SPACE DISTRIBUTION AND METALLICITIES OF GLOBULAR CLUSTERS: THE DISTANCE TO THE GALACTIC CENTRE

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Abstract. The system of globular clusters in the Galaxy is used in order to locate the position of the galactic centre and, consequently, to determine the galacto-centric distance of the Sun, R_0. The space distribution and metallicities of the whole sample of known globular clusters are taken into account, and the obtained results indicate that $8.6 > R_0$ (kpc) > 6.4. Analysis of a selected sample of clusters further suggests that $R_0 = 7.6 \pm 0.4$ kpc.

1. Introduction

The distance to the galactic centre R_0 can be determined by direct and indirect methods. Direct methods do not make use of any "standard candle" calibration, and are presently essentially limited to astrometric measurements of H_2O maser sources within a few parsecs of the galactic centre (Reid, 1989; Reid *et al.*, 1988). Indirect methods are much more common, and basically include the analysis of the distribution of globular clusters, RR Lyrae variables, and red giants, including Mira variables (see for example Reid, 1989; Tello, 1992; Walker and Mack, 1986; Glass and Feast, 1982). Other methods are also used, on the basis of a rotation model for the galactic disk, often coupled with a determination of Oort's constants or the rotation velocity at R_0 (see for example Reid, 1989; Rohlfs *et al.*, 1986; Maciel and Dutra, 1992).

In the past few years, most of these methods have obtained values in the range $8.5 > R_0$(kpc)> 6.0, indicating a systematic decrease relative to the previous IAU recommended value, $R_0 = 10$ kpc, and even to the value $R_0 = 8.5$ kpc which is frequently used today (cf. Clemens, 1985; Maciel and Dutra, 1992).

An accurate determination of R_0 has extremely important astrophysical implications, such as the estimate of kinematic distances, the galactic mass, and the calibration of extragalactic distances. Studies of the chemical evolution of the Galaxy may also be affected, especially through the determination of radial abundance gradients in the galactic disk (Maciel, 1992; 1993; Maciel and Köppen, 1993).

The system of globular clusters has remained a favorite group for the purpose of studying the structure and kinematics of the Galaxy (Harris and Racine, 1979; Hanes, 1980; Madore, 1980). The original idea that the galactic centre lies considerably far from the solar neighbourhood, and the first determination of R_0 based on the assumption that the globular clusters are spherically distributed around the centre go back to Shapley (1918). In the 75 years that followed, several people have

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studied this problem, both increasing the sample of globular clusters and introducing some kind of selection in order to obtain more accurate values for the distance to the galactic centre (Fernie, 1962; Arp, 1965; Van den Bergh, 1968; Woltjer, 1975; Harris, 1976; 1980; de Vaucouleurs and Buta, 1978; Frenk and White, 1982; Racine and Harris, 1989; Thomas, 1989; Tello, 1992).

Typical features used to select from the total globular cluster system are the *extinction* and *chemical composition*. The former has an important effect on the distance of a given cluster, especially those located at low galactic latitudes, for which the line of sight passes through a considerable amount of dust. On the other hand, it has been known for many years that metal-poor globular clusters have a wide spherical distribution around the galactic centre, whereas metal-rich ones are generally distributed more closely to the galactic plane (see for example Morgan, 1956; Arp, 1965; Madore, 1980; Zinn, 1985).

Other characteristics may also play a role, such as the so-called "second-parameter" effect, according to which different colour-magnitude diagrams can be derived for clusters with the same mean metallicity (see for example Harris, 1980; Castellani, 1977).

The analysis of the kinematical properties of the globular clusters also shows some consistency with their space distribution and metallicities, in the sense that the flattened, metal-rich subsystem apparently rotates faster than the metal-poor one (cf. Hartwick and Sargent, 1978; Harris and Racine, 1979; Harris, 1980; Kulessa and Lynden-Bell, 1992).

The total number of globular clusters known in the Galaxy is about 150, corresponding to at least three fourths of the galactic population, which leaves out essentially the clusters hidden beyond the galactic centre (Hanes, 1980; Madore, 1980). In the present work, the space distribution and metallicity variations of the whole sample of globular clusters are used in order to locate the position of the galactic centre and to determine the distance R_0 from the Sun.

2. The data

Comprehensive lists of globular clusters have been recently given by Webbink (1985), Zinn (1985), Armandroff and Zinn (1988), Thomas (1989), Racine and Harris (1989), and Tello (1992), comprising about 150 clusters. Most of these have good distance estimates and also independently derived metallicities. We have obtained a list of objects for which distances d to the Sun and metallicities [Fe/H] = log $(Fe/H)_{cl}$ - log $(Fe/H)_{\odot}$ are known. The objects are listed in order of increasing right ascension in Table I, where the identification of the object is given in column 1; columns 2 and 3 give the galactic coordinates (ℓ, b), column 4 gives the metallicity and column 5 shows the distance to the Sun. (*Table I can be found at the end of this article*).

Distances of globular clusters can be derived from colour-magnitude diagrams and other secondary methods, and the determination of the metallicity index can be made on the basis of integrated properties, such as integrated UBV colours and spectral types. High-dispersion spectrophotometry of individual stars in the cluster generally provide the most reliable data (cf. Bell, 1988). Metal-rich clusters have a maximum [Fe/H] ≈ 0, and the most metal-poor ones may reach two order of magnitudes under solar. In Table I distances and metallicities are from Thomas (1989), except otherwise noted.

For the distance scale, an absolute magnitude $M_v = 0.6$ on the horizontal branch was assumed. On the other hand, the metallicity data by Thomas (1989) has been checked against recent determinations for several globular clusters, namely: NGC 104, 6121, and 6656 (Brown and Wallerstein, 1992); Eri, Pal 12 (Armandroff and Da Costa, 1991); Ret (Walker, 1992); NGC 1904 (Ferraro *et al.*, 1992); Rup 106 (Da Costa *et al.*, 1992); NGC 5897 (Sarajedini, 1992); NGC 6101 (Sarajedini and Da Costa, 1991); NGC 6121 (Clementini *et al.*, 1993); NGC 6171 (Ferraro *et al.*, 1991); NGC 6229 (Carney *et al.*, 1991); NGC 6637 (Davidge and Simons, 1991); Rup 106, Ter 7, Pal 10, and Ter 8 (Tello, 1992). The data from the last reference are explicitly quoted in Table I. For the remaining objects above, there is a good agreement with the values by Thomas (1989), especially in terms of the metallicity groups discussed in the next section, so that we prefer to list the values by Thomas.

