Measurements of Double and Multiple Stars in the Southern Sky in 2002 Using an 8-Inch Schmidt-Cassegrain and a CCD Video Camera.

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Abstract: Measurements of 69 double and multiple star systems at the southern sky made in fall 2002 are presented. The telescope was a C8 Schmidt-Cassegrain equipped with a CCD video camera. The best frames from video recordings were digitized and stacked in a computer. With this method, error limits of ± 0.1 arcsec for separations and less than ± 0.5 degrees for the position angles, depending on the separation, were obtained. The image scale was calibrated with selected reference systems.

Introduction

Among various methods for measuring double stars, video imaging and digital processing offers the possibility to significantly reduce seeing effects, and push the accuracy towards the limits of the telescope. I have already described this technique in detail in earlier papers [1,2]. As a result, using modest amateur telescopes with focal lengths greater than about 2 m, and after careful calibration, the accuracy of separation measurements can be better than ± 0.1 arcsec even under only mediocre seeing conditions. In the following, measurements of double star systems at the southern sky are presented, which were obtained with an 8 inch/f10 telescope at a guest farm in Namibia in September 2002.

Equipment and image processing

A CCD video camera (STV, Santa Barbara Instruments Group) was attached to an 8-inch Schmidt-Cassegrain (C8) telescope via a 2x-Barlow lens and a filter wheel. Filters were of additive, dichroic type (Edmund Scientific Co.) with infrared transmitting above wavelength 700 nm, red above 600 nm, green between 500 and 575 nm, and blue below 500 nm. Exposure times were in the range from 1 ms to 2.2 s per frame, depending on the star brightness and on the seeing. For each setting, i.e. filter and exposure time, image sequences of up to several minutes were stored on tape with a compact digital recorder (Sony GVD 900). Back home, the video sequences were loaded into a computer, and the best frames were selected, registered and stacked. Care was taken in selecting appropriate frames, as seeing effects often make it difficult to judge the quality of individual frames. When images had been recorded under fair seeing conditions and at lower magnifications, 16 good frames were usually found to sufficiently reduce the background noise and to yield reasonably well defined star images. This number was increased to 64 or even 128, when high magnifications were used for close pairs, and/or the seeing less than optimum.

The STV camera is equipped with a CCD chip with 656x480 pixels of size 7.6 µm square, which can be used unbinned ("zoom mode"), or binned 2x2 ("normal"), or 3x3 ("wide field"). Without binning, at a focal length of about 2000 mm and the Barlow lens inserted, the resolution is 0.38 arcsec/pixel per chip. I used the PAL standard video output of the STV camera, which provides a nominal resolution of 720 pixels/line and 576 visible lines. Digitization with 768x576 pixels results in a resolution of 0.189 arcsec/pixel in zoom mode in the final images (see below in sec. III). This figure is multiplied by 2 or 3 in normal and wide field mode, respectively. In most cases, the digital images were re-sampled during stacking by multiplying the number of pixels by 2x2 or sometimes even by 4x4. This resulted in a substantial improvement of the image definition, e.g. the intensity profile of the star images. A number of representative greyscale images are shown in plates 1a and 1b, which are all obtained with a red filter. A few color images are collected in plate 2. These are produced by composition of individual b/w images taken with red, green, and blue filters. In order to take into account the uneven spectral sensitivity of the camera, exposure times were set to about 1.5 times for green, and 2 times for blue, as referred to

red. This generally resulted in a fair rendition of the expected colors. Problems arise for systems with large differences in magnitudes. Either the brighter member is overexposed, or the color of the dimmer one is shifted. See also the remarks following table 2 below.

Star positions and separations were measured from the pixel coordinates of the central peaks of the star images. However, the vertical scale in the images was found to be contracted by about 8% in zoom and normal modes, and by about 11% in wide field mode. This is apparently an artifact of the digital-to-video conversion and requires corresponding corrections in the calculations. Position angles were measured by referring to the east-west direction, which was determined from superpositions of star images recorded while the telesope drive was switched off.

Calibration

Calibration of the image scale was done using 19 selected reference systems, which are contained in table 1 below and marked by shaded lines. These are all known as relatively fixed ("relfix" in Burnham´s Celestial Handbook [3]). However, some systems have nevertheless shown slight variations of separation (ρ) and position angle (PA) in the past. In such cases, data from the literature have been extrapolated to the epoch 2002. Main sources of literature data were the Washington Double Star catalog (WDS) [4], the 4th Catalog of Interferometric Measurements of Binary Stars (INT4) [5], the 6th Catalog of Orbits of Visual Binary Stars (ORB6) [6] and the Sky Catalogue 2000.0 [7].

