Determination of the orbits and estimation of the masses of ADS 7251 and ADS 5983 (δ Gem)

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I. INTRODUCTION.

Our report presents some results of the study of two astrometric binaries: ADS 7251 and ADS 5983 (δ Gem).

The main purpose of our work was the investigation of their dynamics. Also we would like to estimate more precisely the masses of the components in accordance with their spectral classes. After all we were interested on the possible existence of a hidden mass and gravitational influence of probable dark satellites.

ADS 7251 ($\alpha_{2000.0} = 9^h14^m\!.4$, $\delta_{2000.0} = +52°41$; $\mu_\alpha = -0^s.1714$, $\mu_\delta = -0''.615$; $\pi = 0''.166$; $7^m.8$, 7^m9, K2, K2 [1]). For the mean moment of our observations (1979.3) $\rho = 17''.7$ and $\theta_{(2000.0)} = 85^o.8$.

There is a long history of positional observations and the determinations of orbit and masses of the components (see [2–4] and the Table 1). From this table one can see that the elements of its orbit and the estimations of the mass differed. Its spectrum in Hipparcos catalogue is K2, K2 for both components, but in WDS Catalogue [5] **A** and **B** components belong to M0V, M0V classes. We have undertaken some attempts to estimate its orbits and masses on the basis our homogeneous long-term series.

ADS 5983 (δ Gem) ($\alpha_{2000.0} = 7^h20^m\!.1$, $\delta_{2000.0} = +22°00$; $\pi = 0''.061$; $3^m.5$; 8^m2; F2IV, dK6 [1]). For the mean moment 1981.2 $\rho = 6''.0$; $\theta_{(2000.0)} = 221^o$. We are interested in this star as in the object with a suspected massive unseen component $6 \div 10\ M_\odot$ [6–7].

Our observations had not shown any large deviations in the separations between visual components, but a little wave with the period 5.6÷6.1 years [8] has been revealed with a small amplitude ~0".02. The motion of dark companion with a mass about 0.2 solar masses is analyzed. The deviation had a complicated character and it is not excepted that it is an influence of fourth component with a period ~1 year, which have been proposed by [9]. Some hypotheses on the other companion with the period about 1 year are not refuted. But their masses must be lower — 0.1÷0.2 $M_\odot$ as the amplitudes of the deviations are small and now our relative orbit for δ Gem has been obtained with total mass 2.5 $M_\odot$ quite corresponding to **A** and **B** spectrum.

II. OBSERVATIONS

Our data have been founded on homogeneous long-term series of photographic observations by means of Pulkovo observatory refractor (D = 65 cm, F = 10.4 m, M = 19".81 in mm). For ADS 7251 196 plates with 3000 positions have been obtained in 1962–1996. Mean error of the yearly normal point is equal to 0".005. On 115 plates the system of six reference stars has been chosen for the determination of the individual motion of component **A** as a single star.

For ADS 5983 (δ Gem) 126 plates with 1500 positions **B**–**A** have been obtained in 1972–2006. Mean error of yearly normal points reached 0″.012÷0″.018. Some fall of the precision in the recent years is connected with the change for the worse of last photographic material.

All observations of δ Gem are enough difficult because it is not wide pair and also observations have been made with differential grating as two components have difference in the brightness about 5 magnitudes.

In this work we sum up the photographic observations of these stars at Pulkovo observatory and now we have the parallel CCD observations.

Determinations of the orbit and masses of ADS 7251 are given in the Table 1. The most homogeneous observations in WDS catalogue are observations of the Naval Observatory in 1968–1984. Some of our observations are in this catalogue too. The most recent determination of the orbit and masses was the orbit by Chang (1972) [4] and the determination on the basis of Pulkovo observations [10]. Our present set is enough long and it has covered the modern interval of time.

Observations of ADS 5983 (δ Gem) with USNO 26" refractor have been made on the whole in 1966–1976. Also the WDS catalogue contains many observations of ADS 5983, but they have been made by means of various instruments. The homogeneous set of separations ρ and position angles $\theta_{(2000.0)}$ since 1972.2 given in WDS is our Pulkovo set, which now we continued to 2006 year.

III. RESULTS

1. The orbit of ADS 7251

The method of Apparent Motion Parameters (AMP) by Kisselev [10], (also see [12]) has been applied for determinations of orbits of ADS 7251 and ADS 5983. This method is used for determination of the orbit by means of a short arc of observations, but the precise parallax and the relative radial velocity of the components must be used as necessary additional parameters.

The fitting of the orbit to the observations has been made with the variations of the total mass of the system. The solution with AMP method yields two orbits equivalent in the dynamic sense but different due to angle β between vector of relative position and plane perpendicular to the line of sight. The angle β is not determined as single-valued one. As a control the old observations are used. For ADS 7251 we have used the observations of W. and O. Struve in 1821–1878 (see Fig. 2). The parameters of the orbit are given in the Table 1. The mean yearly positions of ADS 7251 are shown in Figure 1.

In the results we obtained two variants of the orbits, which are are shown in figure 2. We adopted the orbit which is agreed with old observations. The periodogram constructed on the basis of the residuals O–C in X and Y coordinates did not any periods over the noise-level (see the Fig. 3).

Table 1. ADS 7251: the determinations of the orbit.