3. Distribution of globular clusters

The distribution of metallicities as a function of the galactocentric distance R clearly suggests the existence of two groups within the system of globular clusters in the Galaxy (see for example Harris and Racine, 1979). Metal-rich clusters have $[\mathrm{Fe/H}] \gtrsim [\mathrm{Fe/H}]_{\mathrm{min}}$, where $-0.8 \gtrsim [\mathrm{Fe/H}]_{\mathrm{min}} \gtrsim -1.2$ (Harris and Racine, 1979; Zinn, 1985; 1988; Norris, 1986; Thomas, 1989). Here, we will adopt the lower limit, $[\mathrm{Fe/H}]_{\mathrm{min}} = -1.2$, which makes sure that the sample of metal-rich clusters is complete. These objects are concentrated in the inner halo ($R \lesssim 8$ kpc), whereas metal-poor ones ($[\mathrm{Fe/H}] < -1$) present a much wider distribution, reaching about $[\mathrm{Fe/H}] \sim -2$ for $R \sim 100$ kpc (see for example Harris and Racine, 1979). Although the correlation is not clear-cut, especially when we take into account the average uncertainties associated with the metallicity index, $\delta[\mathrm{Fe/H}] \sim 0.2$, it is clear that the space distribution of the globular clusters depends on their metallicities. Therefore, our sample of globular clusters was divided into four different subsets, according to the metallicity:

Group 1: all objects (147 clusters)
Group 2: objects with $Z < -1.2$, or unknown (101 clusters)
Group 3: objects with $Z < -1.2$ (93 clusters)
Group 4: objects with $Z \geq -1.2$ (46 clusters)

Assuming that a given set containing n clusters is spherically distributed around

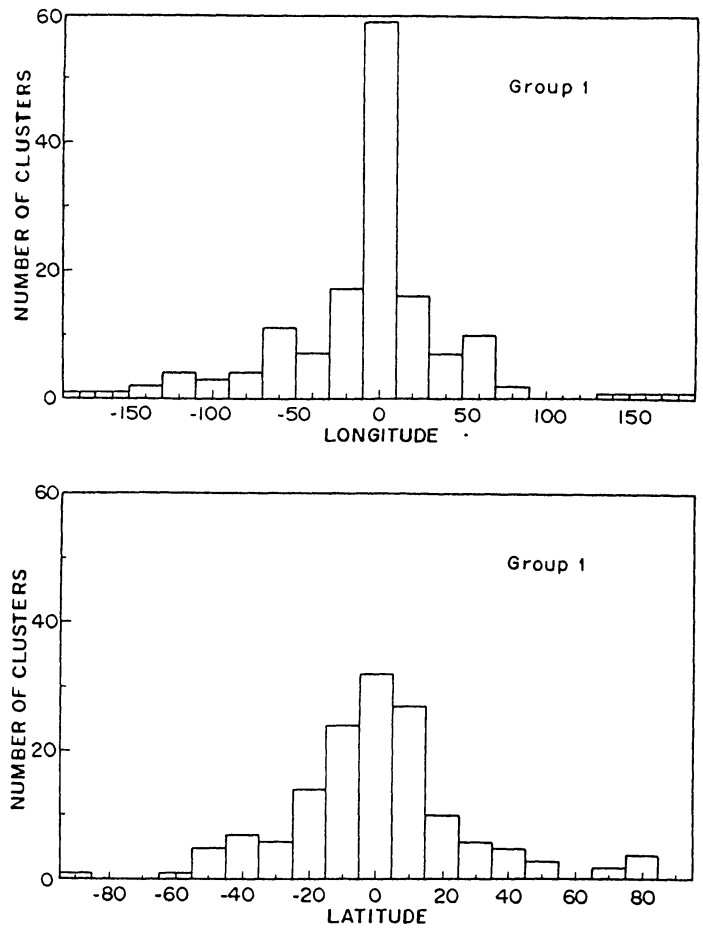

Fig. 1a. Latitude/longitude distribution of globular clusters. Group 1.

the galactic centre, the components of the vector distance R_0 along three perpendicular axes are:

