The OCCASO survey: Presentation and radial velocities of twelve Milky Way Open Clusters

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ABSTRACT
Open clusters (OCs) are crucial for studying the formation and evolution of the Galactic disc. However, the lack of a large number of OCs analyzed homogeneously hampers the investigations about chemical patterns and the existence of Galactocentric radial and vertical gradients, or an age-metallicity relation. To overcome this, we have designed the Open Cluster Chemical Abundances from Spanish Observatories survey (OCCASO). We aim to provide homogeneous radial velocities, physical parameters and individual chemical abundances of six or more Red Clump stars for a sample of 25 old and intermediate-age OCs visible from the Northern hemisphere. To do so, we use high resolution spectroscopic facilities \((R \geq 62,000)\) available at Spanish observatories. We present the motivation, design and current status of the survey, together with the first data release of radial velocities for 77 stars in 12 OCs, which represents about 50% of the survey. We include clusters never studied with high-resolution spectroscopy before (NGC 1907, NGC 6991, NGC 7762), and clusters in common with other large spectroscopic surveys like the Gaia-ESO Survey (NGC 6705) and APOGEE (NGC 2682 and NGC 6819). We perform internal comparisons between instruments to evaluate and correct internal systematics of the results, and compare our radial velocities with previous determinations in the literature, when available. Finally, radial velocities for each cluster are used to perform a preliminary kinematic study in relation with the Galactic disc.

Key words: techniques: spectroscopic; Galaxy: open clusters and associations: general; Galaxy: disc

1 INTRODUCTION
Discs are the defining stellar component of most of late-type galaxies, including the Milky Way. They contain a substantial fraction of the baryonic matter, angular momentum and evolutionary activity of these galaxies, such as formation of stars, spiral arms, or bars, and the various forms of secular evolution (see van der Kruit & Freeman 2011, for a review). Understanding the formation and evolution of discs is, therefore, one of the key goals of galaxy formation research. Two complementary approaches are used to study the growth and evolution of galactic discs over cosmic time. The first one consists in analyzing discs at different redshifts (e.g. Wisnioski et al. 2015). Although these studies are limited to global information integrated over the discs stellar populations, they are able to trace the evolution of discs properties with time. The second approach, so-called galactic archaeology, consists on reconstructing the disc evolution through resolving their stellar populations into individual stars (e.g. Carrera et al. 2011). The disc evolution is

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fossilized in the orbital distribution of stars, their chemical composition and ages as a function of position: i.e. in form of radial and vertical gradients. Part of this information may be diluted through dynamical evolution and radial mixing in the disc, which is less severe for clusters than for field stars. Therefore, the clusters are more suitable targets for discs studies.

The disc of our own galaxy, the Milky Way, offers an excellent testbed for investigating its evolution using all the power of the galactic archaeology approach. In spite of the great observational effort performed to unveil the details of the disc structure, these are still unknown. The vertical density profile has been characterized as a sum of two exponential components, the so-called thin and thick discs (e.g. Yoshii 1982; Gilmore & Reid 1983). Recent studies have focused on dissecting the disc into subsets of stars of very similar chemical composition, also called mono-abundance populations (e.g. Ivezic et al. 2008). These studies found that in the solar neighborhood the vertical structure is composed of a smooth continuum of disc thicknesses (e.g. Boyer et al. 2012). However, the stellar disc population shows a clear bi-modal distribution in ([Fe/H], [α/Fe]) in the solar neighborhood the vertical structure is composed of a smooth continuum of disc thicknesses (e.g. Boyer et al. 2012). However, the stellar disc population shows a clear bi-modal distribution in ([Fe/H], [α/Fe]) with two sequences of high- and low-[α/Fe] (Adibekyan et al. 2012; Nidever et al. 2014). The high-[α/Fe] is more prominent in the inner disc, while the low-[α/Fe], and in particular its metal-poor end, dominates in the outer disc. Eggen et al. (1962) suggested the possibility that the stellar disc formed “upside-down” in the sense that old stars were formed in a relatively thick component, or are kinematically heated very quickly after their birth, while younger populations form in successively thinner discs. It has been thought for a long time that the vertical distribution of the disc is the result of some type of heating either due to satellite mergers (e.g. Abadi et al. 2003) or radial migration (e.g. Sellwood & Binney 2002). However, late results (e.g. Bird et al. 2013) point to an scenario similar to the early suggestion by Eggen et al. (1962).

The radial structure of the Galactic disc has been investigated using different tracers trying to cover as much Galactocentric distances as possible. Some of these tracers are H II regions (e.g. Bailer et al. 2011), B-type stars (e.g. Dafon et al. 2009), Cepheid variables (e.g. Lemasle et al. 2013; Andrievsky et al. 2013; Korotin et al. 2014; Genovali et al. 2015), planetary nebulae (e.g. Stanghellini & Haywood 2010), or open clusters (OCs, see below) and also main sequence (e.g. Nordström et al. 2004; Cheng et al. 2012; Moklatis et al. 2014) or giant field populations (e.g. Hayden et al. 2014; Huang et al. 2015). Although all of them agree on the existence of a radial metallicity gradient in the sense that stellar populations are richer towards the inner disc, there are discrepancies about how this gradient behaves. While the radial gradient described by OCs flattens at large Galactocentric distances (e.g. Carrera & Pancino 2011; Frinchaboy 2013), the Cepheids do not show a slope change in the outer disc (e.g. Lemasle et al. 2013). These discrepancies can be partially explained by the fact that each tracer is representative of stellar populations of different age. Until the recent arrival of large Galactic surveys, most of the studies were limited by the small sample size. The current large surveys are also hampered by the lack of accurate distances. This issue will be improved significantly in the near future by the advent of Gaia space mission data (see Sec. 1.1).

