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# ORBITAL ELEMENTS, DYNAMICAL MASSES AND PARALLAXES FOR FOUR DOUBLE AND ONE TRIPLE SYSTEMS

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**SUMMARY: New orbital elements for four binaries: WDS 00416+2438 = WRH 28, WDS 01554+0257 = A 2407 = ADS 1530, WDS 15031+4439 = CHR 43 and WDS 22550+5132 = HU 785 = ADS 16368 and one triple star WDS 23393+4543 = ADS 16904: CHR 149 Aa and A 643 Aa-B are determined. Preliminary dynamical masses and parallaxes are also given.**

**Key words. binaries: visual**

## 1. INTRODUCTION

New orbital elements for three binaries WRH 28, A 2407, and CHR 43, and for a pair - A 643 Aa-B - belonging to the triple ADS 16904, calculated from observations which were at our disposal were published in the IAUDS Information Circular No. 154 (Olević and Cvetković 2004b). In the case of binary HU 785 and a pair CHR 149 Aa, belonging to the triple system ADS 16904, some missing observational results were kindly provided by Prof. J. Docobo so, that we could calculate their new orbital elements and publish them in the IAUDS Information Circular No. 155 (Olević and Cvetković 2005). Here we give a complete analysis of the obtained results - orbital elements, calculated dynamical masses of the components, i.e. the total mass of the system, and the dynamical parallaxes for the three systems.

Pair WRH 28 was discovered by R.H. Wilson in 1949, but he could not measure the coordinates due to the small separation between the components. From the date of discovery till 1988, there were five successful measurements for this pair, all of them by means of the speckle interferometry. The orbital elements were first calculated from four measurements (Olević and Jovanović 1999). The orbit was also published in the Fifth Catalog of Orbits of Visual Binary Stars (Hartkopf et al. 2001). The obtained values were 3.151 years for the period, $0\farcs285$ for the semi-major axis. The total mass of the system following from these values and the Hipparcos trigonometric parallax $\pi_{\rm HIP}$ (about $30M_{\odot}$) for the given spectral type A7m is too large.

For binary A 2407, the orbital elements were first determined by Baize (1984).

In the case of HU 785, the first to determine the orbital elements was Zulević (1980).

For the triple system ADS 16904 = A 643 Aa-B and ADS 16904 = CHR 149 Aa, the orbital elements were calculated by Balega and they were published in the Sixth Catalog of Orbits of Visual Binary Stars (Hartkopf and Mason 2003).

For these five pairs, recent observations indicate significant deviations from the orbits obtained by the authors mentioned above. Therefore it is necessary to redetermine the orbital elements for these binaries.

For the binary CHR 43, from its discovery in 1985 till 1995, a total of ten measurements is available; all of them were done by means of the speckle interferometry. The observations cover an arc of 119 degrees. For this system no one before us calculated the orbital elements, hence those published in the IAUDS Information Circular No. 154 define the first orbit ever calculated for this pair.

## 2. THE METHOD, RESULTS AND DISCUSSION

### 2.1. Method

In the calculations of orbital elements we used the KOVOLE method, developed by one of us (D. Olević; see Olević and Cvetković 2004a). This method is based on Kovalski's method and yields satisfactory results from interferometric measurements even when only a short orbital arc is covered by the observations. The original method has failed in this situation. A correct estimate of the observational weights is of particular importance. For this purpose we use a criterion analogous to that applied by Mason et al. (1999). Individual masses and dynamical parallaxes are calculated using Angelov's (1993) relation.

### 2.2. Results

The orbital elements (equinox J2000) and the corresponding errors are listed in Table 1: $m_A$ and $m_B$ are the apparent magnitudes of the components taken from the WDS Catalog (Mason et al. 2003); $v$ denotes the total magnitude. The spectral type is also taken from WDS.

Table 2 contains the observational data and their residuals ($\Delta\theta^\circ$ and $\Delta\rho''$). Asterisks (*) mark observations subject to a change of quadrant. Double asterisks (**) indicate the measurements not used in the orbit calculation. The sign ($\diamond$) indicates the interferometric measurements. The corresponding ephemeris values are given in the parentheses.

