# Orbit and estimations of masses of components of ADS 14636 (61 Cygni) on the basis of photographic observations at Pulkovo Observatory

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## Introduction

Double star 61 Cyg (ADS 14636) belongs to Pulkovo list of stars with invisible satellites. This star was an object of research of several generations of the astronomers within many years. The photographic observations of double star 61 Cyg were making at Pulkovo since 1895 by means of Normal astrograph and since 1958 by means of 26″ refractor.

The relative orbit of the 61 Cyg components was determined many times by different researchers including Pulkovo astronomers (see Table 1).

**Table 1.** Elements of relative orbits of 61 Cygni components calculated by different researches and adopted total mass.

| ***a*(″)** | ***P*** (yr) | ***e*** | **ω** | ***i*** | **Ω** | $T_p$ | $M_{A+B}$ | **Author** |
|---|---|---|---|---|---|---|---|---|
| 29.5 | 783 | 0.2 | | 64° | | | | *Peters, 1886* |
| 24.5 | 697 | 0.4 | 154° | 53 | 172° | 1686 | 1.1 $M_{\odot}$ | *Fletcher, 1932* |
| 24.5 | 720 | 0.4 | | 52 | | | | *Strand, 1943* |
| 24.3 | 653 | 0.4 | 147 | 55 | 171 | 1677 | 1.3 | *Caro, Veka, 1948* |
| 24.7 | 722 | 0.4 | 158 | 52 | 172 | 1690 | 1.1 | *Jostis, 1983* |
| 24.9 | 734 | 0.40 | 159 | 52 | 172 | 1687 | 1.1 | *Kiyaeva, 1984* |
| 24.5 | 658 | 0.48 | 146 | 54 | 176 | 1697 | 1.3 | *Kisselev, Romanenko, 1998* |

As it is known, the supposition about presence of a satellite near a star of 61 Cyg was expressed by Wilsing in 1893. In a 1943 Strand has published the message on elements of orbit and about mass of a dark satellite of 61 Cyg (*Strand, 1943*). By Strand's results the period of the satellite is equal 4.9 years; lower limit of mass is 0.016 of the solar mass.

A series of papers on results of reduction of these observations was published by A.N.Deutsch. In the papers the orbit parameters of a possible invisible satellite were determined. The article by *Deutsch and Orlova (1977)* contained outcomes of reduction of observations of Pulkovo normal astrograph and 26" refractor up to 1974. An observation material of the Washington observatory and Sproul observatory also was used and one may interpret obtained periodic deviations in the orbital motion as a perturbation from two invisible satellites with periods of 6 and 12 years. The most sure period of 6.0 years has enabled to construct a model of orbit of photocentre circumscribed under influence of this hypothetical satellite with the elements: $T_p = 1957.0$, $e = 0.2$, $a = 0''.006 \pm 0''.002$, $i = \pm 34°$, $\Omega = 108°$, $\omega = 301°$. The lower mass limit of the probable satellite has appeared equal to 0.004 solar mass.

However the research of radial velocity (*Campbell et al, 1988*) has not given results which are indicative of planet-mass satellites presence near 61 Cyg.

The astrometric observations in Naval observatory of USA have not detected periodic oscillations exceeding noise level in mutual distances between components of 61 Cyg (*Jostis et al., 1983*).

But we suppose that from the point of view of celestial mechanics the characteristics of the components and orbital parameters of 61 Cyg are near to stars for which the existence of planet-mass satellites with long periods is assumed. Some of similar stars are considered in the paper of *Benest, 1997*.

## Observation material

Now there are two series of plates with 61 Cyg in Pulkovo glass archive. The first series concerns to observations of 26" refractor in 1958–2005 and contains about 400 plates. The second series includes observation of Normal astrograph in 1895–2001 and contains about 800 plates.

**Table 2.** Parameters of Pulkovo astrographs.

| Instrument | Aperture diameter | Focal length | Scale | Field of view | Plate size |
|---|---|---|---|---|---|
| I. 26" refractor | 65 cm | 10.4 m | 19."81/mm | 0.°7×1.°0 | 13×18 cm$^2$ |
| II. Normal astrograph | 35 cm | 3.4 m | 59."56/mm | 2.°0×2.°0 | 16×16 cm$^2$ |

The part of the first series (1958–1997) was measured by automatic measuring complex "Fantasy" that was developed in Pulkovo observatory (see *Shakht, Polyakov, Rafalsky, 1997*). The error of one exposure on the plates of 26" refractor at the automatic measurements is $0\overset{''}{.}028$, error of one plate containing 20 exposures is $0\overset{''}{.}007$. The mean errors of one annual normal point consisting of 10 plates are $0\overset{''}{.}007$ for a distance between components of the pair and $0\overset{\circ}{.}01$ for position angle.

