Astron. Astrophys. 288, 751–758 (1994)

ASTRONOMY
AND
ASTROPHYSICS

Galactic orbits of the old open clusters NGC 188, NGC 2682, NGC 2420, NGC 752 and NGC 2506

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Received 5 January 1994 / Accepted 15 March 1994

Abstract. The orbits of five intermediate age and old open clusters, namely NGC 188, NGC2682 (M 67), NGC 2420, NGC 752 and NGC 2506 are computed adopting the new radial velocities by Friel & Janes (1993). For the first three clusters absolute proper motions are available from literature, whereas for the latter two the absolute proper motions are obtained from the relative ones according to the procedure described in the text. The orbital motions of the clusters are calculated by means of the Miyamoto-Nagai like potential by Allen & Santillán (1991) which describes the Galaxy as a three component system, namely Bulge, Disk, and Halo. The orbits are followed backwards for a time interval equal to the age of each cluster, and the main parameters of each orbit are determined. With the aid of these results, we address the question whether or not the original gradient in metallicity relative to the gas from which the clusters have been formed has been later destroyed by their motion. In other words we check whether the gradient derived by the present day position of the clusters is a good indicator of the original gradient. We find that while the radial gradient is very close to the original one, the vertical gradient (if any existed at all) is wiped out by the rapid oscillatory motions of the clusters across the galactic disk.

Key words: Galaxy: structure – Galaxy: open clusters – Galaxy: abundances – Galaxy: kinematics and dynamics

1. Introduction

Over the past few years, the family of Galactic Open Clusters of intermediate and old age has received great attention in order to cast light on the role played by these objects in relation to the structure and evolution of the Galaxy.

Their chemical and kinematical properties have been thoroughly investigated by Friel & Janes (1993). From this analysis it emerges that no age-metallicity relation (AMR) exists, whereas a radial gradient in metallicity is present (the metal content decreases at increasing galactocentric distance) in agreement with other indicators, and finally no gradient along the vertical direction appears.

The kinematical behaviour of the intermediate age and old open clusters indicates that they follow the Galactic rotation curve defined by the population of young open clusters (Hron 1987), thus suggesting that also the bulk of old open clusters belong to the Old Thin Disk, with an handful of clusters departing significantly from this general scheme, like NGC 1193 and NGC 1817 (Friel et al. 1989). However, the motions along the z-direction appears to be closer to that of the Thick Disk population.

A recent ranking of the age of the clusters on consideration has been derived by Carraro & Chiosi (1994) using homogeneous and complete grids of stellar models and isochrones of the Padova group (Bertelli et al. 1994). This study shows that the ages of these clusters range from that of the Hyades ($0.5 \times 10^9 yr$) to that of NGC 6791 ($8.0 \times 10^9 yr$). As already known, only a few clusters are found to be older than M 67, the cause of this likely residing in the dynamical interaction with the Galactic environment (van den Bergh & McClure 1980; Theuns 1992; Friel & Janes 1993). The old clusters that are able to survive own this to special conditions, e.g. height of the birth place above the Galactic Plane, low eccentricity orbits, and others.

Understanding the still poorly known dynamical history of this population would allow us to cast light on all the above questions and to frame them in the more general context of the dynamical and chemical evolution of the Galactic Disk.

The aim of this paper is to calculate the orbits of five old open clusters (NGC 188, M 67, NGC 2420, NGC 752 and NGC 2506), for which sufficiently good kinematical data are available. Assuming the gravitational potential and the present components of the galactocentric space and velocity vectors, the orbits can be uniquely reconstructed back in time.

The knowledge of the orbit of each cluster allows us first to get information about its birth place, entity of the epicyclical motion, orbital period, and maximum height above the galactic plane, and second to answer the fundamental question whether or not the gradient in metallicity traced by the present position

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Table 1. Basic parameters of the studied clusters

Cluster	α_{1950}	δ_{1950}	l	b	d (kpc)	x (kpc)	y (kpc)	z (kpc)	R_{GC} (kpc)	[Fe/H]	Age (Gyr)
NGC188	00 39.4	85 04	122.8	22.5	1.70	9.36	1.32	0.64	9.47	-0.06±0.00	7.5
NGC2682	08 47.7	12 00	215.6	31.7	0.78	9.03	-0.39	0.41	9.05	-0.09±0.07	4.8
NGC2420	07 35.5	21 41	198.1	19.6	2.29	10.55	-0.66	0.78	10.60	-0.42±0.07	2.1
NGC752	01 54.7	37 26	137.2	-23.4	0.43	8.79	0.27	-0.17	8.80	-0.16±0.05	1.5
NGC2506	07 57.8	-10 39	230.6	9.9	3.16	10.45	-2.42	0.55	10.74	-0.52±0.07	1.9

of these clusters is reminiscent of the original gradient existing in the material out of which the clusters have formed.