The ephemerides for 2005-2009 are given in Table 3.

In Figs. 1-6 we give the fitted orbits and the lines of nodes. The visual observations are presented by filled circles and those observed interferometrically by filled squares. The empty circles and empty squares are their corresponding epehemeris positions. The dashed line gives the rejected observations. The arrow indicates the sense of the orbital motion.

### Comments

**WDS 00416+2438 = WRH 28**: By adding the last measurement from 1988.898 unavailable to us in the previous determination of orbital elements (Olević and Jovanović 1999), we found that the measurement from 1983.9307 possessed a large error. Namely, after calculating the orbital elements without it, the values obtained for the period and semimajor axis were: $P$=21.262 years, $a$=0.″126, respectively. Using the Hipparcos trigonometric parallax, $\pi_{\rm HIP} = 0.''00706 \pm 0.''00077$, one obtains $12.6 M_\odot$ for the total mass of the system, which can be expected for the spectral type A7m. Due to the small number of measurements, the results can be considered as preliminary. Since this pair has an interesting spectral type and its calculated period is relatively short, we would recommend it to be observed more frequently.

**WDS 01554+0257 = A 2407**: The individual component masses ($1.0 M_\odot$ and $0.8 M_\odot$) are within those expected for their spectral type K0. The calculated dynamical parallax $\pi_{\rm dyn} = 0.''018$ agrees well with the Hipparcos trigonometric parallax $\pi_{\rm HIP} = 0.''02317 \pm 0.00302$, considering the error limits including the uncertainties for $P$ and $a$, as well. This pair also deserves to be measured more frequently since the orbit part already passed by it is about 50%; consequently one can expect a significantly more reliable determination of orbital elements soon.

**WDS 15031+4439 = CHR 43**: This relatively very bright pair was discovered by means of the speckle interferometry in 1985. It was named after CHARA (Center for High Angular Resolution Astronomy) Programme of the Georgia State University, Atlanta, USA. The fact that it belongs to Luminosity Class IV (HR - F6IV) makes this system interesting. The Hipparcos trigonometric parallax leads to a total mass of $1.6 M_\odot$. The measurements of the position angle bear significant errors. This is due to the impossibility of resolving the components visually.

**WDS 22550+5132 = HU 785**: This faint pair was discovered by Hussey in 1902. However, until 1991 it had been measured 11 times only. The last measurement was made by the Hipparcos Satellite. All the measurements (except the last one) were classical micrometric ones. The pair passed an arc of 124 degrees. Heinz's measurement in 1976 had a large error in the position angle and, it is not used in the calculation of the orbital elements. The obtained individual component masses $1.4 M_\odot$ and $1.3 M_\odot$ are in a good agreement with what can be expected for the spectral type F2. The calculated dynamical parallax $\pi_{\rm dyn} = 0.''0049$ is in agreement with the Hipparcos trigonometric parallax $\pi_{\rm HIP} = 0.''00318 \pm 0.00129$ within the error limits when the uncertainties of all parameters are taken into account.

**WDS 23393+4543**: This system was discovered by Aitken in 1903 as double and given A 643 as its designation. That its A component is also double, i.e. the system as a whole is triple, became known in 1986 in the framework of the CHARA programme. Since that time, the designation for the system discovered first has been **A 643 Aa-B**, whereas the subsystem has been referred to as **CHR 149 Aa**. The first orbital elements for both A 643 Aa-B and CHR 149 Aa were calculated in 1999 by Balega. According to our calculations, the period $P$ for pair A 643 Aa-B is 2.14 times longer than that obtained by Balega; similarly, the period for pair CHR 149 Aa amounts to 0.30 times that obtained by Balega. The dynamical masses of the components for A 643 Aa-B are found to be $2.2 M_\odot$, both being in agreement with the expectations based on the spectral type A2. The calculated dynamical parallax $\pi_{\rm dyn} = 0.''0033$ nearly coincides with the Hipparcos trigonometric parallax $\pi_{\rm HIP} = 0.''00370 \pm 0.00127$. Large residuals of the recent measurements from the orbit fitted on the basis of Balega's elements (e.g. in case of CHR 149 Aa for epoch 1999.821 the residuals are $+126.^\circ 5$ and $-0.''017$, whereas in case of pair A 643 Aa-B the residuals for epoch 1999.7282 are $+5.^\circ 6$ and $+0.''041$) are in favour of our results.

