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GALACTOCENTRIC ORBITS OF 26 MILKY-WAY GLOBULAR CLUSTERS

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Abstract. A sample of 26 Milky-Way globular clusters with determined proper motions is analysed. By using other necessary data and applying a specially chosen form for the Milky-Way potential the authors calculate their galactocentric orbits. For convenience the potential form chosen here is spherically symmetric giving account for the dark corona only, but it has no singularity.

1. INTRODUCTION

For various reasons it is probable that the globular clusters play an important role in the structure and evolution of the Galaxy. Therefore, their galactocentric motion has been subjected to many different studies (e. g. Frenk and White, 1980). A characteristic property of many of these studies is that they had to be carried out without knowing the proper motions of these objects. However, in the meantime the available material concerning the proper motions of the Milky-Way globular clusters has grown in both quantity and quality. Recently a list comprising all proper-motion determinations for the Milky-Way globular clusters ever done was compiled in 1994 by Colin and Dauphole. With regard that by combining the proper motions with other necessary data one can obtain the initial conditions, it is clear that by specifying the Milky-Way potential one can undertake the calculation of the corresponding galactocentric orbits. Such procedures have been already performed, not once (e. g. Dauphole *et al.* 1996 where the list of Colin and Dauphole mentioned above can be found). It is understandable that the results depend on the particular form of the gravitational potential assumed. Therefore, the intention of the present authors is to analyse the results emanating for the case of a spherically symmetric galactic potential assumed by them.

2. PROCEDURE

For many of the globular clusters contained in the list of Colin and Dauphole there has been more than one proper-motion determination. Therefore, in those cases where only one proper-motion determination is available we use it regardless of the quality. If more than one determination is available, we follow Dauphole *et al.* in their choice of the "best" determination. In this way we have at our disposal a sample of 26 Milky-Way globular clusters with known proper motions and also other data necessary for obtaining the initial conditions (celestial coordinates - either α, δ or l, b - heliocentric distance and line-of-sight velocity). The latter ones have been kindly put at our disposal by Dr E. Alfaro. The particular form of the Milky-Way potential assumed by us is spherically symmetric and the formula with the parameter values can be found in an earlier paper of one of us (Ninković, 1988). In the obtaining of the galactocentric position for each cluster we use a galactocentric Cartesian coordinate system in which the coordinates of the Sun are: $X_\odot = -8.5 kpc$, $Y_\odot = Z_\odot = 0$, i. e. the distance of the Sun to the galactic plane is neglected, whereas for its distance to the rotation axis is assumed the value recommended by the IAU. As for the velocity of the Sun in the same coordinate system we assume: $\dot{X}_\odot = \dot{Z}_\odot = 0$, $\dot{Y}_\odot = 220\ km\ s^{-1}$, i. e. the motion with respect to the LSR and the asymmetric drift are neglected, whereas for the circular velocity we assume again the value recommended by the IAU.

3. RESULTS

Our results are presented in Table I. The columns contain respectively: cluster identification, specific energy ($km^2\ s^{-2}$), specific angular momentum ($kpc\ km\ s^{-1}$ - specific means per unit mass), orbital inclination (in degrees - with respect to the galactic plane), perigalactic distance (kpc), apogalactic distance (kpc), orbital eccentricity, mean galactocentric distance (kpc) and maximum distance to the galactic plane (kpc). The eccentricity, the mean galactocentric distance and the maximum distance to the galactic plane are here defined as

$e = \frac{R_a - R_p}{R_a + R_p}$, $R_m = \frac{R_a + R_p}{2}$, $|Z|_{max} = R_a \sin i$,

respectively.