Hopefully, one may attempt to reconstruct the past gradient in metallicity (the so-called paleogradient), and to estimate how this has changed with time because of the orbital motion of the clusters, and finally to assign these objects to their parental population.

Previous calculations of cluster orbits are available only for NGC 188 and M 67. Using galactic gravitational potentials derived from different mass density distributions (Schimdt 1956, 1965; Innanen 1966), Keenan et al. (1973) calculated the orbits of the two clusters and found that they belong to the Old Disk population.

New measurements of radial velocities by Friel & Janes (1993) and reliable absolute proper motions for a larger number of objects allow us first to re-calculate the orbits of NGC 188 and M 67, and second to obtain for the first time those of NGC 2420, NGC 752 and NGC 2506.

The plan of the paper is as follows. Section 2 derives the initial conditions used to calculate the cluster orbits. Section 3 presents the adopted model of mass distribution and gravitational potential. Section 4 describes the results of the orbit calculations. Section 5 deals with the paleogradients in metallicity across the Galactic Disk. Finally, a few concluding remarks are given in section 6.

2. Initial conditions

Basic initial parameters of the orbit calculations are the position and velocity vectors with respect to a galactocentric reference frame. These quantities represent the initial values for the second order differential equations governing the motion of a cluster.

In general, available quantities are the distance from the Sun, the radial velocity, and the components of the relative proper motions, all these referred to the Sun.

Table 1 shows for each cluster the equatorial and galactic coordinates, the distance d from the Sun, the current position in rectangular galactic coordinates defined by

$$x = R_{\odot} - d \cdot \cos b \cdot \sin l \quad (1)$$

$$y = d \cdot \cos b \cdot \sin l \quad (2)$$

$$z = d \cdot \sin b, \quad (3)$$

the distance R_{GC} to the galactic center, the metal content [Fe/H], and finally the age. Distances and metallicities are from Friel & Janes (1993) and Friel (1989), while ages are from Carraro & Chiosi (1994). The typical error affecting these age estimates is about 10% .

The absolute proper motions and radial velocities are given in Table 2 together with the references to the original sources of the relative proper motions.

The components of the absolute proper motions for NGC 188, M 67 and NGC 2420 are taken from the sources listed in Table 2, whereas those for NGC 752 and NGC 2506 have been explicitly calculated by means of the procedure developed by Murray et al. (1965). The method is aimed to transform the relative proper motions into the absolute ones, i.e. relative to zero-parallax stars.

The key assumption of the method is that as far as the kinematics is concerned, all field stars in the color interval $0.50 \leq$ (B-V) ≤ 0.80 are considered as belonging to an homogeneous group of late F and G zero age main sequence dwarfs.

If so, one can refer the motion of a cluster to the mean motion of the field stars assuming that this latter simply reflects the solar motion. Ample justifications of this assumption are given by Murray et al. (1965), to whom the reader should refer for details.

This technique has been applied by Murray et al. (1965) to M 67, Upgren et al. (1972) to NGC 188, and Cannon & Lloyd (1970) to NGC 2420.

The components of the absolute proper motion of a cluster with respect to the field stars are obtained from the following equations:

$$\mu'_x = \frac{\Sigma d^2 \Delta\mu_x}{\Sigma d^2} - \frac{V_{x,\odot}}{4.74057} \frac{\Sigma d}{\Sigma d^2} \quad (4)$$

$$\mu'_y = \frac{\Sigma d^2 \Delta\mu_y}{\Sigma d^2} - \frac{V_{y,\odot}}{4.74057} \frac{\Sigma d}{\Sigma d^2} \ , \quad (5)$$

in which d is the distance (in kpc) of each star from the Sun, while $V_{x,\odot}$ and $V_{y,\odot}$ are the X and Y components of the Standard Solar Motion, namely $V_{x,\odot}$ = +10.4, $V_{y,\odot}$ = +14.8, and $V_{z,\odot}$ = +7.3 $km\ sec^{-1}$ according to Mihalas & Routly (1968). The samples of field stars used for NGC 752 and NGC 2506 consist of 23 and 159 objects, respectively.

The components x and y of the proper motions in the equatorial coordinate system ($\mu_\alpha \cdot \cos\delta$ and μ_δ respectively) with

Table 2. Absolute proper motions and radial velocities

Cluster	μ'_x (''/yr)	μ'_y (''/yr)	Ref[(a)]	$V_R^{(b)}$ (km/sec)
NGC 188[(c)]	-0.00065	-0.003980	1	-42
NGC 2682	-0.00790±0.0080	-0.00730±0.0023	2	33±6
NGC 2420	-0.00240±0.0010	-0.00060±0.0010	3	80±6
NGC 752	+0.00003	-0.00230	4	7±6
NGC 2506	-0.00010	+0.00010	5	87±5

a) Sources of the relative proper motions:
(1) Upgren et al. (1972); (2) Murray et al. (1965); (3) Cannon & Lloyd (1970); (4) Francic (1989); (5) Chiu & Van Altena (1981).
b) Radial velocities from Friel & Janes (1993).
c) Radial velocity from Friel (1989).

respect to the candidate field stars are then calculated from Eqs. (4) and (5).

