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ON THE GALACTOCENTRIC ORBITS OF NEARBY STARS

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SUMMARY: Using the data from the Gliese-Jahreiss Catalogue and a particular form of the galactic potential the authors construct galactocentric orbits for nearby stars. The potential used in our paper is stationary and axially symmetric with three contributors - bulge, disc and dark corona. In the calculating of the galactocentric phase coordinates the distance of the Sun to the galactic plane is neglected, the asymmetric drift is not, whereas the components of the solar motion are varied; the distance of the Sun to the axis of galactic rotation and the corresponding value of the circular velocity are assumed according to the model used in the paper. The obtained orbits (projection on meridional plane) in a vast majority are box-like, or more precisely trapezium-like. The effect of the assumed solar motion is discussed and comparisons with results obtained by applying different potentials and initial conditions are made.

1. INTRODUCTION

The importance of galactocentric orbits in studies of the Milky Way is well known. The usual approach has been to assume a stationary and axially symmetric potential of the Milky Way with three main contributors bulge, disc and dark corona. In this way galactocentric orbits of many objects have been calculated (e. g. Allen and Martos, 1986; Brosche et al., 1991; Dauphole et al., 1996; Mülläri et al., 1998). Projected on the so-called meridional plane these orbits show a variety of shapes. In most cases one finds box-like orbits, however there are also quite different orbits. An interesting example is the case of NGC 4147 (Brosche et al., 1991). There are also indications that only slight changes in initial conditions can cause a significant change of the orbital shape (Orlov, private communication). On the other hand one cannot, of course, avoid to mention the old problem of the third isolating integral of motion. In addition to these theoretical questions once the orbital elements are known, they can always be utilised for the purpose of studying the general kinematics of the Milky Way and the problem of galactic populations. Therefore, there are many reasons why the studying of the galactocentric orbits is of importance.

The scope of the present paper concerns the nearby stars. The advantage of their use is that the data concerning these stars are known with sufficient accuracy level. Besides, the number of such stars is sufficiently large so that statistical studies are possible. Recently, Mülläri et al. (1998) formed a catalogue of orbits of nearby stars. Though the results obtained by them certainly deserve attention, in the opinion of the present authors it would be worthwhile to carry out a new study on the same material but by using a different approach. In this way interesting comparisons become possible.

2. MATERIAL AND APPROACH

The material is the Catalogue of Nearby Stars by Gliese and Jahreiss from 1991 (in further text referred to as the Catalogue). As well known, this Catalogue is unpublished. It is available on diskettes only. We have it at our disposal thanks to the courtesy of our Russian colleagues and this material has already been used by Belgrade astronomers but in another study (Trajkovska and Ninković, 1997).

For the pupose of the present paper we need the initial conditions and a model of the Milky Way (the potential). As for the former ones, the Catalogue offers, certainly, the heliocentric position and velocity vectors. Therefore, for obtaining the corresponding initial conditions, the galactocentric position and velocity vectors of the Sun should be specified. The distance of the Sun to the galactic rotation axis - $R_\odot$ - is fixed in the model adopted here and it will be reported below. The distance of the Sun to the galactic plane is neglected. On the other hand, since all the stars from the Catalogue are, as well known, situated within 25 pc from the Sun, a very small distance compared to the size of the Galaxy, the initial coordinates of all stars involved in the orbit calculation will be the same: $R = R_\odot$, $Z = 0$. The other quantity fixed in the model is the local circular velocity - $u_c(R_\odot)$. Thus we need not specify any value for it, but we take into account the asymmetric drift. Considering that its amount near the Sun is most likely 10-15 km s^{-1} (e.g. Freeman, 1987) we assume here a value of 13 km s^{-1} which is not varied throughout the rest of the paper. Finally we should assume the amount for the solar motion with respect to the local standard of rest. Considering that we expect a vast majority of these nearby stars to belong to the galactic disc, their residual velocities will be of the same order of magnitude as the solar motion and hence the components of the solar motion with respect to the local standard of rest are varied. Therefore, the initial values of the galactocentric velocity components will be (the orientation of axes is the same as in the Catalogue):

U the value given in the Catalogue corrected for solar motion,

V the local rotation velocity plus the value given in the Catalogue corrected for solar motion,

W the value given in the Catalogue corrected for solar motion;

the local rotation velocity is simply equal to $u_c(R_\odot)$ - 13 km s^{-1}.

