# CONSTRAINTS ON DISK AGE AND EVOLUTION FROM THE STUDY OF OLD OPEN CLUSTERS

ANGELA BRAGAGLIA[1], MONICA TOSI[1], GIANNI MARCONI[2]
[1] *Osservatorio Astronomico, Bologna, Italy*
[2] *Osservatorio Astronomico, Monte Porzio (RM), Italy*

**ABSTRACT.** Open clusters can provide information on the chemical abundances in the disk and relative gradients at different epochs, the average stellar ages at different galactic locations, the absolute age of the disk, the interactions between thin and thick disks. Especially important to test the early phases of disk evolution are the old clusters (age more than about 1 Gyr).

We have undertaken a project aimed at deriving in a homogeneous way the age of a selected sample of old clusters by comparing deep colour-magnitude diagrams with the corresponding synthetic diagrams (and luminosity functions) based on various sets of self-consistent stellar evolution tracks. This method allows us to simultaneously derive the age, reddening and distance modulus of each cluster, and the theoretical uncertainty related to the adopted stellar models. We also get an indication of the cluster metallicity from the best-fit models.

We have already obtained results on several clusters, spanning ages from a few hundred to several billion years.

## 1. Why open clusters?

Open clusters are ideal tools to understand the evolution of our Galaxy; they can in fact offer information both on its chemical and dynamical history. They are a large population (more than 1200 clusters are catalogued, even if only for about 80 of them ages $\gtrsim$ 1 Gyr have been measured), are found in different regions of the disk (old clusters show a tendency to be in the outermost regions), cover a large interval in age (from a few million years to $\gtrsim$ 10 Gyr), and in metallicity ([Fe/H] $\gtrsim -1.0$), and finally, their ages and distances are among the very few accurately determined for disk objects. Hence, they offer information i) on the age of the Galactic disk (both on absolute and relative ages for different objects/regions), and ii) on the evolution of disk metallicity in space and time. The present observational situation seems to indicate that there is some sort of temporal continuity between halo and disk formation, and that there are some old clusters rather metal-rich for their age/location.

To define a reliable ranking of cluster properties, we need a large sample with accurate and homogeneous ages and metallicities (see e.g. Carraro & Chiosi 1994; Janes & Phelps 1994; Friel 1995). We have then started a few years ago a project to analyze a sample of clusters at various Galactic locations, and covering a large range in age and metallicity.

**Tab. 1 - Clusters in our sample. $\delta V$ is the distance in magnitude between the red clump and the main sequence turn-off, and is used as an age indicator.**

| Cluster | (m-M)$_0$ | E(B–V) | age (Gyr) | $\delta V$ | Metallicity | Reference |
|---|---|---|---|---|---|---|
| Already analyzed: | | | | | | |
| NGC7790 | 12.65 | 0.54 | $\sim 0.1$ | – | $\sim Z_\odot$ | Romeo et al. (1989) |
| NGC2506 | 12.60 | 0.05 | $\sim 1.7$ | 1.5 | $\sim 0.4\ Z_\odot$ | Marconi et al. (1997) |
| NGC6253 | 10.95 | 0.28 | $\sim 3.0$ | 2.0 | $\sim 2.0\ Z_\odot$ | Bragaglia et al. (1997) |
| NGC2243 | 12.75 | 0.07 | $\gtrsim 3.0$ | 2.2 | $\sim 0.2\ Z_\odot$ | Bonifazi et al. (1990) |
| Cr261 | 11.85 | 0.30 | $\gtrsim 7.0$ | 2.6 | $\leq Z_\odot$ | Gozzoli et al. (1996) |
| Work in progress: | | | | | | |
| Be 21 ; Be 22 ; To 2 ; Mel 71 (intermediate-old) | | | | | | |
| NGC6603 (young, Tosi et al. in preparation) | | | | | | |

As a first step we take deep photometric observations, generally in the UBVI bands. Using the method of synthetic colour-magnitude diagrams (Tosi et al. 1991) we then derive for each cluster metallicity, reddening, distance and age at the same time. In a second phase we intend to take high-res spectra of stars in each cluster to obtain a good definition of the metal content, which is generally lacking for open clusters.

Table 1 gives names and information about the clusters already studied and a few of those we are presently analyzing, while Figure 1 shows the colour-magnitude diagram (CMD) of 4 clusters, ranging from the very young NGC6603 to the very old Cr261.

## 2. Analysis of the photometric data

To obtain metallicity, reddening, distance, age at the same time, we compare observed CMDs and luminosity functions to synthetic ones obtained by a Montecarlo simulation of the same number of stars, above the same limiting magnitude, with an appropriate fraction of binaries, and with the same photometric errors and completeness. The numerical code for CMD simulation is based on homogeneous sets of stellar evolutionary tracks taken from different groups[1]; this permits to evaluate the effects of the adoption of different models on final results. Given a set of evolutionary tracks, the simulated CMD is translated from L,T$_{eff}$ to $V, B-V$ finding the values for reddening and distance modulus that better approximate the observed CMD. The procedure is reiterated for many choices of the parameters, and we choose the combination which gives the best reproduction of the morphology (i.e. shape of the main sequence and subgiant and giant branches, position of the red clump, and turn-off and gaps in main sequance) and of the magnitude and colour distribution (i.e. population ratios).

