Astronomical and Astrophysical Transactions (*AApTr*), 2021, Vol. 32, Issue 2, pp. 89–98,
ISSN 1055-6796, Photocopying permitted by license only, ©Cambridge Scientific Publishers

Investigation of relative motion in the triple system ADS 48 on the basis of Gaia DR2 and Pulkovo 26-inch refractor observations

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Received 1 March, 2020

There are high-precision positions, proper motions, parallaxes and radial velocities at the instant 2015.5 for all three components of the star ADS 48 ABF in the catalog Gaia DR2 (2018). According to these data relative motions and the family of orbits were calculated by the Apparent Motion Parameters (AMP) method (Kiselev and Kiyaeva, 1980), and the best orbit was chosen for the inner pair AB.

A perturbation with the period of 11 years was discovered according to Pulkovo observations of the outer pair. The reasons for the perturbation are discussed.

Keywords: Stars: double and multiple – stars: invisible satellites – stars: individual: ADS 48 – orbits

1 Introduction

A triple star ADS 48 ABF (HIP 473 and HIP 428) was discovered by O. Struve in 1876. This star has been observed with 26-inch refractor of Pulkovo observatory since 1961. There are 137 photographic plates, the images of three components are presented on 115 photographic plates. They were measured by a Fantaziya automatic device (Kiyaeva et al., 2001). CCD observations of the inner pair AB have been carried out since 2003 (see Izmailov et al., 2010 and 2016).

Common data about the components are presented in Table 1. A comparison of apparent motion parameters (AMP) – an apparent separation between components (ρ), a positional angle (θ), an apparent relative motion (μ) and a positional angle of the direction of the relative motion (ψ) – which were obtained according to high-precision observation Gaia DR2, with AMP corresponding to a series of Pulkovo observations, is presented in Table 2. We use a series of CCD observations 2003–2012 for the inner pair and a photographic series 1968–1996 for the outer pair AB–F. A center of masses

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Table 1 Parameters of the star ADS 48.

Component	A	B	F
par, mas	86.8735 ± 0.0484	86.9402 ± 0.0588	86.9567 ± 0.0407
V_{rA}, km/s	$+1.15 \pm 0.16$	-2.26 ± 0.22	-1.24 ± 0.31
G, mag	8.2482	8.3010	9.0794
SP	K6	M0	M2e
Mass, $M_\odot$	0.66	0.65	0.53

Note: Masses are taken from (Neves et al. 2013), spectral classes – from WDS (Mason et al. 2016), all other data are from Gaia DR2 (2018).

Table 2 Apparent motion parameters (AMP) for inner and outer pairs for instant 2015.5.

ADS $T_2 - T_1$	n	$\rho,''$ $\pm$	$\theta,^\circ$ $\pm$	μ, mas $\pm$	$\psi,^\circ$ $\pm$
48 AB					
Gaia		6.03768	188.205	44.9	288.1
		±0.00008	±0.001	±0.2	±0.2
Pulkovo	48	6.009	188.14	42.8	286.8
2003-12		±0.004	±0.02	±0.3	±0.7
48 AB–F					
Gaia		327.1754	254.254329	5.4	37.8
		±0.0002	±0.0000001	±0.1	±1.1
Pulkovo	115	327.19	254.286	4.3	92
1968-96		±0.01	±0.009	±0.6	±19
Pulkovo	30	327.203	254.295	3.8	71
photo		±0.007	±0.003	±0.2	±7

Note: AMP were obtained according to published observation Gaia DR2 (upper rows) and Pulkovo observations (lower rows). The row "photo" corresponds to the smoothed series. $T_1 - T_2$, observations period; n, number of points.

of components A and B is calculated according to relation $M_B/M_A = 0.985$ (Neves et al. 2013).

As we can see, the motion parameters for the inner pair from Gaia and Pulkovo observations fit each other, but the directions of motions for the AB–F pair are different. This question is considered in this paper.

