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Determination of orbits of visual binary and linear elements of double stars

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We determined the orbital elements for two binaries and the linear solutions for eight double stars by using the relative coordinates among which there are those obtained from our CCD frames, taken at NAO Rozhen and AS Vidojevica. Also, we applied existing criteria for establishing the nature of these double stars. The criteria are mostly based on some fundamental properties, such as the energy-conservation law, Kepler's third law, etc, which should be obeyed by bound pairs. Our analysis shows that all eight double stars are most likely not gravitationally bound, i.e. they are optical pairs.

Keywords: Visual double star, orbital elements, linear elements

1 Introduction

The first analytical method for the calculation of the orbital elements was proposed by Koval'skij [12]. Later on many new methods for the purpose of solving some concrete problems were proposed: how to calculate orbital elements on the basis of a low number of measurements; how to obtain high-quality results in the presence of large observational errors and how to avoid a too long calculation. With the introduction of computers Koval'skij's method became more practical with regard to the fact that the "geometric" elements (Kepler's first law) are calculated by using the least-square method. A disadvantage of this method is that the dynamical elements P and T are calculated on the basis of these geometric elements without satisfying Kepler's second law (law of areas) simultaneously. In cases where the observations cover a shorter arc of the orbit or where there are gaps, Olević [7] introduced an improvement by using supplementary, fictive, observations. The fictive position angles are uniformly distributed along the part of the arc not covered with observations. For radius-vectors are determined wide intervals through which the orbit will certainly pass satisfying

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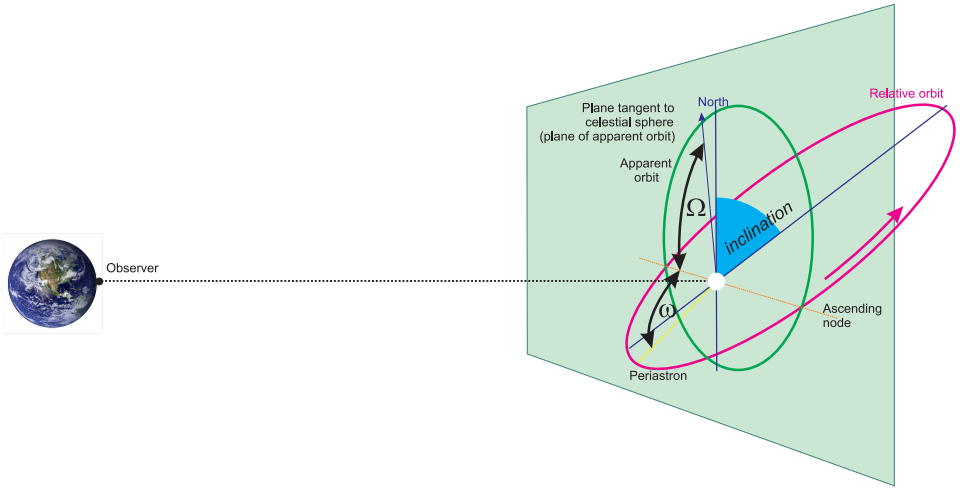


Figure 1 Orbital elements.

optimally the real observations along the arc. These intervals can be determined easily and accurately provided sufficiently wide limits are taken.

The orbital elements (Fig. 1) are: P – orbital period (in years), T – epoch of periastron passage (in fractional Besselian year), a – semi-major axis (in arcseconds), e - eccentricity, i – inclination (in degrees), Ω – longitude of node (equinox 2000, in degrees), and ω – longitude of periastron (in degrees).

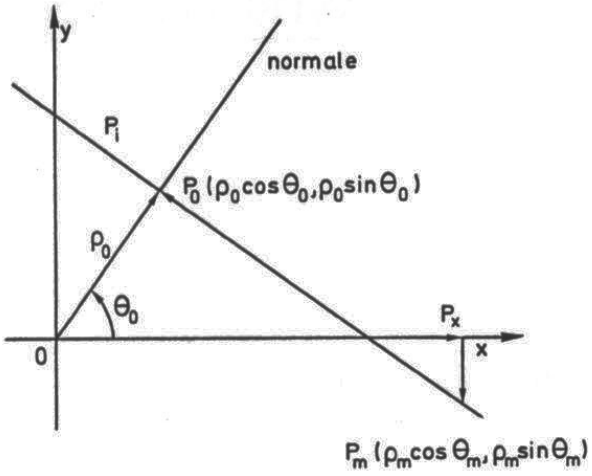


Figure 2 Linear elements.

Many double stars have been established as gravitationally unbound. They are mutually very distant in space so that only their projections are close in the field of view. For the purpose of establishing which of them are physical, i.e. optical, observations within long time intervals are necessary (see [1] and [8]). In the case of

more than 1200 pairs there are linear solutions given in the Catalog of Rectilinear Elements*.

The linear elements (Fig. 2) are: X_0 and Y_0 – coordinates of points with the closest relative separation (in arcseconds), V_x and V_y – components of velocity of relative motion of the secondary with respect to the primary (in arcseconds/year), T_0 – epoch of the closest passage (in fractional Besselian year), ρ_0 – the closest relative separation (in arcseconds), and θ_0 – position angle of the closest passage (in degrees).