$$R_{0x} = \frac{1}{n}\sum_{i=1}^{n} d_{ix} \tag{1}$$

$$R_{0y} = \frac{1}{n}\sum_{i=1}^{n} d_{iy} \tag{2}$$

$$R_{0z} = \frac{1}{n}\sum_{i=1}^{n} d_{iz} \tag{3}$$

so that

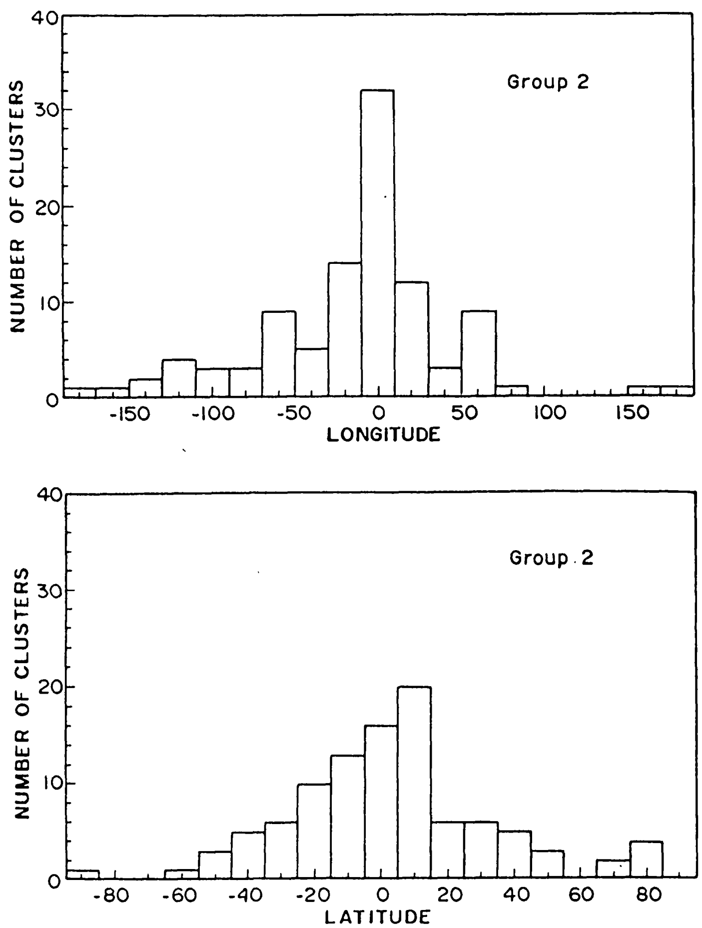

Fig. 1b. Latitude/longitude distribution of globular clusters. Group 2.

$$R_0^2 = R_{0x}^2 + R_{0y}^2 + R_{0z}^2 \ . \tag{4}$$

The distances to each cluster projected along the axes x, y, z are

$$d_x = d \cos b \cos \ell \tag{5}$$

$$d_y = d \cos b \sin \ell \tag{6}$$

$$d_z = d \sin b \ , \tag{7}$$

where ℓ and b are the galactic longitude and latitude, respectively. We have considered a reference system centered in the Sun, where the positive x points to the direction $\ell = 0^{\circ}$, $b = 0^{\circ}$, the y axis is positive in the direction $\ell = 90^{\circ}$, $b = 0^{\circ}$, and the z axis is positive for $b = 0^{\circ}$, as usual. The components d_x, d_y, d_z are given in the last columns of Table I.

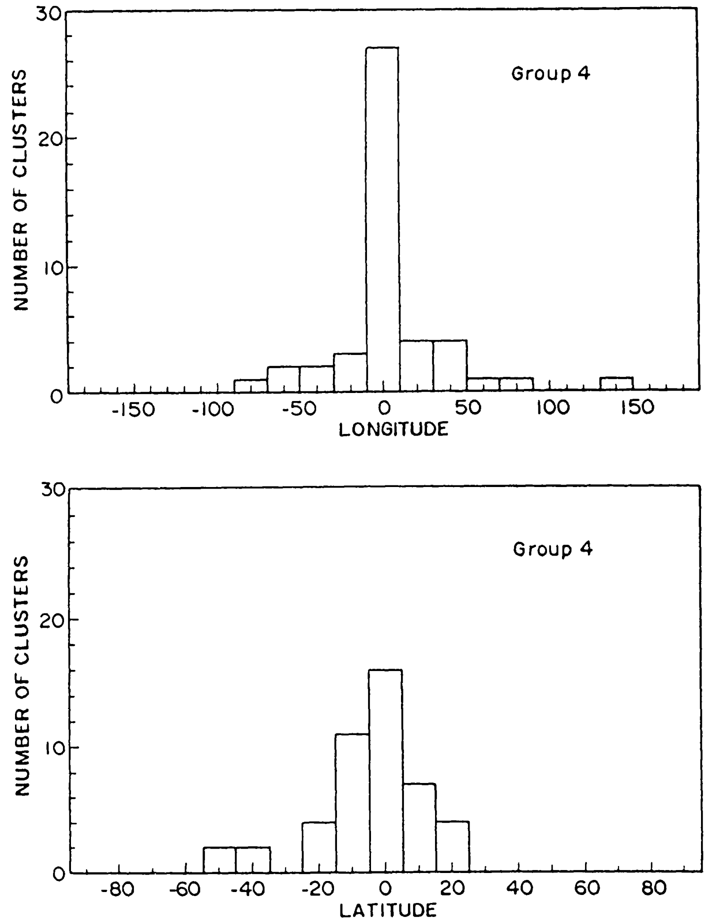

Fig. 1c. Latitude/longitude distribution of globular clusters. Group 4.

Figure 1 shows the longitude/latitude distribution of the sample of globular clusters. All four groups display a general spherical symmetry, which is stronger for groups 1 (Fig. 1a) and 4 (Fig. 1c). Groups 2 (Fig. 1b) and 3 show longer and asymmetric wings, especially in the latitude distribution. This is confirmed by Fig. 2, where the distributions along the components d_x, d_y, d_z are shown. All groups present a sharp maximum at $d_y = d_z = 0$, showing that the distance to the galactic centre is given essentially by the average distance along the x axis, d_x. Again, groups 1 and 4 show a more symmetric distribution, as can be seen from Fig. 2 and from the values of R_0 and R_{0x} given in Table II. For these groups we have $R_0 \gg R_{0y}$, $R_0 \gg R_{0z}$, and $R_0 \approx R_{0x}$ within the average uncertainty of 0.3 kpc. (*Table II can be found at the end of this article*).