ΔT	$a['']$	e	P[yr]	T_p[yr]	i [°]	Ω[°]	ω[°]	$m1/m2$	
1823-1954	22.4	0.2	1555	2091	32	74	53	0.45/0.46	[2]
1832-1954	16.5	0.5	687	2194	40	164	40	1.13/1.13	[3]
1823-1969	16.7	0.3	975	2260	21	174	44	0.41/0.73	[4]
1972-2005	24.9	0.15	1761	1931	142	219	221	0.56/0.54	This report

2. Determination of the mass-ratio of ADS 7251 components

For the determinations of mass-ratio we have some difficulties because our series is not very long. Also the direction of the total proper motion of the centre mass is near to the orbital motion direction. We check some algorithms, but the traditional solution of the equations, projected on R.A. and Decl. axis does not allow to separating the unknown values in the equations. Then we choose the projection on H-axis, which is perpendicular to total proper motion of mass centre $\bar{\mu}$. The following formulae have been used:

$$H_{ai} = -X_{ai}\cos\chi + Y_{ai}\sin\chi$$
$$H_{bi} = -X_{bi}\cos\chi + Y_{bi}\sin\chi \qquad (1)$$

Here X_{ai}, X_{bi}; Y_{ai} , Y_{bi} — **A** and **B** heliocentric positions on the moment $\boldsymbol{t}_i$, parallactic displacement has been eliminated beforehand. These positions are obtained with respect to zero-point on the standard plate for the moment $\boldsymbol{t}_0$, which is 1979.3; $\chi = \arctan\frac{\mu_x}{\mu_y}$, where μ_x, μ_y — the proper motion of the centre of system.

In the Fig. 1 the angles are pointed: $\boldsymbol{\psi}$ — positional angle of the tangent in zero-point (the direction of orbital motion found to be 188°), $\boldsymbol{\chi}$ — positional angle of the system's center motion, it is equal to 250°.

And then the system of following equations has been solved:

$$H_{ai}K1 + H_{bi}K2 = C_h + \mu_h(t_i - t_0) \quad (2)$$

Where $$K1 = \frac{m1}{m1+m2};\ K2 = \frac{m2}{m1+m2} \quad (3)$$

and $m1$, $m2$ are masses of **A** and **B** components.

It is seen, that we solve the equations in the axis perpendicular to the direction of proper motion of the centre mass $\bar{\mu}$ and so the proper motion of the centre mass of system can not be determine. $\boldsymbol{\mu_h}$ is the remaining motion of the centre mass respect to system of reference stars proper motion projected on the H-axis and the errors of measurements. $\boldsymbol{C_h}$ characterizes the errors of the standard plate.

The solutions of the equations (2) have been undertaken with variations of $K1$ and $K2$ to obtain the minimum of error of unit weight — $\boldsymbol{\sigma_0}$. With $\boldsymbol{\sigma_0} = \pm 0.''032$ we obtained mass-ratio 0.52 ± 0.06 and with the sum of the mass consisted 1.1 $M_\odot$ which was found from our orbital solution the mass of the components are 0.56 and 0.54 $M_\odot$ respectively. The error of mass is not less than $\pm 0.1 M_\odot$

3. ADS 5983 (δ Gem) observations

After propositions on the relativistic component belonged to this star some papers have been published with results, which either did not confirm any periods, see for instance [11], or the discovery have made of enough faint wave in radial velocity with period 1.0 years. The mass of suspected or proposed satellite found to be 1 $M_\odot$ [9]. On the basis of our observations during 1972–2006 we have revealed a wave in the separation with a period ~5.6 years and with amplitude 0''.020 ± 0''.006.

Our estimation of total mass of this visual binary yields 2.5 $M_\odot$ and we proposed that it can not be both a relativistic object with great mass and a star with the solar mass, but it could be a star with low limit of the mass about 0.2 $M_\odot$.

We have compared our result with a new data in «5th catalogue of the orbits», where the elements of the orbit of the photocenter are noticed with the remark "9", as the uncertain data.

The value of the major semi-axis 0".014 is like as our one. In the Table 2 we given these elements and in the first line the elements of the relative orbit of ADS 5983 obtained on the basis of our observations by AMP method are given. The part of relative apparent orbit of ADS 5983 with ephemeris is shown in Fig. 4. The change of relative coordinates ΔX, ΔY with time are shown in the Fig. 5–6. The change of relative distances and the periodogram are given in Fig. 7–8. The models of an apparent photocentric orbit constructed on the basis of Pulkovo observations and Hipparcos orbit are shown in Fig. 9.

The error of the period estimated with periodogram is ±0.5 years, but finally we have many variants of the approximations using the comparison of the observations and ephemeris and our preliminary orbit with period 5.6 years is satisfied to our observations in the best way.

The errors of residuals are enough large and similar to the deviations and the construction of the ellipse was difficult. On the fig. 9(a) we give a variant of the orbit with period 5.0 years, which was the best for the geometrical construction of visual ellipse.

The comparison of our ephemerides with our observations in the interval 1972–1999 is given in Fig. 10. Now we have new observations to 2006.3 and all interval of observations is 34 years with 27 normal points and the periods 5.6÷ 6.1 years are repeated, although the precision of last points has been decreased with the absence of good quality of photographic plates. The existence of periods of deviations have been estimated with periodogram and the orbital parameters for the period of 5.6 years have been estimated with fitting, where as the control was the unit weight error $\boldsymbol{\sigma_0}$**,** which decreased since 0″.024 to 0″.018 after the elimination of orbital motion of photocenter from residuals in the separations.

Moreover we have an additional series of observations 1979–1988 (54 plates) of the bright component ADS 5983 **A** obtained in the reference stars frame. We cannot estimate the long periods with the periodogram on the basis of this short series, but the distributions of the observations are sufficiently to reveal of short periods and some periods 1.2÷1.4 and 2.0 years are revealed in the relative positions of star.