The image scale was adjusted with an iterative method such that the average of the differences between measured and published/extrapolated separations (residuals) became virtually zero. This resulted in a calibration constant of 0.189 arcsec/pixel for zoom mode with Barlow, as was already mentioned above. The scatter of this data, as well as of all other measured systems, is shown in fig. 1 a) below. For only the reference systems, the standard deviation of ρ is ± 0.4". Individual error margins are about ± 0.1".

The residuals of the position angles are plotted in fig. 1 b. While for most of the reference systems deviations are less than ± 1 °, some are much larger for unknown reasons, e.g. for nos. 8 (HJ 3750), 13 (γ2 Volantis), and 62 (α1 Capricorni). However, this is not important for the image scale. On the basis of the thus determined calibration constant, the separations of the reference systems as well as of all other systems were calculated. The results, together with the measured position angles, are listed in table 1.

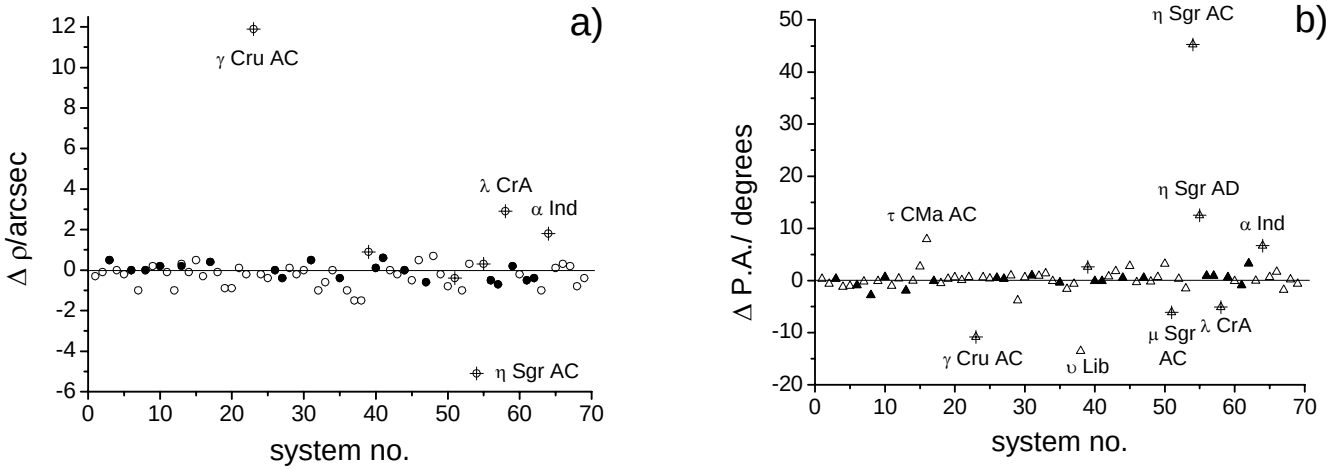

Figure 1. a): Plot of the residuals of the separations of all measured systems. Solid circles refer to relfix systems used for calibration, open circles refer to all other systems, circles with crosses mark systems with old reference data from between 1879 and 1965 (see below in notes to table 1).

b): Plot of the residuals of the position angles of all measured systems. Solid triangles refer to relfix systems used for calibration, open triangles refer to all other systems, triangles with crosses mark systems with old reference data as in a).

Systems exhibiting exceptionally large deviations are marked with their common names.