Thus we have long (40 years), precise and homogeneous series of measured photographic observations of 61 Cygni.

The results of the measurements were processed by two kinds of reduction. First one is obtaining of relative positions of the components — distances and position angles or rectangular coordinates $X$ and $Y$ (secondary component **B** relative to primary **A**). The processing followed in a main to technique of an astrometric reduction stated in the Pulkovo Catalogue of Double Stars (*Kisselev et al., 1988*).

Secondary processing is obtaining of individual positions of the components using surrounding stars as reference. The positions of the components on each plate were calculated in the system of reference plate (near the center of the series) by the six-constant method with some modifications (see *Kisselev, 1982*).

## The relative orbit construction and total mass determination

To construct relative orbit of 61 Cygni components we used apparent motion parameters method (*Kisselev, 1989*). This method allows constructing of an orbit using a short observational arc. Five apparent motion parameters are calculated for the center of the arc:

1) distance between the components,
2) positional angle,
3) apparent relative motion of the components,
4) direction of apparent relative motion,
5) curvature radius of the arc.

Three more parameters are used to construct the orbit:

6) relative radial velocity of the components in the moment corresponding to the center of the arc,
7) trigonometric parallax of the double star,
8) total mass of the pair.

Three of these eight parameters are known insufficiently surely in our case. They are curvature radius, relative radial velocity and total mass. The curvature radius $\rho_C$ is determined with small accuracy because of shortness of the arc.

The relative radial velocity $\Delta v_r$ of the components was determined several times for moments different from central moment of our observational arc (1978.3); see the Table 3. We adopted $\Delta v_r = 1.1$ km/s as initial value.

**Table 3.** Results of determinations of relative radial velocity of 61 Cyg components.

| **Years of measurements** | $v_{rA}$ **(km/s)** | $v_{rB}$ **(km/s)** | $\Delta v_r$ **(km/s)** | **References** |
|---|---|---|---|---|
| 1982 | –66.08 | –65.01 | 1.07 | *Kisselev et al, 1987* |
| 1983–1985 | –64.96 ± 0.05 | –63.88 ± 0.04 | 1.08 ± 0.06 | *Marcy, Benitz, 1989* |
| 1982–1987 | –65.14 | –64.07 | 1.07 ± 0.12<br>1.10 ± 0.08 | *Romanenko, Chentsov, 1994* |
| 1986.4723 | | | 1.169±0.118 | *Campbell et al, 1988* |
| 1989–1992 | –66.06 ± 0.12 | –64.58 ± 0.17 | 1.48 ± 0.21 | *Tokovinin, 1994* |

The components masses may be determined approximately from their spectral types. The mass of 0.7 Solar mass corresponds to K5V spectral type (primary component of 61 Cygni) and 0.6 Solar mass corresponds to K7V (secondary component). Total mass $M_{\mathrm{A+B}}$ of 1.3 solar mass was adopted as initial value.

These three parameters were varied to obtain better orbit. To control the orbit that we calculate from our short observational arc and current values of these parameters we use whole array of 61 Cyg observations made in the world and collected at the site of WDS Catalogue (*http://ad.usno.navy.mil/ad/wds/wds.html*).

The better accordance between calculated orbit and the observational array was achieved with following values:

$\Delta v_r = 0.9 \pm 0.1$ km/s,

$M_{\mathrm{A+B}} = 1.2 \pm 0.1\ M_\odot$.

The elements of orbit corresponding to these values are:

$a = 82 \pm 2$ a.u. ($24''.27 \pm 0''.59$)

$e = 0.49 \pm 0.03$

$i = 129^\circ \pm 2^\circ$ ($51^\circ$)

$\omega = 149^\circ \pm 6^\circ$

$\Omega = 178^\circ \pm 2^\circ$

$P = 678 \pm 34$ yr.

$T_p = 1709 \pm 16$ yr.

(The apparent motion parameters method allows calculation of accuracy of obtained elements.) The Figure 1 demonstrates obtained orbit.