In addition to this, both the components x and y of the proper motions and the radial velocity must be corrected for Galactic differential rotation (see Keenan et al. 1973 and Upgren et al. 1972). The corrections are evaluated by means of the generalized Oort equations:

$$V_R = A \cdot d \cdot \cos^2 b \cdot \sin(2 \cdot l) \quad (6)$$

$$\mu_l = \frac{1}{4740.57} \cdot (A \cdot \cos(2 \cdot l) + B) \cos b \quad (7)$$

$$\mu_b = -\frac{1}{4740.57} \cdot \frac{1}{2} \cdot A \cdot \sin(2 \cdot l) \cdot \sin(2 \cdot b) \quad , \quad (8)$$

where all the symbols have their usual meaning, and $A = 15 \ Km/sec/Kpc$ and $B = -10 \ Km/sec/Kpc$.

While the correction to the radial velocities is straightforward, the one to the components of the proper motions is a more cumbersome affair. To this aim, we transform the Eqs. (7) and (8) into equatorial coordinates by means of the relations

$$\mu_\alpha \cdot \cos\delta = (\frac{\partial\alpha}{\partial l} \cdot \mu_l + \frac{\partial\alpha}{\partial b} \cdot \mu_b) \cdot \cos\delta \quad (9)$$

$$\mu_\delta = \frac{\partial\delta}{\partial l} \cdot \mu_l + \frac{\partial\delta}{\partial b} \cdot \mu_b \quad , \quad (10)$$

where the partial derivatives are calculated from the equations relating the equatorial to galactic coordinates at the equinox 1950.0 (Green 1985). The final values for the absolute proper motions and radial velocities are given in Table 3.

Subsequently, we transform the equatorial velocity components into the corresponding galactocentric components Π, Θ and Z, and correct them for the Standard Solar Motion and the Motion of the Local Standard of Rest (LSR). The procedure literally follows the method by Johnson & Soderblom (1987), however adopting a right-handed reference frame with the x-axis pointed toward the anticenter. The y-axis is along the direction of galactic rotation, and the z-axis is toward the North Galactic Pole. Table 4 shows the results.

Table 3. Corrected proper motions and radial velocities

Cluster	μ_x ("/yr)	μ_y ("/yr)	V_R (km/sec)
NGC 188	-0.00380	-0.00310	-22.0
NGC 2682	-0.00940	-0.00700	+25.0
NGC 2420	-0.00280	-0.00110	+62.0
NGC 752	-0.00180	-0.00300	+12.4
NGC 2506	-0.00310	+0.00210	+42.0

Table 4. Velocity components in the galactocentric reference frame

Cluster	Π (km/sec)	Θ (km/sec)	Z (km/sec)
NGC 188	-43.2	242.5	-23.0
NGC 2682	+19.9	202.2	-15.8
NGC 2420	+55.7	213.8	-2.6
NGC 752	-5.4	242.0	-4.0
NGC 2506	+57.7	231.8	-9.2

3. Galactic model of mass distribution

The equations of motion have been integrated adopting the model for the Galactic gravitational potential and corresponding mass distribution by Allen & Santillán (1991).

In this model, the mass distribution of the Galaxy is described as a three component system: a spherical central bulge, a flattened disk, both of the Miyamoto-Nagai (1975) form, plus a massive spherical halo.

The gravitational potential is time independent, axisymmetric, completely analytical, and mathematically very simple. The potential is continuous everywhere together with its spatial derivatives. As a consequence of it, the potential admits only two classical integrals of motion, i. e. the total energy E and the z-component J_z of the angular momentum.

The model provides accurate representations of the Galactic rotation curve $V_C(R)$ and the force $F_z(z)$ perpendicular to the Galactic Plane, and leads to results that are similar to those obtained from other models of mass distribution, e.g. Caldwell & Ostriker (1981).

In particular, it has been used to derive the galactic orbits both of nearby stars (Allen & Martos 1986) and disk and halo distant globular clusters (Odenkirchen & Brosche 1992; Allen & Santillán 1993).

The greatest advantages with this formulation of the gravitational potential are the rapid integration of the orbits and the high numerical precision, which is much greater than that achievable by deriving the potential from the Poisson equation (Allen & Martos 1986).

