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The Galactic system of old open clusters: age calibration and age-metallicity relation

G. Carraro and C. Chiosi

Department of Astronomy, Vicolo Osservatorio 5, I-35122 Padova, Italy

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Abstract. In this paper, we present a new homogeneous compilation of ages for the system of intermediate age and old open clusters of the Galaxy, and the accompanying age-metallicity relation (AMR).

This study stands on the analysis by Carraro et al. (1991, 1993a,b), who have obtained good estimates for the color excess, distance modulus, and age for a sample of ten clusters, for which modern color-magnitude diagrams (CMD) of good photometric quality and spectroscopic data on the metallicity (Friel & Janes 1991, 1993) were available.

Firstly, we revise the results by Carraro et al. (1991, 1993a,b) to take into account recent developments in the libraries of stellar models (Alongi et al. 1993; Bressan et al. 1993; Fagotto et al. 1993), and secondly we present useful age calibrations based on the correlation between metallicity, age, and magnitude difference between the turn-off and red clump luminosities. The age calibration does not depend on the color excess, distance modulus, but only weakly on the metallicity.

With the aid of the new age calibration, we assign the age to a more numerous sample of clusters. The resulting ages span the range from 0.5×10^9 yr for NGC 5822 to 8.0×10^9 yr for NGC 6791.

With such a compilation, and adopting an homogeneous source for the metal content, we propose a new AMR for the family of Galactic open clusters. The AMR is also corrected for the effect of the gradient in metallicity across the Galactic Disk. Although at any given age the spread in metallicity is high, the AMR together with the distribution of clusters with different age and metallicity across the Galactic Plane, confirms previous suggestions that the metallicity of a cluster is more related to the position than the age.

Key words: open clusters – Galaxy: abundances, evolution

1. Introduction

Intermediate age and old Galactic Open Clusters have received much attention over the last few years, because the understanding of their properties (ages, metallicity, kinematics) is basic to many important topics, such as the history of star formation in the Galactic Disk and the formation and structure of this, e.g. the long debated question of thin-thick disk model (Gilmore & Reid 1983).

Till recently, understanding of these problems was hampered by the paucity of available data on CMDs of good photometric quality, the lack of reliable determinations of metallicities based on spectroscopic analyses, and finally the small number of observed clusters.

Indeed, the sample of open clusters older than the Hyades ($\simeq 0.5 \times 10^9$ yr) is still small, even if many more are suspected to exist (see the compilation by Janes 1988). The reasons for it have been discussed by van den Bergh & McClure (1980).

It goes without saying, that in order to answer the above questions a large number of well studied clusters are required.

Nowadays, the situation has much improved thanks to the studies by many authors, among whom we recall Kaluzny (1990), Friel & Janes (1993), Twarog et al. (1993) and references therein. Accordingly, the number of clusters with good photometric and/or spectroscopic data has increased to a good statistical level of significance, thus rendering feasible a systematic study of this family of stellar objects.

Key parameters for describing star clusters as a class of the stellar populations of the Galaxy are the metallicity, the age, the kinematic, and the location in the Galactic Disk.

Whilst the metal content, kinematics (radial and tangential components of the velocity), and location in the Disk can be directly derived from observations, and therefore different studies lead to determinations with tolerable degree of uncertainty (see the discussion by Geisler et al. 1992), the age is a more cumbersome affair because its determination entirely relies on stellar models.

Therefore, ranking the ages of star clusters requires accurate and adequate stellar models. Accuracy means that the stellar models, isochrones, and synthetic CMDs, must be preliminarily calibrated in order to fix the well known parameters of stellar models, for instance the mixing length of the outermost convection. Adequacy means that all the physical ingredients of the stellar models (opacity, nuclear reaction rates, type of mixing) must be suitably included and up-dated. Finally, homogeneous

Send offprint requests to: G. Carraro

sets of stellar models (isochrones) ought to be used to study the CMDs of different clusters, and to rank them as functions of the age. Indeed, as already amply discussed by Friel & Janes (1993), the use of different, yet inhomogeneous, sources of age determinations may bias the derivation of a reliable AMR.

In this paper, starting from the studies by Carraro (1991) and Carraro et al. (1993a,b), in which the CMDs of ten template clusters have been analyzed with the aid of the synthetic CMD technique and the age assigned, we present an homogeneous compilation of ages for a larger sample of clusters older than 0.4×10^9 yr for which photometric and spectroscopic data are available. These are the CMDs and metallicities.

With the data for the template clusters, firstly we derive a relation linking the magnitude difference ΔV between the turn-off and the clump of red stars, to the age and the metallicity. The obvious advantage with this calibration is that no a priori determination of the distance modulus and color excess is required. Secondly, knowing the metallicity and ΔV for each cluster from observations, we get the age for a larger sample.

