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This issue we have articles from professional, advanced amateur, and beginning amateur astronomers. The accomplishments from the beginning amateurs, though more modest, are no less noteworthy because they have the ambition to strike out in a new direction. Sometimes beginning something new can be difficult. Kudos also to the pros and experienced observers who take the time to assist new observers and bring them to the interesting world of double star astronomy. The picture at right is of Mr. Grisham and his 3" Tasco; see the article beginning on page 10.

We note that this issue begins volume 4 and completes our third year of publishing the JDSO. We want to thank all of you who take the time to read this e-journal. We're especially grateful to all who have contributed articles. It wouldn't happen without you.

The Editors

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# Divinus Lux Observatory Bulletin: Report #12

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**Abstract:** This report contains theta/rho measurements from 98 different double star systems. The time period spans from 2007.570 to 2007.748. Measurements were obtained using a 20-cm Schmidt-Cassegrain telescope and an illuminated reticle micrometer. This report represents a portion of the work that is currently being conducted in double star astronomy at Divinus Lux Observatory in Flagstaff, Arizona.

In my previous article, I made a reference to the work of Charles Lada in regards to the frequency of the occurrences of binary star systems. As a postscript to my eleventh report, I might also mention that as I have been working with the double star listings in the WDS catalog, I've noticed that a substantial number of these doubles appear to be optical in nature. This assessment is based upon the divergent proper motions of the various pairs that I have measured over the past several years. Because of the importance of trying to avoid filling the WDS catalog with even more such listings, it should probably become standard practice to submit only doubles, which display an apparent common proper motion, as new possible pairs. As is well known, while common proper motion is not a sufficient condition, it is a necessary condition in determining whether a given double star is also binary in nature.

Many of the existing optical double listings were submitted during the 19<sup>th</sup> and early 20<sup>th</sup> centuries when the proper motions of many of the stars were unknown. Hence, it would not be appropriate to be overly critical about the cataloging of these double stars in the past. However, with the resources that are now currently available, most of the obvious optical doubles can, and probably should be, identified as such and not be submitted as new double stars. For this reason, I have realized the necessity to become more meticulous with my own research in this regard.

As has been done in previous articles, the selected double star systems, which appear in this report, have been taken from the 2001.0 version of the Washington Double Star Catalog, with published measurements that are no more recent than ten years ago. Several systems are included from the 2006.5 version of the WDS catalog as well. There are also some noteworthy items that are discussed pertaining to the following table.

Consistent with previous reports, several double stars are being highlighted, in this article, for significant theta/rho shifts resulting from proper motion by one or both of the components. To begin with, a decrease of 3.5% in the rho value, for BU 680 AC, appears to have occurred since 1985. Proper motion by the "A" component is responsible for this. Secondly, proper motion by the reference point star, for HJ 951, has caused a 3.5% increase in the rho value since 1997. Thirdly, a combination of only one set of published measurements in 1925 and proper motion by both components, in regards to STF 2952 AC, has caused significant variances from current measurements. The rho value has decreased by almost 34" and the theta value has increased by about 14.5 degrees. The 1925 measurements may have been inaccurate because the proper motion vectors indicate that the theta value should be decreasing. Next, proper motion, mostly by the companion star, for SKF 16, is responsible for an increase of 8.5 degrees in the theta

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value since 1981. Similarly, proper motion by the companion star has caused a rho value shift in regards to B 1918. An increase of 6.5% has been measured since the 1998 listing was published. Lastly, a large proper motion by the reference point star, for LDS 3346, has been responsible for a 4 degrees increase in the theta value and a 2.7% increase in the rho value, since 1998.

Regarding H 18 AD, it is apparent that a large proper motion by the "A" component has caused significant increases in the rho parameter since the first measurements were performed in 1781. However, the 1998 rho values in the 2001.0 and the 2006.5 versions of the WDS catalog differ by 4 seconds. Consequently, the rho value in the table shows a 4% increase over the value listed in the 2001.0 catalog, but the table value is 1.9% less than the rho value in the 2006.5 catalog. Since the rho value is increasing at a rate of approximately ".06" per year, one or both of the catalog versions appear to be in error. The 1781 rho value could also be inaccurate. These components were measured several times because the rho value in the table is not in good agreement with the rho values in either of the catalogs, based upon the rate of a ".06" increase per year. Perhaps additional measurements would help to bring more accuracy to this rho value.

Proper motions in opposite directions, by both components of two optical double stars, are responsible for noteworthy increases in the rho values for these systems. In regards to STF 85 AB, the rho value has increased by 2.4% since 1998. For H 12 AD, the rho value has increased by 3.5%, or 9.5 arc seconds, since 1923. In this second case, the passage of over 80 years, since the 1923 measurement was published, has contributed to this large increase in the rho value.

In contrast to the systems mentioned above, orbital motion appears to be the cause for an increase of 2.5 degrees in theta value, for STT 547 AB, since 1998. These components share a common proper motion

Because of the paucity of measurements that exist for LMP 23 AB-C, and those having been made over 35 years ago, the theta measurement appearing in the table departs significantly from the catalog value. Hence, a difference of 9 degrees is being reported from

the last published measurement in 1970. While the proper motion vector for the "C" component suggests that the theta value should be increasing, the value in the table is less than the 1970 value. Additional measurements might help to establish accurate values for both the theta and rho parameters.

Two possible common proper motion pairs, which do not appear to have been previously cataloged, are also listed in the table. The first one, identified as ARN 98 (21578+5234), is located near the STT 456 multiple star system in Cygnus. The second, listed as ARN 99 (22843+4524), can be found near HJ 1815 in Lacerta.

Some errors, which have appeared in the WDS catalog, are also being noted. First of all, regarding BU 696 AD and AE, the theta/rho measurements have been listed between the wrong components. The "AD" measurements that are listed in the catalog are actually for "CD" and the "AE" values represent measurements for "AD." No "E" component exists for this quadruple star system. Also being noted is a quadrant flip, which appears to have occurred, for the 1998 theta measurements pertaining to ROE 59 AC. A value of 15 degrees would be needed, rather than 195 degrees, in order for the orientation of the theta value of the "AB" components to remain at 213 degrees. The theta value of the "AC" components is listed as 13 degrees for measurements published in 1902.

Next, two double stars have been identified that have coordinates that are slightly different from what are listed in the catalog. The first one, CHE 435, is located near 23067-0412 rather than the listed coordinates of 23072-0411. This matches the coordinates for HJ 978 and the theta/rho measurements for CHE 435 also closely match those for HJ978. Hence, CHE 435 appears to be a duplication of HJ 978 should probably be removed from the WDS catalog. The second double star that has a coordinate variance from the catalog listing is HJ 1808. The catalog coordinates are listed as 22454+4903, but this pair appears closer to the coordinates of 22464+4903. In this case, HJ 1808 is not a duplicate entry, but the coordinate variance might partially explain the reason for only one set of published measurements appearing in the catalog, with those being in 1901.

*Table begins on next page.*

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NAME	RA DEC	MAGS	PA	SEP	DATE	N	NOTES
STF2769	21105+2227	6.7 7.4	300.9	18.27	2007.608	1n	1
SKF 16	21245+1003	10.0 10.2	59.5	53.82	2007.608	1n	2
ES 35 AC	21406+5419	8.6 10.7	29.1	21.23	2007.608	1n	3
ARN 98**	21578+5234	10.1 10.5	264.9	35.55	2007.608	1n	4
HJ 951	22014+3243	9.5 10.5	60.5	12.84	2007.608	1n	5
STT 228 AB	22019+0446	8.0 9.8	23.3	85.91	2007.608	1n	6
S 802 AB	22024-1658	7.1 7.1	246.0	3.95	2007.608	1n	7
BU 696 AC	22045+1551	7.7 8.9	322.1	63.20	2007.570	1n	8
BU 696 AD	22045+1551	7.7 9.9	3.0	120.97	2007.570	1n	8
STF2887	22173-0042	9.8 9.8	29.6	7.90	2007.570	1n	9
HO 615 AB	22213+2820	4.8 10.7	128.7	71.10	2007.570	1n	10
STF2910	22282+2332	9.0 9.6	332.3	5.43	2007.570	1n	11
STF2915	22326+0725	9.4 9.5	126.5	14.81	2007.570	1n	12
HJ 1808	22464+4903	10.5 10.5	317.8	10.86	2007.608	1n	13
ARN 99**	22483+4524	8.4 10.4	229.4	37.53	2007.608	1n	14
STF2945	22497+3119	9.0 9.1	299.7	3.95	2007.570	1n	15
STF2952 AB	22542+2801	7.7 10.4	138.3	17.28	2007.608	1n	16
STF2952 AC	22542+2801	7.7 10.4	244.4	165.90	2007.608	1n	16
BU 847	22546+2020	9.0 10.3	35.0	6.91	2007.570	1n	17
STT 485 AB	23027+5514	6.5 10.1	48.1	18.76	2007.647	1n	18
STT 485 AC	23027+5514	6.5 10.4	79.9	56.29	2007.647	1n	18
STT 242	23065+4655	7.8 8.6	31.1	79.99	2007.647	1n	19
CHE 435	23072-0411	9.2 10.7	288.9	14.81	2007.573	1n	20
STF2978	23075+3250	6.3 7.4	143.8	8.39	2007.647	1n	21
LMP 23 AB-C	23096+0045	10.1 10.5	89.8	238.98	2007.647	1n	22
S 825 AB	23100+3651	7.6 8.1	319.9	66.66	2007.647	1n	23
STF2988	23120-1156	7.8 7.8	98.0	3.46	2007.647	1n	24
STT 494	23208+2158	8.2 8.7	82.0	3.46	2007.647	1n	25
STF 3007 AC	23228+2034	6.7 10.7	306.3	99.74	2007.647	1n	26
LDS 816 A-BC	23328-1651	8.6 10.6	352.3	338.71	2007.573	1n	27
STF 3028	23386+3502	7.1 10.0	200.3	14.81	2007.573	1n	28
HJ 991 AB	23417+2226	10.4 10.7	342.3	16.79	2007.573	1n	29
H 24	23460-1841	5.6 6.4	135.8	6.91	2007.647	1n	30

