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The role of asymptotic giant branch stars in the chemical evolution of the Galaxy

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Abstract. Asymptotic giant branch stars play an important role in enriching galaxies by s-process dominated elements. Recent studies showed that their role in producing neutron-rich elements in the Galactic disk was underestimated and should be reconsidered. We have derived abundances of neutron-capture elements in seven Galactic open clusters to further expand an observational dataset necessary for theoretical modelling of the Galactic chemical evolution. We present elemental enrichment patterns of the Galaxy, based on accurate ages, galactocentric distances and chemical composition of open clusters determined in this and other recent studies.

Key words. Stars: abundances – Stars: atmospheres – Galaxy: abundances

1. Introduction

Abundances of elements above the iron group are thought to have contributions from two main processes, the *r*- and *s*-processes of neutron capture, with a small contribution from the *p*-process (Burbidge et al. 1957). The *s*-process has been further subdivided into the main and weak components. The weak process is generally believed to result from neutrons produced in the ^{22}Ne$(\alpha,n)^{25}$Mg reaction in massive stars at the end of the convective He-burning core and in the subsequent convective C-burning shell (see, e.g., Prantzos et al. 1990; Pignatari et al. 2010). This process contributes to production of lighter elements such as Cu and Zn, which are ejected to the interstellar medium by strong winds and supernova explosions (Käppeler et al. 1989; Heil et al. 2009). The main *s*-process is explained as a consequence of thermal pulses in the asymptotic giant branch (AGB) phase of low-mass ($\sim 1.5\,M_\odot$), moderately low-metallicity stars, in which a small ^{13}C pocket provides neutrons by the ^{13}C$(\alpha,n)^{16}$O reaction (e.g. Hallowell & Iben 1989). The main *s*-process contributes in producing Rb and heavier elements. The modelling of this process is burdened by incomplete knowledge of the ^{13}C pocket masses in different stars, thus an input from observational data is very important. Using chemical abundances in Galactic field stars, Pagel & Tautvaišienė (1997) were the first to model the detailed chemical evolution of twelve neutron-capture elements in the Solar neighbourhood.

Nowadays, an increasing number of open clusters with accurate ages, galactocentric distances and chemical abundances provides new constraints for modelling the chemical evolution of the Galactic disc. For example, D'Orazi et al. (2009) outlined that barium abundances with respect to iron are relatively larger in younger clusters. Other *s*-process chemical elements such as yttrium, zirconium, lanthanum and cerium show a similar tendency (Maiorca et al. 2011). [Zr/Fe] shows no trend with galactocentric distance (Yong et al. 2012), however Jacobson & Friel (2013) state that they find a small growth for this element as R_{gc} increases. Both works show a visible slope of [La/Fe], including data from clusters with different ages. Maiorca et al. (2011) found no distinguishable trend of [Y/Fe] with R_{gc}.

We determined abundances of yttrium, zirconium, barium, lanthanum, cerium, praseodymium, neodymium, and europium in 38 red giant branch (RGB) stars which belong to seven relatively young open clusters (IC 4756, NGC 4609, NGC 5316, NGC 5460, NGC 5822, NGC 6709, NGC 6940).

2. Observations and method of analysis

The spectra were obtained in June of 2013[1] on the 2.2 m MPG/ESO telescope in La Silla using the FEROS (The Fiber-fed Extended Range Optical Spectrograph) instrument (Kaufer et al. 1999) which provided a spectral resolving power of R = 48 000, in the spectral region of 3700–8600 Å. Magnitudes of the observed stars vary from 7 to 12 mag. In order to achieve a high signal to noise ratio, exposure times varied from 2 min to 1 hour. An initial data reduction was done with the FEROS DRS (Data Reduction System) pipeline within MIDAS.

The differential model atmosphere technique was applied for the analysis as described in Stonkutė et al. (2013). The atmospheric parameters were determined spectroscopically using equivalent widths of iron lines. The BSYN program package, developed at the Uppsala Astronomical Observatory, was used to carry out elemental abundance determinations from spectra of Y II, Zr I, Ba II, La II, Ce II, Pr II, Nd II, and Eu II using the MARCS atmosphere models (Gustafsson et al. 2008). The maximal total systematic abundance determination errors due to uncertainties of stellar atmospheric parameters is around 0.2 dex. The approximate value of random errors is around 0.07 dex as evaluated from the scatter of element abundances given from different spectral lines.