Table 5. Constants of the gravitational potential. Masses and parameters a and b are in $M_\odot$ and Kpc, respectively

Bulge	M_B	1.41E+10
	b_B	0.3873
Disk	M_D	8.56E+10
	a_D	5.2178
	b_D	0.25
Halo	M_H	10.71E+10
	a_H	12.0

The adopted expressions for the potential of the central bulge, disk, and massive halo are:

$$\Phi_B(R,z) = -G \cdot \frac{M_B}{(R^2+z^2+b_B^2)^{1/2}} \tag{11}$$

$$\Phi_D(R,z) = -G \cdot \frac{M_D}{\{R^2+[a_2+(z^2+b_D^2)^{1/2}]^2\}^{1/2}} \tag{12}$$

$$\Phi_H(R,z) = -G \cdot \frac{M_H}{a_H} \cdot \frac{1}{R^2+z^2} \cdot \frac{\Upsilon}{1+\Upsilon} \quad , \tag{13}$$

respectively, where R and Υ are

$$R = (x^2+y^2)$$

and

$$\Upsilon = \left[\frac{(R^2+z^2)^{1/2}}{a_H}\right]^{1.02} \quad .$$

In the above equations, R, x, y, and z are referred to the system of galactocentric coordinates defined by Eqs. (1), (2), and (3). Table 5 lists the values of the various constants for the bulge, disk, and massive halo.

In the analysis below, the following characteristic quantities are adopted: galactocentric distance of the Sun $R_\odot = 8.5$ kpc, rotational velocity of the Sun $\Theta(R_\odot) = 220$ km/sec, mass density at the solar position $\rho(R_\odot) = 0.15$ $M_\odot$ pc^{-3}, and finally total mass of the model $9.0\times10^{11} M_\odot$ with the halo extending up to 100 kpc. With these assumptions, the Oort constants turn out to be within the range of currently accepted values (e.g. Kerr & Lynden-Bell 1986).

More details about this model of Galaxy structure can be found in Allen & Santillán (1993), to whom the reader should refer.

4. Galactic orbits

The three second order differential equations that describe the motion of a cluster can be obtained once the radial and vertical components of the gravitational force, F_R and F_z respectively, are calculated summing the derivatives with respect to R and z of the three terms of the gravitational potential.

In cylindrical coordinates they are

$$F_R = -\left(\frac{\partial\Phi_1}{\partial R} + \frac{\partial\Phi_2}{\partial R} + \frac{\partial\Phi_3}{\partial R}\right) \tag{14}$$

$$F_z = -\left(\frac{\partial\Phi_1}{\partial z} + \frac{\partial\Phi_2}{\partial z} + \frac{\partial\Phi_3}{\partial z}\right) \quad . \tag{15}$$

The equations of motions, written in rectangular galactocentric coordinates x, y and z, are integrated backward in time over a time interval equal to the age of each cluster.

To perform the numerical integration, we have adopted the Bulirsh-Stoer method, directly applied to the second order differential equations. This numerical method fairly conserves the total energy and the z-component of the angular momentum J_z. Typical accuracies in the total energy and J_z are $\frac{\Delta E}{E} \simeq 10^{-4}$ and $\frac{\Delta J_z}{J_z} \simeq 10^{-9}$.

Because of the conservation of J_z, the orbits can be plotted in the so-called meridional plane. They are shown in Figs. 1, 2, 4, 5, and 6 for NGC 188, M 67, NGC 2420, NGC 752 and NGC 2506, respectively. For the sake of clarity, the orbits are plotted limited to a time interval of several periods, which is significantly shorter than the cluster ages. The parameters of the 5 orbits are given in Table 6, where E is the total energy, J_z the z-component of the angular momentum (both are per unit mass of the cluster), R_a is the apogalacticon, R_p is the perigalacticon, ΔR is the amplitude of the epicyclical motion, e is the eccentricity defined as $\frac{R_a-R_p}{R_a+R_p}$, T is the orbital period, ν_z is the vertical period, $|z_{max}|$ is the maximum height above the Galactic Plane reached by a cluster. The present accuracy both in age determination and the initial conditions for the clusters in our sample does not allow us to derive the site of formation inside the Galactic Disk. Indeed the uncertainty affecting the age is comparable or even greater than the time scale of the orbital periods (see the data of Tables 1 and 6), which means that the birth place can be located anywhere within the orbital box. However, it might be of some interest to show the site of birth within the orbital box that formally corresponds to the ages listed in Table 1. They are displayed in the series of Figs. 1,2, 4, 5, and 6. The squares and circles are for the site of formation and present day location, respectively. We remind the reader that odd properties such as anti-correlations between current and formation positions both in the radial and vertical direction are merely due to random fluctuations in a small sample.

4.1. NGC 188

The new orbit of NGC 188 closely resembles the one of Keenan et al. (1973) based on the mass distribution by Innanen (1966). Both orbits are "boxy". There are a few differences that can be attributed to the different input constants and numerical method. In particular Keenan et al. (1973) did not correct the radial velocity for the effect of the galactic differential rotation.