The orbits of all the three components are in the same plane (inclination for both pairs is $i = 147$ degrees) which confirms one of the hypotheses on the formation of multiple stars.

**Table 1.** Orbital elements

| Name | WRH 28 | A 2407 | CHR 43 | HU 785 | CHR 149 Aa | A 643 Aa-B |
|---|---|---|---|---|---|---|
| WDS | 00416+2438 | 01554+0257 | 15031+4439 | 22550+5132 | 23393+4543 | 23393+4543 |
| HIP | 3269 | 8958 | 73637 | 113166 | 116726 | 116726 |
| $m_A$ , $m_B$ | $v = 6.0$ | 10.05-10.50 | $v = 6.65$ | 9.91-10.36 | $v = 7.63$ | 8.45-8.49 |
| Sp | A7m | K0 | F6IV | F2 | A2 | A2 |
| $P$(yr) | 21.26±0.94 | 183.87±4.40 | 97.70±4.82 | 266.82±15.00 | 20.28±0.40 | 324.38±6.28 |
| $T$ | 1993.02±0.56 | 1971.43±4.14 | 2078.87±0.45 | 2125.41±5.32 | 1999.65±0.24 | 1926.27±7.12 |
| $a(''$) | 0.126±0.006 | 0.689±0.061 | 0.430±0.056 | 0.285±0.020 | 0.040±0.002 | 0.261±0.003 |
| $e$ | 0.50±0.04 | 0.07±0.03 | 0.52±0.11 | 0.27±0.04 | 0.23±0.04 | 0.11±0.01 |
| $i(^o)$ | 33.4±3.6 | 46.0±2.9 | 71.8±2.4 | 109.8±1.4 | 147.1±4.5 | 147.5±1.4 |
| $\Omega(^o)$ | 145.7±6.7 | 172.8±4.8 | 62.8±3.0 | 87.7±2.5 | 58.7±9.2 | 30.5±2.9 |
| $\omega(^o)$ | 230.5±8.0 | 45.3±25.6 | 358.0±3.8 | 108.6±14.2 | 219.2±12.3 | 152.6±5.4 |
| $\mathcal{M}_A(\odot)$ | – | 1.0 | – | 1.4 | – | 2.2 |
| $\mathcal{M}_B(\odot)$ | – | 0.8 | – | 1.3 | – | 2.2 |
| $\Sigma\mathcal{M}$ | $12.6 \pm 4.9$ | – | $1.6 \pm 1.0$ | – | $3.0 \pm 3.3$ | – |
| $\pi_{\rm dyn}$(mas) | – | 18 | – | 5 | – | 3 |
| $\pi_{\rm HIP}$(mas) | $7.06 \pm 0.77$ | $23.17 \pm 3.02$ | $17.45 \pm 0.67$ | $3.18 \pm 1.29$ | $3.70 \pm 1.27$ | $3.70 \pm 1.27$ |

**Table 2.** Observations and residuals

WDS 00416+2438 = WRH 28

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1980.7232$^\diamond$ | 179.3 | 0.170 | 1 | McA | −0.9 | −0.004 |
| 1982.7601$^\diamond$ | 195.6 | 0.178 | 1 | McA | 2.1 | 0.008 |
| 1983.9307$^{\diamond **}$ | 182.5 | 0.145 | 1 | Bnu | (−19.3 | −0.018) |
| 1984.9991$^\diamond$ | 208.5 | 0.148 | 1 | McA | −1.5 | −0.007 |
| 1988.8982$^\diamond$ | 252.6 | 0.116 | 1 | Hrt | 0.3 | 0.002 |

