The Galaxy Disk in Cosmological Context
Proceedings IAU Symposium No. 254, 2008
J. Andersen, J. Bland-Hawthorn & B. Nordström, eds.

doi:10.1017/S1743921308027634

Open Clusters as tracers of the Galactic disk: the Bologna Open Clusters Chemical Evolution project

Angela Bragaglia[1], Eugenio Carretta[1], Raffaele Gratton[2] and Monica Tosi[1]

[1]INAF-Osservatorio Astronomico di Bologna
via Ranzani 1, I-40127 Bologna, Italy
email: angela.bragaglia, eugenio.carretta, monica.tosi @oabo.inaf.it

[2]INAF-Osservatorio Astronomico di Padova
vicolo dell'Osservatorio 5, I-35122 Padova, Italy
email: raffaele.gratton@oapd.inaf.it

Abstract. We present an update of the Bologna Open Clusters Chemical Evolution project (BOCCE, in short). We are conducting a photometric and spectroscopic survey of Open Clusters, to be used as tracers of the Galactic disk properties and evolution. We obtain the clusters parameters (age, distance, metallicity, and detailed abundances) in a precise and homogeneous way. We have collected data for about 40 Open Clusters and have fully analyzed the photometric data for about one half and the spectra for one quarter of them. We present here results based on these works and indicate what will come next.

Keywords. techniques: photometric, techniques: spectroscopic, stars: abundances, Hertzsprung-Russell diagram, Galaxy: abundances, Galaxy: disk, open clusters and associations: general

1. Overview

Open Clusters (OCs) are very useful tracers of the properties of the Galactic disk (e.g., Friel 1995), because they are seen over the entire disk, their ages and distances are generally measurable with better precision than those of isolated field stars up to large distances, and they cover the entire range of metallicities and ages of the disk.

In particular, OCs are very important to describe the metallicity (and detailed abundances) distribution of the disk, a key ingredient for models of chemical evolution. The metallicity distribution can be traced by other objects, like young stars, Cepheids, and Planetary Nebulae, but they are all rather young and can be used to describe the present-day situation, or the one in the near past. Instead, OCs go back to the first epochs of the disk, so we have access to the history of the disk formation and evolution and we may follow whether and how the metallicity distribution changed with time.

In the past, OCs have been used to define the metallicity distribution, with controversial results. The most commonly held view is that of a negative radial gradient (e.g., Friel *et al.* 2002), but an alternative picture, with two flat distributions at about solar and sub-solar metallicity and a discontinuity near a R_{GC} of 10 kpc, has been presented (Twarog, Ashman & Anthony-Twarog 1997). More recently, the observation of far-away OCs has permitted to reach $R_{GC} > 20$ kpc; these studies seem to indicate a negative gradient in the inner region and a flattening in the outer disk, with the transition at 10-14 kpc, see Yong, Carney & Teixera de Almeida (2005), Carraro *et al.* (2007), Sestito *et al.* (2008).

Table 1. OCs for which photometry and/or spectroscopy has been obtained. In all cases where the analysis has already been completed we give the references. Photometric parameters shown here refer to the (old) Padova tracks to give a ranking. More OCs are in our sample but the data quality has not been checked yet. In three cases (Be 19, NGC 6603, and Cr 110) telescope time has been granted but spectroscopic observations have not been carried out yet. Results obtained within a parallel collaboration (see Randich *et al.* 2005) are indicated within square brackets, since they are not strictly on the BOCCE spectroscopic scale; Cr 261, NGC 3960, NGC 6253 were observed in both programs.

