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Observations of 61 Cyg at Pulkovo

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Abstract. Results of the photographic observations of 61 Cyg are given. The orbital elements and mass ratio of the components of the pair are calculated. The preliminary orbit of a hypothetical satellite with a period of 6.5 yr is given.

Keywords. Photographic observations, 61 Cyg, dark satellite.

1. Introduction

The photographic observations of double star 61 Cyg [$21^h00^m.6$, $+38^o45'$, $\pi = 0''.296$; $5.^m4$, $6.^m1$; K5V, K7V; $\rho = 30''.5$, $\theta = 150^o(2000)$], have been collected at Pulkovo since 1895 by means of the Carte du Ciel (CdC) astrograph, and since 1958 by means of 65 cm refractor ($D = 65$ cm, $F = 10.4$ m, $M_0 = 19''.81/mm$). As it is known, the assumption on the existence of a satellite near a star of 61 Cyg was first made by Wilsing back in a 1893. Strand (1943) published a short message on the elements of orbit, providing also data on a dark satellite of 61 Cyg, with mass of $0.016M_\odot$ and with the period of the rotation 4.9 years. A supposition about the presence of two dark companions of this star with periods of 6 and 12 years has been made on the basis of the deviations in its orbital motion by A. N. Deutsch in 1960's. The most prominent period of 6.0 years enabled to construct a model of an orbit of the photocentre described under the influence of this hypothetical satellite with elements: $T_0 = 1957.0, e = 0.2, a = 0''.006 \pm 0''.002, i = 34^o, \omega = 108^o, \Omega = 301^o$. The lower mass limit of the probable satellite appeared to be $0.004M_\odot$ (Deutsch & Orlova 1977).

Recently all the observations from the period 1958–1997 have been remeasured by means of the automatic machine "Fantasy" (see Gorshanov *et al.* 2002), and some preliminary results have been discussed. The final outcome of processing of the forty-year series of observations of 61 Cyg with 65 cm refractor is presented in this report.

We would like to point out that the history of research of 61 Cyg shows how with increase of the accuracy of observations and with new theoretical work the previous conclusions had to be reconsidered, since they have not always been supported by new observations. There are papers devoted to the study of this star in which the presence of satellites was not confirmed at all (see, for instance, V_r observations in Campbell *et al.* 1988 and astrometric ones in Jostis 1983, as well as some theoretical conclusions by Marcy & Chen 1992).

The period of deviations in orbital motion of 61 Cyg from Pulkovo observations is found to be 6.5 ± 0.5 years, that is close to the main period found by Deutsch. We tried to estimate it accurately and to draw some conlusions on the possible origin of this periodic wave, taking into account the corresponding observations of other authors and some alternative explanations.

We considered in particular:

(a) the sum of masses and the mass-ratio of components,

(b) the change of geometrical scale over some decades,

(c) the behaviour of residuals O–C obtained after the reduction to the relative orbit for 61 Cyg (ADS 14636) with respect to the control stars ADS 14710 and ADS 7251, and also the behaviour of the residuals obtained after the removal of relative proper motion, the parallax and the orbital motion with respect to the center of masses for the components A and B of 61 Cyg, separately,

(d) possible periodic deviations in the motion of reference stars.

2. Observations

There are at present two series of observations of 61 Cyg in Pulkovo plate archive: I – the plates obtained with 65 cm refractor, and II – the ones from Pulkovo Carte du Ciel astrograph. In this paper we consider only the series I. This series of observations with 65 cm refractor have been collected in the period 1958–1997. It contains 326 plates and about 6000 individual positions with mean error for one position from $0.''028$ to $0.''042$. The mean errors of annual positions are $0.''007$ for distance and $0.^o01$ for position angle.