In comparison with other tracers, some of the OCs properties, such as distances or ages, can be accurately determined (see Friel 1995, for a review). In fact, most stars, including the Sun, are formed in stellar clusters although most of them are dissolved in the first few Myr (e.g. Portegies Zwart et al. 2010). Those that survive are the more massive OCs or those that have had less encounters, which contain the fossil record of the disc formation. Moreover, OCs cover a wide range of age that allows also to study the evolution of the disc with time (e.g. Carrera & Pancino 2011; Frinchaboy 2013). The number of clusters old enough (≳ 250 Myr) for such a study will be increased with Gaia observations making this kind of studies even more promising.

For all these reasons, OCs have been used for a long time to investigate the Galactic disc, starting from the pioneering studies by Janes (1979); Panagia & Tosi (1980). A review of the early Galactic disc studies using OCs as tracers can be found in Friel (1995). A great observational effort has been performed to characterize OCs homogeneously (e.g. Friel et al. 2002a, 2010; Sestito et al. 2008; Donati et al. 2015; Bragaglia & Tosi 2006) and/or to increase the observed samples (e.g. Twarog et al. 1997; Carrera & Pancino 2011; Jacobson et al. 2011a,b). All these investigations agree on the fact that the iron content decreases with increasing radius as has been found using other tracers (e.g. Lemasle et al. 2013). Most of the previously cited works were limited to the inner 15 kpc. However, investigations based on samples containing clusters at larger Galactocentric distances (e.g. Carrera & Pancino 2011; Yong et al. 2012; Frinchaboy 2013) found that the gradient appears to flatten from a radius of about 12 kpc, which is near the dynamical signature for Galactic co-rotation (Lépine et al. 2011). Moreover, it seems that the metallicity gradient observed in the inner disc was steeper in the past and has flattened with time (Carrera & Pancino 2011; Jacobson et al. 2011b; Yong et al. 2012; Frinchaboy 2013), as it is seen in M 33 (Beasley et al. 2015). No significant trends with radius have been observed in the abundances of other chemical species (e.g. Yong et al. 2012).

1.1 OCCASO in the context of large surveys

Our understanding of the Milky Way in general and the Galactic disc in particular is going to change significantly in the next years with the Gaia space mission (Perryman et al. 2001; Mignard 2005; Lindegren 2005). Gaia is a full-sky scanning satellite observing all stars down to 20th magnitude with precisions at the µas level. Parallaxes and proper motions of individual stars will be as precise as 1% for the OCs up to a distance of 1.5 kpc, and 10% for almost all known clusters. Importantly, the faint limiting magnitude and the high precision will allow the discovery of distant clusters. However, spectroscopic capabilities to derive chemical abundances are limited due to the low resolution and the small wavelength coverage of the Gaia RVS.

On the other hand, the Kepler space mission and its extension K2 is providing asteroseismic data with unprecedented detail, which will allow to quantify global properties of stars such as age, mass and radii to accuracies near 1% (Gilliland et al. 2010). It is targeting solar-like stars, red giants, classical pulsating stars, and oscillating stars in binaries and clusters. The advantages of asteroseismology for clusters are that, unlike estimates of colors and magnitudes,
seismic data do not suffer from uncertainties in distance or extinction and reddening. Asteroseismic observations of many stars allow testing stellar evolution theory and provide important constraints on the ages and chemical compositions of stars. K2 data (Howell et al. 2014) is particularly interesting because it covers a wider area and more clusters than the original Kepler field.

The Gaia and Kepler space observations are being complemented with several ongoing and forthcoming ground-based spectroscopic surveys. Low- and medium-resolution spectroscopic surveys (\(R < 10,000\)) such as the Radial Velocity Experiment (RAVE; Conrad et al. 2014), the Sloan Extension for Galactic Understanding and Exploration (SEGUE; Lee et al. 2008), and Large Sky Area Multi-Object Fiber Spectroscopic Telescope (LAMOST; Li et al. 2015) survey, provide radial velocities, together with rough information about the chemical content of the studied stars. Large high-resolution spectroscopic surveys (\(R \gtrsim 20,000\)) such as the ongoing Apache Point Observatory Galactic Evolution Experiment (APOGEE; Frinchaboy 2013), the Gaia-ESO Survey (GES; Gilmore et al. 2012; Randich et al. 2013), the GALactic Archaeology with HERMES (GALAH; De Silva et al. 2015) and the forthcoming WEAVE (Dalton et al. 2012) provide detailed information about the chemical composition, in addition to radial velocities.

However, most of the high-resolution spectroscopic surveys do not have dedicated observations of OCs. Except for a few systems observed for calibration purposes, OCs stars are targeted only when they fall in the field of view of other targets. This means that the results for most of the studied clusters are based on observations of one or two members only. Currently, APOGEE is the only survey sampling the Northern hemisphere. GES and GALAH are operating in the South, and WEAVE has not yet defined the observations of OCs and will not start operations until at least 2017. APOGEE is obtaining high-resolution (\(R \sim 22,500\)) spectra in the infrared H-band, which allows to sample the innermost regions of the Galaxy. However, it is sampling OC stars at any evolutionary stage and it 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 for calibration purposes. This makes detailed studies of the Milky Way OCs using APOGEE data difficult.

There are other long-term projects dedicated to the study of the OCs. The Bologna Open Cluster Chemical Evolution project (Bragaglia & Tosi 2006, BOCCCE) uses both color-magnitude diagram synthesis and high-resolution spectra to infer cluster properties such as age, distance, and chemical composition. The WIYN Open cluster study (von Hippel & Sarajedini 1998, WOCS) is also obtaining photometry, astrometric and spectroscopic data for few nearby OCs. However, these surveys have been designed to study each cluster individually and not to provide a sample of OCs to constrain the chemical evolution of the Galactic disc.

