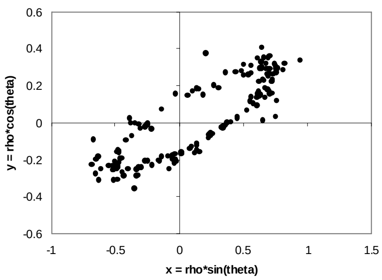
University of South Alabama

Journal of Double Star Observations

VOLUME 6 NUMBER 3 July 1, 2010



Scatter plot of relative motion of the binary 00373-2446BU 395. See the article by E.O. Wiley, pg 217.

Inside this issue:

Divinus Lux Observatory Bulletin: Report #22

Dave Arnold

Program Manager for Double Star Research
2728 North Fox Run Drive
Flagstaff, AZ 86004

dvdarnl@aol.com

Abstract: This report contains theta/rho measurements from 82 different double star systems. The time period spans from 2010.022 to 2010.310. 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.

This article contains a listing of double star measurements that are part of a series, which have been continuously reported at Divinus Lux Observatory, since the spring of 2001. 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* (WDS) published measurements that are no more recent than ten years ago. Several systems are included from the 2006.5 version of the WDS as well. There are also some noteworthy items that are discussed pertaining to the following table.

To begin with, the Castor star system (STF 1110 AB/AC/AD) has displayed some significant theta/rho shifts over the past several years. AB is a common proper motion visual binary star that currently displays a decreasing theta value and an increasing rho value because of orbital motion. The theta/rho values that appear in this report very closely agree with parameters obtained from using the orbital elements, which are rated at grade 3, as reported in *Sky Catalogue 2000.0 Vol. 2.* Since 2005, the theta value for AB has decreased by one degree and the rho value has increased by almost 15%. AC and AD are optical components. Because of the high proper motion being displayed by AB, the theta/rho shifts for AC and AD are caused by proper motion alone. Most noticeably, a rho value decrease of 7.5" appears to have occurred for AD since the 1998 value was recorded in the WDS. Because the proper motion velocity doesn't appear to support this large of a shift, one might question if the 1998 rho value in the catalog is accurate. In any case, this system warrants additional measurements by other researchers in order to bring additional accuracy to all of these parameters.

Another visual binary system that is worthy of mention, which was measured for this report, is STF 1196 AB-C (Zeta Cancri). During this past decade, the theta value appears to have decreased by 4 degrees because of orbital motion. A comparison of the theta/rho values that appear in the table below with the parameters obtained from using the orbital elements, as listed in *Sky Catalogue 2000.0 Vol. 2*, yields a close agreement. Because the calculated orbit carries a grade 5 rating, it is significant that these two sets of theta/rho values display this type of consistency.

A final visual binary star that deserves some comments pertains to STF 1785 in Bootes. During the past 10 years, the theta value appears to have increased by approximately 8.5 degrees, along with a slight decrease in the rho value. These measured values are consistent with what would be obtained when calculating the theta/rho values using the orbital elements, as listed in *Sky Catalogue 2000.0 Vol. 2.* Such a consistency might be expected since the listed orbital elements have been given a grade 2 reliability rating.

Also appearing in this article is one additional double star that has displayed noticeable theta/rho shifts, during the past 10 years, because of proper motion alone. In this regard, PWS 4 AB-C has shown a 4% rho value increase, since 2000, because of proper

Divinus Lux Observatory Bulletin: Report #22

motion by the "C" component.

Listed in the table is one possible common proper motion double star, bearing the "ARN" prefix, that doesn't appear to have been previously cataloged. Labeled as ARN 111 (11387+3238), this pair appears near ES 2285 in Ursa Major.

A possible correction to the WDS catalog is being suggested because of measurements that were made for the STF 1113 (07350+2416) star system. The theta/rho parameters obtained for this report more closely match measurements for the AC components, rather than AB components that appear in the WDS catalog. Hence, the table below lists the measurements as "AC" rather than "AB." This is another system that merits additional measurements by other researchers, in order to determine the accuracy of the parameters listed in this report.

An addition to the WDS catalog is also being proposed. It appears that the BGH 46 Aa-B system (13164+1948) is not listed in either the 2001.0 or the 2006.5 versions. While measurements for "Aa-B" are included in the table below, measurements for "Aa" have not been submitted because the combination of a small rho value and component magnitude difference exceeds the limitations of my instrumentation. Measurements for "Aa" are encouraged for those researchers who have access to larger telescopes.

Finally, the WDS CATALOG 2001.0 version and the 2006.5 version list optical components for the STF 1830 (14157+5640) and the STF 1831 (14161+5643) star systems that are shared in common by both, probably as a consequence of the proximity of these systems to each other. Because of the potential for confusion that could result from this situation, measurements are only being submitted for STF 1830 AB and STF 1831 AB.

NAME	RA+DEC	MAGS	PA	SEP	DATE	NOTES
H 91AC	06003+4436	6.2 10.2	344.5	35.55	2010.022	1
STF 840A-BC	06065+1045	7.2 8.9	248.1	21.73	2010.022	2
STF 889AB	06199+2501	7.4 9.9	242.5	21.23	2010.022	3
STF 928AB	06347+3832	7.8 8.6	132.0	3.46	2010.022	4
BRT1233	07295+1023	10.6 10.7	77.8	4.94	2010.041	5
STF1110AB	07346+3153	1.9 3.0	60.0	4.94	2010.041	6
STF1110AC	07346+3153	1.9 9.8	164.2	70.11	2010.041	6
STF1110AD	07346+3153	1.9 10.0	223.4	177.75	2010.041	6
STF1113AC*	07350+2416	7.7 10.1	179.1	92.33	2010.041	7
HJ 425BC	07350+2416	10.1 10.7	48.0	8.39	2010.041	7
STF1196AB-C	08122+1739	5.2 5.8	68.2	5.93	2010.118	8
STF1196AB-D	08122+1739	5.2 8.8	108.2	277.49	2010.118	8
ENH 1EF	08122+1739	10.0 10.1	106.1	219.23	2010.118	8
STF1209	08157+0738	9.5 10.6	197.8	33.08	2010.118	9
STF1270	08453-0236	6.8 7.6	265.0	4.44	2010.041	10
STF1295	08555-0758	6.7 6.9	4.0	3.95	2010.118	11
PWS 4AB-C	09408+0102	10.2 10.5	211.5	74.06	2010.118	12
GRV 809	10041+3756	10.5 10.7	55.8	78.01	2010.121	13
GRV 812	10092+3320	9.8 9.8	214.2	28.64	2010.121	14
STF1425	10216+4609	9.8 10.7	355.0	4.94	2010.121	15
CHE 148	10284+0310	10.0 10.3	64.3	4.94	2010.121	16
MLB 167	10473+5815	10.0 10.6	321.6	5.43	2010.121	17

Table continues on next page.

Divinus Lux Observatory Bulletin: Report #22

NAME	RA+DEC	MAGS	PA	SEP	DATE	NOTES
STF1526	11187+0250	10.2 10.3	180.6	30.12	2010.121	18
KR 39Aa-B	11333+5748	9.7 10.7	152.0	10.37	2010.123	19
ARN 111*	11387+3238	9.9 10.0	59.8	113.56	2010.214	20
GRV 841	11424+3934	10.0 10.6	202.6	64.68	2010.123	21
STF1568	11433+0046	10.3 10.4	42.6	9.38	2010.123	22
BRT2412	11438+1831	10.0 10.1	292.4	4.94	2010.123	23
GRV 842	11500+3612	10.6 10.7	357.2	31.60	2010.123	24
KU 41	11556+1654	10.1 10.2	68.6	5.43	2010.123	25
GRV 847	11595+1808	9.2 9.9	350.2	32.59	2010.123	26
AG 177AB	12247+0225	9.2 10.6	220.2	7.90	2010.214	27
H 81	12416+1026	6.2 10.5	279.8	77.52	2010.137	28
GRV 857AC	12440+0356	9.0 10.7	205.3	59.25	2010.123	29
ENG 49AB	12489+1206	7.1 10.7	348.5	175.78	2010.137	30
ENG 49BC	12489+1206	10.7 10.2#	328.3	131.34	2010.137	30
HJ 523	12519+3447	10.3 10.7	182.9	14.32	2010.137	31
STF 23AB	12522+1704	6.3 6.9	50.9	196.51	2010.137	32
STF1712	13035+0928	10.2 10.5	332.0	8.89	2010.140	33
STT 122AB	13136+5643	6.8 8.0	216.1	121.46	2010.142	34
STT 122BC	13136+5643	8.0 10.4	246.0	62.21	2010.142	34
H 55AC	13137+2949	7.3 10.7	153.6	71.10	2010.140	35
BU 342	13152-1855	8.6 9.0	35.0	4.30	2010.140	36
BGH 46Aa-B*	13164+1948	6.4 7.6	58.0	203.43	2010.140	37
HJ 227AB	13253+1033	9.0 10.6	314.9	39.99	2010.140	38
HJ 1232	13276+0655	10.0 10.5	306.5	12.84	2010.140	39
STF1755	13324+3649	7.2 8.1	131.5	4.44	2010.214	40
HJ 2662	13349+3314	9.6 10.4	280.4	23.21	2010.140	41
STF1765	13379+0221	10.4 10.6	161.5	38.02	2010.140	42
KU 104	13384+4306	10.1 10.5	54.5	59.25	2010.142	43
STF1772AD	13407+1957	5.8 7.4	1.4	208.36	2010.142	44
STF1785	13491+2659	7.2 8.0	182.5	2.96	2010.214	45
HJ 233	13572+1151	10.6 10.7	133.7	19.75	2010.142	46
STF1793	13591+2549	7.4 8.4	243.0	4.94	2010.142	47
LDS2700AB	14068+5946	9.7 9.2#	150.6	48.39	2010.142	48
STF1830AB	14157+5640	9.2 10.3	311.5	10.37	2010.156	49

Table concludes on next page.

Divinus Lux Observatory Bulletin: Report #22

NAME	RA+DEC	MAGS	PA	SEP	DATE	NOTES
STF1831AB	14161+5643	7.1 9.5	138.8	5.93	2010.156	50
STF1838	14241+1115	7.4 7.7	334.7	9.38	2010.156	51
STF1854AB	14298+3147	6.1 10.5	255.6	25.68	2010.156	52
BU 1443	14308+0446	6.0 10.6	195.4	55.30	2010.156	53
HJ 554AB	14325+3442	10.3 10.6	291.8	11.85	2010.156	54
LDS 968AB-C	14426+1929	9.1 10.1	309.4	135.29	2010.156	55
HJ 241	14485+1203	10.2 10.7	140.7	17.28	2010.156	56
HJ 1267	15032+0740	9.5 10.5	8.5	13.83	2010.271	57
STF1923AB	15138+1427	9.0 10.1	10.1	4.94	2010.271	58
HJ 252AB	15249+1359	9.8 10.7	97.0	11.36	2010.271	59
STF1953	15329+0531	9.6 10.5	252.2	6.56	2010.271	60
STT 141AB	15389+5728	7.4 9.7	204.3	88.38	2010.271	61
STT 141AC	15389+5728	7.4 7.9	335.1	234.04	2010.271	61
GRV 919	16001+1317	10.3 10.3	354.6	45.43	2010.271	62
STF2006AC	16003+5856	8.4 9.6	211.0	47.40	2010.290	63
ARG 29	16058+5637	9.3 10.6	136.2	24.69	2010.290	64
STF3103	16207-0356	9.0 10.7	304.3	24.13	2010.290	65
BAL2414	16260+0312	10.7 10.7	129.0	3.95	2010.290	66
GRV 929	16291+0015	8.2 9.9	70.3	69.62	2010.290	67
KU 113	16405+0937	9.4 10.7	50.5	66.66	2010.290	68
GRV 944	16583+3117	10.7 10.7	217.8	59.74	2010.290	69
BU 45	17179+3229	9.9 10.5	291.3	4.94	2010.290	70
LDS 994	17257+2719	7.5 9.7	299.0	88.88	2010.310	71
GRV 958	17301+1019	9.4 10.1	211.3	49.87	2010.310	72
GRV 959	17302+2901	10.2 10.7	355.4	24.19	2010.310	73
AG 355	17318+1040	9.4 10.7	333.1	22.71	2010.310	74
STF2188	17362+0637	9.2 9.9	202.5	5.43	2010.310	75
BAL2445	17387+0349	10.2 10.6	139.2	4.94	2010.310	76
GRV 964	17495+0911	10.5 10.7	105.1	19.26	2010.310	77
ROE 17	17514+5938	9.7 10.4	53.9	8.89	2010.310	78
BRT2439	17527+1940	10.3 10.7	180.8	4.94	2010.310	79
STF2261AB	17581+5213	7.5 10.0	262.0	9.38	2010.310	80
STF2259	17590+3003	7.2 8.4	277.3	19.75	2010.310	81
ES 79AC	18027+5552	10.7 10.7	92.8	24.69	2010.310	82

* - Not in the Washington Double Star Catalog.
# - Companion star is the brighter component.

Divinus Lux Observatory Bulletin: Report #22

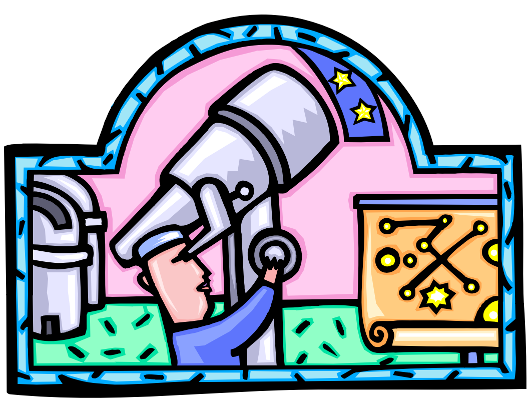
Table Notes

1. In Auriga. Sep. & p.a. increasing. Spect. G5, K0III.
2. In Orion. Relatively fixed. Common proper motion. Spect. A0V, F0.
3. In Gemini. Position angle increasing. Spect. K2.
4. In Auriga. Relatively fixed. Common proper motion. Spect. F5, F5.
5. In Canis Minor. Position angle slightly decreasing.
6. Castor or Alpha Geminorum. AB = sep. inc; p.a. dec; cpm. Spect. A1V, A2V.
7. AC = relatively fixed. BC = p.a. increasing. Spect. M0.
8. Zeta Cancri. AB-C = p.a. dec.; cpm. AB-D = sep. dec. Spect. G0V, G0V, G5.
9. In Cancer. Sep. & p.a. increasing. Spect. A2.
10. In Hydra. Sep. decreasing; p.a. increasing. Spect. F2IV.
11. In Hydra. Position angle increasing. Spect. A2, A2.
12. In Hydra. Sep. increasing; p.a. decreasing. Spect. F5.
13. In Leo Minor. Relatively fixed. Common proper motion.
14. In Leo Minor. Relatively fixed. Common proper motion. Spect. G0, G0.
15. In Ursa Major. Position angle decreasing. Spect. F5, F5.
16. In Sextans. Common proper motion; sep. dec.; p.a. inc. Spect. K2.
17. In Ursa Major. Common proper motion; sep. decreasing.
18. In Leo. Relatively fixed. Common proper motion. Spect. G0, G0.
19. In Ursa Major. Common proper motion; p.a. decreasing. Spect. G5.
20. In Ursa Major. Common proper motion. Near ES 2285 system.
21. In Ursa Major. Relatively fixed. Common proper motion. Spect. K0.
22. In Virgo. Relatively fixed. Common proper motion. Spect. F5, F8.
23. In Leo. Common proper motion; p.a. decreasing. Spect. K5, K5.
24. In Ursa Major. Relatively fixed. Common proper motion. Spect. G, G.
25. In Leo, Sep. increasing; p.a. decreasing. Spect. G0, G0.
26. In Coma Berenices. Relatively fixed. Common proper motion. Spect. G, G.
27. In Virgo. Common proper motion; p.a. increasing. Spect. G5.
28. 27 Virginis. Separation decreasing. Spect. A7V.
29. In Virgo. Relatively fixed. Common proper motion. Spect. F5.
30. In Virgo. AB = sep. inc.; p.a. dec. BC = sep. dec. Spect. AC = G5V, A0.
31. In Canes Venatici. Relatively fixed. Common proper motion. Spect. G0, G0.
32. 32 Comae Berenicis. Sep. & p.a. slightly increasing. Spect. M0III, F8.
33. In Virgo. Common proper motion; p.a. decreasing. Spect. G0, G0.
34. In Ursa Major. AB = sep. & p.a. inc. BC = p.a. slightly inc. Spect. G1, G5.
35. In Coma Berenices. Separation decreasing. Spect. G9III.
36. In Virgo. Relatively fixed. Common proper motion. Spect. F2V, F2V.
37. In Coma Berenices. Relatively fixed. Common proper motion. Spect. A3, A2.
38. In Virgo. Position angle slightly decreasing. Spect. F2, F0.
39. In Virgo. Common proper motion; sep. increasing. Spect. F5, G.
40. In Canes Venatici. Slight decrease in p.a. Spect. G5III, G8III.
41. In Canes Venatici. Sep. increasing; p.a. decreasing. Spect. G8III.
42. In Virgo. Sep. & p.a. slightly decreasing.
43. In Canes Venatici. Sep. & p.a. increasing. Spect. F8.
44. 1 Bootis. Relatively fixed. Common proper motion. Spect. A1V, A2.
45. In Bootes. Common proper motion; p.a. increasing. Spect. K4V, K6V.
46. In Bootes. Position angle decreasing. Spect. G0, G0.
47. In Bootes. Common proper motion; p.a. slightly increasing. Spect. A5V, A5.
48. In Ursa Major. Relfixed. Possible common proper motion. Spect. F5, F5.
49. In Ursa Major. Sep. & p.a. increasing. Spect. G5, F8.
50. In Ursa Major. Common proper motion; p.a.

Divinus Lux Observatory Bulletin: Report #22

decreasing. Spect. A7IV, F0.

51. In Bootes. Relatively fixed. Common proper motion. Spect. F0V, G1V.
52. In Bootes. Sep. & p.a. slightly decreasing. Spect. A0V.
53. In Virgo. Relatively fixed. Spect. K4.
54. In Bootes. Relatively fixed. Common proper motion. Spect. K0, K0.
55. In Bootes. Relatively fixed. Common proper motion. Spect. M0.
56. In Bootes. Separation slightly decreasing. Spect. K0.
57. In Bootes. Relatively fixed. Common proper motion. Spect. G5.
58. In Serpens. Common proper motion; p.a. decreasing. Spect. G0V, G0V.
59. In Serpens. Relatively fixed. Common proper motion. Spect. G9V.
60. In Serpens. Common proper motion; p.a. decreasing. Spect. F5, F5.
61. In Draco. AB = sep. decreasing. AC = relatively fixed. Spect. M3, G5, K0.
62. In Serpens. Relatively fixed. Common proper motion. Spect. K, G5.
63. In Draco. Sep. increasing; p.a. decreasing. Spect. A3, K.
64. In Draco. Sep. & p.a. decreasing. Spect. F8, F8.
65. In Ophiuchus. Relatively fixed. Common proper motion. Spect. K5.
66. In Ophiuchus. Relatively fixed. Common proper motion. Spect. F5.
67. In Ophiuchus. Relatively fixed. Spect. G0, K2.
68. In Hercules. Sep. & p.a. increasing. Spect. K0, F8.
69. In Hercules. Relatively fixed. Common proper motion. Spect. G5.
70. In Hercules. Common proper motion; p.a. increasing.
71. In Hercules. Separation increasing. Spect. K2II, F5.
72. In Ophiuchus. Relatively fixed. Common proper motion. Spect. K2.
73. In Hercules. Relatively fixed. Common proper motion.
74. In Ophiuchus. Relatively fixed. Common proper motion. Spect. F2.
75. In Ophiuchus. Position angle decreasing. Spect. A5, F0.
76. In Ophiuchus. Sep. & p.a. decreasing. Spect. G0.
77. In Ophiuchus. Relatively fixed. Common proper motion. Spect. F8, G0.
78. In Draco. Common proper motion; p.a. increasing. Spect. F5, F5.
79. In Hercules. Common proper motion; p.a. decreasing. Spect. F2, F2.
80. In Draco. Relatively fixed. Common proper motion. Spect. A2, A2.
81. In Hercules. Common proper motion; sep. & p.a. increasing. Spect. A1V, A1V.
82. In Draco. Relatively fixed. Spect. F5, G5.



Lunar Occultation Observations of Known Double Stars – Report #1

Brian Loader, Darfield, New Zealand (BL)
Royal Astronomical Society of New Zealand (RASNZ)
International Occultation Timing Association

Y. Asada, Otsu, Kyoto, Japan (YA)
D. Breit, Morgan Hill, California, USA (DB)
J. Bradshaw, Yugar, Queensland, Australia (JB)
D. Gault, Hawkesbury Heights, NSW, Australia (DG)
D. Herald, Kambah, Canberra, Australia (DH)
E. Iverson, Lufkin, Texas, USA (EI)
M. Ishida, Matusaka, Mie, Japan (MI)
H. Karasaki, Nerima, Tokyo, Japan (HK)
M. Kashiwagura, Oe, Yamagata, Japan (MK)
K. Miyashita, Azumino, Nagano, Japan (KM)
S. Messner, Minneaplois, Minnesota, USA (SM)
T. Oono, Kurashiki, Okayama, Japan (TO)
S. Russell, North Parramatta, Sydney, NSW, Australia (SR)
G. Smith, Black Town, Sydney, NSW, Australia (GS)
J. Talbot, Waikanae, New Zealand (JT)

Email: palbrl@clear.net.nz

Abstract: Reports are presented of lunar occultations of close double stars observed using video including cases where a determination of the position angle and separation of the pair can be made and other cases where no duplicity has been observed.

This report is the first of a continuing series of double star measurements made during lunar occultations. The observations are contributed from observers around the world who observe lunar occultations. Unless noted otherwise, the observations were made using video at 30 fps (observers located in North America and Japan) or 25 fps (observers located in Europe and Australasia). Loader, in New Zealand, normally uses a 30 fps video.

In general, at the lunar occultation of a double star, the light from the star will disappear or reappear in stages, resulting in a stepped light curve of the event. We present the results obtained from the timing of such events of close double stars, in general limited to those with separations less than 2 arc-seconds. When the occultation of a double star is timed from two or more well spread locations an accurate determination of the PA and separation of the pair can be made. Results for a few such events are presented in Table 1. When only one observation is made of a double star occultation a complete solution is not possible, but a vector (minimum) separation of the pair may be determined. Results of such events are presented in Table 2.

The method of analysis of such occultation observations is described by Herald (2009). The occultations are observed using unfiltered video cameras. As indicated by Herald, the unfiltered video cameras have a spectral response somewhere between the V and R magnitude bands.

Observations of occultations of reported double stars when no evidence of a double nature is observed are presented in Tables 3 and 4. The apparent lack of duplicity may be due to a number of factors as indicated in the headings of the tables. Instances are limited to those for which there are at least two observations with no duplicity observed.

In the tables observers are indicated by a two letter code corresponding to their initials codes. Names are listed at the head of this paper. WDS refers to the *Washington Double Star Catalog* and IF to the *Interferometric Catalog*, both published by United States Naval Observatory, Washington. XZ refers to the XZ80 catalog originally put out by the USNO. It includes all stars to magnitude 12.5 within 6°40' of the ecliptic, that is all stars which can be occulted by the moon.

Occultations of the double stars listed in Table 1 were observed at two or more position angles on the same night, allowing a determination of the separation and position angle.

The companion of the double stars listed in Table 2 was observed at a single position angle, allowing the determination of a vector separation and magnitude difference.

In Table 3, the companion of the stars listed in the WDS was not observed. Either the vector separation was too small, or the magnitude difference too large for the circumstances of the event.

Table 4 contains stars with an entry in the Interferometric Catalog but for which no companion was observed. Possible explanations are:

i. the vector separation was too small;
ii. the magnitude difference too large for the circumstances of the event;
iii. the purported companion does not exist.

References

Herald, D. " SAO97883 – a new double star", JDSO, Vol 5, No 4, 2009

Table 1: PA and separation measured

WDS name	XZ	RA Dec	PA	+/-	Sep	+/-	Mag. diff	Date	Observers
HO 345AB	10979	07227+2205	304	4	1.84	0.17	1.4	2009.851	HK, MI, MK
AG 140	101356	07260+2205	165	4	1.38	0.15	0.8	2009.851	HK, MK
A 2768	16040	10426+0335	241	4	0.41	0.08	1.3	2009.413	DB, EI, SM
CHR 78	25788	18448-2501	8	+21 -35	0.016	+0.006 -0.002	2.5	2009.214	DG, BL
FIN 327	26957	19253-2431	275	17	0.095	0.005	1.5	2008.693	DG,DH,GS,JB
CHR 184Aa,Ab	28441	20273-1813	50	7	0.071	0.015	2.6	2009.668	DH,BL
SHJ 323AB	28475	20289-1749	214.8	1.2	1.44	0.02	1.7	2009.668	DH,BL
HDS3054	29697	21274-1335	357	6	0.113	0.013	1.5	2009.747	EI,DB

Lunar Occultation Observations of Known Double Stars – Report #1

Table 2: Vector separation measured

WDS name	XZ	RA Dec	Vector Angle	Vector Sepn.	Mag. Diff	Date	Observer
CHR 127AB	6268	04536+2522	265.910	0.34″	1.75	2009.845	SM
CHR 203	7200	05365+2556	334.873	0.06″	0.98	2009.856	MK
COU 914	9119	06283+2441	280.129	0.20″	0.86	2009.700	SM
HDS 910	9439	06375+2435	273.696	0.45″	2.56	2009.867	SM
HO 247	11655	07461+2107	274.531	0.49″	0.51	2009.770	MI
COU 773	13520	08539+1958	79.721	0.135″	0.52	2008.134	DG
HDS1323	13821	09062+1552	323.032	0.17″	2.55	2009.407	DH
HO 253	14778	09478+1004	348.300	0.77″	2.3	2009.410	EI
BU 932AB	19503	13347-1313	133.397	0.11″	1.6	2007.179	BL
HDS2008	20149	14171-1835	359.764	0.014″	3.5	2009.199	BL
BU 125AB	23196	17122-2703	73.543	1.81″	1.7	2008.611	DH
I 1031	26024	18531-2745	25.709	0.24″	0.97	2005.774	DG

Table 3: Companion not observed (definite double star)

WDS name	XZ	RA Dec	Vector angle	Resolution limit	Limiting Mag. diff	Date	Observer
CHR 124Aa,Ab	4889	03470+2431	222° 118°	0.034″ 0.022″	--- ---	2007.672 2009.095	SM SM
SMK 1Aa,Ab	8068	06010+2734	35° 51°	0.015″ 0.022″	2 3	2009.174 2009.174	DG DH
CHR 170Aa,Ab	10181	06588+2605	57° 52°	0.023″ 0.020″	3 3	2009.177 2009.177	DH DG
MCA 28	10203	06595+2555	89° 88°	0.031″ 0.030″	3 3	2009.177 2009.177	DH DG
TDS9739	40376	16026-2452	86° 82° 135°	0.031″ 0.031″ 0.027″	2.5 2.7 0.7	2009.654 2009.654 2009.654	DH SR JT
FOX 256 See note	29337	21084-1454	113° 114°	0.016″ 0.015″	2.7 3	2009.895 2009.895	KM MI
CHR 116	31135	22583-0224	194° 207° 352°	0.023″ 0.025″ 0.012″	3 2.7 2.5	2009.602 2009.602 2009.826	DG DB YA

[The 'Resolution limit' is set at no less than two frame intervals [0.080s (PAL) or 0.067s (NTSC)] times the vector rate of motion.]

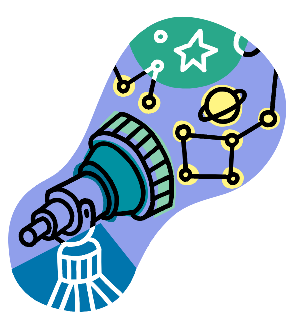
Table note: The WDS shows FOX 256 as a pair with a separation 10.4" measured in 1908. The IF has a single entry for FOX256 from 1991 showing any separation as < 0.1. The light curves from occultation observations show no second star with a vector separation less than ca 1.3".

Lunar Occultation Observations of Known Double Stars – Report #1

Table 4: Companion not observed (possible double star)

Star name	XZ	RA Dec	Vector angle	Resolution limit	Limiting Mag. diff	Date	Observer
BD+06 43	482	00257+0741	265° 95°	0.029" 0.022"	2.5 2.5	2008.709 2008.860	DH BL
Iot Ari	2721	01574+1749	165° 185°	0.008" 0.020"	1.8 2.8	2008.789 2009.461	DH DG
BD+21 416	4151	03107+2154	290° 73° 200°	0.017" 0.029" 0.018"	2.5 4 2.7	2005.648 2006.921 2009.840	BL TO HK
Mel 22 541	4829	03452+2450	309° 237° 88° 101°	0.012" 0.030" 0.025" 0.014"	--- 2 3 3	2005.725 2009.692 2009.917 2010.066	BL DG DH DH
Pleia H256	4831	03453+2428	220° 245°	0.022" 0.037"	--- 3.5	2005.725 2007.672	BL SM
Mel 22 697	4840	03456+2428	211° 238°	0.035" 0.026"	--- 3	2005.725 2007.672	BL DG
OCC 193	4863	03459+2433	217° 105°	0.026" 0.021"	--- ---	2005.725 2009.095	BL SM
Eta Tau	4911	03475+2406	227° 41°	0.026" 0.021"	3 3	2009.618 2009.917	SM YA
BD+25 678	5382	04087+2553	127° 67° 201°	0.015" 0.026" 0.020"	3 3 3	2006.026 2007.075 2009.618	DG SM DG
OCC 115	6938	05263+2836	142° 320°	0.017" 0.017"	2.7 2.5	2008.200 2008.723	DG BL
BD+15 1977	13824	09064+1516	68° 306° 312°	0.018" 0.033" 0.033"	3.5 2.5 2.7	2009.330 2009.930 2009.930	SM DH DG
CP-25 6547	25420	18317-2541	118° 7°	0.028" 0.012"	2.5 2	2008.915 2009.662	DG DB
HR 7039	25814	18457-2659	324° 271°	0.021" 0.031"	--- ---	2004.350 2007.420	BL BL

[The 'Resolution limit' is set at no less than two frame intervals [0.080s (PAL) or 0.067s (NTSC)] times the vector rate of motion.]