*Table continued on next page.*

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NAME	RA DEC	MAGS	PA	SEP	DATE	N	NOTES
STF3040	23481+1009	9.5 9.7	217.8	4.44	2007.573	1n	31
STT 252	23549+2929	6.8 8.2	145.2	110.60	2007.647	1n	32
STI1248	00004+6026	10.3 10.7	48.4	12.34	2007.630	1n	33
STT 254 AB	00013+6021	7.0 8.3	89.4	57.77	2007.707	1n	34
STT 254 Aa	00013+6021	7.0 9.4	324.4	155.04	2007.707	1n	34
STT 254 Bb	00013+6021	8.3 10.3	129.6	133.31	2007.707	1n	34
TOB 9	00040+4942	9.0 9.8	25.9	43.94	2007.630	1n	35
STT 547 AB	00057+4549	8.8 9.0	184.5	5.93	2007.685	1n	36
STT 547 AF	00057+4549	8.8 10.0	253.8	327.85	2007.685	1n	36
STF 1	00089+3713	8.9 10.7	285.9	9.88	2007.685	1n	37
ES 928	00093+5324	9.9 10.6	17.9	8.39	2007.630	1n	38
HJ 1944	00132-1711	7.5 9.0	335.1	66.16	2007.630	1n	39
ROE 59 AC	00138+4648	10.4 10.7	15.2	104.68	2007.630	1n	40
HJ 1959	00226+2140	9.0 10.7	285.9	27.16	2007.630	1n	41
STT 11	00307+3208	7.5 7.7	318.5	197.50	2007.685	1n	42
STT 13 AB	00318+3658	8.2 10.6	131.8	6.42	2007.630	1n	43
STT 13 AD	00318+3658	8.2 10.6	174.3	42.46	2007.630	1n	43
H 18 AD	00405+5632	2.2 8.8	281.8	68.14	2007.685	1n	44
LDS3195 AB	00446-1856	10.7 10.2*	242.0	146.64	2007.630	1n	45
ES 446	00458+4951	8.6 10.7	256.6	13.83	2007.630	1n	46
BU 232 AB-C	00504+5038	8.4 9.9	298.6	24.69	2007.630	1n	47
STF 85 AB	01044-0518	8.6 10.5	157.9	36.04	2007.707	1n	48
STF 88 AB	01057+2128	5.3 5.5	159.3	29.63	2007.707	1n	49
STF 90 AB	01058+0455	6.4 7.2	84.3	33.08	2007.707	1n	50
STF 91	01072-0144	7.4 8.6	316.0	4.44	2007.707	1n	51
BU 236	01121+4700	9.1 9.2	113.9	5.43	2007.633	1n	52
SKI 1	01121-1338	9.1 10.0	250.8	8.39	2007.707	1n	53
STF 97	01122+5132	8.7 9.1	102.1	4.44	2007.633	1n	54
STF 111	01180-0420	9.4 10.5	329.1	20.74	2007.633	1n	55
HJ 2039 AB-C	01220-0927	9.1 10.6	244.1	51.35	2007.633	1n	56
STT 16	01227+1712	7.2 10.1	137.1	71.10	2007.633	1n	57
GAL 307 A-BC	01230-1258	7.8 10.4	313.0	40.49	2007.633	1n	58
ES 759	01348+5209	10.5 10.7	91.0	10.37	2007.707	1n	59

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NAME	RA DEC	MAGS	PA	SEP	DATE	N	NOTES
STT 20 AB	01376+2233	7.8 8.8	315.7	88.88	2007.633	1n	60
GAL 312	01434-1127	9.1 10.7	326.8	43.45	2007.633	1n	61
STF 162 Aa-D	01493+4754	6.5 9.9	96.0	138.74	2007.633	1n	62
STF 179	01532+3719	7.5 8.1	160.0	3.46	2007.685	1n	63
GAL 315	01572-1015	6.4 10.6	133.8	29.63	2007.707	1n	64
H 12 AB	01579+2336	4.8 6.6	47.2	37.53	2007.707	1n	65
H 12 AD	01579+2336	4.8 9.8	84.7	270.58	2007.707	1n	65
S 409 AB	01581+4123	7.6 9.6	83.2	28.64	2007.685	1n	66
BAL 9	02003-0138	9.8 10.3	336.3	5.93	2007.652	1n	67
LDS3346	02076-0037	6.9 10.5	342.1	81.47	2007.748	1n	68
STF 215	02091+4048	9.0 10.3	60.2	19.75	2007.748	1n	69
STF 227	02124+3018	5.2 6.6	69.0	3.95	2007.748	1n	70
ES 1306	02234+4441	10.3 10.5	275.1	9.38	2007.652	1n	71
B 1918	02244-1810	8.8 9.8	116.9	5.43	2007.726	1n	72
HJ 1240	02258-1038	8.0 10.3	265.2	10.86	2007.652	1n	73
HJ 2137	02283+4314	9.1 10.6	132.7	27.65	2007.652	1n	74
MLB1061 AC	02324+3905	10.0 10.7	311.3	24.69	2007.652	1n	75
AG 303 AB	02340+4409	10.2 10.7	292.4	15.80	2007.652	1n	76
AG 42	02343+4017	9.0 9.5	143.8	6.42	2007.748	1n	77
BAL 279	02425-0119	10.0 10.2	41.4	5.93	2007.668	1n	78
STF 300	02446+2928	7.9 8.0	314.5	3.46	2007.748	1n	79
STF 307 AB	02507+5554	3.7 8.5	302.2	28.64	2007.748	1n	80
ROE 67 AB	02517+3854	8.9 10.6	129.8	26.66	2007.652	1n	81
GAL 79	02535-1151	10.5 10.7	354.4	5.93	2007.652	1n	82
STF 330	02572-0034	7.2 9.0	192.4	8.89	2007.652	1n	83
A 208 AC	02584-0135	8.9 10.7	279.2	133.81	2007.652	1n	84
AG 305	03063+5100	10.2 10.3	100.4	11.36	2007.726	1n	85
ALI 514	03113+3805	10.7 10.7	209.8	11.85	2007.726	1n	86
ES 1310 AD	03131+4440	10.4 9.0*	234.8	98.26	2007.726	1n	87
STF 372 AB	03193+4559	10.1 10.5	291.6	7.90	2007.726	1n	88
HJ 3246 AC	03207+1736	9.9 9.9	138.3	172.81	2007.726	1n	89
STF 378	03245+5826	9.5 10.6	314.2	18.76	2007.726	1n	90
STF 384 AC	03285+5954	7.9 10.6	341.9	116.53	2007.726	1n	91

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NAME	RA DEC	MAGS	PA	SEP	DATE	N	NOTES
KR 20	03309+5558	9.9 10.3	297.7	7.41	2007.726	1n	92
BU 532 AC	03332-1003	8.6 7.3*	310.9	79.99	2007.726	1n	93
STF 417	03335-0233	8.7 10.6	180.3	25.68	2007.726	1n	94
SMA 37 AB	03339+4351	9.5 10.7	287.8	31.60	2007.726	1n	95
ROE 76 AC	03340+4048	9.1 10.5	156.1	87.39	2007.726	1n	96
HJ 3583	03377-2028	10.2 10.5	86.8	11.85	2007.726	1n	97
HJ 2201	03412-0517	8.3 10.7	41.7	38.51	2007.726	1n	98

\* Companion star is the brighter component.

\*\* Not listed in the WDS CATALOG.

## Notes

1. In Vulpecula. Relatively fixed. Spect. A1V, A4V.
2. In Equuleus. Sep. decreasing; p.a. increasing. Spect. K3.
3. In Cygnus. Sep. increasing. Spect. M8, A.
4. In Cygnus. Possible common proper motion. Near STT 456 system.
5. In Pegasus. Sep. increasing; p.a. decreasing. Spect. F5.
6. In Pegasus. Sep. increasing; p.a. decreasing. Spect. G5, G0.
7. In Aquarius. Sep. dec.; p.a. inc. Common proper motion. Spect. A2V, A2V.
8. In Pegasus. AC = Sep. & p.a. inc. AD = p.a. inc. Spect. AC = G0V, K0.
9. In Aquarius. Common proper motion; p.a. increasing. Spect. K0.
10. 32 Pegasi. Slight increase in position angle. Spect. B9III.
11. In Pegasus. Common proper motion; p.a. decreasing. Spect. K0IV, K0IV.
12. In Pegasus. Sep increasing; p.a. decreasing. Spect. F0, F0.
13. In Lacerta. Sep. & p.a. increasing.
14. In Lacerta. Possible common proper motion. Near HJ 1815. Spect. B8, A0.
15. In Pegasus. Position angle increasing. Spect. F0, F0.
16. In Pegasus. AB = c.p.m.; p.a. inc. AC = sep. dec. Spect. AB = F8V, F8V.
17. In Pegasus. Common proper motion; p.a. decreasing. Spect. G5.
18. In Cassiopeia. AB = sep. & p.a. dec. AC = sep. inc. Spect. B9III.
19. In Andromeda. Relatively fixed. Spect. B3, B9.
20. In Aquarius. Relatively fixed. Common proper motion. Spect. F2.
21. In Pegasus. Common proper motion; p.a. decreasing. Spect. A3V, A3.
22. In Pisces. Position angle decreasing. Spect. G2.
23. In Andromeda. Relatively fixed. Spect. K2, K2.
24. In Aquarius. Common proper motion; p.a. decreasing. Spect. G8III, G8III.

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25. In Pegasus. Relatively fixed. Spect. F0, F0.
26. In Pegasus. Sep. increasing; p.a. decreasing. Spect. G2V.
27. In Aquarius. Relatively fixed. Common proper motion. Spect. K5.
28. In Andromeda. Sep. & p.a. decreasing; common proper motion. Spect. A2, A2.
29. In Pegasus. Position angle decreasing.
30. 107 Aquarii. Common proper motion; sep. inc.; p.a. dec. Spect. F2V, F2V.
31. In Pegasus. Relatively fixed. Common proper motion. Spect. F5, F5.
32. In Pegasus. Slight increase in position angle. Spect. B9, K0.
33. In Cassiopeia. Sep. decreasing; p.a. increasing. Spect. K0, K.
34. In Cassiopeia. AB, Aa, & Bb = sep. slightly dec. Spect. A, B, a = N1, B5, G5
35. In Cassiopeia. Position angle decreasing. Spect. F0, A2.
36. In Andromeda. A, B, & F = cpm. AB = p.a. increasing. Spect. K6, M0, M2.
37. In Andromeda. Relatively fixed. Spect. A5.
38. In Cassiopeia. Relatively fixed. Common proper motion.
39. In Cetus. Separation increasing; p.a. decreasing. Spect. K0, G0.
40. In Andromeda. Position angle slightly increasing.
41. In Andromeda. Sep. increasing; common proper motion. Spect. K2, G5.
42. In Andromeda. Relatively fixed. Common proper motion. Spect. F2, F5.
43. In Andromeda. AB & AD = sep. inc.; p.a. dec. Spect. AB = G0, G0.
44. Alpha or 18 Cassiopeiae. Sep. & p.a. increasing. Spect. K0III, K0.
45. In Cetus. Sep. & p.a. increasing. Spect. M2.
46. In Cassiopeia. Separation increasing. Spect. K5.
47. In Cassiopeia. Sep. decreasing; p.a. increasing. Spect. F5, G.
48. In Cetus. Separation increasing. Spect. G0.
49. Psi or 74 Piscium. Common proper motion; p.a. dec. Spect. B9.5V, A0V.
50. 77 Piscium. Relatively fixed. Common proper motion. Spect. F3V, F5V.
51. In Cetus. Sep. increasing; p.a. decreasing. Spect. F9V, F5.
52. In Andromeda. Separation increasing. Spect. A0.
53. In Cetus. Common proper motion. Sep. & p.a. slightly dec. Spect. F0, A8V.
54. In Cassiopeia. Relatively fixed. Common proper motion. Spect. A0, A0.
55. In Cetus. Relatively fixed. Common proper motion. Spect. F7.
56. In Cetus. Sep. & p.a. increasing. Spect. F0.
57. In Pisces. Separation increasing. Spect. F5V, F2.
58. In Cetus. Relatively fixed. Common proper motion. Spect. K0IV.
59. In Perseus. Relatively fixed. Spect. G5.
60. In Pisces. Sep. decreasing; p.a. increasing. Spect. F6V, F5.
61. In Cetus. Sep. increasing; p.a. decreasing. Spect. G0, G0.
62. In Perseus. Separation increasing. Spect. A2, F8.