2 The inner pair AB

The comparison of observations is presented on Fig. 1. There is a systematic difference in the separation $\Delta\rho = 30$ mas between Gaia DR2 and our CCD observations (Fig. 1a). After this correction, a number of orbits of the AB pair were calculated by the AMP method on the basis of Gaia DR2 observations only (AMP, parallaxes and radial velocities). The remaining observations were used to choose the best solution and to determine the mass sum of the components. The first observations fit the orbits with

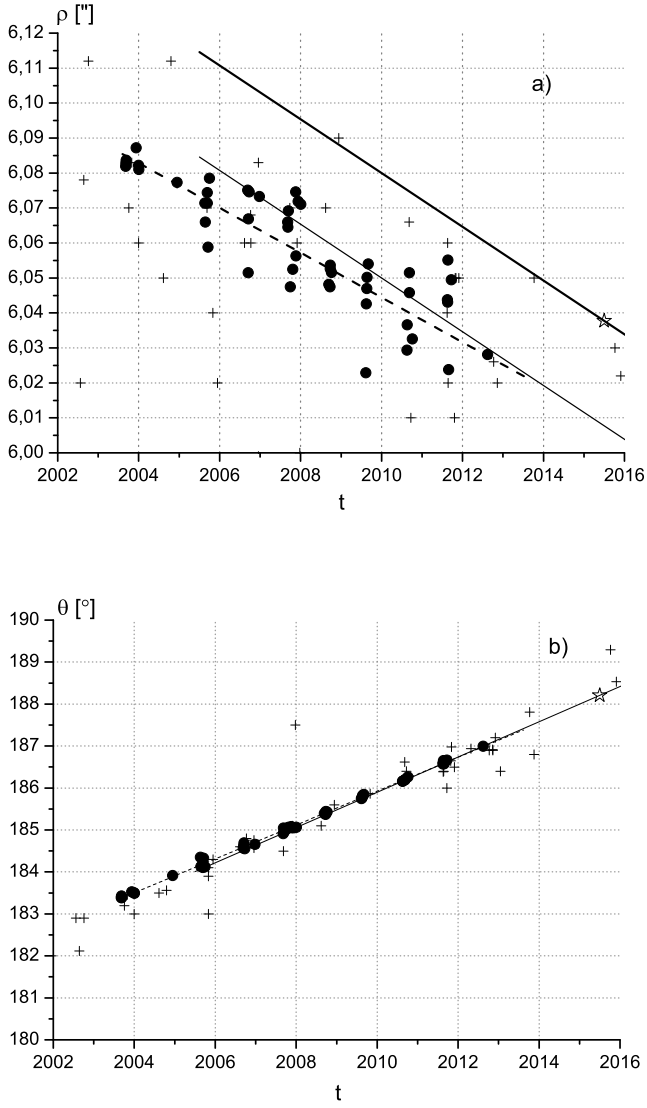


Figure 1 Comparison of the inner pair AB motion with observations: $\rho(t)$ (a),$\theta(t)$ (b). The black circles – Pulkovo CCD observations, the open star – Gaia DR2 position, the crosses – other observations from the WDS catalog. The solid lines denote the Gaia DR2 motion before and after the correction, the dashed line – the motion according to CCD observations.

masses $1.15 < M_A + M_B < 1.4\ M_\odot$ (see Fig. 2a). It is in agreement with published results (Neves et al., 2013; see Table 1).

The orbital elements are presented in Table 3. This orbit fits the AMP orbit which was obtained on the basis of photographic observations (the instant of AMP is equal to 1980.0, see Kiyaeva et al., 2001). Both orbits are obtained independently, but are in good agreement with all observations (Fig. 2).