Double and Multiple Star Measurements in the Northern Sky with a 10” Newtonian and a Fast CCD Camera in 2006 through 2009

Rainer Anton
Altenholz/Kiel, Germany

e-mail: rainer.anton”at”ki.comcity.de

Abstract: Using a 10” Newtonian and a fast CCD camera, recordings of double and multiple stars were made at high frame rates with a notebook computer. From superpositions of “lucky images”, measurements of 139 systems were obtained and compared with literature data. B/w and color images of some noteworthy systems are also presented.

Introduction

By using the technique of “lucky imaging”, seeing effects can strongly be reduced, and not only the resolution of a given telescope can be pushed to its limits, but also the accuracy of position measurements can be better than this by about one order of magnitude. This has already been demonstrated in earlier papers in this journal [1-3]. Standard deviations of separation measurements of less than +/- 0.05 msec were routinely obtained with telescopes of 40 or 50 cm aperture, even under non-optimum seeing conditions. In this report, similar measurements are described, which I obtained with my 10” Newtonian (~25 cm) at home during the course of more than three years, always with the same camera setup. In 139 investigated double and multiple systems, a total of 169 pairs were measured, often several times. Among these, 54 pairs are more or less well known binaries. In some cases, deviations from ephemeris data were found, in accordance with measurements from other authors. These will be discussed in more detail.

Instrumental

The telescope is of Newtonian type with aperture 10” (~25 cm) and a focal ratio of f/6. In all recordings, I used a 2x Barlow lens (*Televue*), which extends the effective focal length of 3 m. With my b/w-CCD camera (DMK21AF04, *The Imaging Source*) with pixel size 5.6 µm square, this results in a resolution of about 0.19 arcsec/pix. An exact calibration was obtained by an iterative method by measuring well documented double stars, as will be described in the next section. Generally, I used a red filter to cope with chromatic aberration of the Barlow lens, as well as to reduce the atmospheric spectrum. For systems with pronounced color contrast, I also made recordings with near-IR, green and blue filters in order to produce composite images. This setup was the same as I used with telescopes under the southern sky, and as I have described previously [1-3]. Exposure times varied between 0.5 msec and 100 msec, depending on the star brightness, and on the seeing. The procedure of image processing was essentially the same as reported earlier. The best “lucky” frames, out of recordings of a few thousands, were usually selected by visual inspection with the program *VirtualDub*. The typical yield was from several tens to more than a hundred frames, which were then re-sampled, and registered (often manually), and finally automatically stacked. Both registering and stacking was performed with the program *Registax*. This process resulted in smooth intensity profiles, and in position measurements with subpixel accuracy.

Calibration

I calibrated the image scale by measuring a number of double stars with sufficiently well known separations. These are mainly selected from the WDS [4], and the so-called speckle catalog [5]. Criterion was that literature data could unambiguously be extrapolated to the actual date. This may even include binaries. In total, 153 measurements of 58 such systems were obtained, which are contained in the table below,

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

and are marked with shaded lines. The residuals of the separations (rho) are plotted in Figure 1. The calibration constant was adjusted such that the sum of the residuals as well as the standard deviation assumed minimum values. Statistical analysis resulted in a value of 0.194 ± 0.001 arcsec/pix, or ± 0.5 %. The standard deviation of the residuals (of the pairs used for calibration) is 0.03 arcsec, with range between maximum and minimum of 0.1 arcsec. The absolute total error margin is the sum of both contributions, which is also plotted in Fig. 1. Clearly, it increases with separation.

Position angles were measured by referring to star trails in east-west direction, which were obtained by superposing frames with short exposures, while the system was drifting across the field with the telescope drive shut off. This was done for every recording of any system in order to avoid errors, which may occur by slight misalignment of the mounting. The error margin was of the order of ±0.1 degree. The residuals of the position angles (PA) are plotted versus the separation rho in Figure 2. Statistics yielded a standard deviation of 0.83 degrees with range between maximum and minimum of +3.5 and -3.1 degrees, respectively. Deviations increase with decreasing separation, mainly because the lateral resolution is fixed by the pixel size. The largest deviations were observed for separations below 1 arcsec.

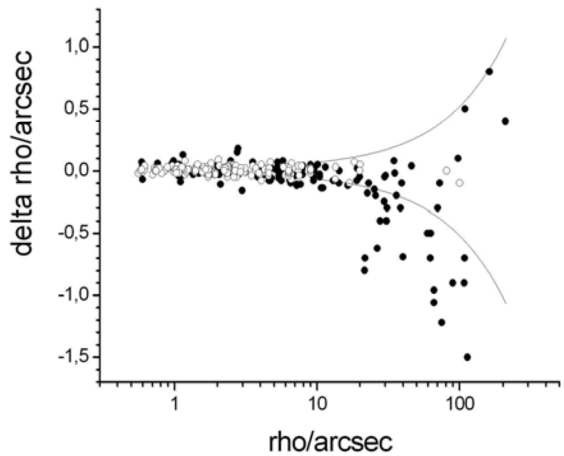


Figure 1: Plot of the residuals of rho versus rho. Semi-logarithmic scale. Open circles represent systems, which have been used for calibration of the image scale, full circles denote all others. The curves mark the total statistical error limits. See text.

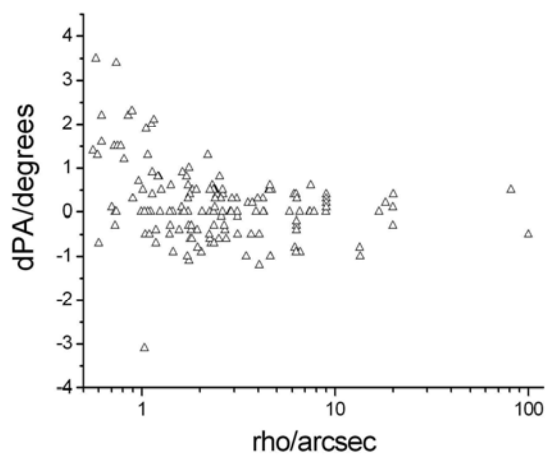


Figure 2: Plot of the residuals of the position angle versus rho. Only systems used for calibration are included here. The increase of scatter towards small separations is mainly caused by the fixed image resolution.

Results

All measurements are listed in the following table, which contains the name of the system, the position in right ascension and declination, the magnitudes of the components (all taken from the WDS), the measured position angles (PA) in degrees, and separations (rho) in arcsec, the date, the number of recordings, the residuals of PA and rho, and the number referring to individual notes, which follow the table. Asterisks denote systems, for which images are shown below. Systems used for calibration of the image scale are marked with shaded lines.

The accompanying images are chosen for different reasons. In general, they show the image quality, which can be obtained with lucky imaging, which is often apparent by the diffraction rings. Images of close systems (Figure 4) demonstrate the resolving power, which is close to the theoretical limit. Other images depict interesting multiple systems. RGB composites are presented of pairs with marked color contrast (Figures 14, 15). In all images, north is down, and east is right. At the bottom, position angles and separations are indicated as measured from the respective image.

(Continued on page 196)

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA meas.	rho meas.	DATE	N	D PA	D rho	NOTES
HJ 1947 AB	00 16.4 +43 36	6.16 9.83	73.9	8.97	2007.797	1	-0.6	+0.05	1
STF 22 AB-C	00 17.4 +08 53	7.13 7.77	234.1	4.00	2008.661	1	-0.4	+0.02	2
STF 24	00 18.5 +26 08	7.79 8.44	248.1 246.8	5.27 5.21	2006.792 2007.797	1 1	+0.2 -1.1?	+0.07 +0.01	3
AC 1	00 20.9 +32 59	7.27 8.26	288.1 287.4	1.89 1.84	2006.792 2007.797	1 1	~0 -0.2	+0.04 -0.01	4
STF 46	00 39.9 +21 26	5.56 8.49	196.0	6.51	2007.764	4	+0.5	-0.10	5
STF 60AB	00 49.1 +57 49	3.52 7.36	320.7 321.3	12.92 13.00	2007.784 2009.789	4 4	~0 ~0	-0.08 -0.08	6*
STF 60AE		3.52 10.15	124.5	81.1	2009.789	1	+0.5	~0	
STF 61	00 49.9 +27 43	6.33 6.34	295.4 295.6 295.3	4.27 4.24 4.26	2007.764 2008.661 2009.803	1 1 1	~0 +0.3 ~0	+0.02 -0.01 0.01	7
STF 73AB	00 55.0 +23 38	6.12 6.54	318.3 323.4	1.04 1.06	2007.756 2009.789	1 1	-0.5 -0.3	+0.01 ~0	8
STF 79	01 00.1 +44 43	6.04 6.77	193.7	7.80	2007.756	1	+0.1	~0	9
STT 21	01 03.0 +47 23	6.76 8.07	174.0 176.4	1.18 1.22	2007.756 2009.647	1 1	-0.7 +0.8	-0.03 -0.01	10
STF 88AB	01 05.7 +21 28	5.27 5.45	159.3 158.4	29.65 29.45	2007.784 2007.808	1 1	-0.3 -1.1	-0.05 -0.25	11
BU 303	01 09.7 +23 48	7.32 7.56	291.6	0.60	2009.803	1	-0.7	-0.01	12
BU 398	01 11.9 +47 48	9.31 9.38	44.3	1.82	2007.756	1	+0.5	0.01	13
STF 100AB	01 13.7 +07 35	5.22 6.15	63.3	22.50	2007.784	1	+0.5	-0.18	14
STF 174	01 50.1 +22 17	6.33 7.21	164.8 164.2	2.81 2.82	2007.764 2009.803	4 4	+0.4 ~0	-0.03 -0.02	15*
STF 180AB	01 53.5 +19 18	4.52 4.58	0.7 0.8	7.38 7.40	2007.808 2009.803	1 1	~0 ~0	~0 +0.04	16
STF 185AB	02 02.2 +75 30	6.77 8.58	8.5	1.14	2007.808	1	-1.0	+0.01	17
STF 208AB	02 03.7 +25 56	5.82 7.87	340.4	1.26	2007.808	1	+0.5	+0.01	18
STF 205	02 03.9 +42 20	2.31 5.02	63.0 62.7 63.3 62.2 62.9	9.53 9.42 9.45 9.52 9.48	2006.794 2007.753 2007.844 2009.647 2009.789	3 4 4 1 4	~0 -0.3 +0.2 -0.6 ~0	+0.02 -0.08 -0.05 +0.03 ~0	19*
STF 222	02 10.9 +39 02	6.05 6.71	35.1	16.46	2007.753	2	-0.6	-0.12	20
STF 227	02 12.4 +30 18	5.26 6.67	69.5 67.2	3.90 3.83	2007.784 2009.803	1 1	+0.9 -1.4	+0.02 -0.05	21
STF 228	02 14.0 +47 29	6.56 7.21	291.1 294.6 293.6	0.90 0.85 0.81	2007.756 2009.647 2009.789	1 1 1	+0.3 +2.2 +1.2	+0.02 ~0 -0.02	22*
STF 232	02 14.7 +30 24	7.82 7.90	66.8	6.53	2007.784	1	+0.9	-0.07	23
STF 245AB	02 18.6 +40 17	7.26 8.03	292.7	10.96	2007.753	4	-0.8	-0.14	24
STF 262Aa-B	02 29.1 +67 24	4.63 6.92	229.6 230.4	2.74 2.78	2007.784 2009.789	1 3	+0.1 +1.2	+0.15 +0.18	25*
STF 262Aa-C		4.63 9.05	115.7 116.1	7.20 7.19	2007.784 2009.789	1 3	-0.3 +0.1	-0.11 -0.12	
STF 262BC		6.92 9.05	98.9 99.0	8.67 8.67	2007.784 2009.789	1 3	- -	- -	

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA	rho	DATE	N	D PA	D rho	NOTES
STF 93	02 31.8 +89 16	2.1 9.1	233.2	18.29	2007.808	1	+0.2	+0.07	26*
STF 305AB	02 47.5 +19 22	7.52 8.25	306.6	3.67	2007.808	1	-0.5	~0	27
STF 333AB	02 59.2 +21 20	5.17 5.57	209.9 208.9 209.6	1.41 1.39 1.39	2007.808 2007.860 2009.803	1 1 1	+0.6 -0.5 ~0	+0.03 +0.01 +0.01	28*
STT 531AB	04 07.6 +38 04	7.32 9.69	356.6 357.0	2.44 2.53	2007.808 2007.844	1 1	+0.4 +0.8	+0.05 -0.03	29
STF 494	04 08.9 +23 06	7.53 7.65	187.8	5.26	2008.967	1	-0.2	+0.03	30
STT 81AB	04 24.6 +33 58	5.84 9.25	15.8	4.29	2007.844	1	-0.6	-0.03	31
STF 616	04 59.3 +37 53	5.00 8.21	2.4	4.75	2008.112	1	-0.6	+0.02	32
STT 92AB	05 00.3 +39 24	6.02 9.50	278.8	4.05	2008.112	1	-1.2	-0.08	33
STF 644AB	05 10.3 +37 18	6.96 6.78	224.2 222.6	1.59 1.59	2007.844 2008.112	3 4	+1.6 ~0	~0 ~0	34*
VBS 10AC	05 10.3 +37 18	6.96 10.48	191.6	72.4	2008.112	1	-0.6	+0.37	34*
STF 681	05 20.7 +46 58	6.61 9.21	180.1	23.0	2008.112	1	-0.6	-0.1	35
STF 718AB	05 32.3 +49 24	7.47 7.54	72.8	7.66	2008.112	1	-0.5	-0.11	36
STF 764	05 41.3 +29 29	6.38 7.08	14.1	25.7	2008.112	1	~0	-0.2	37
STF 845AB	06 11.6 +48 43	6.16 6.86	358.4	7.47	2008.112	1	+0.6	-0.04	38
STF 918AB	06 34.0 +52 28	7.26 8.19	334.5	4.77	2008.112	1	-0.2	-0.06	39
STT 152	06 39.6 +28 16	6.21 7.85	37.2	0.92	2008.112	1	+1.4	+0.03	40
STF1110AB	07 34.6 +31 53	1.93 2.97	58.2 163.7	4.52 70.1	2009.227	1 1	+0.5 -0.3	~0 -0.3	41*
STF1177	08 05.6 +27 32	6.69 7.41	350.2	3.52	2008.128	1	-0.4	+0.07	42
STF1196AB AC	08 12.2 +17 39	5.30 6.25 " 5.85	47.8 44.8 43.1 69.0 68.6 67.8	0.99 1.03 1.07 6.60 6.55 6.57	2007.121 2008.128 2009.208 2007.121 2008.128 2009.208	1 1 1 1 1 1	~0 ~0 +1.3 -0.9 ~0 ~0	-0.01 ~0 +0.02 +0.06 -0.03 -0.07	43*
STF 1223	08 26.8 +26 56	6.16 6.21	218.0	5.15	2008.128	1	~0	+0.01	44
STF 1245 AB AC AD AE Ax Ay	08 35.8 +06 37	5.98 7.16 - 10.70 - 12.0 - 9.6	24.2 109.3 290.1 206.2 71.4 210.6	10.05 97.6 108.3 113.3 46.0 118.8	2008.128 „ „ „ „ „	3 2 2 1 2 1	-1 -0.8 -0.3 -0.8 -1.2 -	+0.05 +0.1 -0.7 -1.5 +0.04 -	45
STF1268 AB	08 46.7 +28 46	4.13 5.99	307.5	30.2	2008.128	4	~0	-0.04	46*
STF1291 AB	08 54.2 +30 35	6.09 6.37	310.2 310.5	1.48 1.52	2008.128 2008.273	1 1	-0.3 ~0	-0.02 +0.02	47
STF1298 AB	09 01.4 +32 15	5.95 8.56	135.3	4.42	2008.128	1	+0.4	-0.01	48
STF1311 AB	09 07.4 +22 59	6.92 7.13 "	199.3 116.5	7.54 27.6	2008.128	3 1	+0.4 -0.5	-0.02 -0.4	49
STF1321 AB	09 14.4 +52 41	7.79 7.88	95.8	16.9	2009.296	1	~0	-0.10	50
STF3121	09 17.9 +28 34	7.9 8.0	220.9	0.60	2008.128	1	+11?	-0.07	51
STF1333	09 18.4 +35 22	6.63 6.69	48.8	1.92	2009.260	1	~0	+0.01	52

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA meas.	rho meas.	DATE	N	D PA	D rho	NOTES
STF1334AB	09 18.8 +36 48	3.92 6.09	224.9	2.62	2009.260	1	+0.4	-0.01	53
STF1338AB	09 21.0 +38 11	6.27 7.08	300.5	1.07	2009.304	1	-1.5	+0.05	54
AC		6.12 11.4	166.5	142.9		1	-	-	
STF1356	09 28.5 +09 03	5.69 7.28	103.1	0.72	2008.128	2	+1.5	+0.02	55
			103.2	0.75	2009.260	3	+1.5	+0.02	
			101.4	0.73	2009.299	1	-0.3	0.0	
			101.8	0.70	2009.301	2	+0.1	-0.03	
			105.3	0.74	2009.304	1	+3.4	+0.01	
STT215	10 16.3 +17 44	7.25 7.46	178.5	1.44	2009.299	1	~0	+0.01	56
STF1424AB	10 20.0 +19 50	2.37 3.64	126.0	4.70	2007.121	1	+0.5	+0.07	57
			124.4	4.63	2008.128	1	-1?	+0.02	
			124.8	4.62	2008.270	5	-1?	+0.02	
			126.2	4.57	2009.244	1	+0.5	-0.04	
			126.4	4.60	2009.301	1	+0.6	-0.02	
STF1426AB	10 20.5 +06 26	7.99 8.30	311.7	0.96	2009.301	2	+0.7	+0.04	58
AC		" 9.43	8.5	7.77		2	~0	+0.04	
STT 217	10 26.9 +17 13	7.85 8.58	149.7	0.78	2009.301	1	+1.5	+0.02	59
STF1450AB	10 35.0 +08 39	5.80 7.90	157.2	2.10	2009.252	1	+0.7	+0.01	60
STF1487	10 55.6 +24 45	4.48 6.30	113.5	6.51	2008.273	1	+1.1	-0.02	61
			112.4	6.45	2009.244	1	~0	-0.08	
STF1523AB	11 18.2 +31 32	4.33 4.80	223.7	1.62	2008.276	2	~0	-0.01	62
			224.6	1.62	2008.311	1	+0.9	-0.01	
			216.9	1.62	2009.244	1	~0	+0.01	
STF1536AB	11 23.9 +10 32	4.06 6.71	102.5	1.91	2008.270	2	+0.5	-0.03	63
			101.1	2.03	2008.273	1	-0.9	+0.09	
			99.9	1.94	2009.244	2	-0.8	-0.02	
			101.1	1.93	2009.301	1	-0.4	-0.03	
STF1543AB	11 29.1 +39 20	5.35 10.67	353.4	5.40	2008.276	1	-0.5	-0.04	64
			354.6	5.38	2009.252	1	+0.7	-0.06	
STF1552AB	11 34.7 +16 48	6.26 7.31	206.9	3.46	2008.270	1	-1	-0.04	65
			208.6	3.54	2009.244	2	+0.2	+0.04	
AC		6.26 9.77	234.0	62.3	2008.270	1	-1	-0.5	
			235.2	62.3	2009.244	2	~0	-0.7	
BC		7.4 8.8?	235.6	59.2	2008.270	1	-1	-0.5	
STF1555AB	11 36.3 +27 47	6.41 6.78	148.1	0.73	2009.299	1	~0	~0	66
			148.3	0.74	2009.304	1	~0	~0	
STF1555AB-C		5.83 11.17	155.8	21.5	2009.299	1	-0.1	-0.8	
			156.5	21.7	2009.304	1	+0.6	-0.7	
STF1561AB	11 38.7 +45 07	6.53 8.23	247.4	8.98	2009.296	1	~0	-0.02	67
STF1579AB-C	11 55.1 +46 29	6.68 8.32	41.6	3.86	2009.296	1	~0	+0.02	68
AB-D		6.68 6.97	113.5	62.5		1	-0.3	-0.5	
STF1596	12 04.3 +21 28	6.18 7.48	235.7	3.73	2008.273	1	+0.2	+0.02	69
STF1622AB	12 16.1 +40 40	5.86 8.71	259.0	11.43	2008.273	4	-0.5	+0.03	70
STF1639AB	12 24.4 +25 35	6.74 7.83	322.7	1.75	2008.276	1	-1.1	-0.03	71
			323.0	1.78	2009.244	1	-0.6	+0.01	
			323.2	1.79	2009.260	1	-0.4	+0.01	
STF1657	12 35.1 +18 23	5.11 6.33	269.8	19.9	2008.273	4	-0.3	-0.05	72
			270.5	20.0	2009.252	4	+0.4	+0.05	
			270.2	19.9	2009.260	1	+0.1	-0.05	
STF1670 AB	12 41.7 -01 27	3.48	38.5	1.01	2008.311	1	+0.5	+0.01	73
		3.53	39.9	1.05	2008.342	1	+1.9	+0.04	
			33.7	1.03	2008.369	1	-3.1?	+0.01	
			30.4	1.21	2009.252	1	+0.8	-0.01	
			28.6	1.24	2009.260	1	~0	+0.01	
			28.6	1.24	2009.296	1	~0	+0.01	

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA meas.	rho meas.	DATE	N	D PA	D rho	NOTES
STF1687 AB	12 53.3 +21 15	5.15 7.08	194.9	1.13	2008.276	1	+0.9	+0.03	74*
			196.2	1.12	2009.208	1	+2.0	+0.02	
			196.5	1.15	2009.244	2	+2.1	+0.01	
			194.0	1.11	2009.260	2	~0	+0.01	
			193.6	1.18	2009.299	2	-0.4	+0.08	
STF1687 AC		5.15 9.76	126.5	28.3	2008.276	1	-	-	
			127.4	28.4	2009.208	1	-	-	
			127.3	28.2	2009.244	2	-	-	
			127.2	28.3	2009.260	2	-	-	
			127.7	28.3	2009.299	2	-	-	
STF1692	12 56.0 +38 19	2.85 5.52	227.9	19.0	2008.273	4	-0.7	-0.08	75
			229.1	19.1	2009.244	4	+0.5	+0.02	
BU1082	13 00.7 +56 22	5.02 7.88	100.7	1.12	2008.311	2	+3.6	-0.04	76
			99.1	1.13	2009.244	1	+0.1	-0.02	
COU 11Aa-B	13 06.4 +21 09	6.10 8.75	314.7	1.69	2008.276	2	-0.8	-0.03	77
			314.2	1.73	2009.260	1	-1.5?	-0.03	
STT261	13 12.0 +32 05	7.40 7.64	338.3	2.50	2008.273	1	-0.6	~0	78
			338.8	2.57	2009.244	1	-0.1	+0.05	
			339.2	2.56	2009.260	1	+0.3	+0.04	
STF1744 AB	13 23.9 +54 56	2.23 3.88	152.7	14.2	2008.311	3	+0.2	-0.10	79
			152.9	14.3	2009.208	1	-0.6	~0	
STF1768 AB	13 37.5 +36 18	4.98 6.95	96.7	1.74	2008.273	1	-0.3	-0.04	80
			97.7	1.75	2009.208	1	+1.0	+0.02	
			97.3	1.73	2009.244	1	+0.6	~0	
			97.1	1.77	2009.260	1	+0.4	+0.04	
STF1772 AB	13 40.7 +19 57	5.76 9.60	132.5	4.58	2008.276	1	-0.8	-0.08	81
STF1770	13 43.1 +03 32	5.55 8.31	226.6	2.73	2008.369	1	-0.6	-0.05	82
STF1785	13 49.1 +26 59	7.36 8.15	179.0	3.13	2008.276	1	-0.5	-0.01	83
			180.5	3.12	2009.244	1	-0.1	~0	
			180.9	3.09	2009.299	1	+0.3	-0.01	
STF1821 AB	14 13.5 +51 47	4.53 6.62	234.4	13.4	2008.276	1	-0.8	-0.07	84
			234.2	13.5	2008.344	1	-1.0	+0.03	
STFA 26 AB	14 16.2 +51 22	4.76 7.39	32.0	38.4	2008.344	1	-0.4	-0.30	85
STF1834	14 20.3 +48 30	8.09 8.29	103.1	1.56	2008.276	1	-0.4	-0.01	86
			102.6	1.60	2009.252	1	+0.1	+0.03	
STF1850 AB	14 28.6 +28 17	7.11 7.56	261.0	25.2	2008.276	1	-0.2	-0.15	87
STF1864 AB	14 40.7 +16 25	4.88 5.79	109.7	5.52	2008.276	1	-0.8	~0	88
STF1865 AB	14 41.1 +13 44	4.46 4.55	298.2	0.62	2008.317	1	+2.2	+0.01	89*
			297.4	0.56	2008.344	1	+1.4	-0.02	
			298.5	0.58	2009.252	1	+3.5	~0	
			296.6	0.62	2009.260	1	+1.6	+0.04	
			296.3	0.59	2009.301	1	+1.3	+0.01	
STF 1877 AB	14 45.0 +27 04	2.58 4.81	343.3	2.86	2009.304	4	~0	+0.01	90
STF 1884	14 48.4 +24 22	6.58 7.48	55.8	2.17	2008.342	1	-	-	91
STF 1890	14 49.7 +48 43	6.31 6.67	45.2	2.69	2008.276	1	-0.4	+0.04	92
STF1888 AB	14 51.4 +19 06	4.76 6.95	309.0	6.18	2008.276	1	-0.8	+0.01	93*
			309.7	6.13	2009.208	1	+0.4	+0.03	
STF1888AC		4.76 12.6	340.4	71.6	2008.311	1	-	-	
STF1888AD		4.76 9.6	286.0	161.1	2008.311	1	~0	+0.8	
ARN11 AE		4.76 8.65	98.3	271.6	2008.311	1	-	-	
STT288	14 53.4 +15 42	6.89 7.55	161.5	1.09	2008.276	1	-0.5	+0.01	94

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA meas.	rho meas.	DATE	N	D PA	D rho	NOTES
STF1909	15 03.8 +47 39	5.20 6.10	57.0 58.6 60.1	1.72 1.73 1.70	2008.276 2008.383 2009.299	1 1 1	-1.0 +0.3 +0.8	-0.05 -0.03 +0.03	95
STFA 28AB	15 24.5 +37 23	4.33 7.09	169.9 170.0 170.8	107.4 108.7 107.4	2008.276 2008.311 2009.299	1 1 1	-1.1 -1.0 -0.2	-0.9 +0.5 -0.9	96
STF1938BC		7.09 7.63	5.1 5.2 5.4	2.28 2.25 2.25	2008.276 2008.311 2009.299	1 1 1	-0.7 -0.6 ~0	+0.03 ~0 ~0	97
STF1954AB	15 34.8 +10 32	4.17 5.16	172.2 173.1	4.05 3.97	2008.342 2008.383	1 1	-0.5 +0.3	+0.05 -0.03	98
STF1965AB	15 39.4 +36 38	4.96 5.91	304.5 305.9 305.2	6.27 6.29 6.31	2008.342 2009.252 2009.260	1 1 1	-0.9 +0.4 -0.3	-0.04 -0.02 ~0	99
STF1967	15 42.7 +26 18	4.04 5.60	114.7	0.76	2009.260	1	+4.7	+0.06	100
STF1970AB	15 46.2 +15 25	3.66 9.96	263.9	30.5	2008.383	1	~0	-0.4	101
STF2032AB	16 14.7 +33 52	5.62 6.49	236.1	7.03	2008.342	1	-0.1	-0.04	102
STF2054AB	16 23.8 +61 42	6.15 7.09	349.7	1.02	2009.304	2	-1.3	+0.03	103
STF2078AB STFA 30AC	16 36.2 +52 55	5.38 6.42 5.38 5.50	104.2 193.3	3.11 89.4	2009.304	1 1	~0 +0.3	+0.02 -0.9	104*
STF2084	16 41.3 +31 36	2.95 5.40	193.3	1.07	2008.369	1	~0	-0.02	105
STF2118AB	16 56.4 +65 02	7.07 7.30	66.9	1.03	2009.304	1	~0	-0.02	106
STF2130AB	17 05.3 +54 28	5.66 5.69	9.8 9.2 10.1 9.2	2.35 2.36 2.39 2.39	2008.369 2008.383 2008.388 2009.304	1 2 1 1	~0 -0.7 +0.3 +0.5	-0.05 +0.01 +0.04 +0.03	107
STF2140AB	17 14.6 +14 23	3.48 5.40	103.1	4.69	2008.369	1	-0.4	-0.08	108
STF2161AB	17 23.7 +37 09	4.50 5.40	318.3	4.01	2008.344	4	-0.5	~0	109
BU 962AB	17 35.0 +61 53	5.28 8.54	320.7	1.10	2008.383	1	~0	-0.09	110
STF2199	17 38.6 +55 46	8.03 8.60	56.8	2.05	2009.304	1	~0	+0.04	111
STF2220A-BC	17 46.5 +27 43	3.42 9.78	248.1	35.1	2008.344	1	-0.6	-0.02	112*
AC 7BC		10.2 10.7	236.4 237.4	1.06 1.13	2008.344 2008.369	1 1	-0.6 +0.4	-0.04 +0.03	
STF2264	18 01.5 +21 36	4.85 5.20	257.5 257.0 256.4	6.34 6.31 6.32	2007.545 2008.344 2009.647	11 1	+0.3 -0.2 -0.4	+0.01 -0.01 ~0	113
STF2383AB	18 44.3 +39 40	5.01 6.10	348.6 349.1 348.6	2.38 2.36 2.31	2008.383 2008.388 2009.647	2 1 1	+0.1 +0.5 +0.6	+0.03 +0.01 -0.02	114*
STF2383CD		5.25 5.38	79.8 79.1 79.3	2.37 2.36 2.35	2008.383 2008.388 2009.647	2 1 1	+0.5 -0.3 +0.5	+0.01 -0.01 -0.02	114*
STF2383AD		5.01 5.38	172.3	208.3	2008.388	1	+0.3	+0.4	114*
Es 2028AB AC	18 54.5 +36 54	4.3 11.2 11.2 11.6	349.4 134.8	86.5 2.09	2008.369 〃	1 1	- -1.6	- -0.11	115
STFA 43AB	19 30.7 +27 58	3.37 4.68	55.3	34.5	2007.518	1	+0.3	+0.08	116*
STFA 46Aa-B	19 41.8 +50 32	6.00 6.23	133.3	39.2	2007.521	1	-0.1	-0.10	117
STF2579AB	19 45.0 +45 08	2.89 6.27	220.6 220.7 219.9	2.61 2.61 2.66	2007.545 2008.383 2008.560	1 1 1	~0 +0.5 -0.3	-0.04 -0.05 ~0	118