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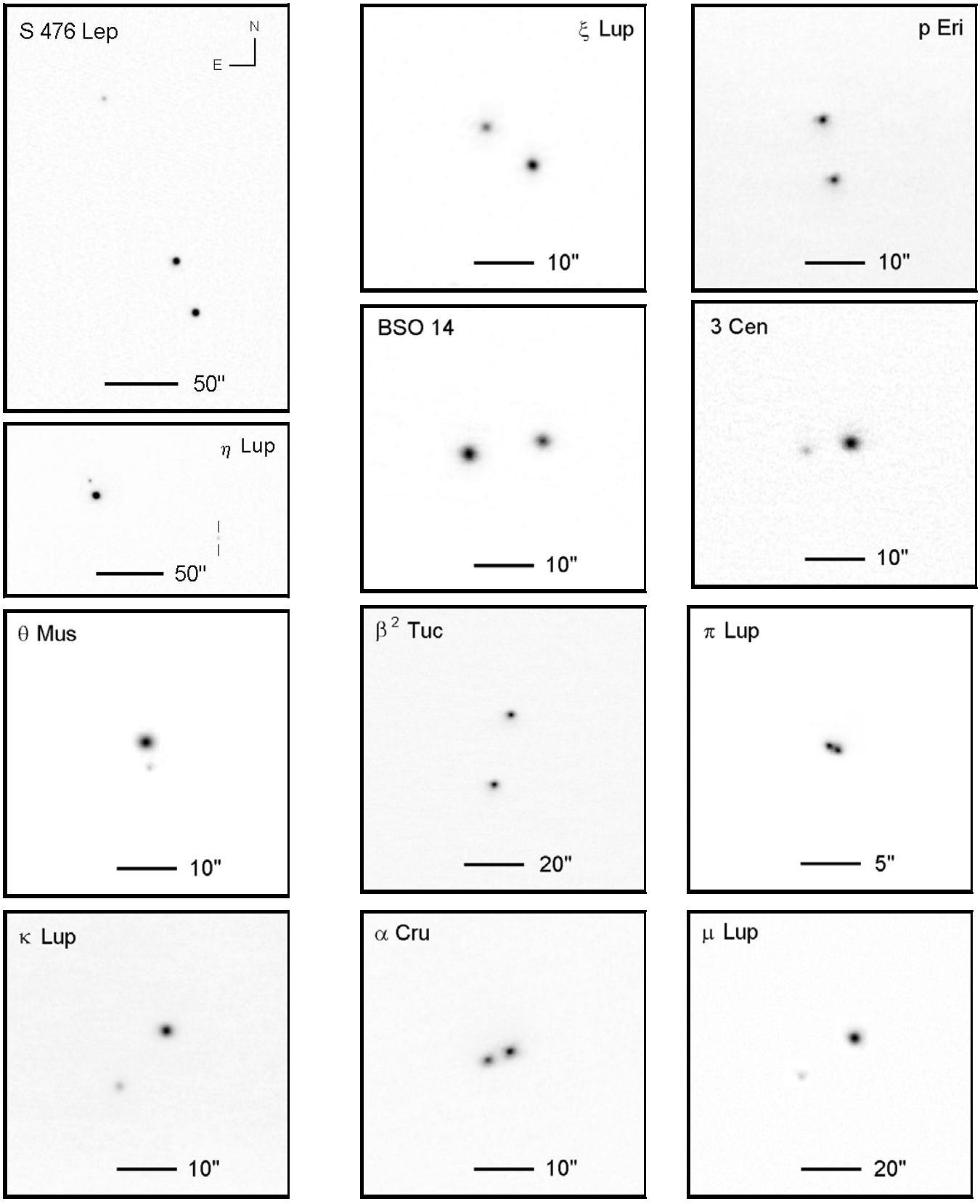

Plate 1A: Selected images of double and multiples stars in the Southern sky.

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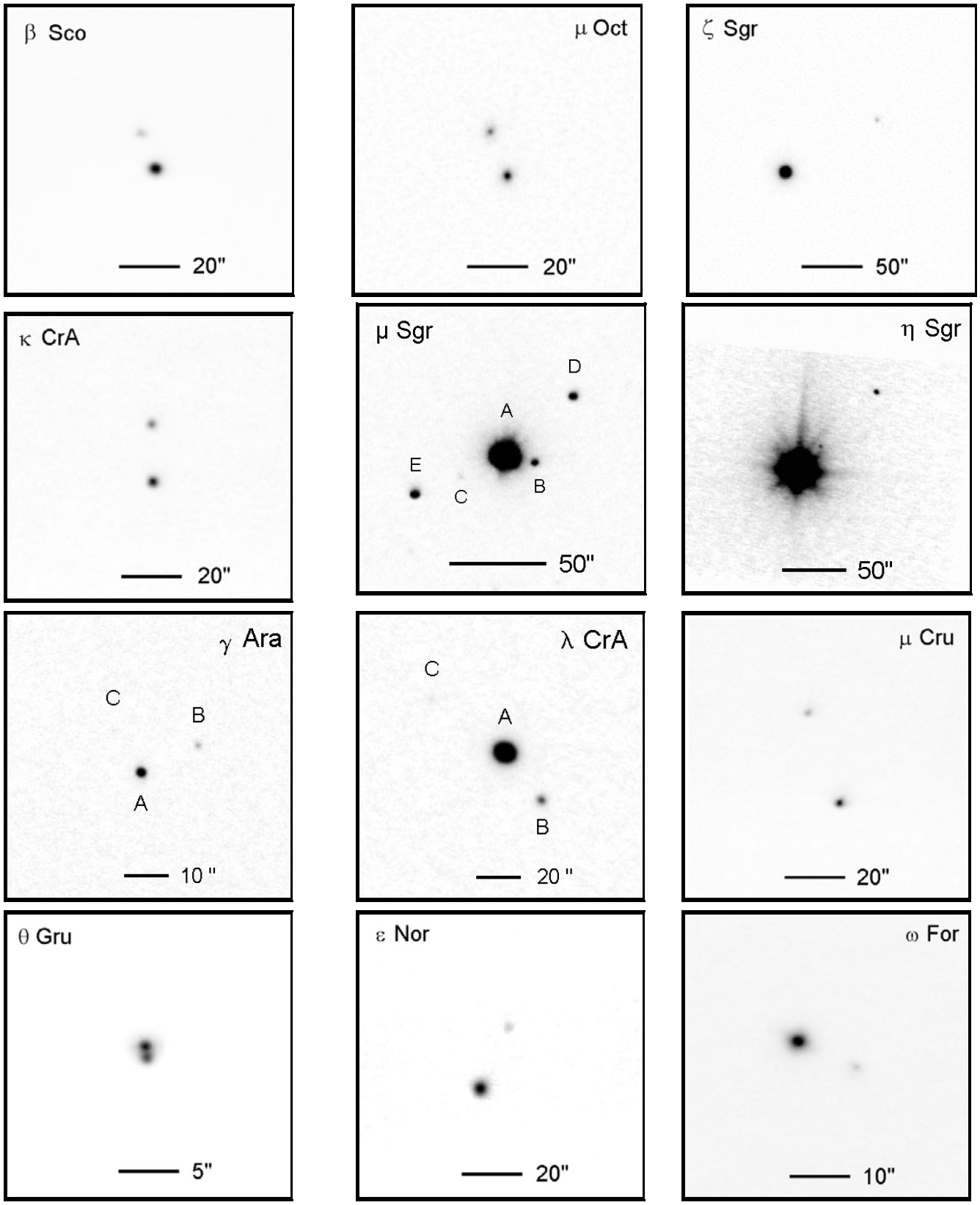