A very straightforward method was used to define the motion of the secondary star relative to the primary:

$$x_i = \rho_i \cos\theta_i \ , \qquad y_i = \rho_i \sin\theta_i$$

$$y_i = a x_i + b$$

$$P_0(x_0, y_0) \equiv P_0(-\frac{ab}{a^2+1}, \frac{b}{a^2+1})$$

$$\rho_0 = \sqrt{x_0^2 + y_0^2} \ , \qquad \theta_0 = \arctan\frac{y_0}{x_0}$$

$$\rho_i \cos(\theta_0 - \theta_i) = \rho_0 \ , \qquad \rho_i \sin(\theta_0 - \theta_i) = v(t_i - T_0).$$

2 Results

We recalculated the orbital elements for two binaries: WDS 21289+1105 = STF 2799 AB for which the first orbit was published in [9] and WDS 22234+3228 = WOR 11 for which the first orbit was published in [10]. These orbits are given in Fig. 3.

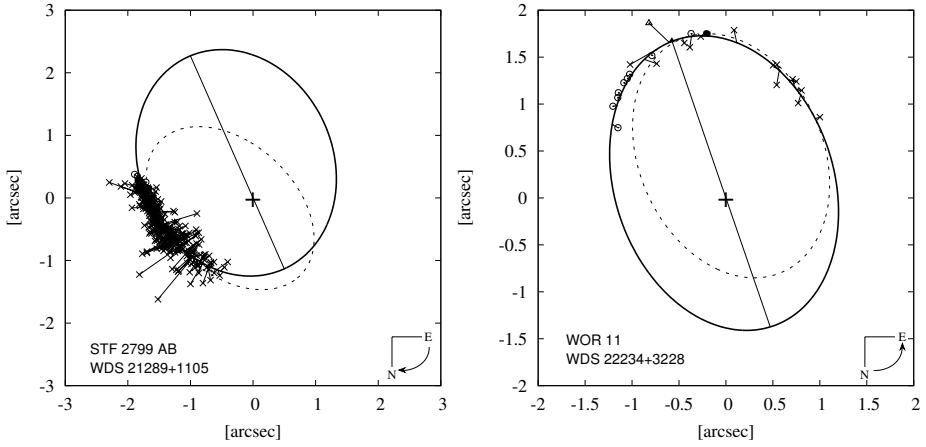


Figure 3 Left: recalculated orbit for binary WDS 21289+1105 = STF 2799 AB [4] and previous orbit calculated [9]; Right: recalculated orbit for binary WDS 22234+3228 = WOR 11 [4] and previous orbit calculated [10]; recalculated orbits are shown with solid line and previous orbits are shown with dashed line.

*http://www.usno.navy.mil/USNO/astrometry/optical-IR-prod/wds/lin1

We calculated first linear solutions for eight pairs for which the measurements show a linear trend [3]: WDS 04312+5858 = STI 2051AB, WDS 04556+1653 = HJ 3263, WDS 05492+2941 = BRT 2521, WDS 09388+0242 = J 78, WDS 17046+3900 = HJ 2804AB, WDS 18489+1615 = STF 2400A-BC, WDS 19500+0637 = J 1336AB and WDS 20087+1223 = J 1338. Detailed analysis of these pairs are given in the paper [2]. The linear fits are given in Fig. 4.