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

PAIR	RA + DEC	MAGS	PA meas.	rho meas.	DATE	N	D PA	D rho	NOTES
STF2583AB	19 48.7 +11 49	6.34 6.75	104.4 105.3 104.9	1.45 1.39 1.40	2008.560 2008.661 2009.647	1 1 1	-0.9 ~0 -0.3	+0.05 -0.01 ~0	119
STF2605AB	19 55.6 +52 26	5.03 7.52	175.7 175.4	2.92 2.89	2007.521 2007.715	1 2	+0.3 ~0	+0.02 -0.01	120
STF2628	20 07.8 +09 24	6.60 8.66	338.3 337.8	2.98 2.97	2008.661 2009.647	1 1	-0.6 -1.1	-0.16 -0.16	121
STF2727	20 46.7 +16 07	4.36 5.03	266.1 266.0 265.8 265.7	9.02 9.00 9.00 8.99	2007.545 2007.715 2008.560 2008.661	41 4 4	+0.4 +0.3 +0.2 +0.1	+0.02 ~0 +0.02 +0.01	122*
STT 413	20 47.4 +36 29	4.73 6.26	8.6 7.1	0.98 0.96	2008.560 2009.647	1 2	+4.2 +3.1	+0.08 +0.06	123
STF2729AB	20 51.4 -05 38	6.40 7.43	27.5	0.89	2007.764	1	+2.3	+0.03	124
STF2737AB	20 59.1 +04 18	5.96 6.31	282.9 287.0	0.60 0.59	2008.661 2009.647	1 1	-1.1 +3.0	+0.04 +0.07	125
STF2737AC AB-C		5.96 7.05 5.30 7.05	67.5 66.9	10.42 10.38	2008.661 2009.647	1 1	+0.4 -0.1	-0.03 -0.05	125
STT 426	21 01.2 +46 09	5.4 9.6	160.5	2.85	2008.560	1	~0	~0	126
STF2745AB	21 04.1 -05 49	5.80 7.50	196.3	2.47	2007.764	1	+0.4	+0.08	127
STF2758AB	21 06.9 +38 45	5.35 6.10	151.2 151.6	30.7 30.9	2007.521 2009.647	1 1	-0.5 +0.5	-0.4 -0.3	128
STFB 11AB	21 22.1 +19 48	4.20 7.56	311.1	35.9	2007.715	2	-0.4	-0.2	129
STF2822	21 44.1 +28 45	4.75 6.18	311.4 312.3 313.3	1.81 1.80 1.73	2007.545 2008.560 2009.647	1 1 1	-0.6 -0.3 ~0	+0.05 +0.06 +0.01	130
STF2863AB	22 03.8 +64 38	4.45 6.40	275.6 273.8 274.7	7.89 7.96 7.85	2007.525 2007.545 2009.647	4 1 1	+0.8 -0.9 ~0	-0.03 +0.04 +0.01	131
STF2854	22 04.4 +13 39	7.77 7.89	83.4	1.65	2009.647	1	~0	+0.01	132
STF2909AB	22 28.8 -00 01	4.34 4.49	171.3 170.6	2.06 2.07	2007.753 2007.764	1 1	+1.0 +0	-0.03 -0.02	133
STF2958	22 56.9 +11 51	6.63 9.09	14.5	3.90	2008.661	1	~0	-0.02	134
STF3007AB AC	23 22.8 +20 34	6.74 9.78 10.86	91.0 304.9	5.80 99.8	2007.545 „	1 1	~0 -0.5	+0.03 -0.1	135
STT 496AB HJ 355AC HJ 1888AE HJ 1888AF HJ 1888AG DA 2CD HJ 1886CH HJ 1887FG	23 30.0 +58 33	4.9 9.3 4.87 7.23 4.9 11.28 4.87 10.59 4.9 11.11 7.23 9.06 7.1 12.9 8.9 9.1	- 268.7 116.9 338.4 347.7 215.4 338.1 73.3	- 74.7 39.9 66.0 66.0 1.35 26.4 10.66	2008.560 „ „ „ „ „ „ „	1 1 1 1 1 1 1 1	- ~0 ~0 ~0 -0.3 +0.4 +1.0 +0.3	- -1.22 -0.69 -0.96 -1.06 -0.03 -0.62 -0.14	136
STF3042	23 51.9 +37 53	7.62 7.75	86.9 86.6	5.76 5.61	2006.792 2007.797	1 1	+0.9 +0.2	+0.08 -0.08	137
BU 728	23 52.2 +43 31	8.69 8.94	9.6	1.22	2007.797	1	+0.3	+0.01	138
STF3050	23 59.5 +33 43	6.46 6.72	335.6 336.2 335.4	2.19 2.25 2.23	2007.797 2009.647 2009.789	1 1 1	+1.3 +0.5 -0.5	+0.02 +0.02 ~0	139*

Notes:

1. in Andromeda, cpm, relfix.
2. 38 Piscium, large scatter of literature data, AB (0.1") not resolved.
3. theta And, relfix, cpm, reference data ambiguous.
4. in Andromeda, rho and PA slowly increasing.
5. 55 Piscium, yellow-blue color contrast, PA increasing, few data.
6. eta Cas, AB binary, P= 480 y, yellow-red color contrast, spectra G0V/dM0. AE: PA increasing, but only few data. Linear decrease of rho allows for trustworthy extrapolation. Another somewhat dimmer component seen at 74.3o/99.5", which also appears on POSS plate from1995 at 78.7o/106.1". This is not listed in WDS. See fig. 5.
7. 65 Piscium, relfix, cpm, rho has slightly increased since the 18th century until the 1950's, then decreased, while PA seems to slowly decrease.
8. 36 Andromedae, binary, P=168 y, many interferometric data with small scatter.
9. in Andromeda, cpm, relfix.
10. in Andromeda, binary, P=450 y, orbit highly tilted, measured separation closely follows trend of speckle data, but is off from ephemeris by about +0.1".
11. psi (74) Piscium, AB relfix, cpm, AC: 11.m2 in ~91 ".
12. in Pisces, rho decreasing.
13. in Andromeda, few literature data with large scatter, large deviation of PA.
14. zeta Piscium, relfix, P.A. (and rho?) decreasing, BC: 12m.2 in 1.8 ".
15. 1 Arietis, cpm, literature data exhibit large scatter. Color contrast yellow-blue, spectra G3 – A, see fig. 15.
16. gamma Arietis, PA increasing, rho decreasing.
17. in Cassiopeia, cpm, AC distance ~120 ", few literature data.
18. 10 Arietis, binary, P=309 y, significant deviation from ephemeris, no recent data.
19. gamma Andromedae, rho decreasing, colors yellow-blue, spectra K3 – B/A. Gamma b binary, P=56 y, rho < 0.3", not resolved here. See fig. 15.
20. 59 Andromedae, relfix.
21. iota Trianguli, cpm, PA decreasing.
22. in Andromeda, binary, P=144 y. See fig. 4.
23. in Triangulum, cpm, relfix.
24. in Andromeda, relfix, colors yellow-blue? not verified in RGBIR-images. Few data.
25. iota Cassiopeiae, multiple, AB binary, P=840 y, literature data exhibit periodic deviations from calculated orbit, which seems to be caused by an unseen companion. Residuals refer to ephemeris. Aa distance ~0.5 "(8.m48). BC: rho seems to rapidly decrease, extrapolation ambiguous. See fig. 6.
26. alpha UMi, Polaris, residuals ambiguous because of too few data. See fig. 6.
27. in Aries, binary, "premature orbit", P=720 y, own measurement of separation as well as speckle data deviate from calculated orbit by about -0.05" to -0.10".
28. epsilon Ari, AB PA slowly increasing, many speckle data. See fig. 4.
29. in Perseus, binary, "premature orbit", P=700 y, both PA and rho deviate from calculated orbit, in accordance with speckle data.
30. in Taurus, relfix, cpm.
31. 56 Persei, cpm, few data.
32. omega Aurigae, PA slowly increasing, rho decreasing, few data.
33. 5 Aurigae, binary, P=1598 y (?), PA and rho increasing.
34. in Auriga, AB relfix, cpm, nice yellow-blue color contrast, large scatter of PA data in the literature. VBS 10 AC: P.A. slowly decreasing ? See fig. 14.
35. in Auriga, relfix, few data with large scatter.
36. in Auriga, relfix.
37. in Auriga, relfix, cpm.
38. 41 Aurigae, relfix, cpm.
39. in Auriga, cpm, PA inc.
40. 54 Aurigae.
41. alpha Geminorum, "Castor", AB binary, P=467 y. AC: in literature only few data with large scatter. See fig. 7.
42. in Cancer, relfix, cpm, large scatter of literature data.
43. zeta Cancri, famous triple system, AB binary, P=59.7 y, AB-C "binary", P=1115 y, C has an invisible companion, which causes periodic deviations from orbit (currently ~0.1"). See fig. 8.
44. phi 2 Cancri, cpm, PA slow inc.

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

45. in Cancer, multiple system, few data, AB relfix, AC: PA dec, rho inc, AD: PA inc, rho dec, AE: PA dec, rho dec. x, y not listed in WDS, but present in POSS plates, AX: PA dec, rho inc, estimated magnitudes ~13m and ~12.3m, respectively. D appears brighter by ~1m than listed (12m.0).
46. iota Cancri, relfix, cpm, nice yellow-blue color contrast. See fig. 15.
47. iota2 (57) Cancri, cpm, PA slow dec, no third component seen.
48. 66 Cancri, relfix, few data, large scatter.
49. in Cancer, relfix, cpm, residuals ambiguous because of too few literature data.
50. in Ursa Major, binary, P= 975 y.
51. in Cancer, binary, P=34.2 y. Residuals ambiguous, because both PA and rho rapidly change.
52. in Lynx, PA & rho inc, large scatter of literature data.
53. 38 Lyncis, PA slow dec.
54. in Lynx, AB binary, P=390 y, PA inc, few data for AB-C.
55. omega (2) Leonis, binary, P=117 y, many interferometric data. See fig. 4.
56. in Leo, binary, P=670 y, own measurement of rho as well as recent speckle data deviate from the ephemeris by -0.1".
57. gamma Leonis, AB binary, P=619 y, color contrast, relatively large scatter of literature data.
58. in Leo, triple system, AB binary, orbit preliminary. See fig. 8.
59. in Leo, binary, P=140 y. See fig. 4.
60. TX (49) Leonis, relfix, cpm, few data in the literature, PA and rho slowly decreasing ?
61. 54 Leonis, cpm, large scatter of literature data, colors?
62. xi Ursae Majoris, binary, well documented orbit, P=59.8 y.
63. iota Leonis, binary, P=183 y, PA decreasing.
64. 57 Ursae Majoris, AB cpm, PA dec, few data in literature.
65. 90 Leonis, triple, AB cpm, relfix, few data with large scatter in literature. See fig. 9.
66. in Leo, AB binary, "premature orbit", P=916 yr, highly inclined. Own measurements of rho, as well as speckle data, deviate from calculated ephemeris. AB-C: few data in literature.
67. in UMa, binary, orbit preliminary, P=2050 y (?).
68. 65 Ursae Majoris, quadruple (AB: ~0.1", not resolved). See fig. 9.
69. zeta (2) Comae Berenices, relfix, scatter of literature data.
70. 2 Canum Venaticorum, relfix, colors.
71. in Coma Berenices, binary, P=678 y.
72. 24 Comae Berenices, relfix, cpm, spectra K2III - ?, colors yellow-bluish. See fig. 15.
73. gamma Virginis, binary, P=169 y. See fig. 4.
74. 35 Comae Berenices, triple, AB binary, P=510 y, all cpm, rho seems to slightly increase and deviate from ephemeris. AC: no residuals because of too few data in the literature. See fig. 10.
75. alpha Canum Venaticorum, cpm, relfix, description of color contrast in literature varies from white - bluish to yellow – reddish. Own RGB composite corresponds to the latter.
76. 78 Ursae Majoris, binary, P=107 y, difficult, residuals ambiguous because of few data.
77. 39 Comae Berenices, relatively large scatter of literature data, PA dec, rho inc.
78. in Canes Venatici, PA dec, r slow inc.
79. zeta Ursae Majoris, "Mizar", PA slow inc, some scatter of literature data.
80. 25 Canum Venaticorum, binary, P=240 y.
81. 1 Bootis, PA dec, few data in literature, large scatter.
82. 84 Virginis, PA slight dec.
83. in Bootes, binary, P=156 y.
84. kappa Bootis, Burnham: "relfix", USNO: binary, P=6101 (6675) y, orbit questionable.
85. iota Bootis, relfix, cpm, few data, large scatter.
86. in Bootes, binary, P=321 y.
87. in Bootes, relfix.
88. pi Bootis, PA slow inc.
89. zeta Bootis, binary, P=123 y. See fig. 4. Five measurements in 2008 and 2009 resulted in a standard deviation of only +/-0.03 ", which compares well with speckle data.
90. epsilon Bootis, yellow-blue color contrast.
91. in Bootes, cpm, large scatter of literature data.
92. 39 Bootis, relfix.
93. xi Bootis, multiple, AB binary, P=151.5 y. AC: PA dec, rho inc, AD: PA about constant in the last 50 years, rho slow inc, AE: rho dec, only

few data. No residuals given for AC and AE, because of too few data. See fig. 11.

94. in Bootes, binary, P=210 y.

95. 44 Bootis, binary, P=225 y, orbit highly inclined.

96. mu Bootis, spectra F2IVa/G0V, cpm, few data in the literature, residuals ambiguous.

97. mu b Bootis, binary, P=246 y.

98. delta Serpentis, binary, “premature orbit”, P=1038 y.

99. zeta Coronae Borealis, relfix.

100. gamma Coronae Borealis, binary, P=93 y. Orbit highly inclined.

101. beta Serpentis, cpm, residuals ambiguous because of too few data.

102. sigma Coronae Borealis, binary, P=1000 y, new orbit rotated by 180 degrees (?).

103. in Draco, PA and rho slow dec.

104. AB: 17 Draconis, PA and rho slow dec. AC: 16 Draconis, cpm, relfix. See fig. 12.

105. zeta Her, binary, P=34.5 y, PA dec.

106. 20 Draconis, binary, “premature orbit”, highly inclined, P=422 y. Recent measurements of rho are smaller than ephemeris data by about -0.1”.

107. mu Draconis, binary, P=672 y, ABC cpm.

108. alpha Herculis, binary, premature orbit, orange-blue color contrast, spectra M5-G5. Descriptions in literature vary: red/greenish, or orange/blue-turquoise.

109. rho Herculis, PA slow inc.

110. 26 Draconis, binary, P=76 y, few data in the literature, difficult, because faint companion on diffraction ring.

111. in Draco, binary, “premature orbit”, P=1298 y (?). Both rho and PA deviate from the calculated ephemeris, which is based on only a small section of the orbit.

112. mu Herculis, PA and rho inc, BC binary, P=43.2 y, few data. See fig. 12.

113. 95 Herculis, cpm, relfix.

114. epsilon Lyrae, “double-double“, AB (epsilon 1): “premature orbit”, P= 1175..1804 y (?), CcD (epsilon 2): P= 724 y, no residuals given for AD, because of too few data. See fig. 13.

115. delta 2 Lyrae, A-BC probably optical, few data in the literature, residuals ambiguous.

116. beta Cygni, Albireo, colours orange-blue, large scatter of literature data. See fig. 15.

117. 16 Cygni, suspected binary, very preliminary orbit.

118. delta Cygni, binary, P=780 y.

119. pi Aquilae, P.A. decreasing, rho: large scatter of literature data.

120. psi Cygni, PA & rho decreasing, few data in literature.

121. in Aquila, PA & rho decreasing, few data.

122. gamma Delphini, PA & rho slowly decreasing, color contrast, spectra K1IV/F7V. See fig. 15.

123. lambda Cygni, binary, P=391 y.

124. 4 Aquarii, binary, P=194 y.

125. epsilon Equuli, triple, all cpm, AB binary, P=101.5 y, highly inclined orbit, C physical.

126. 60 Cygni, in literature few data with large scatter.

127. 12 Aquarii, denoted as cpm, relfix in Burnham´s Celestial Handbook [7], but PA is increasing, rho decreasing. Literature data exhibit large scatter.

128. 61 Cygni, binary, P=653.3 y, large proper motion.

129. 1 Pegasi, AB cpm, relfix.

130. mu Cygni, binary, P=789 y.

131. xi (17) Cephei, cpm, binary, P=3800 y (?). Colors white-blue listed in literature, but own measurements of delta mag at different colors do not significantly vary: near IR (-1.5 mag), red (-1.3), green (-1.5), blue (-1.5).

132. in Pegasus, rho decreasing.

133. zeta (55) Aquarii AB, binary, P=760 y. B has an unseen companion b with period of 25.7 y, which causes wobble on orbit. Residuals refer to currently assumed ephemeris. See ref. [2].

134. in Pegasus, cpm, PA inc, large scatter of literature data for rho.

135. in Pegasus, AB: cpm, rho seems to decrease after increasing for more than a century, PA increasing; AC: rho increasing, PA decreasing, few data in literature.

136. AR Cassiopeiae, multiple, AB not resolved.

137. in Andromeda, rho slightly increasing, P.A. decreasing.

138. in Andromeda, large scatter of literature data.

139. in Andromeda, binary, P=320 y (?), many data in literature, deviation from currently assumed orbit, residuals refer to extrapolated literature data. See fig 3.

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

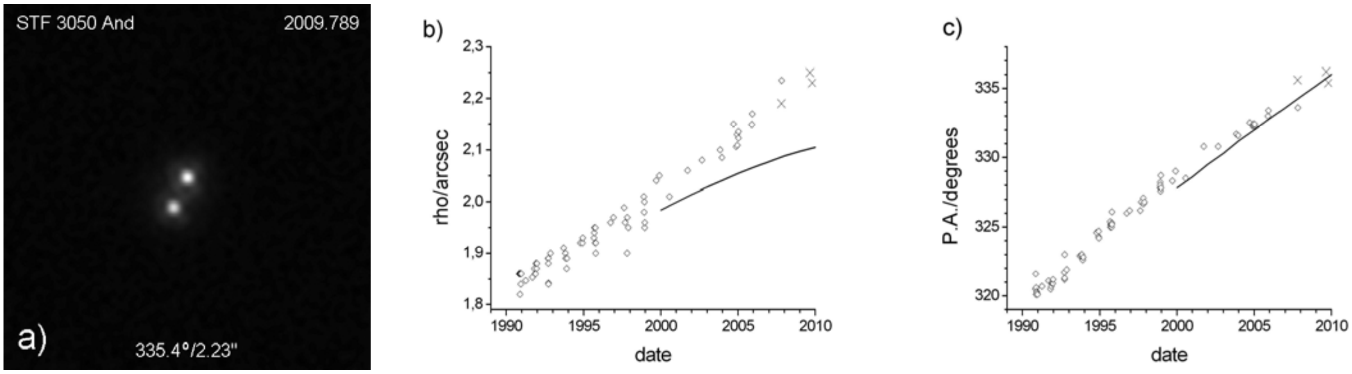


Figure 3: (a) The binary STF 3050 in Andromeda (135 frames x 12 msec). Measurements of P.A. and rho are indicated at the bottom. Note the faint diffraction rings around both components. These are generally more or less well developed depending on the seeing conditions. North is down, east is right, as in all other images. **(b, c)** Separation rho (b), and position angle P.A. (c) of the binary STF 3050 versus date. Open diamonds mark speckle data, crosses own measurements. Curves represent the currently assumed ephemeris, taken from ref. [6].

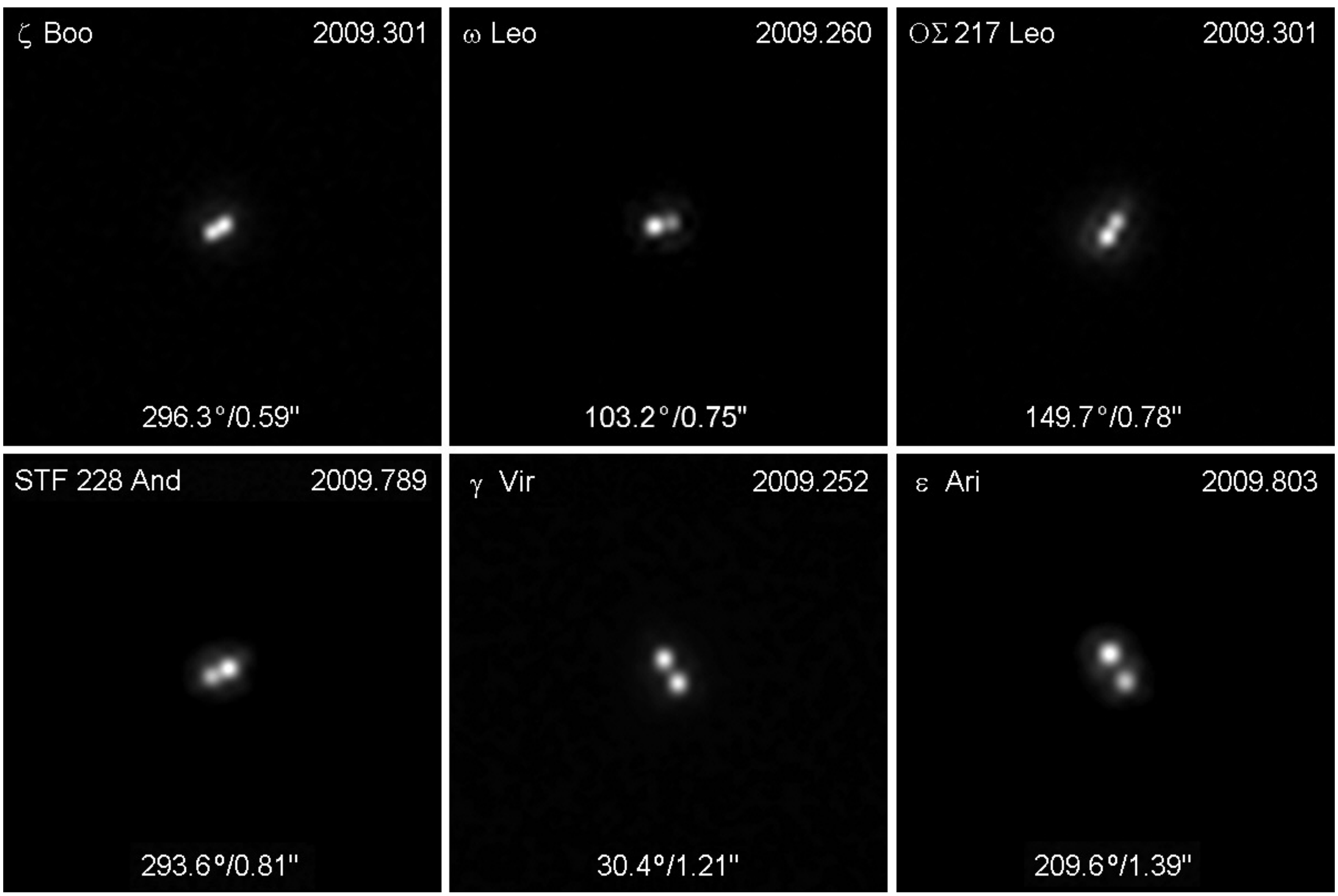


Figure 4: Close pairs: Top row, left: zeta Bootis, binary, period 123 y (93 x 3 msec), middle: omega Leonis, binary, 117 y (240 x 4 msec), right: STT 217 in Leo, binary, 140 y (113 x 63 msec). Bottom row, left: STF 288 in Andromeda, binary, 144 y (82 x 26 msec), middle: gamma Virginis, binary, 169 y (59 x 2 msec), right: epsilon Arietis, (69 x 11 msec). All images are to scale.

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

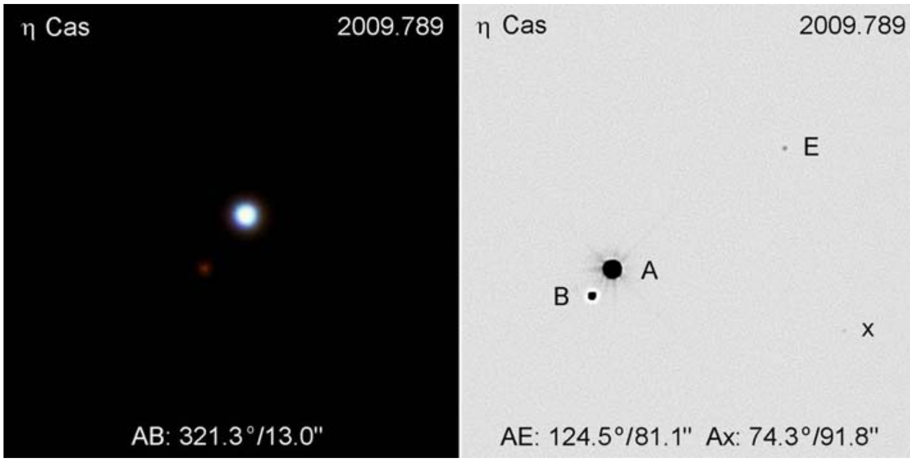


Figure 5: Eta Cassiopeiae. Left: RGB composite of AB. Spectral classes are G - M. (Exposures: R, 126 x 20 msec; G, 98 x 33 msec; B, 129 x 48 msec). Right: Wide field, with components E (~10 mag) and x. The latter is of estimated 11 mag and not listed in WDS (red filter, 32 x 250 msec).

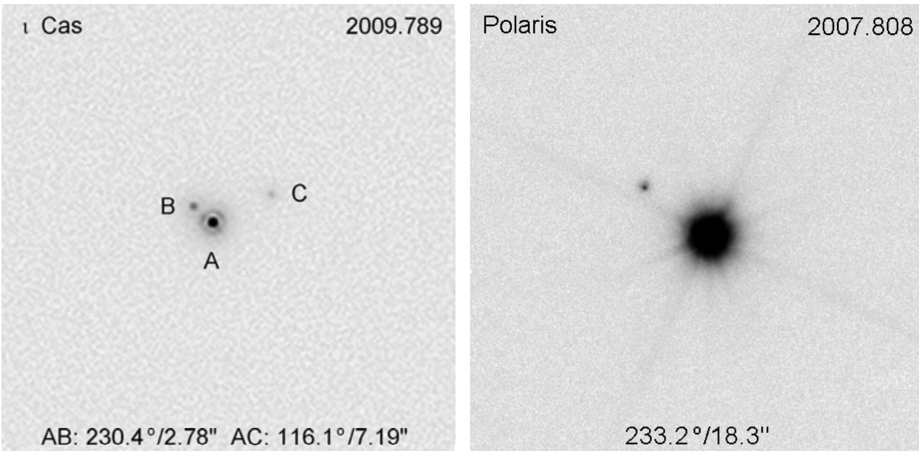


Figure 6: Left: The triple system iota Cas. (102 x 20 msec). AB is a binary with period 840 y. Right: alpha UMi, "Polaris" (32 x 100 msec). In both images, the contrast was strongly enhanced in order to show the dim companions and/or the diffraction spikes.

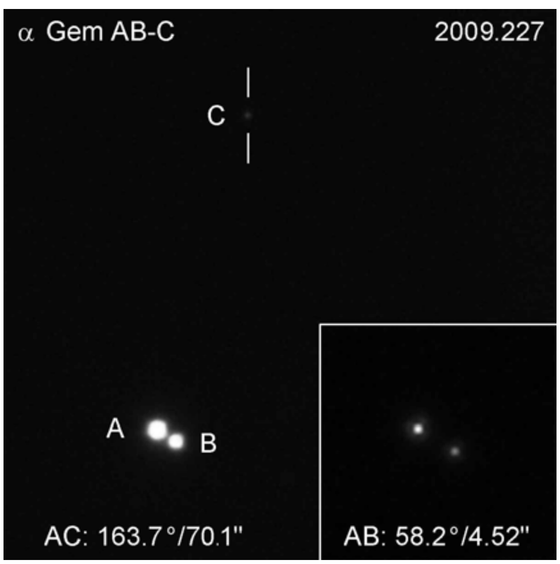


Figure 7: The multiple alpha Geminorum, "Castor" (32 x 33 msec). The inset shows a close-up of the binary AB, recorded with shorter exposure time (82 x 0.5 msec).

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

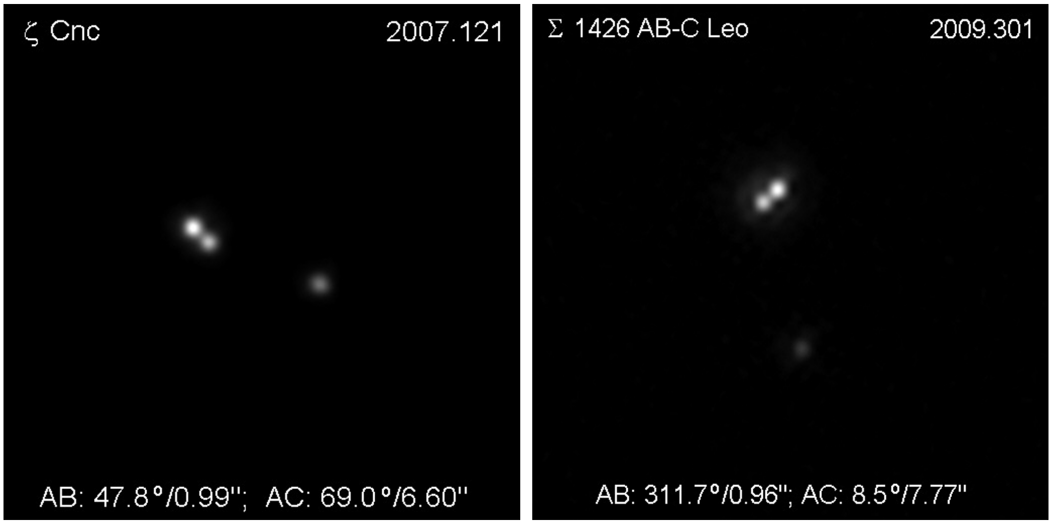


Figure 8: Two similarly looking triple systems: In zeta Cancri (left), B is orbiting A with period of about 60 y, and C orbits AB with period 1115 y (64 x 10 msec). For STF 1426 in Leo (right), a preliminary orbit has only been computed for AB with period 662 y (233 x 48 msec).