Plate 1B More images of double and multiples stars in the Southern sky. In all images North is up and East is left (chart view).

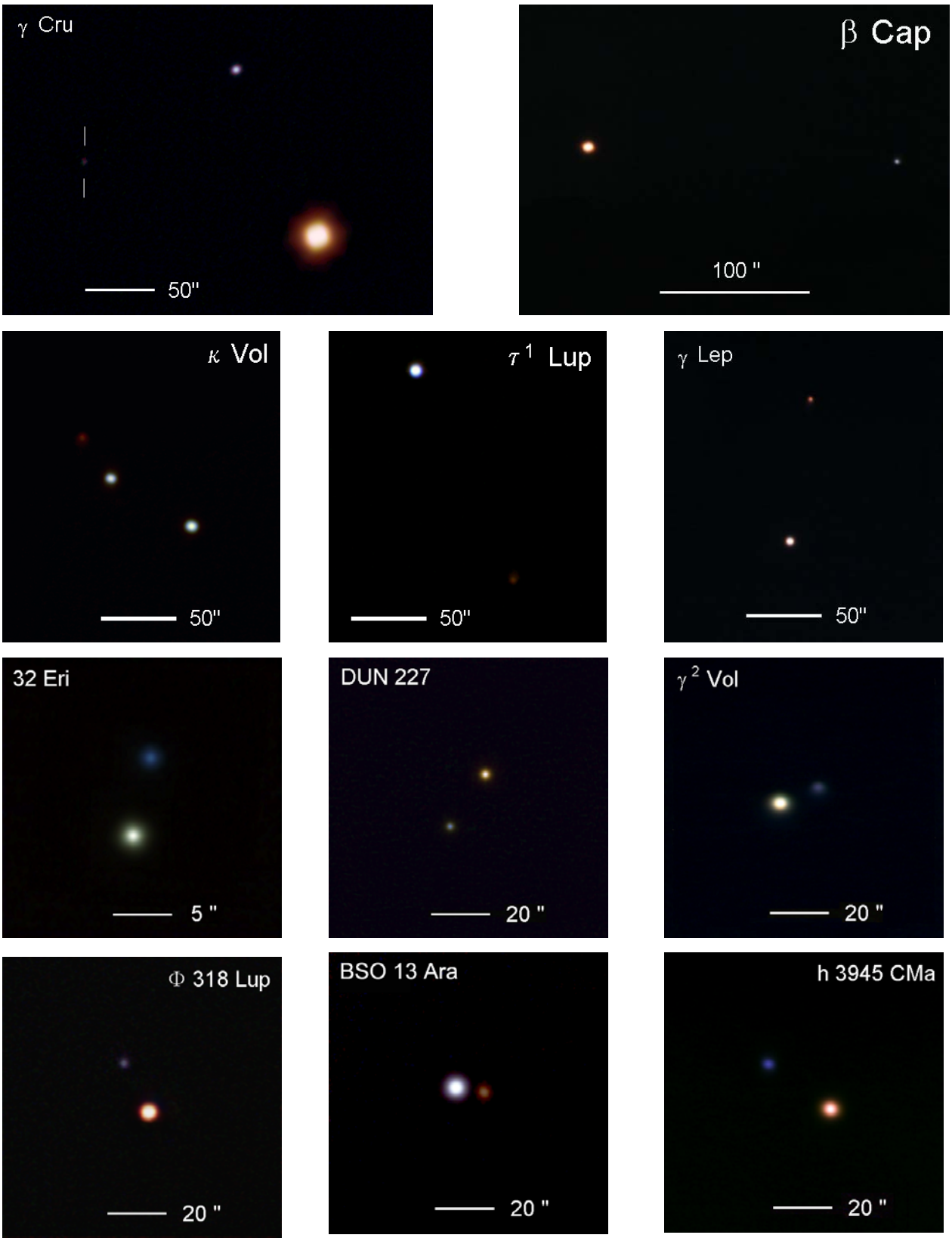

Plate 2: RGB images of double and multiple stars in the southern sky. Orientation as in Plate 1B.

Remarks on color images

For selected systems, differences Δm of the magnitudes of companions A and B in these spectral regions were calculated from the ratios of the integrated pixel values I of the individual star images (after subtraction of the background), using the relation $\Delta m = -2.5\log(I_A/I_B)$. As an example, the results for the system 32 Eridani (see plate 2) were –2.37 for infrared, -2.07 for red, -1.42 for green, and –0.76 for blue. The value for green compares reasonably well with the difference of –1.1 in the visual magnitudes of the pair of 4.8 and 5.9, respectively, as given in the WDS, and even better with the value –1.3, resulting from magnitudes 4.8 and 6.1, as given in the Sky Catalogue 2000.0 [7].

Table 1: List of measured double and multiple star systems. Systems used as reference for calibration of the image scale are marked by shaded lines. Position data are for epoch 2000.0, as listed in the WDS. Magnitudes are also adopted from the WDS. Own measurements of the separations are the result of an iterative procedure, as is explained in the text. Position angles (PA) are given in degrees, separations (ρ, rho) in arcsec. Columns PA ref. and ρ ref. contain reference data taken from the literature (see text). PA values given with one decimal digit are adopted from the INT4. Figure n means the number of measurements with different camera settings or with different filters (R, G, B, and sometimes IR). In the two columns before the last, differences Δ of own measurements minus the respective reference values are given. All measurements and reference data are rounded to one decimal digit.