Therefore, GES is the only large survey that has a program particularly designed to study the existence of trends in the Galactic disc. GES is designed to use the FLAMES capabilities (GIRAFFE+UVES; Pasquini et al. 2002) at the second VLT unit in order to complement the Gaia mission. GES clusters observations include 20-25 OCs older than 0.5 Gyr. For them, GES is using the GIRAFFE fibers to derive radial velocities and chemical abundances in stars at any evolutionary stage brighter than \(V \sim 19\) with a resolution \(R \sim 20,000\). The six UVES fibers, which cover a wavelength range between 4800 and 7000 Å with a resolution of 47,000, are being used to measure accurate radial velocities and detailed chemical abundances for the brightest targets, mostly Red Clump (RC) stars. The UVES observations of old OCs have been designed to obtain a homogeneous sample of chemical abundances to study the Galactic disc. Using stars in the same evolutionary stage avoids the blurring of the trends due to chemical inhomogeneities produced by stellar nucleosynthesis itself, and ensures the homogeneity of the sample.

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, thus will not be observed by GES.

The Open Cluster Chemical Abundances from Spanish Observatories (OCCASO) survey has been designed to overcome many of the above caveats. It will obtain accurate radial velocities and chemical abundances for more than 20 chemical species from high-resolution spectra (\(R \gtrsim 62,000\)) in Northern OCs using the facilities available at Spanish observatories. As such, it is a natural complement to the GES observations from the South and the Gaia mission from space. The goal of this paper is to present the survey, its observations, data reduction, and analysis strategies. We also give a detailed analysis of the radial velocities for the first batch of observations.

The general survey strategy is described in Sec. 2. More in detail: science drivers of the survey (Sec. 2.1) criteria used to select the cluster sample (Sec. 2.2), observational facilities used (Sec. 2.3), observational strategy (Sec. 2.4), and data reduction procedure (2.5). The first data release is described in Sec. 3, which includes the description of the observational material (Sec. 3.1), the accuracy on the wavelength calibration (Sec. 3.2), and the results on the radial velocities (Sec. 3.3). Finally, an external comparison of the stars in common with previous works is done in Sec. 3.4, and a discussion of the results based on the kinematics of the disc and spiral arms are presented in Sec. 3.5. A summary is provided in Sec. 4.

2 THE OCCASO SURVEY

2.1 OCCASO science drivers

As discussed in the previous section, the main OCCASO science driver is the study of the chemical evolution of the Galactic disc. Therefore, the observations and analysis strategies have been optimized for this purpose. However, the OCCASO observational data and results can contribute to our understanding of other astrophysical questions. Here we summarize some of these additional science topics that can be addressed with OCCASO.

- Galactic disc kinematics. The same reasons that make OCs good chemical tracers of the Galactic disc justify their use as tracers to investigate the Galaxy dynamics. The rotation curve described by OCs is similar to that derived...
from other thin disc populations such as Cepheids, H ii regions or molecular clouds (e.g. Hron 1987; Scott et al. 1995; Glushkova et al. 1998; Fried et al. 2002b). It seems that the rotational velocity gradually decreases with age. This is accompanied by a smooth increase of the line-of-sight velocity dispersion (Hayes & Friel 2014). However, there are several OCs with unusual kinematics that keep them away from the disc or the inner regions of the Galaxy. It has been suggested that several OCs in the outer disc could have been accreted during a dwarf galaxy merger. In this sense, two OCs Saurer 1 and Berkeley 29 have been related to the Galactic antecenter stellar structure, also known as Monoceros stream (Prüchaboy et al. 2006). An extragalactic origin has also been proposed for the most metal-rich known OC, NGC 6791 (Carraro et al. 2006). However, accurate proper motions derived from Hubble Space Telescope data suggest that this cluster was formed near the Galactic bulge (Bedin et al. 2006). In addition to the chemical abundances OCCASO will provide radial velocities for observed stars with uncertainties of about 0.5 km s$^{-1}$ (see Sec. 3.3). These radial velocities together with the proper motions provided by the Gaia mission will allow us to study the three-dimensional kinematics of the OCs, trace their orbits and relate them to the spiral structure of the Galactic disc.

- Stellar evolution laboratories. OCs have been widely used to check the applicability of stellar evolutionary models and the validity of their physical parameters and prescriptions such as convective overshooting (e.g. Pietrinferni et al. 2004), and rotation (e.g. Carlberg 2014; Lanzafame & Spada 2015). In spite of the progress performed in last years, current evolutionary models are not able to completely reproduce the colour-magnitude diagrams of many OCs independently of their metallicities (e.g. Ahumada et al. 2013). A possible explanation could be that each cluster has different abundance ratios (Gallart et al. 2005). Stellar evolutionary models for different chemical compositions besides the iron and $\alpha$-elements have not been available until very recently (e.g. VandenBerg et al. 2012). The chemical abundances provided by OCCASO will help to constrain the parameters of such.

OCCASO could also contribute in the understanding of a variety of topics such as the study of the internal dynamics of old (highly evolved) OCs (e.g. Bonatto & Bica 2003; Davenport & Sandquist 2010), and the detection of signs of the existence of multiple stellar populations (Geisler et al. 2012; Carrera 2012b; Cunha et al. 2015). However, the small number of stars sampled in each cluster difficulties these kind of studies from OCCASO data only.

### 2.2 Clusters and stars selection

We select OCs to observe in OCCASO according to the following criteria:

(i) Visible from the Northern hemisphere

(ii) Ages $\geq 0.3$ Gyr, since intermediate-age and old OCs are excellent probes of the structure and chemodynamical evolution of the Galactic disc.

(iii) With six or more stars in the expected position of the RC area of the colour-magnitude diagram (CMD)\(^1\). In general, RC stars are clearly identified even in sparsely populated CMDs. In some cases, however, it is not easy to differentiate a RC star from a Red Giant Branch (RGB) star in OCs, so for simplicity we refer them as RC from now on. Selecting RGB stars instead of RC would not imply abundance changes except maybe for light elements, e.g. C or N. Spectra from these kind of stars are less line-crowded and therefore, easier to analyze than those of the brighter giants. Moreover, targeting objects in the same evolutionary state avoids measuring distinct abundances for some elements due to effects of stellar evolution. The requirement of six stars has been chosen to have reasonable statistics for the chemical abundances of each cluster.

(iv) With RC magnitude brighter than $V \sim 15$ mag, constrained by the available instruments/telescopes.