Two sources of metallicities are considered, namely either the spectroscopic scale by Friel & Janes (1993) and Lynga (1987) or the photometric Washington scale by Geisler et al. (1992). However, a great part of the analysis below is for the Friel & Janes (1993) scale, as the adoption of the Geisler et al. (1992) scale would lead to similar results.

The analysis is made for a sample of 36 clusters of which ten provide the template set. The resulting ages go from 4.5×10^8 yr for NGC 5822 to 8.0×10^9 yr for NGC 6791.

With ages and metallicities for a smaller sample of clusters sorted from the original sample of 36 objects we derive the AMR for clusters located in the Disk at different galactocentric distances R and heights z above the Galactic Plane. We discuss the effects of the gradient in metallicity across the Disk on the AMR, and confirm the results by previous studies (Friel & Janes 1993) that position rather than age governs the metallicity of a cluster.

2. Calibration and assignment of ages

There are several methods for deriving the age of intermediate age and old open clusters. The one adopted here stands on the synthetic CMD technique, which allows us to infer the age of a cluster from the simultaneous fit of several features of the CMD, namely the turn-off luminosity, color and shape, the inclination and location of the red giant branch (RGB), the luminosity of the red stars in the clump, together with the reproduction of star counts (luminosity functions) in selected areas of the CMD. The method allows us also to include the effect of binary stars that appear to be numerous in clusters of this type. To be applicable, the synthetic CMD method requires independent estimates of the metallicity, color excess, and distance modulus which are of course available only for a limited number of well studied clusters.

The analysis by Carraro et al. (1991, 1993a,b) was made by using both classical and overshoot models (see Chiosi et al. 1992 for a recent review of the subject).

The models in usage here have accurate input physics and are based on the recent opacity calculations by the Livermore group (Iglesias et al. 1992). These models are from Bressan et al. (1993), and Fagotto et al. (1993). It is worth clarifying that the type of mixing adopted to determine the extension of convective cores in principle affects the age assigned to a cluster because of the different duration of the core H-burning phase. However, in virtue of the turn-off mass suited to the clusters in question, say from 2 to 1 $M_\odot$ at increasing cluster age, the type of stellar model in use would somewhat affect the age of the youngest clusters, and leave unchanged that of the oldest ones. For the youngest clusters, the age inferred from classical models is about 30% younger than the age obtained from overshoot models. No variation in the age is found for clusters whose turn-off mass is lower than about $1.5 M_\odot$, and hence age older than say $2-3 \times 10^9$ yr. See Bertelli et al. (1992) for a detailed comparison of classical and overshoot models with the observational data.

The reference sample of clusters consists of NGC 752 and NGC 3680, already studied by Carraro et al. (1993a) but revised here to take into account the implementations in the grids of stellar models, M 67, NGC 2243, Berkeley 39, NGC 188, NGC 6791, NGC 2420, NGC 2506, and IC 4651, studied by Fagotto & Carraro (1992), Bertelli et al. (1992), and Carraro et al. (1993b) but revised here for consistency with the new stellar models in use. The details of the revision are not given here for the sake of brevity. For each cluster of this sample, assigned the metallicity, color excess E_{B-V}, distance modulus $(m-M)_o$, and age are simultaneously determined by fitting the CMD with the technique of the synthetic CMDs. The analysis strictly follows the discussion given in the quoted studies.

For the reasons discussed by Bertelli et al. (1992) we prefer to adopt the ages from stellar models with convective overshoot. Had those from classical models been used, the analysis below would not significantly change.

Table 1 summarizes the data for the reference sample. Column (1) is the cluster identification, columns (2) and (3) are the galactic coordinates, column (4) is the source of the CMD, column (5) is the observed magnitude difference ΔV between the turn-off and the red clump, column (6) is the uncertainty on ΔV, column (7) is the original spectroscopic metallicity [Fe/H] according to the Friel & Janes (1993) scale, column (8) is the theoretical global metallicity obtained from the relation

$$logZ = 1.03[Fe/H] - 1.698 \quad (1)$$

Column (9) lists the metallicity of the set of stellar models used to construct isochrones, and synthetic CMDs. Care has been paid to choose from the available grids of models those having the metallicity as close as possible to the observational one. Columns (10), (11), and (12) list the color excess E_{B-V}, distance modulus $(m-M)_o$, and age assigned to each cluster, respectively. Columns (13) and (14) give the galactocentric distances R projected onto the Galactic Plane derived from our analysis and those by Friel & Janes (1993) for comparison. They are labelled R_{CC} and R_{FJ}, respectively. Finally, columns (15) and (16) are the height z above the Galactic Plane, and the source