In the present paper we adopt the model of the Milky Way proposed earlier by one of us (Ninković, 1992). Since the detailed description of this model is contained in that paper, we shall present here its most important characteristics only. Of course, in this model the Milky Way is in a steady state with axial symmetry. The amounts for the two galactic constants assumed, i. e. calculated there, are $R_\odot = 8.5$ kpc, $u_c(R_\odot) = 216$ km s^{-1}. Otherwise, as is usual in recent time, this model also adopts three essential contributors to the galactic potential: bulge, disc and (dark) corona. The parameters used in the present paper are those from Table 2 in Ninković's (1992) paper. In the present paper the model parameters are not varied. In our opinion there is no need for this because all the stars treated here are in the immediate surroundings of the Sun and the effect of model parameters is expected to be weak.

Using the angular-momentum integral (of course, one component only) we form the reduced potential. In this way we have two classical Lagrange equations. They are solved numerically. The other classical integral - that of energy - is used to control the accuracy of the algorithm. The method applied for this purpose is Runge-Kutta-Fehlberg, 4th order. The integration time is 10^{10} years. The typical error in the energy is of the order of 10^{-10} - 10^{-12}.

3. RESULTS

The potentialities of our programme allow us to obtain galactocentric orbits for all stars of the Catalogue (total number about 1950). In this way we have the first version of their orbits in which the values of 8, and 12, 7 (in km s^{-1} - Mülläri et al., 1994), respectively, are used as the solar motion components. Its main characteristic is that a vast majority of orbits belongs to the so-called box orbits with which the box projection on the meridional plane is trapezium-like (e. g. Fig. 5). This result is not surprising. The nearby stars are expected to belong largely to the galactic disc and it is well known that the orbits of disc stars are nearly circular, as indicated by B. Lindblad rather long ago. However, unlike the Lindblad classical orbits, whose projection on the meridional plane should be a rectangle, in our case we have rather a trapezium. The reason of this discrepance is simple. According to Lindblad's solution the amplitude of vertical oscillations is constant, i. e. it does not depend on R, however in the case of a realistic Milky-Way potential like the one assumed here this is true only for extremely low-eccentricity orbits (say less than 0.01).On the other hand the bounds in R are of the type $R =$const as in the Lindblad case. Thus the R values remain within two constant amounts - $R = R_p$, $R = R_a$, i. e. a test particle remains within the corresponding cylinders. It should be said also that the orbital eccentricity is defined as usually, i. e.

$$e = \frac{R_a - R_p}{R_a + R_p} .$$

Such a case is strongly reminiscent of the situation concerning orbits for a spherically symmetric potential so that the orbits may be called nearly planar, a more general case of the Lindbladian nearly circular orbits. For them one can define all classical quantities characteristic for the case of spherical symmetry, for example the anomalistic period - the time between two successive passages through R_p, or R_a respectively. It is quite clear since we deal largely with disc stars, as said above, that the orbital eccentricities and maximal distances to the galactic plane - $|z|_{\max}$ - mainly studied here, are small (see Tables).