NAME	RA+DEC	MAGS	PA meas.	ρ meas.	DATE	N	PA ref.	ρ ref.	Δ PA	Δ SEP	NOTES
LCL 119 AC	00315-6257	4.28,4.51	168.3	26.6	2002.688	2	168	26.9	0.3	-0.3	1
DUN 5	01398-5612	5.78,5.90	189.7	11.4	2002.693	1	190.3	11.5	-0.6	-0.1	2
HJ 3506	02338-2814	4.95,7.71	245.3	11.1	2002.693	1	245	10.6	0.3	0.5	3
HJ 3555	03121-2859	3.98,7.19	297.8	4.96	2002.693	1	299.0	4.9	-1.2	0	4
STF 470 AB	03543-0257	4.80,5.89	347.3	6.7	2002.693	4	348.3	6.9	-1.0	-0.2	5
S 476 AB	05193-1831	6.31,6.48	18.1	39.5	2002.693	1	19	39.5	-0.9	0	6
STU 20 AC	05193-1831	6.31,9.57	20.8	166.1	2002.693	1	21	167.1	-0.2	-1.0	7
HJ 3750	05204-2114	4.7,8.5	277.2	4.1	2002.693	4	280	4.1	-2.8	0	8
H 6 40 AB	05445-2227	3.64,6.28	349.9	97.1	2002.693	3	350	96.9	-0.1	0.2	9
STF 997 AB	06561-1403	5.27,7.14	343.7	3.0	2002.688	2	343.0	2.8	0.7	0.2	10
STF 997 AC	06561-1403	5.27,10.32	287.0	86.5	2002.688	1	288	86.6	-1.0	-0.1	11
STF 997 AD	06561-1403	5.27,10.64	63.4	103.8	2002.688	1	63	104.8	0.4	-1.0	12
DUN 42	07087-7030	3.86,5.43	296.1	14.4	2002.699	3	298.0	14.1	-1.9	0.3	13
HJ 3945	07166-2319	5.00,5.84	52.0	26.7	2002.699	4	52	26.8	0	-0.1	14
H 3948 AB	07187-2457	4.42,10.2	92.7	8.6	2002.699	1	90	8.1	2.7	0.5	15
H 3948 AC	07187-2457	4.42,11.2	86.9	14.2	2002.699	1	79	14.5	7.9	-0.3	16
H 3948 AD	07187-2457	4.42,8.22	76.9	84.8	2002.699	1	77	84.4	-0.1	0.4	17
BRSO 17 AB	08198-7131	5.31,5.59	57.5	64.7	2002.699	4	58	64.8	-0.5	-0.1	18
BRSO 17 AC	08198-7131	5.31,9.5?	48.3	98.8	2002.699	4	48	99.7	0.3	-0.9	19
BRSO 17 BC	08198-7131	5.59,7.67	31.6	36.7	2002.699	4	31	37.6	0.6	-0.9	20