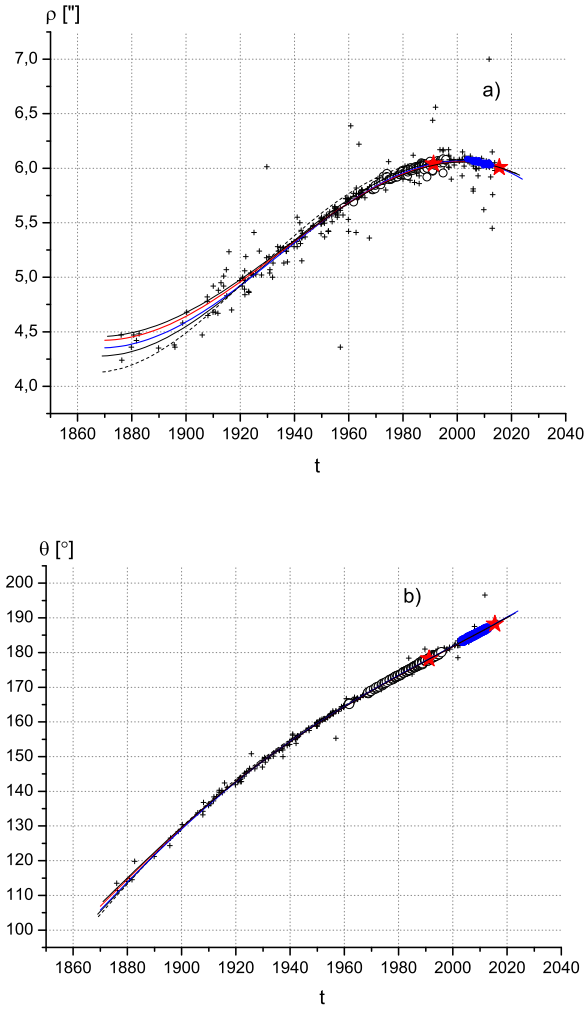


Figure 2 Comparison of the orbit of the pair AB with all observations: $\rho(t)$ (a), $\theta(t)$ (b). WDS observations (Mason et al., 2016) – crosses, Pulkovo photographic observations – open circles, Pulkovo CCD observations – blue filled circles, Hipparcos and Gaia observations – red stars. Solid lines limit the area of orbits with permissible masses $1.15 < M_{A+B} < 1.4\ M_{\odot}$. The ephemerides of orbits from Table 3 are inside this area (the red line corresponds to this work, the blue line corresponds to Kiyaeva et al., 2001). The dashed line corresponds to the mass $M_{A+B} = 1.1\ M_{\odot}$. It crosses the set of all observations.

3 The outer pair AB–F

The comparison of the set of Pulkovo photographic observations with Gaia DR2 is presented on Fig. 3. Since the orbital period of the outer pair is greater than 78000 years (Kiyaeva et al., 2001), the time difference of observations is insignificant.

There is an essential difference in the position angles (Fig. 3a). The mean values were calculated in the sliding window, which is equal to 5 years. Perturbations are