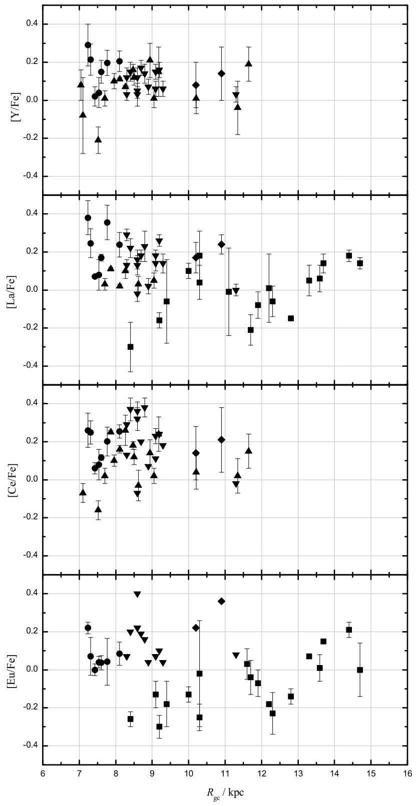

Fig. 1. Average cluster [El/Fe] vs. galactocentric cluster distances. Our results are marked by circles, Maiorca et al. (2011) – triangles, Jacobson & Friel (2013) – squares, Mishenina et al. (2015) – rhombus, Reddy et al. (2012, 2013, 2015) – inverted triangles.

3. Results

In Figs. 1 and 2 we display the mean values of elemental abundances in open clusters as a

[1] The European Southern Observatory programme number 085.D-0093.

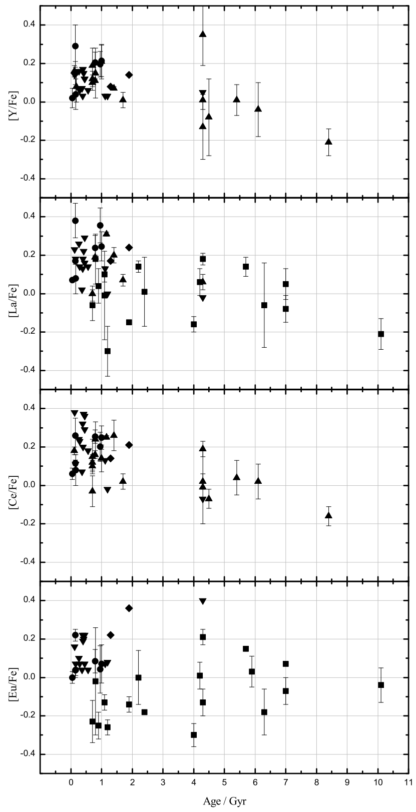

Fig. 2. Average cluster [El/Fe] vs. cluster ages. The meaning of the symbols as in Fig. 1.

function of cluster galactocentric distances and ages. We combined our results with other recent studies (Maiorca et al. 2011; Jacobson & Friel 2013; Mishenina et al. 2015; Reddy et al. 2012, 2013, 2015). The clusters investigated in our work are among the youngest and closest to the Galactic centre. Their ages are from 0.05 to 1 Gyr and galactocentric distances are less than 8.1 kpc. The displayed data do not show obvious s-process dominated element to iron abundance ratio gradients with the galactocentric distance.

As expected, yttrium, lanthanum and cerium show an apparent decrease of abundances as the cluster age increases. Abundances of *r*-process dominated chemical element europium show no distinguishable trend with cluster age. The determined abundances of *s*-process dominated chemical elements in our open clusters are similar to those of other authors at the same age range. Our results confirm and strengthen the suggestion that the young clusters were formed from the material more *s*-process enriched than the old ones. We are continuing this study and more open clusters of different ages and galactocentric distances will be investigated.

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