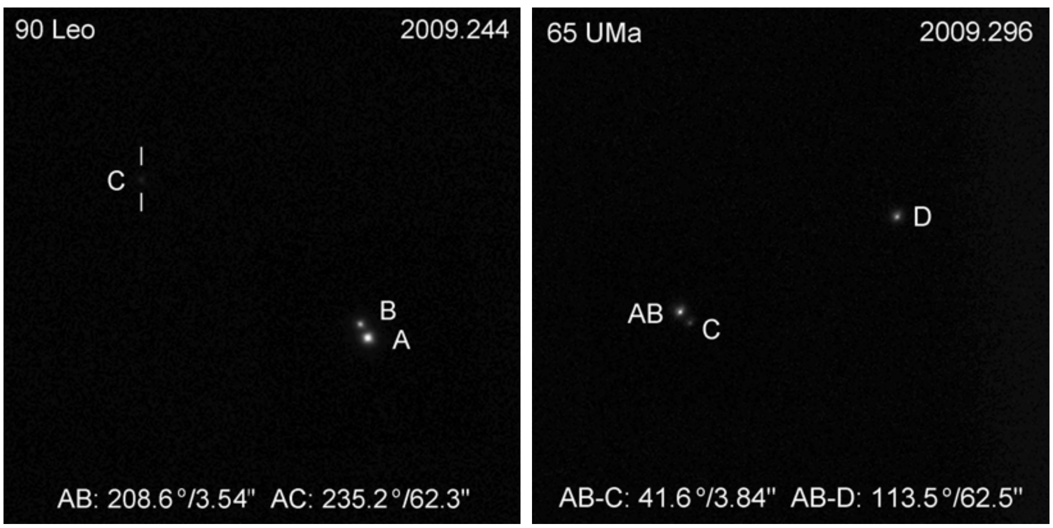


Figure 9: Left: 90 Leonis, AB likely binary (33 x 200 msec), Right: 65 Ursae Majoris, AB very close binary, not resolved (99 x 33 msec).

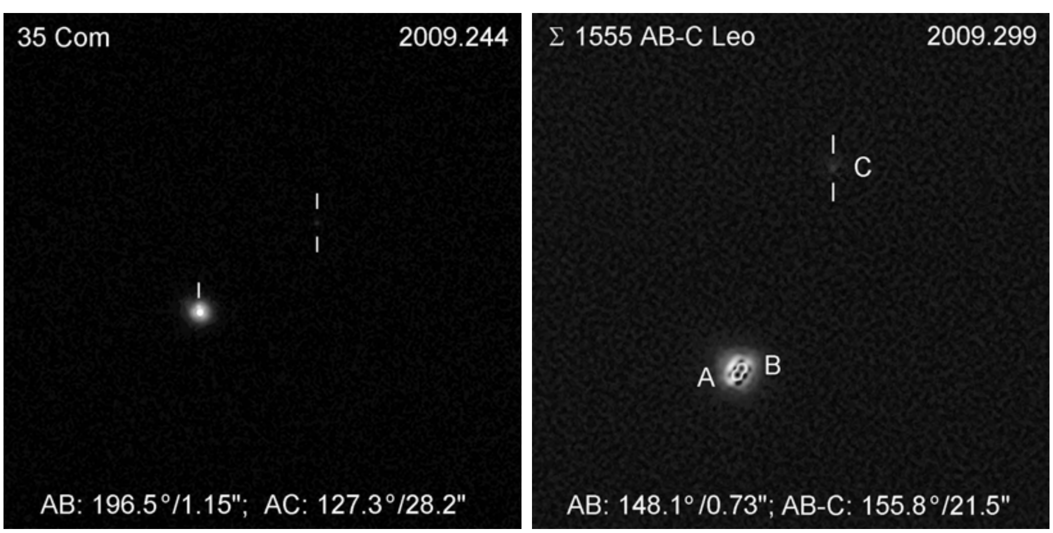


Figure 10: Left: The triple 35 Com. Imaging of AB is difficult, because the rather dim companion coincides with the diffraction ring of A (67 x 33 msec). Right: STF 1555 in Leo. The wide field image is a superposition of 136 frames at 14 msec. The pair AB has been separately recorded with 123 frames at 12 msec. This image is superimposed as a negative.

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

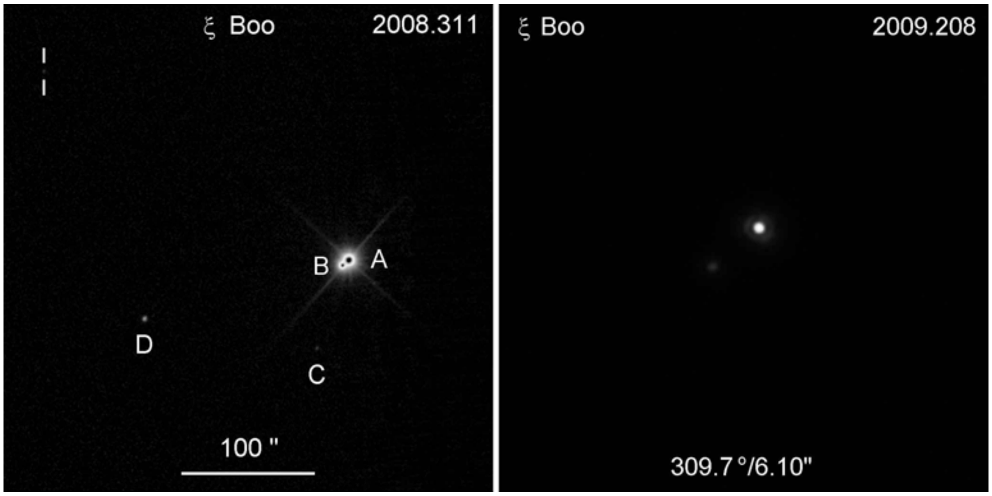


Figure 11: The multiple system xi Bootis. Left: Wide field view with superimposed negative image of AB (42 x 100 msec). The faint star at upper left is not listed in the WDS. Component E is out of the field at right. Right: Close-up of AB (74 x 8.3 msec).

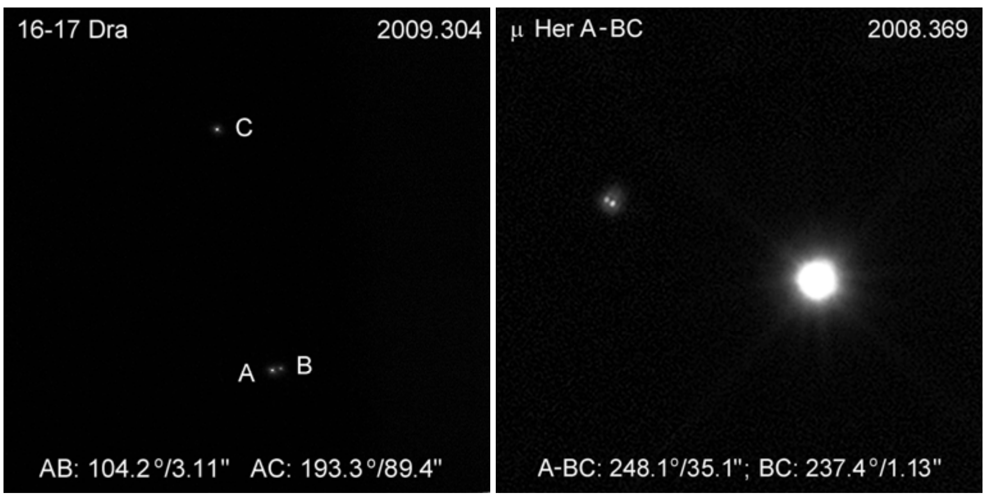


Figure 12: Left: The system 16 (C) - 17 (AB) in Draco (147 x 8.3 msec). Right: Mu Herculis. BC is a binary of faint red dwarfs with period 43.2 y (78 x 100 msec).

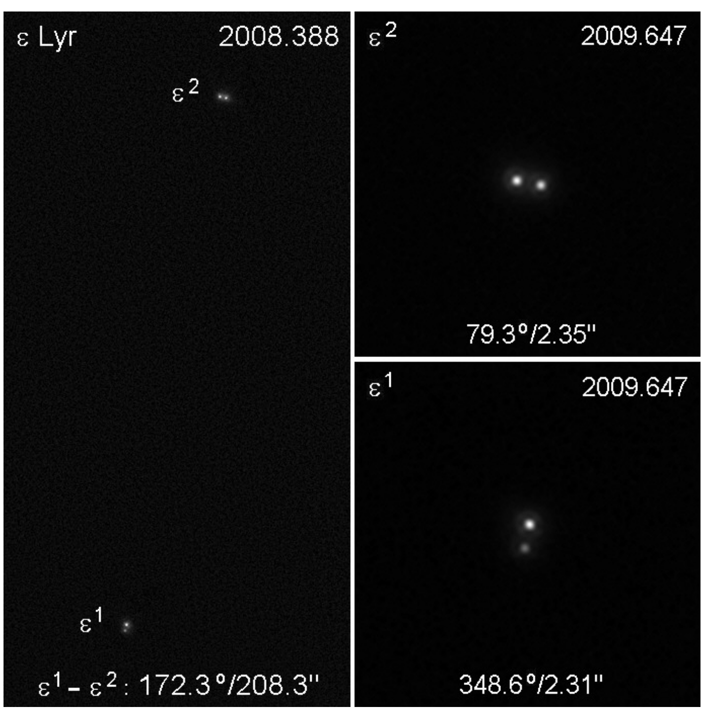


Figure 13: The "double-double" epsilon Lyrae. Left: Wide field view (no composite) obtained at fairly steady seeing (111 x 8.3 msec). Right: Close-ups of epsilon 1 and epsilon 2 recorded about a year later (143 x 8.3 msec, and 79 x 8.3 msec, respectively). Both are binaries, but only small fractions of their orbits are documented. Periods are estimated from 1175 to 1804 y for epsilon[1], and 724 y for epsilon[2].

Double and Multiple Star Measurements in the Northern Sky with a 10" Newtonian ...

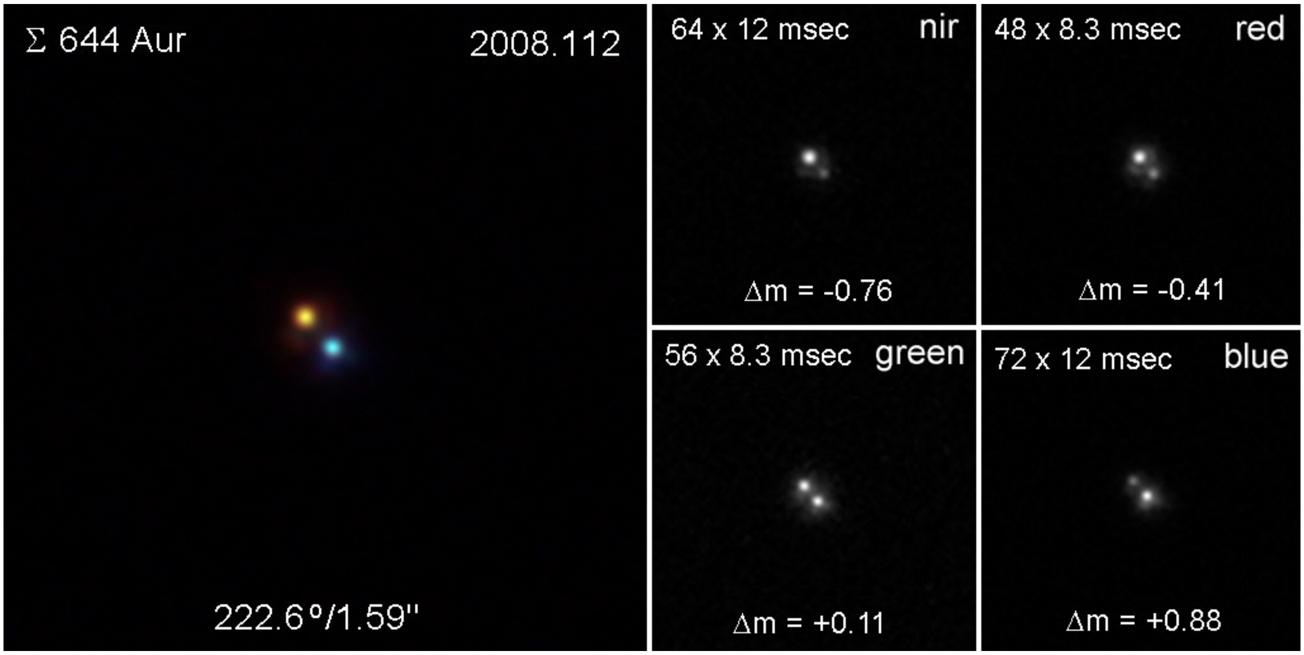


Figure 14: STF 644 Aurigae, left: RGB composite, right: filtered images as indicated. Note smaller scale. Numbers and exposure times of the respective frames are also given. In this rare case, the brightness of the components is about equal in the visible, despite the strong color contrast. Spectra are B2- K3. The blue star is designated as main component of the system. In the WDS, the difference in magnitude ∆(delta)m is given as +0.18, which roughly corresponds to the value measured here in green light.

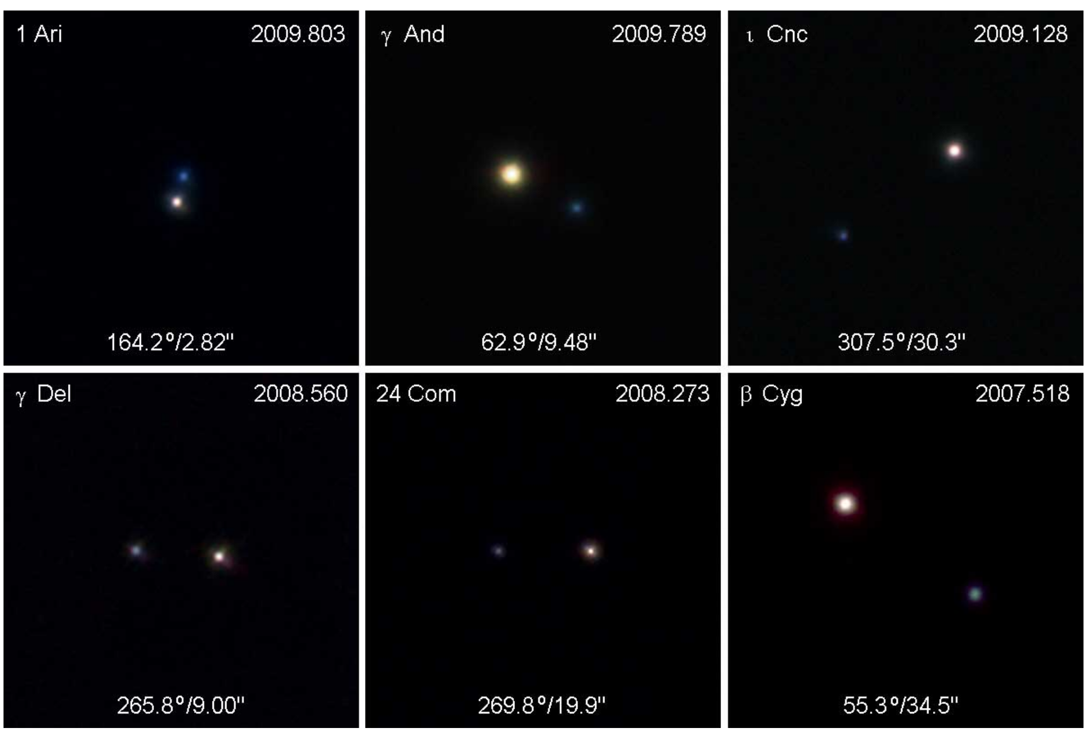


Figure 15: RGB composites. Upper row, left: 1 Arietis, spectra G3- A. Middle: gamma Andromedae, spectra K3 –B/A. The blue companion is a close double, but not resolved here. Right: iota Cancri, spectra G7.5 – ?. Bottom row, left: gamma Delphini, spectra K1 – F7. Middle: 24 Comae, spectra K2 - ?. Right: beta Cygni, "Albireo", spectra K3 – B0. Images are not to scale.

Double and Multiple Star Measurements in the Northern Sky with a 10” Newtonian ...

(Continued from page 181)

Discussion and Conclusion

In this survey, most double and multiple star systems are well known, while the brightness of even the dimmer components is rarely below 10 mag. Nevertheless, in many cases, there are only few data found in the literature, and these often exhibit large scatter. This is especially true for pairs with larger separation, for which mainly visual measurements are listed in the catalogs, and the accuracy is usually not known. Therefore, extrapolation of position data is often somewhat ambiguous. This may be one reason for the scatter of the residuals, as illustrated in Figure 1. In any case, it makes sense to pay attention also to such systems.

On the other hand, pairs with medium to small separations, in particular binaries, are mostly thoroughly investigated with both visual and interferometric methods, and the accuracy can be estimated from the scatter. Among these, numerous systems are suitable for calibration of the image scale. Comparing the scatter of speckle data and that from lucky imaging, the accuracy of the latter at least comes close, and also comes close to the theoretical limit of resolution of the 10” telescope. One example is the pair zeta Bootis with separation 0.6”, which is shown in fig. 4. Therefore, lucky imaging appears to be a suitable complement to speckle measurements for medium sized amateur telescopes.

In several cases, systematic deviations from predicted positions became apparent, which are also documented by recent measurements from other authors, especially in the speckle catalog [5]. A striking example is STF 3050 in Andromeda (note #139), which is illustrated in fig. 3. Currently, the separation increases faster than expected from the ephemeris. The difference has now grown to greater than +0.1”, which is much larger than the error margin of both speckle data and results from lucky imaging. Other binary systems with obvious deviations from calculated orbits are the following:

- STT 21 in Andromeda (note #10),
- iota Cassiopeiae AB (note #25, see fig. 7),
- STF 305 in Aries (note #27),
- STT 531 in Perseus (note #29),
- zeta Cancri AB-C (note #43, see fig. 9),
- STT 215 in Leo (note #56),
- STF 1555 AB (note #66),
- 35 Comae AB (note #74, see fig. 11),
- kappa Bootis (note #84),
- 20 Draconis (note #106),
- STF 2199 in Draco (note #111),
- zeta Aquarii AB (note #133, see also a more detailed discussion in an earlier paper in this Journal [2]).

References

[1] Anton, R., 2008, *Journal of Double Star Observations,* **vol. 4** (2), 40-51.

[2] Anton, R., 2009, *Journal of Double Star Observations,* **vol. 5** (1), 65-71.

[3] Anton, R., 2010, *Journal of Double Star Observations,* submitted.

[4] Mason, B.D. et al., *The Washington Double Star Catalog (WDS)*, U.S. Naval Observatory, online access Dec. 2009.

[5] Hartkopf, W.I. et al., *Fourth Catalog of Interferometric Measurements of Binary Stars,* U.S. Naval Observatory, online access Dec. 2009.

[6] Hartkopf, W.I. et al., *Sixth Catalog of Orbits of Visual Binary Stars,* U.S. Naval Observatory, online access Dec. 2009.

[7] R. Burnham, *Burnham´s Celestial Handbook,* Dover Publications, New York 1978.

The author is a retired physicist from Hamburg University, Germany, and has been measuring double stars in the northern as well as the southern hemisphere since 1995.

Double Star Measurements Using a Webcam, Annual Report of 2009

J. S. Schlimmer

Seeheim-Jugenheim, Hessen, Germany

Email: js@epsilon-lyrae.de

Abstract: I report on the measurements of 166 double stars of 2009 using a standard webcam. For STF 478, STF 950, STF 954, HJ 2452, ES 2028 and STF2427 I recommend companions not yet listed in the WDS catalog.

I report on the measurements of 166 double stars of 2009 using a standard webcam. For STF 478, STF 950, STF 954, HJ 2452, ES 2028 and STF2427 I recommend companions not yet listed in the WDS catalog.

For my observations I use a small 8 inch Newtonian telescope with a standard webcam described in my previous reports (Schlimmer 2007a, Schlimmer 2008b). No changes in the optical system were made. For analyzing the records the program REDUC (Version 3.82) is used.

WDS 03598+1133, STF 478

STF 478 is about 1.5 degrees south of lambda Tauri. The components, with magnitudes of 9.9 and 8.8, can be easy separated. At a distance of 155 a.s. there is a further component which is not yet listed in the WDS catalog (Figure 1). Because of its distance and low brightness, it could be a background star.

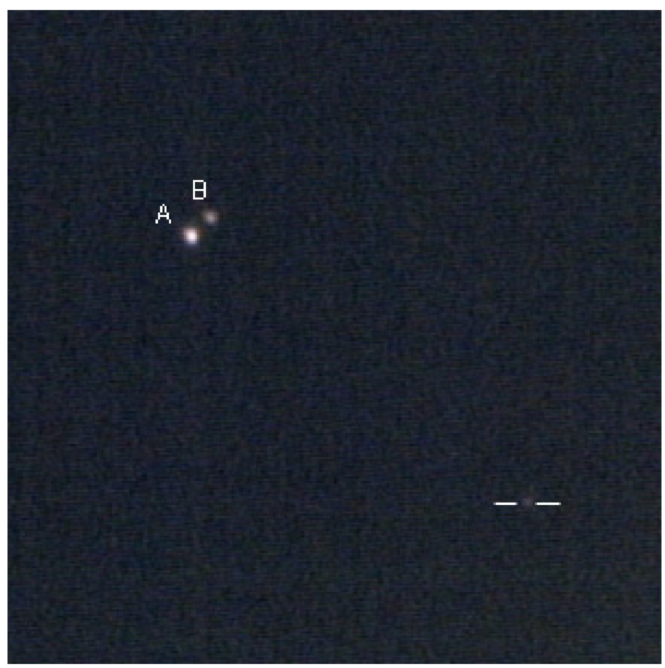


Figure 1: Stacked image of 50 frames of STF 478. The component which is marked with lines is not yet listed in WDS catalog.

WDS 06410+0954, STF 950

The Christmas Tree star cluster was discovered in 1784 by William Herschel. This cluster is of interest to astronomers, because it is an area of star birth. STF 950 is the brightest star in the Christmas tree cluster and is also known as 15 Monocerotis. Many components of STF 950 are described in the WDS catalog. I found 3 further components near STF 950 which are not yet included in WDS catalog (Figure 2). These

Double Star Measurements Using a Webcam, Annual Report of 2009

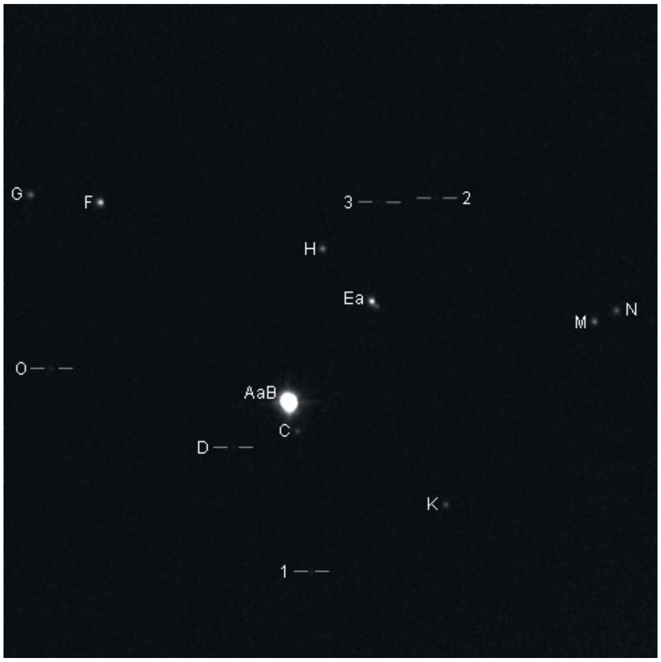


Figure 2: Webcam image of STF950, 16 frames were stacked for analyzing. The numbered components are not yet listed in WDS catalog.

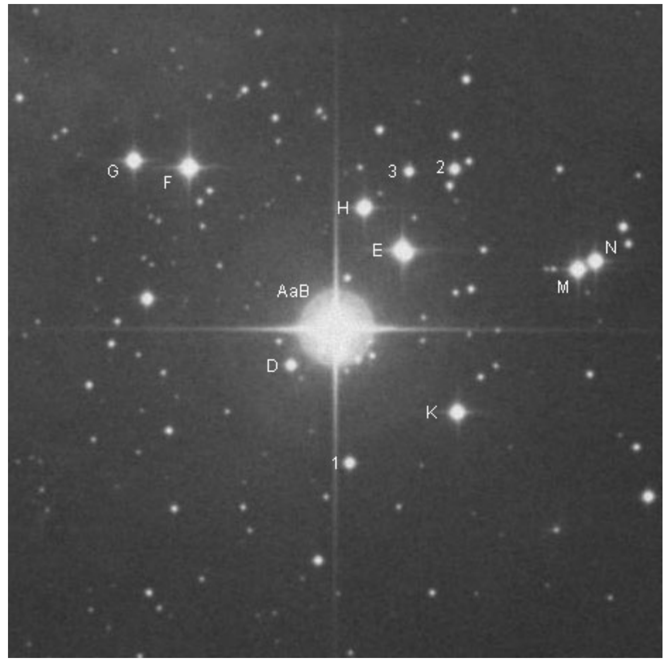


Figure 3: POSS image of the same area (taken from SIMBAD Astronomical Database).

components are also seen on the long time-exposure of the POSS image (Figure 3), which is taken from the SIMBAD Astronomical Database. 1

WDS 06412+0928, STF 954

STF 954 is at the top of the Christmas tree star cluster. Four components are listed in the WDS catalog. In my observations I found 2 further components with a brightness of around 11.5 magnitudes (figure 4). In this image, 50 frames of STF 954 were stacked for analyzing.

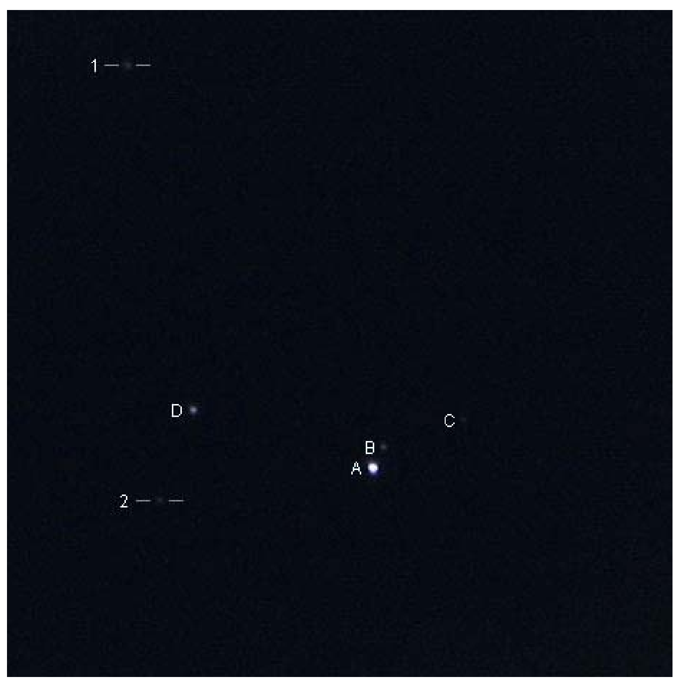


Figure 4: Webcam image of STF 954. The marked components are not yet listed in WDS catalog.

WDS 08316+1806, HJ 2452, θ Canceri

HJ 2452 was first observed in 1831. The brightness of the primary star is 5.35 magnitude and the companion is magnitude 10.0. The distance between both components is 72.22 a.s., the position angle is 63.4 deg. Currently there are 12 measurements in WDS catalog.

At a distance of 345 a.s., I found a background star which is not yet listed in the WDS catalog. The position angle is 214.2 deg. On Figure 5 this star is marked with -1-. A second background star was found at a distance of 226 a.s. with a position angle of 268.3 deg, marked with -2-.

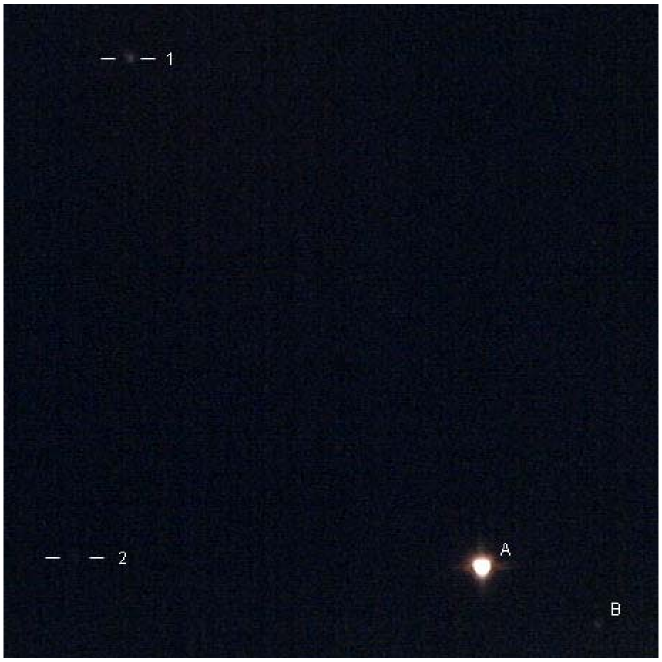


Figure 5: Webcam image of HJ 2452, the components which are labeled with -1- and -2- are not yet listed in WDS catalog.