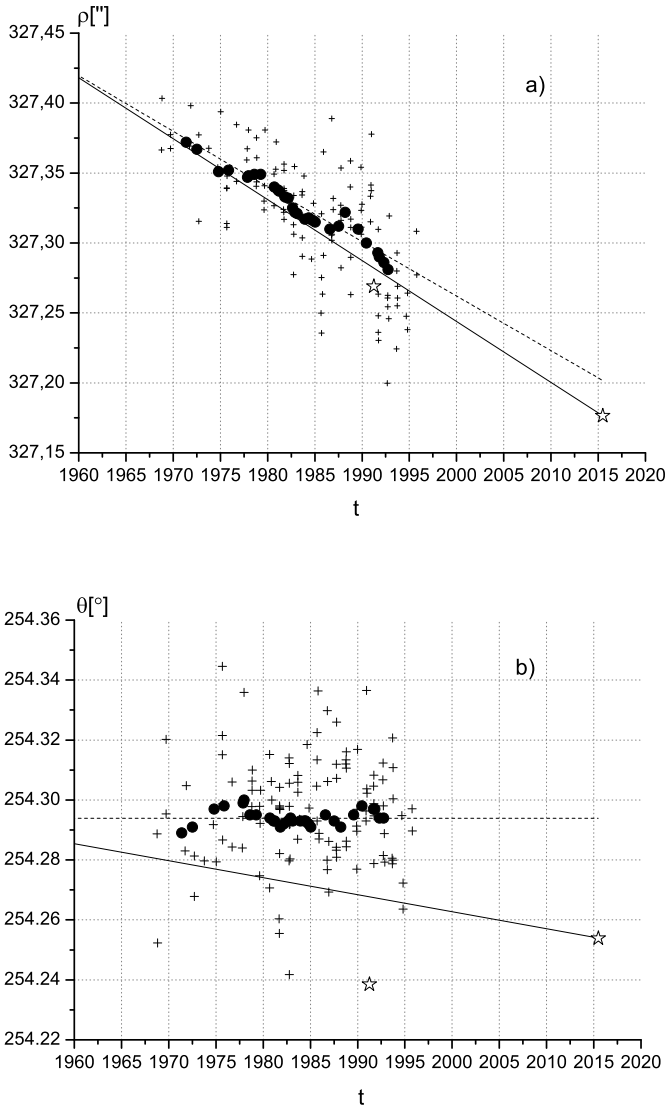


Figure 3 Comparison of the photographic observations of the outer pair AB–F before the smoothing (crosses), after the smoothing (black circles), Hipparcos and Gaia observations (open stars): $\rho(t)$ (a), $\theta(t)$ (b). The solid line corresponds to the Gaia DR2 motion, the dashed line – to the motion according to Pulkovo photographic observations.

discovered in both coordinates with the common period of 11 ± 0.5 years. The amplitudes of these perturbations are small (10 mas in ρ and 0.003° in θ), but we assume that it is not an accidental effect, because the coordinates are independent.

A logical assumption is that there is the fourth body with small mass in the system. It may be a satellite of the distant component F or the satellite in the system AB, which causes fluctuation of their center of masses.

The astrometric orbit was calculated on the basis of these perturbations of the

Table 3 Orbital elements for the inner pair ADS 48 AB.

Ref	This work	Kiyaeva et al., 2001
$M_{A+B}, M_\odot$	1.3	1.40*
a, $''$	6.42 ± 0.89	6.21 ± 0.77
a, a.u.	73.9 ± 10.2	71.5 ± 8.9*
P, y	557.1 ± 120.3	509.6 ± 97.0
e	0.19 ± 0.08	0.22 ± 0.04
$i,^\circ$	54.3 ± 2.3	54.9 ± 2.4
$\omega,^\circ$	255.7 ± 31.4	267.2 ± 27.4
$\Omega,^\circ$	12.5 ± 2.8	13.5 ± 2.3
T	2110.8 ± 28.8	2115.8 ± 19.4

*computed with Gaia parallax 86.90 ± 0.05 mas.

Table 4 The hypothetical astrometric orbits for outer pair (1) and inner pair (2).

Orbital parameters	1	2
a_{ph}, mas	15.0	4.0
P, yr	11.0	10.97
e	0.2	0.3
$i,^\circ$	97	44
$\omega,^\circ$	235	56
$\Omega,^\circ$	147	217
T, yr	1980.0	1982.8

outer pair (see Fig. 4). Here φ is a phase relative to the period of 11.0 years. According to this orbit, the perturbation in radial velocity with an amplitude of 0.47 km/s must be discovered. However, this contradicts the high-precision observations on the Keck 1 telescope, which appear to be more reliable (Tal-Or et al., 2019). According to their observations, additional fluctuations of radial velocity for all components are about 10 m/s.

