# Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019

Rainer Anton

Altenholz/Kiel, Germany
rainer.anton"at"ki.comcity.de

Abstract: Recordings of 82 double and multiple systems, in total 92 pairs, were made with a fast CMOS camera attached to a 50 cm reflector, and were analyzed with "lucky imaging". The scale was calibrated with reference systems, which were selected for the amount and precision of literature data, including from Gaia, so as to obtain trustworthy extrapolations to the epoch of own measurements. In particular, a number of binaries was found to fulfill this criterion, while other pairs exhibited more or less significant deviations from hitherto assumed orbits. A number of interesting systems are discussed in some detail, and a few images are also presented.

## Introduction

The telescope is of Ritchey-Chrétien type, and is maintained at the "Internationale Amateursternwarte" in Namibia, where I have already used it repeatedly in the past [3]. The primary focal length of 4.1 m was extended by a 2x Barlow lens, resulting in an f-ratio of about f/12. For any pair, series of up to 2000 images each were recorded with a monochrome CMOS camera of type QHY5 III 178 M, with pixels of size 2.4 arcsec square. In some cases, the color version of the same type of camera was used instead. When using the monochrome version, a near infrared filter was inserted, which reduces seeing effects, as well as chromatic aberrations of the Barlow lens. Exposure times ranged from less than a millisecond up to some tens of milliseconds, depending on the star brightness, and on the seeing. The resolution was 0.0665 arcsec/pixel, which was determined by calibration with reference systems, as was mentioned above, and is described below. Before stacking, the images were re-sampled 2x2 or 4x4, which resulted in smoothening of the intensity profiles and better definition of the peak centroids. Position angles were measured by reference to star trails, which were recorded while the telescope drive was switched off.

## Results

Figures 1 a and b illustrate the procedure of calibration of the image scale. The binary STF2272 (70 Ophiuchi) was chosen because of the virtually unambiguous evolution with time of both the position angle PA and the separation rho. This is documented by many literature data with low scatter (mostly speckle measurements [4]), by data from Gaia DR2, and by the recently revised ephemeris [Izm, 5]. Fourteen more binaries were found, with separations between one and ten arcsec, with similarly trustworthy data, including from Gaia, so as to serve as reference. In two cases, alpha Cen and gamma Vir, stars are too bright for Gaia, but their orbits are well-known. The image scale was obtained in an iterative way by measuring all 15 pairs and adjusting the calibration factor by minimizing the mean value of the residuals, as well as their standard deviation. The latter resulted in ±0.003 arcsec, within a range of ±0.005 arcsec, which is then taken as standard error margin of the measurements. However, in practice, it can actually be greater under bad seeing conditions.

The calibrated measurements of all 92 pairs are listed in Table 1. Names, nominal coordinates, and magnitudes are adopted from the WDS [6]. As many of the pairs are binaries, residuals mostly refer to actual ephemeris data [5], or to trustworthy extrapolations of literature data, if not otherwise noticed. In several cases, no reasonable residuals could be given, because of a dearth of data, and/or too large scatter. In figure 2, residuals of own measurements are plotted versus rho. Residuals of the 15 calibration systems are indicated with full symbols, see above. Residuals of other pairs either result from statistical errors of measurements, own and/or in the literature, or from systematic deviations from ephemeris data. Exceptionally large values of the latter are marked with their RA numbers. Individual remarks are listed in the notes following table 1 in order of RA values for identification.

Received December 2, 2020

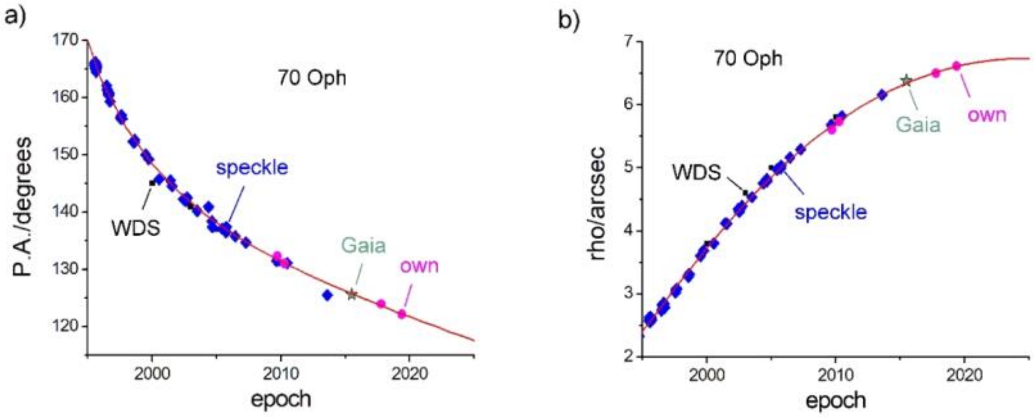


*Figure 1: Evolution with time of the position angle PA (a, left), and of the separation rho (b, right) of the binary STF 2272 (70 Oph). Blue rhombs: speckle data [4], black squares: data from the WDS catalog [6], green star: position from Gaia DR2, circles in magenta: own measurements (since 2007, each after calibration as described in the text), red curves: ephemeris from Izmailov 2019 [5].*

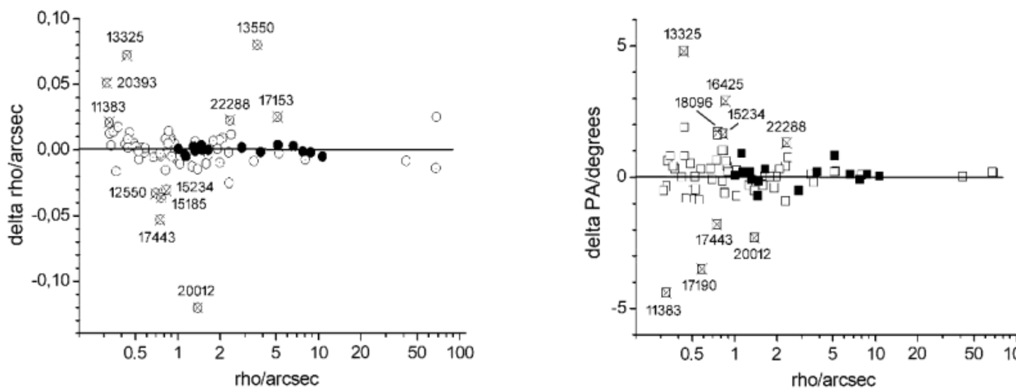


*Figure 2: Plots of the residuals of own measurements. Semi-logarithmic scaling. Left: delta rho versus rho. Right: delta PA versus rho. Residuals of the 15 calibration pairs are indicated with full symbols. Symbols with crosses mark pairs with systematic deviations from ephemeris data. Numbers refer to notes following table 1.*