Table 2. ADS 5983. The elements of the orbit, line 1 — **A** and **B**; lines 2–3 — the orbits of photocenter, *m* — masses in solar masses.

Obs.	***a*** [″]	***e***	***P*** [yr]	T_p [yr]	***i*** [°]	**Ω** [°]	**ω** [°]	***m*** ($M_\odot$)
Pulkovo 1972-2005	6.03	0.75	622	1644.8	118	354	64	2.5 (*m*1+*m*2)
Pulkovo 1972-2005	0.023	0.10	5.6	1973.3	43	207	43	0.2 (*m*3)
Hip1997	0.014	0.35	6.13	1973.5	92.4	70	214	0.2 (*m*3)

IV. CONCLUSIONS

Finally, we have obtained **A** and **B** masses respectively 0.56 and 0.54 solar masses accordingly to their spectral classes in [1]. Any perturbations in the separation and position angles of ADS 7251 have not been discovered.

In the motion of ADS 5983 our astrometric observations have been shown perturbations with period from 5.6 to 6.1 years, which are repeated during all interval of observations and assumed the presence of unseen component with low limit of the mass equal to 0.2 $M_\odot$. This effect is complicated, the values of the period and of the amplitude change, in the motion of a bright component a faint wave with period 1.4 yr is noticed too. That may be testifying in favour of the existence of one more dark satellite with small stellar mass. We would like to attract the attention to this interesting object and to compare our observations and suppositions with other results.

References

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[12] E.A.Grosheva (this Symp.,″A periodic perturbations of relative motion of multiple system ADS 15571″).

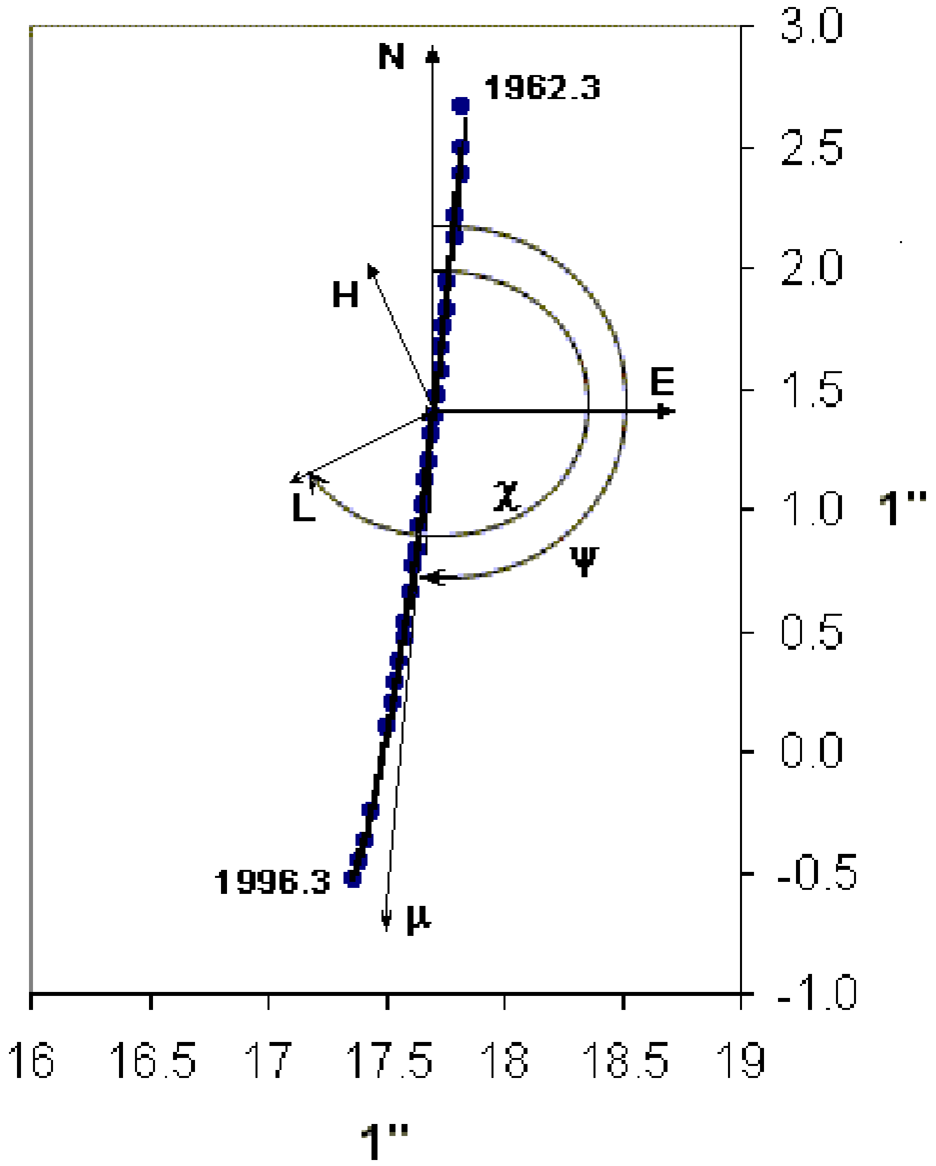

Figure 1. ADS 7251 apparent orbital motion. Here: L — direction of the mass center proper motion and χ — it's positional angle; N — direction to North, E — to East; μ — apparent relative motion of the components and ψ — it's positional angle.

