Near IR Measurements of Double Stars, I

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Abstract: We present position angles, separations, and magnitude differences of 28 double stars, including several new systems.

Introduction

After enjoying 37 years at the University of Pittsburgh's Allegheny Observatory, we retired to a small home in the warmer climate of northern Georgia. Our interest in double stars extended throughout our careers and was not quenched by retirement. Within a few years we found ourselves back at the telescope. In the following we list measurements of double stars we have observed from our backyard Sirius-Two (Gatewood and Gatewood 1978) Observatory.

Facility

We made the 16-inch primary mirror for our F/6.63 Newtonian telescope decades ago. The tube and excellent mount were built by Parallax-Instruments. We constructed the building for the telescope from a shed-kit we modified to have a roll-off roof opened with a garage-door opener. The facility includes a floor-level window-fan that brings ground level air into the building beginning early in the day and running until the end of observing. To further control the seeing, two computer-case fans exhaust air from below the primary mirror. A two-inch Barlow lens provides a scale of 0.1952 arc seconds per pixel on a SIBG 402 CCD. The latter includes photometric B, V, and I_C band pass filters with which the delta magnitudes in Table 1 were acquired. The SBIG 402 was chosen because of the optional photometric filters, it's fast shutter speed, and it is relatively inexpensive. The KAF-0402ME sensor is also quite responsive at 0.81 microns (the central wavelength of the I_C filter).

Procedure

Exposures times, of the double stars we observe, range from 0.04 to 16 seconds. CCDOPS is used to control the CCD camera and acquire the images. ASTROPLANNER is used for observational planning and telescope control. ASTROSURF's REDUC is utilized for the determination of the astrometric parameters while Difraction Limited's MAXIM DL 5 is used for photometry. For further guidance we find GUIDE-8 to be an indispensable reference. Because the seeing is somewhat better at longer wavelengths (Fried 1965), the I_C filter is used for most observations. Thus, all of the observations listed in Table 1 include estimates of the magnitude differences of the components in the I_C band (dM_I). In the following we will refer to observations made in the B, V, and I bandpasses only by those letters.

We measure only those images in which the double star is well resolved and the stellar images are compact and round. The program REDUC includes a feature that sorts exposures by the maximum-count in the image of the primary star. For a set of images acquired within seconds of each other and with the same exposure time, this is an excellent measure of the quality of the seeing during each individual exposure. The program next makes available small images of each exposure for visual inspection. This process allows us to select the images acquired during moments of the best seeing. We only observe when "Clear Sky"(http://cleardarksky.com/) predicts the astronomical seeing will be better than average. Only 5 to 20 percent of the images taken are actually reduced, but those selected are competitive with images obtained at very good astronomical sites. The astrometric parameters are computed from the selected images with the program REDUC. The same images are next stacked with MaxIM DL5 and aperture photometry is used to obtain the magnitude difference in each measured band pass. Generally the I_C images produce both the best and the highest percentage of excellent images. The images acquired with the V filter are seldom of the same quality and produce a smaller fraction of useful images. Thus, the results the V band measurements have only about 0.6 times the weight of those obtained with the I_C filter. The B images are generally more difficult and, because the KAF-0402ME sensor is less sensitive in that part of the spectrum, require a significantly longer exposure. Image quality decreases with increased exposure. Thus, the B band produces relatively few useful images and the B magnitude differences are only observed during the best of conditions.

Magnitude Differences

The V magnitude differences, dM_V, are also included for most of the observed double stars. B magnitude differences are listed in the notes for a few systems. We are particularly aware of the value of accurate measurements of the difference in the magnitudes of the components of double stars. For example, studies of the astrometric orbit of a binary star require observations extending over long periods of time. Thus, they often include material from observatory plate files. On these plates the images of the binary star are often blended and the analysis requires knowledge of the magnitude difference of the components at the wavelength of the optical system with which the plates were taken (van de Kamp, 1967).

The value dM_V - dM_I also hints at the nature of the double star system itself and can be useful when combined with additional information about the system. Where A and B represent the brighter and fainter component of the double star respectively, and $dMv = V_B - V_A$ and $dM_I = I_B - I_A$, a little algebra shows that:

$$dM_V - dM_I = (V\text{-}I)_B - (V\text{-}I)_A \qquad (1)$$

Equation 1) thus yields the value we would get if we could measure the V-I magnitude of each component, of the double star, directly and then find their difference. Since the quantity (V-I) is larger for a cooler star, equation 1) will usually yield a positive value for a binary star composed of a pair of main-sequence stars. If equation 1) yields a significantly negative value, the fainter star is hotter than the primary. This could happen if the primary star is a red giant, or the companion is a white dwarf, or if the companion is a bright background star. For example the primary star of the first three Praesepe doubles (WDS 08404+1940) listed in Table 1 is a red giant and cooler than the secondary star. A similar set of possibilities arise if equation 1 yields a much larger positive value than expected. For example STT268 AB in which the components are so widely separated that they are unlikely to form a physical pair.

