SF2A 2014
J. Ballet, F. Bournaud, F. Martins, R. Monier and C. Reylé (eds)

ON THE CHEMICAL COMPOSITION OF OPEN CLUSTERS

C. Soubiran[1], S. Blanco-Cuaresma[1] and U. Heiter[2]

Abstract. Open clusters are key objects to study the chemical evolution of the Galactic disk, but metallicities and detailed abundances are available for only a small fraction of them. We review here the current status of metallicity determinations. Open clusters are also perfect objects to test the chemical tagging method which intends to identify stars formed from the same molecular cloud. First results about this technique are presented, based on homogeneously derived chemical abundances for a large sample of stars in open clusters.

Keywords: Stars: abundances - Open clusters - Surveys

1 Introduction

Open clusters (OCs) represent an important tool for studying the chemical evolution of the galactic disk, thanks to their spatial distribution all over the disk, and their wide age range. Metallicities are also mandatory for the determination of OC ages by ischrone fitting. The measurement of detailed chemical abundances implies spectroscopic observations at high or medium resolution, which are available for only ∼10% of the currently known OCs (Heiter et al. 2014). The analysis of these observations are made by widely differing methods, so that the resulting chemical abundances are not homogeneous. The situation is changing rapidly thanks to the Gaia ESO survey (Gilmore et al. 2012), and other spectroscopic surveys, which are targetting large samples of OCs. The combination of the results from these different surveys needs however some calibration and homogenization. For faint OCs at large galactocentric distances, only metallicities based on photometric data can be determined. In a few years, Gaia will deliver the metallicities of the ∼2000 OCs known to date (Dias et al. 2002), and probably thousands of newly discovered ones. Here we present the current status of OC metallicities and abundances together with prospects in that field.

With precise elemental abundances for stars in OCs, it is possible to evaluate if stars born from the same molecular cloud have the same chemical signature, and if the chemical signatures are different from one OC to another. This would make it possible to use the chemical tagging method to reconstruct the star formation history in the galactic disk, as proposed by Freeman & Bland-Hawthorn (2002). Here we present an extensive test of the chemical tagging method.

2 The status of open cluster metallicities

Paunzen et al. (2010) have compiled a catalogue of OC metallicities based on photometric data. They searched the literature for [Fe/H] estimates on the basis of photometric calibrations in any available filter system. In total, they find 406 individual metallicity values for 188 OCs within 64 publications, which were averaged. They show that the metallicity distribution near the Sun is patchy and this influences the estimation of the Galactic metallicity gradient, even on a global scale. More distant OCs are needed to study the metallicity distribution beyond several kiloparsecs.

The situation of the metallicity of OCs from high and medium resolution spectroscopy has been evaluated by Heiter et al. (2014). They have considered the mean high-resolution spectroscopic metallicity per publication and they found significant differences, up to 0.6 dex, for the same OC. The largest differences are observed for

[1] LAB UMR 5804 - Univ. Bordeaux - CNRS, 2 rue de l'Observatoire, F-33270 Floirac
[2] Uppsala University, Box 516, 751 20 Uppsala, Sweden

the Hyades, Collinder 21 and NGC 6633. They also demonstrate that the dispersion within an OC can be significantly reduced by carefully selecting non binary star members, and by restricting their effective temperature and surface gravity ranges to 4400 – 6500 K and 2.0 – 4.5. With such criteria, they define a sample of 458 stars in 78 OCs from 86 publications which forms a set of high-quality cluster metallicities. Using this sample and the one by Paunzen et al. (2010), they show that photometric metallicities are systematically more metal-poor than spectroscopic ones by 0.11 dex. This carefully selected spectroscopic sample is the most accurate and homogeneous one to date for testing models predicting the radial metallicity gradient in the Galaxy. Heiter et al. (2014) show that none of the current models is able to reproduce the OC metallicities versus galactocentric distance. The metallicity dispersion in the solar neighbourhood is large, and OCs are on average more metal-rich than predicted by the models. There is a lack of OC at large galactocentric distances to safely constrain the metallicity gradient over the disk.