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NAME	RA+DEC	MAGS	PA meas.	ρ meas.	DATE	N	PA ref.	ρ ref.	Δ PA	Δ SEP	NOTES
DUN 252 AB	12266-6306	1.25,1.55	114.1	4.0	2002.685	1	114	3.9	0.1	0.1	21
DUN 124 AB	12312-5707	1.83,6.45	26.7	125.2	2002.688	1	26	125.4	0.7	-0.2	22
DUN 124 AC	12312-5707	1.83,9.5	71.2	167.0	2002.688	1	82	155.1	-10.8	11.9	23
R 207	12463-6806	3.52,3.98	44.1	1.1	2002.686	1	43.5	1.3	0.6	-0.2	24
I 362 AB	12477-5941	1.25,11.4	326.4	42.2	2002.688	1	326	42.6	0.4	-0.4	25
DUN 126 AB	12546-5711	3.94,4.95	17.7	34.8	2002.688	3	17.2	34.8	0.5	0	26
RMK 16 AB	13081-6518	5.56,7.55	187.2	4.9	2002.686	1	186.9	5.3	0.3	-0.4	27
DUN 131 AC	13152-6754	4.76,7.24	332.0	58.4	2002.695	1	331	58.3	1.0	0.1	28
DUN 148	13518-3300	4.50,5.97	102.0	7.7	2002.688	1	105.8	7.9	-3.8	-0.2	29
DUN 160	14261-4513	4.53,8.92	204.6	157.0	2002.688	4	204.0	157.0	0.6	0	30
HJ 4690 AB	14373-4608	5.55,7.65	26.0	19.6	2002.685	3	25	19.1	1.0	0.5	31
RHD 1 AB	14396-6050	0.14,1.24	224.3	12.5	2002.688	1	223.4	13.5	0.9	-1.0	32
DUN 166	14425-6459	3.18,8.47	227.4	15.1	2002.688	1	226.0	15.7	1.4	-0.6	33
HJ 4728	15051-4703	4.56,4.60	65.5	1.7	2002.689	1	65.6	1.70	-0.1	0	34
DUN 177	15119-4844	3.83,5.52	142.6	26.1	2002.695	1	143	26.5	-0.4	-0.4	35
DUN 180 AC	15185-4753	4.99,6.34	127.4	22.7	2002.688	1	129	23.7	-1.6	-1.0	36
DUN 182 AC	15227-4441	3.6,9.1	167.8	24.9	2002.686	1	168.4	26.3	-0.6	-1.5	37
I 1271	15370-2808	3.58,10.8	150.5	2.0	2002.695	1	164	3.5	-13.5	-1.5	38
HDO 250	15381-4234	4.33,11.2	30.6	12.7	2002.686	1	28	11.8	2.6	0.9	39
DUN 196	15569-3358	5.09,5.56	48.9	10.4	2002.686	1	49	10.3	-0.1	0.1	40
RMK 21 AB	16001-3824	3.37,7.50	18.9	15.5	2002.688	1	19	14.9	-0.1	0.6	41
RMK 21 AC	16001-3824	3.37,9.27	248.8	115.0	2002.688	1	248 ?	115.0	0.8	0	42
H 3 7 AC	16054-1948	2.59,4.52	21.0	13.8	2002.695	1	20	13.6	1.0	0.2	43
HJ 4853	16272-4733	4.51,6.12	334.7	22.8	2002.688	1	334.2	22.8	0.5	0	44
BSO 13 AB	17191-4638	5.61,8.88	255.8	9.2	2002.688	3	253	9.7	2.8	-0.5	45
HDO 271	17233-4728	5.5,10.8	59.7	45.4	2002.695	1	60.0	44.9	-0.3	0.5	46
HJ 4942 AB	17254-5623	3.32,10.2	327.5	17.8	2002.686	1	327	18.4	0.5	-0.6	47
HJ 4942 AC	17254-5623	3.32,12.2	64.8	42.9	2002.686	1	65	42.2	-0.2	0.7	48
HJ 4951	17311-6041	3.64,10.96	322.7	49.7	2002.686	1	322	49.9	0.7	-0.2	49
H5 7 AB	18138-2104	3.85,10.48	261.2	16.0	2002.688	4	258	16.8	3.2	-0.8	50
BU 292 AC	18138-2104	3.85,13.5	111.9	25.2	2002.688	4	118	25.6	-6.1	-0.4	51
HJ 2822 AD	18138-2104	3.85,9.96	312.3	47.7	2002.688	4	312	48.7	0.3	-1.0	52
HJ 2822 AE	18138-2104	3.85,9.22	113.5	50.4	2002.688	4	115	50.1	-1.5	0.3	53