Since the difference in the temperature of two stars is related to their difference in absolute magnitude, a positive value resulting from equation 1) usually indicates that, as expected, the fainter star has a lower absolute magnitude. In a study of stars within 8 parsecs of the Sun, at the Space Telescope Institute (http://www.stsci.edu/~inr/8pc.html), the relationship between a star's V-I magnitude and its absolute magnitude was shown to be roughly linear, Fig 1.8. Over a broad range the slope is a little less than 5. Unfortunately the relationship is only approximate, and except in the broadest terms, is dependent upon several things that are usually unknown at this point in their investigation.

Results

Because many of the observations listed in Table 1 are based on less than a statistically significant sample, we have chosen to list weights instead of

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Table 1

NAME	WDS	PA	SEP	W	Va-Vb	Ia-Ib	W	DATE	N	notes
STF1066	07201+2159	227.76	5.600	2.4	4.66	4.03	1.1	2012.202	2	1
STF1110AB	07346+3153	56.28	4.831	2.3	0.99	0.87	1.4	2012.115	2	2
HEI 131	07349+1435	20.59	2.685	1.5	0.59	0.58	0.8	2012.203	1	
HEI 51	07436+1445	101.39	2.935	1.8	1.22	1.30	1.2	2012.203	1	
GAT 1	08239+6610	93.45	4.030	1.7	2.40	2.21	1.1	2012.079	2	3
HEI 144	08289+1550	145.48	2.182	2.0	0.67	0.63	0.9	2012.220	1	
STF1254AB	08404+1940	54.42	20.544	1.9	4.04	4.37	1.6	2012.236	1	4
STF1254AC	08404+1940	342.75	63.413	2.4	1.24	2.04	1.6	2012.231	3	5
STF1254AD	08404+1940	43.96	82.710	1.9	2.94	3.46	1.6	2012.236	1	6
S 572CD	08404+1940	90.80	76.227	1.9	1.70	1.41	1.6	2012.236	1	7
HJ 2494	09244+5813	27.56	6.097	2.4	1.99	2.09	1.8	2012.236	1	8
STF1374AB	09414+3857	309.94	2.835	2.6	1.23	1.21	1.0	2012.232	2	
COU2502	09428+4350	134.46	1.848	1.2		0.94	0.7	2012.236	1	
new		208.91	2.379	1.4		2.64	0.8	2011.290	2	9
new		209.76	2.454	1.4		2.61	0.9	2012.203	2	10
STF1472	10470+1302	37.06	43.225	1.7	1.02	0.96	1.2	2012.329	1	
STT 231AB	11111+3027	262.58	34.196	2.3	1.67	1.10	1.0	2012.079	3	11
HJ 1196AB	11456+0354	204.25	45.727	1.7	1.09	0.54	1.0	2012.329	1	12
new, Aa,Ab	11456+0354	157.32	0.809	1.2	0.15	0.04	1.0	2012.329	1	13
STF1579AB,C	11551+4629	41.80	3.863	4.0	1.91	1.98	1.1	2012.237	4	14
STF1579AB,D	11551+4629	113.88	63.047	4.1	0.31	0.37	1.0	2012.239	4	15
HJ 1210	12069+0548	115.45	6.992	2.1	2.36	1.58	1.4	2012.220	1	
COU2103	12185+5037	136.42	2.534	1.8	-0.04	-0.02	1.2	2012.267	1	16
STT 268AB	13309+2414	75.87	19.597	0.5		4.33	0.3	2011.423	1	
STT 268AB	13309+2414	75.82	19.584	3.2	6.01	4.34	1.8	2012.267	1	
H 5 70AC	13309+2414	256.43	76.677	0.6	0.62	0.20	1.8	2011.423	1	
GAT 2Ba,Bb	13309+2414	36.43	1.460	0.5		0.05	0.3	2011.423	1	17
GAT 2Ba,Bb	13309+2414	36.63	1.529	2.7	0.10	0.07	1.8	2012.301	2	18
STF2055	16309+0159	39.28	1.397	5.8	1.028	1.057	2.5	2012.401	1	19
GAT 3AB	18483+5752	113.12	2.270	1.7	5.42	1.69	0.9	2011.594	2	20
stI2390AC	18483+5752	97.79	5.090	1.7	2.85	2.24	0.9	2011.594	2	

NOTES

1. Wasat
2. Castor
3. Russell, J., Gatewood, G., Stein, J.W. 1976, A.J., Vol. 81, 545
4. member of the Praesepe open star cluster
5. member of the Praesepe open star cluster
6. member of the Praesepe open star cluster
7. member of the Praesepe open star cluster
8. the observations of this star approximate a straight line
9. newly discovered companion to Hip 49544
10. 2nd year of observations of new companion of Hip 49544
11. incomplete orbit
12. A is a well resolved double making it difficult to measure dMv or dMi
13. newly discovered companion to STF1579 A
14. A and B are not resolved. dMb=1.952 magnitudes with a weight of 1.0
15. dMb = 0.373 magnitudes with a weight of 0.8
16. the B component is slightly brighter in both V and I
17. newly discovered
18. the newly discovered star is brighter than B
19. Lambda Oph, dMb = 1.053 with a weight of 1.0
20. newly discovered companion, dMv is based on only 2 images