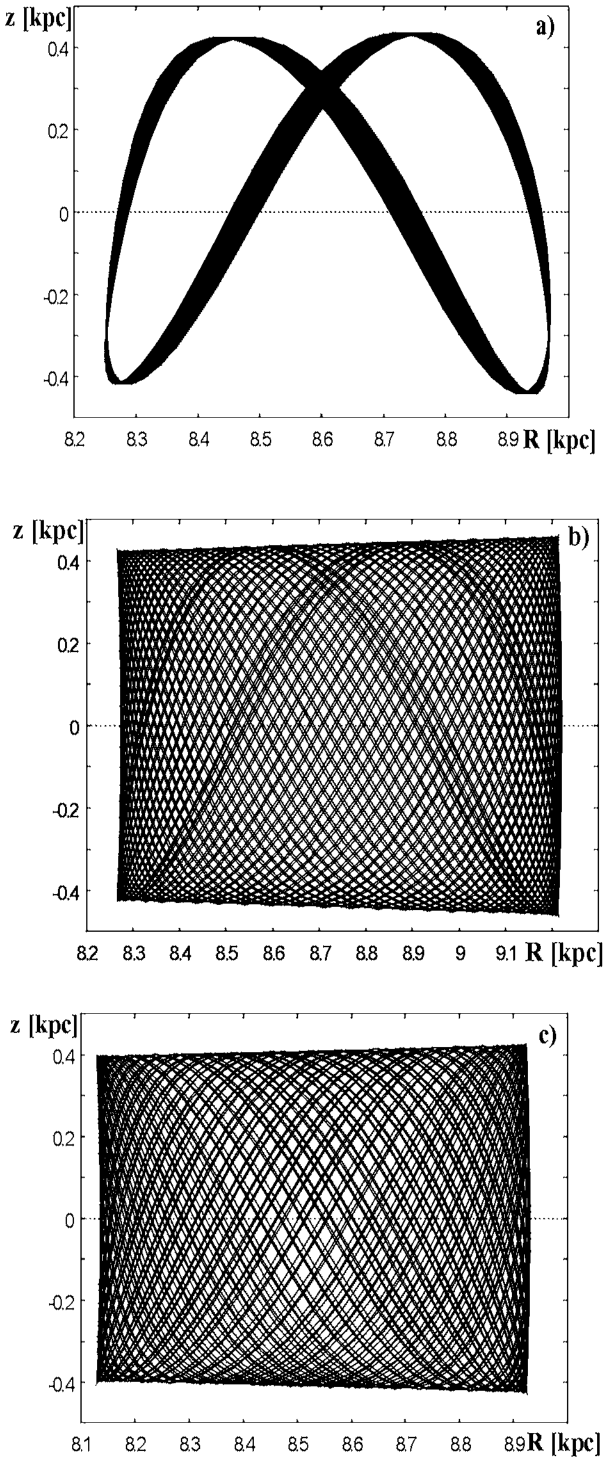

Fig. 1: Galactocentric orbit of GJ1061($\alpha=3^h 34^m 16^s$, $\delta=-44^\circ 40'.3$) for three different sets of solar-motion components:
a) 8, 12, 7
b) 10.2, 15.1, 7.4
c) 10, 10, 6
(units km s^{-1})

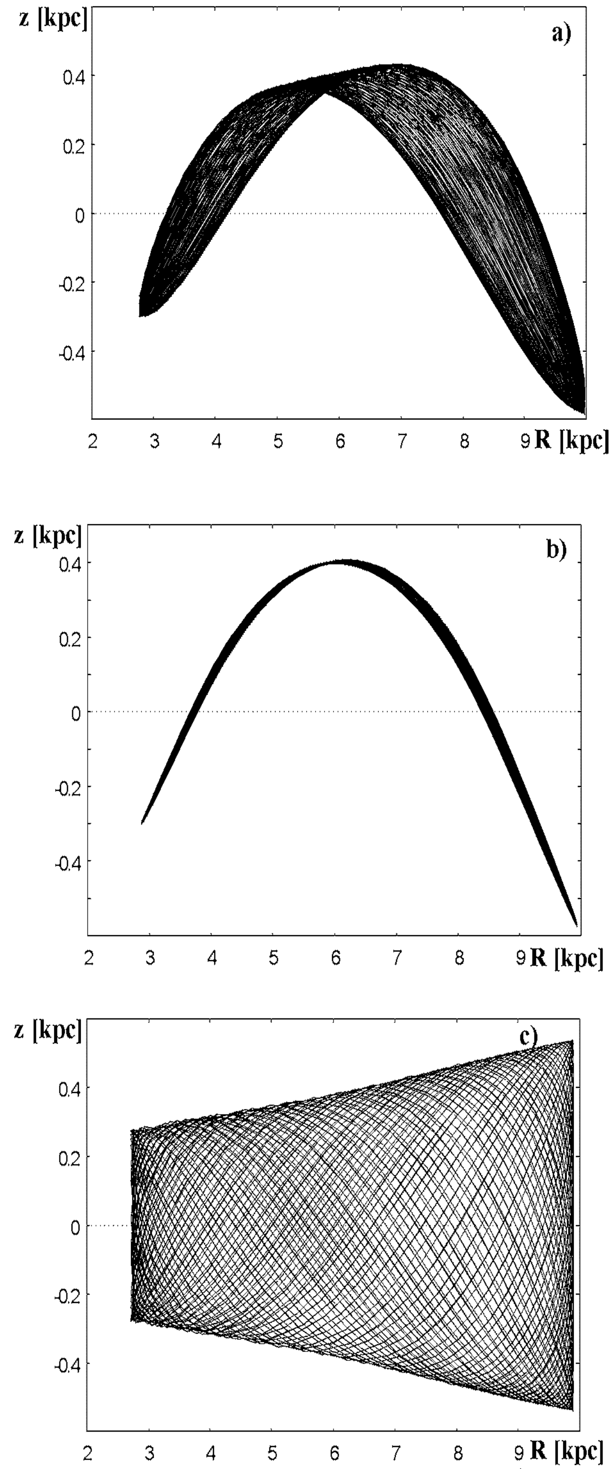

Fig. 2: Galactocentric orbit of GJ1110($\alpha=8^h 25^m 20^s$, $\delta=20^\circ 18'.9$) for three different sets of solar-motion components:
a) 8, 12, 7
b) 10.2, 15.1, 7.4
c) 10, 10, 6
(units km s^{-1})