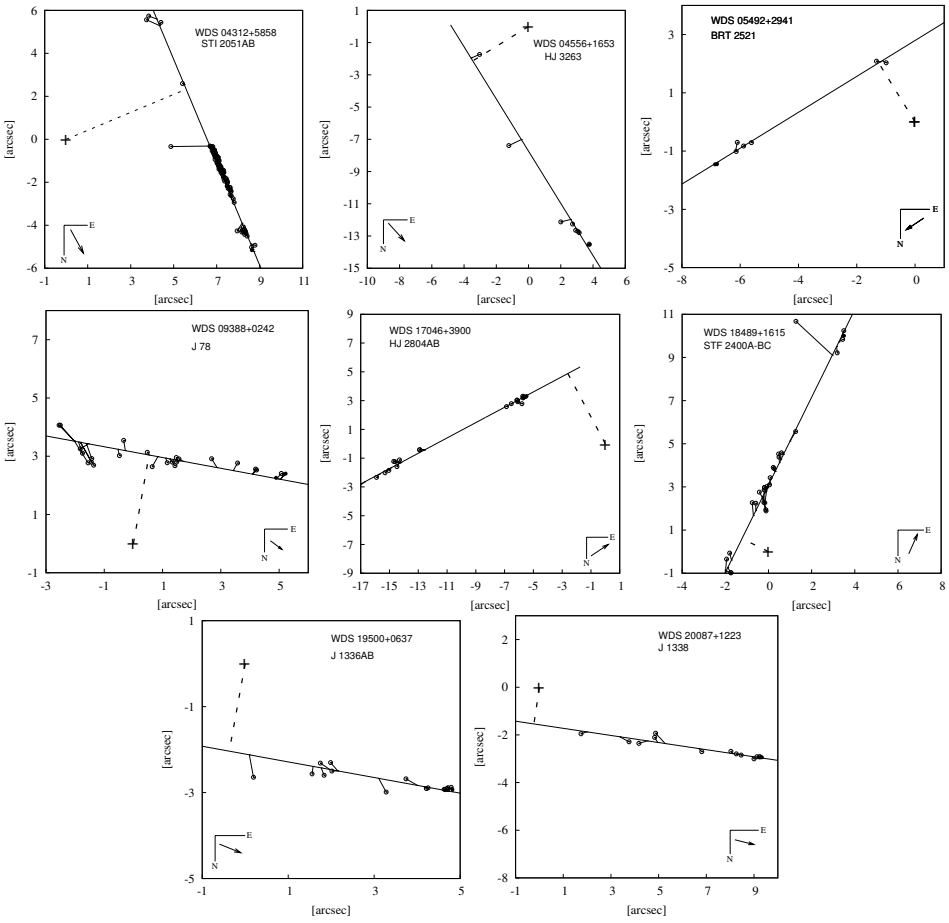


Figure 4 Linear fits for eight pairs are presented. Our measurements of these pairs shown in these figures (filled circles) are included in the calculation of the linear solutions. In the lower right (or left) corner the arrow indicates the sense of the motion for the secondaries with respect to the primary (brighter star).

The components V_x and V_y are used to calculate the velocity V of relative motion of the secondary with respect to the primary. The proper motion in right ascension $\mu_\alpha \cos\delta$ and the proper motion in declination μ_δ are taken from SIMBAD database for one or both components of pair (the primary A and secondary B) if it is available. They are given in Table 1. Using them, we can calculate the relative proper motion μ_{rel} for the pairs

Table 1 Magnitudes, components of proper motion, velocity and relative proper motion of pairs STI 2051AB, HJ 3263, BRT 2521, J 78, HJ 2804AB, STF 2400A-BC, J 1336AB, and J 1338.

Pair	m_A	m_B	$\mu_{\alpha A}\cos\delta$ [″/yr]	$\mu_{\delta A}$ [″/yr]	$\mu_{\alpha B}\cos\delta$ [″/yr]	$\mu_{\delta B}$ [″/yr]	V [″/yr]	μ_{rel} [″/yr]
STI 2051AB	11.38	12.13	1.3002	−2.0490	1.3356	−1.9626	0.093	0.111
HJ 3263	11.34	12.35	−0.044	−0.057	0.006	0.006	0.080	0.075
BRT 2521	9.8	11.2	0.092	−0.056	−0.015	−0.042	0.108	0.090
J 78	11.14	12.9	−0.076	0.000	−0.031	−0.058	0.073	0.069
HJ 2804AB	11.00	13.3	−0.052	0.002	0.025	−0.044	0.090	0.095
STF 2400A-BC	8.08	10.2	−0.033	0.064	–	–	0.072	0.072
J 1336AB	11.0	11.4	−0.011	−0.018	0.029	0.009	0.048	0.048
J 1338	11.75	12.3	−0.022	−0.011	–	–	0.025	0.075

$$\mu_{rel} = \sqrt{(\mu_{\alpha A}\cos\delta - \mu_{\alpha B}\cos\delta)^2 + (\mu_{\delta A} - \mu_{\delta B})^2}\ .$$

Then, we can compare the proper motion μ_{rel} with the values of the relative velocity V for all eight components in linear solutions. An agreement between them is an argument in favor of the fact that pairs are not gravitationally bound, but they are optical pairs. As can be seen in Table 1, the values of V and μ_{rel} are in good or excellent agreement for seven pairs. In the remaining one pair there is a small disagreement and the reason for that may be due to unreliably determined components of proper motion for the primary and/or secondary.

3 Nature of double stars

Our aim is to establish the nature of all observed pairs, i.e. whether they are gravitationally bound or they are mutually very distant in space so that only their projections are close in the field of view.

With regard to the fact that all measured pairs are rather wide, and to answer the question concerning the nature of their motion we need observations covering very long time intervals. The only possibility is to apply existing criteria for establishing the nature of this system. These criteria are mostly based on some fundamental properties, such as the energy-conservation law, Kepler's third law, etc, which should be obeyed by bound pairs.

According to Dommanget's criterion [5, 6] one calculates the minimum parallax (maximum distance) for which the pair is still bound.

The criterion [11] studies the compatibility of the observed relative proper motion (tangential velocity) with the maximum orbital velocity that follows from Kepler's third law. For a double star with bound components, it must obey $V_{tan} < V_{max}$. When it is $V_{tan} > 3V_{max}$, then it will be considered an optical pair.

Conclusion

There is a good agreement between the relative velocity V obtained from our linear fits and relative proper motion μ_{rel} for almost all pairs. This fact supports the view that these pairs are optical (not gravitationally bound).

This conclusion is strengthened by applying dynamical criteria based on well-known laws (Kepler's third law, energy conservation, etc.).

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