| PAIR | RA + Dec | MAGS | PA | rho | Date | N | delta PA | delta rho |
|---|---|---|---|---|---|---|---|---|
| COP 1 * | 09 30.7 -40 28 | 3.91 5.12 | 132.16 | 0.958 | 2019.405 | 1 | 0.16 | -0.007 |
| AC 5 AB | 09 52.5 -08 06 | 5.43 6.41 | 37.70 | 0.494 | 2019.405 | 1 | 0.50 | 0.005 |
| I 173 | 10 06.2 -47 22 | 5.32 7.10 | 10.30 | 0.973 | 2019.405 | 1 | 0.20 | -0.005 |
| I 13 AB | 10 09.5 -68 41 | 6.63 6.47 | 104.30 | 0.562 | 2019.405 | 1 | -0.86 | 0.002 |
| BU 411 | 10 36.1 -26 41 | 6.68 7.77 | 303.20 | 1.327 | 2019.416 | 1 | -0.10 | -0.001 |
| I 860 AB | 10 42.0 -63 30 | 8.01 8.14 | 250.90 | 0.444 | 2019.405 | 1 | -- | -- |
| I 294 | 10 45.3 -80 28 | 6.15 6.49 | 89.40 | 0.831 | 2019.433 | 1 | -- | -- |
| R 155 | 10 46.8 -49 25 | 2.82 5.65 | 58.20 | 2.287 | 2019.405 | 1 | -0.40 | -0.025 |
| BSO 5 | 11 24.7 -61 39 | 7.68 8.76 | 248.80 | 7.737 | 2019.399 | 1 | -0.10 | -0.001 |
| I 78 | 11 33.6 -40 35 | 6.13 6.16 | 103.30 | 0.486 | 2019.405 | 1 | -- | -- |
| I 422 AB | 11 38.3 -63 22 | 7.10 7.42 | 116.40 | 0.350 | 2019.405 | 1 | -4.40 | 0.021 |
| AC | | 7.10 9.91 | 5.17 | 1.658 | | 1 | -- | -- |
| HLD 114 | 11 55.0 -56 06 | 7.60 7.81 | 168.60 | 3.868 | 2019.438 | 1 | 0.20 | -0.002 |

## Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| SEE 143 | 12 03.6 -39 01 | 7.05 7.65 | 347.40 | 0.343 | 2019.405 | 2 | -0.36 | 0.012 |
| HJ 4498 AB | 12 06.4 -65 43 | 6.13 7.74 | 59.10 | 8.769 | 2019.405 | 1 | 0.10 | -0.002 |
| BU 920 Crv | 12 15.8 -23 21 | 6.86 8.22 | 307.40 | 1.978 | 2019.438 | 1 | 0.10 | 0.010 |
| BSO 8 | 12 24.9 -58 07 | 7.84 7.98 | 334.81 | 5.223 | 2019.405 | 1 | 0.15 | -0.003 |
| DUN 252 AB | 12 26.6 -63 06 | 1.25 1.55 | 111.17 | 3.841 | 2019.405 | 1 | -- | -- |
| A-C | | 1.25 4.80 | 202.17 | 89.544 | | 1 | -- | -- |
| CPO 12 AB | 12 28.3 -61 46 | 7.32 8.24 | 184.20 | 2.092 | 2019.438 | 1 | 0.30 | 0.009 |
| HJ 4539 AB * | 12 41.5 -48 58 | 2.82 2.88 | 33.13 | 0.341 | 2019.42 | 3 | 0.61 | 0.003 |
| STF 1670 AB | 12 41.7 -01 27 | 3.48 3.53 | 357.40 | 2.852 | 2019.405 | 1 | -0.50 | 0.002 |
| R 207 AB | 12 46.3 -68 07 | 3.52 3.98 | 57.95 | 0.956 | 2019.405 | 2 | 0.20 | 0.004 |
| RST 2819 | 12 55.0 -85 07 | 5.94 6.86 | 240.40 | 0.662 | 2019.433 | 1 | -0.10 | -0.033 |
| I 83 | 12 56.7 -47 41 | 7.39 7.68 | 237.60 | 0.838 | 2019.399 | 1 | 1.00 | -0.003 |
| R 213 | 13 07.4 -59 52 | 6.59 7.04 | 19.60 | 0.643 | 2019.405 | 1 | -- | -- |
| I 424 A-C | 13 12.3 -59 55 | 4.8 8.4 | 14.40 | 1.911 | 2019.405 | 1 | -0.40 | 6E-4 |
| I 1227 * | 13 13.4 -50 42 | 6.56 6.78 | 136.0 | 0.365 | 2019.405 | 1 | 0.80 | 0.013 |
| I 298 | 13 32.5 -69 14 | 7.36 8.54 | 151.10 | 0.507 | 2019.438 | 1 | 4.80 | 0.072 |
| STF 1757 AB | 13 34.3 -00 19 | 7.82 8.75 | 144.00 | 1.645 | 2019.405 | 1 | 0.30 | 0 |
| BU 932 AB * | 13 34.7 -13 13 | 6.30 7.29 | 66.90 | 0.429 | 2019.405 | 1 | 0 | 0.004 |
| HWE 95 | 13 43.8 -40 11 | 7.51 7.85 | 185.20 | 0.899 | 2019.438 | 1 | 0.40 | 0.009 |
| STF 1781 | 13 46.1 +05 07 | 7.89 8.10 | 197.00 | 1.030 | 2019.405 | 1 | -0.70 | -0.005 |
| HWE 28 AB | 13 53.5 -35 40 | 6.27 6.38 | 316.12 | 1.011 | 2019.42 | 3 | 0.06 | 0.001 |
| H V 124 AE | | 6.27 8.65 | 7.22 | 68.22 | | 1 | 0.15 | 0.025 |
| BE | | 6.38 8.65 | 7.90 | 67.58 | | 1 | 0.18 | -0.014 |
| STF 1788 | 13 55.0 -08 04 | 6.68 7.26 | 100.90 | 3.740 | 2019.438 | 1 | -0.20 | 0.080 |
| SLR 19 | 14 07.7 -49 52 | 7.14 7.38 | 331.20 | 1.029 | 2019.399 | 1 | 0.25 | -0.011 |
| STF 1819 AB | 14 15.3 +03 08 | 7.73 7.92 | 158.80 | 0.888 | 2019.405 | 1 | -- | -- |
| RHD 1 | 14 39.6 -60 50 | -0.01 1.33 | 341.20 | 5.150 | 2019.41 | 2 | 0.80 | 0.004 |
| I 236 | 14 53.2 -73 11 | 5.87 7.59 | 128.10 | 2.298 | 2019.416 | 1 | -0.90 | -0.002 |
| HJ 4707 | 14 54.2 -66 25 | 7.53 8.09 | 267.70 | 1.248 | 2019.438 | 1 | -0.30 | -0.012 |
| BU 239 | 14 58.7 -27 39 | 6.17 6.79 | 16.20 | 0.467 | 2019.438 | 1 | -0.80 | 0.013 |
| HJ 4728 | 15 05.1 -47 03 | 4.56 4.60 | 63.54 | 1.636 | 2019.405 | 1 | 0.04 | -0.004 |
| HJ 4753 AB | 15 18.5 -47 53 | 4.93 4.99 | 296.11 | 0.724 | 2019.405 | 1 | 1.71 | -0.036 |
| DUN 180 AC | | 4.93 6.34 | 128.40 | 23.13 | | 1 | -- | -- |
| HJ 4757 * | 15 23.4 -59 19 | 4.94 5.73 | 354.50 | 0.781 | 2019.438 | 1 | 1.64 | -0.031 |
| HJ 4786 AB * | 15 35.1 -41 10 | 2.95 4.45 | 275.90 | 0.830 | 2019.405 | 1 | -0.15 | 0.008 |
| BU 36 | 15 53.6 -25 20 | 4.69 6.98 | 273.02 | 1.987 | 2019.438 | 1 | 0.02 | 0.007 |
| I 977 | 15 55.7 -26 45 | 7.99 8.48 | 263.10 | 0.578 | 2019.438 | 2 | 0.30 | -0.002 |
| I 333 | 15 59.9 -78 02 | 6.92 7.53 | 323.20 | 0.855 | 2019.416 | 1 | -0.60 | 0.005 |
| HJ4825 AB-C | 16 03.5 -57 47 | 5.20 5.76 | 242.00 | 11.018 | 2019.399 | 1 | -- | -- |
| STF 1998 AB | 16 04.4 -11 22 | 5.16 4.87 | 371.30 | 1.119 | 2019.416 | 2 | 0.90 | -0.004 |
| BC | | 4.87 7.30 | 46.47 | 7.066 | | 2 | -- | -- |
| AC | | 5.16 7.30 | 41.50 | 8.012 | | 2 | 0.07 | -0.008 |

## Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| BU 120 AB | | 4.35 5.31 | 1.66 | 1.331 | | 2 | -0.10 | 0.006 |
| MTL 2 CD | 16 12.0 -19 28 | 6.60 7.23 | 56.60 | 2.409 | 2019.41 | 2 | 0.75 | 0.012 |
| H 5 6 AC | | 4.35 6.60 | 335.95 | 41.512 | | 2 | 0.02 | -0.009 |
| GNT 1 AB | 16 29.4 -26 26 | 0.96 5.4 | 275.30 | 2.764 | 2019.416 | 2 | -- | -- |
| STF 2055 AB | 16 30.9 01 59 | 4.15 5.15 | 44.20 | 1.364 | 2019.405 | 1 | 0.50 | -0.015 |
| R 283 | 16 42.5 -37 05 | 6.98 7.83 | 247.10 | 0.847 | 2019.408 | 2 | 3.80 | -0.013 |
| STF 2106 AB | 16 51.1 +09 24 | 7.07 8.20 | 171.40 | 0.805 | 2019.405 | 1 | 1.00 | -0.015 |
| BU 1118AB* | 17 10.4 -15 44 | 3.05 3.27 | 227.50 | 0.506 | 2019.405 | 1 | -0.50 | 0.002 |
| SHJ 243 AB | 17 15.3 -26 36 | 5.12 5.12 | 139.45 | 5.125 | 2019.42 | 2 | 0.20 | 0.025 |
| MLO 4 AB * | 17 19.0 -34 59 | 6.37 7.38 | 6.20 | 0.585 | 2019.42 | 3 | -3.50 | 0.001 |
| BU 416 AC | | 6.37 10.6 | 140.00 | 32.708 | | 2 | -- | -- |
| BSO 13 AB | 17 19.1 -46 38 | 5.61 8.88 | 258.73 | 10.640 | 2019.438 | 1 | 0.03 | -0.005 |
| HJ 4931 | 17 20.6 -59 26 | 7.76 7.78 | 255.49 | 0.781 | 2019.438 | 1 | -- | -- |
| STF 2173 AB | 17 30.4 -01 04 | 6.06 6.17 | 129.00 | 0.395 | 2019.405 | 1 | 0.32 | 0.018 |
| HDO 275 | 17 44.3 -72 13 | 6.85 8.11 | 62.80 | 0.697 | 2019.438 | 1 | -1.80 | -0.053 |
| STF 2244 * | 17 57.1 +00 04 | 6.89 6.56 | 100.51 | 0.667 | 2019.433 | 2 | 0.31 | -0.006 |
| STF 2262 AB | 18 03.1 -08 11 | 5.27 5.86 | 289.73 | 1.482 | 2019.433 | 2 | -0.17 | 0 |
| STF 2272 AB | 18 05.5 +02 30 | 4.22 6.17 | 122.10 | 6.609 | 2019.405 | 1 | 0.10 | 0.003 |
| HJ 5014 | 18 06.8 -43 25 | 5.65 5.68 | 0.12 | 1.798 | 2019.416 | 1 | 0.02 | 0.007 |
| STF 2281 AB | 18 09.6 +04 00 | 5.97 7.52 | 282.50 | 0.754 | 2019.405 | 1 | 1.60 | -0.005 |
| AC 11 | 18 25.0 -01 35 | 6.71 7.21 | 354.90 | 0.901 | 2019.433 | 1 | 0.20 | -0.005 |
| STT 357 | 18 36.0 +11 44 | 8.08 8.87 | 68.40 | 0.350 | 2019.405 | 1 | 0.40 | -0.016 |
| HDO 150 AB | 19 02.6 -29 53 | 3.27 3.48 | 237.70 | 0.451 | 2019.416 | 2 | 1.90 | 0.008 |
| HN 126 | 19 04.3 -21 32 | 7.87 8.06 | 182.50 | 1.290 | 2019.416 | 1 | 0.20 | 0.002 |
| HJ 5084 | 19 06.4 -37 04 | 4.53 6.42 | 330.84 | 1.469 | 2019.416 | 1 | -0.70 | 0.004 |
| GLE 3 | 19 17.2 -66 40 | 6.12 6.42 | 354.60 | 0.522 | 2019.433 | 1 | -0.46 | -0.007 |
| I 253 AB | 19 19.0 -33 17 | 8.77 7.25 | 141.12 | 0.524 | 2019.416 | 1 | 0.02 | -0.001 |
| SCJ 22 | 19 28.2 -12 09 | 8.12 8.69 | 292.80 | 1.142 | 2019.416 | 2 | 0.20 | -0.005 |
| I 120 AB | 19 49.1 -61 49 | 8.31 8.69 | 165.80 | 0.445 | 2019.433 | 1 | 0.80 | 0.002 |
| HDO 294 | 20 01.2 -38 35 | 8.08 9.11 | 33.28 | 1.260 | 2019.416 | 1 | -2.30 | -0.012 |
| R 321 | 20 26.9 -37 24 | 6.58 8.09 | 123.03 | 1.580 | 2019.408 | 1 | -0.32 | -0.010 |
| BU 60 AB | 20 27.3 -18 13 | 5.13 8.53 | 147.80 | 3.459 | 2019.438 | 1 | 0.10 | -0.009 |
| HU 200 AB * | 20 39.3 -14 57 | 5.38 7.31 | 123.00 | 0.367 | 2019.438 | 1 | -0.50 | 0.051 |
| STF 2729 | 20 51.4 -05 38 | 6.40 7.43 | 32.64 | 0.747 | 2019.438 | 1 | 0.64 | -0.003 |
| BU 766 AB | 21 24.4 -41 00 | 6.24 6.88 | 171.00 | 0.320 | 2019.438 | 2 | -- | -- |
| SHJ 345 AB | 22 26.6 -16 45 | 6.29 6.39 | 86.80 | 1.217 | 2019.438 | 1 | -- | -- |
| STF 2909 AB | 22 28.8 -00 01 | 4.34 4.49 | 159.70 | 2.360 | 2019.438 | 1 | 1.30 | 0.023 |

*Table 1: List of PA and rho measurements. Position angles (PA) are in degrees, separations rho in arc seconds. N is the number recordings. For N>1, measures are mean values. Shaded lines indicate systems, which are used for calibration of the image scale. Residuals are given, when reasonable. Asterisks in column "PAIR" refer to images shown below.*

**Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019**

Notes: For binaries, periods P and the corresponding authors are taken from the "Sixth Catalog of Orbits of Visual Binary Stars" [5].

09 307: psi Velorum, binary, P = 34.1 y (Msn2017). See figure 3.

09 525: gamma Sextantis, close binary, P = 77.8 y (USN2007), many speckle data until 2011.

10 062: in Vela, binary, P = 187.2 y (Izm2019).

10 095: in Carina, PA and rho decreasing.

10 361: in Hydra, binary, P = 159.3 y (Izm2019), many speckle data, also listed in Gaia DR2.

10 420: in Carina, few data, PA and rho decreasing.

10 453: in Chameleon, few data, PA and rho increase ing.

10 468: mu Velorum, binary, P = 142.9 y (Izm2019).

11 247: in Centaurus, binary, P = 416.8 y (Izm2019), few data, but small scatter, also listed in Gaia DR2. Linear extrapolation appears reasonable.

11 336: in Centaurus, few data, PA increasing, rho decreasing.

11 383: in Centaurus, AB close binary, P = 1715.8 y (Zas2009), few data with large scatter, own measure significantly deviates from ephemeris, in accordance with trend of recent speckle measurements. AC: few data.

11 550: in Centaurus, binary, P = 972.5 y (Izm2019), few data, but small scatter, also listed in Gaia DR2.

12 036: in Centaurus, close binary, P = 111.0 y (Tok2014).

12 064: in Musca, few data, but listed in Gaia DR2. Linear extrapolation appears reasonable.

12 158: in Corvus, binary, P = 2089.1 y (Izm2019). Many speckle data, also listed in Gaia DR2.

12 249: in Crux, few data with some scatter. Listed in Gaia DR2.

12 266: alpha Crucis, Few data in the literature for both AB and AC, with large scatter for AC. Extrap olation ambiguous.

12 283: in Crux, binary, P = 574.0 y (Izm2019). PA measures from the speckle catalog, from Gaia data, as well as ours are close to ephemeris calculations by both Tokovinin (Tok 2018) and by Izmailov, while measures of rho, besides some scatter, better fit to that from Tokovinin. Less than a quarter of the assumed orbit is covered with measurements. Residuals refer to Tok 2018.

12 415: gamma Centauri, close binary, P = 83.6 y (Ary2015), orbit well documented. The apparent separation has passed a minimum of 0.12" in 2016, and is now widening again. See figure 3.