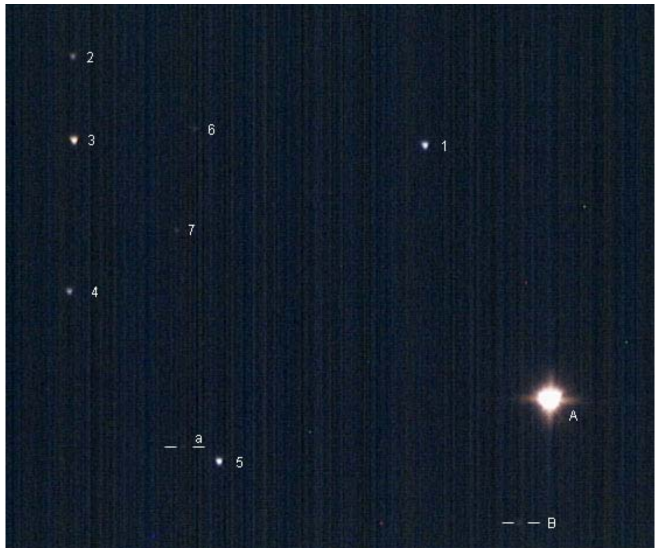


Figure 6: Webcam image of WDS 18545+3654. The marked components are not yet listed in WDS catalog, except AB

WDS 18545+3654, Stephenson 1, δ Lyrae Cluster

Delta Lyrae is the brightest star of a galactic star cluster which is also known as Stephenson 1. A couple of stars between 8 to 10 magnitudes are located near delta Lyrae (Figure 6). For later research of the relative motion between members of this star cluster, distance and position angle of the brightest stars were analyzed. Those stars haven't been listed yet in the WDS catalog.

WDS 18581+3813, STF2427, CTT 11, SP 2

In the WDS catalog, 5 components are listed. The components AB and AC are known as STF2427, AD is listed as CTT 11 and AE is listed in the WDS catalog as SP 2. At a distance of about 83 a.s. from the brightest component E, I found a further background star with a brightness of magnitude 11.0 (Figure 7).

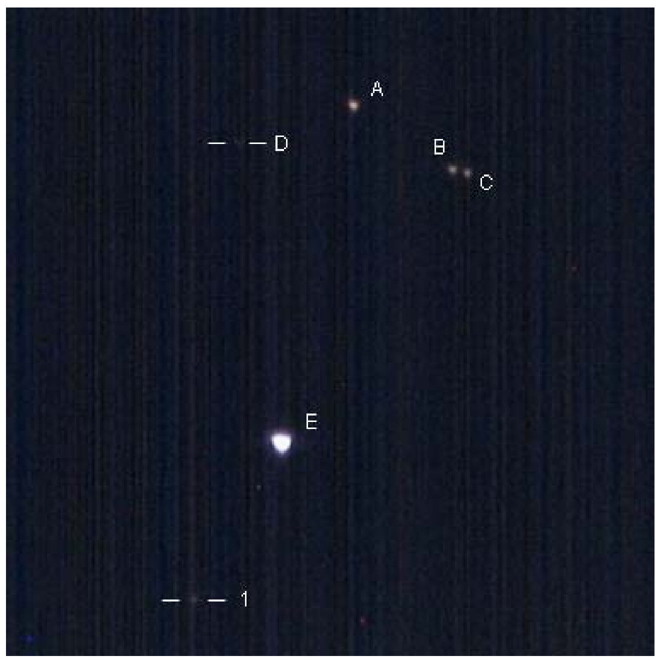


Figure 7: Webcam image of STF2427, the component labeled "1" is not yet listed in WDS catalog.

Double Star Measurements Using a Webcam, Annual Report of 2009

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Note
H 518AD	00405+5632	2.35 8.98	282.1	70.42	2009.798		α Cas
STF 60AB	00491+5749	3.52 7.36	321.6	13.09	2009.798		η Cas
STF 60AE	00491+5749	3.52 10.15	125.0	81.29	2009.798		η Cas
SMR 2AI	00491+5749	3.52	74.3	92.66	2009.798		η Cas
SMR 2AJ	00491+5749	3.52	261.7	233.82	2009.798		η Cas
ARG 3	00573+6020	8.51 9.41	200.3	20.55	2009.798		
STF 478	03598+1133	9.9 10.22	137.9	9.59	2009.069	47	note 1
	03598+1133	9.9	55.1	155.22	2009.069	1	note 2
BUP 74	05078-0505	2.79 10.9	136.8	117.15	2009.080	1	β Eri
STF 649AB	05083-0840	5.80 8.97	68.7	21.58	2009.080	39	note 3
STF 649AC	05083-0840	5.80	4.3	85.89	2009.080	1	
A 483AB	05099-0906	9.74 10.08	50.2	2.56	2009.069	1	
OL 202AC	05099-0906	9.74 10.10	156.7	61.67	2009.069	1	
BUP 76	05119-0907	8.13 9.86	257.6	86.84	2009.069	47	
STF 752AB	05354-0555	2.9 7.0	138.3	10.78	2009.080	15	44 Ori
A 499AB	05487-0856	8.27 10.51	215.7	12.60	2009.080	1	
STF 950AC	06410+0954	4.66 9.9	16.1	17.00	2009.135	30	S Mon
STF 950AD	06410+0954	4.66 9.7	309.3	40.04	2009.135	1	S Mon
STF 950AE	06410+0954	4.66 8.86	139.5	73.41	2009.135	42	S Mon
STF 950AF	06410+0954	4.66 9.0	222.3	154.28	2009.135	40	S Mon
STF 950AG	06410+0954	4.66 10.01	230.3	186.10	2009.135	42	S Mon
STF 950AH	06410+0954	4.66 9.81	166.6	88.27	2009.135	35	S Mon
STF 950AK	06410+0954	4.66 8.2	55.9	105.40	2009.135	36	S Mon
STF 950AM	06410+0954	4.66 9.75	103.8	177.45	2009.135	39	S Mon
STF 950AO	06410+0954	4.66 9.7	261.1	135.13	2009.135	1	S Mon
D 11EP	06410+0954	8.86 10.4	44.1	3.84	2009.135	16	S Mon
STF 950FG	06410+0954	9.00 10.01	263.1	39.63	2009.135	1	S Mon
STF 952MN	06410+0954	9.75 10.05	115.1	13.85	2009.135	13	S Mon
A1	06410+0954	9.75 11.5	6.5	96.44	2009.135	1	note 4
A2	06410+0954	9.75 11.5	143.2	141.38	2009.135	1	note 4
A3	06410+0954	9.75 11.5	154.7	122.36	2009.135	1	note 4
A23	06410+0954	11.5 11.5	274.6	32.43	2009.135	1	note 5
STF 954AB	06412+0928	7.18 10.23	153.1	12.88	2009.135	38	note 6
SLE 558AC	06412+0928	7.18 12.2	117.6	56.79	2009.135	1	
ARN 40AD	06412+0928	7.18 9.09	251.8	104.25	2009.135	36	
A1	06412+0928	7.18	211.1	259.84	2009.135	38	note 7
A2	06412+0928	7.18	278.3	118.92	2009.135	32	note 8

Table continued on next page.

Double Star Measurements Using a Webcam, Annual Report of 2009

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Note
STF1110AB	07346+3153	1.93 2.97	58.1	4.61	2009.299	74	Castor
STF1110AB-C	07346+3153	1.93 9.83	164.5	69.87	2009.080	42	Castor
STF1110AB-C	07346+3153	1.93 10.07	221.9	181.72	2009.080	26	Castor
STF1110CD	07346+3153	9.83 10.07	244.1	155.55	2009.080	1	
D 29AE	07393+0514	0.38	67.4	467.44	2009.135	37	Prokyon
	07393+0514	0.38	312.5	353.18	2009.135	24	note 9
STF1196AB	08122+1739	5.30 6.25	38.0	1.03	2009.217	43	ζ Cnc
STF1196AC	08122+1739	5.30 5.85	68.8	6.43	2009.217	123	ζ Cnc
STF1196AB-C	08122+1739	5.30 6.20	69.1	6.38	2009.217	40	ζ Cnc
STF1196AB-D	08122+1739	5.31 8.89	107.0	274.42	2009.217	39	ζ Cnc
HJ 2452	08316+1806	5.35 10.0	63.4	72.22	2009.217	1	θ Cnc
	08316+1806	5.35	214.2	344.57	2009.217	1	notes 10
	08316+1806	5.35	268.3	225.89	2009.217	1	notes 10
STF1300	09013+1516	9.47 9.73	180.7	4.91	2009.247	134	
STT 569AC	09123+1500	6.56 10.40	215.0	203.95	2009.247		Pi1 Cnc
H 6 111AB	09276-0840	1.98 9.7	153.6	282.25	2009.299	1	α Hya
SHJ 107	09320+0943	5.22 9.30	74.6	37.69	2009.299	33	6 Leo
H 676AB	09412+0954	3.56 10.83	47.7	95.80	2009.299	18	ο Leo
STFB 6AB	10084+1158	1.40 8.24	308.2	174.33	2009.247	39	Regulus
STF1424AB	10200+1950	2.37 3.64	126.3	4.65	2009.299	66	Algieba
STF1424AC	10200+1950	2.37 9.64	288.2	334.04	2009.217	41	AD Leo
STF1424AD	10200+1950	2.60 10.0	301.8	367.56	2009.217	38	
STF1523AB	11182+3132	4.33 4.80	215.3	1.61	2009.283	46	Xi UMa
STF1561AB	11387+4507	6.53 8.23	248.1	9.11	2009.305	31	
STF1561AC	11387+4507	6.53 9.46	90.7	166.63	2009.305	42	
STF1561AE	11387+4507	6.53 12.08	335.7	64.34	2009.305	1	
STF1570	11455+4536	8.86 9.60	48.9	10.78	2009.305	49	
STT 245	12175+2856	5.7 10.2	281.0	8.30	2009.390	1	
STF1643	12272+2701	9.03 9.45	2.3	2.37	2009.390	25	
STFA 21AB	12289+2555	5.23 6.64	251.2	144.23	2009.390	42	17 Com
SHJ 145	12299-1631	2.95 8.47	215.4	23.36	2009.390	31	δ Crv
STF1651	12317+2701	8.65 10.07	215.2	6.94	2009.390	38	
STF1657	12351+1823	5.11 6.33	270.9	19.85	2009.390	45	24 Com
STF1670AB	12417-0127	3.48 3.53	25.8	1.27	2009.299	50	γ Vir
STF1670AE	12417-0127	3.48 8.94	168.5	259.08	2009.299	51	γ Vir
STF1670AF	12417-0127	3.48 9.53	267.8	423.76	2009.299	48	γ Vir
SHJ 162AB	13149-1122	7.11 8.18	44.8	109.50	2009.305	70	note 11

Table continued on next page.

Double Star Measurements Using a Webcam, Annual Report of 2009

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Note
STF1825	14165+2007	6.47 8.42	151.6	4.46	2009.450	39	note 12
STF1864AB	14407+1625	4.88 5.79	111.0	5.58	2009.390	71	Pi Boo
STF1864AC	14407+1625	4.88 10.63	163.3	127.01	2009.390	30	Pi Boo
STF1888AB	14514+1906	4.76 6.95	308.9	6.13	2009.395	66	37 Boo
STT 291	15006+4717	6.33 9.62	156.4	35.42	2009.395	34	BSC5597
STF1909	15038+4739	5.20 6.10	60.7	1.66	2009.395	86	44 Boo
STF1955AB	15339+2643	9.84 10.32	236.4	7.62	2009.430	65	note 13
HLM 6	15499+2547	10.72 11.69	181.1	23.34	2009.409	28	
AGC 7AC	15576+2653	4.2 11.5	173.8	94.92	2009.409	1	eps CrB
STF2031AB	16163-0139	7.18 8.74	229.3	20.74	2009.592	35	note 14
STT 305AB	16117+3321	6.44 10.17	263.7	5.89	2009.409	34	
STF2032AB	16147+3352	5.62 6.49	238.0	7.04	2009.409	42	17 CrB
STF2032AD	16147+3352	5.62 10.78	82.2	91.24	2009.409	13	17 CrB
STFA 31AB	16406+0413	5.76 6.92	230.3	69.31	2009.584	75	36 Her
ENG 58AB	16469+0215	6.75 8.83	216.8	148.51	2009.584	40	note 15
STF2096AB	16472+0204	6.09 9.68	87.3	23.98	2009.584	41	19 Oph
STF2241AB	17419+7209	4.60 5.59	16.4	30.04	2009.691	69	Psi 31 Dra
STF2216	17470+0542	8.01 10.09	26.6	26.81	2009.573	38	note 16
BU 633AE	17566+5129	2.23 11.9	234.2	94.39	2009.691	1	γ Dra
BU 633AF	17566+5129	2.23 11.2	113.9	124.27	2009.691	1	γ Dra
BU 633AG	17566+5129	2.23 11.9	26.9	141.68	2009.691	1	γ Dra
STF2272AB	18055+0230	4.20 6.20	133.2	5.69	2009.579	120	70 Oph
H 539AB	18369+3846	0.02 9.5	183.3	80.25	2009.581	43	Vega
STFB 9AE	18369+3846	0.02 9.5	38.8	88.66	2009.581	1	Vega
STFA 37AB-CD	18443+3940	5.15 5.25	172.3	208.17	2009.706	101	note 17
STFA 37AI	18443+3940	6.10 10.43	137.6	149.60	2009.716	55	note 17
STFA 38AD	18448+3736	4.34 5.62	150.4	43.47	2009.641	44	6,7 Lyr
H 540AB	18498+3249	5.93 10.89	75.6	34.09	2009.581	1	v1 Lyrae
H 540AC	18498+3249	5.93 10.3	119.7	57.52	2009.581	23	v1 Lyrae
STFA 39AB	18501+3322	3.63 6.69	147.6	45.37	2009.581	17	β Lyrae
BU 293AE	18501+3322	3.63 10.14	317.8	66.76	2009.581	17	β Lyrae
BU 293AF	18501+3322	3.63 10.62	18.5	86.33	2009.581	15	β Lyrae
H 6 3	18537+3658	5.55 9.93	19.7	175.24	2009.641	34	δ Lyr1
ES 2028AB	18545+3654	4.30 11.2	351.0	86.55	2009.644		δ Lyr2
A1	18545+3654	4.30	210.1	191.74	2009.644	39	
A2	18545+3654	4.30	238.2	398.43	2009.644	37	
A3	18545+3654	4.30	245.3	367.42	2009.644	41	

Table continued on next page.

Double Star Measurements Using a Webcam, Annual Report of 2009

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Note
A4	18545+3654	4.30	261.2	334.11	2009.644	43	
A5	18545+3654	4.30	284.5	228.46	2009.644	38	
5a	18545+3654	4.30	251.6	26.21	2009.644	1	
A6	18545+3654	4.30	249.6	277.52	2009.644	1	
A7	18545+3654	4.30	236.5	302.16	2009.644	1	
STF2427AB	18581+3813	9.61 9.93	59.5	54.77	2009.641	43	
STF2427AC	18581+3813	9.61 10.20	61.7	61.58	2009.641	41	
CTT 11AD	18581+3813	9.61 11.8	290.7	55.42	2009.641	1	
SP 2AE	18581+3813	9.61 5.87	350.4	159.94	2009.641	38	
STF2427BC	18581+3813	9.93 10.20	79.8	6.91	2009.641		
EF	18581+3813	5.87	332.7	83.41	2009.641	1	note 18
SHJ 289	19135+3902	8.01 8.71	56.6	38.95	2009.737	43	
STF2487AB	19138+3909	4.38 8.58	80.4	28.55	2009.737	34	η Lyr
STF2487AC	19138+3909	4.38 11.42	151.1	160.89	2009.737	30	η Lyr
SHJ 292AB	19164+3808	4.48 10.14	70.0	99.03	2009.737	37	θ Lyr
SHJ 292AC	19164+3808	4.48 11.1	128.3	100.56	2009.737	1	θ Lyr
J 121AB	19401+1801	4.37 13.2	178.2	29.87	2009.522	1	α Sge
WAL 118AD	19401+1801	4.37 11.21	147.8	82.53	2009.622	38	α Sge
STF2585AB-C	19490+1909	5.04 9.01	311.2	8.19	2009.622	76	ζ Sge
STFB 10AB	19508+0852	0.95 9.82	285.8	191.98	2009.798	39	Altair
STFB 10AC	19508+0852	0.77 10.1	107.4	188.25	2009.798	24	Altair
SMR 5AE	19508+0852	0.77 11.0	354.9	153.10	2009.798	1	
SMR 5AF	19508+0852	0.77	47.0	296.26	2009.798	1	
H 4 100AB	20001+1731	9.96 10.12	255.6	23.92	2009.633	41	13 Sge
H 4 100AC	20001+1731	9.96 5.57	296.1	112.68	2009.633	41	13 Sge
S 730AB	20001+1737	7.16 8.45	14.5	112.94	2009.633	30	
S 730AC	20001+1737	7.16 10.21	338.0	78.54	2009.633	37	
S 730AD	20001+1737	7.16 9.9	198.0	40.44	2009.633	37	
STF2622AB	20041+1700	8.74 9.46	194.2	5.83	2009.633	37	note 19
STF2622AC	20041+1700	8.74 11.70	303.4	16.79	2009.633	1	
STT 592AB	20041+1704	5.86 9.50	290.1	163.04	2009.633	25	15 Sge
STT 592AC	20041+1704	5.86 6.92	334.7	214.79	2009.633	25	15 Sge
BUP 202AD	20041+1704	5.86 11.34	2.3	86.79	2009.633	1	15 Sge
STF2637AB	20099+2055	6.56 8.85	331.6	11.54	2009.641	62	17 Sge
STF2637AC	20099+2055	6.56 7.52	221.5	89.92	2009.641	85	17 Sge
S 737	20099+2100	7.93 9.26	128.1	100.27	2006.641	83	
LAU 4	20309+1126	10.0 11.26	270.0	27.43	2009.740	1	

Table concludes on next page.

Double Star Measurements Using a Webcam, Annual Report of 2009

NAME	RA+DEC	MAGS	PA	SEP	DATE	N	Note
STF2690Aa-BC	20312+1116	7.12 7.39	255.1	17.32	2009.740	62	note 20
STF2703AB	20368+1444	8.35 8.42	290.2	25.03	2009.740	34	
STF2703AC	20368+1444	8.35 8.76	233.8	77.12	2009.740	14	
STF2703BC	20368+1444	8.42 8.76	215.6	66.46	2009.740	35	
STF2704AB-D	20375+1436	3.68 11.4	319.0	46.73	2009.740	1	β Del
STF2715	20418+1231	7.80 10.22	3.3	12.26	2009.740	35	
STF2718AB	20426+1244	8.28 8.39	87.4	8.26	2009.740	31	
STF2718AC	20426+1244	8.28 9.02	165.4	166.57	2009.740	51	
STF2718BC	20426+1244	8.39 9.02	162.7	168.42	2009.740	39	
STF2727	20467+1607	4.36 5.03	266.1	9.02	2009.740	73	γ Del
STF2758AB	21069+3845	5.35 6.10	151.5	31.10	2009.798	39	61 Cyg
STF2758AE	21069+3845	5.35 9.63	270.1	309.90	2009.798	29	61 Cyg
STF2758AF	21069+3845	5.35 11.32	240.7	333.84	2009.798	1	61 Cyg
STF2758AG	21069+3845	5.35 10.84	236.3	223.49	2009.798	1	61 Cyg
STF2758AH	21069+3845	5.35 10.89	284.7	85.31	2009.798	1	61 Cyg
SMR 1AI	21069+3845	5.35	39.3	14.49	2009.798	1	61 Cyg
BU 1516AC	22415+1050	3.40 11.0	9.1	175.76	2009.800	1	42 Peg
SMR 6AD	22415+1050	3.40	165.0	146.90	2009.800	1	
BU 1144Aa-BC	22430+3013	3.02 9.87	338.4	93.34	2009.800	42	η Peg

Notes:

1. 1.5 degree south from lambda Tauri
2. not yet in WDS
3. BSC1671 in constellation Eridanus
4. not yet in WDS
5. not yet in WDS, pa and distance between A1 and A2
6. STF 954AB is the head of the Christmas Tree star cluster
7. not yet in WDS, I estimate a brightness of about 11.5 mag
8. not yet in WDS, I estimate a brightness of about 11.5 mag
9. not yet in WDS
10. not yet in WDS
11. Mayer 36 (Schlimmer, 2007b)
12. Ca. 1° north of Arcturus
13. 11 arc minutes in western of alpha CrB
14. About 2° north of delta Ophiuchi
15. Next to 19 Oph
16. Double star in star cluster IC4665
17. Epsilon Lyrae was observed on September, the 9th and 26th. Separation, angle and date was linear weighted against the number of analyzed single frames from videos
18. not yet in WDS
19. 250 as from 15 Sge
20. STF2690Aa-BC = Mayer 65 (Schlimmer, 2007b)

Double Star Measurements Using a Webcam, Annual Report of 2009

Acknowledgements

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

References

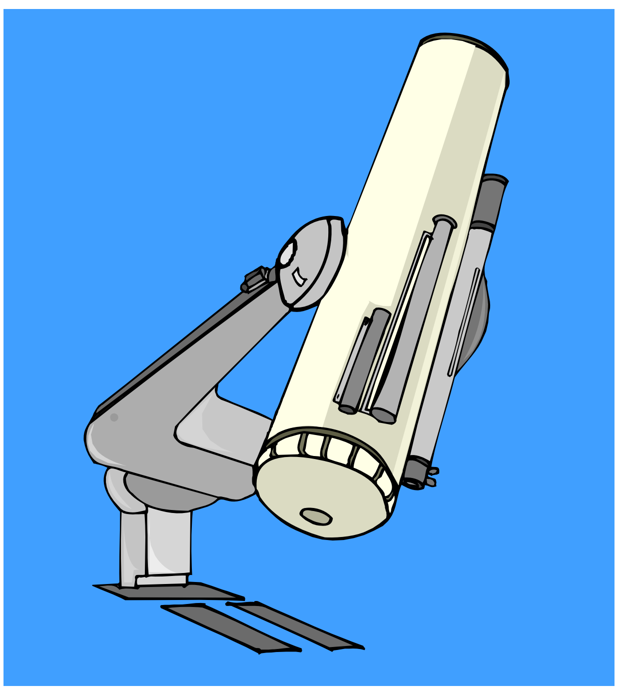
Schlimmer 2007a: Double Star Measurement Using a Webcam, Journal of Double Star Observations,Vol. 3 No. 3, Pages 131-134

Schlimmer 2007b: Christian Mayer's Double Star Catalog of 1779, Journal of Double Star Observations,Vol. 3 No. 4, Pages 151-158

Schlimmer 2008b: Double Star Measurement Using a Webcam - Annual Report of 2007, Journal of Double Star Observations, Vol. 4 No. 2 Pages 56-58

SIMBAD Astronomical Database, http://simbad.u-strasbg.fr/simbad/

WDS Catalog, The Washington Double Star Catalog, Mason, Wycoff, Hartkopf, Astrometry Department, U.S. Naval Observatory



New Common Proper-Motion Pairs from the PPMX Catalog

Rafael Caballero, Blanca Collado-Iglesias, Sara Pozuelo-González, Antonio Fernández-Sánchez

Agrupación Astronómica Hubble,
Martos, Jaén, Spain

Email: rafa@sip.ucm.es

Abstract: We use data mining techniques for finding 82 previously unreported common proper motion pairs from the PPM-Extended catalogue. Special-purpose software automating the different phases of the process has been developed. The software simplifies the detection of the new pairs by integrating a set of basic operations over catalogues. The operations can be combined by the user in scripts representing different filtering criteria. This procedure facilitates testing the software and employing the same scripts for different projects.

Introduction

In previous papers (Caballero 2009, Caballero 2010) we data mined different catalogs using some criteria to obtain new common proper-motion pairs (CPMP's from now on) not included in the WDS (Washington Double Star Catalog, Mason, et al., 2003). This idea is not new and has been used for instance by Greaves (2004).

During the development of the projects it became clear that the process was almost the same in all the cases, with a few changes due to the particular characteristics of each catalog. Therefore it seemed interesting to develop a special-purpose software. Such a project was suggested as a Master's thesis topic at the faculty of Computer Science at the University Complutense of Madrid (Spain). The project was developed by Blanca Collado-Iglesias, Sara Pozuelo-González and Antonio Fernández-Sánchez, and directed by Rafael Caballero. This paper presents 82 new CPMPs from the PPM-Extended catalog (PPMX, see Röser, 2008) obtained with the help of this application.

The Data Mining Process

The overall data mining process can be described as follows:

1. Downloading (part of) the main catalog C, usually from the online VizieR Service web page (Allende & Dambert 1999). Sometimes portions of auxiliary catalogs are also needed, for instance to complete the information about spectra, visual magnitude, etc.
2. Importing C data into a relational database such as Access or MySQL (and also the auxiliary catalogs).
3. Obtain the Cartesian product $D = C \times C$. D is thus a table of pairs.
4. Delete from D all the pairs with separation greater than some arbitrary number, for instance 100 seconds.
5. Remove from D all the pairs that are already part of the WDS.
6. Apply some criteria, in order to keep in D only possible CPMPs. A typical case is the Halbwachs' criteria (Halbwachs, 1986).
7. If possible, introduce further criteria that can help to increase the data quality, i.e. to reject those pairs that are more likely not physically attached.
8. Finally, check every pair in the photographic plates available at ALADIN (Bonnarel et al., 2000), looking for two stars with noticeable motion and roughly the same astrometry data in the expected position.

9. Complete the data with astrometry and other suitable data from auxiliary catalogs.

The Software Application

The opening screen of the application is shown in Figure 1. It was developed in the Java programming language. This language was chosen because it easily allows connecting to different databases using a convenient JDBC (Java Database Connectivity) driver. Initially, the system is configured for using the relational database MySQL, but it can be readily adapted for other databases such as Oracle or Access. The program allows the user importing catalogs obtained from Vizier in text format with the fields separated by ";". By parsing the header produced by VizieR, the type and size of the different attributes is detected, and a suitable SQL table created.

Other options for general management of catalogs are included. Probably one of the most useful ones is the "Join Catalogs" option. With this option the user can cross two tables containing individual stars yielding a new table containing those pairs with separation less than a parameter in seconds (steps 3 and 4 of the overall process described in the previous section). This table will contain the set of initial candidates.

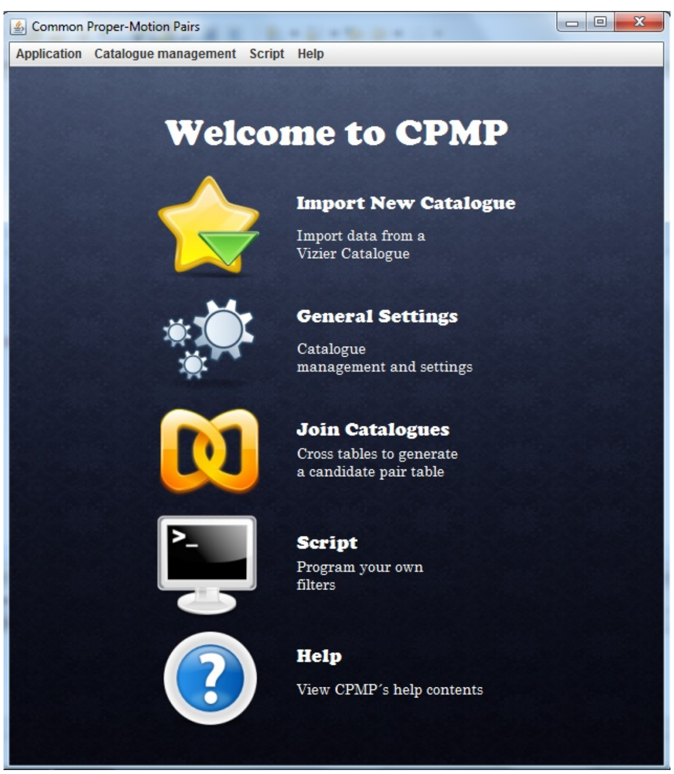


Figure 1: Application main screen.

However, the most appealing feature of the program is that it allows the users to program their own scripts for filtering the candidate pairs. The scripts can be saved and are defined by combining a few core operations, like adding a new field to an existing table, setting the value for some field for all the rows fulfilling some condition, combining catalogs to produce a new one, or deleting all the rows that do not satisfy a given condition. Furthermore, the system allows defining parameterized functions that will be used from different scripts. As a simple example consider the following user-defined function:

```
function setFilterPM(2)
begin
 temp1<-newAttribute($1,mu,double);
 temp2<-newAttribute(temp1,b_mu,double);
 temp3<-attribute(temp2,mu,'sqrt
(pmra*pmra+pmde*pmde)')[true];
 temp4<-attribute(temp3,b_mu,'sqrt
(b_pmra*b_pmra+b_pmde*b_pmde)')[true];
 $2<-filter(temp4)[mu>=50 and b_mu>=50];
end
```

The function receives as input a table $1 of pairs, which is assumed to contain fields *pmra*, *pmde*, *b_pmra*, and *b_pmde*, which represent the proper motion in RA and DEC of the two components, and it creates a new table $2 such that:

- It contains two new fields *mu* and *b_mu* such that for each row $mu = \sqrt{(pmra^2 + pmde^2)}$ and $b\_mu = \sqrt{(b\_pmra^2 + b\_pmde^2)}$.
- It only contains those rows verifying *mu*>=50 and *b_mu*>=50 (i.e. both components with proper motion over 50 millisecond of arc/year).

The function is self-explanatory: the two first statements after the reserved word *begin* add the new fields, both of type *double* (real numbers). The two next lines give value to the new fields. The condition *[true]* at the end of each statement specifies that the new values must affect all the rows. Finally, the last statement before the reserved word *end* removes all the rows corresponding to pairs where some of the components have proper motion below 50 mas/yr.