The situation will improve in the coming years thanks to several spectroscopic surveys focused on OCs and their chemical abundances. The Gaia ESO Survey (Gilmore et al. 2012) has a list of ∼100 OCs to be observed with FLAMES at the VLT. APOGEE will target OCs at large distances (Frinchaboy et al. 2013). The HERMES (Zucker et al. 2012) and WEAVE (Dalton et al. 2012) multi-object spectrographs also intend to investigate the OC chemical abundances. Metallicities will thus be available for a much larger number of OCs than today. However these surveys will use different instruments, resolutions, spectral ranges, line lists and methods to determine the stellar properties. If we want to avoid the current situation found in the literature where a large dispersion is seen in the OC metallicities, it is essential that these surveys coordinate their calibration procedures with common OCs. This will enable the stellar parameters and metallicities to be on the same scale, homogeneous, and thus the combination of the surveys will be possible for a better investigation of the chemical evolution of the galactic disk.

However, even if many more OCs will be soon observed at high spectral resolution, this will still represent a small fraction of all the known OCs : 2174 in the version 3.3 of the catalogues by Dias et al. (2002).

When considering only the metallicity, which is essential for the age determination of OCs, one should rely on photometric data. The new method developed by Netopil & Paunzen (2013) shows a better agreement of photometric and spectroscopic metallicities and will be applied to a large number of OCs. Thanks to this project, photometric and spectroscopic samples of OCs will be on a consistent metallicity scale which is essential for galactic studies. With photometric surveys, the sample of OCs can be extended to the outskirts of the Milky Way, where spectroscopic studies are almost impossible. In a few years, Gaia will provide the metallicity of all known OCs thanks to the APSIS pipeline based on spectrophotometric data for one billion stars (Bailer-Jones et al. 2013).

3 Chemical tagging in open clusters

The chemical tagging is a technique to identify stars formed from the same molecular cloud but subsequently separated. It is based on the principle that stars formed from the same molecular cloud share the same abundance pattern, assuming that the progenitor cloud was chemically homogeneous and well-mixed. Thus stars having the same abundance pattern are supposed to have formed in the same molecular cloud. It was suggested by Freeman & Bland-Hawthorn (2002) that this technique could enable to track individual stars back to their common formation sites and to reconstruct the history of star formation in the Galaxy. Before the chemical tagging technique can be applied to large scale studies, it is necessary to test it with stars known to have formed together, such as in OCs. The use of the chemical tagging technique with OCs should allow us to verify whether stars born together have a unique chemical signature, and whether the chemical signatures of OCs are distinguishable.

Before large spectroscopic surveys are available, some tests can be done using high-resolution spectra of OC stars available in public archives, complementing our own observations made in the frame of the Gaia preparation. A very homogeneous analysis of nearly 300 spectra of 189 stars in 32 OCs was performed using the iSpec code (Blanco-Cuaresma et al. 2014). Atmospheric parameters and elemental abundances were determined using 275 481 lines and 12 153 elemental abundances of 17 species. The sample was carefully cleaned of poor data and outliers in order to test the chemical tagging method in ideal conditions. First, a Principle Component Analysis (PCA) was performed to reduce the parameter dimension from 17 to 2. Then a clustering analysis was perfomed with the K-Means algorithm to group stars with similar chemical signatures.

The first result is that the dwarf and giant stars have different chemical signatures, and have to be considered separately when comparing OCs, as seen in Fig. 1. For instance in M67 (Fig. 2) the dispersion of chemical abundances is in general of the order of 0.10 dex when dwarfs and giants are mixed. When dwarfs and giants are considered separately, the dispersion in each group decreases below 0.05 dex for most of the elements. There are two main possible explanations for this finding, one astrophysical, one methodological : it could be due to different diffusion and mixing processes in the dwarf and giant phases, or it could also be due to the assumptions and simplifications (e.g. LTE and 1D model atmospheres) made in the spectral analysis.