12 417: gamma Virginis, binary, P = 169.1 y (Sca2007), orbit well documented.

12 463: beta Muscae, binary, P = 459.5 y (Izm2019).

12 550: in Octans, few data.

12 567: in Centaurus, binary, P = 173.8 y (Izm2019). While ephemeris data for rho fit the recent measure ments, including data from Gaia DR2, quite well, that for PA seem to deviate.

13 074: in Centaurus, "relfix", but rho seems to be decreasing. Large scatter of literature data for PA.

13 123: SEE 170, in Centaurus, few data.

13 134: in Centaurus, close binary, P = 100.9 y (Zir2013). Few data, deviation from ephemeris. See figure 3.

13 325: in Musca, close binary, P = 590 y (USN2002). Few data, own measures, as well as re cent speckle data deviate from ephemeris.

13 343: in Virgo, binary, P = 344.1 y (Izm2019). Many data with low scatter, also listed in Gaia DR1 and DR2.

13 347: in Virgo, close binary, P = 177.7 y (Sca2014). Many data with some scatter. See figure 3.

13 438: in Centaurus, few data with some scatter, also listed in Gaia DR2.

13 461: in Virgo, binary, P = 253.7 y (Izm2019). Many data with low scatter, including Gaia DR1 und DR2.

13 535: HWE 28 AB: binary, P = 363 y (Izm2019). Many data, also listed in Gaia DR2. Few data for H V 124 AE and BE. Residuals of AB refer to the ephemeris, of AE and BE to Gaia.

13 550: in Virgo, binary, P = 1036.5 y (Izm2019). Many recent speckle data, but only short arc on as sumed orbit is covered with measurements. While the position from Gaia DR2 corresponds to past speckle observations, recent ephemeris calculations deviate, in particular for rho.

14 077: in Centaurus, binary, P = 414.9 y (Izm2019).

14 153: in Virgo, binary, P = 223.5 y (Sca2012).

14 396: alpha Centauri, binary, P = 79.7 y (Pbx2016). Orbit well documented.

14 532: in Apus, few data, also listed in Gaia DR2.

14 542: in Circinus, binary, P = 313.7 y (Izm2019), also listed in Gaia DR2.

14 587: in Hydra, close binary, P = 429.2 y (Lin1998), literature data of PA as well own meas urements tend to deviate from ephemeris.

15 051: pi Lupi, rather few data, rho data exhibit some scatter, extrapolation ambiguous.

15 185: mu Lupi, AB: close binary, P = 772 y (Zir2015), PA and rho seem to deviate from ephem eris. AC: literature data exhibit scatter, extrapolation ambiguous.

15 234: gamma Circini, binary, P = 258 y (Hrt2010). Some scatter of recent rho data, which also seem to deviate from ephemeris. See figure 3.

15 351: gamma Lupi, binary, P = 190 y (Hei1990), orbit highly inclined. See figure 3.

**Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019**

15 536: in Scorpius, few data, but listed in Gaia DR2. Own measure appears to correspond to extrapola tion.

15 557: in Scorpius, close binary, P = 274.5 y or 816.8 y (?) (Sca2013). Two orbit calculations by Scardia are listed in the Sixth Catalog of Orbits with about similar values for PA, but differences of rho, besides P. Past speckle data as well as own measure ments better fit to the one with lower values of rho and P.

15 599: in Apus, few data, but listed in Gaia DR2. Own measure reasonably fits to extrapolation.

16 035: iota Normae, only few data in the literature. Close pair SEE 258 AB not resolved here.

16 044: xi Scorpii, triple system, all three listed in Gaia DR2. AB: binary, P = 45.9 y (Doc2009). Many past speckle data with low scatter. AC: P = 1514.4 y (Zir2008). Significant deviation of ephemeris from observations.

16 120: nu Scorpii, "double-double", in fact a multi ple system. The pair AB is deemed a binary, but no orbital motion is known. Parallax values from Gaia for A and B are rather similar with largely overlap ping error margins, resulting in a nominal separation of about 4 light years. Parallax values for C and D give a nominal separation of about 44 Ly with non-overlapping error margins, while the distance from A to C is about 17 Ly. Thus, C and D appear to be optical. Nevertheless, all four stars show roughly similar proper motions. Measurements: Literature values of rho (AB) are slowly increasing, while PA values exhibit considerable scatter. A close compa ny ion to A was not resolved here. For CD, PA is slowly increasing, but rho data exhibit scatter, as do both, PA and rho measures for AC. Residuals of own measurements refer to estimated extrapolations from Gaia data. See figure 6.

16 294: alpha Scorpii, Antares, binary, P = 2666.5 y (Izm2019). Only small arc of orbit covered by meas urements. Difficult, due to large differences of brightness and color. Residuals ambiguous. See fig ure 7.

16 309: lambda Ophiuchi, binary, P = 129 y (Izm2019). Many speckle data, own measure fol lows trend, and is close to recently revised ephemer is, while PA value from Gaia DR2 is somewhat off.

16 425: in Scorpius, binary, P = 691 y (Ary2015). Measure of rho follows literature data and ephemer is, while PA seems to deviate.

16 511: in Ophiuchus, binary, P = 1270 y (Sca2001). Many past speckle data, own measures follow trend, but seems to slightly deviate from ephemeris.

17 104: eta Ophiuchi, close binary, P = 87.6 y (Doc2007). Many speckle data, own measures close ly follow trend and/or ephemeris. Rho is currently rapidly decreasing. See figure 3.

17 153: 36 Ophiuchi, binary, P = 470.9 y (Irw1996). Few data. Own measures of PA since 2010 as well as the value from Gaia DR2 closely fit the ephemer is, while rho data, both own and from Gaia, deviate.

17 190: in Scorpius, AB binary, P = 42.2 y (Izm2019). Rho, having passed periastron in 2018, is increasing again. Own measure of PA deviates, reason unclear. AC: few data, extrapolation ambigu ous, PA and rho slowly increasing. See figure 3.

17 191: in Ara, binary, P = 608.6 y (Izm2019). Own measures of PA and rho, as well as from Gaia DR2, closely fit the recently revised ephemeris.