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Table 2

WDS	NAME	Va-Vb	SIMBAD	Residual
08404+1940	STF1254AB	4.04	3.93	0.11
08404+1940	STF1254AC	1.24	1.26	-0.02
08404+1940	STF1254AD	2.94	2.94	0.00
08404+1940	S 572CD	1.70	1.68	0.02
11111+3027	STT 231AB	1.67	1.64	0.02
11551+4629	STF1579AB,D	0.31	0.45	-0.14
13309+2414	H 5 70AC	0.62	0.55	0.07

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standard errors. We have arbitrarily set a weight of 1.0 to equal the average internal standard error of 5 good images. This value was chosen because we suspect that systematic errors will become an increasingly significant factor in the application of data with a much higher precision. The values reflected by the weights are internal errors only. Our estimate at this time is that a weight of 1.0 indicates a photometric precision of approximately 0.03 magnitudes or better. Similarly a weight of 1.0 indicates astrometric standard error of approximately 0.035 arc seconds or better. We believe that these numbers reflect the short duration of the exposures more than the limitations of the instrumentation or software (Gatewood, G.D. 1987, Gatewood, G. 1991). Since the position angle and separation are derived from measurements made in Cartesian coordinates, the geometrical relationship between the errors of separation and position -angle apply.

Table 1 lists the discovery designation of each star followed by its WDS (Mason, B., G. L. Wycoff, W. I. Hartkopf, online) number. The observed, not adjusted for precession, position angle and separation are followed by the astrometric weight. Next are the observed differences in the V and I magnitudes followed by their weight. As noted above the V magnitudes are usually based on less data. Thus the internal error of the I data is somewhat better than that of the V measurements. Where B magnitude differences are given, in the notes, a weight estimate is also given for that measurement. The epoch of observation, weighted if there is more than one night of observations within a given year, is in fractional Besselian years. The number of nights of observation and a column of note numbers are on the far right of the Table. Individual notes are listed by number at the end of the Table.

As the first in what we hope is a series of papers on double stars, the present work does not contain enough data to determine the systematic or external errors of our observations. Table 2 and Table 3 are a first attempt to put a range on the outcome of more detailed future investigations. Since one of our goals is to provide magnitude differences in the photometric B, V, and I_C bands we compare our data with that found on the SIMBAD http://simbad.harvard.edu/simbad/sim-fid data base for the wide double stars in the present work. The value we list in Table 2 is the difference in the straight mean of the V values listed in the UBV data, on that site for each of the components. We find that this reference material has an average standard error of approximately 0.025 magnitudes. Table 2 lists the WDS number of each double star followed by the dM_V listed in Table 1 and that calculated as noted. The last column is the difference. The average difference is +0.009 magnitudes and the standard deviation is 0.079 magnitudes. We note that both of the largest differences are for stars with a component within 20 arc seconds of the primary and that each photoelectric estimate in these two cases is based upon only one reference. We believe that the magnitude differences in the B, V, and I_C have similar accuracies.

Table 3 is a comparison of the measured position angle and separation with that predicted in the ephemeris listed either in the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf, W.I. and Mason, B.D. (online) or the Catalog of Rectilinear Elements (Hartkopf, W.I. and Mason, B.D. 2011). We note that the average standard deviation of the differences in the position angles and separations is 0.051 arc seconds. Table 3 lists the WDS number, the discovery designation, and the Besselian epoch date of our observation. This is followed by the observed position angle and separation. Next we list the residual to each of these respectively. The last column is the reference code used in the respective catalog.

Table 3

WDS	NAME	DATE	PA	SEP	O-C PA	O-C SEP	Reference
07201+2159	STF1066	2012.202	227.76	5.600	0.12	0.044	Hop1960a
07346+3153	STF1110AB	2012.115	56.28	4.831	-0.05	0.016	DRs2012
10470+1302	STF1472	2012.329	37.06	43.225	0.11	0.004	Hrt2011c
11456+0354	HJ 1196AB	2012.329	204.25	45.727	0.02	-0.076	Hrt2011c
13309+2414	H 5 70AC	2011.423	256.43	76.677	-0.05	0.079	Hrt2001c
16309+0159	STF2055AB	2012.401	39.28	1.397	0.36	-0.044	Hei1993b

Our ability to estimate the precision and the accuracy of our data will improve as our data base increases. No attempt has been made to adjust any of the data listed in the present manuscript for any suspected systematic error.

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We would like to thank Brian Mason and William Hartkopf of the US Naval Observatory for their advice and guidance. We would also like to thank Florent Losse for his guidance and the use of his free software REDUC. We have made use of the *Catalog of Rectilinear Elements,* the SIMBAD data base, the *Sixth Catalog of Orbits of Visual Binary Stars*, and the *Washington Double Star Catalog*. We thank the institutions and people who support these ongoing efforts.

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