Table 1. Basic parameters of the reference sample of Galactic Open Clusters

Cluster	l	b	*Ref*	ΔV	$\Delta(\Delta V)$	$[Fe/H]$	Z_{der}	Z_{ad}	E_{B-V}	$(m-M)_0$	*Age*	R_{CC}	R_{FJ}	z	*Ref*
NGC752	137.2	-23.4	(1)	1.00	0.30	-0.16±0.05	0.014	0.014	0.02	8.20	1.5	8.8	8.7	-145	*a*
IC4651	340.0	-8.0	(2)	1.30	0.10	-0.16±0.10	0.014	0.014	0.10	9.90	1.6	7.8	7.8	-100	*b*
NGC3680	286.8	+16.9	(3)	1.70	0.10	-0.16±0.05	0.014	0.014	0.04	9.90	1.8	8.3	8.3	230	*a*
NGC2506	230.6	+9.9	(4)	1.75	0.20	-0.52±0.07	0.006	0.008	0.08	12.50	1.9	10.4	10.4	460	*a*
NGC2420	198.1	+19.7	(5)	1.90	0.10	-0.42±0.07	0.007	0.008	0.08	11.80	2.1	10.3	10.3	655	*a*
NGC2243	239.5	-18.0	(6)	2.15	0.10	-0.56±0.17	0.005	0.004	0.02	12.90	4.5	10.8	11.1	-1260	*a*
M67	215.6	+31.7	(7)	2.25	0.10	-0.09±0.07	0.016	0.020	0.01	9.47	4.8	8.9	9.1	415	*a*
Berkeley39	223.5	+10.1	(8)	2.50	0.30	-0.31±0.08	0.009	0.008	0.10	13.20	6.5	11.7	11.7	705	*a*
NGC188	123.0	+22.0	(9)	2.70	0.10	-0.06±0.10	0.017	0.020	0.03	11.16	7.5	9.3	9.3	570	*b*
NGC6791	70.0	+11.0	(10)	2.95	0.20	+0.19±0.19	0.031	0.030	0.01	13.20	8.0	8.2	8.4	1010	*a*

(1) Latham *et al.* (1991); (2) Anthony-Twarog *et al.* (1988); (3) Anthony-Twarog *et al.* (1991);
(4) McClure *et al.* (1981); (5) McClure *et al.* (1974); (6) Bergbusch *et al.* (1991); (7) Gilliland *et al.* (1990);
(8) Kaluzny & Richtler (1989); (9) McClure & Twarog (1976); (10) Kaluzny (1990).

a) Metallicity, distance R_{FJ} (kpc) ad height Z (pc) from Friel & Janes (1993).

b) Metallicity, distance R_{FJ} (Kpc) and height Z (pc) from Lynga 1987.

of data, respectively. Radial distances are in Kpc with the reference solar distance of $R_{\odot} = 8.5Kpc$, while vertical heights are in pc.

We emphasize the point that the ages listed in Table 1 constitute an homogeneous set of values because they all have been derived from homogeneous grids of stellar models having the same physical input, and from the same method.

Long ago, Cannon (1970) recognized that the red stars in the clump of intermediate age and old open clusters is the analog of the horizontal branch of globular clusters, and that this luminosity is almost age independent for ages in the age range 4.0×10^8 yr to 10×10^9 yr. This combined with the dependence of the turn-off luminosity on the cluster age, makes the magnitude difference ΔV between the clump and the turn-off a potential good age indicator, with the advantage of being independent of distance modulus and color excess.

It goes without saying that other methods have been used to derive cluster ages. For instance, Cameron (1985) and Barbaro & Pigatto (1984) used the color $(B-V)_{0,TO}$ at the turn-off. This method requires the knowledge of the color excess of the cluster. Anthony-Twarog & Twarog (1985) made use of the so-called "Morphological Age Ratio Index", $\Delta(B-V)/\Delta V$, defined as the ratio of the color difference between the turn-off and bottom of the RGB to the magnitude difference between clump and turn-off. This ratio depends on the metallicity, however since $\Delta(B-V)$ and ΔV act in opposite sense the resulting age determination is metallicity independent (see the authors for more details). The drawback of this method is that it cannot be applied to clusters whose RGB is poorly defined in the CMD, e.g. NGC 7789, NGC 752, IC 4651.

In light of the above considerations we prefer to rely on the ΔV method, which however is not free of difficulties.

Specifically, the clump of red stars, while easily detectable in the CMDs of the oldest clusters, becomes less and less evident going to younger clusters, e.g. NGC 752. The turn-off luminosity can be blurred by the presence of unresolved binary