17 206: in Ara, few data, rho slowly decreasing.

17 304: in Ophiuchus, close binary, P = 46.4 y (Hei1994). Many speckle data, orbit well document ed.

17 443: in Apus, binary, P = 98.6 y (Hrt2010). Few data, own measure of rho deviates from ephemeris.

17 571: in Ophiuchus, binary, P = 474.9 y (Msn2017). Orbit highly inclined. Many speckle data, own measures of PA and rho are close to recently revised ephemeris. See figure 3.

18 031: tau Ophiuchi, binary, P = 257 y (Sod1999). Many past speckle data. Also listed in Gaia DR2. Own measure of rho is close to extrapolation and ephemeris, while PA slightly deviates, but corre sponds to extrapolation from Gaia.

18 055: 70 Ophiuchi, binary, P = 88.4 y (Izm2019). Many data, orbit best documented. Also listed in Gaia DR2. Own measures close to ephemeris. See also figure 1.

18 068: in Corona Australis, binary, P = 450 y (Ary2001). Past speckle measurements, as well as data from Gaia and own measures significantly de viate from ephemeris. Residuals refer to linear ex trapolation of observations.

18 096: 73 Ophiuchi, close binary, P = 294 y (Sod1999). Many data. Past speckle values of PA as well as own measure deviate from ephemeris.

18 250: in Serpens, binary, P = 340 y (Tok2017). Or bit almost edge-on. Many data, but with some scat ter. Own measures are close to recently revised ephemeris.

18 360: in Ophiuchus, close binary, P = 411.1 y (Sca2011). Literature data exhibit some scatter. Own measure of PA is close to ephemeris, while rho devi ates.

19 026: zeta Sagittarii, close binary, P = 21 y (DRs2012). Many data, orbit well documented.

19 043: in Sagittarius, binary, P = 502.4 y (Izm2019). Past literature data exhibit scatter. Measurements from Gaia DR2 and of our own are close to recently

revised ephemeris.

19 064: gamma Coronae Australis, binary, P = 122.2 y (Izm2019). Past speckle measurements exhibit low scatter. Also listed in Gaia DR2. Own measures are close to ephemeris.

19 172: in Pavo, close binary, P = 156.8 y (Doc2007). Own measures follow trend of recent speckle data and are close to ephemeris.

19 190: in Sagittarius, close binary, P = 60 y (B_1954). Orbit almost edge-on. Own measure ments of PA since 2012 are close to ephemeris, while rho measures deviate, in accordance with past speckle data. Residuals refer to trend of measure ments.

19 282: also known as BU 142, in Sagittarius, binary, P = 167.7 y (Izm20219). Many past speckle data. Also listed in Gaia DR2. Own measurements are close to recently revised ephemeris.

19 491: in Pavo, close binary, P = 64.1 y (Tok2018). Few data, own measurements are close to recently revised ephemeris.

20 012: in Sagittarius, binary, P = 4484.5 y (Dom1978). Only short arc of assumed orbit cov ered with measurements. Also listed in Gaia Dr1 and DR2. Significant deviations from ephemeris. Residuals refer to extrapolation.

20 269: in Sagittarius, binary, P = 186.4 y (Izm2019). Also listed in Gaia DR2. Relatively few recent data. Own measure of rho, as well as the value from Gaia are somewhat off from the recently revised ephem eris.

20 273: pi Capricorni, few data, listed in Gaia DR2. Residuals refer to the latter.

20 393: tau2 Capricorni, close binary, P = 420 y (Hei1998). Literature data exhibit large scatter. Re siduals refer to ephemeris. See figure 3.

20 514: 4 Aquarii, binary, P = 200.7 y (Mdz2017). Also listed in Gaia DR2. Own measures are close to recently revised ephemeris.

21 244: in Microscopium, close pair, at the resolution limit of the telescope, so the error margins may be higher than usual. Few data in the literature, extrap olation ambiguous.

22 266: 53 Aquarii, binary, P = 596.8 y (Izm2019). Past literature data exhibit relatively low scatter and have closely followed the ephemeris from Hle1994, but the recently revised ephemeris seems to deviate, in particular for rho. See figure 4 and comments be low.

22 288: zeta Aquarii, binary, P = 426.7 y (Izm2019). Special case: An unseen companion, which is at tributed to component A, causes a wobble on the orbit of AB with period of about 26 y. A new orbit has been calculated by Izmailov in 2019. Both ephemeris data do not reflect this wobble. Rather, separate orbit calculations for Aa,Ab have been made by both authors. Residuals refer to ephemeris from Izm2019. See figure 5 and comments below.

## Discussion

Many of the pairs in table 1 are very close, and are not resolved by Gaia. Figure 3 shows a collection of such systems with separations between 0.32" and 0.96", while the lower value virtually corresponds to Rayleigh´s resolution limit of our telescope (here with NIR filter). Except BU 766, all others are known as binaries with periods between 42.2 y (MLO 4) and 474.9 y (STF 2244).

Of the 92 pairs investigated here, about two thirds are true binaries, with more or less well-known orbits. Many of these have recently been revised by Izmailov in 2019 [5], and own measurements fit the new ephemeris data generally better than older ones. However, there are several systems exhibiting noticeable deviations of the PA and/or the separation, which are commented in the individual notes, and are summarized in table 2 below. In any case, more measurements are desirable, so as to possibly allow for further refinement of orbit calculations.

In the table, the latter two, 53 Aquarii and zeta Aquarii, are especially interesting cases, as was already mentioned in the notes. The orbit of 53 Aqr is highly eccentric, and the pair is just about near periastron. Thus, the position angle changes rather fast with about 4 degrees per year. According to the orbit calculation by Hale (1994), the period would be 3500 years, and periastron will be passed in 2023. In contrast, Izmailov derived in 2019 a much smaller period of nearly 600 years, and the periastron is expected in 2021. Also, the size of the orbit is about halved, and the inclination increased. Figure 4 shows the evolution with time of the position angle and of the separation for the two solutions in recent years, together with observational data. Recent measurements, including our own do not fit either of the ephemeris data, but are closer to the orbit from Hale. Clearly, more measurements in the near future should help to clarify the situation.