A Test Case: the PPMX Catalog

In order to check the software the PPMX catalog was chosen. In particular we started downloading the catalog for entries with available V magnitude and with proper motion over 50 milliseconds of arc per year. Then we used the option "join catalogs" to produce the initial set of candidate pairs. 2171 pairs with separation under 100 seconds were obtained. Then a new, more restrictive, version of the Halbwachs' criteria was applied (see next section), further reducing the set of pairs to 979. Then the pairs already in the WDS, or those likely to be included in the catalog in the near future, were removed leaving 85 pairs. Another three pairs were excluded after using the Reduced Proper Motion (RPM) discriminator proposed by Salim & Gould (2003). Finally, all the pairs were checked in the photographic plates, finding all of them. The summary of this process is shown in Table 1.

Table 1: Summary of the data mining process for PPMX

Phase	Rows
PPMX initial subset	172115
Candidate pairs	2171
After (modified) Halbwachs criteria	979
After removing pairs already in WDS	213
After removing pairs in other lists	85
After RPM criterion	82
After checking photographic plates	82

Halbwachs revisited

The three criteria originally proposed by Halbwachs for distinguishing physical and optical pairs from their proper motion are:

1. $(\mu_1 - \mu_2)^2 < -2\ (\sigma_1^2 + \sigma_2^2) \ln (0.05)$
2. $|\mu_1|,\ |\mu_2| \geq 50$ mas/yr
3. $\rho / |\mu_1|,\ \rho / |\mu_2| < 1000$ yr

where μ_1, μ_2 are the two proper motion vectors, σ_i is the mean error of the projections on the coordinate axes of μ_i, and ρ is the angular separation of the two stars. The first condition checks if the hypothesis $\mu_1 = \mu_2$ is admissible with a 95% confidence considering the given errors σ_1 and σ_2. If $\mu_1 = (\mu_{11}, \mu_{12})$, $\mu_2 = (\mu_{21}, \mu_{22})$ then this condition can be rewritten as

$$(1')\quad (\mu_{11} - \mu_{21})^2 + (\mu_{21} - \mu_{21})^2 < -2\ (\sigma_{12} + \sigma_{22}) \ln (0.05)$$

However in previous experiences it was observed that this criterion allowed pairs with noticeably different values in some axes, and thus some additional criterion was needed. In this project we propose using the condition for each axis separately, i.e. to replace condition (1) (or (1')) by:

$$(1.a)\ (\mu_{11} - \mu_{21})^2 < -2\ \sigma_{12} \ln (0.05)$$
$$(1.b)\ (\mu_{12} - \mu_{22})^2 < -2\ \sigma_{22} \ln (0.05)$$

It is straightforward to check that the conjunction of (1.a) and (1.b) imply (1'), and therefore the new condition is more restrictive. In particular, in the case of the PPMX project replacing the condition (1) by (1.a) and (1.b), results in 15 additional pairs filtered out. These pairs are precisely those with noticeable differences in any axis. Hence, we think that substituting (1) by (1.a) and (1.b) is a good practice that improves the quality of the results.

Results

Table 2 shows the final list with the new CPMP obtained. The astrometry (precise coordinates, position angle, separation, and date) have been obtained from the 2MASS catalog. The visual magnitudes correspond to the values in PPMX. The pair separation ranges from 8.64" to 99.40", and the visual magnitudes are between 6.25 and 13.07. The pair at RA-dec 21 36 58.08 -35 53 02.93 is especially remarkable, since the parallax of both components is known and compatible: 14.95 ±0.93 mas for A and 15.09 ±1.21 mas for B. In this case it seems quite safe to say that this bright pair (mags. 7.35 and 8.60) is physically attached. For another 15 pairs the parallax of the primary is known, and for a larger number the spectral type of one or the two components is available either from Hipparcos (Perryman, 1997) or from Tycho-2 (Wright, 2003). In three cases the secondary of the new pair is a close pair already in WDS, see notes 13, 21, and 34.

Table 3 contains the proper motion data of the new CPMP. The data corresponds to PPMX.

Conclusions

Ensuring the data quality must be one of the main goals of any data mining project. With this purpose we have developed a software application that simplifies the different phases of the project. The filters for selecting and reducing the number of candidate pairs are easily prepared by the user by employing a small subset of basic operations over catalogues, which constitutes the core language offered by the application. The

(Continued on page 215)

New Common Proper-Motion Pairs from the PPMX Catalog

Discovery Designation	RA DEC	Mags		PA	SEP	DATE	NOTES
CBL	00 32 19.099 -21 50 33.69	11.7	12.29	208.45	49.78	2000.783	
CBL	00 55 33.213 -43 16 11.73	12.24	12.63	134.53	28.20	1999.713	
CBL	01 00 52.512 -18 56 57.08	11.44	11.57	220.88	25.25	1998.626	
CBL	01 52 27.571 -49 31 25.56	9.04	9.16	207.56	42.41	1999.812	(1)
CBL	02 04 18.761 -70 59 40.88	10.48	11.77	103.88	24.05	1999.894	
CBL	02 05 27.334 +38 20 57.02	12.29	13.07	130.16	31.88	1998.810	
CBL	03 10 41.550 -20 06 41.54	7.62	10.61	313.69	59.79	1998.878	(2)
CBL	03 24 54.681 -43 12 55.77	9.86	11.62	192.09	26.63	1999.648	(3)
CBL	03 46 09.569 -41 12 22.33	9.25	11.48	257.08	66.28	1999.629	(4)
CBL	04 23 48.192 -76 43 09.45	11.13	11.29	265.20	45.21	1998.840	
CBL	05 01 36.173 -44 49 49.05	7.55	10.58	265.53	50.77	1999.722	(5)
CBL	05 23 39.978 -38 18 48.09	11.82	12.20	193.43	24.06	1999.173	
CBL	05 57 24.758 -40 23 51.78	8.15	11.28	350.10	45.10	1999.190	(6)
CBL	06 15 01.664 -63 20 38.82	11.71	12.57	219.59	15.59	1998.947	
CBL	06 38 17.669 +18 28 24.58	11.44	11.79	63.63	55.81	1997.898	
CBL	07 03 08.446 -73 50 13.91	11.12	11.34	140.15	51.35	2000.167	
CBL	07 08 55.244 -11 23 29.58	11.22	12.32	31.21	48.15	1999.138	
CBL	09 33 19.911 -07 11 24.75	6.25	10.78	19.14	57.81	1999.048	(7)
CBL	09 51 08.004 -18 39 31.43	7.37	10.83	115.95	50.68	1998.322	(8)
CBL	10 14 38.104 -13 33 29.10	9.04	10.34	177.99	28.62	1999.299	(9)
CBL	10 15 08.028 -65 26 11.04	11.15	11.47	304.57	31.11	2000.230	
CBL	10 16 15.352 -17 11 13.12	10.67	11.78	282.61	41.57	1998.234	
CBL	10 32 03.297 -30 28 05.49	11.46	11.78	29.56	14.49	1999.223	
CBL	10 47 27.741 -11 54 08.72	9.83	10.46	48.64	27.76	1998.256	(10)
CBL	11 29 03.259 -38 17 05.77	9.48	11.35	109.61	38.72	1999.272	(11)
CBL	11 35 52.047 -40 40 36.43	11.85	12.18	247.31	20.08	1999.275	
CBL	11 53 22.088 -67 07 05.56	10.78	11.88	119.24	36.11	2001.121	
CBL	12 05 25.156 +17 17 21.69	7.63	10.04	311.55	43.20	1998.033	(12)
CBL	12 13 30.463 -48 47 46.64	8.80	10.57	347.83	49.99	1999.357	(13),(14)
CBL	12 34 19.535 -35 22 46.48	10.46	11.63	162.81	44.30	1999.258	
CBL	12 35 15.748 -09 10 57.84	10.91	10.95	142.98	28.20	1999.089	

Table continues on next page.

New Common Proper-Motion Pairs from the PPMX Catalog

Discovery Designation	RA DEC	Mags		PA	SEP	DATE	NOTES
CBL	12 35 43.067 -03 00 58.10	8.49	9.79	280.18	60.70	1999.149	(15)
CBL	12 36 16.407 -79 31 34.45	10.95	11.34	254.57	14.99	2000.102	
CBL	13 17 35.429 -11 57 01.34	11.04	12.70	344.71	24.29	1999.138	
CBL	13 53 54.390 -07 45 44.87	11.30	11.84	216.02	18.76	1999.163	
CBL	14 08 01.294 -13 16 09.22	11.84	12.31	180.53	13.24	1999.299	
CBL	14 12 31.776 -30 06 17.68	11.48	11.77	216.48	31.32	1999.262	
CBL	14 35 32.025 -35 26 39.17	11.44	11.72	211.37	41.19	2000.310	
CBL	14 37 23.205 -66 50 27.83	9.95	10.47	305.18	27.02	2000.258	(16)
CBL	14 53 52.152 -63 53 53.17	9.28	11.02	83.26	41.56	2000.223	(17)
CBL	14 55 28.254 -56 48 55.15	9.85	11.00	265.59	26.29	2000.146	(18)
CBL	14 58 31.045 -27 24 06.18	10.79	11.48	91.00	15.09	1998.486	
CBL	15 04 08.091 -26 23 26.83	10.97	11.56	322.81	26.24	1998.486	
CBL	15 07 12.834 -41 41 31.12	9.36	9.46	286.51	8.64	1999.374	(19)
CBL	15 13 59.433 -58 37 15.68	9.88	10.30	319.51	45.32	1999.431	(20)
CBL	16 31 42.851 +70 55 59.84	8.22	11.45	312.31	39.95	1999.398	(21), (22)
CBL	16 37 35.305 +69 19 17.25	9.07	10.76	124.95	99.40	1999.399	
CBL	17 01 49.674 +14 42 27.70	10.37	10.63	12.39	19.29	1999.158	
CBL	17 40 21.442 +05 43 37.44	11.19	11.98	342.16	34.69	2000.404	
CBL	17 54 51.203 +28 51 38.93	11.27	12.36	244.01	41.01	2000.204	
CBL	17 56 59.673 -46 06 31.92	10.91	10.94	207.38	11.21	1999.551	
CBL	17 59 53.975 -45 17 20.72	10.94	11.67	192.86	14.26	1999.551	
CBL	18 07 28.944 +00 29 27.19	11.23	11.54	355.05	49.82	1999.548	
CBL	18 13 05.162 +18 40 45.60	8.37	10.50	260.54	34.30	2000.209	(23)
CBL	18 21 26.185 -15 22 18.08	9.72	11.08	26.29	18.82	1999.333	
CBL	18 22 44.038 -40 44 59.30	10.32	10.73	159.99	12.69	2000.427	
CBL	18 27 24.762 +21 51 53.42	10.22	11.99	159.94	26.67	2000.242	
CBL	18 38 36.531 +49 00 42.13	9.42	10.72	260.52	47.47	1998.478	(24)
CBL	18 41 25.436 -44 32 30.63	10.78	11.14	53.29	36.30	2000.474	
CBL	18 45 04.604 -23 15 07.22	8.45	11.24	93.96	25.15	1998.478	(25)
CBL	18 54 43.138 -50 07 46.85	9.18	11.72	280.23	27.51	1999.726	(26)
CBL	19 01 33.281 -24 08 28.08	9.20	11.43	83.49	31.00	1999.262	(27)

Table concludes on next page.

New Common Proper-Motion Pairs from the PPMX Catalog

Discovery Designation	RA DEC	Mags		PA	SEP	DATE	NOTES
CBL	19 07 06.084 -14 04 09.97	8.64	10.38	317.61	20.69	2000.247	(28)
CBL	20 06 03.948 -41 37 36.45	11.49	11.68	8.99	23.71	1999.505	
CBL	20 33 53.250 -27 10 17.31	9.35	11.97	39.94	52.00	2000.561	(29)
CBL	20 36 05.730 -67 05 22.53	10.50	11.32	107.53	24.53	2000.542	
CBL	20 46 51.514 -49 28 39.62	10.71	11.39	197.77	27.90	1999.710	
CBL	21 10 18.359 -13 04 05.84	11.13	11.15	246.88	16.80	1999.483	
CBL	21 16 13.422 -40 40 51.94	11.30	12.07	151.91	31.23	1999.691	
CBL	21 29 36.229 -44 13 50.10	10.36	10.71	261.71	90.54	1999.633	
CBL	21 36 58.092 -35 53 03.02	7.35	8.60	265.34	78.45	2000.562	(30)
CBL	21 54 22.594 -44 09 46.37	11.10	11.90	73.80	17.96	1999.718	
CBL	22 08 27.535 -57 06 52.51	11.08	11.45	327.83	26.33	2000.543	
CBL	22 09 42.632 -33 45 15.41	9.28	10.25	278.32	49.90	1999.560	(31)
CBL	22 32 09.402 -13 35 51.81	7.72	9.71	93.97	41.94	1998.481	(32)
CBL	22 33 45.700 +61 45 26.85	9.94	10.90	222.22	38.29	1999.746	
CBL	22 41 49.606 +59 47 35.64	9.03	11.02	104.02	47.92	1999.741	(33)
CBL	22 47 55.497 +03 36 07.26	11.28	11.35	154.24	23.20	2000.608	
CBL	22 53 55.679 -37 09 40.50	10.22	10.59	313.30	54.44	1999.734	
CBL	22 54 19.523 +30 22 18.31	10.46	11.40	233.61	14.46	1998.473	
CBL	23 28 08.467 -02 26 53.36	8.05	8.43	226.37	57.33	1998.730	(34), (35)
CBL	23 37 40.086 +00 46 36.37	10.63	12.3	156.89	34.18	2000.658	

Table Notes:

1. Parallax primary: 8.29 ±1.06 (Hipparcos). Spectral Type primary: F7V (Hipparcos), spectral type secondary: G (Tycho-2 Spectral Type Catalog).
2. Parallax primary: 3.57 ±0.91 (Hipparcos). Spectral Type primary: G8/K0IV (Hipparcos) .
3. Spectral Type primary: G5/8 (Tycho-2 Spectral Type Catalog).
4. Parallax primary: 12.1 ±1 (Hipparcos). Spectral Type primary: G5/G6 (Hipparcos) .
5. Parallax primary: 10.1 ±0.72 (Hipparcos). Spectral Type primary: G8/K0 (Hipparcos) .
6. Parallax primary: 7.84 ±0.71 (Hipparcos). Spectral Type primary: F0 V (Tycho-2 Spectral Type Catalog).
7. Parallax primary: 7.75 ±1.4 (Hipparcos). Spectral Type primary: K0 (Hipparcos) .
8. Parallax primary: 8.94 ±0.89 (Hipparcos). Spectral Type primary: F6/F7V (Hipparcos) .
9. Spectral Type primary: G6 IV (Tycho-2 Spectral Type Catalog).
10. Spectral Type primary: K5 (Tycho-2 Spectral Type Catalog).
11. Spectral Type primary: F3/5 V (Tycho-2 Spectral Type Catalog).
12. Parallax primary: 9.94 ±0.94 (Hipparcos). Spectral Type primary: F2 (Hipparcos).
13. The secondary is TDS8273.
14. Parallax primary: 3.49 ±1.25 (Hipparcos). Spectral Type primary: K1III (Hipparcos) .
15. Parallax primary: 13.2 ±1.11 (Hipparcos).

(Continued on page 212)

New Common Proper-Motion Pairs from the PPMX Catalog

(Continued from page 211)

Spectral Type primary: F5 (Hipparcos), spectral type secondary: K2 (Tycho-2 Spectral Type Catalog).

16. Spectral Type primary: F7/G0 (Tycho-2 Spectral Type Catalog).
17. Spectral Type primary: F2/5 III/IV (Tycho-2 Spectral Type Catalog).
18. Spectral Type primary: F8/G0 V (Tycho-2 Spectral Type Catalog).
19. Spectral Type primary: F3/5 V (Tycho-2 Spectral Type Catalog).
20. Spectral Type primary: F6/8 V (Tycho-2 Spectral Type Catalog).
21. The secondary is TDS 819.
22. Parallax primary: 7.32 ±0.61 (Hipparcos). Spectral Type primary: F5 (Hipparcos), spectral type secondary: F8 (Tycho-2 Spectral Type Catalog).
23. Spectral Type primary: G5 (Tycho-2 Spectral Type Catalog).
24. Spectral Type primary: F8 (Tycho-2 Spectral Type Catalog).
25. Parallax primary: 14.4±1.16 (Hipparcos). Spectral Type primary: G3/G5V (Hipparcos).
26. Spectral Type primary: G0 (Tycho-2 Spectral Type Catalog).
27. Spectral Type primary: G8 V (Tycho-2 Spectral Type Catalog).
28. Spectral Type primary: G0 (Tycho-2 Spectral Type Catalog).
29. Parallax primary: 15.2±1.35 (Hipparcos). Spectral Type primary: G8V (Hipparcos).
30. Parallax primary: 14.95 ±0.93(Hipparcos), parallax secondary: 15.09 ±1.21 (Hipparcos). Spectral Type primary: F3V (Hipparcos), secondary: G5V (Tycho-2 Spectral Type Catalog)..
31. Spectral Type primary: G0 V (Tycho-2 Spectral Type Catalog).
32. Parallax primary: 9.78±1.1 (Hipparcos). Spectral Type primary: G0V (Hipparcos).
33. Spectral Type primary: G0 (Tycho-2 Spectral Type Catalog).
34. Secondary is RST4724.
35. Parallax primary: 8.84 ±1.09 (Hipparcos). Spectral Type primary: F2 (Hipparcos), spectral type secondary: F5 V (Tycho-2 Spectral Type Catalog).

Table 3: Proper Motion of Each Component (mas/yr)

RA DEC	μ_1	μ_2	σ_1	σ_2
00 32 19.099 -21 50 33.69	(58.0, -2.6)	(63.8, 0.5)	(2.8, 3.1)	(2.8, 3.1)
00 55 33.213 -43 16 11.73	(14.3, -87.7)	(7.3, -89.7)	(2.2, 2.2)	(2.2, 2.2)
01 00 52.512 -18 56 57.08	(50.5, -7.8)	(53.2, -11.3)	(2.3, 2.3)	(2.3, 2.3)
01 52 27.571 -49 31 25.56	(31.2, -51.8)	(29.6, -50.5)	(1.5, 1.4)	(1.5, 1.4)
02 04 18.761 -70 59 40.88	(119.0, -29.9)	(124.9, -33.4)	(1.7, 2.0)	(1.9, 1.9)
02 05 27.334 +38 20 57.02	(33.1, -70.5)	(23.5, -83.2)	(2.4, 2.3)	(10.1, 10.6)
03 10 41.550 -20 06 41.54	(60.9, 3.4)	(65.7, 4.4)	(1.8, 1.8)	(2.4, 2.5)
03 24 54.681 -43 12 55.77	(3.0, 53.4)	(3.7, 58.6)	(1.8, 1.8)	(2.1, 2.1)
03 46 09.569 -41 12 22.33	(66.6, 25.0)	(71.9, 24.9)	(0.7, 0.8)	(2.1, 2.1)
04 23 48.192 -76 43 09.45	(36.4, -43.3)	(38.4, -43.5)	(1.4, 1.4)	(1.4, 1.4)
05 01 36.173 -44 49 49.05	(8.3, -65.8)	(5.2, -68.8)	(1.6, 1.6)	(2.1, 2.0)
05 23 39.978 -38 18 48.09	(29.5, 41.5)	(34.1, 37.2)	(2.3, 2.2)	(2.3, 2.3)

Table continues on next page.

New Common Proper-Motion Pairs from the PPMX Catalog

Table 3 (continued): Proper Motion of Each Component (mas/yr)

RA DEC	μ_1	μ_2	σ_1	σ_2
05 57 24.758 -40 23 51.78	(-1.3, 62.8)	(-3.0, 60.5)	(1.5, 1.5)	(2.3, 2.3)
06 15 01.664 -63 20 38.82	(-2.4, 84.8)	(-7.4, 83.7)	(3.8, 3.8)	(3.9, 3.9)
06 38 17.669 +18 28 24.58	(-78.3, -21.0)	(-73.4, -20.9)	(1.6, 1.6)	(1.6, 1.6)
07 03 08.446 -73 50 13.91	(-7.6, 64.2)	(-5.1, 57.0)	(6.0, 6.3)	(1.9, 1.9)
07 08 55.244 -11 23 29.58	(-5.5, -74.1)	(-2.4, -73.0)	(1.6, 1.7)	(2.0, 2.1)
09 33 19.911 -07 11 24.75	(-59.3, -26.5)	(-59.9, -23.8)	(1.5, 1.7)	(2.2, 2.2)
09 51 08.004 -18 39 31.43	(-97.4, 26.1)	(-101.1, 21.8)	(1.7, 1.6)	(3.0, 3.0)
10 14 38.104 -13 33 29.10	(-50.9, -17.8)	(-52.5, -21.1)	(1.3, 1.3)	(1.6, 1.6)
10 15 08.028 -65 26 11.04	(-62.0, 13.9)	(-60.0, 15.2)	(2.2, 2.2)	(2.2, 2.2)
10 16 15.352 -17 11 13.12	(-94.0, -27.8)	(-94.1, -35.4)	(2.6, 2.7)	(2.5, 2.5)
10 32 03.297 -30 28 05.49	(28.3, -42.4)	(38.2, -35.9)	(4.1, 4.1)	(3.4, 3.4)
10 47 27.741 -11 54 08.72	(21.8, -63.6)	(20.0, -64.3)	(1.5, 1.5)	(1.9, 2.0)
11 29 03.259 -38 17 05.77	(-9.3, -70.4)	(-12.1, -68.8)	(2.4, 2.5)	(2.9, 2.9)
11 35 52.047 -40 40 36.43	(-84.5, 8.0)	(-78.7, 10.5)	(2.8, 2.8)	(2.9, 2.9)
11 53 22.088 -67 07 05.56	(-9.1, -55.5)	(-5.9, -56.8)	(2.3, 2.3)	(2.4, 2.4)
12 05 25.156 +17 17 21.69	(-62.8, -53.3)	(-63.9, -51.8)	(1.1, 1.2)	(1.2, 1.3)
12 13 30.463 -48 47 46.64	(37.1, -54.7)	(33.7, -53.0)	(1.5, 1.5)	(2.0, 2.0)
12 34 19.535 -35 22 46.48	(-60.9, 8.7)	(-63.7, 3.6)	(2.5, 2.5)	(2.8, 2.8)
12 35 15.748 -09 10 57.84	(-49.4, -13.5)	(-48.5, -13.9)	(1.8, 1.9)	(1.9, 1.9)
12 35 43.067 -03 00 58.10	(-76.3, 13.9)	(-76.1, 14.3)	(0.7, 0.6)	(1.5, 1.5)
12 36 16.407 -79 31 34.45	(-58.2, -11.7)	(-60.5, -5.6)	(1.6, 1.6)	(2.0, 2.0)
13 17 35.429 -11 57 01.34	(-85.6, 35.8)	(-82.6, 36.2)	(1.7, 1.7)	(2.1, 2.1)
13 53 54.390 -07 45 44.87	(-48.1, -26.1)	(-45.8, -28.9)	(2.0, 2.0)	(2.7, 2.7)
14 08 01.294 -13 16 09.22	(-68.9, 0.9)	(-55.9, -15.5)	(9.7, 12.0)	(2.1, 2.1)
14 12 31.776 -30 06 17.68	(-72.7, -15.6)	(-67.0, -23.3)	(2.7, 2.7)	(2.7, 2.7)
14 35 32.025 -35 26 39.17	(-41.8, -28.4)	(-43.9, -25.8)	(2.3, 2.4)	(2.4, 2.4)
14 37 23.205 -66 50 27.83	(-56.1, -14.1)	(-55.0, -16.2)	(1.9, 1.9)	(1.8, 1.8)
14 53 52.152 -63 53 53.17	(86.2, -26.2)	(85.7, -25.7)	(2.7, 2.7)	(3.4, 3.2)
14 55 28.254 -56 48 55.15	(-46.1, -37.2)	(-51.6, -41.0)	(2.1, 2.1)	(2.2, 2.2)
14 58 31.045 -27 24 06.18	(13.8, -104.4)	(8.9, -104.8)	(3.7, 3.5)	(3.5, 3.4)
15 04 08.091 -26 23 26.83	(56.8, -8.6)	(52.8, -4.9)	(3.5, 3.2)	(2.7, 2.5)

Table continues on next page.

New Common Proper-Motion Pairs from the PPMX Catalog

Table 3 (continued): Proper Motion of Each Component (mas/yr)

RA DEC	μ_1	μ_2	σ_1	σ_2
15 07 12.834 -41 41 31.12	(-44.4, -25.3)	(-46.0, -28.6)	(1.8, 1.8)	(2.4, 2.4)
15 13 59.433 -58 37 15.68	(-61.8, -45.9)	(-62.2, -42.9)	(1.6, 1.6)	(2.4, 2.4)
16 31 42.851 +70 55 59.84	(-65.0, 22.5)	(-63.5, 23.4)	(1.3, 1.4)	(1.9, 1.9)
16 37 35.305 +69 19 17.25	(-82.0, 103.8)	(-82.4, 105.4)	(1.3, 1.4)	(1.8, 1.8)
17 01 49.674 +14 42 27.70	(-17.9, -47.2)	(-19.0, -47.1)	(1.6, 1.7)	(0.9, 0.9)
17 40 21.442 +05 43 37.44	(-24.4, -74.9)	(-25.2, -68.4)	(2.9, 2.9)	(2.9, 2.9)
17 54 51.203 +28 51 38.93	(-20.1, -47.0)	(-23.5, -45.9)	(1.7, 1.7)	(1.7, 1.7)
17 56 59.673 -46 06 31.92	(70.6, -20.9)	(72.6, -19.3)	(1.8, 1.8)	(1.8, 1.8)
17 59 53.975 -45 17 20.72	(5.9, -55.5)	(6.4, -53.5)	(2.1, 2.2)	(2.2, 2.3)
18 07 28.944 +00 29 27.19	(-18.2, -48.3)	(-18.4, -49.4)	(1.8, 1.8)	(1.8, 1.8)
18 13 05.162 +18 40 45.60	(5.4, -50.6)	(5.1, -52.0)	(1.1, 1.1)	(1.6, 1.6)
18 21 26.185 -15 22 18.08	(12.8, -82.3)	(12.2, -82.8)	(1.7, 1.8)	(1.8, 1.8)
18 22 44.038 -40 44 59.30	(-32.4, -38.8)	(-31.2, -40.2)	(2.2, 2.2)	(2.3, 2.4)
18 27 24.762 +21 51 53.42	(-16.4, 53.7)	(-18.0, 50.4)	(1.5, 1.5)	(2.2, 2.2)
18 38 36.531 +49 00 42.13	(69.8, 43.1)	(65.8, 42.7)	(1.4, 1.4)	(1.1, 1.1)
18 41 25.436 -44 32 30.63	(16.7, -51.9)	(14.9, -56.7)	(2.2, 2.2)	(2.2, 2.2)
18 45 04.604 -23 15 07.22	(17.7, -119.5)	(21.4, -126.1)	(1.7, 1.6)	(2.8, 2.8)
18 54 43.138 -50 07 46.85	(-2.6, -76.9)	(-1.7, -75.8)	(1.5, 1.5)	(2.2, 2.2)
19 01 33.281 -24 08 28.08	(-25.6, -83.0)	(-30.1, -82.5)	(1.6, 1.5)	(2.5, 2.6)
19 07 06.084 -14 04 09.97	(94.3, 27.6)	(91.4, 28.0)	(1.6, 1.6)	(2.2, 2.1)
20 06 03.948 -41 37 36.45	(59.1, -53.6)	(58.6, -57.6)	(2.1, 2.1)	(2.1, 2.1)
20 33 53.250 -27 10 17.31	(68.4, -82.3)	(71.2, -89.2)	(1.6, 1.6)	(3.3, 3.3)
20 36 05.730 -67 05 22.53	(-29.0, -63.8)	(-28.6, -67.9)	(1.7, 1.7)	(1.8, 1.8)
20 46 51.514 -49 28 39.62	(71.9, -2.3)	(74.1, -1.0)	(2.1, 2.2)	(2.2, 2.2)
21 10 18.359 -13 04 05.84	(73.1, -41.2)	(65.6, -42.8)	(5.2, 6.4)	(2.1, 2.1)
21 16 13.422 -40 40 51.94	(45.3, -27.1)	(46.0, -27.0)	(1.8, 1.8)	(1.8, 1.8)
21 29 36.229 -44 13 50.10	(86.8, -53.0)	(86.4, -49.2)	(2.0, 2.0)	(2.0, 2.1)
21 36 58.092 -35 53 03.02	(90.9, -10.1)	(90.7, -9.2)	(0.8, 0.5)	(1.4, 1.4)
21 54 22.594 -44 09 46.37	(13.7, -89.1)	(18.8, -92.5)	(2.1, 2.2)	(3.1, 3.1)
22 08 27.535 -57 06 52.51	(10.6, -73.0)	(11.0, -68.4)	(2.3, 2.3)	(2.4, 2.4)
22 09 42.632 -33 45 15.41	(49.3, -84.1)	(47.8, -82.7)	(1.5, 1.4)	(2.4, 2.4)

Table concludes on next page.

New Common Proper-Motion Pairs from the PPMX Catalog

Table 3 (continued): Proper Motion of Each Component (mas/yr)

RA DEC	μ_1	μ_2	σ_1	σ_2
22 32 09.402 -13 35 51.81	(-19.4, -65.9)	(-20.1, -62.8)	(1.6, 1.6)	(1.5, 1.5)
22 33 45.700 +61 45 26.85	(-18.6, -61.7)	(-15.8, -58.4)	(2.3, 2.1)	(2.0, 2.0)
22 41 49.606 +59 47 35.64	(16.9, -79.0)	(15.4, -77.5)	(1.2, 1.3)	(1.6, 1.6)
22 47 55.497 +03 36 07.26	(67.9, 3.3)	(69.6, 3.3)	(1.9, 1.9)	(1.6, 1.6)
22 53 55.679 -37 09 40.50	(108.1, 5.4)	(106.4, -0.8)	(1.4, 1.6)	(3.1, 3.1)
22 54 19.523 +30 22 18.31	(142.7, -4.6)	(142.0, -9.8)	(1.5, 1.5)	(1.6, 1.6)
23 28 08.467 -02 26 53.36	(69.8, 10.4)	(70.5, 8.4)	(1.2, 1.3)	(1.3, 1.4)
23 37 40.086 +00 46 36.37	(-30.0, -69.7)	(-29.8, -85.9)	(1.7, 1.8)	(10.7, 10.7)

(Continued from page 208)

advantages of this approach are:

- The basic core operations are easier to test and debug than the usual complex operations required by the data mining process.
- Assuming that the basic operations have been thoroughly checked, the whole process becomes less prone to errors. This holds true because the different filters are now written in a higher abstraction level, instead of directly in SQL. This makes them more understandable and easier to test and modify.
- The same user-scripts can be employed in different projects, facilitating the reusability of the code. The language allows defining parameterized functions with this purpose.
- This possibility of easily modifying the code is very useful for proving variations of the same filter and designing new ones. In our case it has been crucial for comparing the two versions of the first Halbwachs' condition examined above.