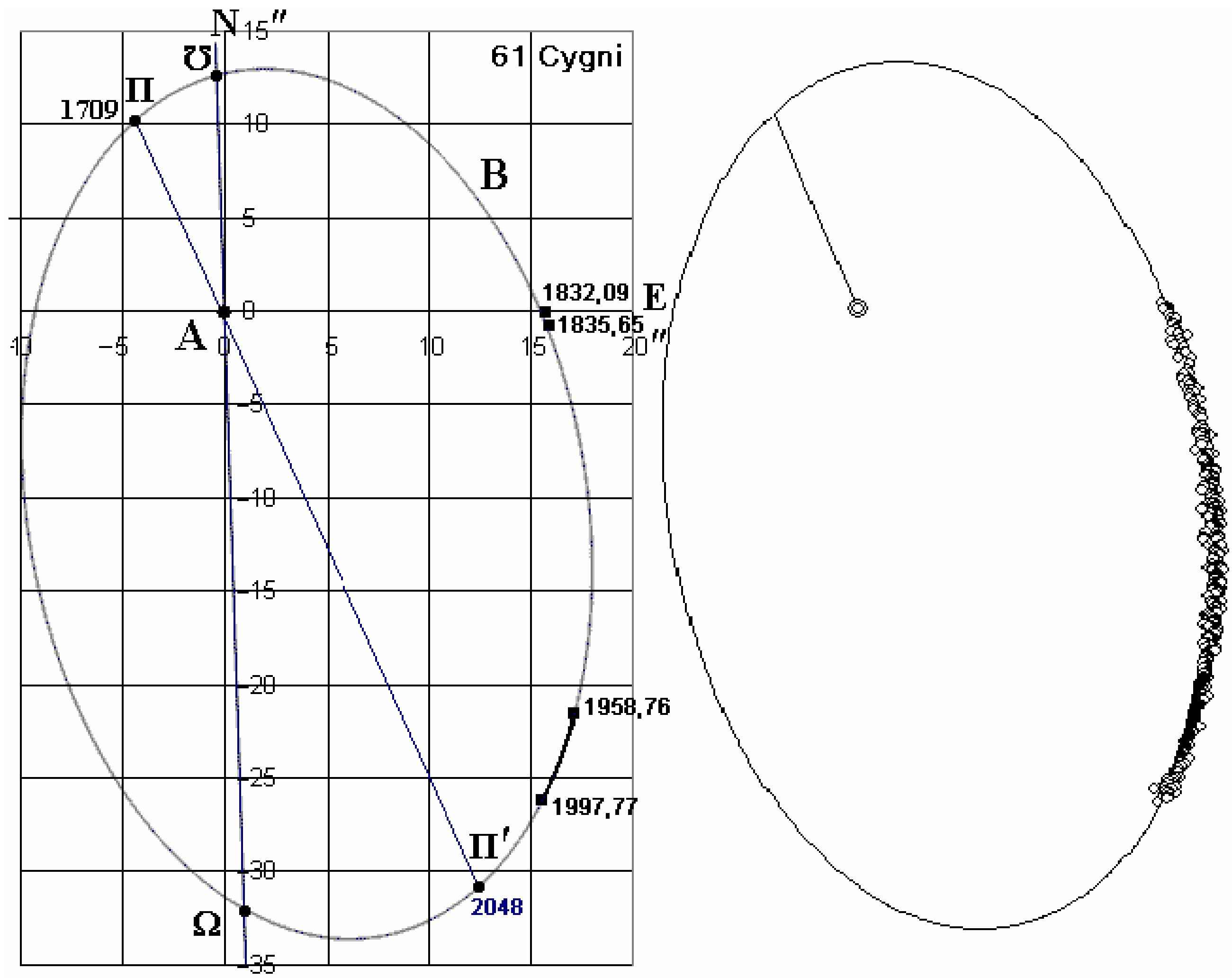


**Fig. 1.** The visible relative orbit of 61 Cyg components with Pulkovo 26" refractor observational arc (left) and whole array of observations made in the world (right).

## Determination of mass ratio of 61 Cygni components

The attempts to determine the mass ratio of 61 Cyg components were made by *van de Camp (1940, 1981)*. He used two methods and obtained two values of coefficient $K_{\mathbf{B}} = M_{\mathbf{B}} / M_{\mathbf{A+B}}$: 0.38 and 0.5.

We used our forty-years-long series of individual positions of 61 Cyg components to determine their mass ratio. We try to apply several methods. The following one was found to be the better.