(v) Prioritizing those with ages, metallicities, heights from the plane, or Galactocentric distances lying in poorly studied regions of the $R_{CC}$-[Fe/H], Age-[Fe/H], $z$-[Fe/H] diagrams. In this way, we will improve the sampling homogeneity of the Galactic disc.

(vi) Some clusters with previous high-resolution studies in the literature (e.g. Carrera & Pancino 2011; Carrera 2012a; Bragaglia & Tosi 2006), and OCs selected in other surveys (GES, APOGEE) for comparison purposes.

Following the outlined criteria, we selected a list of 25 candidate OCs, distributed in the $R_{CC}$-[Fe/H], Age-[Fe/H], $z$-[Fe/H] diagrams as seen in Fig. 1. This paper focuses on the first 12 OCs for which observations were completed by January 2015. Some basic properties of these clusters are listed in Table 1, and they are represented as red squares in Fig. 1.

To select individual stars within each cluster we use the available literature information, with the following procedure:

(a) the targets are first selected among the stars located in the expected position of the RC in the CMD from the available photometries (see Fig. 2);

(b) membership information based on radial velocities and proper motions, if available, is taken into account (see Table 6);

(c) stars already flagged as non-members or spectroscopic binaries are avoided.

In some cases where membership information is not available (poor photometry, no prior information about radial velocities or proper motions), we acquire complementary medium-resolution spectroscopy. The strategy is to obtain radial velocities and overall metallicities for a large selection of objects in the line of sight of the cluster, to constrain the selection of members (see Carrera et al. 2015, for further details).

\(^1\) Actually, some bright clusters not fulfilling this condition were added to be observed during nights of non optimal weather conditions.
2.3 Observational facilities

There is no easy access for the European community to a spectrograph with similar multi-object capabilities as UVES, in the Northern hemisphere. However, at Spanish Observatories there are several echelle high-resolution spectrographs available with resolutions and wavelength coverage ranges similar to, or larger than UVES. In particular, for OCCASO we have selected: CAFE at the 2.2m telescope in the Centro Astronómico Hispano-Alemán (CAHA), FIES at the 2.5m NOT telescope in the Observatorio del Roque de los Muchachos (ORM), and HERMES at the 1.2m Mercator telescope also in the ORM. See Table 2 for a summary of the instrument characteristics.

The high-resolution Fibre-fed Echelle Spectrograph (FIES; Teling et al. 2014) is a cross-dispersed echelle spectrograph mounted at the 2.5m Nordic Optical Telescope (NOT), and located in the ORM in the island of La Palma (Spain). FIES is mounted in a heavily isolated building separated from the NOT building. It is connected to the Cassegrain focus of the telescope with a fiber bundle offer-

Table 1. Completed clusters of OCCASO by the end of January 2015. \(D\), \(R_{GC}\), \(z\) and Age are from Dias et al. (2002). We list the \(V\) magnitude of the RC and the number of stars observed in the last two columns. The photometry used to select the stars in each OC is indicated as a footnote.

| Cluster     | \(D\) (kpc) | \(R_{GC}\) (kpc) | \(z\) (pc) | Age (Gyr) | \(V_{RC}\) | Stars |
|-------------|-------------|-----------------|------------|-----------|-----------|-------|
| IC 4756\(^1\) | 0.48        | 8.14            | +41        | 0.50      | 9         | 7     |
| NGC 752\(^2\) | 0.46        | 8.80            | -160       | 1.12      | 9         | 7     |
| NGC 1907\(^3\) | 1.80      | 10.24           | +9         | 0.31      | 9         | 6     |
| NGC 2096\(^4\) | 1.38        | 9.87            | +74        | 0.34      | 12        | 7     |
| NGC 2539\(^5\) | 1.36        | 9.37            | +250       | 0.37      | 11        | 6     |
| NGC 2682\(^6\) | 0.81        | 9.16            | +426       | 2.81      | 10.5      | 8     |
| NGC 6637\(^7\) | 0.38        | 8.20            | +54        | 0.42      | 8.5       | 4*    |
| NGC 6705\(^8\) | 1.88        | 6.83            | -90        | 0.25      | 11.5      | 7     |
| NGC 6819\(^9\) | 2.51        | 7.81            | +370       | 2.39      | 13        | 6     |
| NGC 6991\(^10\) | 0.70        | 8.47            | +19        | 1.28      | 10        | 6     |
| NGC 7762\(^11\) | 0.78        | 8.86            | -79        | 1.99      | 12.5      | 6     |
| NGC 7769\(^12\) | 1.80        | 9.27            | -168       | 1.41      | 13        | 7     |

\(^{1}\)Alcaino (1965); \(^{2}\)Johnson (1953); \(^{3}\)Pandey et al. (2007); \(^{4}\)Kiss et al. (2001); \(^{5}\)Choo et al. (2003); \(^{6}\)Montgomery et al. (1993); \(^{7}\)Harmer et al. (2001); \(^{8}\)Sung et al. (1999); \(^{9}\)Rosvick \& Vandenberg (1998); \(^{10}\)Kharchenko et al. (2005a); \(^{11}\)Maciejewski \& Niedzielski (2007); \(^{12}\)Mochejska \& Kaluzny (1999); McNamara \& Solomon (1981).

\(^{*}\)It has only 4 stars in the RC but was included for observation in a night with non optimal weather conditions.

The High Efficiency and Resolution Mercator Echelle Spectrograph (HERMES; Raskin et al. 2011) is a fibre-fed prism-cross-dispersed echelle spectrograph at the 1.2m Mercator telescope, located in the ORM as well. It is mounted in a temperature-controlled room and fibre-fed from the Nasmyth A focal station through an atmospheric dispersion corrector. The size of the detector enables a coverage of the 3770 – 9000 Å wavelength range, with a maximum resolution of \(R \approx 85,000\).

The Calar Alto Fiber-fed Echelle spectrograph (CAFE; Aceituno et al. 2013) is an instrument constructed at the 2.2m telescope in the CAHA in Calar Alto, Almería (Spain). CAFE is installed in a temperature and vibration controlled room. It offers a maximum resolution of \(R \approx 62,000\), and a spectral coverage of 3900 – 9500 Å.