WDS 01554+0257 = A 2407

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1912.74 | 103.9 | 0.53 | 3 | A | 2.5 | 0.021 |
| 1919.88 | 117.8 | 0.53 | 2 | A | −0.6 | −0.007 |
| 1939.73 | 158.8 | 0.56 | 1 | VBS | 3.4 | −0.079 |
| 1940.676 | 159.7 | 0.55 | 1 | VBS | 2.8 | −0.092 |
| 1941.906 | 159.0 | 0.62 | 1 | VBs | 0.2 | −0.025 |
| 1948.786 | 160.3 | 0.74 | 1 | VBS | −8.9 | 0.086 |
| 1951.420 | 171.2 | 0.63 | 1 | VBS | −1.9 | −0.022 |
| 1950.930 | 177.5 | 0.78 | 1 | MRZ | 5.1 | 0.127 |
| 1951.920 | 174.6 | 0.69 | 1 | MRZ | 0.7 | 0.039 |
| 1955.026 | 184.8 | 0.56 | 1 | COU | 6.1 | −0.084 |
| 1958.060 | 178.3 | 0.54 | 4 | VBS | −5.2 | −0.094 |
| 1960.770 | 190.1 | 0.67 | 4 | WOR | 2.2 | 0.049 |
| 1961.758 | 189.7 | 0.55 | 3 | WOR | 0.1 | −0.065 |
| 1963.850 | 191.9 | 0.74 | 2 | VBS | −1.3 | 0.137 |
| 1974.970 | 207.3 | 0.61 | 3 | HEI | −8.6 | 0.088 |
| 1978.810 | 226.5 | 0.44 | 3 | HEI | 1.0 | −0.055 |
| 1981.860 | 235.6 | 0.42 | 3 | HEI | 1.9 | −0.057 |
| 1984.996 | 250.4 | 0.44 | 4 | WOR | 7.5 | −0.022 |
| 1991.250 | 267.0 | 0.472 | 1 | HIP | 4.6 | 0.019 |
| 1991.750 | 261.4 | 0.500 | 1 | TYC | −2.6 | 0.047 |

**Table 2.** (continued)

WDS 15031+4439 = CHR 43

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1985.5171$^\diamond$ | 84.4 | 0.169 | 1 | McA | 0.4 | 0.007 |
| 1986.4070$^\diamond$ | 90.9 | 0.168 | 1 | McA | −0.0 | 0.023 |
| 1988.1628$^\diamond$ | 112.0 | 0.128 | 1 | McA | 1.5 | 0.014 |
| 1988.2527$^\diamond$ | 104.9 | 0.115 | 1 | McA | −6.8 | 0.002 |
| 1989.2274$^\diamond$ | 116.8 | 0.083 | 1 | McA | −10.5 | −0.019 |
| 1991.3246$^\diamond$ | 175.4 | 0.100 | 1 | McA | 10.3 | −0.006 |
| 1991.3297$^\diamond$ | 173.9 | 0.102 | 2 | McA | 8.8 | −0.004 |
| 1992.3102$^\diamond$ | 184.1 | 0.134 | 1 | McA | 4.8 | 0.014 |
| 1995.1498$^\diamond$ | 200.1 | 0.191 | 1 | Hrt | −3.3 | 0.010 |
| 1995.3109$^\diamond$ | 203.6 | 0.180 | 1 | Hrt | −0.7 | −0.005 |

WDS 22550+5132 = HU 785

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1902.5300 | 261.5 | 0.250 | 1 | HU | 0.2 | −0.002 |
| 1903.5800 | 260.2 | 0.250 | 2 | HU | −0.5 | −0.002 |
| 1922.7400 | 250.1 | 0.230 | 3 | VBS | 1.3 | 0.006 |
| 1946.4000 | 227.5 | 0.190 | 4 | VBS | 2.5 | 0.033 |
| 1954.7000 | 202.7 | 0.120 | 5 | VBS | −8.3 | −0.016 |
| 1957.0000 | 198.9 | 0.100 | 1 | IDS | −7.5 | −0.031 |
| 1976.8100$^{**}$ | 63.7 | 0.170 | 2 | HEI | (−96.1 | 0.043) |
| 1980.7000 | 172.9 | 0.130 | 2 | HEI | 21.3 | −0.004 |
| 1981.5900 | 157.4 | 0.120 | 3 | HEI | 7.5 | −0.016 |
| 1988.8270 | 124.1 | 0.180 | 1 | GIL | −13.4 | 0.026 |
| 1991.2500$^*$ | 317.0 | 0.176 | 1 | HIP | 3.0 | 0.015 |

