3/17	15/ 2/13	-
A	193/45/23	18/ 4/22	21/ 1/ 5	-
F	87/16/18	28/ 4/14	13/ 2/15	-
G	31/ 7/23	12/ 1/ 8	38/ 4/11	-
K	8/ 0/ 0	4/ 0/ 0	59/ 2/ 3	1/ 0/ 0
M	-	-	17/ 1/ 6	1/ 0/ 0
All	426/86/20	80/12/15	163/12/ 7	2/ 0/ 0

HR 7048 and HR 7840, contribute two systems each to Table II, but the primary spectral types are included only once each in Table V. Thus there were 670 different primary spectral types available for the 672 stars observed. Dwarf primaries accounted for 63.5% of the survey sample, whereas dwarfs comprise approximately one-third of the complete BSC. Our selection of dwarfs over giants was based upon the need to extrapolate to the apparent-magnitude range ($V = 9.0\text{--}14.5$) characteristic of HST guide stars in which dwarfs dominate over giants. For the 424 luminosity class V stars in our sample, 86 were found to be double with an overall frequency of occurrence of 20%. Forty of these dwarf binaries are newly discovered. There were 164 luminosity class III stars observed, of which 12, or 7%, were found to be double. Five of the giant binaries are newly resolved. It is interesting to note that the fraction of observed binaries previously unknown is similar across all luminosity types and confirms the anticipated decrease in detected duplicity rate for evolved stars, owing to significant increases in magnitude difference when one star leaves its companion behind on the main sequence. The 9.4% increase in the overall frequency of dwarf binaries found for the survey sample leads to the prediction that another 250 binary stars would be discovered in a complete speckle interferometric survey of BSC dwarfs. Our results would also imply the existence of an equal number of newly resolvable giants and subgiants. This is a substantial increase in the incidence of close visual binaries among the bright stars. Discovery and continued speckle measurement of these objects would eventually result in a significant increase in the number of binary stars for which fundamental determinations of masses and luminosities can be made. The routine observation of these stars by modern programs of high-accuracy radial-velocity measurement is extremely important to this potentially rich harvest.

Estimates of the orbital periods for the newly resolved binary systems in Table I were calculated by assuming that Δm is typically 0.5 mag, that the total mass of each system is 1.8 times the mass of the primary for which the mass and absolute magnitude can be estimated from Allen (1973), that the unknown inclinations are randomly distributed and result in a mean projection factor of 0.64, and that the orbits have a mean eccentricity of 0.5. The estimated values for the distances, orbital semimajor axes, and periods are given in the last three columns of Table I. Seventeen of the new binaries have periods in excess of a century, while 17 systems have periods of less than 40 yr. Five systems (HR 6956, 7272, 7677, 8246, 8581) have periods of 15 yr or less. Although the period estimates are based upon a model and thus are highly uncertain, they can serve as a guide for those objects that should be routinely measured by speckle observers and/or offer a possibility for the determination of spectroscopic orbits.

Figure 1 is a histogram of angular separations smaller than $0''.64$ measured for the survey sample. The sample is subdivided in Fig. 1 according to whether or not the system is newly resolved, and furthermore, whether previously known binaries were discovered visually or with speckle interferometry. The figure omits 22 systems with angular separations exceeding $0''.65$, including the newly discovered wide pair comprising HR 8690. Inspection of Fig. 1 leads to the conclusion that for separations exceeding $0''.25$ visual surveys have reached a completeness which cannot be substantially improved by speckle interferometry. For this "wide" separation regime, five new binaries were found compared to

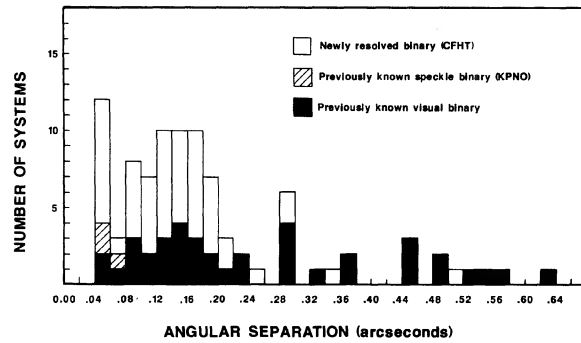


FIG. 1. The histogram of angular separations from 93 measurements of binary systems clearly shows the increase in newly resolved systems at separations less than 0.25 arcsec. An additional 22 measures of systems with separations exceeding 0.65 arcsec are not shown here. Those "wide" binaries include only one newly resolved system.

53 previously known systems. For "close" binaries with separations less than $0''.25$, our results nearly triple the incidence of duplicity by finding 47 new binaries compared with 26 previously known systems.

The sensitivity of speckle interferometry as a tool for the discovery of close binaries is made even more apparent when it is realized that three of the 26 previously known binaries were originally first resolved by speckle rather than by visual micrometer methods and that another three were discovered by visual interferometry. Table VI lists for comparison the separations at both the survey epochs and the epochs of discovery for the ten visual binaries with current separations less than $0''.150$. In nearly every case, the discovery separation was substantially larger than what we measured at 1985.5, when the average separation was $0''.109$ compared with $0''.230$ at discovery. It is likely that systems with separations less than $0''.12$ would be overlooked by even the best micrometer observers so that another four visual binaries that we have measured would probably not have been previously resolved had their orbits not presented wider separations at earlier epochs. This discussion would lead to the conclusion that only approximately 14 of the 72 bright close visual binaries we have observed would be detectable by visual observers were the argument not biased by the lack of separation histories of the new binaries and by the fact that bright stars have not been systematically surveyed for many decades. We can only state in summary that, within our survey sample, 52 new binaries have been found by speckle interferometry in the separation regime of $0''.04\text{--}0''.25$, compared with 22 previously known visual binaries. This implies a 240% increase in the known incidence of close visual binaries among the bright stars.