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63. In Andromeda. Relatively fixed. Common proper motion. Spect. F2V, F5.
64. In Cetus. Position angle slightly increasing. Spect. G5IV.
65. In Aries. AB = reifix; cpm. AD = sep.inc. Spect. F0IV, F7V, K0.
66. In Andromeda. Sep. & p.a. increasing. Spect. G5, G5.
67. In Cetus. Common proper motion; p.a. slightly increasing. Spect. F8, F8.
68. In Cetus. Sep. & p.a. increasing. Spect. G2V, K.
69. In Andromeda. Sep. & p.a. slightly increasing. Spect. F2V.
70. 6 Trianguli. Common proper motion; p.a. decreasing. Spect. G0III, F5V.
71. In Andromeda. Position angle slightly decreasing.
72. In Cetus. Sep. & p.a. increasing. Spect. G0, G5.
73. In Cetus. Sep. & p.a. increasing. Spect. F5.
74. In Andromeda. Sep. increasing; p.a. decreasing. Spect. F0.
75. In Andromeda. Sep. increasing; p.a. decreasing. Spect. G3V.
76. In Andromeda. Relatively fixed. Common proper motion. Spect. K3III, A2.
77. In Andromeda. Sep. increasing. p.a. decreasing. Spect. A2.
78. In Cetus. Common proper motion; p.a. increasing. Spect. G0, G0.
79. In Aries. Common proper motion; sep. & p.a. increasing. Spect. F0IV, F0.
80. Eta or 15 Persei. Sep. & p.a. slightly increasing. Spect. M3I, A0.
81. In Perseus. Sep. increasing; p.a. decreasing. Spect. F8.
82. In Eridanus. Common proper motion; p.a. decreasing.
83. In Cetus. Relatively fixed. Common proper motion. Spect. G8III, G8III.
84. In Eridanus. Sep. & p.a. decreasing. Spect. F0.
85. In Perseus. Relatively fixed. Common proper motion. Spect. F2, F2.
86. In Perseus. Relatively fixed. Common proper motion.
87. In Perseus. Sep. increasing; p.a. decreasing. Spect. K0.
88. In Perseus. Relatively fixed. Common proper motion. Spect. A9V, F0.
89. In Aries. Separation decreasing.
90. In Camelopardus. Relatively fixed. Common proper motion. Spect. B8, A.
91. In Camelopardus. Position angle increasing. Spect. F8.
92. In Camelopardus. Relatively fixed. Spect. A2.
93. In Eridanus. Relatively fixed. Common proper motion. Spect. F2, A3.
94. In Eridanus. Relatively fixed. Common proper motion. Spect. K0.
95. In Perseus. Relatively fixed. Common proper motion. Spect. A0.
96. In Perseus. Sep. & p.a. increasing. Spect. F5, F5.
97. In Eridanus. Relatively fixed. Common proper motion. Spect. F5.
98. In Eridanus. Sep. decreasing; p.a. increasing. Spect. F8.

# Double Star Measurements with a Three Inch Tasco Telescope

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**Abstract:** Observations were made of three double stars with known separations and position angles using a three inch 1960's Tasco telescope equipped with a Meade astrometric eyepiece. After these observations were completed, their mean values were compared with cataloged values. It was concluded that, under appropriate conditions, a modest aperture Tasco telescope can provide remarkably accurate and precise results.

## Introduction and Experimental Design

We report below on a project conducted as part of the Fall 2007 Physics Research Seminar at Cuesta College near San Luis Obispo, California. We decided to determine how precisely and accurately observations could be made of visual double stars with a three inch Tasco telescope (Figure 1) and a low cost (\$150) Meade astrometric eyepiece.

The observer (Grisham) was assigned three visual double stars to observe by Genet, the research seminar's leader. Grisham was not given any indication of the catalog position angles and separations of these three stars, nor did he have any access to such information at his remote observatory. After Grisham completed his observations, he, Johnson, and Genet calculated the means, standard deviations, and standard errors of the mean for Grisham's data. Only then did Genet reveal the catalog values (Haas 2006) for the three stars (Figure 2).

## Observatory and Equipment

All observations were made at the Grisham Observatory in California Valley, seventy miles east of San Luis Obispo, California, at an elevation of 1,996 feet. The closest small town to this very dark site is thirty-eight miles away.

The 1960's three inch aperture vintage Tasco telescope features an air-spaced objective lens with

crystal-sharp images, a German equatorial mount, and manual controls in both right ascension and declination. Play in the axes' journals was removed by shimming to close the tolerances. The eyepiece holder was modified from its original 0.965" to accommodate the 1.25" astrometric eyepiece. A Deluxe Reflex Sight Red-Dot Finder by Orion was added to facilitate "star hopping." Due to the added weight of the diagonal and larger eyepiece, the counter-balance bar was lengthened. A six inch diameter steel pier was imbedded three feet into 500 lbs. of concrete. The 12mm Meade astrometric eyepiece and a Meade 2x Barlow were used for all observations.

## Procedures

The scale constant of the linear scale, in arc seconds per division, was independently determined for two different stars using the drift method (Argyle 2004). The eyepiece was rotated until the stars drifted from east to west exactly along the linear scale. The star drifts were then timed to one hundredth of a second. Ten drift times were recorded and averaged for each star.

To determine angular separation, the assigned double stars were aligned along the bottom of the 180° "fan" scale. They were then allowed to drift through the central calibrated linear scale. This process was repeated as many times as necessary to develop confidence that the resulting estimate of the separa-

### Double Star Measurements with a Three Inch Tasco Telescope



**Figure 1:** Grisham with his modified 1960's vintage three inch Tasco telescope on its optional tripod. Normally it is installed on a permanent steel pier imbedded in concrete. Its air-spaced objective provides remarkably sharp images.

tion was precise to within about one tenth of a division. Only then was the separation in divisions recorded. The average separation of multiple observations was multiplied by the scale constant to yield the final separation in arc seconds.

Position angles were determined using the drift method, taking the position angle directly from the protractor scale (Argyle 2004). First, the primary and secondary were aligned on the linear scale by rotating the astrometric eyepiece. Then, using the manual

controls, the primary star was taken past the center of the linear scale and allowed to drift through the center. If the star drifted off to either side of the exact center, the process was repeated until the crosshairs in the center cleanly bisected the drifting star. If the star was so dim it was hidden behind the illuminated lines, it was required to disappear completely as it went through the center. Once the star properly passed through the exact center, it was allowed to drift to the 360° protractor. The position of the primary star as it crossed the protractor was then noted and recorded. This process was repeated ten times for each double star and the resulting position angles were averaged.

### Observations

Two well known double stars in Ursa Major, Dubhe and Mizar, were used to calibrate the linear scale. The average drift times, standard deviations, and standard errors of the mean for the calibration stars are shown in Table 1, along with the calculated scale constant given in arc seconds per division.

The three double stars assigned by Genet for observation (with separations and position angles unknown to the observer, Grisham) were 100 Hercules, Kappa Hercules, and Nu Draco. Their cataloged coordinates and apparent magnitudes are shown in Table 2 (Haas 2006).

Star	RA	Dec	Mag 1	Mag 2
100 Her	18h 08m	+26° 06m	5.8	5.8
Kappa Her	16h 08m	+17° 03m	5.1	6.2
Nu Dra	17h 32m	+55° 11m	4.9	4.9

**Table 2:** Catalog coordinates and magnitudes of three assigned double stars

Grisham's measurements of the assigned double stars are shown in Table 3, along with their standard deviations and standard errors of the mean. Ten observations were made of position angles and separations and the results averaged.

Star	Epoch	Declination	Drift (sec)	Std. Dev.	Mean Error	Scale Const.
Dubhe	B2007.392	+61° 45m	72.62	0.13	0.04	10.34
Mizar	B2007.392	+54° 56m	60.00	0.19	0.06	10.37

**Table 1:** Scale constant determination

**Double Star Measurements with a Three Inch Tasco Telescope**

Star	Epoch	Obs. PA	St. Dev.	Mean Error	Obs. Sep.	St. Dev.	Mean Error
100 Her	B2007.460	183.3°	0.4°	0.1°	14.2"	0.9"	0.3"
Kappa Her	B2007.463	14.2°	0.3°	0.1°	27.1"	0.8"	0.3"
Nu Dra	B2007.466	311.1°	0.4°	0.1°	62.5"	0.7"	0.2"

**Table 3:** Observational results of the three assigned double stars

**Results and Conclusions**

Table 4 compares Grisham’s observations with published values for the three stars (Haas 2006).

We concluded that there were no systematic or gross errors with respect to precision, and that the observed values were not significantly different from the cataloged values except for the observed position angle of Kappa Hercules. Kappa Hercules differed from the catalog by 1.2°, far greater than the calculated standard error of the mean (0.1°).

The reason for the variance in the position angle for Kappa Hercules may be that it is an optical double star which has increased its position angle because of proper motion from both components. Specifically, the proper motion in right ascension for the reference point star amounts to about -33 milliarcseconds (mas) per year, while that of the companion is approximately -27 mas per year. In declination, the proper motion of the primary star is approximately -7.9 mas per year, while that of the companion is -30.6 mas per year. It may be the combined effects of these proper motions that are causing the position angle to increase. As a consequence of these shifts, various catalogs are not in agreement concerning the position angle value, varying from 12 to 15 degrees. This double star warrants additional measurements by other researchers to obtain greater accuracy for its position angle.

We attribute the generally remarkable accuracy

and precision of Grisham’s observations to the high quality of his 1960’s three inch Tasco telescope, not to mention its careful shimming, precise equatorial



**Figure 2:** The moment of truth! With observations completed and mean values calculated, Genet (center) finally reveals the catalog values to Johnson (left) and Grisham (right). Both were very pleased with the remarkably close agreements!

alignment, and stout pier. We also attribute this precision to the dark, clear skies of California Valley, and to the refined and painstaking observational procedures Grisham meticulously followed.