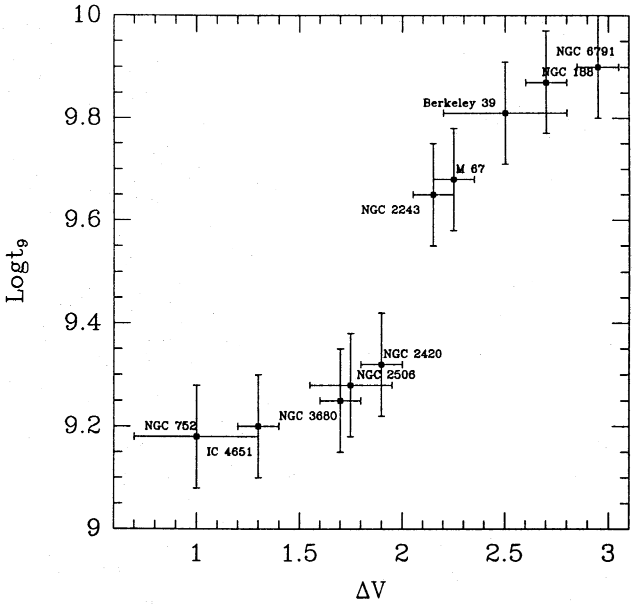

Fig. 1. The magnitude difference ΔV between the turn-off and red clump luminosities as a function of logarithm of the age in 10^9 yr ($Logt_9$)

stars which tend to brighten the turn-off luminosity by a certain amount that depends on the mass ratio. To cope with this effect, we have assumed that the reference turn-off luminosity is 0.25 magnitude fainter than observed in the CMD. See for instance Anthony-Twarog & Twarog (1985) for a similar evaluation of the turn-off luminosity for clusters in common. Finally, ΔV somewhat depends on the metallicity, in the sense that at increasing metallicity ΔV increases too.

Figure 1 displays the relation between the logarithm of the age (in units of 10^9 yr) and the magnitude difference ΔV. The error bars show the uncertainty affecting the age and ΔV assigned to each cluster.

The least square fit on the data of Table 1 yields the following relation:

$$Log(t_9) = 0.45(\pm0.04) \cdot \Delta V + 0.08(\pm0.01) \cdot [Fe/H] + 8.59(\pm0.23) \quad (2)$$

from which one can notice that the metallicity term has little effect on the age. The above relation represents the data of Table 1 at 99% confidence level.

With aid of the above relation, the age of clusters for which the ΔV and [Fe/H] are known, can be determined. However, because of the small dependence on the metallicity shown by Eq. (3) and the fact that for many clusters determinations of [Fe/H] are not available, the metallicity term of Eq. (3) has been dropped. The age-ΔV calibration in use is

$$Log(t_9) = 0.45(\pm0.04)\Delta V + 8.59(\pm0.23) \quad , \quad (3)$$

which has a 96% confidence level. The uncertainty on the age caused by the uncertainty on ΔV is calculated by differentiating Eq. (3).

But for the case of NGC 1193, Table 2 lists all the clusters with measured ΔV to which Eq. (3) has been applied to derive the age. Column (1) is the cluster identification, column (2) and (3) the coordinates, column (4) is the source of the CMD from which ΔV has been measured, column (5) is the magnitude difference ΔV, columns (6) is the corresponding uncertainty $\Delta(\Delta V)$. This quantity is estimated as follows. Since the turn-off magnitude is better defined than the clump magnitude, we keep fixed the former and with respect to the mean magnitude of the clump we estimate the minimum and maximum ΔV. Columns (7) and (8) are the age and the age uncertainty assigned to each cluster, respectively. Column (9) is the galactocentric distance taken from Friel & Janes (1993). The reasons for this latter choice will be clarified below. Finally, columns (10) and (11) are the vertical height above the galactic Plane (in pc) and the source of the data, respectively.

Ages marked with an asterisk correspond to cases (Berkeley 21 and 19) for which difficulties have been encountered in detecting the position either of the clump or the turn-off.

The cluster NGC 1193 has been studied with a different method. The CMD of this cluster (Kaluzny 1988) shows no evidence of a clump, but for two stars at V=15.7, B-V=1.08. Whether or not these two stars really correspond to the red clump is hard to say. Kaluzny (1988) assigned the age of 10×10^9 yr. In order to check for this age estimate, we proceeded as follows. At given metallicity, the color difference $\Delta(B-V)$ between the turn-off and the RGB bottom is known to decrease with the age (see Anthony-Twarog & Twarog 1985). According to the metallicity determination by Friel & Janes (1993) this cluster has a metallicity close to Z=0.008.

With aid of the synthetic CMDs technique and the stellar models of the same metallicity we are able to match the observed $\Delta(B-V)$ with an age of 5×10^9 yr, and get color excess and distance modulus in good agreement with the values in Table 3 of Kaluzny (1988), namely $E_{B-V} = 0.16$ and $(m-M)_o = 13.22$. The expected luminosity of the clump is V=14.8, where no red stars in a clump are seen in the CMD, and the expected value of ΔV is 2.45 magnitude. The new age is given in Table 2.