Since only one star can be observed at once in each of the spectrographs, we distribute our observations among the three different telescopes/instruments according to the magnitude of the stars. This allows us to develop OCCASO on a timeline similar to GES. The brightest targets (\(V \leq 13\)) are assigned to HERMES@Mercator, and the faintest stars (\(V > 13\)) are assigned mainly to FIES@NOT and CAFE@2.2m CAHA. Current efficiency of CAFE is lower than expected and all the faint stars were finally moved to FIES.

2.4 Observational strategy

All stars are observed in at least 3 exposures lasting 80-3600 s, depending on their magnitude, until a global signal-to-noise ratio (SNR) of at least 70 per pixel at \(\lambda \approx 6000\) Å.
Figure 2. (B-V), V colour-magnitude diagrams of the 12 completed clusters (from the photometry listed in Table 1). The red crosses indicate the target stars, cyan squares indicate the stars that we have found to be non members in this study (see Sec. 3.3.3).

Table 2. Characteristics of the instruments and telescopes used for the OCCASO Survey.

| Telescope/Instrument | Diameter | Spectral range | Resolution |
|----------------------|----------|----------------|------------|
| NOT/FIES             | 2.5 m    | 3700 – 7300 Å  | 67,000     |
| Mercator/HERMES      | 1.2 m    | 3770 – 9000 Å  | 85,000     |
| 2.2mCAHA/CAFE        | 2.2 m    | 3900 – 9500 Å  | 62,000     |

is reached. For the faintest targets (V > 14), this condition is relaxed to a SNR ~ 50. Each run we take a sky exposure to subtract the sky emission lines and, when relevant, the sky background level (see Sec 2.5). Hot, rapidly rotating stars were observed twice per run to remove sky absorption features, like telluric bands of O$_2$ and H$_2$O. Standard calibration images (flat, bias and arcs) were also taken at the beginning and end of each night. In general we assign each cluster to one instrument to maximize the precision in our measurements. In order to guarantee the homogeneity of our whole sample, at the beginning of the survey we have repeated observations of a set of few stars with the three instruments. Additionally, Arcturus (α-Bootes) and μ-Leonis, two extensively studied stars, part of the Gaia Benchmark stars (Jofré et al. 2014; Blanco-Cuaresma et al. 2014; Heiter et al. 2015) and the APOGEE reference stars (Smith et al. 2013), were observed with the three telescopes for the sake of comparison. We distribute the target stars among the observing runs (see Sec 3.1) taking into account their magnitudes, the quality of the nights and the characteristics of the instruments.

2.5 Data reduction

The first part of the data reduction consists in bias subtraction, flat-field normalization, order tracing and extraction, wavelength calibration and order merge. This step is performed with the dedicated pipelines for each instrument: HERMESDRS for HERMES@Mercator (Raskin et al. 2011), FIESTool for FIES@NOT (Telting et al. 2014), and the pipeline developed by J. Maíz-Apellániz for CAFE@2.2m CAHA, and used in Negueruela et al. (2014). We have checked that the results from the pipelines are appropriate: the spectra are correctly extracted, calibration in $\lambda$ is realistic and the merging of the orders does not introduce artefacts and defects in the regions were orders overlap. The useful range from CAFE spectra is taken as 4500 – 9000 Å to avoid saturated telluric lines and other instrumental defects at the red and blue edges. We take the whole wavelength range for HERMES and FIES.

After these initial steps of reduction, the spectra from...
the three instruments are handled in the same way. The established reduction protocol consists in:

(i) Subtraction of sky emission lines using sky exposures. It was only applied to those cases where the levels of the sky lines were higher than 3% of the continuum, to avoid adding noise to the spectra.
(ii) Normalization by fitting the continuum with a polynomial function and radial velocity determination of the individual spectra using DAOsSpec (Stetson & Pancino 2008) (see details in Sec. 3.3).
(iii) Correction of telluric features using the IRAF2 task telluric. To do so we acquire one or two exposures of a hot, rapidly rotating star (among HR551, HR7235, HR2198, HR8762 or HR3982, taking into account visibility) in each run. The strong O2 band around 7600 Å in HERMES and CAFE spectra is saturated and cannot be removed properly.
(iv) Heliocentric correction to account for observer’s motion is obtained with the IRAF task rvcorrect.
(v) The accuracy of the wavelength calibration is tested through the measurement of the radial velocity of sky emission lines. For each run, we measure the radial velocities of the skylines: 6300.304, 6363.78, 6863.95, 7276.405, 7913.708, 8344.692, and 8827.096 Å when visible, in all sky exposures and/or in target star exposures before applying the heliocentric correction. The obtained offset, if any, is used to correct the individual exposures with the IRAF task dopcor (see Sec. 3.2).
(vi) Combination of the single normalized spectra of the same star and telescope. We use the IRAF task scombine with a median algorithm and a sigma-clipping rejection. This aims to reach the maximum SNR for final radial velocity determination and further abundance analysis.
(vii) Final radial velocity determination and normalization of the combined spectra using DAOsSpec.

As an example of the results of the reduction protocol, we show three regions of the combined and normalized spectrum of the star NGC 2682 W141 in Fig. 3.

3 OCCASO FIRST DATA RELEASE: RADIAL VELOCITIES

In this section we present the radial velocities obtained from the reduced spectra acquired until January 2015 for the completed clusters.

3.1 Observational material

OCCASO observations started in January 2013. Until January 2015, we have completed a total of 53 nights of observations. The number of nights, dates and instrument of each run are summarized in Table 3 together with the percentage of time lost due to bad weather, and a description of the quality of the sky.

2 IRAF is distributed by the National Optical Astronomy Observatory, which is operated by the Association of Universities for Research in Astronomy (AURA) under a cooperative agreement with the National Science Foundation.