Table 1 gives our "average preferred values" for metallicity, reddening, distance and

[1] FRANEC: Castellani et al. 1993, A&AS, 78, 517; GENEVA: Shaerer et al. 1993, A&AS, 102, 339; Shaller et al. 1992, A&AS, 96, 269; PADOVA: Alongi et al. 1993, A&AS, 97, 851, Bressan et al. 1994, A&AS, 100, 647, Fagotto et al. 1994, A&AS, 104, 365; CM: D'antona et al. 1992, A&AS, 257, 539

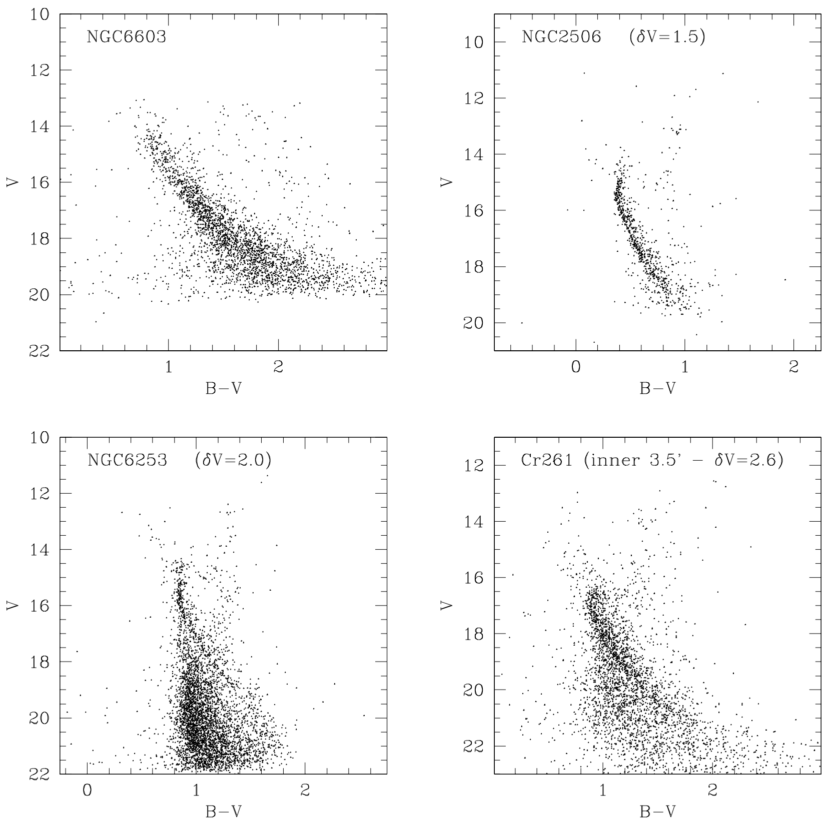


Fig. 1. CMDs for 4 of the clusters recently analyzed, with ages going from about 0.2 Gyr (NGC6603), to more than 7 Gyr (Cr261).

age of the analyzed clusters, but we get a best-fit quadruple for each set of stellar models. Variations of parameters represent a sort of theoretical uncertainty, due solely to the adoption of a chosen model-set, which has to be taken into account if we whish to obtain a reliable ranking in any of the properties. As an example, in Table 2 we show the possible solutions for NGC2506.

## 3. Preliminary conclusions

a) Concerning the absolute age of the Galactic disk, open clusters indicate that the disk is older than about 8-9 Gyr, and possibly than 12 Gyr. In fact: Cr261 is at least 7 Gyr

**Tab. 2 - Range in metallicity, distance, reddening and age found for NGC2506**

| Model | Z | $(m\text{-}M)_0$ | E(B–V) | age (Gyr) | note |
|---|---|---|---|---|---|
| FRANEC | 0.01 | 12.6 | 0.07 | 1.6 | OK |
| FRANEC | 0.02 | 12.7 | 0.01 | 1.5 | $\sim$ OK |
| Padova | 0.008 | 12.5 | 0.05 | 1.7 | OK |
| Padova | 0.02 | 12.6 | 0.00 | 1.7 | $\sim$ OK |
| Geneva | 0.008 | 12.5 | 0.05 | 2.2 | $\sim$ OK |
| Geneva | 0.02 | 12.5-12.6 | 0.00 | 1.7-2.0 | $\sim$ OK?? |

old (but 11 Gyr with the Padova tracks); NGC6791 is at least as old; NGC188, Be32, Be39, Be54 have similar ages; and Be17 is older and apparently the oldest known open cluster (age $\gtrsim$ 12 Gyr, Phelps 1997)

b) About the evolution of disk metallicity, present results are qualitatively consistent with standard evolutionary scenarios of negative radial abundance gradients and positive time - metallicity relations. In fact: 4 of the examined clusters are at least as metal rich as the Sun; the only cluster in our sample older than the Sun (Cr261) may be slightly more metal poor, in agreement with the age - metallicity relation for its position (Tosi 1995); at all Galactic locations most metal poor clusters are the outermost ones; and at similar $R_{GC}$, younger clusters are more metal rich than older ones.

Of course our sample is still too small to generalize to the whole system of open clusters. We then intend to obtain new data and reanalyze data from literature. Finally, more and more accurate metallicities of old clusters are needed, and those can only be obtained from high-res spectroscopy.

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