For the purpose of control, a wide pair (located far enough from the program star) – ADS 14710 [$21^h\ 10^m.5$, $+22^o\ 27'$, $6.^m9$, $7.^m8$; A1V, A0; $\rho = 18''.1$; $\pi = 0''.002$] has been observed after 61 Cyg each night since 1976. The detection of identical periodic variations with both pairs of stars thus indicates some instrumental problems or astro-climate variations, excluding the misinterpretation in terms of the presence of invisible satellites. So far we collected and measured 170 plates (2600 individual positions) of ADS 14710.

For the additional control we used a series of observations of another double star ADS 7251 [$9^h14^m.4$; $+52^o41'$; $7^m.8, 7^m.9$; K2, K2; $\pi = 0.''166; \rho = 17.''3$]. The series consists of about 220 plates (3300 individual positions) with equal number of the nights and it covers nearly the same period of time (1962–1998) as the series of 61 Cyg.

3. Results

The first stage of our procedure was the determination of the preliminary relative orbit of the visual components and analysis of the residuals O–C in the distances and position angles, or in coordinates X and Y. The data processing followed in general the technique of astrometric reduction described in the Pulkovo Catalogue of Double Stars (Kisselev *et al.* 1988). On the basis of these measurements, the orbit of the visible components was determined (Kisselev *et al.* 1997), yielding: $a = 24.''4., P = 659$ years, $e = 0.48, i = 146^o, T_0 = 1697.0, \omega = 146^o, \Omega = 176^o$. To use the method of the Apparent Visible Parameters (see, Kisselev *et al.* 1997), we had to take into account the relative radial velocity ($\Delta V_r = 1.1$ km/s) of the components. Also for the best fitting of the orbit the old observations far enough in time from present ones are used. The total mass of the visible components was found to be $1.3M_\odot$, and this value is in the best agreement with the mass – luminosity relation ($M - L$).

In the next stage we have determined the mass ratio $B = M_B/(M_A + M_B)$ using the measurements of two components B and A of the visual pair with respect to reference star. The time interval 1958–1997 was sufficient for the determination of the mass ratio B with an error less than 10%. The following equations for 240 positions have been solved in X and Y coordinates:

$$X_i = C_X + \mu_X(t_i - t_0) - B\Delta X_i$$
$$Y_i = C_Y + \mu_Y(t_i - t_0) - B\Delta Y_i$$

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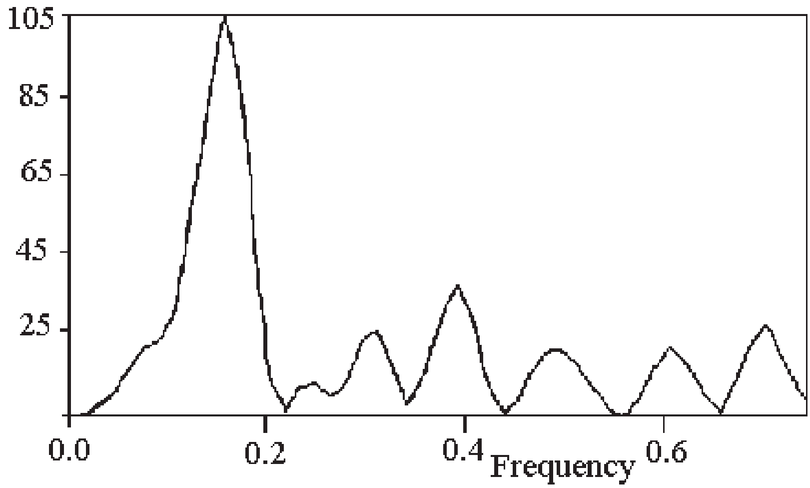

Figure 1. The periodogram of O–C in X projection of B–A distance. The main peak corresponds to the period of 6.5 yr. The power P on y-axis is in relative units.