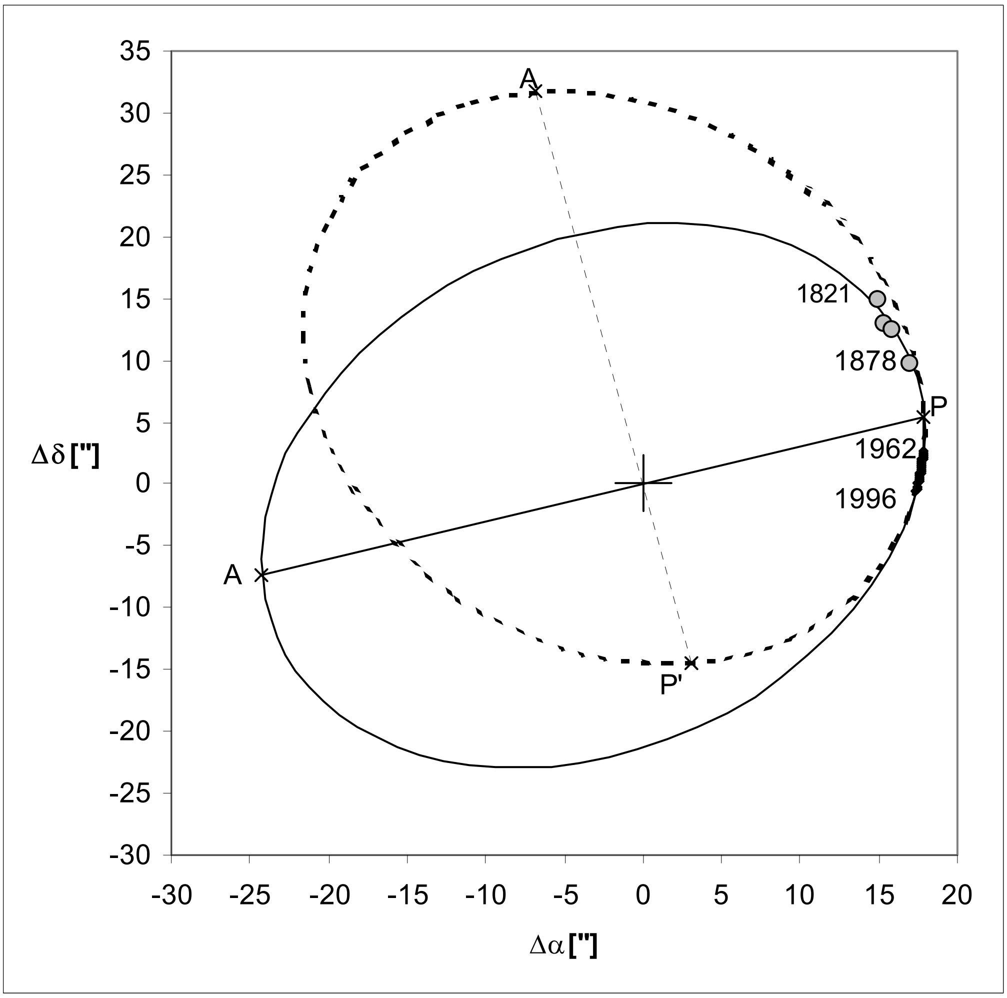

Figure 2. ADS 7251 orbits were obtained using Pulkovo's set of observations. Dashed line corresponds to orbital solution for β ≈ +30°, but this orbit doesn't satisfy to Struve observations what are shown by gray circles. Solid line shows orbit for β ≈ –30° and this variant is in good agreement with Pulkovo's set observation and with positions by Struve.

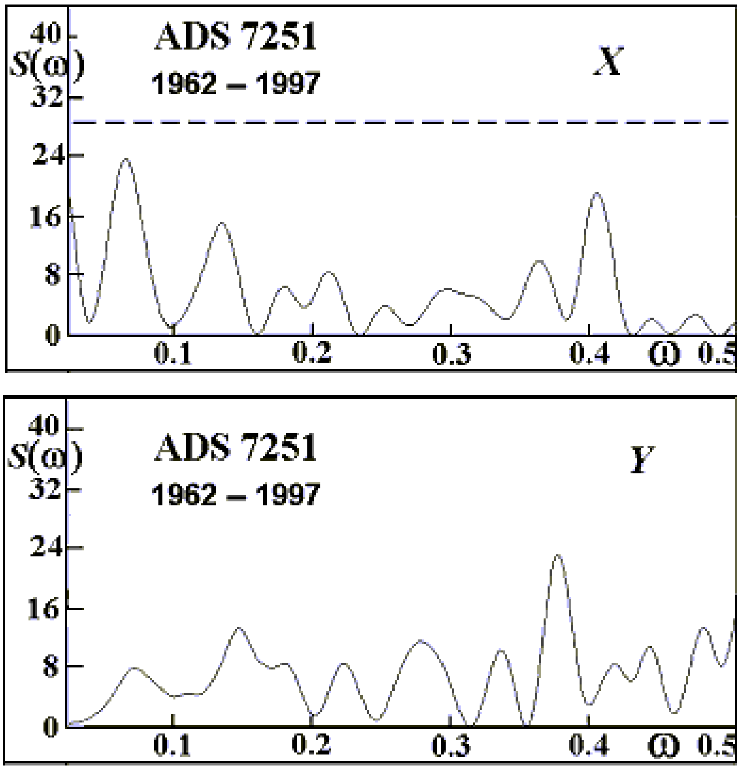

Figure 3. Periodograms for ADS 7251.