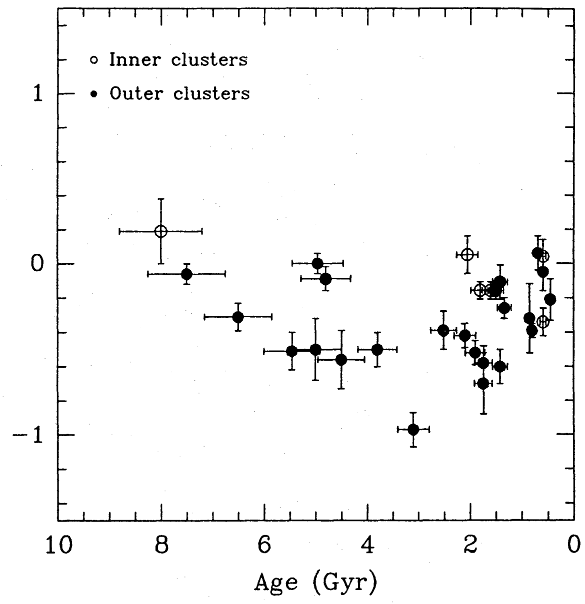

Fig. 2. The age-metallicity relation (AMR) for the clusters of Table 1 and 2 having homogeneous determinations of the ages (this paper) and metal content [Fe/H] (Friel & Janes 1993). Open symbols are for clusters inside the solar circles, whereas full symbols are for those outside. Ages are in 10^9 yr (Gyr)

In total, we have sampled 36 clusters (10 in Table 1 and 26 in Table 2) for which an homogeneous determination of the age is available. The ages span from 4.5×10^8 yr (NGC 5822) to 8.0×10^9 yr (NGC 6791). In view of the discussion below, it is worth emphasizing that owing to the calibrator in use, the above ages weakly depend on the precise knowledge of metallicities.

3. Age-metallicity-position relation

The existence of an AMR for the family of open clusters has been debated for long time with contrasting results (see Janes et al. 1988 for recent discussion).

The observational determination of the AMR is complicated by the small number of open clusters with ages older than 1×10^9 yr (Twarog 1980) and the fact that since the clusters are located at different distances from the Galactic Center their age could be affected by the existence of a gradient in metallicity across the Galactic Disk (see Pagel 1989 for a recent discussion of the subject).

In this section, taking advantage of the improved statistics and new homogeneous age ranking, we endeavor to address the question of the existence for open clusters of a general relation connecting the age, the metallicity, and the position on the Galactic Disk.

To this aim, first we present the AMR for the subset of clusters in Tables 1 and 2 for which for which the metallicity is available in the Friel & Janes (1993) scale (29 objects in total). The AMR is shown in Fig. 2. We remind the reader that we

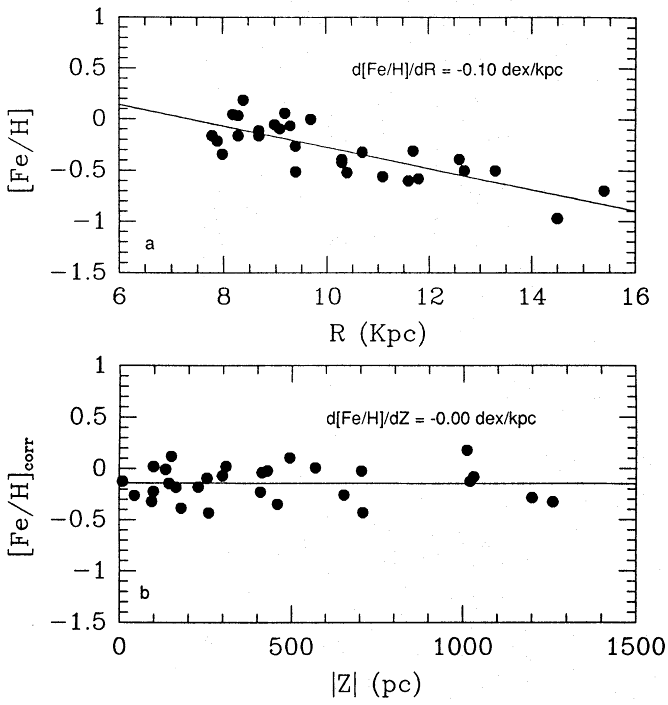

Fig. 3. a and **b** Panel **a**: the radial gradient in metallicity across the Galactic Disk derived from the clusters in Fig. 2. Panel **b**: the vertical gradient in metallicity for the same clusters, however corrected for the effect of the radial gradient. Metallicities are from Friel & Janes (1993). Radial distances R are in kpc, while heights z above the Galactic Plane are in pc