A better estimate of R_0 can be made assuming that the distances of the globular clusters along the x axis have a normal (gaussian) distribution. In this case, the observed number of clusters N_o in each bin of width $\Delta(d_x)$ can be written as

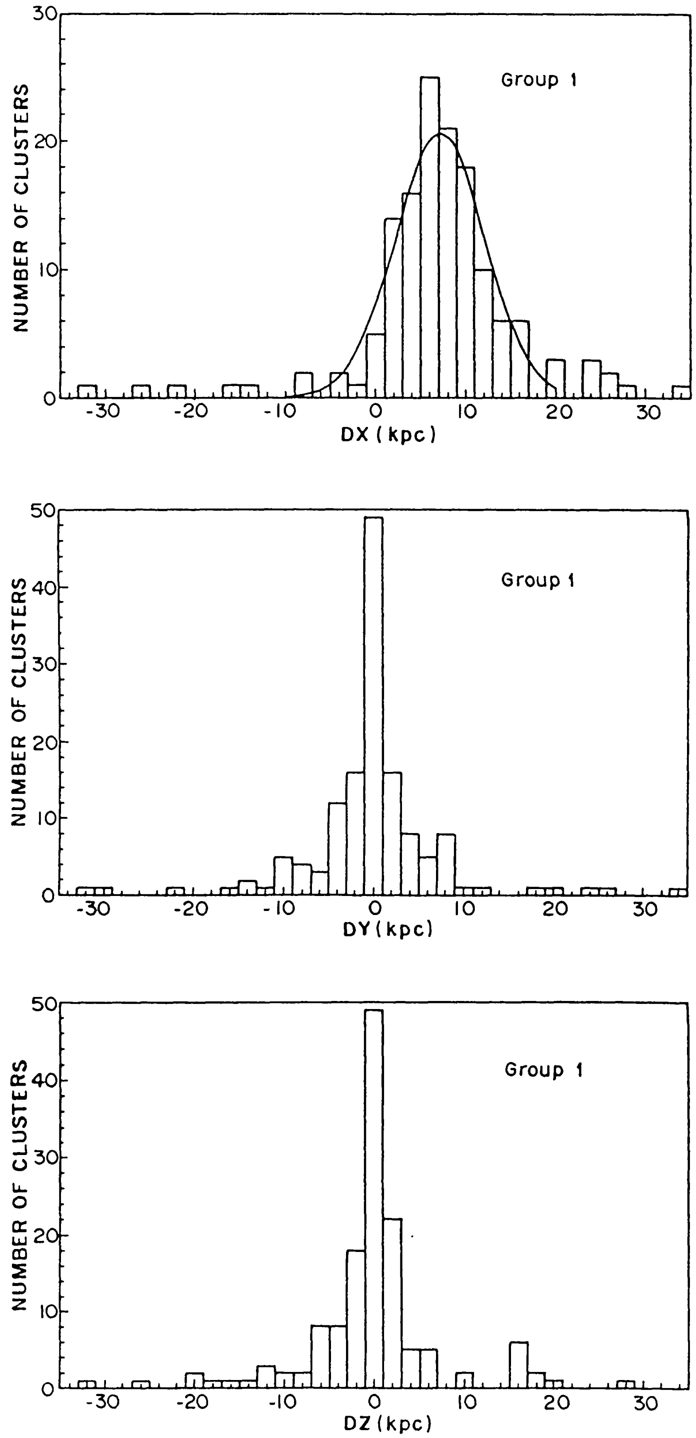

Fig. 2a. Distribution along the components d_x, d_y, and d_z. The first panel shows the gaussian fit. Group 1.

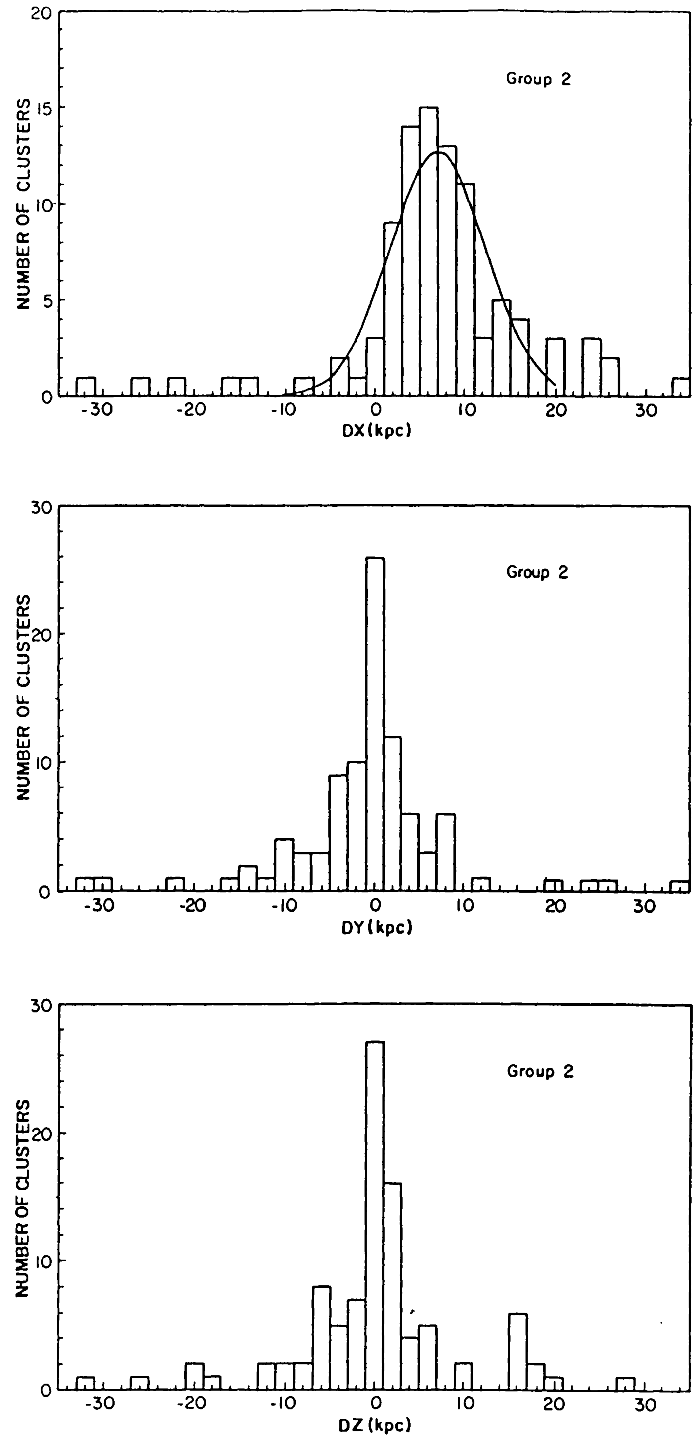

Fig. 2b. Distribution along the components d_x, d_y, and d_z. The first panel shows the gaussian fit. Group 2.