NGC 188 is the oldest cluster of the sample, and the reason for its survival has perhaps to be sought in the characteristics of the orbit. In other words, the low eccentricity and small epiciclycal amplitude reflect an almost circular orbit confined in

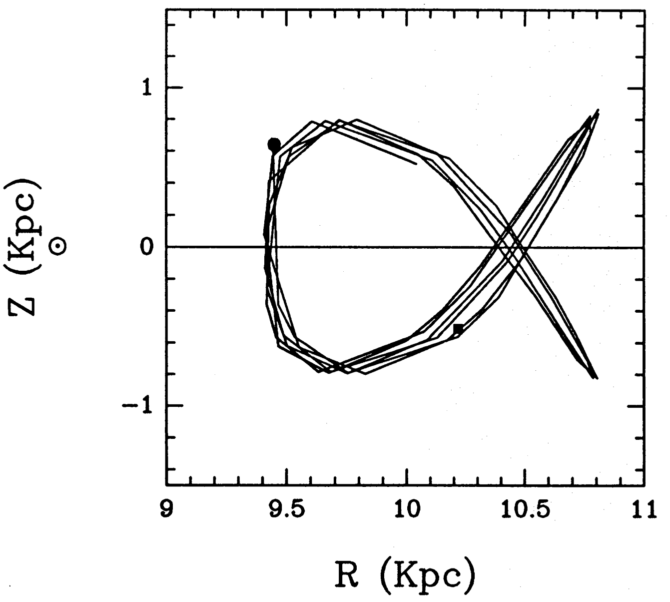

Fig. 1. Galactic orbit of NGC 188. The square and circle show the site of formation and present day location, respectively

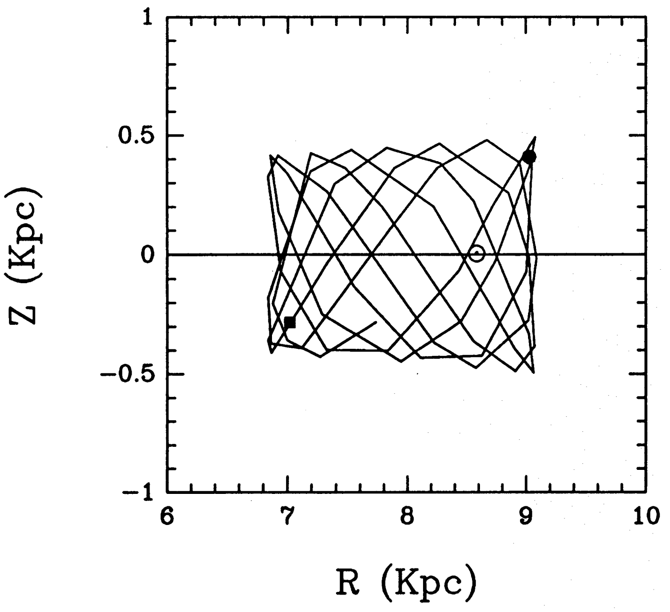

Fig. 2. Galactic orbit of M 67. The square and circle show the site of formation and present day location, respectively

the box $9.4 \leq R \leq 10.8$, and $-1.0 \leq z \leq 1$. During its life, NGC 188 has avoided the inner regions of the disk, where the density of giant molecular clouds and consequent dynamical interactions are much greater. This agrees with the results by Upgren et al. (1972) based upon pure kinematical considerations.

4.2. M 67

As for the case of NGC 188, the orbit of M 67 has been calculated by Keenan et al. (1973) using various mass distributions. The new orbit shown in Fig. 2 closely agrees with the old one determined from the mass distribution by Innanen (1966).

The orbit is of boxy type, however more eccentric than that of NGC 188. Indeed it spans more than 2 *kpc* in the R direction (see Fig 2). In order to understand the possible effects of this large epiciclycal amplitude on the determination of the metallicity gradient across the Galactic Disk (see below) we have calculated the probability of detection during the orbital period as function of the radial distance R.

With the aid of the relation between the velocity $V = (\Pi^2 + \Theta^2)^{0.5}$ and R, we define the following normalized probability P:

$$P(R) = A \cdot \frac{1}{T} \cdot \frac{R}{V(R)} \tag{16}$$

where A is an adimensional normalization constant obeying the condition

$$\int_{R_p}^{R_a} P(R)\, dR = 1 \tag{17}$$

where, R_p and R_a are the perigalacticon and apogalacticon (in Kpc), and T is the orbital period (in Myr). A turns out to be 2.57. The relation displayed in panel (a) of Fig. 3 shows that the probability to observe M 67 within about 200 pc from the apogalacticon, i.e. near the present position, is about 50%.

This means that the use of this cluster to trace the gradient in metallicity across the galactic Disk cannot be much influenced by its orbital motion.

4.3. NGC 2420

No previous calculations of the orbit of NGC 2420 exist. However, the overall good agreement found for the new orbits of NGC 188 and M 67 with the previous ones by Keenan et al. (1973) based on a different law for the mass distribution across the Galactic Disk, first confirms that the mass distribution model we have adopted provides a good representation of the gravitational potential, and second that our method of orbit calculations works properly.

