



<b>Publication Year</b>	2015
<b>Acceptance in OA</b>	2020-03-04T16:31:27Z
<b>Title</b>	The Open Cluster Chemical Abundances from Spanish Observatories survey (OCCASO)
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<b>Handle</b>	<a href="http://hdl.handle.net/20.500.12386/23124">http://hdl.handle.net/20.500.12386/23124</a>

# The Open Cluster Chemical Abundances from Spanish Observatories survey (OCCASO)

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## Abstract

We present the motivation, design and current status of the Open Cluster Chemical Abundances from Spanish Observatories survey (OCCASO). Using the high resolution spectroscopic facilities available at Spanish observatories, OCCASO will derive chemical abundances in a sample of 20 to 25 OCs older than 0.5 Gyr. This sample will be used to study in detail the formation and evolution of the Galactic disc using OCs as tracers.

## 1 Introduction

Stellar clusters are crucial in the study of a variety of topics including the star formation process, stellar nucleosynthesis and evolution, dynamical interaction among stars, or the assembly and evolution of galaxies. In particular, Open Clusters (OCs), which cover large ranges of ages and metallicities, have been widely used to constrain the formation and evolution of the Milky Way disc (e.g. [12]). This is because some of their features, such as ages or distances, are more accurately determined in comparison with field stars. They provide information about the chemical patterns and the existence of radial and vertical gradients or

an age-metallicity relation. However, all these investigations are hampered by the fact that only a small fraction of clusters have been studied homogeneously.

Galactic surveys performed from the ground such as the APO Galactic Evolution Experiment (APOGEE; [9]), the Gaia-ESO Survey (GES; [10]), or the GALactic Archaeology with HERMES (GALAH; [2]) include OCs among their targets, providing radial velocities and chemical abundances. OCs are also sampled from the space by the Gaia (e.g. [15]) and Kepler missions. The first will provide accurate parallaxes, from which distances will be derived, and proper motions, and the second is providing accurate photometry.

## 2 Survey design

The GES was designed to use the FLAMES ([13]; GIRAFFE+UVES) capabilities at one of the VLT units in order to complement the Gaia mission. Among GES clusters observations are including 20-25 OCs older than 0.5 Gyr. For them, GES is using the GIRAFFE fibers to derive radial velocities and abundances in stars at any evolutionary stage brighter than  $V \sim 17$  with a resolution lower than 20000. The six UVES fibers, which cover a wavelength range between 480 and 700 nm with a resolution of 47000, are being used to measure accurate radial velocities and detailed chemical abundances only in red clump stars. The UVES observations of old OCs have been designed to obtain an homogeneous sample of chemical abundances in order to study the Galactic disc. Using stars in the same evolutionary stage ensures the homogeneity of the sample.

Unfortunately, GES is sampling only the Southern hemisphere. However, several key OCs such as the most metal-rich, NGC 6791, and the oldest, Berkeley 17, together with several systems towards the Galactic anticenter or those observed by the Kepler mission are only visible from the North. APOGEE is the only survey that is sampling northern clusters in the  $H$  band with a resolution of 22500. However, APOGEE is sampling OC stars at any evolutionary stage, like GES-GIRAFFE. Moreover, APOGEE is not observing a minimum of stars in each cluster. In fact, six or more cluster members have been analyzed only in 7 of the OCs observed, those selected for calibration purposes ([9]).

The Open Cluster Chemical Abundances from Spanish Observatories survey (OCCASO) has been designed to complement from the North the GES-UVES observations of intermediate-age and old OCs in the South using the facilities available at the Spanish Observatories. OCCASO is being developed in parallel with GES. Like GES-UVES, OCCASO is observing a minimum of six red clump stars in a sample of 20 to 25 OCs older than 0.5 Gyr. Red clump stars are selected because they are easily identified even in the sparsely populated color-magnitude diagrams and their spectra are less line crowded and therefore, easier to analyze than that of brighter giants. Moreover, targeting objects in the same evolutionary stage avoids measuring anomalous abundances for some elements due to the effects of stellar evolution. Therefore, at the end we will double the sample of OCs with homogeneous chemical abundance determinations. To ensure obtain abundances in the same scale than GES we are observing several stars in common and we are using some of the analysis methods also used in GES (see Sections 4 and 5). APOGEE is the only spectrograph with similar multi-