A PCA and clustering analysis was performed with all the giants as shown in Fig. 3. A few OCs are well separated from the others, such as M67 and NGC6705, but for the vast majority, it is not possible to reliably distinguish the chemical properties of the stars of one cluster from those of another; although the clusters form clear groups, the overlap in derived abundances does not allow for clear discrimination.

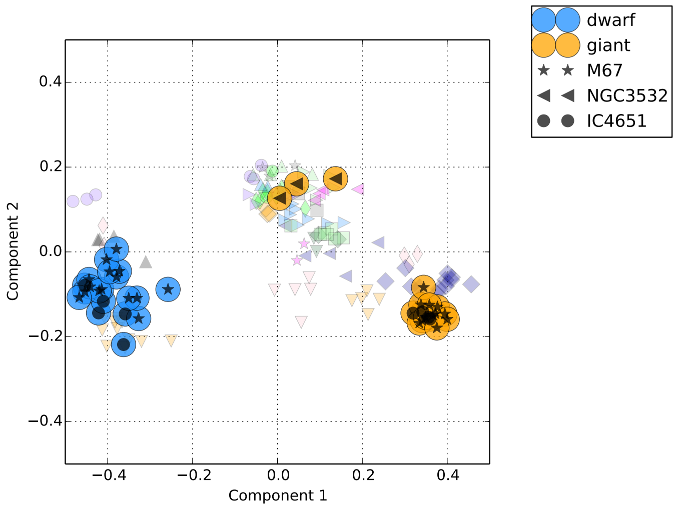

Fig. 1. Result of a PCA on OCs having both giants and dwarfs. The two groups well separated correspond to dwarfs and giants stars.

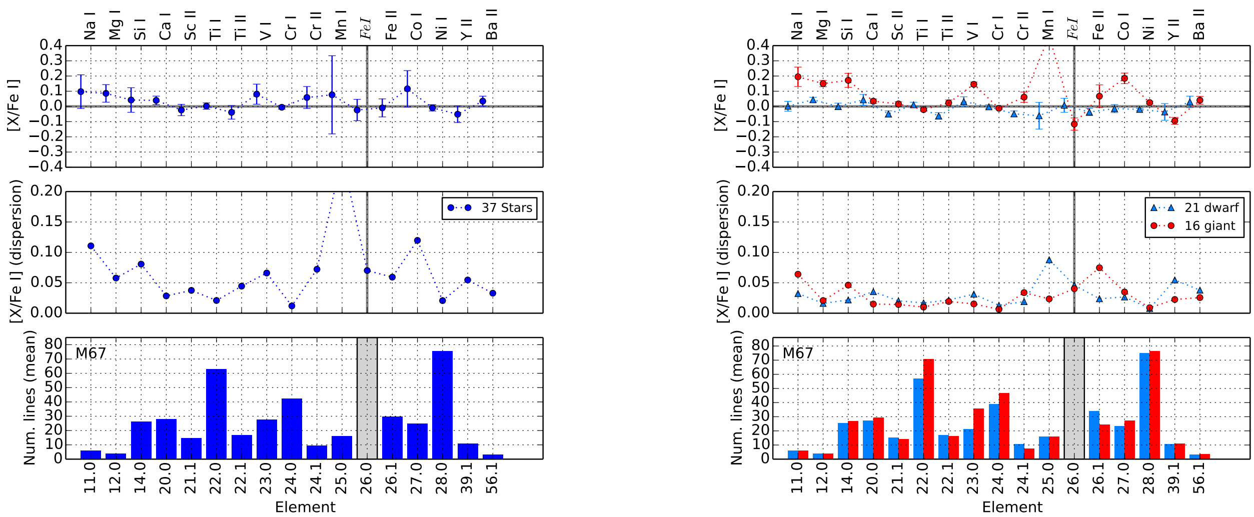

Fig. 2. Average chemical abundances (top), dispersion (middle) and mean number of lines (bottom) used for M67 stars (left) and divided into dwarfs and giants (right). All the abundance ratios are referenced to iron except iron itself, which is relative to hydrogen.