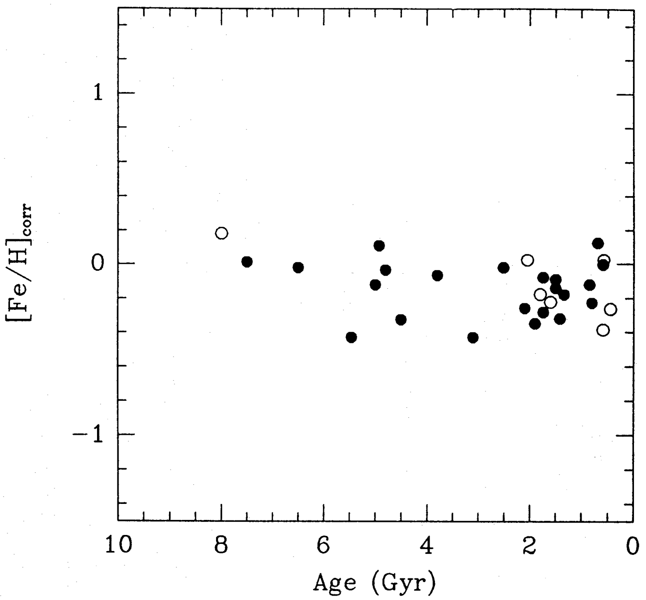

Fig. 4. The age-metallicity relation for the clusters of Tables 1 and 2 having an estimate of the metallicity [Fe/H] in the Friel & Janes (1993) scale, after correction for the gradient in metallicity across the Galactic Plane. Open circles stand for clusters inside the solar circle ($R = 8.5\ Kpc$) whereas filled circles stand for those outside. Ages are in units of 10^9 yr (Gyr)

would obtain almost identical relation adopting the Geisler et al. (1992) scale of metallicity.

In view of the discussion below, the clusters located closer and further away than the solar position with respect to the Galactic Center taken at 8.5 Kpc are indicated with different symbols. For all the clusters we adopt the distances by Friel & Janes (1993), which are consistent with our determinations for the template clusters im Table 1. Indeed the difference between the two determinations are within the range $\Delta(R_{CC} - R_{FJ}) = 0.08 \pm 0.10$.

The data displayed in Fig. 2 confirm what was already found by Friel & Janes (1991, 1993), i.e. that a large scatter in metallicity exists and no significant trend with the age appears. However, compared to the AMR by Friel & Janes (1993), where an age gap between 5 and 8 $\times$ 10^9 yr is present, with our age ranking several clusters fall in this age range. Finally, we call the attention that present AMR has the advantage with respect to previous ones (e.g. Strobel 1991; Friel & Janes 1993) of being derived from a uniform and homogeneous set of data.

Because the clusters on consideration span a large range both of radial distances (8 Kpc) and vertical heights above the plane ($\simeq$ 1 Kpc), one should correct the above AMR for the existence of gradients in chemical abundances in both directions in order to isolate in the AMR the sole age dependence.

Panels (a) and (b) of Fig. 3 show gradients in metallicity along the radial and vertical directions, respectively, as obtained from the data for the 29 clusters of Fig. 2. As clarified in the discussion below, the vertical gradient is already corrected for the effect of the radial gradient. The results are identical to those by Friel & Janes (1993).

The metallicity of each cluster is scaled to the value it would have if located at the solar distance and on the Galactic Plane. The correction is expressed by

$$[Fe/H]_{corr} = [Fe/H]_{measured} - (d[Fe/H]/dR) \cdot \Delta R - (d[Fe/H]/dz) \cdot \Delta z \quad (4)$$

The radial gradient $d[Fe/H]/dR$ of Fig. 3 (panel a) is -0.10 $dex\ Kpc^{-1}$, in agreement with the value from many independent studies both of abundances in the interstellar medium (see Pagel et al. 1992 for a recent discussion of the subject) and other samples of clusters (e.g. Cameron 1985; Grenon 1987; Friel & Janes 1993). We adopted the gradient of $-0.095\ dex\ Kpc^{-1}$ by Friel & Janes (1993) because of its consistency with the scale of metallicity in use.

With the aid of the metallicities corrected for the radial gradient, we look at the dependence of the metallicity as a function of the height above the plane. The results are shown in Fig. 3 (panel b). No gradient can be seen and therefore no correction of the AMR for the vertical gradient is required.

The AMR corrected for the radial gradient in metallicity is shown in Fig. 4. With respect to the AMR of Fig. 2, the scatter is now much smaller and no relation with the age can be noticed.

As far as the dependence of the age on the position is concerned, this is shown in panels (a) and (b) of Fig.5 displaying the age versus R and z, respectively.