![Figure 3.](image)

Figure 3. The Ca triplet (bottom), Hα (middle) and Hβ (top) regions of the final combined and normalized spectrum of the star NGC 2682 W141 observed with HERMES (SNR ~ 77). A small gap from the order merging can be seen around 8580 Å.

| Run     | Period          | Instrument | # nights | Time lost | Q1 |
|---------|-----------------|------------|----------|-----------|----|
| 1       | 1-2 Apr 2013    | FIES       | 2        | 50%       | 2  |
| 2       | 25-29 Jul 2013  | HERMES     | 5        | 0%        | 1  |
| 3       | 23-25 Sep 2013  | HERMES     | 3        | 50%       | 2  |
| 4       | 1-6 Oct 2013    | HERMES     | 5        | 30%       | 1  |
| 5       | 25-29 Nov 2013  | FIES       | 5        | 40%       | 2  |
| 6       | 3-7 Jan 2014    | CAFE       | 5        | 100%      | 3  |
| 7       | 26 Jan 20142    | FIES       | 1        | 0%        | 2  |
| 8       | 29-30 Jan 2014  | CAFE       | 2        | 100%      | 3  |
| 9       | 21-25 May 2014  | HERMES     | 5        | 15%       | 1  |
| 10      | 14-15 Jul 2014  | CAFE       | 2        | 0%        | 2  |
| 11      | 6-8/10-11 Sep 2014 | FIES | 5 | 10% | 2 |
| 12      | 7-11 Oct 2014   | FIES       | 5        | 25%       | 1  |
| 13      | 18-22 Dec 2014  | HERMES     | 5        | 15%       | 1  |
| 14      | 1-3 Jan 2015    | CAFE       | 3        | 0%        | 1  |

1Quality of the night: 1: good seeing (< 1″), no clouds; 2: medium seeing (1 − 2″), disperse thin clouds, low dust, we were forced to observe stars 1-2 mag brighter than expected; 3: bad seeing (> 2″), clouds, no observations.
2Shared period, only a fraction of the night was used for this project.

In this period we have finished observations of 12 clusters which comprise a total of 77 stars (401 spectra), together with Arcturus and µ Leo used for comparison purposes. For these clusters we have achieved the initial requirement of observing at least 6 stars per cluster with a SNR ~ 70.
Table 4. Mean radial velocity offsets and standard deviations for each run (number as in Table 3) from visible skylines in the spectra (see text for more details).

| Run | Instrument | $v_r$ (km s$^{-1}$) | # measured lines |
|-----|------------|---------------------|------------------|
| 1   | FIES       | 5.09 ± 0.44         | 9                |
| 3   | FIES       | 0.09 ± 0.26         | 5                |
| 5   | FIES       | 0.07 ± 0.24         | 6                |
| 7   | FIES       | −0.04 ± 0.17        | 7                |
| 11  | FIES       | −0.5 ± 0.7          | 6                |
| 12  | FIES       | 0.00 ± 0.19         | 7                |
| 2   | HERMES     | −0.16 ± 0.28        | 9                |
| 4   | HERMES     | −0.26 ± 0.77        | 7                |
| 9   | HERMES     | −0.42 ± 0.72        | 7                |
| 13  | HERMES     | −0.29 ± 0.89        | 7                |
| 10  | CAFE       | 2.45 ± 0.52         | 6                |
| 14  | CAFE       | 2.64 ± 0.72         | 7                |

3.2 Wavelength calibration accuracy

The wavelength calibration accuracy is key for the radial velocity determination. To re-assess it, we calculate the radial velocity offsets of sky emission lines as described in Sec. 2.5. The mean values and standard deviations of the radial velocity offsets are listed in Table 4. We can conclude that:

(i) All FIES runs have negligible offset except for run#1, for which it has a value of 5.09 ± 0.44 km s$^{-1}$. The pipeline could not be run in the telescope during the observing run, and it was run a posteriori using a version built to be used outside the NOT. The origin of the offset could be related to the use of inappropriate calibration images when running the pipeline. We have corrected the individual spectra of this run using this value.

(ii) All HERMES offsets are compatible with 0 km s$^{-1}$ within the errors. The mean value is −0.28 ± 0.11 km s$^{-1}$. This offset can be neglected given the spectral resolution of the instrument.

(iii) Both runs from CAFE present a roughly constant offset of unknown origin, with a mean value and standard deviation of 2.55 ± 0.62 km s$^{-1}$. We have shifted all the spectra from these runs by −2.55 km s$^{-1}$.

3.3 Radial velocities

We present here the results of the radial velocities for stars in the 12 completed clusters (77 stars), and the reference stars Arcturus and µ-Leo. This is a total of 79 stars from which 17 have repeated observations with more than one telescope: 25 were observed with FIES@NOT; 66 were observed with HERMES@Mercator, and 11 were observed with CAFE@2.2m CAHA.

All radial velocities are measured using DAOSPEC (Stetson & Pancino 2008). DAOSPEC is a Fortran code that finds absorption lines in a stellar spectrum, fits the continuum, identifies lines from a provided linelist, and measures equivalent widths. DAOSPEC also provides radial velocity estimates using a cross-correlation procedure based on the line centers and on their reference laboratory wavelength in the linelist (i.e., a sort of line mask cross-correlation). To run DAOSPEC we used the DOOp code (Cantat-Gaudin et al. 2014a), an algorithm that optimizes its most critical parameters in order to obtain the best measurements of equivalent widths (EW). In brief, it fine tunes the FWHM and the continuum placement among other parameters, through a fully automatic and iterative procedure.

We built our linelist starting from the public GES linelist version 3, which contains 47098 lines. However, this linelist goes from 4700 < $\lambda$ < 6800 Å and our covered spectral range is much wider. Therefore, we extended our linelist redder than 6800 Å using the linelist described in Pancino et al. (2010). The final linelist has 1400 lines, from which ~1000 (after a sigma clipping rejection criteria) are used for the radial velocities. Further details will be provided in Casamiquela et al. (in preparation), where we will release the linelist together with the physical parameters and individual abundance determinations from OCCASO.