Several perturbations were discovered also in photographic observations of the pair AB with a very small amplitude of 4 mas and the same period of 11 years (see Fig. 5). The corresponding astrometric orbit was calculated, the corresponding fluctuations in radial velocity with an amplitude of 91 m/s must be detected, but no systematic deviations in orbital radial velocity were found. The parameters of both hypothetical astrometric orbits are different (see Table 4). Therefore, we cannot explain the perturbations by the presence of any invisible satellite.

We analyzed published observations of the radial velocity for the separate component F (see Fig. 6). Despite a small amplitude of 6 m/s (level of noise), the perturbation with a period of $1006^d = 2.7543^y$ was detected. These fluctuations are very small, but what is remarkable is that a period of 11 years is a multiple of the given period. Hence, may be, there is a common reason for fluctuations of independent positional and radial velocity observations.

Perhaps the reason is not connected with an additional companion in the star system, but there is some periodic natural phenomenon.

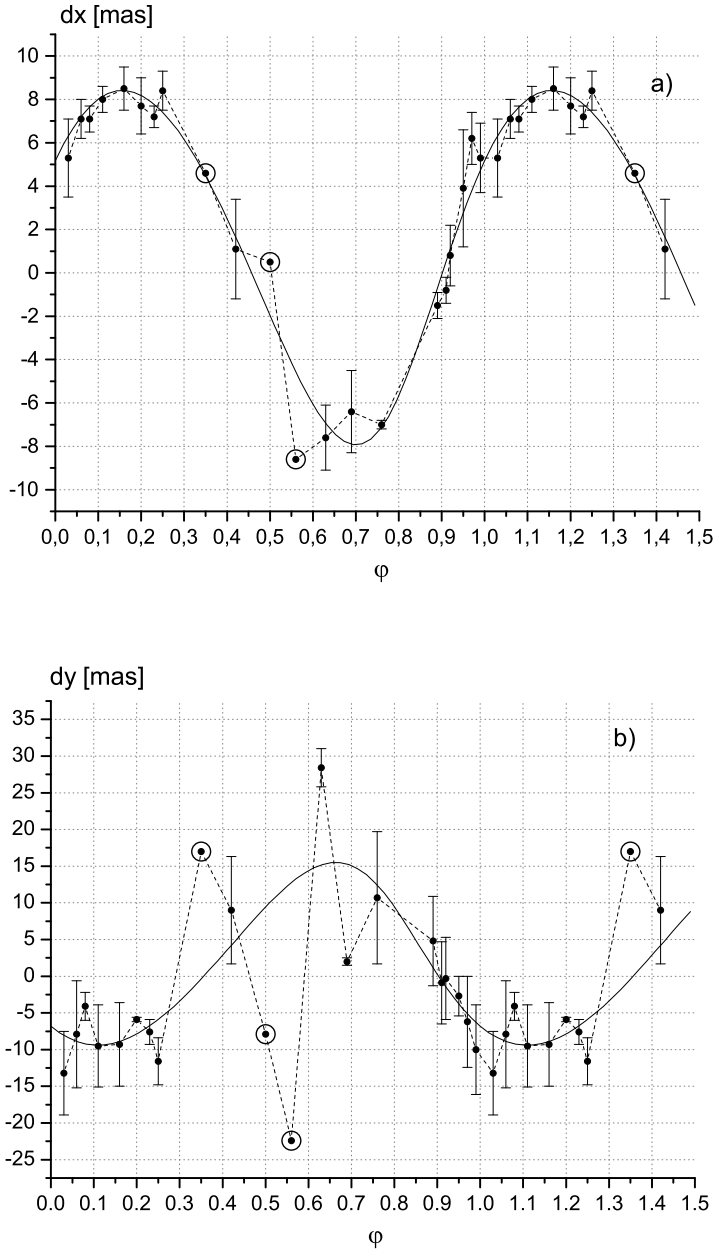


Figure 4 The outer pair AB–F. The deviations in right ascension (a) and in declination (b) relative to phases of the period $P = 11$years. Error denotes the convergence inside the window $\Delta\varphi = 0.05P$. If there is only one observation in the window, it is in the circle. The lines correspond to the photocentric orbit.

