ESTIMATIONS OF DYNAMIC PARAMETERS AND POSSIBLE HABITABLE ZONES FOR SELECTED STARS OF PULKOVO PROGRAM

N.A. Shakht[1] and L.G. Romanenko[2]

Central (Pulkovo) Astronomical Observation of RAS, St-Petersburg, Russia
[1]*shakht@gao.spb.ru* , [2]*lrom@gao.spb.ru*

ABSTRACT. We give the results of a study of selected stars located in the neighborhood of the Sun .Their observations have been made by means of Pulkovo 26-inch refractor. An interest to these objects is raised in connection with expected results of the planned space missions.. We have made an estimation of habitable zones for possible planets rotating around of these stars.

Key words: binary stars, exoplanets, HZ, space projects Gaia, NEAT.

1. Introduction

Some results of observations of wide astrometric double stars on a 26–inch refractor in Pulkovo are represented.

The program of observation includes about 400 selected single and double stars located in the neighborhood of the Sun. The most part of stars of our program contain near stars of late spectral classes. Many of them are observed during some decades.

Thus we have long-term photographic and CCD-series with total duration more 50 years of relative positions with the error of 0".01 for mean annual normal place.

On the basis of Pulkovo observations more than 50 orbits of double stars were received with calculated sum of masses of components (Kiselev et al., 2009). In some cases we can estimate the individual mass of a component (Gorshanov et al., 2006, Shakht et al., 2010).

We would like to review some our stars as the possible objects for combined researches with the space and ground-based means.

2. Actuality

As examples we took stars with long series (more then 40 years) of observations: 61 Cyg, Stein 2051, ADS 7251, 16 Cyg with the parallaxes of Hipparcos which equaled 0".287, 0".180, 0".164 and 0".047 correspondingly. The more remote star ADS 8002 (π = 0".051 $\pm$ 0".007 was calculated on Pulkovo data, see, Grosheva, et al. , 2013) has the precise positions during 35 years.

ADS 14636 (61 Cyg) and ADS 7251 − the nearest stars with possible planetary satellites − are selected to NASA Star and Exoplanets Database as the first targets for observations from space. 61 Cyg is also one of the main targets for observations with future NEAT (Nearby Earth Astrometric Telescope) program (Malbet et al., 2012). The component B of star ADS 12 815 (16 Cyg) has a planet with low limit of mass about 1.6 masses of Jupiter and with a period of 2.2 years (Cochran et al., 1997). The component B of double star Stein 2051 is "excellent astrometric microlensing candidate LSPM J0431+5858E " (Proft et al., 2011) and it is planned for observations with space telescope Gaia in the January, 2014. According to Agol (2011) such stars also can have planets in habitable zone.

In this connection the detailed study of dynamical properties of these stars seems very useful.

3. Results and Discussion

The information about selected stars is given in the table 1. We have calculated orbits of 61 Cyg and ADS 7251 (Gorshanov et al. 2006; Shakht et al 2010) and now we made the revision of this orbit with all Pulkovo photographic data till to 2007. Two variants of preliminary orbits of double star Stein 2051AB are calculated depending on prospective mass of component B − the white dwarf. The analysis of this star is shown, that there is a problem with determination of the curvature on a short arc of its orbit, which our observations cover, and orbital period P can be much longer .

Star 16 Cyg (ADS 12815) has been investigated by Romanenko in Pulkovo. The precise parameters of motion of this star and orbital elements have been derived. Total mass of the system has been estimated. (Kiselev et al., 1997; Kiselev & Romanenko, 2011). The orbit of ADS 8002 is calculated by Kiselev et al. (1997) with Pulkovo parallax.

We give examples of habitable zones (HZ) of possible planets rotating around each component of a double star. HZ are calculated according to formulas of Kasting from the work of Selsis et al. (2007):

$$l_{in} = (l_{in(Sun)} - a_{in} T_{*} - b_{in} T_{*}^{2}) \sqrt{\frac{L_{*}}{L_{(Sun)}}} \quad (1)$$

$$l_{out} = (l_{out(Sun)} - a_{out} T_{*} - b_{out} T_{*}^{2}) \sqrt{\frac{L_{*}}{L_{(Sun)}}} \quad (2)$$

The internal (*l in*) and the external (*l out*) borders of HZ of Solar system are used in these formulas, where *l in(Sun)* = 0.72 *a.u.* and *l out(Sun)* = 1.77 *a.u.* Here also $T_* = Teff - 5700^{o}$ K, L_* = bolometric luminosity of a star and *a* and *b* are constants.

For estimation of limits of HZ by formulas (1-2) it was necessary to know the luminosity and temperature of a star. For those stars, whose effective temperatures and radii *R* were estimated experimentally (61 Cyg – by van Bell & von Brown (2009), for 16 Cyg – by Metcalfe et al. (2012), for ADS 7251– by Passinetti – Fracassini et al. (2001)), bolometric luminosity has been calculated according to Stefan-Boltzmann law. The relation "spectrum - luminosity" has been used for Stein 2051**A** and for of ADS 8002, which are stars of the main sequence For Stein 2051**B** we used the luminosity calculated accordingly to the *R* and *Teff* of Liebert, 1976. The results are represented in the table 3.