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NAME	RA+DEC	MAGS	PA meas.	ρ meas.	DATE	N	PA ref.	ρ ref.	Δ PA	Δ SEP	NOTES
BU 760 AC	18176-3646	3.2,13.0	321.3	28.2	2002.688	4	276	33.3	45.3	-5.1	54
BU 760 AD	18176-3646	3.2,10.0	318.5	92.9	2002.688	4	306	92.6	12.5	0.3	55
DUN 222	18334-3844	5.58,6.16	358.9	20.8	2002.688	1	358	21.3	0.9	-0.5	56
COO 227 AB	18438-3819	5.12,10.0	214.9	28.5	2002.688	1	214	29.2	0.9	-0.7	57
COO 227 AC	18438-3819	5.12, ?	51.9	42.9	2002.688	1	57	40.0	-5.1	2.9	58
BSO 14	19011-3704	6.33,6.58	280.9	13.0	2002.688	1	280.3	12.8	0.6	0.2	59
H5 78 AB-C	19026-2953	2.60,10.63	301.9	72.0	2002.688	1	302	72.2	-0.1	-0.2	60
DUN 227	19526-5458	5.80,6.39	147.1	22.5	2002.688	4	148	23.0	-0.9	-0.5	61
HJ 607 AC	20176-1230	4.24,9.6	224.3	45.6	2002.694	4	221	46.0	3.3	-0.4	62
STFA 52 AB	20210-1447	3.15,6.08	267.0	206.0	2002.694	4	267	207.0	0	-1.0	63
HJ 5209 AB	20376-4717	3.11,12.0	205.7	69.2	2002.700	1	199	67.4	6.7	1.8	64
DUN 232	20417-7521	6.51,7.07	19.7	16.8	2002.688	1	19	16.7	0.7	0.1	65
HJ 5258	21199-5327	4.50,6.93	273.3	7.0	2002.688	4	271.6	6.7	1.7	0.3	66
HJ 5278	21509-8243	5.56,7.26	62.9	3.5	2002.688	3	62.4	3.30	-1.8	0.2	67
PZ 7	22315-3221	4.28,7.12	172.3	29.6	2002.688	1	173	30.4	0.2	-0.8	68
Jc 20 AC	23069-4331	4.45,7.77	291.5	158.9	2002.686	1	292.1	159.3	-0.6	-0.4	69

Notes

In the following, common names of the systems are given, as well as other characteristics, like "cpm" (common proper motion), or "relfix" (relatively fixed) (both designations are adopted from Burnham´s Celestial Handbook [8]). Also, some remarks on reference data, on colors, as well as references to the image plates, if applicable, are added.

1: β^2 Tucanae, see plate 1a.
2: p Eridani; own measures fit rather well to published orbit.
3: ω Fornacis, relfix, see plate 1b.
4: α Fornacis, reference data taken from published orbit, which, however, is based on not too many data with significant scatter.
5: 32 Eridani, cpm, color contrast yellow-blue, see plate 2 and remarks on color imaging above.
6, 7: in Lepus, triple system, AB relfix, see plate 1a.
8: in Lepus, relfix.
9: γ Leporis, nice color contrast, see plate 2.
10, 11, 12: μ Canis Majoris, multiple system, AB reflix.
13: γ^2 Volantis, relfix, see plate 2.
14: in Canis Major, nice color contrast, see plate 2.
15, 16, 1 7: τ Canis Majoris, multiple system, AD relfix.
18, 19, 20: κ Volantis, multiple system, color contrast, see plate 2.
21: α Crucis, see plate 1a.
22, 23: γ Crucis, possibly optical, AC reference from 1879, C has markedly changed position, color contrast,

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see Plate 2.