We compute radial velocities from both individual and combined exposures for each star, as mentioned in Sec. 2.5. Using the combined exposures, we perform a comparison among the three instruments, and we compute the final values per star. We perform a membership selection after which we compute the average radial velocity for each of the 12 clusters. Details are given in the following subsections.

3.3.1 Individual exposures

We measure radial velocities from individual exposures after rectifying the offsets calculated in Sec. 3.2, and once heliocentric corrections are applied. The values obtained are listed in Table 5. The first, second and third columns denote the star identifier (taken from WEBDA3), night of observation, and instrument, respectively; the fourth column indicates the Heliocentric Julian Date (HJD) of the observation; and the fifth column lists the measured radial velocity and the uncertainty. The quoted uncertainties are those calculated by DAOSPEC, which correspond to the line-by-line radial velocity variance.

The uncertainties on the individual radial velocities are constrained by the resolution and wavelength range (which limits the number of lines used) of the instrument, and the SNR of the spectrum. The distribution of uncertainties is shown in Fig. 4, with median values of 0.6 ± 0.1 km s$^{-1}$ for FIES, 0.8 ± 0.4 km s$^{-1}$ for HERMES, and 1.2 ± 0.3 km s$^{-1}$ for CAFE.

Although our observations are not designed to look for spectroscopic binaries, we can detect them by comparing the radial velocity obtained from different exposures of the same star. Individual radial velocities for all stars agree within the errors but one, NGC 6839 W983, with a radial velocity of 3.2 ± 0.8 km s$^{-1}$ from the exposure in the night 25 Jul 2013, and −8.3 ± 0.8 km s$^{-1}$ from the three consecutive exposures in the night 29 Jul 2013. We flag this star as possible spectroscopic binary, (see Sec. 3.3.3 for further discussions).

There can be other single-line spectroscopic binaries within our sample that we are not detecting because in most

3 http://www.univie.ac.at/webda/
4 in many cases several observations are consecutive
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0.5 1.0 1.5 2.0
σcombined (km s\(^{-1}\))
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Frequency
FIES
HERMES
CAFE

0.5 1.0 1.5 2.0
σindiv (km s\(^{-1}\))
0.00
0.05
0.10
0.15
0.20
0.25
0.30
0.35
0.40
0.45
Frequency

Figure 4. Radial velocity uncertainty distributions from the individual spectra (top panel), and the combined spectra (bottom panel), for each instrument. The histograms are scaled to facilitate the visualization.

Table 5. Radial velocities from individual spectra. The complete version of the table can be found in the electronic version of the Journal, and in the CDS.

| Star   | Night  | Instr  | HJD     | \(v_r,\text{indiv}\) (km s\(^{-1}\)) |
|--------|--------|--------|---------|----------------------------------|
| IC4756 W0042 | 20130729 | HERMES | 2456503.42986657 | −24.7 ± 0.6 |
| IC4756 W0042 | 20130729 | HERMES | 2456503.4350752  | −24.7 ± 0.6 |
| IC4756 W0042 | 20130729 | HERMES | 2456503.44028436 | −24.7 ± 0.6 |
| IC4756 W0042 | 20140521 | HERMES | 2456799.71796826 | −24.5 ± 0.7 |
| IC4756 W0042 | 20140521 | HERMES | 2456799.72317693 | −24.5 ± 0.7 |

cases we have taken the individual exposures in the same night. In this case we would only detect them if the period is very short.

3.3.2 Combined spectra and comparison among instruments

The final values of the radial velocities are obtained running again DOOp on the combined spectra. The results of each star and instrument are specified in columns 9, 10 and 11 (for FIES, HERMES and CAFE, respectively) of Table 6.

The radial velocity uncertainties are reduced with respect to the ones from individual spectra due to the higher SNR, as shown in the lower pannel of Fig. 4. Now the median dispersion values for each instrument are: 0.5 ± 0.1 km s\(^{-1}\) for FIES, 0.7 ± 0.3 km s\(^{-1}\) for HERMES, and 0.93 ± 0.07 km s\(^{-1}\) for CAFE.

We use the final combined spectra of the repeated stars to make a comparison among instruments (see Fig. 5). Fifteen stars were observed with both FIES@NOT and HERMES@Mercator, nine stars observed with both CAFE@2.2m CAHA and FIES@NOT, and five stars observed with both HERMES@Mercator and CAFE@2.2m CAHA. We notice:

(i) For HERMES-FIES comparison, we find a mean offset and dispersion of \(\langle \Delta v_r \rangle = −0.10 ± 0.12\) km s\(^{-1}\).
(ii) For CAFE-FIES, we find a mean offset of \(\langle \Delta v_r \rangle = 0.40 ± 0.20\) km s\(^{-1}\).
(iii) For the CAFE-HERMES case, we find a mean offset of \(\langle \Delta v_r \rangle = 0.60 ± 0.28\) km s\(^{-1}\).

All offsets are in agreement within the observational uncertainties and follow the expectations from sky emission lines results (see Table 4, Sec 3.2).

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Figure 5. Differences in $v_r$ obtained for the stars in common between HERMES@Mercator and FIES@NOT (top panel), CAFE@2.2m CAHA and FIES@NOT (central panel), and CAFE@2.2m CAHA and HERMES@Mercator (bottom panel). The error bars are the sum in quadrature of the two uncertainties.
Table 6. Radial velocities obtained with FIES, HERMES and CAFE, and the combination of all instruments $v_r^\text{OCCASO}$. Values from literature are $v_r^\text{ref}$, and differences with literature are computed as $\Delta v_r = v_r^\text{OCCASO} - v_r^\text{ref}$. Information on membership in the literature is shown: probability from proper motion ($P_\mu$), from radial velocity ($P_v$), and membership classification (Class). Last column points out special cases discussed in the text. Star IDs are from WEBDA. The complete table can be found in the electronic version of the Journal, and in the CDS.