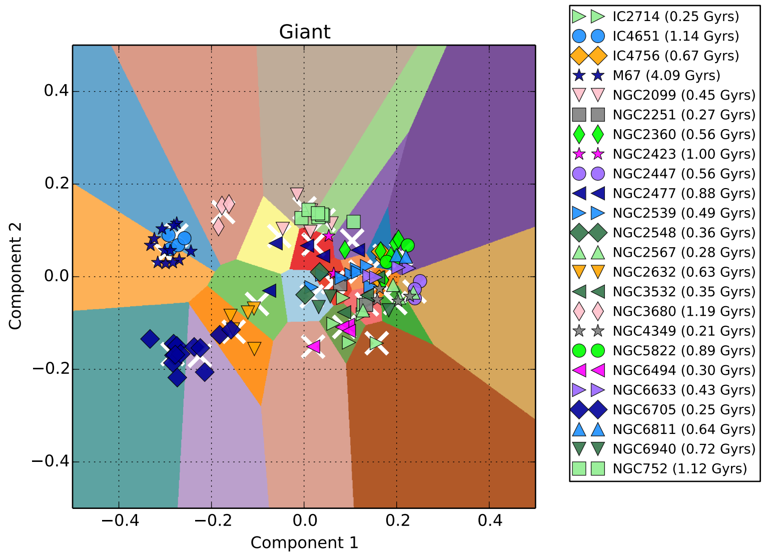

Fig. 3. Giants in OCs represented using the first two components of PCA. Background colors correspond to the clusters found by the K-Means algorithm.

4 Conclusions

To date less than 100 OCs have metallicities determined from high resolution spectroscopy. With photometric calibrations, and later with Gaia spectrophotometry, metallicities for all known OCs will be determined. Detailed abundances will be provided by high resolution spectroscopic surveys (Gaia ESO Survey, APOGEE, HERMES, WEAVE, etc), and other focused observing programmes, for a small fraction of OCs. Calibration and homogeneity is crucial when combining the results coming from these different sources.

From high quality spectra already available for a number of OCs, it was possible to test the chemical tagging method. It is shown that dwarfs and giants need to be considered separately when comparing elemental abundances from one OC to another. It is shown that only a few OCs have a distinct chemical signature from the bulk population. At the current level of precision, it seems difficult to apply the chemical tagging method to reconstruct the star formation history in the galactic disk.

Gaia will provide distances and proper motions, essential for membership, and ages for all known OCs, and will likely discover thousands of new ones. Highly valuable material will be available to probe the properties and evolution of the Milky Way thin disc with OCs, through their chemical abundance distribution and evolution with time.

References

Bailer-Jones, C. A. L., Andrae, R., Arcay, B., et al. 2013, A&A, 559, A74

Blanco-Cuaresma, S., Soubiran, C., Heiter, U., & Jofré, P. 2014, A&A, 569, A111

Dalton, G., Trager, S. C., Abrams, D. C., et al. 2012, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series, Vol. 8446, Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series

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

Freeman, K. & Bland-Hawthorn, J. 2002, ARA&A, 40, 487

Frinchaboy, P. M., Thompson, B., Jackson, K. M., et al. 2013, ApJ, 777, L1

Gilmore, G., Randich, S., Asplund, M., et al. 2012, The Messenger, 147, 25

Heiter, U., Soubiran, C., Netopil, M., & Paunzen, E. 2014, A&A, 561, A93

Netopil, M. & Paunzen, E. 2013, A&A, 557, A10

Paunzen, E., Heiter, U., Netopil, M., & Soubiran, C. 2010, A&A, 517, A32

Zucker, D. B., de Silva, G., Freeman, K., Bland-Hawthorn, J., & Hermes Team. 2012, in Astronomical Society of the Pacific Conference Series, Vol. 458, Galactic Archaeology: Near-Field Cosmology and the Formation of the Milky Way, ed. W. Aoki, M. Ishigaki, T. Suda, T. Tsujimoto, & N. Arimoto, 421