object capabilities than UVES in the North but with lower resolution ( $\sim 22500$ ) and in the infrared. However, at Spanish observatories there are available several echelle high-resolution spectrographs with resolutions and wavelength coverage ranges similar or larger than UVES. In particular for this project we have selected CAFE@CAHA 2.2m ([1];  $396 < \lambda < 950$  nm,  $R \sim 60000$ ), FIES@NOT 2.5m ([19];  $370 < \lambda < 750$  nm,  $R \sim 67000$ ) and HERMES@Mercator 1.2m ([16];  $377 < \lambda < 900$  nm,  $R \sim 60000$ ). Although only one star can be observed at once in each of them, the fact that we have distributed our observations among three different telescopes/instruments is allowing us to develop OCCASO in a timeline similar to GES. The brightest targets ( $V \leq 12.5$ ) are being observed with MERCATOR/HERMES, those stars with  $12 \leq V \leq 14$  are being observing with CAFE/CAHA 2.2m, and the faintest objects with FIES/NOT. For sake of homogeneity, we are observing stars in common in all telescopes.

### 3 Observations, data reduction and radial velocity determination

OCCASO obtained 5 nights in each NOT and Mercator telescopes in semester 13B, and it was selected as a large program in the same telescopes from semester 14A which ensured 5 nights per semester and telescope during 4 semesters, till semester 15A. Moreover, it is regularly obtaining Director Discretionary and Spanish Guaranteed Times at the CAHA 2.2m telescope from semester 14A. Until November of 2014 we have completed a total of 44 observing nights with about 20% of them lost by bad sky conditions. Moreover, the sky conditions of several of the observing nights were not good enough and we had to observe brighter stars than expected. In total, we have acquired 524 spectra for 87 stars belonging to 18 OCs. A minimum of 6 stars have been observed in 11 clusters.

The FIES and HERMES spectrographs have dedicated pipelines which perform the bias subtraction, flat-field normalization, order trace and extraction, wavelength calibration, and order merge. For spectra acquired with CAFE we are using the pipeline developed by J. Maiz-Apellaniz. After this basic reduction, the spectra of the three telescopes are handled in the same way. Firstly, the sky emission lines are subtracted using a sky spectrum acquired during each run. Next, each spectrum is normalized by fitting the continuum with a polynomial function using DAOSPEC [18]. The degree of the polynomial function changes from instrument to instrument. The telluric absorption lines are removed in the normalized spectra using a telluric star spectrum acquired in each run. The wavelength calibration is corrected of the heliocentric velocity. All the spectra of the same star and instrument are combined to reach the required signal-to-noise ratio. Finally, the radial velocity of each star is computed from the combined spectra using DAOSPEC and the same linelist used in the chemical abundance determination (see Section 4).

### 4 Chemical abundance determination

The OCCASO goal is to derive abundances for more than 20 chemical species, including light-elements (C, N), Fe-peak elements (Sc, V, Cr, Fe, Co, Ni),  $\alpha$ -elements (O, Mg, Si,

Ca, Ti), s-process elements (Y, Z, Ba, La, Nd, Ce), proton-capture elements (Na, Al); the r-process element Eu; and Cu and Mn, elements with still unclear nucleosynthesis (e.g. [7]). In order to ensure the reliability of the derived chemical abundances, these will be derived using different analysis techniques similar to what is being performed by GES.

The first approach is the classical one in which the abundances are derived from equivalent widths. In our case, the equivalent widths are measured with the automated wrapper DAOSPEC Option Optimizer (DOOp; [5]) which automatically optimizes the best DAOSPEC inputs before determining the equivalent widths. In the next step, the abundances of individual spectral lines are derived using the WIDTH9 code developed by R. L. Kurucz implemented in GALA [11]. Briefly, GALA determines the best model atmosphere by optimizing temperature, surface gravity, microturbulent velocity and metallicity, after rejecting the discrepant lines and it computes accurate internal errors for each atmospheric parameter and abundance. The GES linelist is used but extended to the blue by the [6] linelist.

The second approach is the spectral synthesis in which the observed spectrum is compared with a library of synthetic spectra of known features in order to derive that which better reproduces the observed one. We are using three different tools to perform the spectral synthesis. FERRE [3] identifies the model parameters that best reproduce the observations by means of an optimization algorithm that uses the chi-squared as metric. The MATrix Inversion for Spectral SynthEsis (MATISSE) algorithm ([17]) determines the atmosphere parameters on the basis of a linear combination of a grid of theoretical spectra. iSpec ([4]) compares an observed spectrum with synthetic ones generated on the fly, using a least-squares algorithm but only in specific regions of the spectrum to minimize the computation time.