NGC 2420 is a cluster of intermediate age and low metallicity, and therefore its dynamical behaviour is particularly relevant to the aims of this study. The orbit (shown in Fig. 4) has a significant eccentricity and a large epiciclycal amplitude. The orbit is boxy, but more complicated than that of NGC 188 and M 67. Also for this cluster we calculated the normalized probability of detection displayed in panel (b) of Fig. 3. In this case the costant A is 2.04. It turns out that NGC 2420 has spent most of its life near the apogalacticon. In fact a probabibilty greater than about 45% to find the cluster within 400 pc form the apogalacticon can be found. Therefore also in such a case the motion of the cluster cannot have strongly modified the slope of the paleogradient.

4.4. NGC 752

The orbit of NGC 752 is shown in Fig. 5. From the very low eccentricity and small epiciclycal motion one can infer a nearly

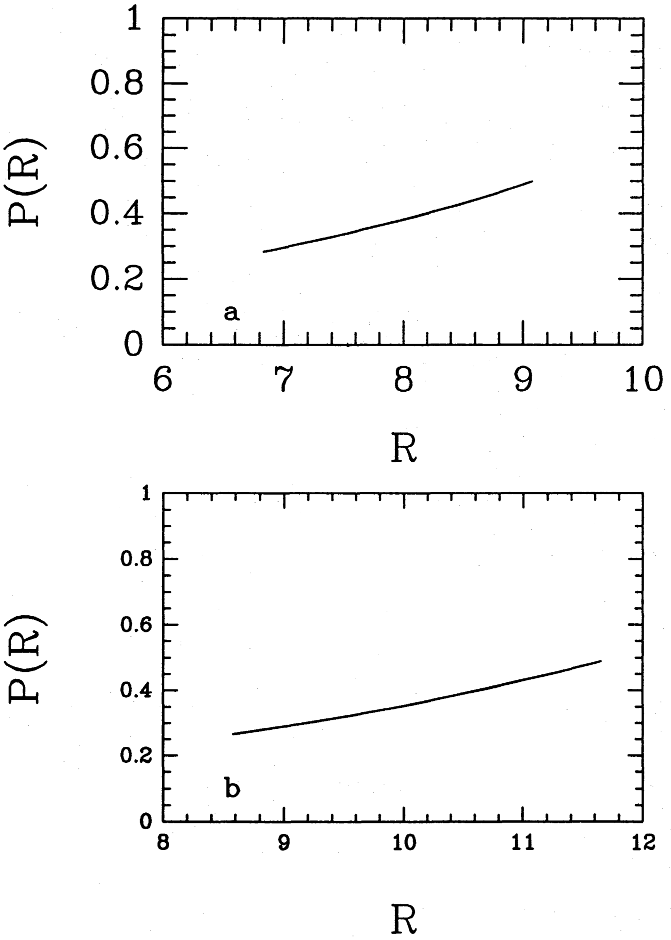

Fig. 3. **a** Normalized detection probability of M 67; **b** Normalized detection probability of NGC 2420

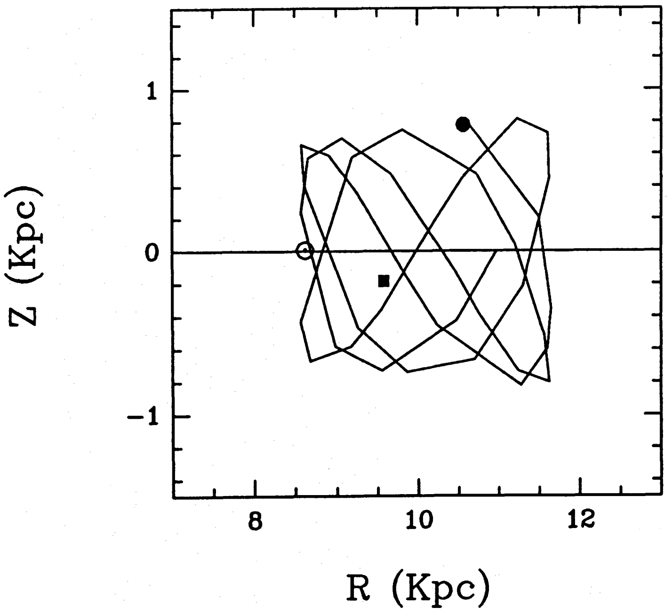

Fig. 4. Galactic orbit of NGC 2420. The square and circle show the site of formation and present day location, respectively