For 61 Cyg in a column 3 (the top line) the radius of Jonson and Wright (1983) is given, and the radius obtained by van Bell & von Brown (2009) is placed in the low line. Two values of the luminosity and limits HZ are given correspondingly.

Masses in a column 7 for nearest stars are taken from a database RECONS.org, for 16 Cyg – from the work: Metcalfe et al. (2012). The mass of ADS 8002 is estimated according to a relation mass–luminosity (Kiselev et al., 1997). In the bottom line of a column 7 for ADS 7251 the values of masses determined in Pulkovo (Shakht et al.2010) are given. We have calculated them by means of the estimation of total mass and the mass-ratio of this binary .

Then we have calculated *A* – the expected astrometric signal, that is an amplitude of angular replacement of a star under the influence of planet. We used the following formula from the work of Malbet et all (2012):

$$A = 3\left(\frac{Mp}{1M\oplus}\right)\left(\frac{a}{a.u.}\right)\left(\frac{M_{*}}{1M_{Sun}}\right)^{-1}\left(\frac{D}{1pc}\right)^{-1} \quad (3)$$

Here *Mp* and M_* are accordingly the mass of a planet and the mass of the star. The value of *a* is the semimajor axis of an orbit. *D* – the distance from the Sun to the star with planetary system. *A1* is the expected signal from the planet with Earth's mass, *A2* – a signal caused by a planet with the Jupiter's mass. Results are located in table 3 depending on *D*.

We have chosen the distance from a star to the middle of HZ as the semimajor axis *a1* for the Earth-like planets. And for possible Jupiter-like planets we used *a2* that is more than *a1* in 5.2 times by analogy with Solar system.

3. Conclusions

We represented a short description of our program with examples of stars of different spectral classes. We can see that our nearby stars are available for observations with telescope similar to NEAT with expected positional precision of 0.30 μas. Our stars have precise parameters of the motions and can be useful for investigation as host-stars. In some cases for estimation of habitable zones we can use masses and parallaxes obtained with 26-inch refractor in Pulkovo.

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Table 1. The parameters of selected stars.

Name	*RA* 2000.0	*Dec* 2000.0	m_A m_B	Sp_A Sp_B
Stein	$4^h\,31^m.2$	+58° 58′	$12^m.0$	M4V
2051			13.0	DC5VII
ADS	9 14.4	+52 41	7.4	M0V
7251			7.4	M0V
ADS	10 59.6	+25 26	8.5	K0V
8002			8.9	K5V
16 Cyg	19 41.8	+50 31	6.0	G2V
			6.2	G2V
61 Cyg	21 06.9	+38 45	5.4	K5V
			6.1	K7V

Table 2. Orbital elements of selected stars

Name	***a, a.u.***	***P, yr***	***e***	***i,°***	***ω,°***	***Ω,°***	***Tp, yr***
Stein 2051 (1)	181	2505	0.59	72	7.5	194	1788.1
Stein 2051 (2)	152	1918	0.57	70	0.5	193	1798.0
ADS 7251	136.9	1528.0	0.08	141.0	210.4	216.6	1882.8
ADS 8002	4.2	397.0	0.64	138	283	351	1767.0
16 Cyg	956	20 900	0.84	140	37	314	-7
61 Cyg	81.8	674. 3	0.50	132.5	156. 3	177. 1	1728.5

Table 3. The estimated habitable zones and astrometric signal

Name	***Teff, °K***	***R/R⊙***	***L/L⊙***	***l in, a.u.***	***l out a.u.***	***M, M⊙***	***a1 , a.u.***	***a2, a.u.***	***D, pc***	*A 1, μas*	*A 2, μas*
1	2	3	4	5	6	7	8	9	10	11	12
61 Cyg A	4640 *4526*	0.72 *0.61*	0.215 *0.140*	0.34 *0.28*	0.89 *0.72*	0.70	0.62 *0.50*	3.2 2.6	3.5	0.76 *0.61*	1247 *1013*
61 Cyg B	4400 *4077*	0.67 *0.63*	0.151 *0.098*	0.29 *0.23*	0.76 *060*	0.63	0.52 *0.42*	2.7 2.2		0.71 *0.57*	1169 *953*
St 2051 A	3200	0.10	0.0008	0.02	0.06	0.22	0.04	0.21	5.6	0.10	156
St 2051 B	7050	0.01	0.0003	0.01	0.03	0.50	0.02	0.10		0.02	34
ADS 7251 A	4060	0.68	0.113	0.25	0.67	0.60 *0.57*	0.46	2.4	6.1	0.38 *0.48*	625 *803*
ADS 7251 B	3850	0.65	0.083	0.22	0.58	0.60 *0.53*	0.40	2.1		0.32 *0.45*	548 756
ADS 8002 A	5200	0.84	0.463	0.50	1.25	0.55	0.88	4.6	19.6	0.24	406
ADS 8002 B	4600	0.72	0.208	0.34	0.88	0.45	0.61	3.2		0.21	343
16 Cyg A	5825	1.24	1.57	0.90	2.21	1.11	1.56	8.1	21.3	0.19	320
16 Cyg B	5750	1.13	1.27	0.81	1.99	1.07	1.40	7.3		0.18	299

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