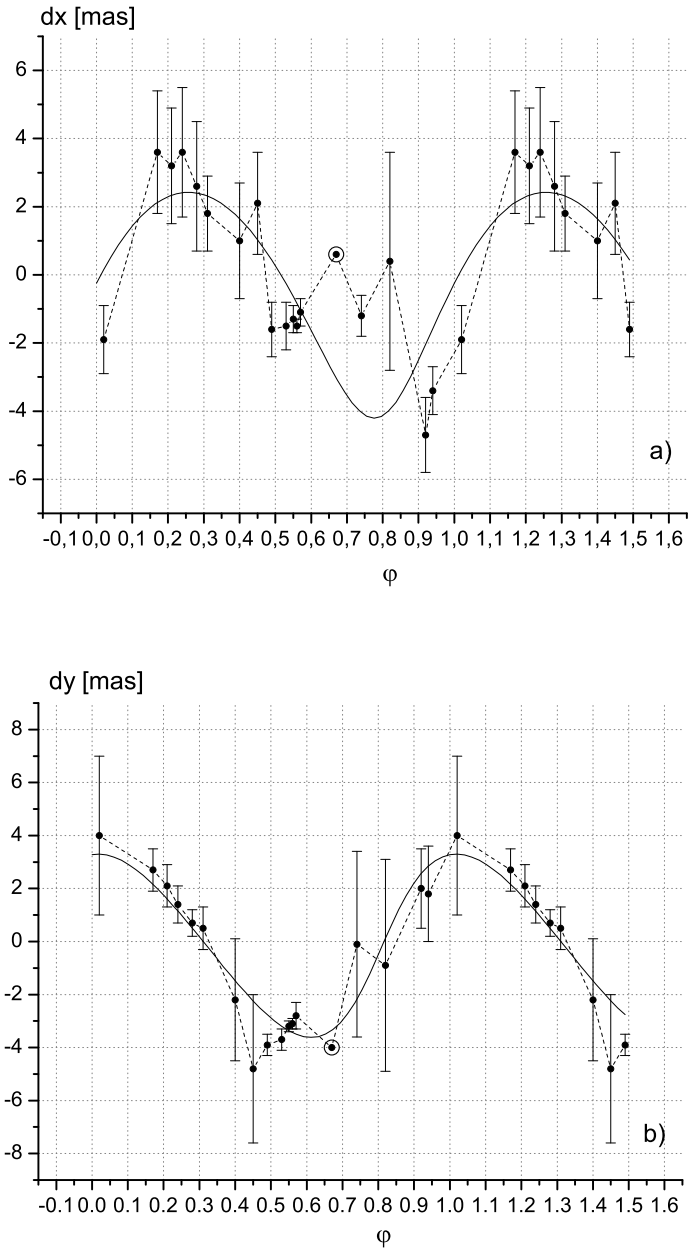


Figure 5 The astrometric orbit of the inner pair AB. The deviations in right ascension (a) and in declination (b) relative to phases of the period $P = 10.97$ years. Error denotes the convergence inside the window $\Delta\varphi = 0.05P$. If there is only one observation in the window, it is in the circle. The lines correspond to the photocentric orbit.