Cluster	photom.	publ.?	$(m-M)_0$	E(B-V)	Z	age (Gyr)	high-res spec.	[Fe/H]
NGC 752	–	–					SARG@TNG	–
Be 66	TNG	(1)	13.20	1.22	0.008	3.80	no	–
NGC 1193	TNG	no					no	–
Be 17	TNG	(2)	12.20	0.62	0.008	8.50	SARG@TNG	–
Be 19	TNG	in prep					SARG@TNG?	–
Be 20	TNG	(1)	14.70	0.13	0.008	5.80	[FLAMES]	[−0.30 (6)]
Be 21	Danish	(3)	13.50	0.78	0.004	2.20	no	–
NGC 2099	CFHT	(3)	10.50	0.36	0.008	0.43	SARG@TNG	–
Be 22	NTT	(3)	13.80	0.64	0.020	2.40	no	–
NGC 2168	CFHT	(3)	9.80	0.20	0.008	0.18	SARG@TNG	–
NGC 2204	WFI	no					UVES	in prep
NGC 2243	Danish	(3)	12.74	0.08	0.004	4.80	FLAMES/SV	–
Tr 5	WFI	no					(archive)	–
Cr 110	DFOSC	(3)	11.45	0.57	0.004	1.70	SARG@TNG?	–
NGC 2266	TNG	no					SARG@TNG	–
Biu 11/Be 27	SuSI2	no					no	–
Be 29	NTT	(3)	15.60	0.12	0.004	3.70	[FLAMES]	[−0.31 (6)]
Be 32	TNG	(4)	12.60	0.12	0.008	5.20	[FLAMES]	[−0.29 (7)]
Biu 13/Be 34	SuSI2	no					no	–
NGC 2323	CFHT	(3)	10.20	0.22	0.020	0.12	no	–
To 2	Danish	in prep					[FLAMES]	–
NGC 2324	WFI	no					[FLAMES]	[−0.17 (8)]
Be 36	SuSI2	no					no	–
Mel 66	–	–					[FLAMES]	[−0.33 (6)]
Mel 71	Danish	in prep					FEROS	in prep
NGC 2477	–	–					[FLAMES]	[+0.07 (8)]
NGC 2506	mosaic	(3)	12.60	0.00	0.020	1.70	FEROS	−0.20 (9)
Pi 2	Danish	(3)	12.70	1.29	0.020	1.10	no	–
NGC 2660	Dutch	(3)	12.30	0.40	0.020	0.95	[FLAMES]	[+0.04 (7)]
NGC 2849	Dutch	no					no	–
NGC 3960	DFOSC	(5)	11.60	0.29	0.020	0.90	FEROS	−0.12 (5)
Cr 261	mosaic	(3)	12.20	0.30	0.020	6.00	FEROS	−0.03 (10)
NGC 4815	FORS	no					no	–
NGC 6134	DFOSC	no					FEROS	+0.15 (9)
NGC 6253	Danish	(3)	11.00	0.23	0.050	3.00	FEROS+UVES	+0.46 (11)
IC 4651	DFOSC	no					FEROS	+0.11 (9)
NGC 6603	Danish	no					SARG@TNG?	–
IC 4756	DFOSC	no					FEROS	–
NGC 6791	CFHT	in prep					SARG@TNG	+0.47 (12)
IC 1311	TNG	no					no	–
NGC 6819	CFHT	(3)	12.20	0.12	0.020	2.00	SARG@TNG	+0.07 (13)
NGC 6939	TNG	(3)	11.30	0.34	0.020	1.30	SARG@TNG	–
King 11	TNG	(4)	11.75	1.04	0.010	4.25	no	–
NGC 7789	CFHT	no					SARG@TNG	–
NGC 7790	Loiano	(3)	12.65	0.54	0.020	0.10	SARG@TNG	–

(1) Andreuzzi, Bragaglia & Tosi (2008); (2) Bragaglia *et al.* (2006b); (3) Bragaglia & Tosi (2006), where references to the original papers are given; (4) Tosi *et al.* (2007); (5) Bragaglia *et al.* (2006a); (6) Sestito *et al.* (2008); (7) Sestito *et al.* (2006); (8) Bragaglia *et al.* (2008); (9) Carretta *et al.* (2004); (10) Carretta *et al.* (2005); (11) Carretta, Bragaglia & Gratton (2007); (12) Gratton *et al.* (2006); (13) Bragaglia *et al.* (2001)

https://doi.org/10.1017/S1743921308027634 Published online by Cambridge University Press