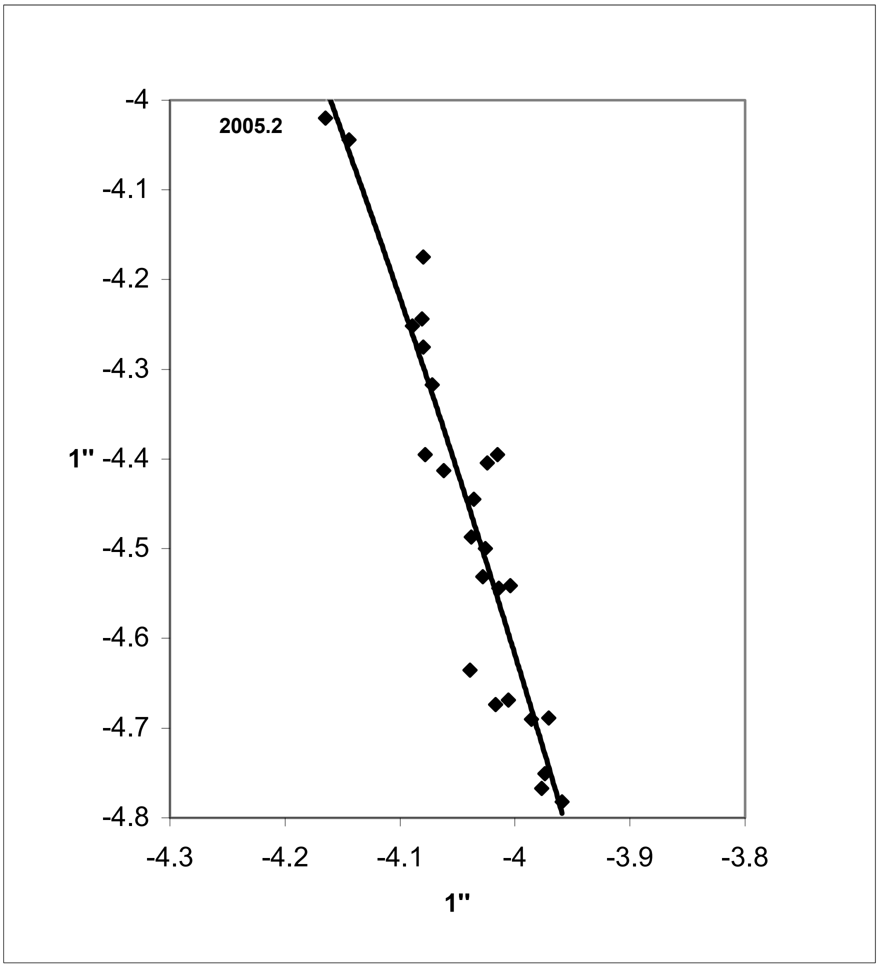

Figure 4. ADS 5983 (δ Gem): orbital ephemerides and observed positions.

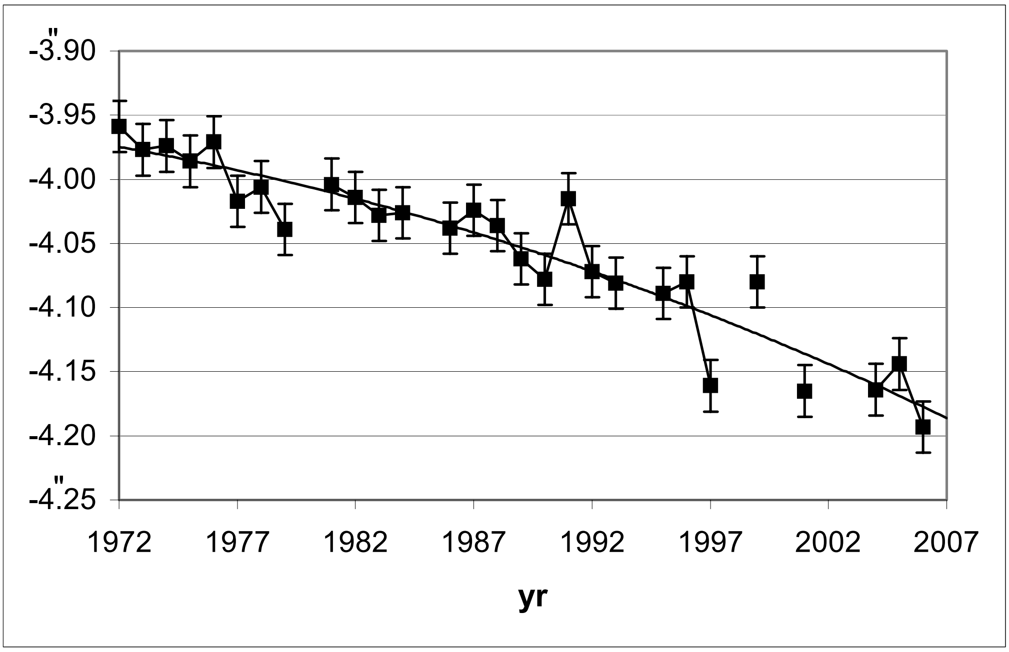

Figure 5. ADS 5389 (δ Gem): differences in *X*-coordinate (Δ*X*).