We suppose that center of mass of the double system moves in space uniformly. The following equations constructed for each plate express this:

$$C_X + \mu_X t = X_{\mathbf{A}} (1 - K_{\mathbf{B}}) + X_{\mathbf{B}} K_{\mathbf{B}} - \pi_{tr} P_X - Q_X t^2 ,$$
$$C_Y + \mu_Y t = Y_{\mathbf{A}} (1 - K_{\mathbf{B}}) + Y_{\mathbf{B}} K_{\mathbf{B}} - \pi_{tr} P_Y - Q_Y t^2 .$$

Here

| | |
|---|---|
| $C_X$, $C_Y$ | are coordinates of center of mass relative to point of origin of the reference plate, |
| $\mu_X$, $\mu_Y$ | are components of proper motion of center of mass relative to reference stars, |
| ($X_{\mathbf{A}}$, $Y_{\mathbf{A}}$), ($X_{\mathbf{B}}$, $Y_{\mathbf{B}}$) | are coordinates of primary and secondary components on current plate relative to reference stars on the reference plate, |
| $\pi_{tr}$ | is trigonometric parallax of the double star, |
| $P_X$, $P_Y$ | are parallactic factors, |
| $t$ | is time relative to the moment of the reference plate, |
| $Q_X$, $Q_Y$ | are quadratic terms consisting of two effects:<br>perspective acceleration,<br>quadratic effect in movement of the reference stars system. |

The systems of the equations for both coordinates $X$ and $Y$ are solved by the least square method for $C_X$, $\mu_X$ and $C_Y$, $\mu_Y$. Parameters $K_{\mathbf{B}}$, $Q_X$, $Q_Y$ are varied to achieve least standard deviations with conformed value of $K_{\mathbf{B}}$ for both systems.

Using this method we obtained value of coefficient $K_{\mathbf{B}} = 0.38 \pm 0.05$.

From total mass of 61 Cyg components and their mass ratio we obtained:

$$M_{\mathbf{A}} = 0.74 \pm 0.12\ M_{\odot} ,$$
$$M_{\mathbf{B}} = 0.46 \pm 0.06\ M_{\odot} .$$

## Periodic deviations in orbital movement of 61 Cygni

After the construction of the relative orbit of 61 Cygni we obtained (O–C) values for our observational relative positions of the components. Periodograms were constructed for the series of this (O–C) to check the presence of some periodic disturbance in orbital movement of 61 Cygni.

Two wide double stars were used as control pairs. These stars are observed by Pulkovo 26" refractor too. ADS 14710 is observed in the same nights as 61 Cygni since 1976. ADS 7251 has almost the same spectral types of components and almost the same duration of observational series as 61 Cygni. The parameters of the three double stars are shown in Table 4.

**Table 4. Parameters of investigated double stars and their observational series**

| 2000 | 61 Cyg | ADS 14710 | ADS 7251 |
|---|---|---|---|
| $\alpha$ | $21^h0^m.6$ | $21^h10^m.5$ | $9^h14^m.4$ |
| $\delta$ | 38°45' | 22°27' | 52°41' |
| $\mu_\alpha$ ($^s$/year) | 0.3519 | 0.0017 | –0.1714 |
| $\mu_\delta$ (″/year) | 3.128 | –0.013 | –0.615 |
| $\pi$ (″) | 0.296 | 0.0016 | 0.166 |
| $\rho$ (″) | 30.5 | 18.1 | 17.3 |
| $\theta$ (°) | 150 | 119 | 272 |
| ***m*** | 5.4 6.1 | 6.9 7.7 | 7.8 7.9 |
| **Sp** | K5V K7V | A1V A0 | K2 K2 |
| **Measured series** | 1958–1997 | 1976–1998 | 1962–1997 |
| **Number of plates** | 362 | 158 | 233 |
| **Av. accuracy *X* (″)** | 0.007 | 0.007 | 0.006 |
| **Av. accuracy *Y* (″)** | 0.008 | 0.009 | 0.006 |

The series of plates of these two double stars were measured by automatic measuring complex “Fantasy” and processed by the same methods of astrometric reduction as 61 Cygni. The detection of identical periodic deviation at any two pairs could serve as the indication of presence of any common instrumental or astroclimatic reasons but not the indication of invisible satellites presence.

The periodograms constructed for series of deviations of relative rectangle coordinates of components of three investigated double stars are shown on Fig. 2. One can see that only periodogram of 61 Cyg coordinate *X* has two substantial peaks. The larger peak corresponds to period of 6.5 years and the smaller one corresponds to 11.2 years. These values are very close to periods detected by Deutsch (*Deutsch and Orlova, 1977*).

We suppose that the period of 11.2 years may be due to some instrumental reason (for example, to periodic changes of geometrical scale of the refractor). But the period of 6.5 years may be due to presence of the minor mass satellite in the system of 61 Cygni.