WDS 23393+4543 = CHR 149 Aa

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1986.8914$^\diamond$ | 53.5 | 0.048 | 1 | McA | 2.1 | 0.001 |
| 1988.6578$^\diamond$ | 31.0 | 0.048 | 1 | McA | −2.3 | 0.001 |
| 1993.8413$^\diamond$ | 323.6 | 0.040 | 1 | Bag | −2.4 | 0.003 |
| 1994.7237$^{\diamond *}$ | 131.0 | 0.033 | 1 | Sco | 0.6 | −0.002 |
| 1998.7745$^\diamond$ | 223.1 | 0.029 | 1 | Bag | −3.9 | −0.002 |
| 1999.8210$^{\diamond *}$ | 26.2 | 0.028 | 1 | Bag | 6.8 | 0.000 |

**Table 2.** (continued)

WDS 23393+4543 = A 643 Aa-B

| $t$ | $\theta^\circ$ | $\rho''$ | $n$ | Obs. | $\Delta\theta^\circ$ | $\Delta\rho''$ |
|---|---|---|---|---|---|---|
| 1903.9300 | 264.3 | 0.210 | 1 | A | −0.1 | 0.001 |
| 1911.6300 | 251.5 | 0.190 | 1 | A | −1.9 | −0.024 |
| 1916.9400 | 247.4 | 0.230 | 1 | A | 1.2 | 0.013 |
| 1921.5500 | 241.5 | 0.220 | 1 | A | 1.4 | −0.001 |
| 1934.6700 | 223.9 | 0.240 | 1 | A | 0.3 | 0.011 |
| 1944.5700 | 208.3 | 0.220 | 1 | VOU | −3.7 | −0.014 |
| 1944.8300 | 219.8 | 0.230 | 1 | VBS | 8.1 | −0.004 |
| 1953.7500 | 202.2 | 0.260 | 3 | MUL | 0.1 | 0.025 |
| 1956.8600 | 195.8 | 0.270 | 2 | COU | −2.1 | 0.035 |
| 1959.0000 | 195.0 | 0.200 | 1 | IDS | −0.4 | −0.035 |
| 1959.8400* | 11.0 | 0.270 | 1 | COU | −3.4 | 0.035 |
| 1961.8100* | 10.6 | 0.230 | 1 | COU | −1.6 | −0.005 |
| 1962.7800 | 190.8 | 0.240 | 1 | HEI | −0.3 | 0.005 |
| 1964.8900 | 187.3 | 0.240 | 1 | HIE | −1.3 | 0.005 |
| 1965.4900 | 181.7 | 0.220 | 2 | COU | −6.2 | −0.014 |
| 1966.2600 | 195.5 | 0.240 | 2 | MUL | 8.4 | 0.006 |
| 1971.8100 | 183.9 | 0.240 | 1 | HEI | 3.2 | 0.007 |
| 1973.2370* | 2.0 | 0.260 | 1 | WOR | 3.1 | 0.027 |
| 1975.7626** | 155.6 | 0.220 | 5 | HAR | (−20.4 | −0.012) |
| 1976.7100 | 178.9 | 0.240 | 1 | HEI | 4.1 | 0.008 |
| 1983.7103◇ | 165.7 | 0.235 | 1 | McA | −0.8 | 0.006 |
| 1985.8373◇ | 157.3 | 0.226 | 1 | McA | −6.6 | −0.003 |
| 1986.8914◇ | 156.4 | 0.225 | 1 | McA | −6.2 | −0.004 |
| 1987.7540◇ | 155.2 | 0.229 | 1 | McA | −6.4 | 0.001 |
| 1988.6578◇ | 156.3 | 0.218 | 1 | McA | −4.2 | −0.010 |
| 1989.7173◇ | 158.1 | 0.210 | 1 | Hrt | −1.1 | −0.018 |
| 1989.7173 | 158.1 | 0.210 | 1 | HEI | −1.0 | −0.018 |
| 1991.2500 | 158.0 | 0.226 | 1 | HIP | 0.7 | −0.001 |
| 1993.8413◇ | 154.1 | 0.214 | 1 | Bag | 0.0 | −0.013 |
| 1994.7237◇* | 335.5 | 0.212 | 1 | Sco | 2.5 | −0.015 |
| 1994.9000 | 151.5 | 0.250 | 1 | HEI | −1.3 | 0.023 |
| 1995.7626◇ | 155.6 | 0.220 | 1 | Hrt | 3.9 | −0.007 |
| 1996.5404◇ | 154.2 | 0.226 | 1 | Hrt | 3.4 | 0.000 |
| 1998.7745◇* | 333.3 | 0.237 | 1 | Bag | 5.3 | 0.011 |
| 1999.7282◇ | 150.2 | 0.239 | 1 | Doc | 3.4 | 0.013 |