Currently, we are improving the application in order to make it publicly available in the near future. Regarding our test-case, the PPMX catalog, we would like to point out two main conclusions:

- The catalog was chosen to check the software, assuming that all the interesting pairs had been already extracted. Indeed most of them were in the WDS, but still there were a few possible interesting pairs to find.
- In all the projects examined up to now many of the pairs detected by data mining did not exist in the plates. Instead they corresponded to erroneous data obtained while processing the images. However, in this catalog no false pairs were found, attesting to the quality of its data.

As usual, it is important to remark that we don't claim that the CPMPs found are true binaries. The data mining process only suggests that these pairs might deserve more measurements and a deeper study.

Acknowledgements

This research makes use of the ALADIN Interactive Sky Atlas and of the VizieR database of astronomical catalogs, all maintained at the Centre de Données Astronomiques, Strasbourg, France, and of the data products from the Two Micron All Sky Survey, which is a joint project of the University of Massachusetts and the Infrared Processing and Analysis Center/California Institute of Technology, funded by the National Aeronautics and Space Administration and the National Science Foundation. This work has been partially supported by the Spanish projects TIN2008-06622-C03-01, S-0505/TIC/0407, S2009TIC-1465 and UCM-BSCH-GR58/08-910502.

References

Allende Prieto, C; Dambert D.L.; 1999, "Fundamental parameters of nearby stars from the comparison with evolutionary calculations: masses, radii and effective temperatures". *Astronomy and Astrophysics*, 352, p.555-562 (1999)

New Common Proper-Motion Pairs from the PPMX Catalog

Bonnarel, F.; Fernique, P.; Bienaymé, O.; Egret, D.; Genova, F.; Louys, M.; Ochsenbein, F.; Wenger, M.; Bartlett, J. G.; 2000, "The ALADIN interactive sky atlas. A reference tool for identification of astronomical sources", *Astronomy and Astrophysics Supplement*, 143, p.33-40.

Caballero, R.; 2009, "Finding New Common Proper-Motion Binaries by Data Mining", *Journal of Double Star Observations*, 5(3), 156-167.

Caballero, R.; 2010, "New Northern Hemisphere Common Proper-Motion Pairs from the UCAC-3 Catalog", *Journal of Double Star Observations*, 6(1), 97-113.

Greaves, J., 2004, "New Northern hemisphere common proper-motion pairs". *Monthly Notices of the Royal Astronomical Society* 355, 585-590.

Halbwachs, J.L., 1986, "Common proper motion stars in the AGK3". *Bull. Inf. Centre Donnees Stellaires*, 30, p.129.

Mason, B. D.; Wycoff, G.; Hartkopf, W. I., 2003, "The Washington Double Star Catalog", http://ad.usno.navy.mil/proj/WDS/wds.html

Perryman, M. A. C.; ESA, 1997, *The HIPPARCOS and TYCHO catalogues. Astrometric and photometric star catalogues derived from the ESA HIPPARCOS Space Astrometry Mission*, Publisher: Noordwijk, Netherlands: ESA Publications Division, 1997, Series: ESA SP Series vol no: 1200, ISBN: 9290923997.

Röser, S.; Schilbach, E.; Schwan, H.; Kharchenko, N. V.; Piskunov, A. E.; Scholz, R.-D.; 2008 "PPM-Extended (PPMX) – a catalogue of positions and proper motions". *Astronomy and Astrophysics*, 488 (1), 401-408.

Salim, S.; Gould, A., 2003, "Improved Astrometry and Photometry for the Luyten Catalog. II. Faint Stars and the Revised Catalog", *The Astrophysical Journal*, 582, 1011-1031.

Wright, Candace O.; Egan, Michael P.; Kraemer, Kathleen E.; Price, Stephan D.; 2003, "The Tycho-2 Spectral Type Catalog", *The Astronomical Journal*, 125(1), 359-363.

Relative Motion of the WDS 05110+3203 STF 648 System, With a Protocol for Calculating Relative Motion

E. O. Wiley

Remote Astronomical Society Observatory,
Mayhill, NM, USA

Mailing address: 2503 Atchison Ave., Lawrence KS 66047

edwiley@sunflower.com

Abstract: Relative motion studies of visual double stars can be investigated using least squares regression techniques and readily accessible programs such as Microsoft Excel® and a calculator. Optical pairs differ from physical pairs under most geometries in both their simple scatter plots and their regression models. A step-by-step protocol for estimating the rectilinear elements of an optical pair is presented. The characteristics of physical pairs using these techniques are discussed.

Introduction

I was inspired to look into studies of relative motion by papers published in the JDSO by Schlimmer (2009a, b) who used least squares analysis to determine the rectilinear elements of several optical pairs. A similar approach was used by Rico Romero (2000). This lead to an incomplete literature review (e.g., Torres, 1985; Clark et al., 2005; Kiyaeva et al., 2008) in the primary literature and a discussion of the uses of regression analysis in astronomy by Isobe et al. (1990) and Feigelson and Babu (1992). I concluded that studies of relative motion were within the skills of amateurs wishing to expand their research program, but that the protocols available in the literature are a bit obscure. This paper is an attempt to outline protocols that can be used by amateurs with modest math skills (such as myself) to study relative motion of double stars with relatively high proper motions (at least one of the pair with a total pm 50 mas/yr).

The system studied, WDS 05110+3203STF 648, consists of four stars. STF 648AB has been recognized as either a common proper motion pair or a binary at least since Burnham (1906) and Lewis (1906). The pair has a similar proper motion (UCAC2.0), parallax and velocity (Kharchenko et al., 2007). There are 62 measures in the WDS and the pair is moving toward the west (ca. 260º) at about -139 mas/yr. The relationships between the AC and AD components are almost certainly optical as evidenced by very different proper motions. The system offers the opportunity to explore the use of least squares techniques and some simple algebra and analytic geometry to study relative motion of both a physically associated and two optical pairs of the same system while making it possible to duplicate the calculations with a hand calculator since neither AC nor AD have many observational measures.

In a nutshell, linear regression is a least-square technique that fits a straight line describing the linear relationships of two variables, usually labeled x and y. These variables are functions of the angle and separation between the primary and secondary that have been converted from polar to Cartesian coordinates. In most applications, x is the independent variable (and without error) while y is the dependent or response variable. Informally, how well can you predict y if you know x by fitting a straight line to the measures? In terms of Isobe et al. (1990), the models employed here are ordinary least squares (OLS) either regressing Y on X (OLS Y|X) or each on Epoch (e.g., OLS Y|Epoch), with a check of the residuals regressed against Epoch. Using the regression functions in Excel, I was able to duplicate the results of Schlimmer (2009a), which piqued my interest in seeing if I could estimate the rectilinear elements that appear in the Catalog of Rectilinear Elements (Hartkopf et al, 2008 et seq., hereafter referred to as CRE).

Below I present a protocol for estimating the rectilinear elements of an optical pair, using STF 648AC as an example. I have used what I think is a relatively intuitive approach, not the most efficient one. However, and in the spirit of Tanguay (1998), learning to work these things out manually helps one to understand exactly what is happening in the analysis. After presenting the protocol, I compare the results of a comparative study of calculations of known rectilinear pairs using this protocol with the values that appear in the CRE. I will then discuss the results of the analysis of STF 648AB and suggest that least squares techniques, used with caution, may be one approach to studying physical pairs.

Table 1: New measures of 05110+3203STF 686AC and 05110+3203STF 686AD.

WDS	Disc. Code	Epoch	PA	SEP	PAsd	SEPsd	N	Notes
05110+3203	STF 648AC	2009.152	113.2	48.1	0.26	0.229	4	1, 2
05110+3203	STF 648AD	2009.152	73	45.9	0.03	0.063	4	1, 2

[1] 0.25m cassegrain, 1.65 arcsec/pixel resolution

[2]N = number of images, single night

Table 2: All measurements of 05110+3203STF 686AC, 1906-2009.152. Coordinates (x, y) are corrected for precession and referred to the pole of 2000.00.

Epoch	PA	RA corrected	Sep	x	y
1906.73	115.7	116.3	36.65	32.856	16.24
1927.2	114.3	114.77	40.25	36.547	16.864
1999.9	113.3	113.3	47.69	43.8	18.864
2009.152	113.14	113.14	48.1	44.23	19.903

Relative Rectilinear Motion of the Optical Pairs 05110+3203STF 648AC and AD

My measures of both STF 648AC and STF 648AD are shown in Table 1. The goal is to calculate the parameters of closest approach including the angle (THETA0), separation (RHO0) and time of approach (T0). The protocol consists of several steps illustrated using STF 648AC. Results of the relative motion study for both pairs are shown in Tables 2 and 3.

1. Gather all WDS catalog measures of the pair through request from the USNO.

Observation requests forms are on the WDS Web pages (see Mason, 2006). All measures for STF648AC are shown in Table 2.

2. Correct angle for changes due to precession.

Theta can change as a function of precession. Formulae for correcting theta are provided by Aitken (1935: 73) and Greaney (2004) and can be easily programmed in Excel. I have used both an Excel sheet kindly provided by Francisco Rica Romero of LIADA. Below, I work an example the calculation based on the original observation of STF 648AC (Epoch 1906.73). See Table 2 for all corrected measures.

$$\Delta\theta_p = -0.0056^o \sin\alpha \sec\delta\left(t - t_o\right)$$

Where $\Delta\theta p$ is the angle correction for precession, α is the right ascension of the primary in decimal degrees (= 77.746625°), -0.0056° is the constant for precession, t is the common epoch to which all measures will be referred and to is the epoch of observation.

$$\Delta\theta_p = -0.0056^o \sin(77.746625^o)\left[\sec(32.03875^o\right](2000.00-1906.73)$$

$$\Delta\theta_p = 0.60212^o$$

$$\Delta\theta(corrected) = 115.70^o + .0.60212^o = 116.30^o$$

If one also corrects for the proper motion of the primary, then the resulting calculations will not measure the relative motion of the pair but the motion of the secondary relative to a stationary primary. That calculation would assume that the proper motion of the primary is correct, which does not allow for checking errors in that proper motion (Dr. William I. Hartkopf, personal communication).

3. Place theta and rho in the Cartesian coordinate system and inspect a scatter plot of the converted measures.

Use the formulae:

$$x = -\rho\sin(\theta)$$

$$y = \rho\sin(\theta)$$

These values are also found in Table 2. Several Internet utilities exist that can make the conversion or they can be easily calculated. Conversion from polar to

Table 3: Rectilinear elements and informal errors for 05110+3203, STF 686AC.

WDS	Disc. Code	X_0	X_A	Y_0	Y_A	θ_1	ρ_0	T_0
05110+3203	STF 648AC	-1.8678	0.10796	7.6435	0.02661	193.7	7.87	1584.1
	Error	0.77	0.008	0.102	0.001	4.6	0.55	1.9
05110+3203	STF 648AD	5.98906	0.11482	-23.161	0.0288	14.5	23.92	1666
	Error	0.49594	0.00654	0.07365	0.00349	1.2	0.058	3.81

Cartesian coordinates allows use of least squares modeling and simple analytic geometry to study relative motion. Signs should be checked to insure that the converted coordinates are in the correct quadrant. The units of the axes are, conveniently, arcseconds. A simple inspection of a scatter plot of an optical pair such as STF 648AC reveals a linear series of plots with observations ordered by Epoch (Figure 1). This is typical of a pair where there is no significant measurement error. The greater the number of measures with error, the greater the scatter and in some cases, measures will have to be eliminated in order to estimate the rectilinear elements (for example, see Schlimmer, 2009a).

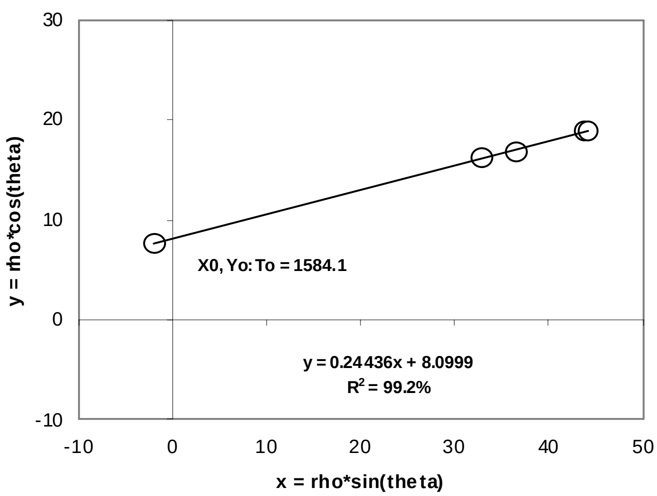


Figure 1: Relative motion of 05110+3203STF 648AC. X0 and Y0 were not included in the analysis and are included to show relative position of the primary and secondary at estimated closest approach. Rho0 is the distance from X0,Y0 to the origin. North is down, east is right.

4. Model the relationship between x and y using linear regression and save the residuals.

This takes the form of the familiar regression model:

$$y = mx + b$$

where y is the dependent variable, b is the intercept of the line through the y-axis, m is the slope of the line, and x is any value of the x variable. Excel has an easy to use regression analysis routine, but it does not calculate the regression model to the satisfaction of statisticians. For results that will be as close as possible to the CRE either a statistical package should be employed or the exact functions used in Excel. I used Minitab (V. 14; see Meyer and Krueger, 2004). Values of x are treated as the "independent" variable and those of y as the dependent variable. Regression results in the OLS (Y|X) regression were:

$$y = 0.24436x + 8.0999$$

The error of the slope is ±0.01532. The model is highly significant ($p = 0.006$) with a coefficient of determination (R^2) of 99.2%. A high value for the coefficient of determination is an indication that there is little scatter in the measures relative to the slope of the model. This would be typical of a pair where measurement error is low.

5. Inspect the behavior of residuals by regressing the residual measures against epoch of observation.

Even if you do not prune what seem to be erroneous measures, a plot of residuals against epoch of observation should show a random scatter of residuals

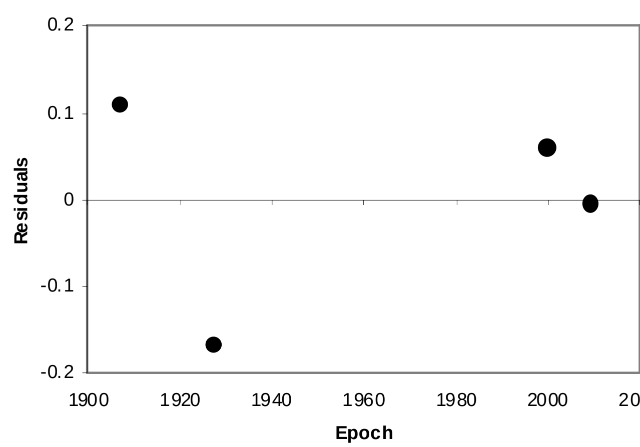


Figure 2: Regression of residuals derived from y on x regression of 05110+3203STF 648AC coordinates suggests no systematic deviation over time.

with an insignificant regression model (Figure 2).

6. Determine the (x,y) coordinates of the closest approach.

This is accomplished in two steps. First, determine a formula for a regression equation that is perpendicular to the calculated equation and that goes through the origin (the position of the primary). The slope is the "normal" of the calculated slope and is defined as (-1/*m*). Further calculations take advantage of the alternate form of the regression equation where (X_0, Y_0) are the coordinates at closest approach and (x_2, y_2) are the coordinates of the primary:

$$Y_0 - y_2 = (-1/m)(X_0 - x_2)$$

Since (x_2, y_2) is the position of the primary at the origin (0,0), then the formula simplifies to:

$$Y_0 = (-1/m)X_0$$

Simultaneously solve for X0:

$$mX_0 + b = (-1/m)X_0$$

Rearranged:

$$X_0 = -b/(m + 1/m)$$
$$X_0 = -8.0999/\left[0.24436 + (1/0.24436)\right]$$
$$X_0 = -1.86776$$

Substitute the value of X0 in the regression equation to solve for Y0:

$$Y_0 = 0.24436X_0 + 8.0999$$
$$Y_0 = (0.24436)(-1.86776) + 8.0999 = 7.64349$$

7. Determine ρ_0, the distance at closest approach.

To do this, use the distance formula:

$$d = \sqrt{\left(X_0 - x_2\right)^2 + \left(Y_0 - y_2\right)^2}$$

Since (x_2, y_2) is at the origin (0,0), the formula simplifies to

$$\rho_0 = \sqrt{X_0{}^2 + Y_0{}^2}$$
$$\rho_0 = \sqrt{(-1.86776)^2 + (8.0999)^2}$$
$$\rho_0 = 7.87 \text{ arcsec}$$

8. Calculate θ_0, the angle (PA) at closest approach.

This calculation requires some attention to the quadrant. An initial angle can be easily calculated by taking the tangent of a right triangle with opposite and adjacent sides corresponding to X_0 and Y_0:

$$\tan(\theta) = 1.86776/7.64349 = 0.23967$$
$$\theta = 13.7^\circ$$

The result assumes that the angle is in the first quadrant (+,+) measured from zero . However, (X_0, Y_0) is in the third quadrant. If we plot (X_0, Y_0) we see that it is about 14° west of south, so this angle is added to 180°.

$$\theta_0 = 13.7^\circ + 180^\circ = 193.7^\circ$$

9. Calculate T_0, the epoch of closest approach.

This calculation takes advantage of the formulas used in the CRE to calculate the ephemeris:

$$x = X_A(t - T_0) + X_0$$
$$y = Y_A(t - T_0) + Y_0$$

Calculation requires slopes X_A and Y_A, which are the slopes (*m*) of *x* versus Epoch and *y* versus Epoch respectively. For STF648AC values of X_A = 0.107959 and Y_A = 0.026608 were obtained. It is then a simple matter to substitute numbers for terms: pick an Epoch with (*x*,*y*) coordinates and solve the equation. The results are a function of the residuals, so I picked a recent measure with a small residual: 2009.152, with (*x*,*y*) = (44.230,18.903):

$$y = Y_A(t - T_0) + Y_0$$

Rearranged:

$$T_0 = \left(y - Y_A t - Y_0\right)/Y_A$$
$$T_0 = \left[18.903 - (0.026608 \bullet 2009.152) - 7.64349\right]/0.026608$$
$$T_0 = 1585.99$$

The other calculation, with X_A and X_0, resulted in T_0 = 1582.16; the difference of which I take as a measure of the range of the estimate and the average as the estimate of T_0. An alternative method, perhaps superior, would be to calculate a T_0-value for each observation and then take the average of all estimates.

10. Errors

Errors are a complex matter because the parameters estimated may fall outside the data. For example, calculating an error for time of closest approach is not intuitively obvious given that we are asked to calculate an error for the Epoch 1586 when our oldest measure is from Epoch 1907. The only errors easily derived from the analysis are the errors of X_A and Y_A, which are simply the errors of their respective slopes. Estimates of errors of X_0 and Y_0 are not intuitive. I have

Table 4: A comparison of rectilinear elements for three optical pairs using methods in the paper (EOW) and values from the Catalog of Rectilinear Elements (CRE). "D" is the absolute difference between the measures; other abbreviations as in the text. Numbers are rounded, R^2 varies between 97.5-99.9%. Note: the 1910.95 measure of 06553+1235 measure not included in EOW calculations due to high residuals.

	06553+1235 J273AC			01190-0856 ENG5			08453+4140 STF1263AB		
Element	**EOW**	**CRE**	**D**	**EOW**	**CRE**	**D**	**EOW**	**CRE**	**D**
X0	1.793	1.832	0.039	77.67	77.15	0.52	-1.993	-1.983	0.01
XA	0.0505	0.0515	0.001	0.229	0.232	0.003	0.2695	0.2751	0.006
Y0	2.14	2.26	0.12	39.393	39.447	0.051	-0.8556	-0.842	0.014
YA	-0.0422	-0.0417	0.001	-0.452	-0.453	0.001	-0.6272	-0.644	0.017
T0	2082.5	2088.7	6.2	1636.6	1637.3	0.7	1823.8	1822	1.8
Rho0	2.792	2.909	0.12	87.089	86.654	0.435	2.168	2.156	0.012
Theta0	140.1	140	0.1	117	117	0	293.7	293	0.7

chosen one approach, but I do not claim that the results are more than an informal estimate.

In Minitab one can calculate a predicted value of the dependent variable given the independent variable. The only true independent variable in the analysis is Epoch, so I performed OLS on X|Epoch and Y|Epoch and asked the program to predict X and Y respectively at time T_0. I took the difference between the predicted value derived from the respective analysis and the calculated value as a measure of error. It is then an easy matter to add (or subtract) the error to the calculated X_0 and Y_0-values, recompute ρ_0 and θ_0, and subtract the results from the original measures to obtain errors.

So, for example, the upper bound of ρ_0 was recalculated by adding the errors to the original X_0 and Y_0 and then using the new values to calculate a perturbated ρ_0. The difference between the original ρ_0 and the new value was taken as an error term. The error of T_0 is simply half of the difference between the estimates given above. The alternative would be to take the standard deviation of all estimates if T_0 is averaged over all observations.

Comparing the Protocol with Known Optical Pairs

I calculated elements for three pairs that appear in the CRE in order to access the validity of the protocol presented here. While a tiny sample, the results shown in Table 4 indicate that this method finds similar results using techniques available to amateurs as does the professional algorithm used by Dr. Hartkopf and colleagues at the USNO. They are not likely to be identical because elements in the CRE are based on a weighted analysis that takes into account the many factors considered in weighting orbital elements.

05110+3203STF 648AB, a Physical Pair

Intuitively, the relative motions of CPMs and binaries should yield different results from optical pairs since their motions are not rectilinear. Regression analysis of Cartesian coordinates (OLS $y|x$) of the 62 measures of STF 648AB resulted in a significant regression model (p <.05) but with little explanatory power (R^2 = 20.1%). The positions of the secondary relative to the primary are tightly clustered but show some indication of motion (Figure 3). The combination of tight clustering and low explanatory power suggests that this pair has a common origin and is either a CPM pair or perhaps a binary with a very long period. For this pair, the result is not surprising given the other physical data mentioned above.

Residuals derived from OLS $y|x$ of a CPM pair should show random residuals; changes of theta and rho should vary over time only as functions of measurement error. Residuals derived from OLS $y|x$ of a bi-

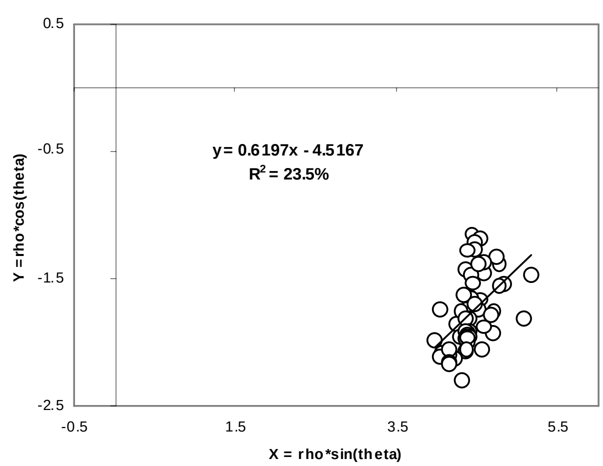


Figure 3. Relative motion of 05110+3203STF 648AB.

Relative Motion of the WDS 05110+3203 STF 648 System, ...

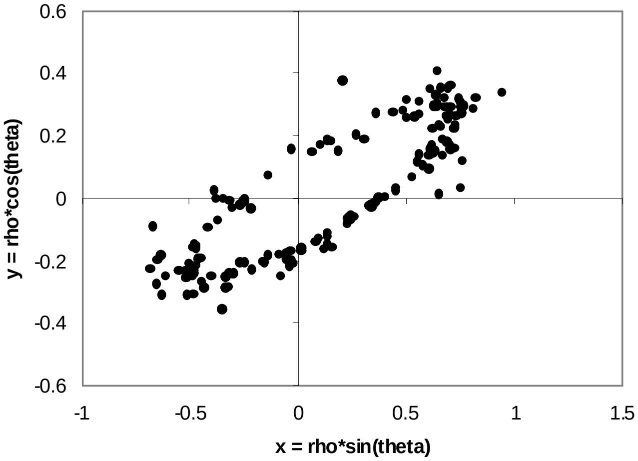


Figure 4. Scatter plot of relative motion of the binary 00373 -2446BU 395.

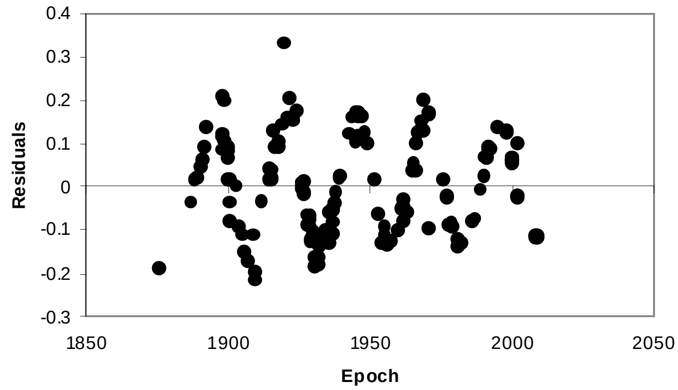


Figure 5: Regression of residuals versus Epoch of 00373-2446BU 395 shows systematic behavior and suggests orbital period of ca. 25 years over the history of observations.

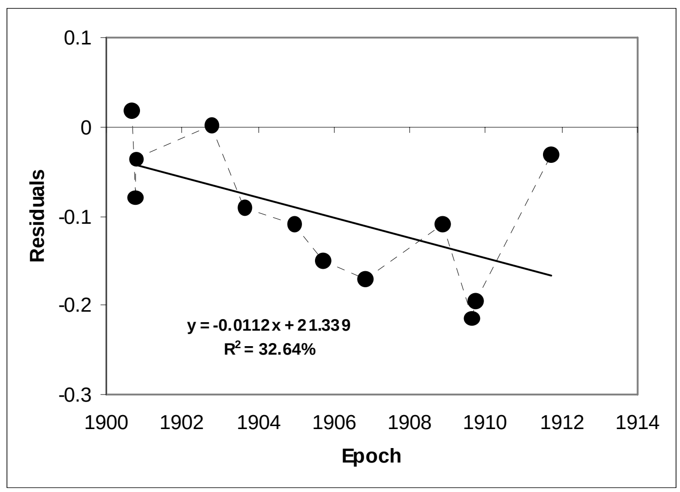


Figure 6: Residuals versus Epoch for the dates 1900.69 to 1911.73 for 00373-2446BU 395. This represents observations taken from approximately one-half of an orbit. Note the similarity in residual variation to 05110+3203STF 648AB in the next figure albeit over a much longer period of the orbit.

nary pair should show systematic, rather than random; changes of theta and rho over time would be functions of orbital motion (Aitken, 1935). To see if the techniques used here could uncover such behavior, I analyzed data for the known binary 00373-2446BU 395. The scatter plot is a nice picture of the orbital motion (Figure 4). Further, a plot of the residuals versus Epoch of observation shows the systematic variation of the residuals (Figure 5). One can even roughly estimate the orbital period of about 25 years. I then analyzed the residuals from only part of one orbit. This shows that the residuals display a non-random pattern of residual variation (Figure 6) with later measures following earlier measures in a coherent time series in the *y* versus *x* scatter plot. STF 648AB shows a similar non-random residual pattern (Figure 7). This suggests that STF 648AB may be binary albeit with a very long period. However, unlike BU 395, the order of measures in the *y* versus *x* scatter plot do not form a consistent time series (later dates do not always follow earlier dates along the apparent path), so the resulting non-random behavior of the residuals may simply be tracking noise. How to parse this out without using weighting functions will require study of additional pairs.

Discussion

In cases where the proper motions of a pair are known and different, classifying a pair as optical is trivial. However, there are many pairs for which the proper motion is known only for only one of the components. These techniques can be used to investigate such pairs. However, there are known caveats.

First, a true binary may display rectilinear motion if the companion is on one leg of a highly eccentric orbit. If the orbit is highly eccentric the residuals may not show systematic variation. This has long been recognized (e.g., Burnham, 1906; Hartkopf et al. 2008, CRE). Thus if other factors such as proper motion and parallax are similar, these data may trump the conclusion that the pair is optical based on relative motion studies. The second caveat was suggested by Dr. Hartkopf and concerns the geometry of approach. A direct approach along either of *x*-axis or *y*-axis will result in

Relative Motion of the WDS 05110+3203 STF 648 System, ...

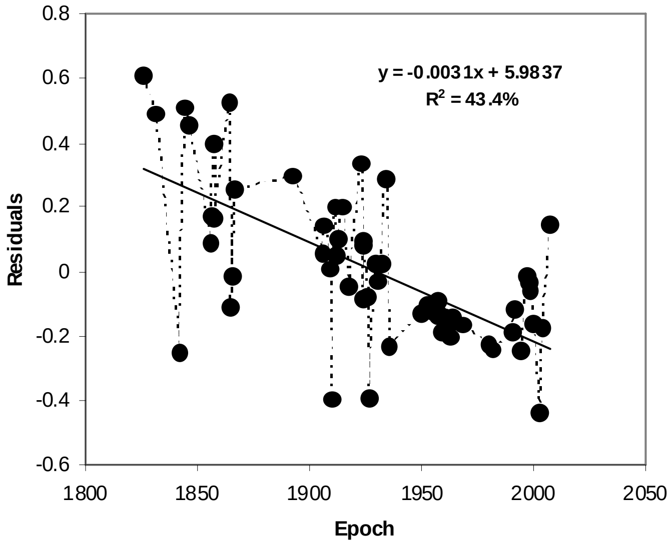


Figure 7: Regression of residuals versus Epoch for 05110+3203STF 648AB suggests systematic variation of residuals over time.

either a failure to model (direct approach along the y-axis) or a model of $y = 0$ (direct approach along the x-axis). I have not seen either geometries but they are sure to exist. θ_0 could be calculated based on a simple distance measure (how long to the origin given the relative motion), but ρ_0 and θ_0 would simply be "zero."