To put Grisham’s observational accuracy in context, Ronald Tanguay, who has had many years of experience working with reticle micrometers, states

Star	Obs. PA	Cat. PA	Diff.	Obs. Sep.	Cat. Sep.	Diff.
100 Her	183.3°	183°	0.3°	14.2"	14.2"	0.0"
Kappa Her	14.2°	13°	1.2°	27.1"	27.4"	-0.3"
Nu Dra	311.1°	311°	0.1°	62.5"	63.4"	-0.9"

**Table 4:** Comparison of observation values to catalog values

## Double Star Measurements with a Three Inch Tasco Telescope

that, "Measurements within 5% of catalog values can be considered good and measurements within 1% or less can be looked upon as excellent work. With a well calibrated reticle micrometer, we may expect measurements to average about  $\pm 1$  degree in the position angle and  $\pm 2\%$  in separation from the data listed in the WDS Catalog. The reticle micrometer, if carefully calibrated, can be a reasonably accurate tool for use in measuring double stars." Note that Grisham's average difference from the catalog position angles is only  $0.5^\circ$  and his average difference in separations is 0.8%, both twice as accurate as what Tanguay says is "excellent work."

### Acknowledgements

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# Neglected Double Observations for 2006 No. 4: Some 22<sup>nd</sup> Hour Doubles

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**Abstract:** I report measures for 64 neglected doubles, many having a single previous observation reported in the WDS as of manuscript submission. In addition, I report measures of 15 recently measured pairs. Observations were made with the GRAS002 robotic telescope located at the Remote Astronomical Society Observatory, Mayhill, NM, USA (<http://www.remote-astronomical-society.org/>). In addition to theta and rho values (and standard deviations), I report catalog numbers and magnitude differences of pairs, some of which lack precise positional information and delta-M values.

In this paper, I report a total of 79 mean and standard deviation measures of theta (PA) and rho (Sep) values of double stars imaged using a Takahashi Mewlon 300 Dall-Kirkham cassegrainian reflector located at the Remote Astronomical Society Observatory in Mayhill, New Mexico. The instrument, with a focal reducer, works at F9.1, with an approximate focal length of 2730mm. It is equipped with a non-antiblooming ST8E CCD camera (9 micron pixels) and the combination has an approximate resolution of 0.6arcseconds/pixel with a field of view of 11.5x17.3 arcminutes. The OTA is mounted on a Bisque Paramount 1100 GEM.

## Methods

Methods largely follow Wiley (2007). Observing lists were requested from the USNO (Mason, 2006). The list is processed as detailed in Wiley (2006) using the Aladin interactive sky atlas (Bonnarel et al., 2000), the Washington Double Star Catalog (Mason et al., 2006) and a number of catalogs, minimally

UCAC2.0 (Zacharias et al., 2004), GSC2.3.2 (STScI, 2006), 2MASS (Skrutskie et al., 2006), and AC2000.2 (Urban, 1998).

Exposures are carried out with a clear filter and the initial image was checked by downloading a JPEG of the FITS image to insure that the correct field was imaged. Exposures ranged from 20-40 seconds. MPO Canopus (Warner, 2006) is used to reduce the images as detailed in Wiley (2007). Magnitudes reported are V-magnitudes from the GSC2.3.2 catalog or J-magnitudes from 2MASS catalog. Discoverer code terminology follows Hartkopf and Mason (2004).

## Results

Measures for all pairs, neglected and recently measured are presented in Table 1. This is followed by a discussion of selected pairs.

## Discussion of Selected Measured Pairs

*(Continued on page 18)*

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WDS	Disc	Primary	Secondary	Primary Mag	Secondary Mag	Delta-M	PA	PAsd	Sep	Dsd	Epoch	No. Obs	Notes
22000+2454	POU5605	N2Y0000936	N2Y0012080	13.18	13.78	0.60	63.9	0.55	6.77	0.10	2006.822	4	1,2
22001+4001	MLB1024	N2WX000912	N2WX000913	11.82	12.06	0.24	222.1	0.09	23.52	0.05	2006.822	4	1,2
22003+2922	MLB 497	2M91040187	2M91040178	8.615	11.984	3.37	184.2	0.48	7.54	0.05	2006.822	4	1,3
22006+2510	POU5610	2M 910152516	2M 910152519	10.842	12.698	1.86	145.7	1.94	4.16	0.14	2006.822	4	1,3
22016+2421	POU5615	N2M9000031	N2M9021441	12.82	12.98	0.16	142.5	0.51	7.79	0.04	2006.822	4	1,2
22042+3507	SEI11554	N2W5000147	N2W5000149	11.25	12.06	0.81	114.6	0.18	16.34	0.01	2006.822	4	1,2,4
22042+3806	SEI11555	2M1103119226	2M1103119230	10.297	10.661	0.36	178.4	0.13	7.15	0.11	2006.822	4	1,3
22043+2401	J 1224AB	N2MB000374	N2MB000373	11.11	12.18	1.07	75.6	0.05	28.57	0.03	2006.822	4	1,2,5
22045+2758	MLB 622	2M1185514702	2M1185514700	12.043	12.92	0.88	280.3	0.71	4.02	0.04	2006.822	4	1,3
22050+1130	HJ 290	2M996699436	2M996699435	10.877	11.661	0.78	88.0	0.17	8.75	0.05	2006.822	4	1,3
22058+3059	ES 2361	2M279833675	2M 279833674	9.049	11.997	2.95	291.0	99.9	4.89	99.90	2006.822	1	1,3
22065+2806	MLB 722AB	2M 117315408	2M 117315406	11.427	11.567	0.14	253.2	1.54	2.18	0.19	2006.822	4	1,3
22065+2806	MLB 722AC	2M 117315408	2m117315422	11.427	12.056	0.63	322.8	0.36	32.34	0.07	2006.822	4	1,3
22077+2521	POU5641	2M 117322539	2M 117322532	9.067	14.993	5.93	237.2	0.93	7.40	0.08	2006.822	4	1,3
22080+0358	BAL2566	NOHD000299	NOHD000301	12.35	11.99	0.36	176.8	0.31	15.76	0.07	2006.822	4	1,2
22084+3919	MLB 793	2M 851976056	2M 851976062	11.656	12.533	0.88	209.4	0.42	6.37	0.12	2006.822	4	1,3
22096+2425	POU5650	N2Y0001074	N2Y0001073	12.96	14.1	1.14	293.8	0.32	15.88	0.07	2006.835	4	1,2
22098+0800	HJ 955	NOGM002945	NOGM002946	11.4	12.26	0.86	139.2	0.18	9.77	0.04	2006.835	4	1,2
22100+0757	STF2867	NOGM000166	NOGM000169	8.31	9.31	1.00	208.4	0.1	10.30	0.08	2006.835	4	1,2
22100+3343	GYL 72	N2WM000023	N2WM000021	11.82	11.96	0.14	344.1	0.09	21.79	0.04	2006.835	4	1,2
22105+2421	POU5655	N2Y0000031	N2Y0000033	13.26	13.48	0.22	223.6	0.2	13.69	0.03	2006.835	4	1,2
22102+2418	POU5653	N2Y0000058	N2Y0000053	11.94	12.54	0.60	310.6	0.29	21.46	0.07	2006.835	4	1,2,5
22107+3322	GYL 73	N2WM000238	N2WM000278	11.22	12.52	1.30	339.2	0.08	18.03	0.04	2006.835	4	1,2,4
22109+1159	CHE 330	N0JL000116	N0JL000117	11.05	13.03	1.98	113.3	0.05	15.64	0.03	2006.835	4	1,2
22111+4032	MLB 963	2M 350955569	2M 350955576	12.035	13.081	1.05	9.7	0.66	6.57	0.11	2006.835	4	1,3
22114+0057	BAL1240	N0G8000159	N0G8000158	11.89	12.38	0.49	274.5	0.07	10.18	0.02	2006.838	4	1,2,4
22122+0553	HJ 3097AB	2M1165327003	2M1165327018	7.797	11.432	3.64	38.1	0.09	20.41	0.03	2006.838	4	1,3,5
22122+0553	HJ 3097AC	2M1165327003	2M1165327029	7.797	12.903	5.11	334.0	0.22	26.71	0.02	2006.838	4	1,3,5

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WDS	Disc	Primary	Secondary	Primary Mag	Secondary Mag	Delta-M	PA	PAsd	Sep	Dsd	Epoch	No. Obs	Notes
22122+0553	HJ 3097Bb	2M1165327018	2M1165327025	11.432	12.657	1.23	324.3	0.27	7.20	0.16	2006.838	4	1,3
22123+3952	MLB1100	N2X3000831	N2X3029267	11.31	12.97	1.66	301.3	0.59	8.54	0.07	2006.838	4	1,2
22127+1134	HJ 3099	N0JL000204	N0JL000203	11.89	13.01	1.12	57.7	0.39	11.25	0.09	2006.838	4	1,2
22145+2452	POU5673	2M118180014	2M118180022	12.898	12.765	0.13	226.5	0.7	7.21	0.05	2006.838	4	1,3
22156+2500	POU5678	N2V4000764	N2V4000766	13.38	13.95	0.57	175.0	0.16	15.58	0.07	2006.838	4	1,2
22156+3811	ES 2530	2M 351076399	2M 351076396	10.347	10.304	0.04	307.0	0.84	4.69	0.19	2006.838	4	1,3
22172+2502	POU5681	N08W000264	N08W000263	13.21	13.48	0.27	85.5	0.5	8.44	0.12	2006.838	4	1,2
22178+3857	MLB 795	2M 351140792	2M 351140791	11.533	11.853	0.32	80.5	0.37	6.53	0.10	2006.838	4	1,3
22183+0442	HJ 3103	N0HN000096	N0HN000099	12.58	13.08	0.50	111.6	0.36	14.58	0.05	2006.838	4	1,2
22183+2529	POU5683	N2V4000365	N2V4000372	12.43	13.16	0.73	168.4	0.14	12.84	0.04	2006.838	4	1,2
22189+3807	ALJ 701	N2W8000865	N2W8000869	11.38	11.03	0.35	193.9	0.09	14.13	0.02	2006.857	4	1,2
22190+3912	MLB 994	2M 351173167	2M 351173168	12.883	13.914	1.03	253.7	0.32	3.86	0.22	2006.857	4	1,2
22199+1553	HJ 1750	N0M1015466	N0M101000312	9.01	11.61	2.60	247.7	0.1	22.29	0.02	2006.857	4	1,2
22211+3544	ES 2389	2M1306284260	2M1306284266	10.048	11.417	1.37	30.1	0.58	6.04	0.08	2006.857	4	1,3
22234+2300	ROE 129AB	N0LP000434	N0LP000452	9.69	11.36	1.67	206.5	0.04	89.98	0.04	2006.857	4	1,2,5
22234+2300	ROE 129BC	2M1112443147	2M1112443146	10.425	12.008	1.58	301.2	1.73	5.13	0.13	2006.857	4	1,3
22239+3226	ES 2390	2M 280742413	2M 280742407	8.749	8.821	0.07	323.9	0.4	7.30	0.09	2006.857	5	1,3
22244+3648	J 3166AB	2M1125008057	2M1125008053	10.737	11.59	0.85	176.1	0.35	3.42	0.18	2006.857	4	1,3,5
22244+3648	J 3166AC	2M1125008057	2M1125008045	10.737	12.982	2.25	144.4	0.21	23.39	0.08	2006.857	4	1,3
22248+2233	HO 183AC	N0LR000634	N0LR000618	9.02	12.9	3.88	51.7	0.02	72.99	0.02	2006.857	4	1,2
22248+2833	MLB 583AB	2M 936245849	2M 936245851	9.769	11.577	1.81	97.3	0.36	5.73	0.12	2006.857	4	1,3,5
22248+2833	MLB 583AC	2M 936245849	2M 936245867	9.769	12.473	2.70	211.6	0.15	20.96	0.06	2006.857	4	1,3
22264+2355	POU5705	N0LP000016	N0LP000015	11.27	12.6	1.33	9.4	0.2	11.98	0.02	2006.857	4	1,2
22292+2621	J 3168AB	2M 366337398	2M 366337403	10.409	10.7	0.29	149.4	0.15	7.91	0.04	2006.857	4	1,3,5
22292+2621	J 3168AC	2M 366337398	2M 366337400	10.409	11.105	0.70	260.8	0.09	26.18	0.01	2006.857	4	1,3
22293+3008	MLB 581AC	N2V8000818	N2V8000815	11.19	12.71	1.52	8.9	0.25	27.94	0.07	2006.857	4	1,2,5
22306+1309	HJ 296	N0RN000191	N0RN000195	11.09	13.63	2.54	209.0	0.15	23.50	0.05	2006.874	4	1,2
22306+3706	HJ 1774AB	N2V0000936	N2V0000934	10.51	12.67	2.16	53.3	0.24	16.25	0.02	2006.874	4	1,2