2. The BOCCE survey

We have started a survey of OCs to derive in the most precise and homogeneous way their main parameters: age, distance, reddening, metallicity (and detailed abundances). As one of our main interest is the chemical evolution of the disk, we named our survey the "Bologna Open Clusters Chemical Evolution" project, BOCCE in short. Our goal is to build a sample large enough to be representative of the whole cluster population (in age, metallicity and position in the Galaxy). Of course, if we want to study the history of the disk we have to concentrate on old OCs: of the about 120 OCs with age larger than 1 Gyr found in the Dias *et al.* (2002) catalogue, we have collected data for a fair fraction, and have already studied 16 clusters in detail. We employ:

• Photometry and the Synthetic Colour-Magnitude diagrams technique to derive at the same time age, distance, reddening and a first indication of metallicity; for a review of the method and results see Bragaglia & Tosi (2006). This is the more advanced part of our survey, having already published results for more than half the original sample.

• Medium resolution spectroscopy to derive radial velocities, hence membership, for stars in crucial evolutionary phases, like the main sequence Turn-Off or the Red Giant Branch; for an application, see e.g. D'Orazi *et al.* (2006). This is a secondary part of our project.

• High resolution spectroscopy to measure chemical abundances, using both equivalent widths and spectrum synthesis; for a presentation of the method, see Bragaglia *et al.* (2001), Carretta *et al.* (2004). This part of the work started later and we still have to catch up with the photometric survey, but we have recently acquired spectra for many OCs. We also plan to use archive data and homogenize results obtained within a parallel program (see Randich *et al.* 2005).

Table 1 shows the present status of our project; in summary we have observed clusters with ages from 0.1 to 9 Gyr, R_{GC} from about 7 to 21 kpc, and metallicity from less than half solar to more than double solar.

We have a few very interesting objects in our sample, e.g., Be 17 and NGC 6791 (the oldest OCs known, with age near 9 Gyr) or Be 20, Be 29 (with R_{GC} of abour 16 and 21 kpc) and Cr 261, NGC 6253 (inside the solar circle) very important to define the metallicity gradient. Two of these clusters, NGC 6791 and NGC 6253, are also the most metal-rich OC presently known.

In the Table, to give an uniform ranking of properties, we put the values derived from photometry using the (old) Padova tracks (e.g., Bressan *et al.* 1993), but we always use three sets of evolutionary tracks (without overshooting and with two treatment of it). This way we are better able to quantify the systematics between results based on different stellar models. We always use the same sets of tracks even if a newer version of the same code has become available (as in the case of the Padova models) to maintain the maximum homogeneity in our determinations†

The metallicity shown in the last column of Table 1 has been obtained from the high resolution spectra. We observe a few stars per clusters, chosen if possible among confirmed members; we usually target Red Clump stars since they are the best compromise between luminosity and temperature: we can obtain high S/N spectra of stars not too cool to be a problem for model atmospheres. Figure 1 (left panel) shows an example of the quality of our data in the case of the two very metal-rich clusters NGC 6253 and NGC 6791. We

† An exception will be NGC 6791, for which we are employing new tracks at Z = 0.04 or 0.05, computed on purpose or retrieved from recent publications, because of the combination of very high metallicity and old age.