The amplitude of the periodic deviations is changing. It is ≈0″.020±0″.007 for the first half of the series and ≈0″.012±0″.008 for the last half. (The period is changing too — from 6.2 to 6.7 years for different parts of the investigated series.) The mass of invisible satellite causing the deviations of such amplitude in orbital motion of 61 Cygni components can not exceed 0.01 solar mass. We suppose that its mass is about 0.006–0.008 solar mass.

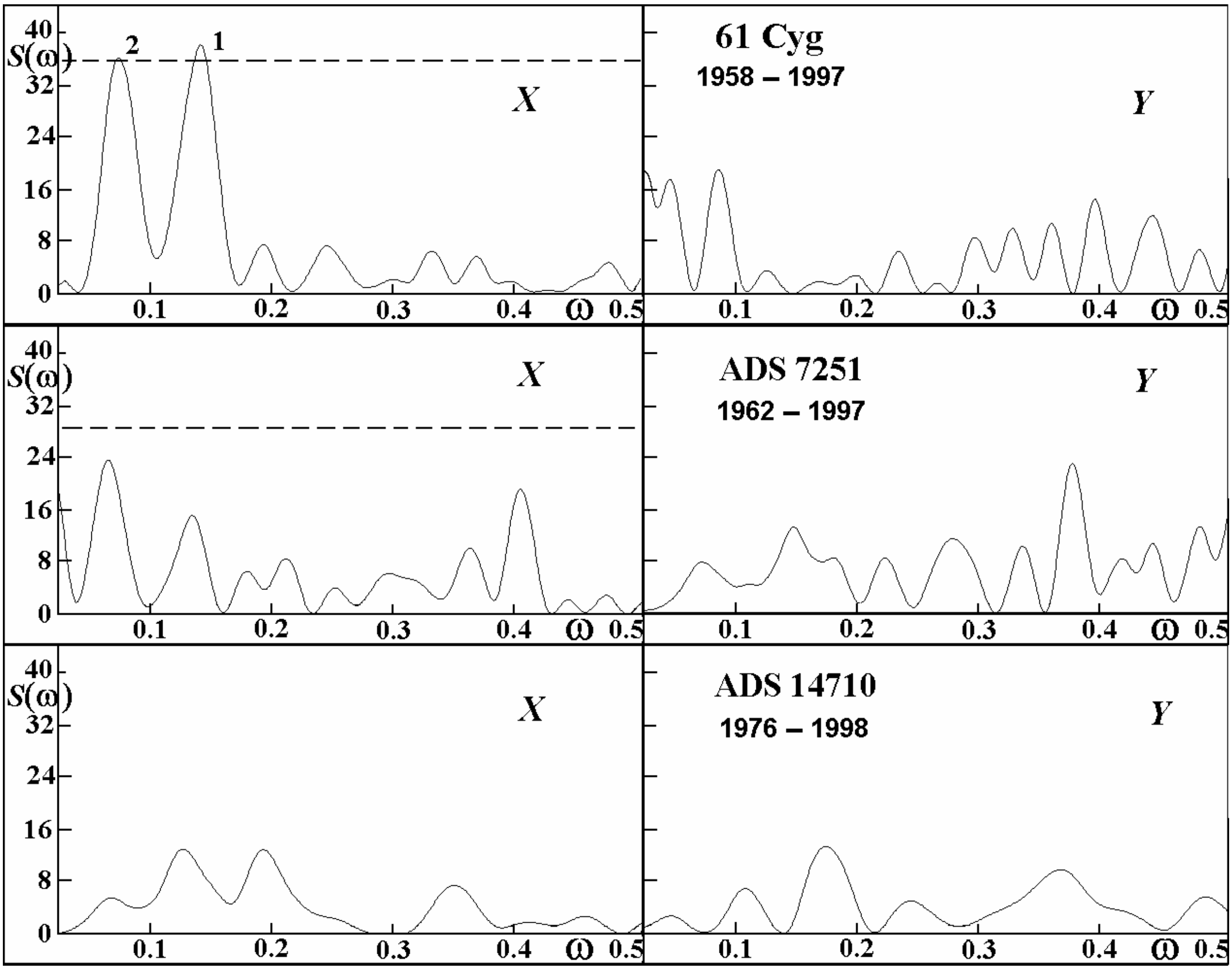


**Fig. 2.** The periodograms of series of deviations of relative rectangle coordinates of three investigated double stars components.

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