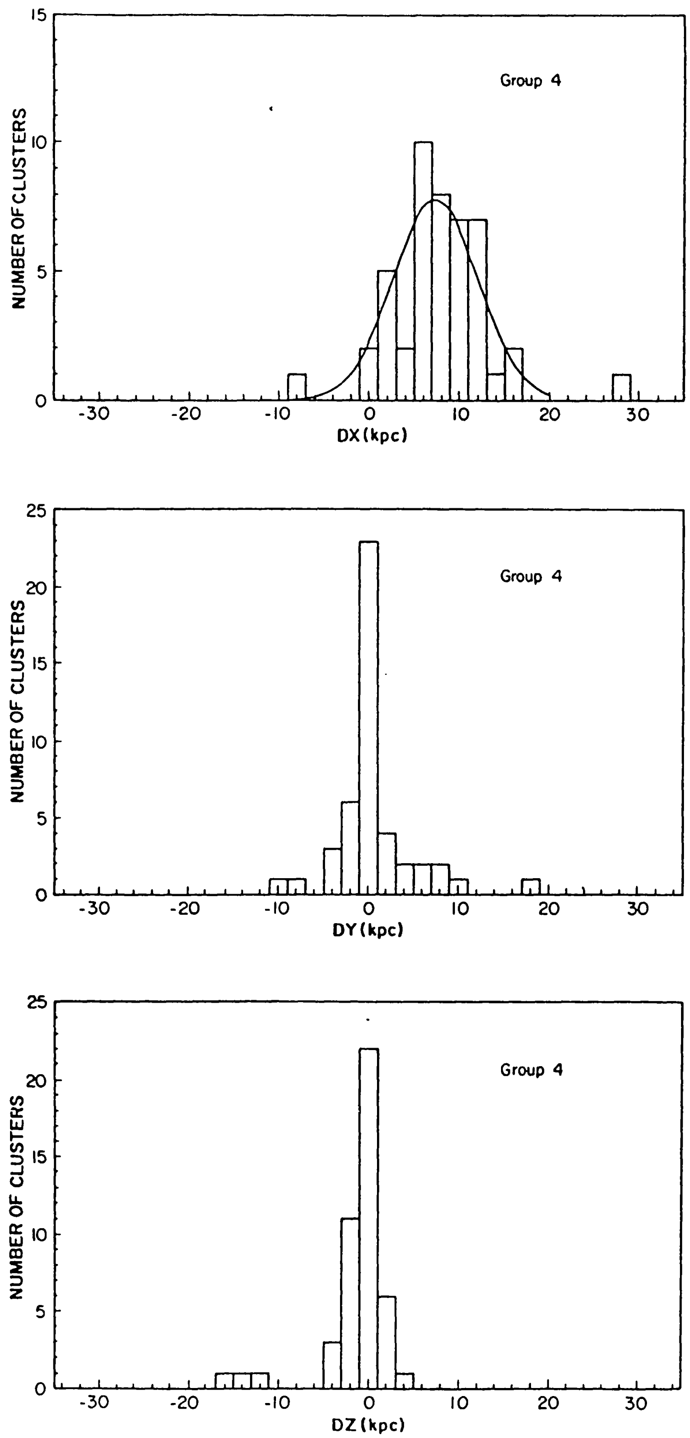

Fig. 2c. Distribution along the components d_x, d_y, and d_z. The first panel shows the gaussian fit. Group 4.

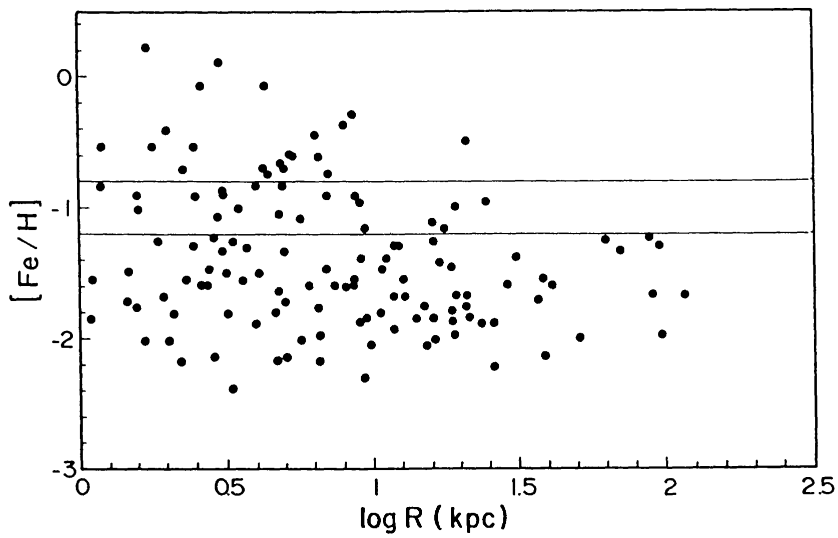

Fig. 3. Metallicity distribution of the globular clusters of Table I, with distances to the galactic centre calculated by equation (11). Lines indicate the approximate limits at [Fe/H] = −0.8 and −1.2.

$$N_o(d_x, R_0, \sigma) = \frac{N\Delta(d_x)}{\sigma\sqrt{2\pi}} \exp\left[-\frac{1}{2}\left(\frac{d_x - R_0}{\sigma}\right)^2\right] \tag{8}$$

where σ is the estimated deviation.

The estimate of R_0 for a gaussian distribution depends slightly on the total adopted range of distances along the x axis. From the distributions shown in the upper panels of Fig. 2, it is clear that the distribution fails at large distances, corresponding to a total range of $\sim$ 30 kpc. Therefore, we will take this value as an upper limit for the maximum width of the distribution, so that we will only include the objects in the interval $20 \gtrsim d_x$ (kpc) $\gtrsim -10$. This does not change the final value of R_0 more than $\sim$ 0.4 kpc, and includes the vast majority of clusters ($>$ 80%), as shown in Table II. The best gaussian fits corresponding to the values of R_0 and σ given in columns 4 and 5 of Table II are plotted with the histograms of the upper panels of Fig. 2. Group 4 shows again the best result, as the metal-rich clusters are already concentrated near the galactic centre.