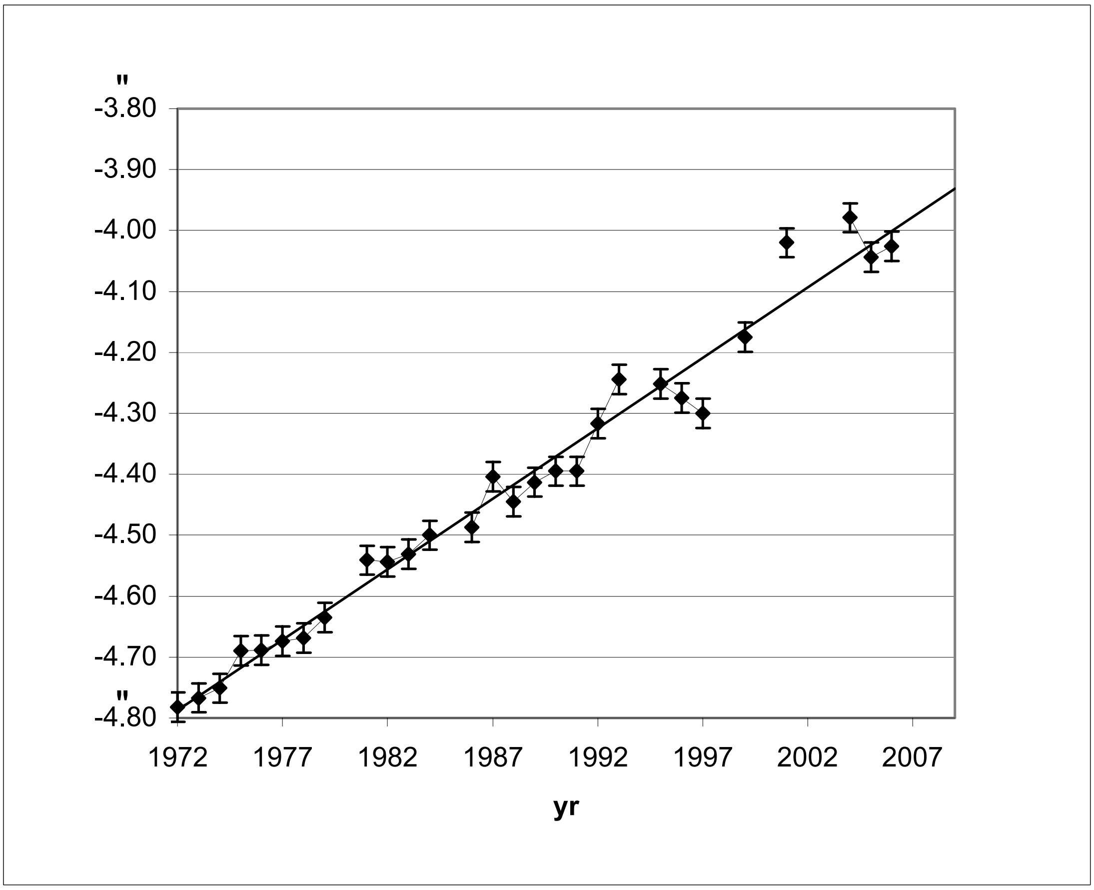

Figure 6. ADS 5389 (δ Gem): differences in *Y*-coordinate (Δ*Y*).

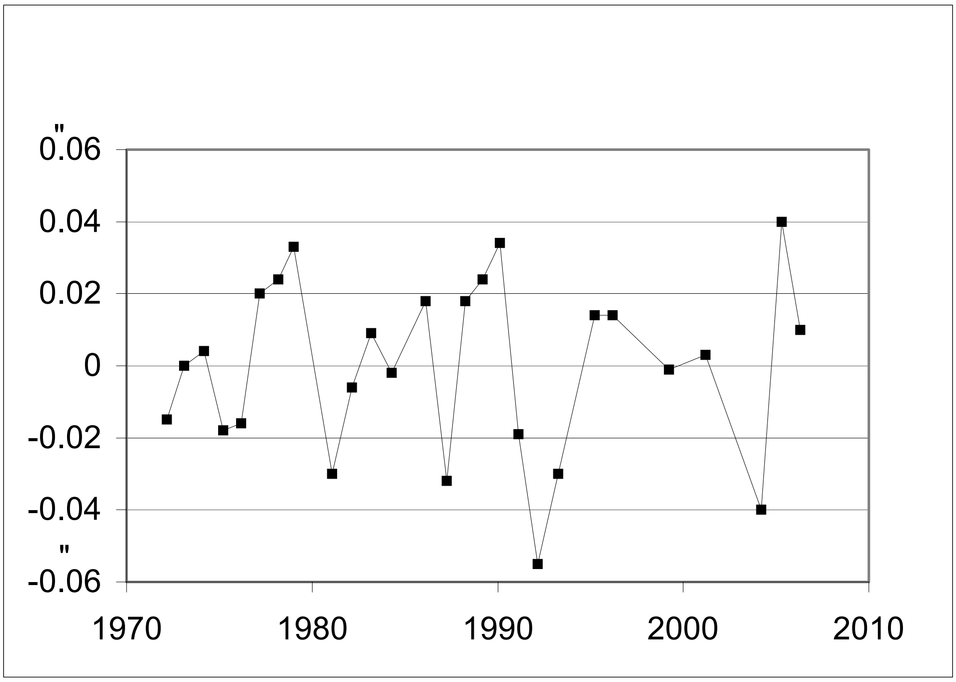

Figure 7. ADS 5983: the residuals in the distances ρ.