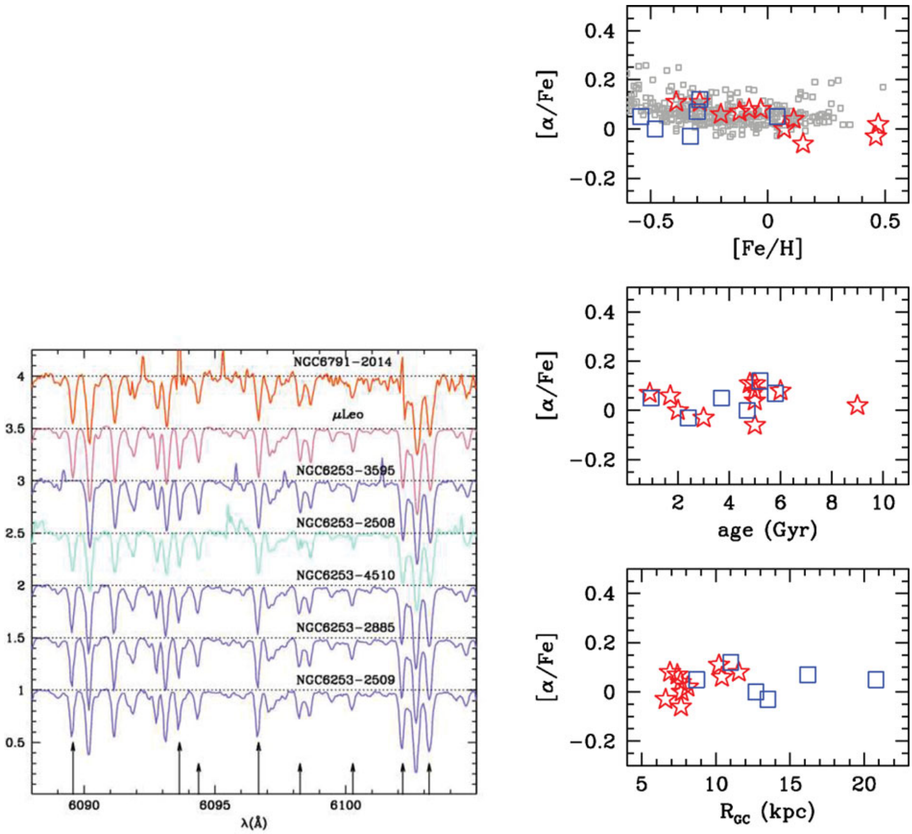

Figure 1. Left panel: Spectra obtained with FEROS and UVES for NGC 6253 (Carretta *et al.* 2007), with SARG for NGC 6791 (Gratton *et al.* 2006); also shown is the very metal-rich field giant μ Leo. The arrows indicate lines used in the abundance determination. Right panels: [α/Fe] ratio for OCs in the BOCCE sample, compared to thin disk field stars (upper plot) and shown in fuction of age (middle plot) and R_{GC} (lower plot). Red stars indicate abundances strictly on the BOCCE scale, open squares are from Sestito *et al.* (2006), Sestito *et al.* (2008), Bragaglia *et al.* (2008) for four OCs (from the parallel program), and Villanova *et al.* (2005), Carraro *et al.* (2004) for two OCs.

try to maintain also in this case the most homogeneous procedure, using the same line lists, gf's, model atmospheres, solar reference values, way to measure equivalent widths, synthesis, and kind of stars.

Since the photometric and spectroscopic parts of our programs are not "aligned" yet, we are not presently able to derive in a fully self-consistent way the metallicity gradient or the properties of our whole sample. However, putting together our results, literature ones, and the FLAMES survey, we confirm the presence of a radial metallicity gradient flattening in the outer regions; an indication of this was already present in Bragaglia & Tosi (2006) from the photometric metallicities, but it has recently been found on the basis of more precise metallicity determinations by Yong *et al.* (2005), Carraro *et al.* (2007), and Sestito *et al.* (2008).

Fig.1 (right panels) shows some results on the [α/Fe] ratios found for clusters in our sample, based on our published OCs, on work in progress, on literature, and FLAMES data. The OCs follow the same relation of [α/Fe] versus [Fe/H] of the field thin disk stars and do not seem to show any trend with age. Perhaps the most interesting feature is

https://doi.org/10.1017/S1743921308027634 Published online by Cambridge University Press

shown in the bottom panel, where [α/Fe] is plotted against R_{GC}: from the clusters in the BOCCE sample there is no apparent trend of increased [α/Fe] for the outer parts of the disk (see Sestito *et al.* 2008 for an extended discussion, since the two outermost clusters have abundances measured in that paper), at variance with what had been advocated by Carraro *et al.* (2004) and Yong *et al.* (2005), but in agreement with Carraro *et al.* (2007). However, we do not wish to make any strong statement until all clusters have been measured strictly on the BOCCE scale.

In summary, our effort to build a large, significant sample of open clusters with ages, distances, metallicities and detailed abundances measured with homogeneous methods is well under way and has already produced interesting results. Future efforts will be mainly directed towards increasing the number of clusters with chemical abundances measured on a common scale. Only the kind of homogeneity we are trying to achieve can guarantee that features are not created or lost because of systematic differences between analyses.