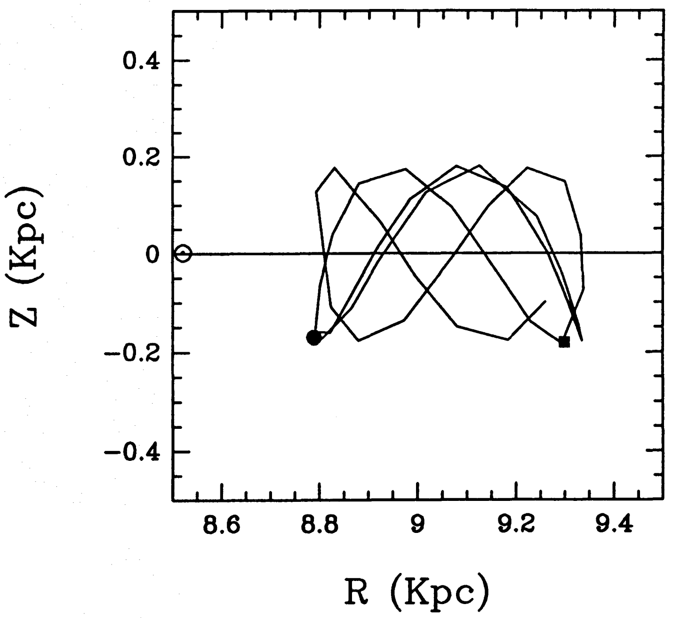

Fig. 5. Galactic orbit of NGC 752. The square and circle show the site of formation and present day location, respectively

circular orbit around the galactic center. The same considerations made for NGC 188 can be applied to the case of NGC 752.

4.5. NGC 2506

The orbit of NGC 2506 is shown in Fig. 6. This cluster has the smallest eccentricity and epiciclycal amplitude of the sample under consideration, suggesting that it has not moved far away from the site of formation. The orbit remains confined at radial distances between 10.7 and 11.6 *kpc*, and along the z-direction does not extend beyond 0.6 *kpc*.

5. Paleogradients across the Galactic Disk

Intermediate age and old open clusters clearly trace a radial gradient in metallicity (measured by [Fe/H]) across the Galactic Disk. The most recent determination by Friel & Janes (1993) yields d[Fe/H]/dR = -0.095 $dex \ \ kpc^{-1}$. The situation is shown in panel (a) of Fig.7 where the full dots are the clusters from the Friel & Janes (1993) list and the solid line is the above mean gradient. In the same diagram we draw for the five clusters the amplitudes of their epicyclical motions (horizontal bars) already given in Table 6. This allows us to check whether the gradient has changed from the past to present because of the radial motions of the clusters (Grenon 1987).

Looking at the data of Table 6 and the epiciclycal amplitudes drawn in Fig. 7 (panel a), clusters like NGC 188, NGC 752 and NGC 2506 have not moved far away from their site of formation, so that the gradient traced by them is very close to the original one. As far as NGC 2420 and M 67 are concerned, despite their large radial excursions, they are found to spend most of their life near the apogalacticon, where they are observed to-

Table 6. Orbital parameters of the studied clusters

Cluster	E $km^2 \cdot sec^{-2}$	J_z $kpc \cdot km \cdot sec^{-1}$	R_a (kpc)	R_p (kpc)	ΔR (kpc)	e	T (Myr)	ν_z (Myr)	$\|z_{max}\|$ (kpc)
NGC188	-9235.8	2362.8	10.83	9.38	1.45	0.07	274	112	0.83
NGC2682	-20815.5	1833.6	9.09	6.83	2.23	0.14	225	78	0.49
NGC2420	-11919.2	2292.3	11.65	8.56	3.09	0.14	272	140	0.81
NGC752	-13480.2	2128.6	9.34	8.79	0.55	0.03	241	86	0.19
NGC2506	-7598.8	2561.9	11.56	10.72	0.84	0.03	310	112	0.61

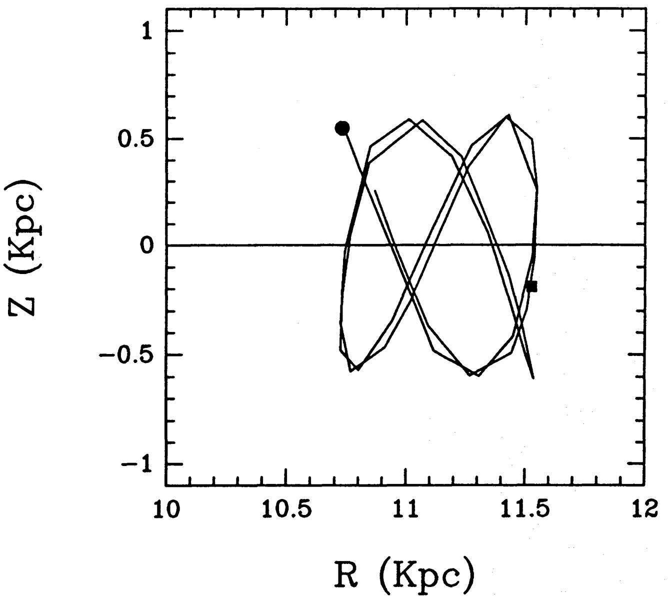

Fig. 6. Galactic orbit of NGC 2506. The square and circle show the site of formation and present day position, respectively