The limit $R \sim 30$ kpc can be understood in terms of a three-component system of globular clusters (cf. Harris, 1990; Zinn, 1985; 1988): (i) the *metal-rich* group at short galactocentric distances, (ii) the *normal-halo* clusters, or the spherically symmetric metal-poor group distributed from the centre to $R \sim$ 30–40 kpc, and (iii) the *outermost halo* clusters, metal-poor objects located at distances larger than this limit. The third group includes objects that are not spherically distributed in space, and are probably associated with neighbouring systems.

4. Conclusions

In view of the results shown in Table II, we can realistically conclude that the distance to the galactic centre lies in the range

$$8.6 > R_0(\text{kpc}) > 6.4 \tag{9}$$

Following the discussion in Section 3, the best distributions are presented by groups 1 and 4, so that it seems appropriate to suggest the adopted value

$$R_0 = 7.6 \pm 0.4 \text{ kpc}. \tag{10}$$

The present results indicate that the distance to the galactic centre $R_0 < 10$ kpc, the previously recommended IAU value and certainly lower than the commonly adopted value, R_0 =8.5 kpc (cf. Clemens, 1985). The value given in (10) is similar to the weighted average $R_0 = 7.7 \pm 0.7$ kpc given by Reid (1989), which is based on four classes of determinations, namely, (i) direct measurements, (ii) centroid of distributions, (iii) Galaxy models, and (iv) Eddington luminosity.

Racine and Harris (1989) have recently made an accurate determination of R_0, based on the fact that the space distribution of globular clusters around the galactic centre approximately follows an R^{-3} law. They obtain a value $R_0 = 7.6 \pm 0.9$ kpc, which is close to the average value given in this paper.

In order to confirm the metallicity variations that led to the definition of groups 1-4, it is interesting to calculate the new galactocentric distances R given approximately by

$$R^2 \approx R_0^2 + d^2 - 2R_0 d \cos b \cos \ell, \tag{11}$$

where we have substituted $R_0 = 7.6$ kpc from (10) for R_{0x}, making use of the fact that $R_{0x} \gg R_{0y}$ and $R_{0x} \gg R_{0z}$. Figure 3 shows that metal-rich clusters are generally confined within $R < 10$ kpc, and metal-poor ones are more evenly distributed between $R \sim 3$ and 100 kpc, in good agreement with the metallicity-distance relation from Harris and Racine (1979).

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TABLE I
Properties of globular clusters

	name	ℓ	b	[Fe/H]	d	d_x	d_y	d_z
1	NGC 104	305.895	–44.889	–0.75	4.6	1.9	–2.6	–3.2
2	NGC 288	151.147	–89.377	–1.39	8.2	–0.1	0.0	–8.2
3	NGC 362	301.533	–46.247	–1.39	8.7	3.1	–5.1	–6.3
4	NGC 1261	270.539	–52.127	–1.17	16.1	0.1	–9.9	–12.7
5	Pal 1	130.967	19.023	–1.01	13.7	–8.5	9.8	4.5
6	NGC 1466	286.700	–39.537	–2.15	39.4	8.7	–29.1	–25.1
7	AM 1	258.360	–48.472	–1.68	116.4	–15.6	–75.6	–87.1
8	Eri	218.108	–41.331	–1.22	84.7	–50.0	–39.3	–55.9
9	Ret	268.664	–40.269	–2.01	50.4	–0.9	–38.4	–32.6
10	Pal 2	170.532	–9.070	–1.68	13.6	–13.2	2.2	–2.1
11	NGC 1841	297.016	–30.147	–1.56	40.9	16.1	–31.5	–20.5
12	NGC 1851	244.512	–35.036	–1.25	12.0	–4.2	–8.9	–6.9
13	NGC 1904	227.231	–29.350	–1.47	13.0	–7.7	–8.3	–6.4
14	NGC 2298	245.629	–16.007	–2.06	10.6	–4.2	–9.3	–2.9
15	NGC 2419	180.370	25.242	–1.98	91.4	–82.7	–0.5	39.0
16	AM 2	248.126	–5.876		57.7	–21.4	–53.3	–5.9
17	NGC 2808	282.193	–11.252	–1.47	9.5	2.0	–9.1	–1.9
18	E 3	292.269	–19.018	–0.96	8.3	3.0	–7.3	–2.7
19	Pal 3	240.142	41.866	–1.68	87.9	–32.6	–56.8	58.7
20	NGC 3201	277.229	8.641	–1.60	5.0	0.6	–4.9	0.8
21	ESO 09	293.508	–4.041		59.5	23.7	–54.4	–4.2
22	Pal 4	202.293	71.801	–1.30	93.3	–27.0	–11.1	88.6
23	NGC 4147	252.848	77.189	–1.68	17.3	–1.1	–3.7	16.9
24	NGC 4372	300.995	–9.881	–1.77	4.9	2.5	–4.1	–0.8
25	Rup 106	300.888	11.670	–1.9*	26.7	13.4	–22.4	5.4
26	NGC 4590	299.625	36.051	–1.85	9.6	3.8	–6.7	5.6
27	NGC 4833	303.604	–8.014	–1.98	5.8	3.2	–4.8	–0.8
28	NGC 5024	332.965	79.764	–1.89	18.5	2.9	–1.5	18.2
29	NGC 5053	335.675	78.946	–2.02	15.8	2.8	–1.2	15.5
30	NGC 5139	309.100	14.971	–1.60	5.2	3.2	–3.9	1.3
31	NGC 5272	42.218	78.707	–1.30	10.4	1.5	1.4	10.2
32	NGC 5286	311.614	10.568	–1.60	9.7	6.3	–7.1	1.8
33	AM 4	320.280	33.506	–2.23	30.3	19.4	–16.1	16.7
34	NGC 5466	42.137	73.593	–1.85	15.8	3.3	3.0	15.2
35	NGC 5634	342.210	49.260	–1.77	25.0	15.5	–5.0	18.9
36	NGC 5694	331.056	30.360	–1.89	31.3	23.6	–13.1	15.8
37	IC 4499	307.354	–20.473	–1.77	18.0	10.2	–13.4	–6.3
38	NGC 5824	332.555	22.071	–1.98	24.6	20.2	–10.5	9.2
39	Pal 5	0.847	45.853	–1.43	21.4	14.9	0.2	15.4
40	NGC 5897	342.948	30.294	–1.47	11.8	9.7	–3.0	6.0