Stellar parameters and chemical abundances for all observed stars until now have been derived with the classical method. We are working at this moment on deriving atmosphere parameters and abundances with the other methods. Derived stellar atmosphere parameters and Fe abundances for all stars observed until now will be released in the first data release scheduled for the first semester of 2015. Detailed chemical abundances for at least ten clusters in which six or more stars have been observed will be published in the second data release.

## 5 Consistency

One of the OCCASO requirements is the homogeneity between telescopes, method and model atmospheres used, and in the same scale than the GES-UVES abundances. For this reason we are performing different tests. For example, to ensure the homogeneity among telescopes we have observed several stars in common in all of them. The preliminary results in the comparison between NOT and Mercator telescopes using the DAOSPEC+GALA approach are shown in Fig. 1. The values obtained for each telescope agree within the uncertainties. We are working on the other comparisons described above such as results obtained from different methods, different atmosphere models, wavelength ranges, etc.

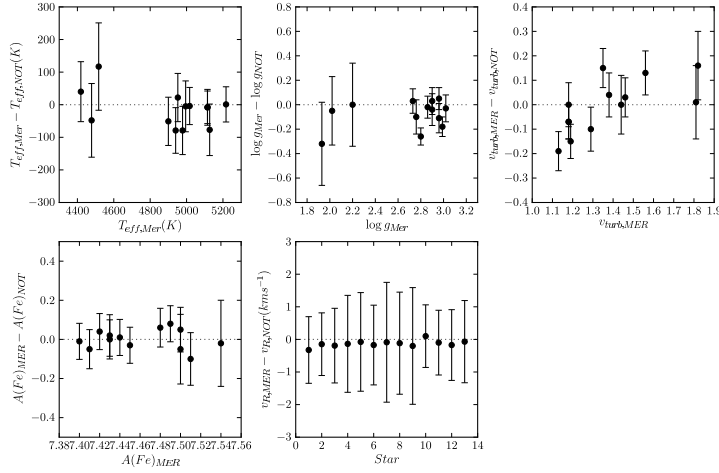


Figure 1: Comparison among stellar parameters derived for spectra acquired with FIES@NOT and HERMES@Mercator for the same stars using DAOSPEC+GALA approach.

## 6 Summary and future work

The OCCASO survey has been designed as the northern counterpart of the GES-UVES observations using the high-resolution spectroscopic facilities available at the Spanish observatories. OCCASO aims to derive abundances for a sample of 20-25 OCs older than 0.5 Gyr. Together with the other 20-25 OCs in the same age range included in the Southern sample of GES-UVES it will constitute the largest homogeneous sample available until now, and that will be key in the study of the formation and evolution of the Galactic disc.

Up to November of 2014, OCCASO has completed 44 observing nights in which 524 spectra for 87 stars belonging to 18 OCs have been acquired. The minimum requirement of at least 6 stars has been met for 11 clusters. The data reduction of all spectra acquired until now with the NOT and Mercator telescopes have been completed with the dedicated pipelines available for each instrument. The atmosphere parameters and chemical abundances for these stars have been obtained using the classical equivalent width approach as implemented by DAOSPEC and GALA. The data from the CAHA 2.2m telescope is being reduced with a new pipeline developed and kindly provided to us by J. Maiz-Apellaniz. Moreover we are working on deriving atmosphere parameters and abundances with spectral synthesis methods such as FERRE, MATISSE and iSpec.

One of the goals of OCCASO is the internal homogeneity, in addition to derive abundances in the same scale than the GES-UVES. To ensure this, we have observed several stars in common among telescopes and also with GES. We are performing exhaustive tests to achieve the level of homogeneity needed for the scientific goals.

The observing time awarded by OCCASO will finish in semester 15A. However, because of the bad weather in previous observing runs we will need more time at NOT to complete

the faintest clusters in our sample. In any case, we plan to publish the first OCCASO data release in the first semester of 2015. It will include the atmosphere parameters and iron abundances for all the stars observed until now. In a second data release, expected for the second semester of 2015, we will publish the detailed abundances for at least ten OCs in which six or more stars have already been observed. Finally we are planning an extension of OCCASO to fainter clusters using HORS [14], a new high-resolution spectrograph for the 10m GTC telescope expected to see first light in 2015.

## Acknowledgments

This work was supported by the Spanish Ministry of Economy and Competitiveness MINECO-FEDER through grants AYA2012-39551-C02-01, AYA2010-16717 and ESP2013-48318-C2-1-R. The work reported on in this publication has been fully or partially supported by the European Science Foundation (ESF), in the framework of the GREAT Research Networking Programme.

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