The work described here was made possible by the collaboration of many researchers, among them Gloria Andreuzzi and Luca Di Fabrizio (INAF - Fundación Galilei), Michele Cignoni (Bologna University), Jason Kalirai (UCO-Lick), and Gianni Marconi (ESO). We thank Paola Sestito and Sofia Randich for useful discussions; we make use here of results obtained in collaboration with them. We made large and fruitful use of the WEBDA (http://www.univie.ac.at/webda/). Generous allocation of observing time at Italian telescopes (TNG and Loiano), at the CFHT, and at ESO telescopes (La Silla and Paranal) is acknowledged.

References

Andreuzzi, G., Bragaglia, A., & Tosi, M. 2008,*A&A*, in press

Bragaglia, A., *et al.* 2001, *AJ*, 121, 327

Bragaglia, A. & Tosi, M. 2006, *AJ*, 131, 1544

Bragaglia, A., Tosi, M., Carretta, E., Gratton, R. G., Marconi, G., & Pompei, E. 2006a, *MNRAS*, 366, 1493

Bragaglia, A., Tosi, M., Andreuzzi, G., & Marconi, G. 2006b, *MNRAS*, 368, 1971

Bragaglia, A., Sestito, P., Villanova, S., Carretta, E., Randich, S., & Tosi, M. 2008, *A&A*, 480, 79

Bressan, A., Fagotto, F., Bertelli, G., & Chiosi, C. 1993, *A&AS*, 100, 647

Carraro, G., Bresolin, F., Villanova, S., Matteucci, F., Patat, F., Romaniello, M. 2004, *ApJ*, 128, 1676

Carraro, G., Geisler, D., Villanova, S., Frinchaboy, P. M., & Majewski, S. R. 2007, *A&A*, 476, 217

Carretta, E., Bragaglia, A., Gratton, R. G., & Tosi, M. 2004, *A&A*, 422, 951

Carretta, E., Bragaglia, A., Gratton, R. G., & Tosi, M. 2005, *A&A*, 441, 131

Carretta, E., Bragaglia, A., & Gratton, R. G. 2007, *A&A*, 473, 129

D'Orazi, V., Bragaglia, A., Tosi, M., Di Fabrizio, L., & Held, E. V. 2006, *MNRAS*, 368, 471

Dias, W. S., Alessi, B. S., Moitinho, A., & Lépine, J. R. D. 2002, *A&A*, 389, 871

Dominguez, I., Chieffi, A., Limongi, M., & Straniero, O., *ApJ*, 524, 226

Friel, E. D. 1995, *ARAA*, 33, 381

Friel, E. D., Janes, K. A., Tavarez, M., Scott, J., Katsanis, R., Lotz, J., Hong, L., & Miller, N. 2002, *AJ*, 124, 2693

Gratton, R., Bragaglia, A., Carretta, E., & Tosi, M. 2006, *ApJ*, 642, 462

Randich, S., *et al.* 2005, *ESO Messenger*, 121, 18

Sestito, P., Bragaglia, A., Randich, S., Carretta, E., Prisinzano, L., & Tosi, M. 2006, *A&A*, 458, 121

Sestito, P., Bragaglia, A., Randich, S., Pallavicini, R., Andrievski, S. M., & Korotin, S. A. 2008, *A&A*, in press

Tosi, M., Bragaglia, A., & Cignoni, M. 2007, *MNRAS*, 378, 730
Twarog, B. A., Ashman, K. M., & Anthony-Twarog, B. J. 1997, *AJ*, 114, 2556
Ventura, P., Zeppieri, A., Mazzitelli, I, & D'Antona, F. 1998, *A&A*, 334, 953
Villanova, S., Carraro, G., Bresolin, F., Patat, F. 2005, *ApJ*, 130, 652
Yong, D., Carney, B. W., & Teixera de Almeida, M. L. 2005, *AJ*, 130, 597

Hans Zinnecker and Pavel Kroupa in a joint accretion experiment at Carlsberg. Jens Hjorth in the background (photo: Bruce Elmegreen).

https://doi.org/10.1017/S1743921308027634 Published online by Cambridge University Press