Another interesting system is the triple STF2909 (zeta Aquarii). The orbit of the main pair AB has repeatedly been revised in recent years, e. g. by Scardia in 2010, by Tokovinin in 2016, and by Izmailov in 2019, while only half of the orbit is documented with measurements. According to Tokovinin, the period is about 540 years, which was reduced to 426 years by Izmailov. Figure 5 shows a small section covering the time span from 1990 to 2023. This includes little more than a full revolution (≈ 26 y) of the companion to A, which is responsible for the periodic variations of the measured

**Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019**

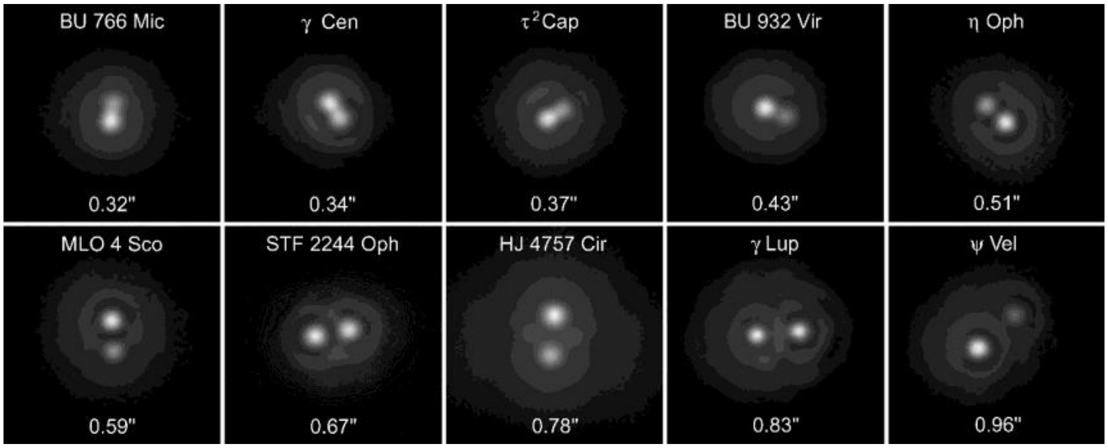


*Figure 3: Selection of close double stars. All except BU 766 are binaries, and none is resolved by Gaia. A closer look reveals variations of the peak widths, which are caused by the seeing. This was rather good when recording gamma Lupi, but apparently somewhat less, when HJ 4757 was recorded at another night. See also notes 21 244, 12 415, 20 393, 13 347, 17 104 (top row), and 17 190, 17 571, 15 234, 15 351, 09 307 (bottom row), respectively. North is down, east is right, as in all other star images.*

| name/constellation | note | remarks |
|---|---|---|
| I 422 AB Cen | 11 383 | both, PA and rho measures deviate from ephemeris |
| I 298 Mus | 13 325 | both, PA and rho measures deviate from ephemeris |
| STF 1788 Vir | 13 550 | PA measures, own, speckle and Gaia, deviate from ephemeris |
| HJ 4757 (gamma) Cir | 15 234 | both, PA and rho measures seem to deviate from ephemeris |
| R 283 Sco | 16 425 | PA measure seems to deviate from ephemeris |
| SHJ 243 AB (36) Oph | 17 153 | rho measures, also from Gaia, deviate from ephemeris |
| HDO 275 Aps | 17 443 | rho measures tend to be lower than ephemeris |
| STF 2281 AB (73) Oph | 18 096 | ephemeris of PA tend to be a little lower than observations |
| HDO 294 Sgr | 20 012 | significant deviation of ephemeris from observations |
| HU 200 AB ($tau^2$) Cap | 20 393 | rho measures tend to deviate from ephemeris |
| SHJ 345 AB (53) Aqr | 22 266 | both, PA and rho measures deviate from ephemeris |
| STF 2909 (zeta) Aqr | 22 288 | ephemeris as reference unclear |

*Table 2: List of binaries with deviations of measurements from ephemeris data.*

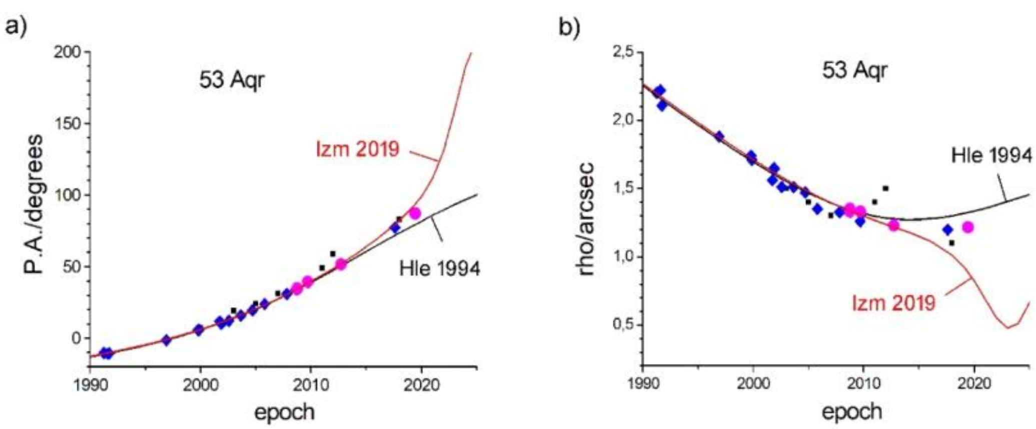


*Figure 4: Plots of the position angle (a, left) und separation (b, right) versus time of the binary SHJ 345 AB (53 Aqr). The meaning of the symbols is as in figure 1. No data is available from Gaia, as only one star is listed in DR2. Up to 2010, the ephemeris data by Hale and by Izmailov are about identical, and represent quite well the observations. But in the following years, they drift apart, while the few observations are lying in between.*

**Double Star Measurements at the Southern Sky with a 50 cm Reflector in 2019**

positions. This companion has been indirectly detected earlier in the infrared, and was finally seen by Tokovinin in 2016. The recent periastron of the pair Aa,Ab was at 2006.5, so that in 2019 the apastron should have followed. The future behavior of the main pair AB will remain interesting.