**Table 3.** Ephemerides

| | A 2145 | | BU 368 AB | | STF 2909 AB | | A 2695 | | FIN 375 Aa | | McA 76 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $t$ | $\theta^\circ$ | $\rho''$ | $\theta^\circ$ | $\rho''$ | $\theta^\circ$ | $\rho''$ | $\theta^\circ$ | $\rho''$ | $\theta^\circ$ | $\rho''$ | $\theta^\circ$ | $\rho''$ |
| 2005.0 | 200.4 | .164 | 301.2 | .522 | 227.2 | .405 | 119.1 | .204 | 76.2 | .042 | 140.3 | .226 |
| 2006.0 | 207.9 | .157 | 303.6 | .530 | 228.3 | .424 | 118.2 | .208 | 64.1 | .045 | 139.1 | .226 |
| 2007.0 | 216.2 | .149 | 305.8 | .538 | 229.3 | .442 | 117.4 | .211 | 53.2 | .047 | 137.8 | .226 |
| 2008.0 | 225.7 | .139 | 308.0 | .547 | 230.2 | .460 | 116.6 | .214 | 42.9 | .047 | 136.6 | .226 |
| 2009.0 | 236.7 | .128 | 310.2 | .555 | 231.0 | .476 | 115.8 | .217 | 32.6 | .047 | 135.3 | .226 |