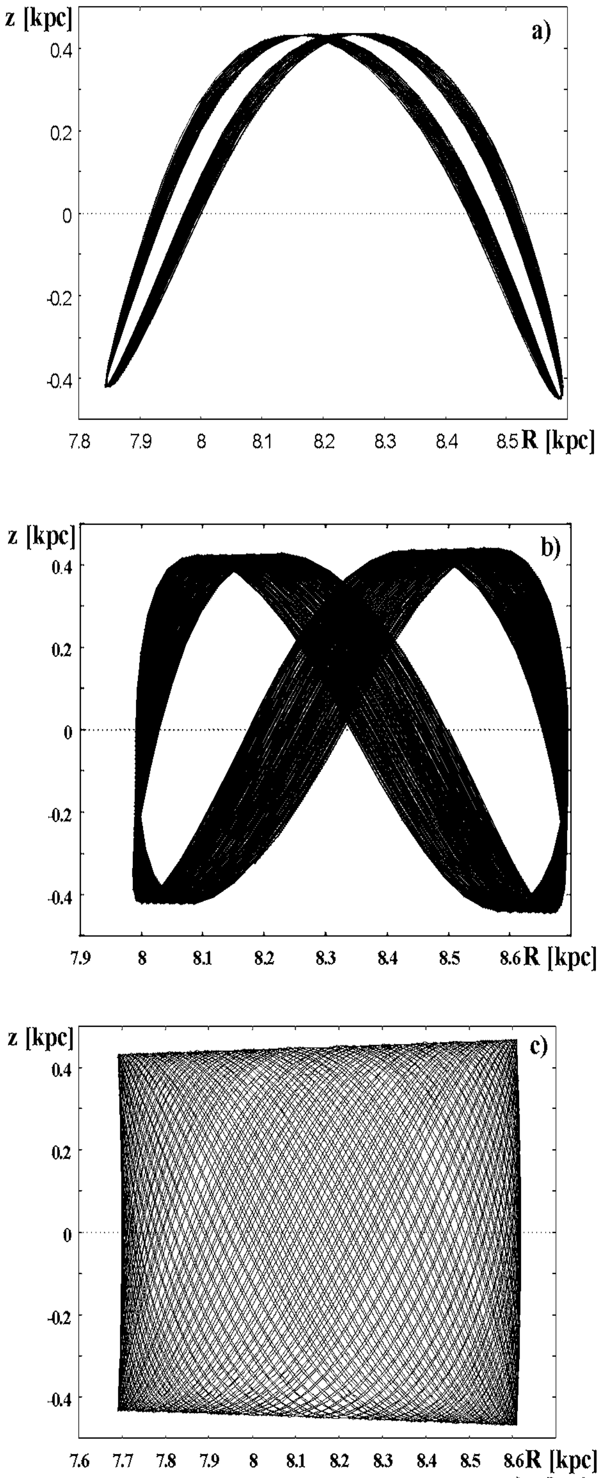

Fig. 3: Galactocentric orbit of Wo9336 ($\alpha=10^h 50^m 39^s$, $\delta=-20^\circ 21'.5$) for three different sets of solar-motion components:
a)8, 12, 7
b)10.2, 15.1, 7.4
c)10, 10, 6
(units km s^{-1})