Table 2. Age determination for the Galactic Open Clusters

Cluster	l	b	*Ref*	ΔV	$\Delta(\Delta V)$	t_9	$\Delta(t_9)$	R	z	*Ref*
NGC5822	321.7	+3.6	(1)	0.15	0.30	0.45	0.06	7.9	45	a
NGC6603	12.8	-1.3	(2)	0.35	0.40	0.56	0.10	...	...	...
NGC6940	69.9	-7.2	(3)	0.40	0.40	0.59	0.11	8.3	-100	b
NGC2477	253.6	-5.8	(4)	0.40	0.40	0.59	0.11	9.0	-135	a
NGC3960	294.4	+6.2	(5)	0.40	0.40	0.59	0.11	8.0	180	a
IC1311	77.7	+4.2	(6)	0.50	0.50	0.65	0.15	...	...	...
NGC2660	265.9	-3.0	(7)	0.55	0.40	0.69	0.12	9.2	152	b
NGC1817	186.1	-13.1	(8)	0.70	0.30	0.80	0.11	10.3	410	a
IC166	130.1	-0.2	(9)	0.75	0.40	0.85	0.15	10.7	-10	a
NGC7044	86.4	-4.2	(10)	1.15	0.50	1.28	0.29	...	...	...
NGC7789	115.5	-5.4	(11)	1.20	0.30	1.34	0.18	9.4	-165	a
NGC6939	95.9	+12.3	(12)	1.25	0.30	1.42	0.19	8.7	255	b
NGC2158	186.7	+1.8	(13)	1.25	0.30	1.42	0.19	11.6	95	b
Tombaugh2	232.9	-6.8	(14)	1.45	0.50	1.74	0.39	15.4	-1030	a
NGC2204	226.0	-16.1	(15)	1.45	0.30	1.74	0.23	11.8	-1200	b
NGC6819	74.0	+8.5	(16)	1.60	0.40	2.05	0.36	8.2	310	a
NGC2141	198.1	-5.8	(17)	1.80	0.40	2.51	0.45	12.6	-430	a
Berkeley21(*)	186.8	-2.5	(18)	2.00	0.50	3.10	0.69	14.5	-260	a
Berkeley19(*)	176.9	-3.6	(19)	2.20	0.40	3.80	0.68	13.3	-300	b
King11	117.2	+6.5	(20)	2.35	0.30	4.44	0.60	...	...	...
King2	122.9	-4.7	(21)	2.35	0.30	4.44	0.60	...	...	...
NGC7142	105.4	+9.4	(22)	2.45	0.40	4.92	0.88	9.7	495	a
NGC1193(*)	146.8	-12.2	(23)	...	...	5.00	...	12.7	-1020	a
Berkeley32	208.0	+4.4	(24)	2.50	0.40	5.18	0.93	...	...	...
Melotte66	259.6	-14.3	(25)	2.55	0.40	5.46	0.98	9.4	-710	a
AM2	248.1	-5.9	(26)	2.55	0.40	5.46	0.98	...	...	...

(1) Twarog *et al.* (1993); (2) Bica *et al.* (1993); (3) Larsson-Leander (1963);
(4) Hartwick *et al.* (1972); (5) Janes (1981); (6) Alfaro *et al.* (1992);
(7) Hartwick & Hesser (1973); (8) Harris *et al.* (1977); (9) Burkhead(1969);
(10) Kaluzny (1989); (11) Burbidge *et al.* (1958); 12) Cannon & Lloyd (1969);
(13) Christian *et al.* (1985); (14) Kubiak *et al.* (1992); (15) Hawarden (1975);
(16) Auner (1974); (17) Burkhead *et al.* (1972) (18) Christian *et al.* (1979);
(19) Christian (1980); (20) Aparicio *et al.* (1991); (21) Aparicio *et al.* (1990);
(22) Crinklaw & Talbert (1991); (23) Kaluzny (1988); (24) Kaluzny & Mazur (1991);
(25) Anthony-Twarog *et al.* (1979); (26) Gratton & Ortolani (1988).

a) Distance R (kpc) and height Z (pc) from Friel & Janes 1993.

b) Distance R (kpc) and height Z (pc) from Lynga 1987.

As already known from past work on the same subject (van den Bergh & McClure 1981; Janes & Adler 1982; Janes et al. 1988), also our sample of data confirms that (1) no cluster is observed beyond 1 kpc of the Sun toward the Galactic Center; (2) clusters older than 1×10^9 are mostly located towards the Galactic Anticenter; and (3) clusters older than about $2 \div 3 \times 10^9$ yr are on the average located at high galactic latitudes. However, large scatter, selection effects, and dynamical processes, in the sense that old clusters either with low z or high eccentricity could have been already disrupted, prevent us from attributing strong significance to the above trends.

Despite all these uncertainties, we summarize the results obtained in so far projecting all the clusters onto the Galactic Plane and grouping them as a function of the age and metallicity. This is shown in Fig.6. Three bins of metallicity and age are considered. Specifically, the metallicity is grouped according to $[Fe/H] \leq -0.7$ (triangles), $-0.7 < [Fe/H] < -0.3$ (circles), and $[Fe/H] > -0.3$ (squares). Ages are divided in younger than 3×10^9 yr (open symbols), in the range 3 to 5×10^9 yr (filled symbols), and older than 5×10^9 (barred symbols).

In agreement with previous results on the same subject (Friel & Janes 1993; Friel & Boesgaard 1990, 1992; Boesgard 1989), the data displayed in Fig.6 suggest that the metal content of a cluster is more sensitive to position than the age.