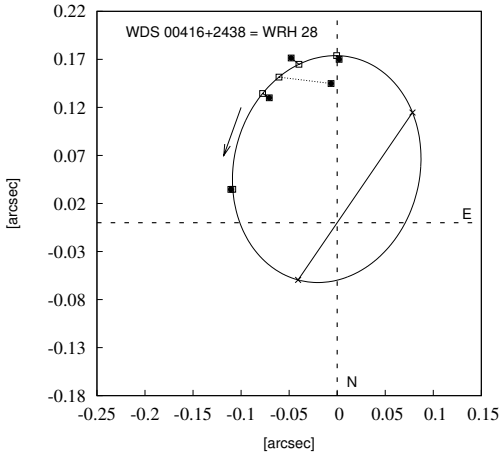


**Fig. 1.** *Orbit of WRH 28.*

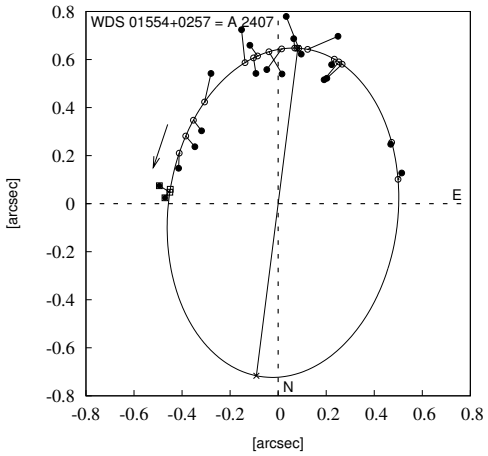


**Fig. 2.** *Orbit of A 2407.*

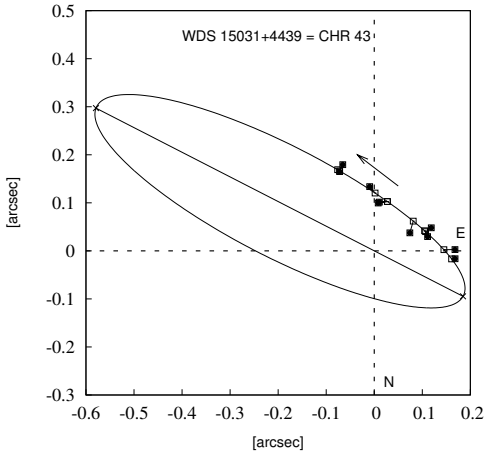


**Fig. 3.** *Orbit of CHR 43.*

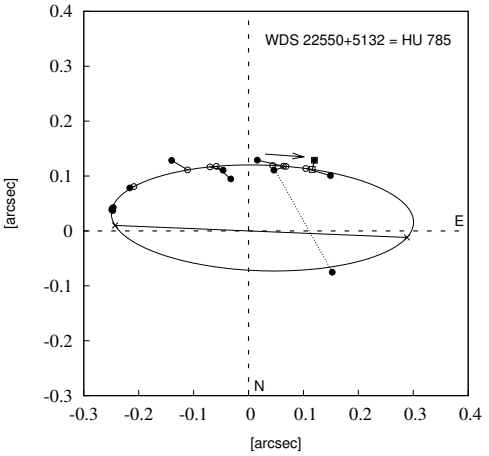


**Fig. 4.** *Orbit of HU 785.*

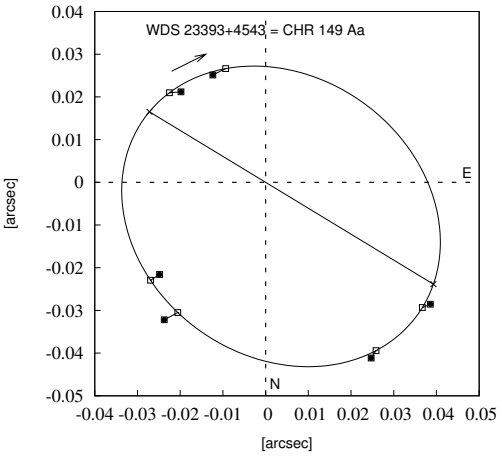


**Fig. 5.** *Orbit of CHR 149 Aa.*

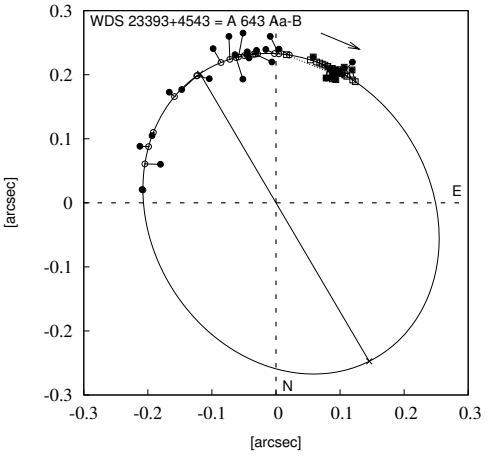


**Fig. 6.** *Orbit of A 643 Aa-B.*

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## ОРБИТАЛНИ ЕЛЕМЕНТИ, ДИНАМИЧКЕ МАСЕ И ПАРАЛАКСЕ ЗА ЧЕТИРИ ДВОЈНА И ЈЕДАН ТРОЈНИ СИСТЕМ

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*Оригинални научни рад*

У раду су дати нови путањски елементи за четири двојна система: WDS 00416+2438 = WRH 28, WDS 01554+0257 = A 2407 = ADS 1530, WDS 15031+4439 = CHR 43 и WDS 22550+5132 = HU 785 = ADS 16368 и за тројни систем WDS 23393+4543 = ADS 16904: CHR 149 Aa и A 643 Aa-B. Поред тога дате су и прелиминарне динамичке масе и динамичке паралаксе.