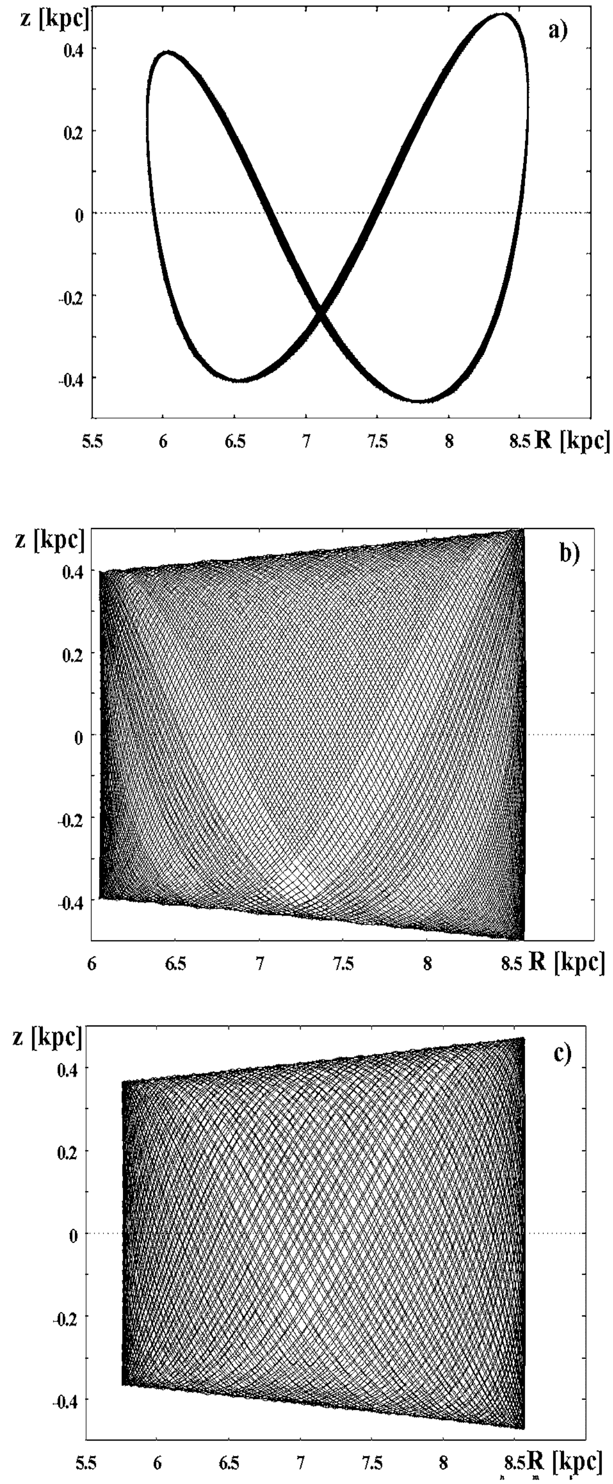

Fig. 4: Galactocentric orbit of NN ($\alpha=12^h 22^m 25^s$, $\delta=-3^\circ 56'.7$) for three different sets of solar-motion components:
a)8, 12, 7
b)10.2, 15.1, 7.4
c)10, 10, 6
(units km s^{-1})