4. Discussion and conclusions

We have presented an homogeneous age compilation for a sample of intermediate age and old open clusters.

The clusters have been selected on the basis of the quality of their CMDs and availability of spectroscopic and photometric independent determinations of the corresponding metallicities.

The resulting ages go from 4.5×10^8 yr for NGC 5822 to 8.0×10^9 yr for NGC 6791.

The AMR derived from these new determinations of the age and the abundance scale of Friel & Janes (1993) confirms the results in older studies, namely that at any age there is a large spread in metallicity. However, the new AMR does not show evidence of an age gap (5 to 8×10^9 yr), because a significant

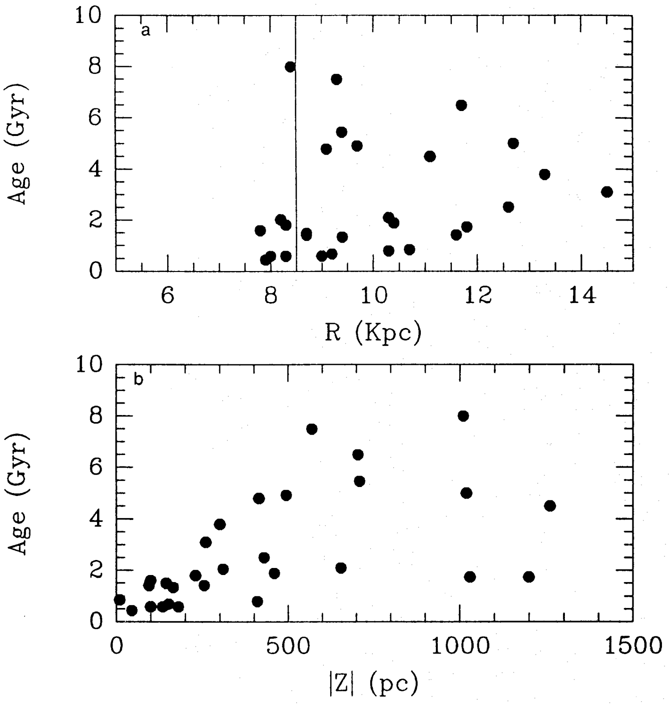

Fig. 5. a and **b** Panel **a**: the relation between age and radial distance R from the Galactic Center. Panel **b**: the relation between age and height z above the Galactic Plane. Ages are in 10^9 yr (Gyr), while the distances are in kpc and the heights in pc

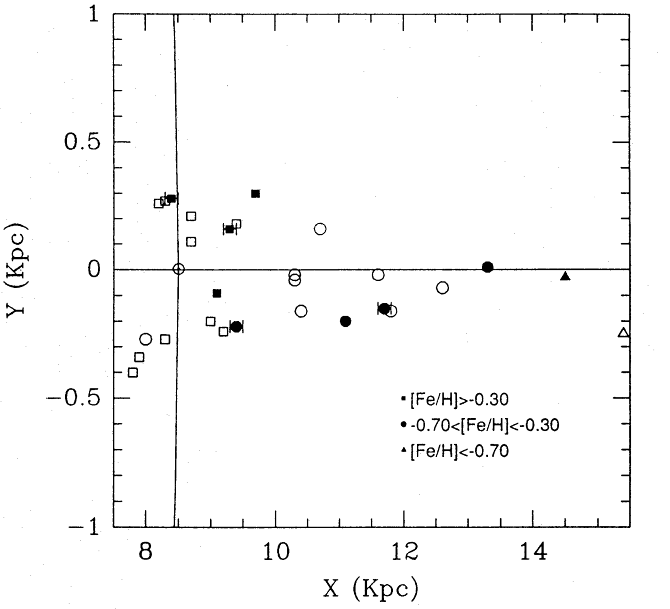

Fig. 6. The projected distribution of clusters with different metallicity onto the Galactic Plane. Different symbols indicate clusters with different metallicities. Triangles are for clusters with $[Fe/H] \leq -0.7$, circles are for clusters with $-0.7 < [Fe/H] < -0.3$, finally, squares are for clusters with $[Fe/H] > -0.3$. Open symbols are for ages younger than 3×10^9 yr, filled symbols are for ages in the range 3 to 5×10^9 yr, and barred symbols are for ages older than 5×10^9. Distances from the Galactic Center are in Kpc. The galactocentric distance of the Sun is 8.5 Kpc

number of clusters is found in this age range. Similar conclusion holds for the Geisler et al. (1992) scale.

Combining the AMR with information on the cluster position with respect to the Galactic Center and height above the Galactic Plane, we confirm the results of previous studies that the metal content of a cluster does not seem to depend on its age but rather on its position on the Galactic Disk. The implications of this trend on the chemical history of the Galactic Disk are beyond the scope of this study.

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