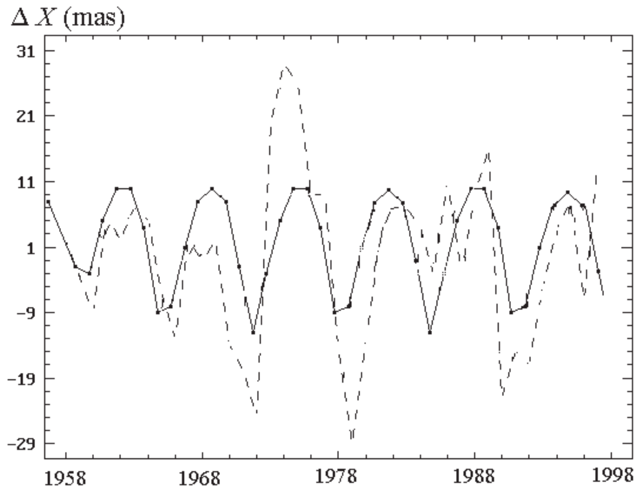

Figure 2. The comparison of residuals in orbital motion of 61 Cyg (dashed line) with the ephemerides calculated on the basis of our new data for photocentric orbit (solid line)

where X_i, Y_i are the positions of the component A on the current plate, with respect to standard plate at the middle epoch t_0. The parallactic displacement and the secular acceleration have been derived from X_i, Y_i;
C_X, C_Y are the positions of the center of the mass at zero epoch;
ΔX_i, ΔY_i are relative positions B–A of the components.

The value of B from the solutions of these equations is equal to 0.38 ± 0.03, and this mass ratio and the sum do not contradict to $M - L$ regularity and to spectral classes of the components.

As a result, the residuals O–C obtained after removal of the preliminary orbital motion from the relative positions B–A of 61 Cyg have shown a small periodic deviations with 6.5 ± 0.5 yr period, which were repeated in two parts of the observation interval, in

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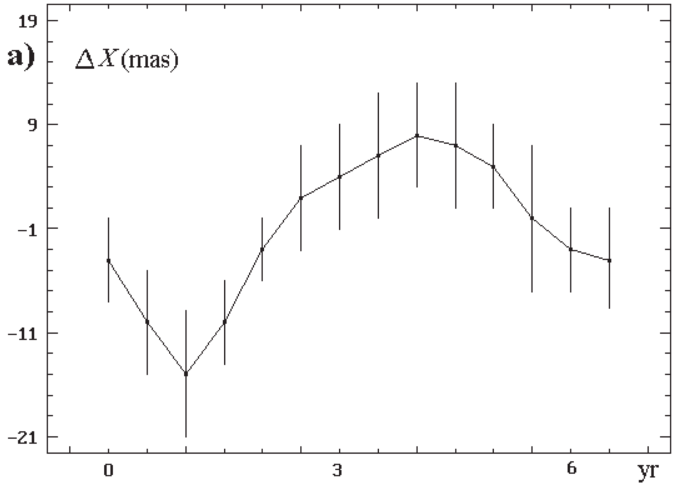

Figure 3. Residuals ΔX averaged over the period of 6.5 years in mas.

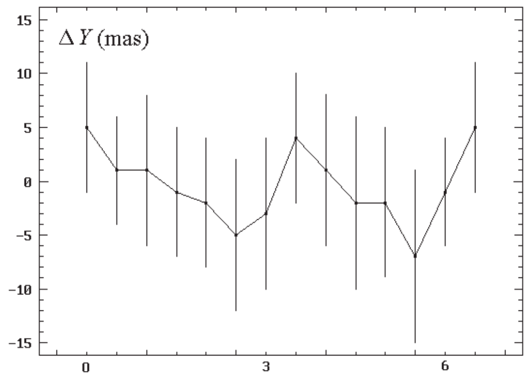

Figure 4. Residuals ΔY averaged over the period of 6.5 years in mas.

1958–1976, and in 1976–1997. However, these periodic deviations were found only in the projection on the RA axis (see Figs. 1–4), but not in the individual motion of each component with respect to the reference stars.