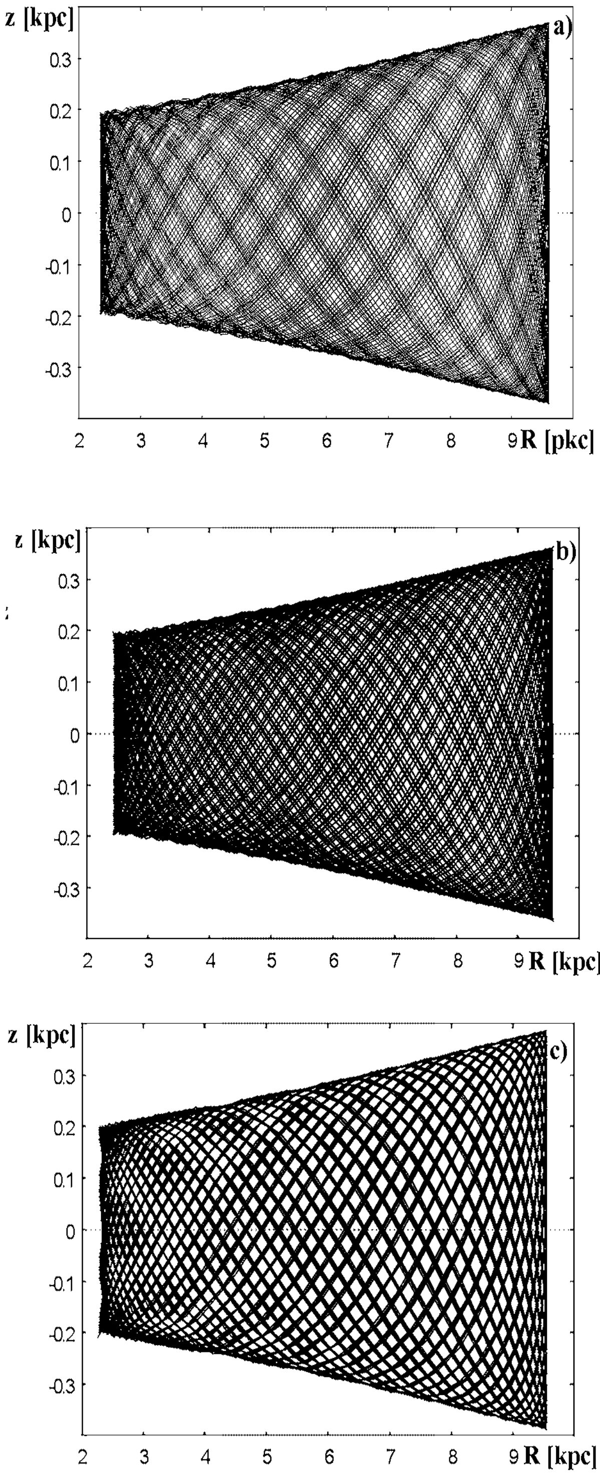

Fig. 5: Galactocentric orbit of Gl 630.1A ($\alpha=16^h\ 33^m\ 29^s$, $\delta=57^\circ\ 14'.8$) for three different sets of solar-motion components:
a)8, 12, 7
b)10.2, 15.1, 7.4
c)10, 10, 6
(units km s^{-1})

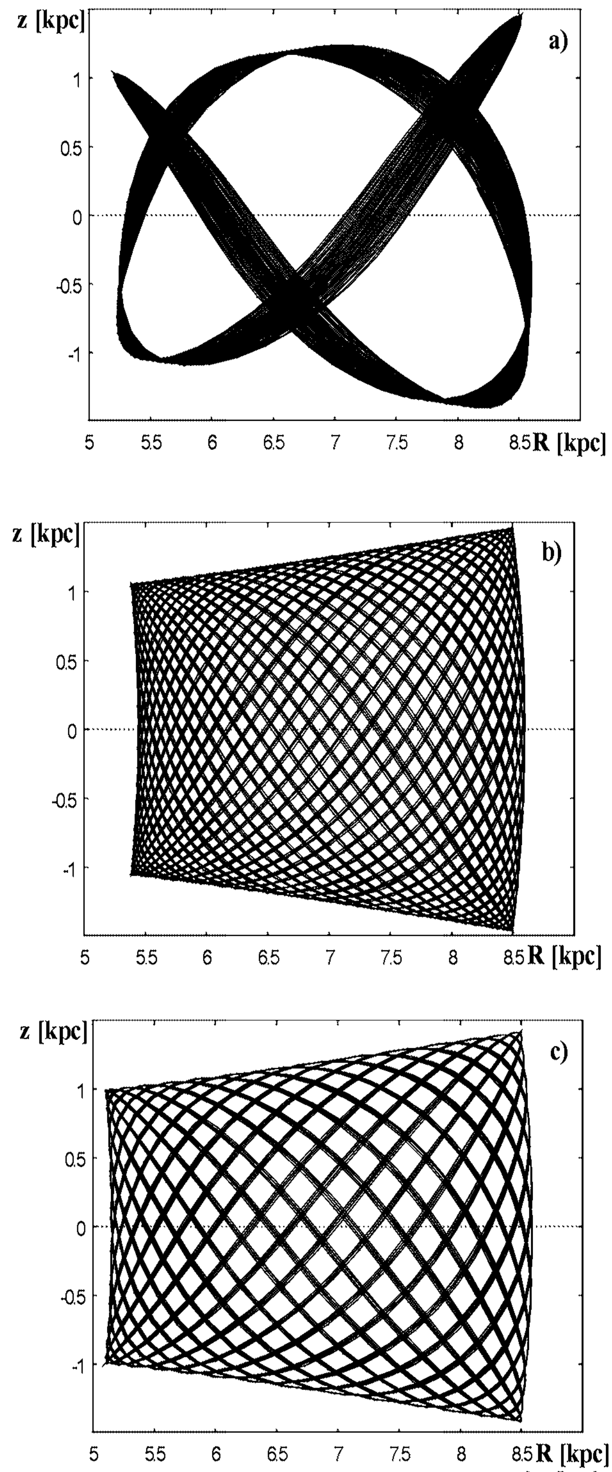

Fig. 6: Galactocentric orbit of Gl712 ($\alpha=18^h\ 19^m\ 44^s$, $\delta=6^\circ\ 18'.9$) for three different sets of solar-motion components:
a)8, 12, 7
b)10.2, 15.1, 7.4
c)10, 10, 6
(units km s^{-1})