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WDS	Disc	Primary	Secondary	Primary Mag	Secondary Mag	Delta-M	PA	PAsd	Sep	Dsd	Epoch	No. Obs	Notes
22306+3706	HJ 1774AC	N2Y0000936	N2Y0000930	10.51	13.55	3.04	322.7	0.05	29.01	0.03	2006.874	4	1,2
22308+3708	ALI 456	N2Y0000923	N2Y0000924	12.28	12.87	0.59	212.0	0.18	14.44	0.02	2006.874	4	1,2,5
22316+2331	POU5712	N0LN000135	N0LN000134	12.36	13.16	0.80	271.8	0.26	11.05	0.07	2006.874	4	1,2
22329+3021	ES 391AB	2M1164342489	2M1164342486	9.17	11.94	2.77	347.5	1.06	5.18	0.19	2006.874	4	1,3
22340+2417	POU5720	N093000010	N093000012	13.04	13.37	0.33	143.7	0.06	24.73	0.08	2006.874	4	1,2
22362+0010	STF2921AB	N03N000345	N03N000346	8.422	9.89	1.47	236.1	0.05	29.08	0.03	2006.874	4	1,3,5
22362+0010	STF2921AC	N03N000345	N03N0003185	9.95	11.24	1.29	175.2	0.03	84.90	0.07	2006.874	4	1,2,5
22368+2732	MLB 584AB	2M366620718	2M3666520720	11.91	11.797	0.11	311.1	1.22	4.76	0.18	2006.874	4	1,3,5
22368+2732	MLB 584BC	2M366520720	2M366520717	11.797	13.452	1.66	231.3	0.39	12.19	0.04	2006.874	4	1,3
22377+2443	POU5725	N090000397	N090000396	13.27	13.32	0.05	43.6	0.05	16.71	0.04	2006.874	4	1,2
22389+3010	CHE 331	N09W000455	N09W000454	13.81	13.95	0.14	15.0	0.29	12.44	0.05	2006.874	4	1,2
22391+2336	POU5727	N0MS000127	N0MS010225	-10.90	-7.3	3.60	342.9	0.44	8.52	0.05	2006.874	4	1,6
22394+3926	MLB 798	N2X0000408	N2X0000409	12.72	14.26	1.54	266.4	0.46	8.37	0.11	2006.874	4	1,2
22396+3040	CHE 332	N09W000281	N09W000280	12.98	12.89	0.09	83.2	0.1	27.86	0.05	2006.901	4	1,2
22407+3222	CHE 346	N2VT000653	N2VT000648	11.70	11.97	0.27	336.5	0.09	17.75	0.01	2006.901	4	1,2,5
22412+3223	CHE 355	N2VT000637	N2VT000627	13.97	14.25	0.28	24.4	0.09	32.46	0.05	2006.901	4	1,2
22416+3224	CHE 364	N2VT000616	N2VT000614	13.42	13.79	0.37	83.8	0.13	31.56	0.04	2006.901	4	1,2,5
22417+3047	CHE 369AB	N09W000249	N09W000250	11.86	12.95	1.09	148.8	0.19	17.54	0.05	2006.901	4	1,2,5
22417+3047	CHE 369AC	N09W000249	N09W000248	11.86	12.76	0.90	279.7	0.12	23.56	0.07	2006.901	4	1,2,5
22417+3059	CHE 368	N09Z000149	N09Z000147	13.28	13.53	0.25	345.1	0.11	9.45	0.04	2006.901	4	1,2
22418+2355	POU5733	N0MC000087	N0MC000089	13.54	14	0.46	255.5	0.43	8.35	0.20	2006.901	4	1,2
22418+3041	CHE 370AB	N09W000284	N09W000288	12.76	13.11	0.35	205.6	0.23	10.85	0.09	2006.901	4	1,2
22418+3041	CHE 370AC	N09W000284	N09W000293	12.76	13.21	0.45	156.4	0.08	28.80	0.11	2006.901	4	1,2

Table Footnotes

1. Measures taken with a Takahashi Mewlon 300 Dall-Kirkham, F9.1, focal length 2730mm. equipped with ST8E CCD camera (9 micron pixels): approximate resolution is 0.6arcseconds/pixel.
2. V-magnitudes from GSC2.3.2
3. J-magnitudes from 2MASS
4. PA reversed based on obvious magnitude difference
5. Recently measured
6. Raw instrument magnitude, clear filter

### Neglected Double Observations for 2006 No. 4: Some 22<sup>nd</sup> Hour Doubles

(Continued from page 14)

22001+4001 MLB1024. Although the measures reported here are very different from the originals measures, I believe this is the pair based on the large proper motion of the primary (ca. +163 mas/year RA (\*cosDec) and 147 mas/year DEC). Proper motion of the secondary indicates that this is an optical pair that is diverging (USNOB1.0: -36 mas/year RA, -24 mas/yr DEC relative to YS4.0).

22016+2421 POU5615. The primary has a significant proper motion (UCAC2.0 pmRA (\*cos(Dec)) = 21.8 mas/yr; pmDec = 41.1 mas/yr). Unfortunately the secondary is not associated with proper motion values to test the difference between the original measure (PA = 197°, Sep = 14.6") and the reported measure.

22042+3806 SEI1555. The proper motion of the primary is relatively large (UCAC2.0 45258708; pmRA (\*cos(Dec)) = 12.8±3.4, pm Dec = 170.8±1.7. There are three other pairings in the immediate vicinity, but all are fainter.

22065+2806 MLB 722AC. Proper motions fail to explain the discrepancy between the original separation (Sep = 24") and the reported separation of 32.3"; the angles agree.

22077+2521 POU5641. The primary has a large proper motion (+108 mas.yr. RA, -20 mas/yr Dec, relative to YS4.0; from USNO B1.0). No catalog measure of the secondary proper motion is available, but the secondary appears also to have a large proper motion and is closing on the primary (approximations based on 1899 theta and rho plus AC2002.2 catalog position of primary in 1894).

22102+2418 POU5653. This is probably a common proper motion pair. UCAC catalog numbers and proper motions are as follows. A is UCAC2.0 4044476, pmRA(\*cos(dec) = 13.3±0.7, pmDec = 14.1±0.6. B is UCAC 4044473, pmRA(\*cos(dec) = 12.3±1.6, pmDec = 11.7±1.0.

22107+3322 GYL 73 This is probably the pair. AC2002.2 shows this cataloged pair in the correct positions for the measure reported by Goyal and Khandelwal (1968), but there is no star in the position of the secondary in the POSS II or POSS I plates. Perhaps there is a mistake in position of the secondary in the catalog used? UCAC proper motions of the primary and secondary do not address the discrepancy.

22109+1159 CHE330 and CHE 329. The measure reported here is CHE330. The 2006 entry for this pair

in the WDS (theta=129°, rho = 33.1") is, I suspect, a measure of the A component of CHE 329 and a star of equal magnitude lying SE of this pair. The USNO catalog numbers for this 2006 entry are A = 36218156 and "B" = 36218159. Although of similar magnitude, they do not share similar motions.

22135+3336 GLY 75. Goyal and Kahandelwal (1968) reported measures of theta = 186.3° and rho of 29.19" suggesting a problem with the original measure or identity of the pair.

22183+0442 HJ 3103. Proper motion values overlap, but this is due to large errors. A is UCAC2.033498870; pmRA = -11.9±5.6mas/year (\*cos(Dec)), pmDec = -18.2±5.6 mas/year. B is UCAC2.0 33498871; pmRA = -7.4±5.6 mas/year (\*cos(Dec)), pmDec = -13.4±5.6 mas/year.

22189+3807 ALI 701. There is a 14-15<sup>th</sup> magnitude star at PA = 281, SEP = 8.6 from the B component. No proper motions are large enough to evaluate the relationships among these stars.

22234+2300 ROE129BC. Proper motions of component of Roe129BC are highly similar, suggesting either a true binary or a common proper motion pair. Component B is UCAC 2.0 39947606: pmRA (\*cos(Dec) = -6.6 ± 2.0 mas/yr; pmDec = 15.5 ± 2.1 mas/yr. C is UCAC2.0 39947604: pmDec (cos\*(Dec) = -6.9 ± 2.0 mas/yr; pmDec = 16.1 ± 2.1 mas/yr.

22239+3226 ES 2390 Lies in a field bracketed by NGC 7275, NGC 7270, and MCG +05-52-0.8.

22292+2621 J 3168AB. Proper motions of component of J 3168AB are highly similar, suggesting either a true binary or a common proper motion pair. Component A is UCAC 2.0 41123972: pmRA (\*cos(Dec) = -9.1 ± 1.0 mas/yr; pmDec = 10.3 ± 0.7 mas/yr. C is UCAC2.0 41123974: pmDec (cos\*(Dec) = 8.3 ± 0.7 mas/yr; pmDec = 12.7 ± 1.1 mas/yr.

22329+3021 ES 391. The proper motion of the primary and relative positions of the secondary since 1906 suggests astrometric study. A third faint component is present on the POSS II (J) plate (Epoch 1992.801) that is not recorded on the POSS I (O) plate (epoch 1954.604). It is 2M1164342478

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database of astronomical catalogs and associated catalogs (UCAC2.0, USNOB1.0, GSC 2.3.2, Tycho-2, 2MASS and AC2000.2), all maintained at the Centre de Données astronomiques de Strasbourg, France.. Special thanks to Arnie Rosner and Brad Moore, Global Rent-A-Scope (<http://www.global-rent-a-scope.com/>) for their support of research to the Remote Astronomical Society Observatory and to Mike and Lynne Rice of New Mexico Skies (<http://www.nmskies.com/>) for ground support for the observatory.