* Tello, 1992

TABLE I *Continued*

	name	ℓ	b	[Fe/H]	d	d_x	d_y	d_z
41	NGC 5904	3.860	46.797	−1.60	7.6	5.2	0.4	5.5
42	NGC 5927	326.605	4.859	−0.67	8.8	7.3	−4.8	0.7
43	NGC 5946	327.582	4.192	−1.34	9.2	7.7	−4.9	0.7
44	BH 176	328.417	4.344		85.7	72.8	−44.8	6.5
45	NGC 5986	337.028	13.273	−1.72	10.5	9.4	−4.0	2.4
46	Pal 14	28.755	42.177	−1.34	75.3	48.9	26.8	50.6
47	NGC 6093	352.674	19.462	−2.15	8.0	7.5	−1.0	2.7
48	NGC 6101	317.751	−15.828	−1.68	16.1	11.5	−10.4	−4.4
49	NGC 6121	350.975	15.974	−1.09	2.1	2.0	−0.3	0.6
50	NGC 6144	351.929	15.702	−1.81	9.5	9.1	−1.3	2.6
51	NGC 6139	342.365	6.939	−1.60	8.1	7.7	−2.4	1.0
52	Ter 3	345.083	9.190		27.2	25.9	−6.9	4.3
53	NGC 6171	3.371	23.012	−0.88	6.2	5.7	0.3	2.4
54	ESO 45	351.912	12.097	−1.01	10.3	10.0	−1.4	2.2
55	NGC 6205	59.006	40.914	−1.61	7.1	2.8	4.6	4.6
56	NGC 6218	15.715	26.313	−1.89	5.3	4.6	1.3	2.3
57	NGC 6229	73.638	40.306	−1.39	31.6	6.8	23.1	20.4
58	NGC 6235	358.918	13.520	−1.60	9.5	9.2	−0.2	2.2
59	NGC 6254	15.138	23.074	−1.51	4.5	4.0	1.1	1.8
60	NGC 6256	347.791	3.307	−1.56	9.1	8.9	−1.9	0.5
61	Pal 15	18.873	24.293	−1.26	69.7	60.1	20.5	28.7
62	NGC 6266	353.575	7.317	−1.26	6.1	6.0	−0.7	0.8
63	NGC 6273	356.869	9.381	−2.40	10.6	10.4	−0.6	1.7
64	NGC 6284	358.347	9.939	−1.34	10.3	10.1	−0.3	1.8
65	NGC 6287	0.132	11.023	−1.72	7.2	7.1	0.0	1.4
66	NGC 6293	357.620	7.834	−1.85	7.7	7.6	−0.3	1.0
67	NGC 6304	355.825	5.374	−0.54	6.0	6.0	−0.4	0.6
68	NGC 6316	357.175	5.765	−0.62	12.8	12.7	−0.6	1.3
69	NGC 6325	0.973	8.003	−2.02	6.2	6.1	0.1	0.9
70	NGC 6341	68.339	34.858	−1.89	7.7	2.3	5.9	4.4
71	NGC 6333	5.544	10.705	−1.77	7.5	7.3	0.7	1.4
72	NGC 6342	4.899	9.725	−0.75	11.6	11.4	1.0	2.0
73	NGC 6356	6.723	10.220	−1.17	16.7	16.3	1.9	3.0
74	NGC 6355	359.585	5.428	−1.34	7.1	7.1	−0.1	0.7
75	NGC 6352	341.421	−7.164	−0.07	6.6	6.2	−2.1	−0.8
76	Ter 2	356.320	2.298	−0.54	10.0	10.0	−0.6	0.4
77	NGC 6366	18.411	16.041	−0.71	4.0	3.6	1.2	1.1
78	NGC 6362	325.555	−17.569	−0.71	7.7	6.1	−4.2	−2.3
79	Ter 4	356.024	1.308	−0.29	16.1	16.1	−1.1	0.4
80	HP 1	357.423	2.113	−1.68	9.5	9.5	−0.4	0.4