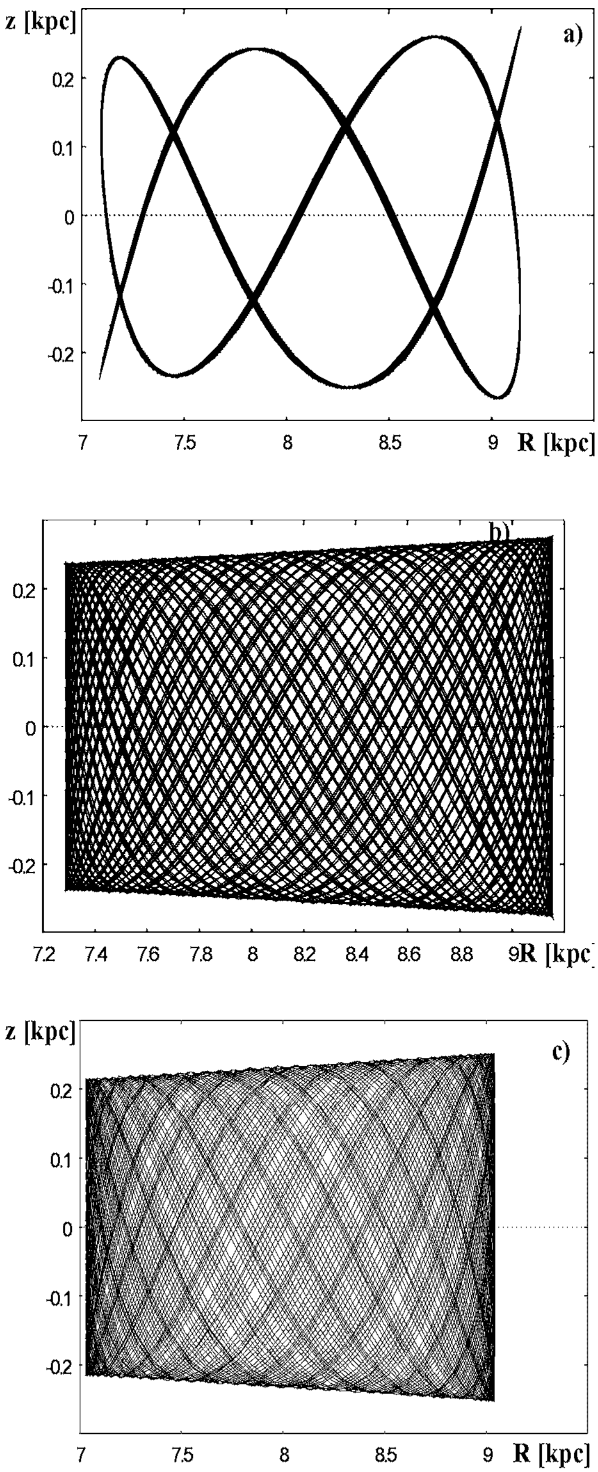

Fig. 7: Galactocentric orbit of Gl 797 B (α=20^{h}38^{m}29^s, δ=19°43'.1) for three different sets of solar-motion components:
a)8, 12, 7
b)10.2, 15.1, 7.4
c)10, 10, 6
(units km s^{-1})

The trapeziums for a vast majority of calculated orbits are filled almost completely. The time within which an orbit is integrated is, of course, sufficiently long (more precisely much longer than the anomalistic period), but such a view of an orbit need not be due to this circumstance only. We find a certain number of orbits in which in spite of long integration time the entire area of the orbital trapezium is not filled. Orbits not completely filled even after a long integration time are usually referred to as tube orbits (orbital terminology in more details in Müllari et al., 1998).

In varying of the values of the solar-motion components we use two additional sets: the so-called standard-apex motion - 10.2, 15.1, 7.4 - and basic-apex motion - 10, 10, 6 (units km s^{-1}, reference for both Kulikovskij, 1985, pp. 73-74). Due to lack of time we cannot subject all stars to this varying so that we choose some cases of special interest to us. In doing so we obtained a total of 44 stars for orbit recalculation. These are largely disc stars or more precisely stars moving along nearly planar orbits. We expect the galactocentric motion of such stars to be affected by the assumed amounts of the solar-motion components rather than typical halo stars since for the latter ones the heliocentric velocities are very large compared to the amounts of the solar-motion components. The effect of the varying is seen in Figures. There is, certainly, no need to present the orbits of all the 44 chosen stars, therefore we present the cases of only seven of them. For each star we give the identification (including the equatorial 1950.0 coordinates) and the corresponding set of solar-motion components. The basic elements of the orbits, as defined above, are given in Tables for each solar-motion components set separately.