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# CCD Double Star Measures: Jack Jones Memorial Observatory Report #1

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**Abstract:** This paper reports on 63 CCD measurements of 58 multiple star systems observed between 2003 and 2007. It also reports on delta mag(V) measurements of selected doubles. Measurements were made using a CCD camera and 8" or 11" SCT. A brief description of methods used is provided.

This paper reports observations and measurements of double stars made between late 2003 and 2007. In all cases except one, observations were made using an 11-inch (28 cm) f/10 SCT with a Meade f/6.3 focal reducer/field flattener. The single exception was made with an 8-inch (20 cm) f/10 SCT. A SBIG ST7 camera with a KAF401E non anti-blooming (NAB) sensor was used for all observations. All observations made after 2004.664 utilized a Schuler V filter.

At least 20 images were taken of each double on each observing session. Images were calibrated with dark frames and flat fields. Five to ten images were selected from the original 20 and analyzed. Pre-selection of images provides an opportunity to remove images that were degraded by seeing, drive tracking, cosmic rays or other potential problems.

Exposure times were normally 20 or 30 seconds. Exposure times were shortened to 10 seconds to observe doubles with bright primaries to avoid saturation. In some cases, images were stacked in order to reduce the effects of scintillation in short exposures or to increase the SNR of dim stars. MaxIm DL was used to stack images.

Images were analyzed using Herbert Raab's "Astrometrica" program. The UCAC-2 catalog was used in most cases for analysis. Where UCAC-2 was unavailable or didn't provide adequate reference stars, USNO-B1.0 was used. The precision of each

observation was quantified and reported by calculating the standard deviation of the image set.

Delta magnitude measurements were made of selected pairs utilizing a Schuler V filter (540+/-115 nm). These measurements are summarized in Table 1. The error stated in Table 1 was calculated by taking the standard deviation of multiple images and thus represents the precision of the measurement. It does not include systematic errors.

A negative entry in Table 1 indicates that, as listed in the WDS, the secondary is brighter than the primary.

Color corrections were made to instrumental magnitudes where reliable B-V data was available for both stars. The V transform coefficient for the author's system has been calculated from observations of a wide range of different colored stars in M67 (Henden, 2000).

Position Angle and separation measurements are summarized in Table 2. Errors in separation (SEPerr) and Position Angle (PAerr) were calculated as the standard deviation of multiple images. They represent the precision of the measurement and do not include systematic errors.

Observations made in different observing seasons are reported as separate measurements.

Che 146 (WDS: 10002+2058, Rho = 29.6, Theta = 212, mags 10.5, 11.4) appears to consist of

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GSC1418.231 (mag  $11.93 \pm 0.41$ ) and GSC1418.168 (mag  $13.48 \pm 0.41$ ). The delta V magnitude of this pair was measured as  $-1.52 \pm 0.02$  mag as stated in Table 1. It appears that a PA reversal is in order.

Che 143 (WDS: 09585+2159, Rho = 22.9, Theta = 137, mags 10.3, 11.4) appears to consist of GSC1418.966 (mag  $12.96 \pm 0.41$ ) and GSC1418.958 (mag  $11.48 \pm 0.41$ ). The delta V magnitude of this pair was measured as  $-1.22 \pm 0.02$  as stated in Table 1. Again, the phase angle appears to be reversed.

Che 412 (WDS: 22449+3221. Rho = 29.1, Theta = 251, mags 10.52, 12.0) was discovered by P.S. Chevalier in 1910 and not observed since. The WDS does

not include a Precise Coordinate for this pair. The author measured the position of the primary as RA = 22:44:48.7 ( $\pm 0.0004$ ), Dec = +32:20:15.0 ( $\pm 0.004$ ).

### Acknowledgements

This paper has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory.

### References

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RA/DEC	NAME/COMP	DeltaM	N	Filter	error	epoch
09585+2159	CHE 143	-1.22	2	540 $\pm$ 115	0.02	2006.109
10002+2058	CHE 146	-1.52	2	540 $\pm$ 115	0.02	2006.124
15550+2953	HJ 2797	1.08	2	540 $\pm$ 115	0.01	2006.342
15333+3827	HJ 2786	3.57	1	540 $\pm$ 115	0.01	2006.358
15503+3224	HJ 574AB	2.92	2	540 $\pm$ 115	0.01	2006.358
15503+3224	HJ 574AC	1.57	2	540 $\pm$ 115	0.01	2006.358
20404+3758	SEI1212	2.37	1	540 $\pm$ 115	0.02	2006.616

**Table 1:** Delta magnitudes for selected doubles. Negative DeltaM indicates that secondary is brighter than the primary.

*Table 2 begins on next page.*

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NAME	RA DEC	MAGS	PA	PAerr	SEP	SEPerr	DATE	N	NOTES
HLM 12	18581+3308	10.5 11.5	356.9	0.10	14.00	0.02	2004.625	1	
GYL 13	19011+3210	10.00 10.45	304.9	0.02	34.93	0.04	2004.625	1	
SEI1554	22042+3507	10.5 11.0	294.9	0.06	16.28	0.03	2004.682	1	
CHE 391	22429+2958	12.53 13.50	52.5	0.06	28.51	0.03	2004.581	1	
STF3005	23215+2457	8.9 12.2	23.6	0.13	20.64	0.02	2003.732	1	1
ALI 890	19316+3820	11.9 11.9	115.0	0.05	15.05	0.01	2004.551	1	
GYL 48	21059+3232	10.0 10.2	180.1	0.04	31.65	0.02	2004.556	1	
HJ 2767	15095+3208	10. 11.	263.0	0.16	11.48	0.04	2005.192	1	
HJ 815	09300+3254	9.2 12.8	150.1	0.09	15.50	0.07	2006.122	1	
HJ 1628	21157+3235	10.24 11.44	251.7	0.05	15.17	0.01	2004.551	1	
HJ 2872AC	19290+0343	9.1 13.0	229.7	0.07	13.20	0.02	2004.541	2	
SEI1443	21125+3217	10.36 11.48	139.8	0.09	25.47	0.06	2004.541	1	
SEI1423	21102+3151	10.22 12.18	225.6	0.07	13.62	0.01	2004.551	1	
SLE 122	18436+4020	10.74 11.95	151.3	0.06	17.90	0.01	2004.576	1	
SLE 92	18404+4028	9.8 12.0	99.0	0.05	15.96	0.02	2004.576	1	
SLE 94	18413+4102	10.4 10.4	102.6	0.04	15.95	0.01	2004.626	1	
SLE 187	18310+3857	9.7 10.8	210.7	0.05	23.41	0.03	2004.626	1	
CHE 415	22451+3003	11.17 12.81	231.2	0.06	11.72	0.03	2004.581	1	
CHE 422	22458+2957	10.8 12.3	311.7	0.08	8.78	0.02	2004.581	1	
BU 1528	23121+4517	9.9 10.6	191.2	0.04	33.84	0.04	2004.600	1	
CHE 287	20180+1501	11.0 11.5	135.0	0.04	27.20	0.03	2004.600	1	
CHE 303	20190+1456	9.97 11.0	259.4	0.06	20.50	0.03	2004.600	1	
CHE 451	23246+4244	9.82 10.69	295.1	0.02	36.42	0.01	2004.600	1	
HJ 1794	22383+4659	9.4 11.0	317.3	0.02	16.42	0.02	2004.600	1	
HJ 1793	22383+4702	11.38 12.36	288.7	0.08	15.40	0.02	2004.600	1	
HJ 1815	22494+4528	9.5 9.8	30.9	0.05	10.09	0.01	2004.600	1	
HJ 1841AB	23029+4610	9.69 10.18	344.2	0.02	18.22	0.01	2004.600	1	
HJ 1841AC	23029+4610	9.69 10.42	285.5	0.01	33.65	0.01	2004.600	1	
HJ 2962	20263+1743	10.0 11.0	103.8	0.06	13.36	0.02	2004.600	1	
HO 499	19265+2722	9.3 12.6	177.6	0.04	14.56	0.02	2004.600	1	
ES 499AB	20110+4536	8.2 12.2	332.1	0.15	13.62	0.05	2004.582	1	
ES 499AC	20110+4536	8.2 13.2	84.9	0.05	25.90	0.04	2004.582	1	
HJ 1488	20107+4547	11.86 11.77	131.9	0.08	12.99	0.09	2004.576	1	
CHE 386	22428+3021	10.93 12.30	270.1	0.13	10.72	0.02	2004.616	1	
HJ 2651	13256+2116	11.0 11.5	339.1	0.13	13.79	0.03	2005.192	1	

Table 2: Measures of double stars.

*Table 2 continued on next page*

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NAME	RA DEC	MAGS	PA	PAerr	SEP	SEPerr	DATE	N	NOTES
POU3130	12402+2430	12.5 12.7	104.4	0.14	11.45	0.01	2005.200	1	
HJ 514	12028+2841	10. 11.	87.7	0.03	21.04	0.03	2005.192	1	
KU 130	21057+3215	10.21 11.36	57.9	0.04	19.35	0.01	2004.551	1	
ES 2569	18107+3903	9.5 10.0	275.4	0.11	9.94	0.02	2004.620	1	
CHE 143	09585+2159	10.3 11.4	317.3	0.07	22.89	0.03	2006.109	2	2, 3
CHE 144	09585+2119	10.6 11.0	85.8	0.01	27.28	0.01	2006.120	3	
CHE 145	09596+2122	10.8 11.4	302.9	0.06	27.10	0.06	2006.124	2	
HJ 415AB	07178+3328	11.1 12.1	291.3	0.09	14.57	0.02	2006.122	1	
HJ 415AC	07178+3328	10.9 12.9	308.6	0.12	26.39	0.04	2006.122	1	
CHE 146	10002+2058	12.0 13.3	35.5	0.09	29.71	0.08	2006.124	2	2, 3
SMA 68	07014+2941	11.5 11.7	195.5	0.07	10.04	0.01	2006.122	1	
POU3096	11077+2308	13.2 14.0	154.3	0.14	13.23	0.04	2006.325	2	
POU3088	10458+2354	11.3 12.9	111.6	0.07	14.24	0.03	2006.333	2	
HJ 2797	15550+2953	10.82 11.99	77.2	0.01	34.23	0.01	2006.342	2	3
POU3098	11148+2257	10.5 10.9	128.7	0.10	8.45	0.01	2006.325	2	
HJ 2786	15333+3827	8.3 11.7	169.6	0.04	26.52	0.03	2006.358	1	3
HJ 574 AB	15503+3224	9.3 11.3	93.5	0.05	15.81	0.02	2004.339	1	
HJ 574 AB	15503+3224	9.3 11.3	93.5	0.03	15.77	0.01	2006.358	2	3
HJ 574 AC	15503+3224	9.30 10.90	96.4	0.01	76.42	0.02	2006.358	2	3
HJ 574 AC	15503+3224	9.30 10.90	96.4	0.04	76.43	0.02	2004.339	1	
SEI1212	20404+3758	10.3 11.8	194.3	0.09	19.51	0.04	2006.616	1	3
SEI1170	20340+3737	10.0 11.0	28.4	0.12	17.30	0.03	2006.617	1	
SEI1178	20350+3757	10.0 11.0	173.2	0.10	18.90	0.02	2006.616	1	
POU 340	03592+2338	12.9 13.3	28.8	0.08	20.17	0.03	2006.756	2	
HJ 2672	13422+2307	11.49 13.0	311.4	0.02	39.63	0.03	2007.304	2	
HJ 2678	13460+1216	11.39 13.39	119.9	0.04	25.46	0.02	2007.377	2	
LDS 949	13488+1244	12.5 13.4	28.9	0.04	16.65	0.006	2007.395	1	
CHE 412	22449+3221	10.52 12.0	250.3	0.02	30.49	0.05	2007.736	1	4

Table 2 (continued)

## Notes:

1. 8 inch SCT
2. Significant PA reversal
3. DeltaMag: See Table 1
4. Primary Position 224448.7+322015.0

# High School Observations of the Visual Double Star 3 Pegasi

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**Abstract:** Using a Meade 10" LX200 telescope and a Celestron Micro Guide eyepiece, students from Arroyo Grande High School learned proper techniques for visually measuring the separation and position angle of a visual double star (3 Pegasi). The project was part of a physics research seminar at Cuesta College in San Luis Obispo, California.