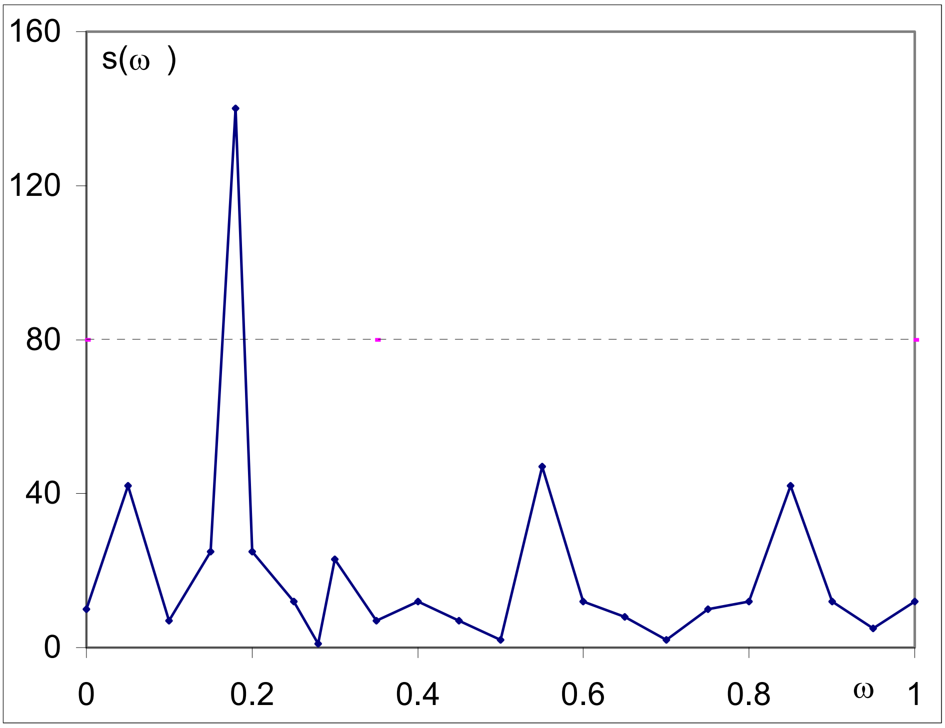

Figure 8. ADS 5983: the periodogram.

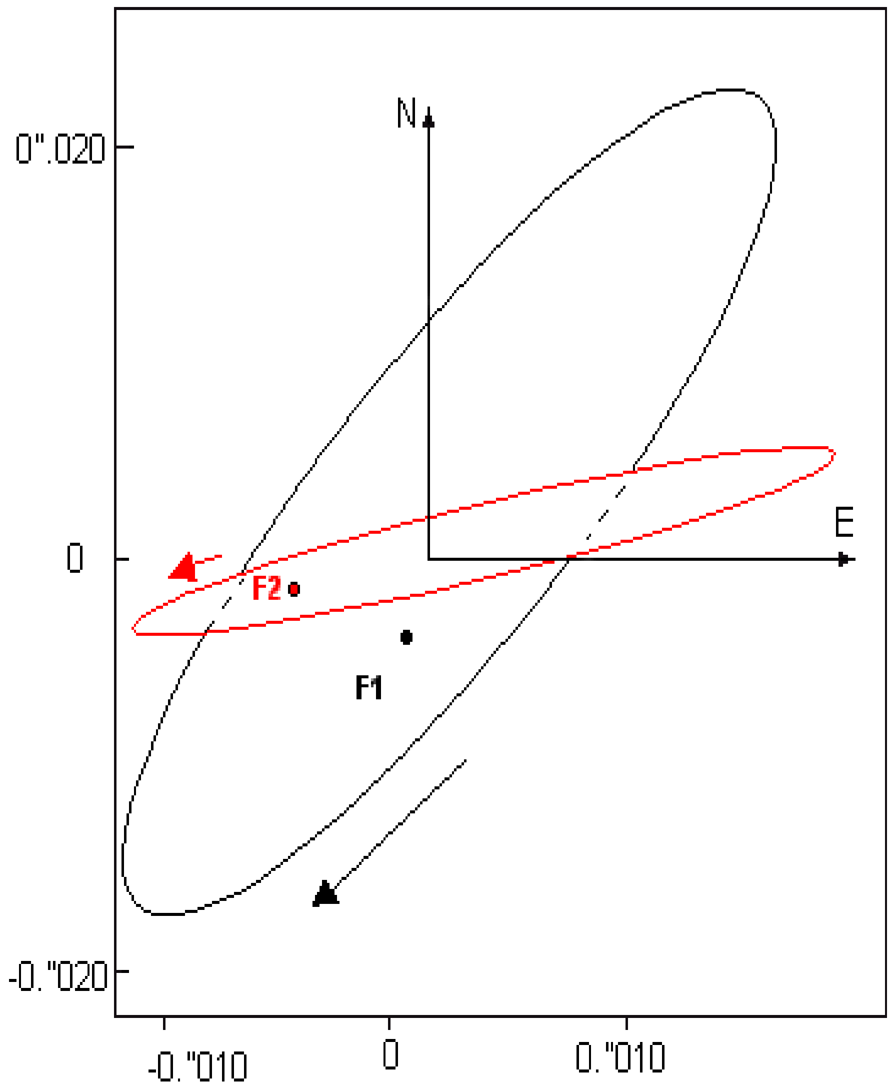

Fig. 9 (a).