24: β Muscae, orbit, own measure of rho is somewhat smaller than expected from calculated orbit, but seems to better fit to extrapolation from interferometric data from 1991.
25: β Crucis, optical ?
26: μ Crucis, relfix, see plate 1b.
27: θ Muscae, relfix.
28: η Muscae.
29: κ or 3 Centauri, cpm, see plate 1a.
30: τ^1 Lupi, color contrast, see plate 2.
31: in Lupus, also known as Φ 318, color contrast, relfix, see plate 2.
32: α Centauri, orbit. I have already measured this system in 2000 with the same equipment at the same location, resulting in PA = 224 o, and rho = 13.3 ". Both measures fit reasonably well to published orbit. A decrease of rho is expected.
33: α Circini, PA slowly decreasing.
34: π Lupi, cpm, PA decreasing, rho increasing, own measures fit well to extrapolation from last published data as from 1991 to 1996 in INT4. See plate 1a.
35: κ Lupi. Although designated as relfix, PA and rho seem to slowly decrease. See plate 1a.
36: μ Lupi, cpm, see plate 1a.
37: ε Lupi.
38: υ Librae, last published measurement from 1965.
39: ω Lupi, cpm, last published measurement from 1933.
40: ξ Lupi, relfix, see plate 1a.
41, 42: η Lupi; triple system, AB relfix, AC reference from 1935. PA for C given in WDS as 148 o probably is a printing error. See plate 1a.
43: β Scorpii, see plate 1b.
44: ε Normae, relfix.
45: in Ara, L7194. Published orbital data is based on only a small section of the suspected orbit. This system is reported in the Guide 8.0 program as problematic, as the position possibly is imprecise. Color contrast, see plate 2.
46: ι Arae.
47, 48: γ Arae, AB relfix, see plate 1b.
49: δ Arae.
50 – 53: μ Sagittarii, multiple system, AC reference from 1901, see plate 1b.
54, 55: η Sagittarii, multiple system, cpm, AC reference from 1896, AD reference from 1913, see plate 1b. (The close pair AB (rho = 3.1") is overexposed and not resolved in this wide field image. The diffraction spikes of the main star A were used for determining its exact position).
56: κ Coronae Australis, relfix, see plate 1b.
57, 58: λ Coronae Australis; AB relfix, AC reference from 1900, magnitude of component C has no entry in WDS, own estimate is roughly 12th mag in the red spectral region, see plate 1b.
59: in Corona Australis.
60: ζ Sagittarii, AB close binary, see plate 1b.
61: in Telescopium, relfix, color contrast, see plate 2.
62: α^1 Capricorni, multiple system, AC relfix.
63: β Capricorni, cpm, color contrast, see plate 2.
64: α Indi; reference from 1914.
65: μ^2 Octantis, cpm, PA increasing, rho decreasing, see plate 1b.
66: θ Indi, cpm, PA decreasing (?), rho increasing, color contrast.
67: λ Octantis; PA slowly decreasing.
68: θ Gruis, cpm, see plate 1b.
69: β Piscis Austrini.

Summary

An attempt was made to assess the accuracy of double star measurements from digitized video images by comparison with reference data. Provided that the image quality is sufficient, values for rho and PA can be calculated with errors less than 0.1 " and 1 °, respectively, with the equipment used here. However, the standard deviation of +/- 0.4 " obtained on the basis of 19 reference systems includes both possible systematic errors of the actual measurements and of the data from the literature. For the latter, error margins are difficult to estimate, with the exception perhaps of interferometric data. Nevertheless, it appears that the accuracy of digital image analysis of suitably processed video recordings is at least comparable to visual methods, and provides the additional feature of non-volatile documentation.

For a number of cases, differences between own measurements and reference data are significant. For some systems, these are probably due to rather long time intervals of several decades since last published measurements. For other systems, the reason for deviations is less clear. In any case, it would be worthwhile to independently check the questionable systems in the near future.

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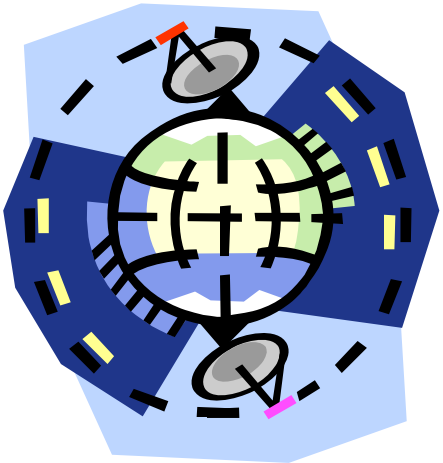
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