TABLE I *Continued*

	name	ℓ	b	[Fe/H]	d	d_x	d_y	d_z
81	Gri 1	354.304	−0.151		11.8	11.7	−1.2	0.0
82	Lil 1	354.841	−0.161	−0.29	7.9	7.9	−0.7	0.0
83	NGC 6380	350.182	−3.414	−1.30	4.0	3.9	−0.7	−0.2
84	Ter 1	357.558	0.992	0.10	10.6	10.6	−0.5	0.2
85	NGC 6388	345.557	−6.738	−0.62	13.5	13.0	−3.3	−1.6
86	Ton 2	350.797	−3.419		8.7	8.6	−1.4	−0.5
87	NGC 6402	21.322	14.803	−2.19	10.2	9.2	3.6	2.6
88	NGC 6401	3.451	3.978	−1.01	7.1	7.1	0.4	0.5
89	NGC 6397	338.165	−11.959	−2.02	2.2	2.0	−0.8	−0.5
90	Pal 6	2.092	1.779	0.22	5.9	5.9	0.2	0.2
91	NGC 6426	28.088	16.233	−1.94	17.5	14.8	7.9	4.9
92	Ter 5	3.838	1.687	−0.71	7.1	7.1	0.5	0.2
93	NGC 6440	7.729	3.800	−0.54	7.1	7.0	1.0	0.5
94	NGC 6441	353.532	−5.006	−0.07	11.7	11.6	−1.3	−1.0
95	NGC 6453	355.717	−3.873	−1.51	10.7	10.6	−0.8	−0.7
96	Ter 6	358.572	−2.163	−0.61	12.8	12.8	−0.3	−0.5
97	UKS 1	5.125	0.764	−1.22	10.4	10.4	0.9	0.1
98	NGC 6496	348.026	−10.012	−0.71	6.3	6.1	−1.3	−1.1
99	Ter 9	3.603	−1.988	−0.45	7.0	7.0	0.4	−0.2
100	NGC 6517	19.225	6.762	−1.47	6.1	5.7	2.0	0.7
101	Ter 10	4.421	−1.864		14.6	14.5	1.1	−0.5
102	NGC 6522	1.026	−3.929	−1.56	6.6	6.6	0.1	−0.5
103	NGC 6535	27.176	10.435	−1.56	6.9	6.0	3.1	1.2
104	NGC 6528	1.138	−4.175	−0.96	6.8	6.8	0.1	−0.5
105	NGC 6539	20.795	6.775	−1.05	3.1	2.9	1.1	0.4
106	NGC 6544	5.837	−2.201	−2.15	2.6	2.6	0.3	−0.1
107	NGC 6541	349.286	−11.189	−2.02	7.0	6.7	−1.3	−1.4
108	NGC 6553	5.253	−3.029	−0.41	5.7	5.7	0.5	−0.3
109	NGC 6558	0.200	−6.024	−1.51	8.8	8.8	0.0	−0.9
110	Pal 7	21.832	5.666	−0.84	9.8	9.1	3.6	1.0
111	Ter 11	8.357	−2.100		23.7	23.4	3.4	−0.9
112	NGC 6569	0.481	−6.681	−1.01	8.9	8.8	0.1	−1.0
113	NGC 6584	342.144	−16.413	−1.56	15.0	13.7	−4.4	−4.2
114	NGC 6624	2.788	−7.913	−0.84	8.0	7.9	0.4	−1.1
115	NGC 6626	7.799	−5.580	−1.81	5.8	5.7	0.8	−0.6
116	NGC 6638	7.897	−7.153	−0.92	6.7	6.6	0.9	−0.8
117	NGC 6637	1.722	−10.269	−0.92	10.3	10.1	0.3	−1.8
118	NGC 6642	9.814	−6.439	−1.30	5.5	5.4	0.9	−0.6
119	NGC 6652	1.535	−11.377	−0.92	14.3	14.0	0.4	−2.8
120	NGC 6656	9.890	−7.552	−1.81	3.1	3.0	0.5	−0.4

TABLE I *Continued*

	name	ℓ	b	[Fe/H]	d	d_x	d_y	d_z
121	Pal 8	14.103	−6.797	−0.50	28.1	27.1	6.8	−3.3
122	NGC 6681	2.853	−12.510	−0.92	9.3	9.1	0.5	−2.0
123	NGC 6712	25.353	−4.318	−1.26	6.2	5.6	2.6	−0.5
124	NGC 6715	5.607	−14.088	−1.85	21.5	20.8	2.0	−5.2
125	NGC 6717	12.876	−10.901	−2.19	7.8	7.5	1.7	−1.5
126	NGC 6723	0.072	−17.298	−1.09	9.2	8.8	0.0	−2.7
127	NGC 6749	6.201	−2.204	−0.37	12.8	10.3	7.6	−0.5
128	NGC 6752	336.495	−25.628	−1.64	4.1	3.4	−1.5	−1.8
129	NGC 6760	36.108	−3.924	−0.84	4.1	3.3	2.4	−0.3
130	Ter 7	3.387	−20.063	−1.6*	36.4	34.1	2.0	−12.5
131	NGC 6779	62.659	8.336	−2.32	9.8	4.5	8.6	1.4
132	Pal 10	52.437	2.726	−1.6*	10.6	6.5	8.4	0.5
133	Arp 2	8.543	−20.787	−1.85	28.3	26.2	3.9	−10.0
134	NGC 6809	8.798	−23.272	−1.56	5.1	4.6	0.7	−2.0
135	Ter 8	5.758	−24.558	−1.6*	48.2	43.6	4.4	−20.0
136	Pal 11	31.806	−15.577	−0.92	13.8	11.3	7.0	−3.7
137	NGC 6838	56.742	−4.562	−0.45	4.4	2.4	3.7	−0.3
138	NGC 6864	20.304	−25.748	−1.68	18.5	15.6	5.8	−8.0
139	NGC 6934	52.105	−18.894	−1.30	14.9	8.7	11.1	−4.8
140	NGC 6981	35.163	−32.683	−1.56	17.0	11.7	8.2	−9.2
141	NGC 7006	63.769	−19.407	−1.72	39.1	16.3	33.1	−13.0
142	NGC 7078	65.013	−27.313	−2.06	9.7	3.6	7.8	−4.5
143	NGC 7089	53.371	−35.770	−1.81	11.9	5.8	7.7	−7.0
144	NGC 7099	27.179	−46.835	−2.19	7.2	4.4	2.2	−5.3
145	Pal 12	30.510	−47.680	−1.13	19.4	11.3	6.6	−14.3
146	Pal 13	87.104	−42.699	−0.96	24.4	0.9	17.9	−16.5
147	NGC 7492	53.392	−63.479	−1.81	19.1	5.1	6.8	−17.1

* Tello, 1992

TABLE II
Distance to the galactic centre (kpc)

Group	R_0(average)	R_{0x} (average)	R_0(gauss)	σ	% included	R_0 (adopted)
1	7.8	7.4	7.2	5.0	88	7.5±0.4
2	8.3	7.2	7.0	5.3	83	7.7±0.9
3	6.8	6.1	6.9	5.3	87	6.9±0.1
4	8.0	7.9	7.4	4.6	98	7.7±0.4