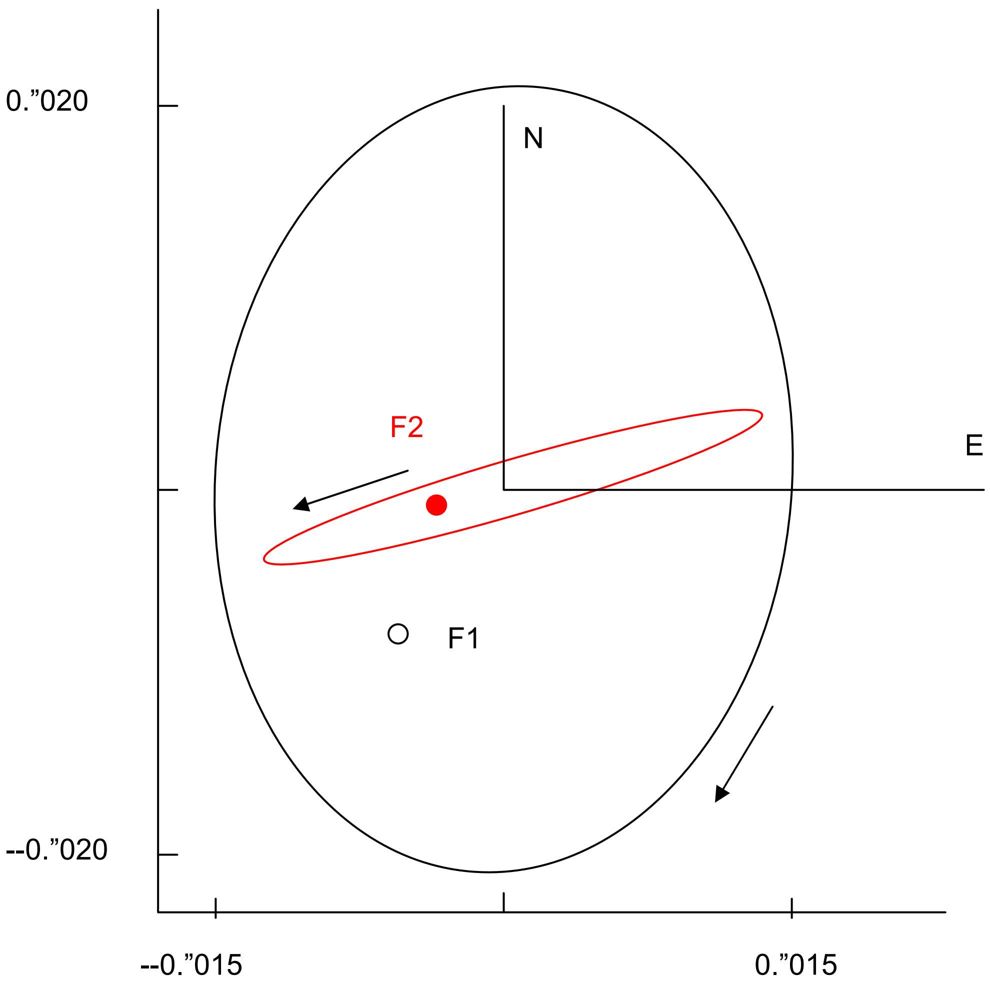

Fig. 9 (b).

Figure 9. ADS 5389 (δ Gem): Two possible models of apparent photocenter orbit. Orbit on Fig. 9 (b) is according to Table 2. Orbit on Fig. 9 (a) has following parameters: $P = 5.0$ yr, $a = 0''.020$, $e = 0.6$, $i = 75^o$, $T_p = 1973.3$. Red ellipse is orbit from HIPPARCOS data.

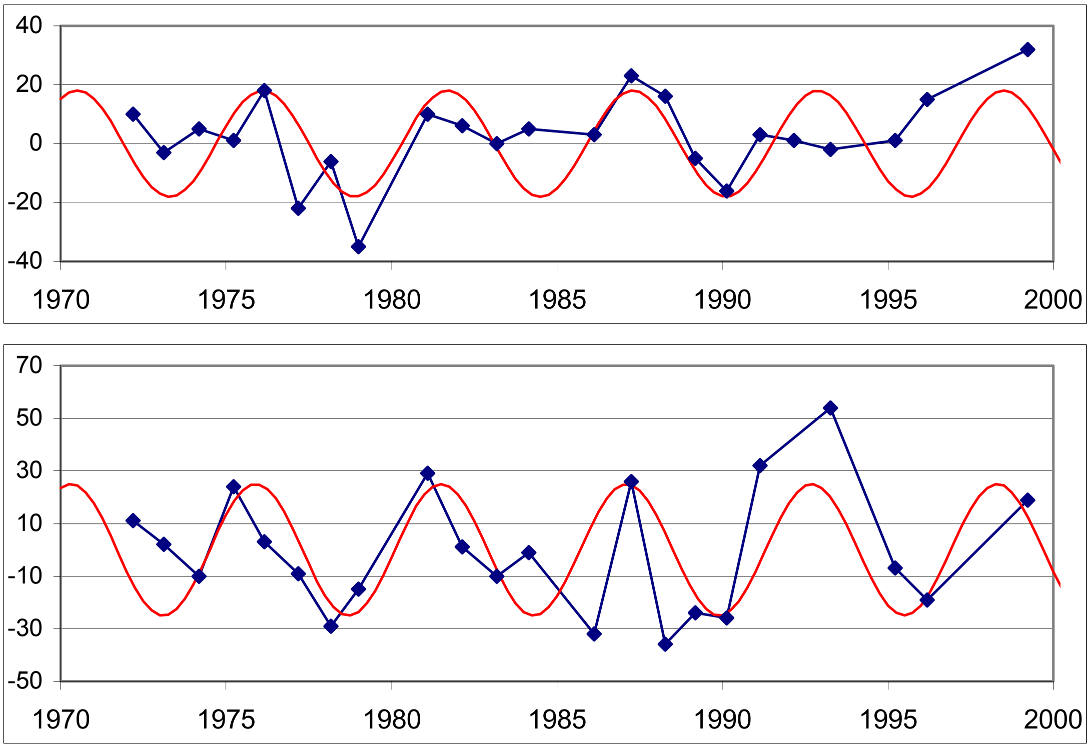

Figure 10. ADS 5389 (δ Gem): the comparison of our ephemerides according to Table 2 (red line)with our observations in the interval 1972–1999. (O–C) for *X* and *Y* are given in mas.