Table 1. Orbital elements for chosen stars - solar motion: $u_{\odot} = 8$ km s^{-1}, $v_{\odot} = 12$ km s^{-1}, $w_{\odot} = 7$ km s^{-1}

Name	R_p	R_a	e	$z_{\max}$
GJ 1061	8.25	8.97	0.042	0.44
GJ 1110	2.27	9.97	0.565	0.58
Wo 9336	7.84	8.59	0.045	0.45
NN	5.88	8.56	0.185	0.48
Gl 630.1A	2.35	9.61	0.607	0.37
Gl 712	5.21	8.60	0.246	1.46
Gl 797 B	7.09	9.14	0.126	0.27

Table 2. Orbital elements for chosen stars - solar motion: $u_{\odot} = 10$ km s^{-1}, $v_{\odot} = 15.1$ km s^{-1}, $w_{\odot} = 7.4$ km s^{-1}

Name	R_p	R_a	e	$z_{\max}$
GJ 1061	8.27	9.22	0.055	0.46
GJ 1110	2.88	9.93	0.551	0.57
Wo 9336	7.99	8.70	0.042	0.44
NN	6.05	8.59	0.174	0.50
Gl 630.1A	2.45	9.57	0.592	0.36
Gl 712	5.38	8.60	0.230	1.46
Gl 797 B	7.29	9.16	0.114	0.28

Table 3. Orbital elements for chosen stars - solar motion: $u_{\cdot} = 10$ km s^{-1}, $v_{\cdot} = 10$ km s^{-1}, $w_{\cdot} = 6$ km s^{-1}

Name	R_p	R_a	e	$z_{\max}$
GJ 1061	8.13	8.93	0.047	0.42
GJ 1110	2.71	9.90	0.570	0.54
Wo 9336	7.69	8.62	0.057	0.47
NN	5.75	8.56	0.197	0.47
Gl 630.1A	2.29	9.55	0.613	0.39
Gl 712	5.10	8.59	0.255	1.42
Gl 797 B	7.03	9.04	0.125	0.25

As seen from Tables, the changes of these orbital elements due to the variations in the solar motion are insignificant. By contrast the corresponding changes in the orbit views can be very significant (see Figures).

4. DISCUSSION AND CONCLUSIONS

There are differences between our results and those of Mülläri et al. (1998). They can, certainly, be explained not only as a consequence of the use of a different potential, but also by different initial conditions due to the taking into account in the present paper of the asymmetric drift and solar motion. The general picture is rather similar, but the concepts of the two papers are different. The intention of Mülläri et al. was to study the orbits for fixed initial conditions statistically, while the present authors are rather interested in the effect of variations in the initial conditions.

As seen from the results the small variations in the initial conditions due to the uncertainty in the solar motion, although contribute only slightly to the quantitative picture of the galactocentric orbits (Tables), can change the qualitative one significantly. This phenomenon may be ascribed to resonances connected with the so-called third integral of motion and this is the main result of the present contribution.

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О ГАЛАКТОЦЕНТРИЧНИМ ПУТАЊАМА ОБЛИЖЊИХ ЗВЕЗДА

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УДК 524.6–34
Оригинални научни рад

Користећи податке из Глизе-Јарајсовог каталога и један конкретан облик галактичког потенцијала аутори рачунају галактоцентричне путање за оближње звезде. Потенцијал коришћен у нашем раду је стационаран са обртном симетријом у коме му три подсистема дају допринос - централни овал, диск и тамна корона. Приликом израчунавања галактоцентричних фазних координата занемарује се удаљеност Сунца од галактичке равни, док се узима у обзир разлика између кружне брзине и брзине ротације; компоненте Сунчеве својствене брзине се варирају. Удаљеност Сунца од осе галактичке ротације и вредност одговарајуће кружне брзине се усвајају према коришћеном моделу. Добијене путање су у огромној већини "кутијасте", односно прецизније облика трапеза (у пројекцији на меридијанску раван). Дискутован је утицај усвојене вредности Сунчеве својствене брзине и начињена су поређења са резултатима добијеним применом различитих потенцијала и почетних услова.