As seen, only one cluster (Pal 3) has a positive energy. This need not mean that it is an escaper. The potential assumed here corresponds to a total mass of the Galaxy of 433 $G\mathcal{M}_\odot$. It is chosen in such a way to yield a value of 500 $km\ s^{-1}$ for the local escape velocity. This quantity is, as well known, uncertain because it depends on the total mass of the Galaxy. It is very possible, bearing in mind certain kinds of evidence concerning the Local Group (e. g. Lee, 1993), that the total mass of the Milky Way exceeds 1 $T\mathcal{M}_\odot$. If this is really the case, our preliminary calculations show that then Pal 3 can remain in the potential well of the Galaxy. As for the other clusters, only NGC 5466 has a significant apogalactic distance ($> 100\ kpc$). This may be also understood as an indication of a higher Milky-Way total mass than that assumed here.

4. DISCUSSION AND CONCLUSIONS

This paper will contain no extensive conclusion. It is clear that any detailed galactocentric-orbit calculation must be based on a more rigorous potential form - for example an axially symmetric one.

We may only say that, as could be expected, globular clusters in general have sufficiently high orbital eccentricities, whereas the inclinations are rather equally distributed within the range $0^o - 180^o$. Two clear exceptions are NGC 104 and NGC 6838. We should note that in the coordinate system assumed here an inclination of

180° means motion along the galactic rotation. On the other hand, the two exceptional cases are usually classified as disc globular clusters because they have metallicity over -1 (in our contribution such data are not given). Bearing in mind their inclinations and eccentricities we may say that expectations based on this connexion (with the galactic disc) are here confirmed.

Table I

name	E	J	i	R_p	R_a	e	R_m	$\|Z\|_{max}$
NGC 104	−111398.88	1434	156.5	5.46	8.42	0.21	6.94	3.36
NGC 288	−102160.12	1286	44.0	3.73	12.14	0.53	7.94	8.44
NGC 362	−115817.75	495	56.6	1.27	10.10	0.78	5.69	8.43
Pal 3	49407.55	33984	109.8	90.30	∞	> 1	∞	∞
NGC 4147	−32323.09	5204	116.0	14.14	51.69	0.57	32.92	46.46
NGC 5024	−57232.38	3565	78.3	10.47	27.76	0.45	19.12	27.18
NGC 5139	−125421.92	744	43.3	2.30	7.72	0.54	5.01	5.30
NGC 5272	−99833.71	636	99.4	1.51	13.90	0.80	7.71	13.71
NGC 5466	−14223.45	5869	80.5	14.15	126.33	0.68	70.24	126.31
Pal 5	−83756.71	1795	91.1	4.92	17.52	0.56	11.22	17.52
NGC 5904	−55338.29	2154	109.0	4.95	32.64	0.74	18.80	30.86
NGC 6121	−135592.06	159	168.4	0.44	6.82	0.88	3.63	1.37
NGC 6171	−150197.88	533	140.5	2.24	3.95	0.28	3.10	2.51
NGC 6205	−76073.22	1368	73.9	3.21	21.66	0.74	12.44	20.81
NGC 6218	−128662.70	845	132.3	2.93	6.72	0.39	4.83	4.97
NGC 6254	−125409.31	312	72.8	0.82	8.39	0.82	4.61	8.01
NGC 6341	−109314.40	974	79.1	2.74	10.87	0.60	6.81	10.68
NGC 6397	−124517.49	741	167.2	2.26	7.91	0.56	5.09	1.76
NGC 6626	−137518.78	791	176.6	3.33	4.89	0.19	4.11	0.29
NGC 6656	−109359.91	935	172.1	2.60	10.94	0.62	6.77	1.51
NGC 6712	−129826.93	611	101.3	1.87	7.18	0.59	4.53	7.04
NGC 6779	−49317.18	1567	20.5	3.23	38.15	0.84	20.69	13.37
NGC 6838	−116047.61	1337	179.2	5.51	7.23	0.14	6.37	0.10
NGC 6934	−52670.83	3903	48.5	11.46	30.46	0.45	20.96	22.82
NGC 7078	−45078.49	2855	125.6	6.66	40.40	0.72	23.53	32.84
NGC 7089	−54223.68	4065	79.6	12.69	28.28	0.38	20.49	27.81

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