## Introduction

This project was part of the Fall 2007 Physics Research Seminar at Cuesta College near San Luis Obispo, California. The observers, all students at Arroyo Grande High School, met with their instructor, Genet, and Johnson on October 6, 2007 (B2007.763) at Marble's home, located in Arroyo Grande, California to conduct the observations. White brought his Meade 10" LX200 telescope, which was used with a Celestron Micro Guide eyepiece for all observations.

The authors had a wide variety of astronomical experience. Most had never made astronomical observations before, while a few were seasoned observers. The high school students learned one procedure for measuring the separation and the position angle of a visual double star using a reticle eyepiece.

## Procedures

The drift method was used to calculate the scale constant in arc seconds per division for the linear scale of the Celestron Micro Guide eyepiece (Teague 2004). A bright star was aligned at one end of the linear scale and the telescope was moved with the fine controls east and west in right ascension. If the star

deviated from the linear scale, the eyepiece was rotated until there were no deviations. The right ascension motor was then turned off and the time taken for the star to drift from one end of the linear scale to the other was recorded. The mean value of repeated observations was used in the following equation to calculate the scale constant for the Celestron Micro Guide eyepiece:

$$z = \frac{15.0411 t \cos(d)}{D}$$

where

$z$  is the scale constant in arc seconds per division

15.0411 is the number of arc seconds per second of the Earth's rotation

$t$  is the average drift time in seconds

$d$  is the declination of the star

$D$  is the number of divisions on the linear scale (60)

The angular separation, i.e. the distance between the primary and secondary stars in arc seconds, was found by using the linear scale to count the number of divisions between the two stars and estimating the

## High School Observations of the Visual Double Star 3 Pegasi

separation to the nearest tenth of a division. The mean value of several observations was then multiplied by the scale constant to obtain the angular separation.

To measure the position angle, i.e. the position of the secondary with respect to the primary in relation to the north celestial pole, the authors first aligned the primary with the center of the linear scale. The eyepiece was then rotated until the linear scale bisected the secondary. The right ascension motor was turned off to let the primary and secondary drift out to the protractor at the edge of the field of view. When the primary reached the protractor, the motor was turned back on to hold its position. The angle on the protractor, indicated by the position of the primary star, was noted and recorded. The mean position angle from several such observations was calculated. The position angle correction for the Celestron Micro Guide eyepiece, given on page 153 of *Observing and Measuring Visual Double Stars* (Teague 2004), was applied to give the correct measured position angle.

### Visual Observations

To eliminate timing errors, the observers chose Delta Cephei with a high declination of  $+58^\circ 17.31m$  to determine the scale constant of the linear scale. Twelve trials resulted in an average drift time of 58.36 seconds with a standard deviation of 0.57 and a standard error of the mean of 0.17. This yielded a scale constant of 7.69" per division with a standard deviation of 0.08 and a standard error of the mean of 0.02.

Professor Tom Frey, a visual double star observer in San Luis Obispo, California, suggested that the observers measure the bright visual double star 3 Pegasi (WDS STFA 56) which is located at right ascension 21h 37.7m and declination  $+06^\circ 37m$  with a primary magnitude of 6.2 and a secondary magnitude of 7.3 (Mason 2007). After ten trials, the authors determined the average separation to be 39.8" with a standard deviation of 2.2" and a standard error of the mean of 0.7". Eight trials gave a position angle of  $349.0^\circ$  with a standard deviation of  $0.5^\circ$  and a standard error of the mean of  $0.2^\circ$ .

### Analysis and Conclusions

Our measurement of the separation of 3 Pegasi was 39.8", while the Washington Double Star (WDS) Catalog value is 39.1". This difference of 0.7" was well within our error expectations. The standard deviation for the observed separation was 2.2", which is higher than expected. This could be due to the inexperience of some of the observers. The measured position angle was  $349.0^\circ$  while the double star catalog in *Double Stars for Small Telescopes* (Haas 2006) also gives a position angle of  $349^\circ$ . However, the WDS Catalog

gives a position angle is  $348^\circ$ , a  $1^\circ$  difference from the authors' position angle.

Ronald Tanguay, an experienced double star observer, says in *The Double Star Observer's Handbook* that "With a well calibrated reticle micrometer, we may expect measurements to average about  $\pm 1$  degree in the position angle and  $\pm 2\%$  in separation from the data listed in the WDS Catalog" (Tanguay 2003). The observed average difference from the WDS Catalog position angle was  $1^\circ$  and the average difference in separation was 1.8%. Both parameters fit within what Tanguay says are "excellent work."

Upon further investigation into the proper motions of 3 Pegasi, double star observer Dave Arnold kindly suggested to us that

*Analysis of the proper motion vectors for both stars indicates that this is a common proper motion pair, with motions in right ascension and declination that are almost identical, so this provides verification that this pair's parameters really are relatively fixed. This pair is not listed in the visual binary section of Sky Catalog 2000.0 because no orbit has been determined. However, it doesn't appear that this pair has shifted significantly since it was discovered in the [position angle/separation] parameters.*

The common proper motion of the primary and secondary components suggests this may be a binary star. If 3 Pegasi is a binary star, further analysis over several hundred years may provide both the orbital period and the masses of both stars.

### Acknowledgements

We thank Tom Frey, Professor Emeritus of Chemistry at California Polytechnic State University, for suggesting this double star to measure and for reviewing our paper. We also thank John and Chrissie Marble for the use of their premises to conduct the observations. Finally, we thank David Arnold, Robert Buchheim, Tom Smith, Morgan Spangle, and Vera Wallen for their helpful reviews of this paper.

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*Stephanie M. Marble, Christianne M. Gonzalez, Corey M. Cameron, James B. Johandes, Brett R. Chapman, and Sarah F. Fishbein are students at Arroyo Grande High School and were enrolled in the physics research seminar at Cuesta College. Jolyon M. Johnson is starting his second year as a student at Cuesta College and is also enrolled in the physics research seminar. Robin White, the observatory assistant at Cuesta College, is a highly experienced observer. Russell M. Genet is a Professor of Astronomy and leads a research seminar at Cuesta College. He is also a Research Scholar in Residence at California Polytechnic State University and Director of the Orion Observatory, [www.OrionObservatory.org](http://www.OrionObservatory.org).*



# CCD Double-Star Measurements at Altimira Observatory in 2007

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**Abstract:** CCD measurements of the separation and position angle of 16 systems, mostly taken from the WDS list of “neglected doubles”, are reported. The V-band delta-magnitude values were also measured for most of the reported systems.

## Introduction

Altimira Observatory is located in my backyard in southern California. It is equipped with an 11-inch Schmidt-Cassegrain telescope (Celestron NexStar-11) operating with an  $f/6.3$  focal reducer, a non-anti-blooming CCD imager (SBIG ST-8XE) with photometric filters (Custom Scientific B, V, and R filters in an SBIG CFW-8A filter wheel). All images used for this study were taken through the V-band filter, that provides a spectral sensitivity curve that very closely matches the Johnson-Cousins standard V-band response ( $\lambda_{\text{center}} \approx 0.55 \mu\text{m}$ ,  $\Delta\lambda_{\text{FWHM}} \approx 0.09$ ). The images are well-sampled, with 1.1 arc-sec pixels and typical “seeing” of 2-3 arc-sec from my low-altitude suburban site. The equipment is housed inside a small domed observatory (see reference 1).

The observatory was originally built for photometric projects, however double-star measurement has proven to be an interesting and useful project for nights when conditions do not permit photometry.

## Procedure

The observational procedure is to take a series of V-band images of the selected double-star fields. In no case are images taken at air mass greater than  $X=2$ , and usually air mass is less than  $X=1.75$ . In general, two or three different exposure durations were used for each field, in order ensure that at least

one set of exposures would provide a high SNR without saturating any pixels in the star images; and six images were taken at each exposure duration. For some targets, images were taken on 2 nights, to test whether results were consistent (they were). Dark-subtraction and flat-field correction of the images was performed with CCDSoft (Software Bisque), and images with poor guiding or other problems were eliminated by visual examination. This approach provided a set of at least 4 images for each system that could be measured to determine the positions and separation angles.

Astrometric analysis of the images was done with both MPO Canopus (by BDW Publishing) and Astrometrica (by Herbert Raab), using the UCAC2 catalog for reference stars. (A few stars are located outside of the range of UCAC2; in those cases, the MPO Canopus Star Catalog, which merges the Tycho 2 and USNO A2.0 catalogs, was used). Measurements (means) reported here are based on at least 4 images of each system.

The MPO Canopus package provides a convenient double-star utility that reports the separation and position angle directly. Astrometrica offers higher-order modeling of plate constants (which I did not require), and excellent visualization of the stellar image intensity function (which is particularly handy in dealing with closely-spaced pairs). Because Astrometrica reports the RA and Dec coordinates of the

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individual stars, I use an Excel spreadsheet to calculate the resulting separation and position angle. Several pairs were evaluated using both methods, to confirm that the results were consistent.

Measurements from all good images (good tracking and focus, SNR > 10 on all targets stars, and no saturated pixels) were averaged to achieve a single “mean” for the pair. In those cases where images were taken on multiple nights, the means from all nights are averaged, and the reported Besselian epoch is the average of the times of all images. The reported standard deviations of separation and position angle are based on the complete data set for each pair.

Tests on calibration systems (not reported here) have shown that my equipment can reliably and accurately ( $\pm 0.2$  arc-sec) measure equal-brightness pairs that are separated by more than about 4 arc-sec. Larger separations are required in order to reliably measure pairs that present significant brightness difference.