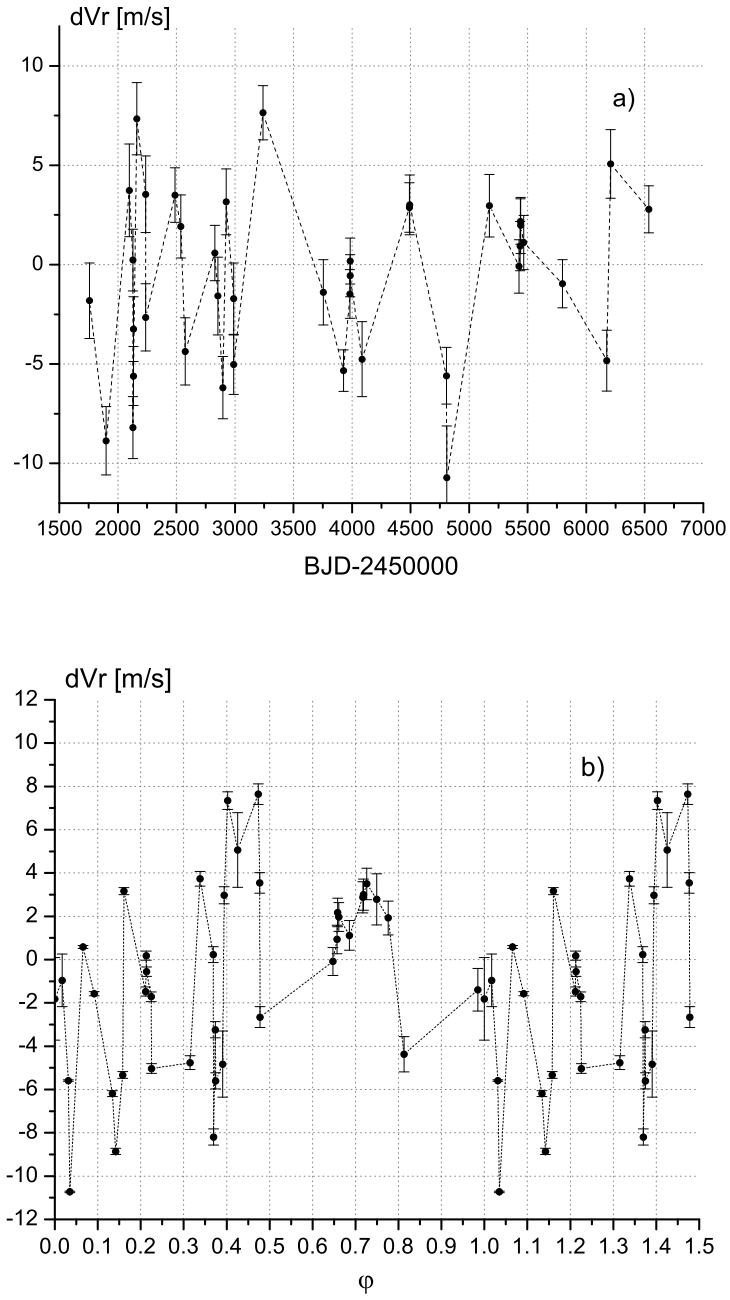


Figure 6 The radial velocity observations with the telescope Keck-1 (fluctuations about the mean value) relative to the real time (a) and relative to the phases of the period of 1006 days (b).

4 Conclusion

The AMP method was proposed for a determination of orbits of double stars on the basis of short arcs of observations in 1980. New possibilities of the application of the AMP method application for modern high-precision observations Gaia DR2 are shown in the example of the binary star ADS 48 AB in this work.

Besides, we have an additional possibility to discover the stars with probable companions by the comparison of the instant motion Gaia DR2 with the mean motion during several years.

Thus, we detected the small perturbations in the series of independent positional observations of the inner pair AB and outer pair AB–F with the same period, which is close to 11 years. Also very small fluctuations in spectroscopic observations were detected with a period of 2.75 years (it is multiple to 11 years).

The most probable reason of named variations are scale fluctuations, for example, due to refraction anomalies. This effect could be measured at extremely wide systems as ADS 48 AB–F. It is important that those fluctuations have an affect on the result and we should check carefully if we have a natural or instrumental effect.

The investigation will be continued.

Acknowledgements

The authors used the data from the Gaia DR2 and WDS catalogs. We thank the authors of these catalogs.

This work was fulfilled under a support by the Russian Foundation for Basic Research (project 20-02-00563A).

The work is performed according to the Russian Government Program of Competitive Growth of Kazan Federal University.

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