We can estimate the number of binary stars that have been overlooked in any separation interval owing to the finite lower limit of resolution imposed upon speckle interferometry by diffraction principles. For the CFHT, we take the diffraction limit as defined by the Rayleigh criterion and adopt a limiting resolution of $0''.038$. A simple model from which we can then estimate discovery incompleteness is provided by considering a sphere whose radius equals the upper limit R to an observable separation interval. The sphere then contains all possible vector separations which we assume to be randomly distributed and which would project onto the

TABLE VI. Visual binaries with observed separations less than 0.150 arcsec.

HR	ADS	Disc.	1985.5 Separation	Discovery Separation	Discovery Year
5774	9688	A 1634 AB	0".040	0".09	1907
6488	10531	Hu 1179 AB	0.069	0.23	1905
6560	-	M1r 571	0.140	0.18	1979
6814	11149	B 2545 AB	0.102	0.11	1958
6999	11520	A 88 AB	0.141	0.14	1900
7033	11593	B 2546 AB	0.145	0.2	1958
7840 B	13946	Da 1 BC	0.108	0.5	1841
8116	14761	Hu 767	0.090	0.17	1904
8533	15902	Bu 172 AB	0.121	0.46	1875
8612	16130	A 2695	0.136	0.22	1913

plane of the sky bisecting the sphere to present the distribution of angular separations we attempt to observe. The fraction of the vector separations that would be unresolvable is then given by the intersection of a cylinder of radius r , the diffraction limit, with the sphere such that the cylinder's long axis is perpendicular to the plane of the sky and passes through the center of the sphere. The fraction of the binaries that would then be unresolved can be shown to be given by

$$f = (2r^2H + 3Rh^2 - h^3)/2R^3,$$

where

$$H \equiv R \cos(\arcsin r/R)$$

and

$$h \equiv R - H.$$

With the limitations of this simple model in mind, we show in Table VII the resulting incompleteness for observed separation intervals beginning at the CFHT diffraction limit, where everything is unresolved, to a separation of 1 arcsec, where an insignificantly small percentage will be overlooked. In the range of separations out to 0".12, 10% of the binaries will be unresolved due to their orbital inclinations. This implies that approximately three close systems were overlooked in the survey sample due to this effect. The effect of nonzero orbital eccentricities will be to increase the probability of a given system being resolved because of the resulting bias, arising from Kepler's second law, toward larger separations. This effect is complicated and somewhat nullified by the distribution of the longitudes of perihelion. In the present estimate, we expect that a more realistic incompleteness model would not alter the conclusion that three close systems have been overlooked due to the distribution of the orbital elements i , e , and ω .

IV. CONCLUSIONS

From a survey of 672 stars selected from the Yale *Bright Star Catalogue* and observed with speckle interferometry at

TABLE VII. Estimated incompleteness fractions.

R	f	R	f	R	f
0".038	1.000	0".065	0.327	0".140	0.073
0.040	0.829	0.070	0.284	0.160	0.056
0.042	0.748	0.075	0.249	0.180	0.044
0.045	0.655	0.080	0.219	0.200	0.036
0.048	0.581	0.085	0.195	0.300	0.016
0.050	0.538	0.090	0.174	0.400	0.009
0.055	0.450	0.095	0.157	0.500	0.006
0.058	0.407	0.100	0.142	0.600	0.004
0.060	0.381	0.120	0.099	1.000	0.001

the 3.6 m Canada-France-Hawaii telescope, we detected and measured the duplicity of 52 stars not previously directly resolved. The separations and position angles of 60 additional, previously known visual binaries have been measured with high accuracy. For 560 stars, our observations showed no indications of companions within a resolution window whose lower limit is approximately 0".038 and magnitude difference $\Delta m < 2$. From these observations we conclude that:

(1) About 500 previously unresolved binary stars can be expected to be discovered from a complete speckle interferometric inspection of all the stars in the BSC.

(2) These new binaries primarily fall into orbital-period regimes likely to be overlooked in traditional radial-velocity and visual-micrometry surveys for duplicity and consequently serve to increase the known overall duplicity rates for stars. Without regard to spectral type, this overall increase of duplicity frequency is approximately 7%.

(3) The number of visual binaries in the separation range 0".038–0".25 is found to be 11% of our sample. This more than triples the value based upon previously existing statistics for classically resolved binaries.

(4) Continued discovery and measurement by interferometric means of binaries among the bright stars can result in a substantial increase in the collection of fundamental data for stellar masses and luminosities, as well as in a significant refinement in our knowledge of the frequency of binary and multiple star systems.

This project was made possible with the generous support of the Space Telescope Science Institute, and we thank R. Giacconi, P. Stockmann, and R. Milkey for their encouragement and for providing contingency funds for the project. We thank STScI staff members P. Garnevič and M. Potter for providing observing lists and finder charts, and J. Russell for her comments on the manuscript. We are especially grateful to G. Lelievre for providing Director's discretionary time on the CFHT, to B. McLaren for his advice and assistance at the telescope, to K. Barton for his superb job in operating the telescope, and to the entire CFHT staff for their kind assistance in adapting our instrumentation to the telescope and in helping with a tight shipping schedule. The task of handling the shipping with only five days between observing runs was skillfully managed by W. G. Robinson. Research activities in speckle interferometry at Georgia State University are supported by grants from the National Science Foundation and the U.S. Air Force Office of Scientific Research.

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