The residuals obtained after the removal of preliminary orbital motion in the relative positions B–A of ADS 7251 and ADS 14710 have also not shown any noticeable periodic deviations in the preliminary orbital motion of the visual components on the all interval of observations.

4. Conclusions

The long term series of observations of 61 Cyg obtained with 65 cm refractor allow to determine the relative orbit and the mass ratio for visual components. The sum and the mass ratio did not show the presence of a noticeable hidden mass of any stellar or substellar component type.

Nevertheless our long series show the periodic deviations in $(B-A)_X$ differences, with periods ranging from 6.2 to 6.7 years, with an average amplitude from 0.″015 to 0.″010, and with mean error of 0.″006 for both, the first part (1958–1974), and the second part (1975–1997) of the series, which were repeated over all the interval of the observations.

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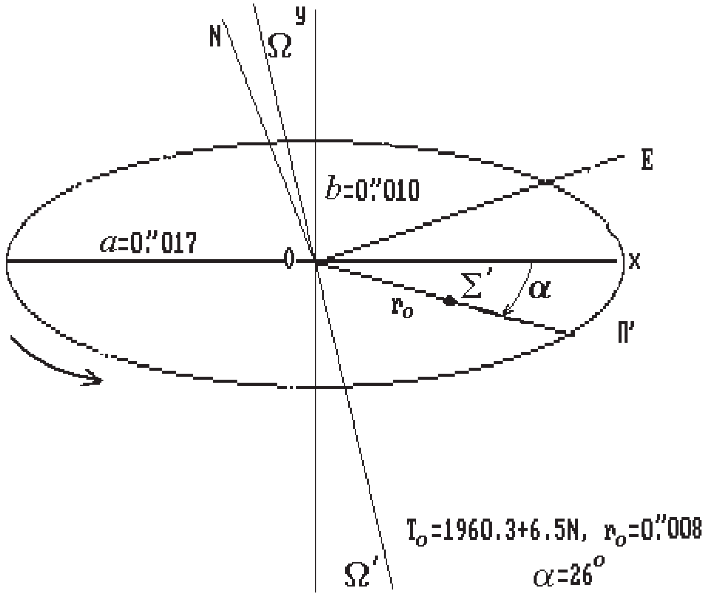

Figure 5. The visible ellipse constructed as a model of the preliminary photocentric orbit for 61 Cyg with orientation to semi-axis and with the period of 6.5 yr. The elements of visual orbit a, b, r_o, T_o are obtained by graphical method of Kisselev (1997) (Σ' is the projection of the center of masses; Π' is the projection of the periastron). The elements of true orbit are $A = 0.''018, E = 0.55, i = 126^o, \omega = 50^o, \Omega = 9^o$. The lower limit of mass of the hypothetical satellite is $0.014M_\odot$.

The construction of the visible ellipse by using these results (see Fig. 5) was quite uncertain. But on the basis of this ellipse and using the method of Kisselev *et al.* 1997 we have calculated a preliminary orbit of the hypothetical satellite with the lower limit of the mass of about $0.014M_\odot$. Probably, we can accept that there are no satellites with masses greater than $0.015M_\odot$ and with periods in the range 3.5–20 years which is accessible for our estimations. But it is possible that some complicated phenomenon created by few satellites with possibly unstable orbits may perturb the observed motion.

We have investigated also the motion of control stars and we studied the geometrical scale, the probable temperature factors and the reduction (in particular, whether any small perturbations exist in the motion of reference stars) etc., looking for alternative explanations of the observed deviations. But our control stars did not exhibit any similar periodic behaviour and the change of the scale allows to consider only the period of 12.0 years as a consequence of some instrumental or astroclimatic causes.

We have taken into account all results of the observers of this star and the other authors, and all arguments against the planetary satellites of this star. But we are aware that the problem of possible existence of one or more unseen satellites of 61 Cyg with the long periods of revolutions and maybe with unstable orbits is not yet solved neither from the astrophysical, nor from the celestial mechanics points of view.

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