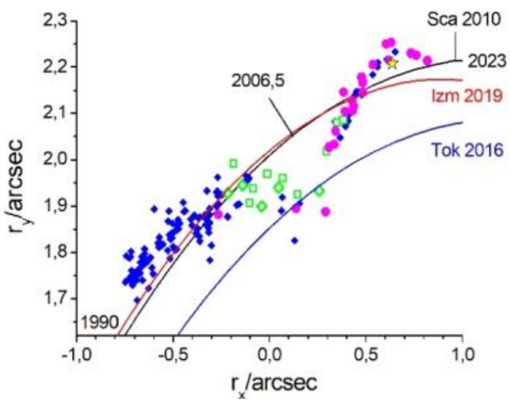


*Figure 5: A section of the orbit of STF2909 AB (zeta Aquarii), plotted in cartesian coordinates, and covering the years 1990 to 2023. The main star is located at coordinates (0,0). Note different scales for x and y. Blue rhombs are speckle data, circles in magenta own measurements from 2000 to 2019, green open rhombs and squares are visual measurements with micrometers by A. Alzner and R. Argyle, respectively. The yellow star is from Gaia data. Solid curves are orbit calculations by Scardia (2010, black), Tokovinin (2016, blue), and Izmailov (2019, red). The year 2006.5 indicates the time of periastron in the system Aa,Ab.*

The multiple nu Scorpii has already been discussed in note 16 120 above. Figure 6 shows an image of the system. While the pair AB probably is a binary, stars C and D are not related, but all share roughly similar proper motions.

Measuring Antares is a challenge, because of the large difference in brightness and color of the components, so that detection of the weak secondary leads to overexposure of the main star. The image in figure 7 was produced with the color version of the QHY178 camera, and is a superposition from two recordings obtained at two nights. A total of about 300 frames were registered on the blue companion, and the resulting image was superimposed on the same image with strongly increased contrast, such as to reveal the diffraction spikes of the secondary mirror of the telescope. Their virtual crossing was determined as position of the main star.

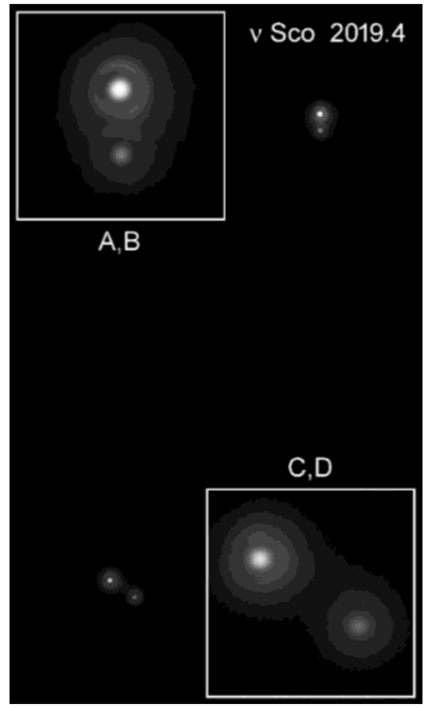


*Figure 6: The "double-double" BU 120 AB – MTL 2 CD (nu Scorpii). The magnitudes of the two pairs are rather different. Therefore, two series were recorded with exposure times 25 msec and 80 msec, respectively, and were superposed here. The insets show magnified images of the two pairs.*

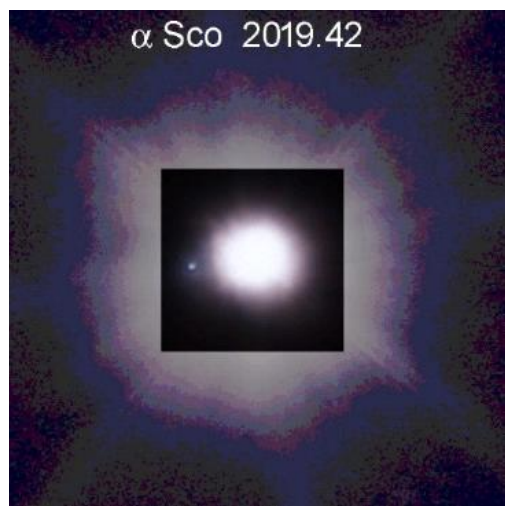


*Figure 7: Color image of Antares. Superposition of about 300 frames on the background of the same image with a larger field of view and strongly increased contrast, which reveals the diffraction spikes of the secondary mirror. North is down, east is right. See also note 16 294 above.*

## Conclusion

This work concentrates on close pairs, which are mostly not resolved by Gaia. However, data from Gaia were helpful for pairs with larger separations, greater than about 1“, in particular binaries, which served for calibration of the image scale. As a result, the nominal accuracy of measurements was shown to be better than ±0.005”. For many other pairs, residuals were of the same order, depending on how trustworthy the reference data are. In a number of cases, greater residuals indicate that more measurements for further refinement of orbit calculations are desirable. Some of these have been mentioned in the discussion above.

## Acknowledgements

This work has made extensive use of data from the double star catalogs provided by the U.S. Naval Observatory, as well as data from the Gaia satellite mission, which are published by the ESA consortium.

## References

[1] Anton, R., “Lucky Imaging”, in Observing and Measuring Visual Double Stars, 2nd edition, Robert Argyle, ed. Springer New York 2012.

[2] Gaia Archive, DR1 and DR2: http://esac.esa.int/ ar chive/, online access Oct. 2020.

[3] IAS, http://www.ias-ev.org

[4] Hartkopf, W.I. et al., Fourth Catalog of Interfero metric Measurements of Binary Stars, U.S. Naval Observatory, online access Oct. 2020.

[5] Hartkopf, W.I. et al., Sixth Catalog of Orbits of Vis ual Binary Stars, U.S. Naval Observatory, online access Oct. 2020.

[6] Mason, B.D. et al., The Washington Double Star Catalog (WDS), U.S. Naval Observatory, online access Oct. 2020.