Dates have been converted from UT of observation by using the AAVSO “JD converter” utility to determine the Julian Date, and then applying the following formula (Lieske, 1979) to compute the Besselian epoch:

$$B = 1900 + \frac{[JD - 2,415,020.31352]}{365.2422}$$

During this project I discovered that some commonly-used references mis-state the equations for calculating the separation and position angle of a pair of stars, given their RA and Dec coordinates. As described in Smolinski and Osborn (2006), standard formulae from spherical trigonometry give:

$$\rho = \cos^{-1} [\cos(\Delta\alpha) \cdot \cos \delta_1 \cdot \cos(\delta_2 - \delta_1)]$$

$$\Theta = \left(\frac{\pi}{2}\right) - \tan^{-1} \left[ \frac{\sin(\delta_2 - \delta_1)}{\cos(\delta_2 - \delta_1) \cdot \sin(\Delta\alpha \cdot \cos \delta_1)} \right]$$

where  $\delta_1$  and  $\delta_2$  are the declination of the primary and secondary stars, respectively, and  $\alpha_1$  and  $\alpha_2$  are the right ascension of the primary and secondary stars, respectively.  $\Delta\alpha = \alpha_2 - \alpha_1$  is the difference of RA and all angles are in radians.

In the small angle approximation, where

$$|\Delta\alpha| \ll 1 \text{ and } |\delta_2 - \delta_1| \ll 1$$

we can simplify the equations for separation and position angle to

$$\rho = \sqrt{(\Delta\alpha \cdot \cos \delta_1)^2 + (\delta_2 - \delta_1)^2} \text{ (radians) (1)}$$

$$\Theta = \left(\frac{\pi}{2}\right) - \tan^{-1} \left[ \frac{(\delta_2 - \delta_1)}{\Delta\alpha \cdot \cos \delta_1} \right] \\ = \tan^{-1} \left[ \frac{\Delta\alpha \cos \delta_1}{\delta_2 - \delta_1} \right] \text{ (radians) (2)}$$

The calculated position angle,  $\theta$ , must be resolved to the correct quadrant in order to yield the astronomical position angle (measured from celestial north, toward celestial east):

	sign of $\alpha_2 - \alpha_1$	sign of $\delta_2 - \delta_1$	quadrant	position angle $\theta$
I	+	+	I	$\theta = \Theta$
IV	+	-	II	$\theta = \pi + \Theta$
II	-	-	III	$\theta = \pi + \Theta$
III	-	+	IV	$\theta = 2\pi + \Theta$

The Excel spreadsheet that I use to translate RA, Dec into  $\rho$ ,  $\theta$  uses Eq 1 and Eq 2.

During the course of this project I noticed a few cases where the star’s CCD brightness appeared to be very different from the WDS listed magnitudes. This prompted me to use MPO Photored (a photometric program contained within MPO Canopus) to estimate the V-band delta-mag on my images. The reported delta-mags are typically derived from measurement of 4 images, with the faint component having SNR  $\geq 10$  in each image. These delta-mags are subject to some caveats. First, the images were taken on non-photometric nights (either hazy or moonlit, or both). Second, no transforms were applied. These caveats are balanced by the fact that my system with V-band filter is very close to standard Johnson-Cousins V band: the measured transform equation is

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## CCD Double-Star Measurements at Altimira Observatory in 2007

Name	WDS	WDS	meas	Position Angle (deg)		Separation (as)		Epoch	N nights	N images	Notes
	RA+DEC	Mags	$\Delta V_{mag}$	PA	s.d.	Sep	s.d.				
STT 23AB	01101+5145	8.14, 8.59		191.3	0.02	14.64	0.03	2007.896	1	6	
STT 23AC	01101+5145	7.7, 12.2		93.0	0.10	57.12	0.17	2007.896	1	6	A
KZA 44AB	13104+3744	9.5, 9.5	0.16	208.7	0.03	76.77	0.06	2007.512	2	11	
KZA 44AC	13104+3744	12.32, 11.38	-0.86	4.5	0.04	93.29	0.08	2007.512	2	11	
KZA 55AB	13221+4354	6.35, 11.5	6.0	307.2	0.10	45.67	0.04	2007.530	1	4	
KZA 55AC	13221+4354	6.35, 9	5.3	58.7	0.09	67.70	0.15	2007.530	1	4	
KZA 55AD	13221+4354	6.35, 10.5	6.0	247.9	0.09	75.55	0.09	2007.530	1	4	
KZA 71AB	13363+3514	9.5, 10	1.5	147.6	0.09	62.51	0.03	2007.512	1	4	
KZA 71AC	13363+3514	9.5, 11	2.6	185.8	0.14	78.86	0.06	2007.512	1	4	
STF1888AB	14514+1906	4.76, 6.95		310.9	0.50	6.30	0.06	2007.505	1	5	
STF1888AD	14514+1906	4.76, 9.6		286.4	0.10	159.60	0.20	2007.505	1	5	
STF1888AE	14514+1906	4.76, 8.65		98.5	0.20	269.20	0.30	2007.505	1	5	
STF1888AF	14514+1906	4.76, 9.2		38.2	0.02	333.70	0.20	2007.505	1	5	
STF1888BE	14514+1906	6.95, 8.65		99.3	0.02	274.50	0.20	2007.505	1	5	
HLD 120AB	14527+0746	8.3, 9.9	3.6	224.6	0.32	16.13	0.05	2007.541	2	12	
SKF 10	15111+4424	10.1, 10.8	0.6	284.4	0.20	13.90	0.06	2007.518	2	9	
ARY 52	15124+5256	7.6, 8.4	0.8	330.5	0.06	147.90	0.20	2007.530	1	8	
BGH 57	15171+2851	8.8, 9	-0.4	220.8	0.03	574.27	0.30	2007.505	1	4	B
ARY 53	15198+5217	8.93, 9.43	0.5	148.5	0.01	106.98	0.09	2007.541	2	8	
KZA 105AB	15367+3954	9.5, 11	0.9	73.3	0.04	88.00	0.04	2007.530	1	4	
KZA 105AC	15367+3954	9.5, 11	1.6	118.5	0.02	133.30	0.10	2007.530	1	4	
KZA 105AD	15367+3954	12.22, 11.87	-0.8	156.7	0.02	164.30	0.02	2007.530	1	4	
KZA 105AE	15367+3954	9.5, 10.5	0.7	132.3	0.03	267.90	0.10	2007.530	1	4	
KZA 105AF	15367+3954	9.5, 10	-0.6	178.0	0.01	357.10	0.10	2007.530	1	4	
KZA 105AH	15367+3954	12.22, 11.67	-0.8	134.7	0.02	535.40	0.20	2007.530	1	4	
KZA 105DF	15367+3954	11.87, 12.21	0.2	194.3	0.01	212.50	0.10	2007.530	1	4	

Table 1: Measurements of systems

Table continued on next page

### CCD Double-Star Measurements at Altimira Observatory in 2007

Name	WDS	WDS	meas	Position Angle (deg)		Separation (as)		Epoch	N nights	N images	Notes
	RA+DEC	Mags	$\Delta V_{\text{mag}}$	PA	s.d.	Sep	s.d.				
SPN 1	15569+3613	9.8, 10.8	5.6	86.5	0.32	25.70	0.24	2007.505	1	5	
BU 692AC	21501+3151	7.3, 11	5.3	292.6		40.65		2007.880	1	6	C
FOX 264AE	21501+3151	7.46 --	6.0	178.0		54.37		2007.880	1	6	
FOX 264AD	21501+3151	7.46 --	6.7	149.7		40.37		2007.880	1	6	
MLB 788	21509+3918	10, 10.1		51.8	0.64	4.90	0.07	2007.880	1	7	
SEI1527	21378+3739	9.88, 12.71	3.2	332.1	0.12	25.21	0.05	2007.880	1	6	
CHE 447	23234+4224	10.53, 10.92		286.0	0.29	27.12	0.23	2007.861	1	8	

Table 1 (continued): Measurements of systems

#### Table Notes:

- A. These CCD measurements confirm a visual measurement by Tom Frey (personal communication).
- B. Note that the "primary" is the fainter of the two stars.
- C. I saw no evidence of star "B" (which WDS reports at mag 10.8) on CCD images going as deep as mag 15

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$V-v = -0.05 (B-V) + Z_v$ , so color effects are small. It is reasonable to expect that even on the nights used for these double-star measurements, the differential magnitudes should be accurate, to within about  $\pm 0.1$  magnitude.

## Results

Target pairs were selected from the Washington Double-Star Catalog listing of "Neglected Doubles", with the goal of providing modern data points for these systems. In some cases, these observations confirm the existence of the pair (i.e. when only a single previous measurement is reported).

Table 1 provides the measured parameters of all the systems I examined. The standard deviations of PA and SEP are the internal variability of the individual image measurements, over the total number of images used. Of the systems measured, six show significant motion since the last measurement. These are STT 23 AC (7 arc-sec change in separation), STF 1888 AD (3 arc-sec change in separation), HLD 120 AB (8 arc-sec change in separation), KZA 105 AE (7

arc-sec change in separation), and FOX 264 AE (7 arc-sec change in separation).

In some cases the delta-mags observed are very different than those listed in the WDS Catalog. The case of SPN-1 is particularly remarkable in this regard: the WDS record shows a delta-mag of 1.0 magnitude, whereas my CCD images show the secondary 5.6 magnitudes fainter than the primary. Other systems showing delta-mags that are quite different from the WDS are: KZA 55 AC and KZA 55 AD, HLD 120 AB.

## Acknowledgements

This research has made use of the Washington Double Star Catalogs, maintained at the U.S. Naval Observatory. I appreciate the enthusiasm of Russ Genet, who prompted me to add double-star measurements to my astronomical schedule, and Tom Frey for sharing his visual measurements of STT 23 AC. I am grateful to my wife, Eileen, who gave up a portion of her garden for the construction of Altimira Observatory.

(Continued on page 31)

**CCD Double-Star Measurements at Altimira Observatory in 2007****References**

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*Mr. Buchheim is also the author of the book **The Sky is Your Laboratory: Advanced Astronomy Projects for Amateurs** recently published by Springer-Praxis.*



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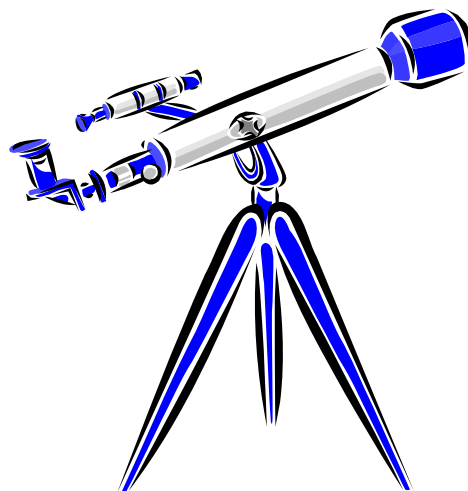
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