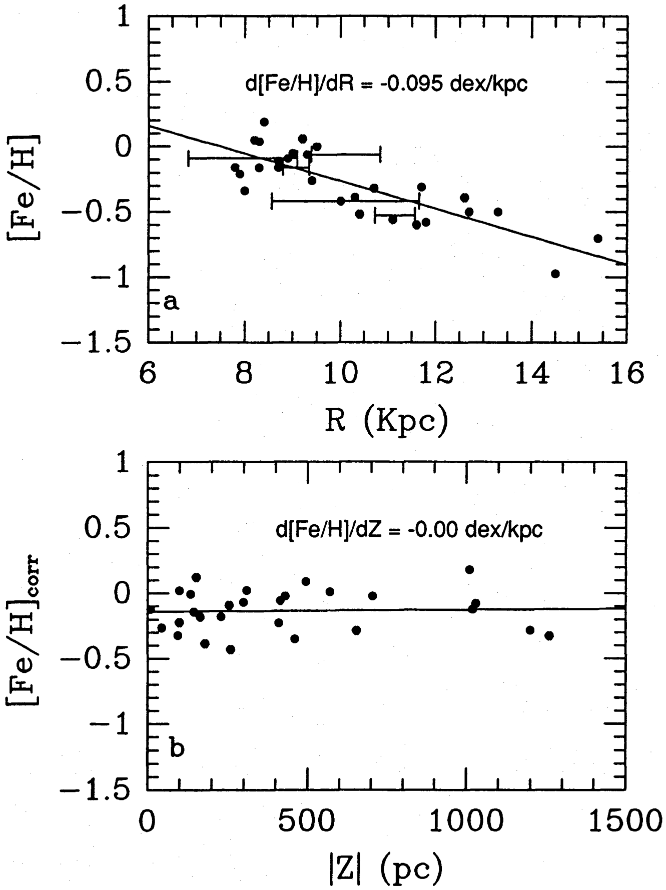

Fig. 7. Metallicity gradients across the Galactic Disk

day. Therefore also in this case the effect on the paleogradient is likely to be negligible.

The suggestion arising from this preliminary study (no better conclusions are possible owing to the small number of clusters for which orbits are available) is that the gradient in metallicity derived from the present day position of the clusters is likely to be very similar to the paleogradient.

As far as the gradient in metallicity along the z-direction, current observations indicate that no gradient exist. This is shown in panel (b) of Fig. 7, where the data of Friel & Janes (1993) are displayed (full dots) together with the mean value of the gradient. The values of the metallicity used to plot the data in panel (b) have been corrected for the effect of the radial gradient in metallicity (see Carraro & Chiosi 1994).

The lack of a gradient along the z-direction can be understood as due to the rapid vertical motion of these clusters that rapidly destroys any initial trend in metallicity (see the periods ν_z of the vertical motion presented in Table 6).

6. Summary and conclusions

In this paper we have calculated the galactic orbits of the five old open clusters NGC 188, M 67, NGC 2420, NGC 752, and NGC 2506.

To this aim, we have adopted the new determinations of radial velocities by Friel & Janes (1993). Furthermore, we have calculated the absolute proper motions for NGC 752 and NGC 2506, whereas for the remaining clusters we have used values from literature. Finally, we have corrected the velocities for the effect of the galactic differential rotation.

To derive the equations of motions we have made use of the analytical model of mass distribution and gravitational potential for the Galaxy proposed by Allen & Santillán (1991), and computed the orbits backward in time for a time interval corresponding to the age of each clusters. The ages are from the recent compilation by Carraro & Chiosi (1994).

For two clusters with previous calculations of the orbits (M 67 and NGC 188) we find good agreement with the results by Keenan et al. (1973) in the case of the Innanen (1966) mass model, provided that the differences in the input parameters and numerical method are taken into account.

In general, the orbits of the five clusters are all of "boxy" type.

The orbital parameters we have obtained show that the five clusters here considered belong to the old Thin Disk population, in agreement with the indication arising from their ages and metallicities (Friel & Janes 1993).

The existing uncertainty on the age of each cluster does not allow us to infer the exact site of formation within its orbital box.

Finally, we have addressed the question whether the gradient in metallicity traced by the present day position of the clusters is reminiscent of the paleogradient, namely the gradient in the metallicity of the gas out of which the clusters have been generated. We find that the radial gradient in metallicity is not too seriously affected by the motions of the clusters. Indeed, either the clusters do not travel too far away from their birth-place or spend the largest fraction of their life near it.

On the contrary, the observational lack of a gradient in metallicity along the z-direction is the result of the rapid oscillatory motion of the clusters across the galactic plane.

Acknowledgements. It is a great pleasure to thank Dr. S. J. Aarseth for making available his code ORBIT from which the one used in this study has been adapted, and to Dr. G. Galletta for very useful discussions. Finally we would like to thank the referee, Dr P. Grosbol, for his useful comments and suggestions. This work has been financially supported by the Italian Ministry of University, Scientific Research and Tecnology (MURST) and the Italian Space Agency (ASI).

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