I am currently investigating the characteristics of common proper motion pairs and binaries using these techniques. What I am predicting is that (1) CPM pairs can be distinguished by $y|x$ scatter plots that are tightly clustered, regression models with low R^2, and with $y|x$ regression residuals that are random relative to epoch of observation and that (2) binaries with observations covering only part of their periods (that is, those not yet characterized as binaries) will have $y|x$ scatter plots correlated with the inclination of their apparent orbits, R^2-values related to the eccentricity of their orbits (e.g. a circular orbit would have a relatively low R^2 value), and OLS $y|x$ regression residuals that vary systematically.

Acknowledgements

Dr. Bill Hartkopf, U. S. Naval Observatory, has been very kind to take time out of his professional obligations to answer my email inquiries about calculating rectilinear elements and to provide a review of the original manuscript. I greatly appreciate his assistance. An anonymous reviewer made substantial contribution to sorting out how corrections should be made and Dr. Hartkopf provided guidance in helping me interpret the reviewer's comments. Sr. Francisco Rica Romero of LIADA kindly shared his Excel spread sheet that allows calculation of corrected angles and I look forward to his planned publication of his methods. Both Robert K. Buchheim and Dave Arnold provided valuable comments on an earlier version of the manuscript. Joerg S. Schlimmer was kind enough to answer questions about his analyses that have appeared in the JDSO. This research has made use of the Washington Double Star Catalog maintained at the U.S. Naval Observatory, including the WDS, the Sixth Orbital Catalog and the Catalogue of Rectilinear Elements. Resources of the CDS, Strasbourg, France (Bonnarel et al., 2000), used in this study include Aladin, POSS and 2MASS images, and the UCAC2.0 (Zacharias et al., 2004), USNO-B1.0 (Monet et al., 2003) and 2Mass (Skrutskie et al., 2006) catalogs. Thanks to Arnie Rosner and Brad Moore, Global Rent-A-Scope, (http://wiki.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. This project was partly supported by a matching grant of telescope time from Global Rent-A-Scope to the Remote Astronomical Society Observatory for astronomical research.

References

Aitken, R. G., *The Binary Stars*. Dover Publications, New York, 1964 (reprint of 1935 edition, McGraw-Hill).

Bonnarel, F., Fernique, P., Bienayme, O., Egret., D. Genova., F., Louys, M., Ochsenbein, F., Wenger, M., & Bartlett, J. G., 2000, *Astron. Astrophys., Suppl. Ser.* ***143**, 33-40.*

Burnham, S. W. *A General Catalogue of Double Stars Within 121° of the North Pole. Part II. Notes to the Catalogue*, Carnegie Institution, Washington, 1906.

Clark, R. K., Cunningham, J., Guidry, J., Pearce, J., Sanders, J. M. & Scarborough, T. 2005, *JDSO*, **1 (2)**, 44-48.

Feigelson, E. D. & Babu, G. J., 1992, *Astrophys. J.* **397**, 55-67.

Greaney, M., Some useful formulae, pp. 273-290, In: Argyle, B. (ed.). *Observing and Measuring Visual Double Stars*. Springer, NY, 2004

Relative Motion of the WDS 05110+3203 STF 648 System, ...

Hartkopf, W. I. & Mason, B. D., 2008 et seq., *Sixth Catalog of Orbits of Visual Binary Stars*, U. S. Naval Observatory, Washington, D. C. on-line.

Hartkopf, W. I., Mason, B. D., Wycoff, G. L. & Kang, D., 2008 et seq., *Catalog of Rectilinear Elements*. U. S. Naval Observatory, Washington, D. C., on-line.

Isobe, T., Feigelson, E. D., Akritas, M. G., & Babu, G. J., 1990, *Astrophys. J.*, **364**, 104-113.

Kharchenko, N. V., Scholz, R.-D., Piskunov, A. E., Roeser, S. & Schilbach, E., 2007, *Astron. Nachr.* **328**, 889.

Kiyaeva, O. V., Kiselev, A. A. & Izmailov, I. S. 2008. *Astro. Lttrs.*, **34**, 405-412.

Lewis, T., 1906, *Mem. RAS*, **56**, 1-715.

Mason, B. D., 2006, *JDSO*, **2(1)**, 21-35.

Meyer, R. K &. Krueger, D. D., *A Minitab Guide to Statistics (3rd ed.). Prentice-Hall, Upper Saddle River, New Jersey, 2004.*

Monet, D., Levine, S., Canzian, B., Ables, H., Bird, A., Dahn, C., Guetter, H., Harris, H., Henden, A. & et al., 2003. *Astron. J.* **125**, 984-993.

Rica Romero, F. M., 2000, (http://www.carbonar.es/s33/Articles/stf889English.PDF).

Schlimmer, J. S., 2009a, *JDSO* **5(1)**, 10-17.

Schlimmer, J. S., 2009b, *JDSO* **5(2)**, 102-111.

Skrutskie, M. F., Cutri, R. M., Stiening, R., Weinberg, M. D., Schneider, S., Carpenter, J. M., Beichman, Capps, C. R. & et al. 2006, *Astron. J.,* **131**, 1163-1183.

Tanguay, R. C. *The Double Star Observer's Handbook*. The Double Star Observer, Saugus, Massachusetts, 1998.

Torres, G., 1985, *Astron & Astrophysics Suppl. Ser.* **62**, 191-195.

Zacharias N., Urban, S. E., Zacharias, M. I., Wycoff, G. L., Hall, D. M., Monet, D. G., and Rafferty, T. J., 2004, *Astronom. J.* **127**, 3043-3059.

Ed Wiley teaches biology and studies the evolution of fishes at the University of Kansas. He has been an amateur astronomer since 1956. Ed works through the Remote Astronomical Society to promote the use of Global Rent-A-Scope facilities for astronomical research. http://wiki.global-rent-a-scope.com/RAS_MainPage.ashx

Visual Measurements of Double Stars with a NexStar 6 SE at the Pine Mountain Observatory Summer Research Workshop 2009

Austin B. Schrader
University of Oregon, Eugene, Oregon

Amanda M. Walker-LaFollette
South Eugene High School, Eugene, Oregon

Jolyon M. Johnson
California State University, Chico, California

Danyal J. Medley
Celestron, LLC

Russell Genet
Cuesta College, San Luis Obispo, California
California Polytechnic State University, San Luis Obispo, California

Abstract: As part of the Pine Mountain Observatory Summer Research Workshop 2009, high school and college students joined with an experienced double star observer and an engineer from Celestron to test a portable observatory utilizing a Celestron NexStar 6 SE with a Celestron Micro Guide eyepiece. This was the first time the students operated a telescope to make quantitative measurements, thus the secondary goal was to make the workshop an educational experience. The observations included a double star with a well known separation and position angle and then a neglected double star.

Introduction

This project was part of a research workshop held at Pine Mountain Observatory (PMO) near Bend, Oregon in July 2009 (B2009.543). The workshop observers, mostly students from various high schools and colleges, met with instructors at PMO for a weekend of learning and observation (Figure 1). Double stars were chosen as the primary research targets because of their suitability for student projects. They also offer students the opportunity to work cooperatively in groups.

The primary goal of this particular project was to evaluate the capabilities of a portable 6-inch telescope that can be used for scientific research primarily by students. The secondary goal was to allow the students to gain experience operating telescopes and to learn the specific techniques used to measure double stars. The final goal was to observe a neglected double star from the Washington Double Star (WDS) Catalog to make a modest contribution to double star research.

Equipment

The telescope used to make the astrometric observations was a Celestron NexStar 6 SE (SE 6). The SE 6 is an altitude-azimuth (alt-az) telescope with a 6-inch (150mm) f/10 Schmidt-Cassegrain optical tube assembly (OTA) with a 1500mm focal length. A standard tripod and integrated wedge were used to configure the SE 6 for equatorial use (Figure 2). A 1.25-inch Star Diagonal was also used.

The eyepiece used was a Celestron 12.5 mm illuminated Micro Guide eyepiece. The reticle contains two scales that were used for making observations. A 6mm scale with 60 divisions across the center and the large circular scale were used (see Figure 3 below). A

Figure 1: The observational team (left to right) consisted of Austin Schrader, a student at the University of Oregon in Eugene and a former student at St. Mary's School in Medford, Oregon, Russ Genet, the PMO Workshop Director, Dan Medley, Celestron's Principal Engineer, Jo Johnson, a PMO Workshop Instructor and student at California State University, Chico, and Mandy Walker-LaFollette a student at South Eugene High School in Eugene, Oregon.

Figure 2: The Celeston NexStar 6 SE mounted on a light tripod for easy portability with an integrated equatorial wedge.

stopwatch that reads out to the nearest 0.01 seconds was used to calibrate the linear scale.

Some equipment that was replaced on the NexStar 6 SE included the LED reflex finder. An Orion 9x50 right-angle finder was used instead. The 25mm standard plössl eyepiece was replaced with a 40mm eyepiece to make locating objects easier.

At points during the process of locating objects, TheSky 6 planetarium software was used to obtain visual references. A standard bound notebook, pen, and portable table were used for the annotation of the observations. A flashlight with a red filter was used to see at night and preserve night vision. A comfy chair made observations through the eyepiece easier, particularly near the zenith. A spreadsheet was used to calculate the average, standard deviations, and standard errors of the mean of the observations.

Methods

Before any observations or measurements were recorded, the Micro Guide eyepiece was calibrated. The team used the drift method to calculate the scale constant in arc seconds per division. The observers used a stopwatch to measure the time it took for a relatively bright star to travel across the linear scale. This was achieved by turning off the tracking motors once the star was on the east side of the linear scale, and turning them back on once the star reached the west side of

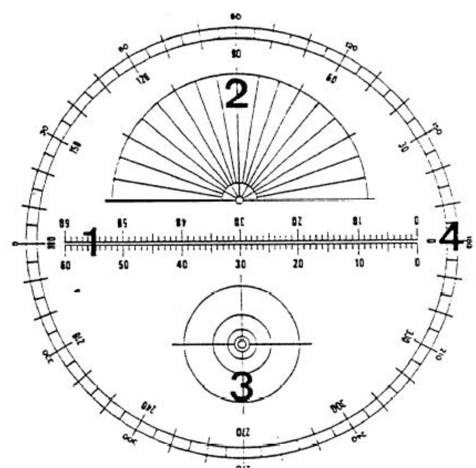


Figure 3: The four scales of the 12.5 mm Celestron Micro Guide eyepiece are (1) the linear scale, (2) the semicircular position angle scale, (3) the concentric guiding circles, and (4) the large circular scale. Only 1 and 4 were used.

the scale. The mean value of several trials was then taken and entered into the following equation to calculate the scale constant for the eyepiece (Teague 2004):

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

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, also known as the sidereal rate,
- t is the average drift time in seconds (recorded by the stopwatch),
- d is the declination of the star, and
- D is the number of divisions on the linear scale (60).

To determine the double star's angular separation, the observers aligned both of the stars on the linear scale. Using the Micro Guide eyepiece, the team oriented the stars in such a way that the positions of the two stars were clearly visible on the divisions of the linear scale. Each observer moved the telescope to view the stars at different points of the linear scale to reduce observational bias. The distance between the two stars was estimated by counting the number of divisions between the stars on the linear scale to the nearest tenth of a division (Teague 2004). In total, ten trials were taken. The data was then entered into a spreadsheet from which the average, standard deviation, and mean error were obtained and recorded.

The position angle was measured by meticulously placing the primary, or apparently brighter of the two stars, in the center of the eyepiece. It was crucial for the team to attain maximum accuracy with this step or the angle could be as much as five to ten degrees off. Once the primary star was properly aligned with the center of the eyepiece, the tracking motor was turned off. The observers then recorded the degree measurement where the primary star crossed the inner part of the large circular scale of the eyepiece (Teague 2004). The star was then realigned in the middle of the linear scale and the process was repeated until the team had ten trials. The data from the position angle measurements were entered into a spreadsheet and the statistical information calculated.

Results

The observers chose Alpha Cephei to calibrate the linear scale in arc seconds per division because of its optimal declination at 62.58°, not too close to the equator or pole (Teague 2004). The results of the drift and the scale constant calculation are shown in Table 1.

Table 1: Average drift time and calculated scale constant with standard deviations and standard errors of the mean.

	Average	St. Dev.	Mean Error
Drift Time (sec.)	105.96	1.68	0.56
Scale Constant (a.s./div.)	12.23	0.19	0.06

To test the methods of observation and practice making measurements, the team selected the well known double star Iota Boötis. This double star has a separation of 39.0" and a position angle of 32.5°. The team's measurements compared to the literature values are shown in Table 2.

Table 2: Measured values for Iota Boötis with standard deviation and standard error of the mean compared to literature values.

	Measured	Literature
Separation	38.7″	39.0″
St. Dev.	1.1″	
Mean Error	0.4″	
Position Angle	34.1°	32.5°
St. Dev.	1.1°	
Mean Error	0.4°	

The observed separation differs from the established value by 0.7%, while the measured position angle differed by -4.8%. Ronald Tanguay (1998), an experienced visual observer, states that, "Measurements within 5% of catalog values can be considered good..." and both the separation and position angle measurements were within the 5% discrepancy. With these results, the observers felt confident enough to measure a neglected double star from the (WDS) Catalog.

The double star ARY 52 (RA 15h 12.4m Dec 52° 56m) was selected because it was bright for a neglected double star, had a wide separation, and was measured recently (2005), thus giving it a higher probability of being found. Atmospheric conditions were less than optimal on the night of observation, so the stars appeared dimmer than normal. This was compounded by the LED light in the Micro Guide eyepiece that was bright enough that the star could not be seen. A method was created by Medley to compensate, particularly during the position angle measurement where the primary must be in the center of the linear scale. When the primary star was near the center of the eyepiece, the LED light was turned off and the telescope moved slightly to better center the star. The position of the star was remembered and the light turned back on to see if the star was in the center. This process was repeated until the star was in the exact center of the linear scale. Once the observers collected all of the data it was clear that one of the separation trials was a random outlier and was thus rejected. The results of the observations are shown in Table 3 along with catalog values.

Table 3: Measured values for ARY 52 with standard deviation and standard error of the mean compared to WDS Catalog values.

	2009	2005
Separation	149.1″	147.1″
St. Dev.	1.7″	
Mean Error	0.6″	
Position Angle	326.7°	331.0°
St. Dev.	1.1°	
Mean Error	0.3°	

The team's data shows a difference from the WDS Catalog value of the separation of 2.0 arc seconds, and a difference from the recorded value of the position angle of 5.3°. One reason the team's observations could have differed from the literature value is because of the poor seeing conditions. On the night of observation there were many high cirrus clouds drifting through the field of view and seeing was less than optimal. Also, it is possible that there was an imprecise alignment of the stars relative to the linear scale, which could have greatly affected the accuracy of the recorded position angle, even with good precision. Another possible source of discrepancy is the motion of the stars since the last data was taken in 2005.

Conclusions

The primary objective of this project was to test the equipment as a portable observatory. The observers found that setting up and polar aligning the telescope on the tripod was simple and could be done in a few minutes, and most importantly it was easy to move the telescope when needed. However, the equatorial wedge that was used was built into the tripod and was somewhat unstable. This meant that gusts of wind moved the stars enough to make measurements difficult. This has serious implications for CCD research using this set-up. In the future the team will use a more stable wedge that can be fixed on the tripod. Also, there was a significant amount of backlash that made centering the stars difficult. This was overcome by using a feature of the Celestron hand control that allows quick bursts of fast slewing when centering a star at a slower rate. When using a given direction button, pressing the opposite button at the same time activates the faster slewing rate. Using this feature made working through the backlash more tenable when having to change directions for centering.

In the future, the team also plans to try different ways of dimming the reticule. One way to do this is to use a weaker battery or letting the battery drain down before use. This is not desirable as a sub-goal of the portable observatory is to be inexpensive and buying many batteries would undermine this feature. Perhaps a more suitable way to dim the reticule is to put a piece of toilet paper in to cover the LED. This was attempted by Howard Banich, another observer at the PMO workshop, using a 28-inch alt-az telescope. While he succeeded in dimming the light, the numbers on the outermost ring of the large circular scale were obscured and almost illegible. As the observers were using a Schmitt-Cassegrain telescope with a right-angle eyepiece, this would not have been an issue since the inner ring was used for that configuration. However, this can be compensated for by Newtonian observers as well by using the inner ring and making a 180° correction when calculating the position angle. One other option suggested by PMO instructor Richard Berry is to replace the red LED with a weak green LED.

The second objective was to instruct students in the proper use of telescopes as well as the proper techniques used to measure double stars. The students demonstrated the ability to manipulate the telescope during polar alignment and the centering of the stars as well as rotating the eyepiece to take the necessary measurements.

They also learned to deal with the frustrations associated with astronomy, including staying up late, slewing a telescope with notable backlash, and making tedious observations. They participated in data reduction, scale constant calculations, and statistical analysis. The students were particularly surprised by the determination of the separation. It was hard for them to imagine that the number of divisions separating the stars would appear different each time they looked through the telescope.

Perhaps the most crucial piece of the science puzzle is communicating results so that other scientists can use the data gathered and repeat the experiment. The students gained experience writing a scientific paper during the workshop and presented the paper at a symposium before their peers. Each student was assigned a section of the paper and helped to meld the sections together to avoid redundancy. Once the paper was done, the students found the experience of critical reviews particularly beneficial. One lesson they learned was that a reviewer's suggestions are not to be taken as insults. In fact, the more critical and specific reviewers are, the more useful their comments can be.

The final goal was to research a neglected double star. The observations made in this study differ from the 2005 observations by more than the calculated standard deviation. This discrepancy may be due to several factors including weather, experience, and the motions of the stars. Because of the large differences in proper motion vectors and trigonometric parallaxes noted by Frey et al. 2009, the authors were also able to conclude that the double star is optical rather than binary in nature.

Acknowledgments

Our team would like to thank Thomas Frey, Professor Emeritus of Chemistry at California Polytechnic State University (Cal Poly), for suggesting known and neglected double stars for us to observe and record and for reviewing this paper. Thanks go to Gregory Bothun, Director of Pine Mountain Observatory for allowing us to use their facilities. Thanks also go to Vera Wallen and Dave Arnold for reviewing this paper. Special thanks to St. Mary’s School in Medford, Oregon and South Eugene High School in Eugene, Oregon for their participation and encouragement.

References

Frey, T. et al., “Visual Measurements of the Neglected Double Star ARY 52 at Pine Mountain Observatory’s Summer Science Workshop.” (2009).

Mason, Brian, The Washington Double Star Catalog. July 2009, Astrometry Department, U.S. Naval Observatory, http://ad.usno.navy.mil/wds/wds.html.

Tanguay, Ronald, *The Double Star Observer’s Handbook*, Saugus, MA: Double Star Observer (1998).

Teague, Tom, “Simple Techniques of Measurement”, *Observing and Measuring Visual Double Stars*, Ed. Bob Argyle, London: Springer (2004).

Austin Schrader graduated from St. Mary’s School in Eugene, Oregon after having participated in their astronomy program. He now attends the University of Oregon. Amanda Walker-LaFollette attends South Eugene High School and plans to attend a university majoring in Physics or Astronomy. She was a volunteer during summer 2009 at Pine Mountain Observatory. Jolyon Johnson is a transfer student from Cuesta College in San Luis Obispo, California to California State University, Chico, majoring in Geology. He is the Science Advisor for Orion Observatory in Santa Margarita, California and was an instructor for the Pine Mountain Observatory Summer Research Workshop 2009. Danyal Medley is the Principal Engineer for Technology at Celestron, where he has worked for seven years. He has been an avid amateur astronomer for 14 years and is interested in both recreational and scientific astronomy. Russell Genet is the Director of Orion Observatory and Director of the Pine Mountain Observatory Summer Research Workshop 2009. He is also a Research Scholar in Residence at California Polytechnic State University and a Professor of Astronomy at Cuesta College in San Luis Obispo, California.

Astrometric Measurements of the Visual Double Star H 5 12AB

Chris Estrada
Allen Hancock College, Santa Maria, CA

Jolyon Johnson
California State University, Chico, CA

Eric Weise, Jonny Fisher, Tanner Howard, Akash Salam,
Arroyo Grande High School, Arroyo Grande, CA

Chris, Almich
California Polytechnic State University, San Luis Obispo, CA

Doug Kessinger, Stephanie Cavanillas, Tim Matakovich, Kendra Maly, Vera Wallen
Cuesta College, San Luis Obispo, CA

Russell Genet
California Polytechnic State University, San Luis Obispo, CA
Cuesta College, San Luis Obispo, CA

Abstract: As part of the fall 2009 astronomy research seminar at Cuesta College, high school and undergraduate students made observations of the visual double star H 5 12AB. They measured the angular separation to be 40.4" with a standard deviation of 4.6". They measured the position angle to be 44° with a standard deviation of 3°. The students then determined that the double star is likely gravitationally bound because the proper motion vectors of the primary and secondary stars only differ by ~2.5°.

Introduction

The fourth fall 2009 astronomy research seminar at Cuesta College consisted of students from Arroyo Grande High School, California Polytechnic State University, Cuesta College, Hancock College, and University of California, Chico. They met with the instructor, Genet, at Cuesta College for observation planning and guidance. Some students with prior experience in measuring double stars acted as team leaders to the students making their first quantitative measurements (Genet et al 2010).

This project had three goals in mind:

1) Give new students the opportunity to make their first quantitative measurements while providing returning students with the opportunity to lead the project. Visual double stars make ideal targets for students because the concepts are relatively straightforward, the equipment is affordable, and the skills they learn—quantitative statistical analysis, experiencing the peer review process, publishing a paper in a journal, and reporting their results at a symposium—are directly applicable to masters theses and doctoral dissertations (Johnson 2008).

2) Contribute observations of a double star. The students chose H 5 12AB because of its ideal location in the sky (RA: 01h 57m 55.71s Dec: +23° 35m 45.8s) and its relatively bright primary and secondary magnitudes (4.8 and 6.65, respectively).

3) Use proper motion vectors to determine if the double star is an optical pair or a gravitationally bound binary system.

Equipment and Procedure

Estrada provided a 10-inch, f/6 German equatorial mounted reflector with a tracking motor. A Celestron 12.5mm Micro-Guide eyepiece was used for all observations. Drift timings were made with a stopwatch

Figure 1: Research seminar students and instructor pose during their analysis of the double star data. An outline of a research paper can be seen on the whiteboard behind them.

which read to 0.01s. All observations were made on October 25, 2009 (B2009.8153) at Weise's parent's property east of Arroyo Grande.

Calibration

The observers calibrated the linear scale of the eyepiece once Estrada polar aligned the telescope. The observers selected a star with a declination between 60° and 75° so it would not drift either too slowly or too quickly to get a precise time (Teague 2004). The star was set at the east end of the field of view and was allowed to drift parallel to the linear scale when the right ascension motor was turned off. Each observer started the stopwatch when the star hit the first division and ended it when the star hit the last division. The students made 14 trials and recorded the time to the nearest 0.01s. The times were averaged and used in the equation:

$$Z = \frac{15.0411\,t\cos\delta}{60}$$

where Z is the scale constant in arc seconds per division, 15.0411 is the number of arc seconds per second that the Earth rotates, t is the average time it took for the star to drift across the linear scale, δ is the declination of the star, and 60 is the number of divisions along the linear scale.

The students used β Cassiopeia which has a declination of 59° 08m 59s. The average drift time was 104.86 seconds. This yielded a scale constant of 13.48"/div with a standard deviation of 0.08"/div and a standard error of the mean of 0.02"/div.

Separation

To measure the angular separation, the observers aimed the telescope at the target star and rotated the eyepiece so the linear scale was parallel to the double star. The observers counted the number of divisions to the nearest 0.1 division and recorded the trial. To reduce observing bias, the telescope was moved so that the primary star was at a different spot along the linear scale after each trial (Frey 2010). The number of divisions for each trial was then multiplied by the scale constant (Z) to determine the angular separation in arc seconds. 14 trials were made with an average of 40.4", a standard deviation of 4.6", and a standard error of the mean of 1.2".

Position Angle

The position angle was measured using the drift method (Teague 2004) where the primary star was positioned in the exact center of the linear scale. The eyepiece was rotated so that the secondary star was on the linear scale. The right ascension motor was then turned off and the star drifted to the outer protractor in the eyepiece. The angle that the primary star passed was estimated to the nearest degree and recorded. 14

Figure 2: Vera Wallen looks through Chris Estrada's telescope at dusk.

Astrometric Measurements of the Visual Double Star H 5 12AB

Figure 3: Chris Estrada, Vera Wallen, and Eric Weise look at star charts to find H 5 12AB.

trials were made with an average of 224° with a standard deviation of 3° and a standard error of the mean of 1°. The students later applied the position angle correction for the Celestron eyepiece (Teague 2004), giving a final position angle of 44°.

Analysis and Discussion

The measured separation of 40.4" was 3.3" (8.2%) more than the last reported value of 37.1" (Mason 2010) and within the standard deviation of 4.6". The measured position angle of 44° was 3° less than the last reported value of 47° (Mason 2010), one standard deviation less.

The proper motion vectors reported in the Washington Double Star (WDS) Catalog show that the primary star is moving -92 milli-arc seconds per year in right ascension and -14 milli-arc seconds per year in declination. The secondary star is moving -91 milli-arc seconds per year in right ascension and -18 milli-arc seconds per year in declination. This difference of only ~2.5° strongly suggests that the two components are moving together in space as a gravitationally bound binary system (Arnold 2010).

In completing this project, the students learned how to set up and operate a telescope and measure double stars. In this effort, they dealt with many of the challenges facing astronomers including unusually cold, late nights, re-weighting a telescope to compensate for backlash, and star hopping to their target. They also calculated the scale constant and conducted a statistical analysis of their data, each of which applied mathematics they learned in school. Finally, the project allowed the students to communicate their results both through writing a scientific paper and presenting their results at a special seminar where both students and teachers heard their presentation.

References

Arnold, Dave. 2010. Considering proper motion in the analysis of visual double star observations. In *Small Telescopes and Astronomical Research*, eds. R. Genet, J. Johnson, V. Wallen. Santa Margarita, CA: Collins Foundation Press.

Frey, Thomas G., Johnson, Jolyon M., Almich, Christopher J., and Genet, Russell M. 2010. Visual double star measurements with equatorial and alt-azimuth telescopes. *Amateur Astronomy*, 66.

Genet, Russell M., Johnson, Johnson M., Wallen, Vera. 2010. One-semester astronomical research seminars. In *Small Telescopes and Astronomical Research*, eds. R. Genet, J. Johnson, V. Wallen. Santa Margarita, CA: Collins Foundation Press.

Johnson, Jolyon M. 2008. Double star research as a form of education for community college and high school students. In *Proceedings for the 27th Annual Conference for the Society of Astronomical Sciences*, eds. B. Warner, J. Foote, D. Kenyon, and D. Mais.

Mason, Brian. 2010. *The Washington Double Star Catalog*. Astronomy Department, U.S. Naval Observatory. http://ad.usno.navy.mil/wds/.

Teague, Tom. 2004. Simple techniques of measurement. *Observing and Measuring Visual Double Stars*, ed. Bob Argyle. London: Springer.

Chris Estrada is a bio-chemistry major at Allen Hancock College. Jolyon Johnson is a geology major at California State University, Chico, and was a science advisor for the research seminar. Eric Weise, Jonny Fisher, Tanner Howard, and Akash Salam are students at Arroyo Grande High School. Chris Almich is majoring in physics and minoring in astronomy at California Polytechnic State University. Doug Kessinger, Stephanie Cavanillas, Tim Matakovich, and Kendra Maly are students at Cuesta College. Vera Wallen is a retired superintendent of schools taking classes at Cuesta College. Russell Genet led the research seminar and is a Research Scholar in Residence at California Polytechnic State University and an astronomy instructor at Cuesta College.

Journal of Double Star Observations

July 1, 2010
Volume 6, Number 3

The Journal of Double Star Observations is an electronic journal published quarterly by the University of South Alabama. Copies can be freely downloaded from http://www.jdso.org.

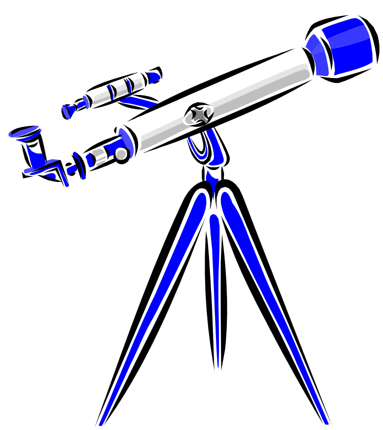
Questions, comments, or submissions may be directed to rclark@jaguar1.usouthal.edu or to rmollise@bellsouth.net

The *Journal of Double Star Observations* (*JDSO*) publishes articles on any and all aspects of astronomy involving double and binary stars. The *JDSO* is especially interested in observations made by amateur astronomers. Submitted articles announcing measurements, discoveries, or conclusions about double or binary stars may undergo a peer review. This means that a paper submitted by an amateur astronomer will be reviewed by other amateur astronomers doing similar work.

Not all articles will undergo a peer-review. Articles that are of more general interest but that have little new scientific content such as articles generally describing double stars, observing sessions, star parties, etc. will not be refereed.

Submitted manuscripts must be original, unpublished material and written in English. They should contain an abstract and a short description or biography (2 or 3 sentences) of the author(s). For more information about format of submitted articles, please see our web site at www.jdso.org

Submissions should be made electronically via e-mail to rclark@jaguar1.usouthal.edu or to rmollise@bellsouth.net. Articles should be attached to the email in Microsoft Word, Word Perfect, Open Office, or text format. All images should be in jpg or fits format.



We're on the web!

http://www.jdso.org