| Cluster | Star | RA | DEC | $V$ | $P_\mu$ | $P_v$ | $v_r^\text{FIES}$ | $v_r^\text{HERMES}$ | $v_r^\text{CAFE}$ | $v_r^\text{OCCASO}$ | $v_r^\text{ref}$ | $\Delta v_r$ | Reference | Remark |
|---------|------|----|-----|-----|--------|------|--------------|--------------|--------------|---------------|-------------|-----------|-----------|--------|
| NGC 752 | W0841 | 01:55:12.60 | +37:50:14.60 | 9.48 | 0.9329, 0.9510 | M* | 5.3 ± 0.4 | 5.3 ± 0.4 | 5.2 ± 0.1 | 1.0 | Mermilliod et al. (2008) | Böeck Topcu et al. (2015) |
| NGC 1907 | W0862 | 05:27:49:053 | +35:20:10.13 | 12.41 | 0.9410 | M* | 2.6 ± 1.6 | 2.6 ± 1.6 | 2.0 ± 0.7 | 0.9 | Glushkova & Rastorguev (1991) | Glushkova & Rastorguev (1991) |
| NGC 2095 | W087 | 05:23:24.14 | +32:33:49.3 | 11.42 | 0.853, 0.9010 | M* | 3.0 ± 0.6 | 3.0 ± 0.6 | 3.0 ± 0.2 | 3.5 | Mermilliod et al. (2008) | Böeck Topcu et al. (2015) |
| NGC 2539 | W233 | 08:10:33.60 | -12:54:49.8 | 11.20 | 0.9910 | M* | 2.8 ± 0.8 | 2.8 ± 0.8 | 2.8 ± 0.8 | 2.8 | Mermilliod et al. (2008) | Böeck Topcu et al. (2015) |
| Membership probabilities: $P_\mu$: 1 Herzog et al. (1975), 2 Platais (1991), 3 Zhao et al. (1985), 4 Sanders (1977), 5 Sanders (1973), 6 McNamara et al. (1977), 7 Sanders (1972), 8 Kharchenko et al. (2005b), 9 McNamara & Solomon (1981), 10 Dias et al. (2014); $P_v$: 1 Böeck Topcu et al. (2015), 2 Geller et al. (2015), 3 Millman et al. (2014).

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The final values of the radial velocity for each star are derived from the combined spectra. For the cases of stars observed with several instruments we adopt the weighted mean of all the determinations, and of the mean of the nominal errors as the uncertainty. These final values are found in column 12 of Table 6.

In general, stars have compatible radial velocities within the same cluster. This is because they were already pre-selected to be very likely cluster members, as explained in Sec. 2.2. However, a re-analysis of membership is performed. We flag as non-members those stars which have \( v_r \) not compatible at 3σ level of the radial velocity of the cluster. We have used the median and the mean absolute deviation (MAD). We iterate this by rejecting the non-members and recalculating the median radial velocity, until we find a sample of compatible stars. Under this criterion we flag the following five stars:

(i) NGC 1907 W2087 has a significant difference of \( \sim 60 \text{ km s}^{-1} \) with respect to the other stars from the same cluster. The four values from individual exposures of this star (see Table 5) are compatible with each other, so probably it is a non-member star or a large period spectroscopic binary. This has no other measurement in the literature for comparison.

(ii) NGC 2539 W233 has a radial velocity of \( 34.8 \pm 1.1 \text{ km s}^{-1} \), which is \( 5.4 \text{ km s}^{-1} \) above the median of the other five stars. It was already flagged as spectroscopic binary by Mermilliod et al. (2008). They obtain a variability with the maximum at \( 28.3 \pm 1.1 \text{ km s}^{-1} \). This value is compatible with ours within 3σ.

(iii) NGC 2682 W224 has a radial velocity of \( 6.5 \text{ km s}^{-1} \) under the median of the cluster. The four individual spectra were taken in two consecutive days and the individual radial velocities are in agreement. It was already flagged as member spectroscopic binary by Jacobson et al. (2011b) and Geller et al. (2015).

(iv) NGC 6819 W983 has a variable radial velocity as shown in Table 5 and discussed in Sec. 3.3.1. For this reason we do not give a final value of the radial velocity, and we do not include it in Table 6. Neither Hole et al. (2009) nor Milliman et al. (2014) identify this star as a radial velocity variable, obtaining a final radial velocity of \( 2.36 \pm 0.20 \text{ km s}^{-1} \). Both studies are based in the same spectra (6 observations) and classify this star as single member for having e/i<4 (external error divided by internal error). If this star was confirmed to be a cluster member, we could consider it in the abundance analysis of the cluster.

(v) NGC 7762 W0084 has a large difference of \( \sim 40 \text{ km s}^{-1} \) with respect to the other stars from the same cluster. Radial velocities obtained from the three individual spectra acquired in two consecutive nights are consistent within the uncertainties. There are neither previous radial velocity measurements nor information on membership for this cluster.

Special attention must be payed to NGC 7789. Following the iterative procedure described above, two stars should be rejected: W08260 and W07714. Radial velocities of all stars in this OC compare well with the literature for stars in common (Gim et al. 1998; Jacobson et al. 2011b, see Table 6), which considers all of them as members. Moreover, Jacobson et al. (2011b) reported that they find a broader dispersion compared with other OCs. Taking into account the OC mean radial velocity and dispersion from the three large samples in the literature (Table 7), all the seven stars studied here fall inside the distribution. Therefore, we have decided to keep these two stars as members.

The rest of studied stars from the observed clusters are compatible with being members of their parent cluster. We point out that stars NGC 1907 W0133, NGC 6819 W978, and NGC 7762 W0003, have radial velocities outside of the 3MAD margin of the cluster, but when also considering the uncertainties on these radial velocities, these stars are still within the cluster distributions, and are included as members in our sample (see Fig. 6). The doubtful cases of membership will be probably solved when doing the abundance analysis.

### 3.3.4 Radial velocities of clusters

The sample of non-spectroscopic binaries and bona-fide member stars is used to compute the cluster radial velocity. Median values and MAD are found in Table 7 and plotted in Fig. 6. We also list in Table 7 previous determinations of the cluster radial velocity, for those references where a mean value is given. All values from literature are compatible within 3σ with the ones derived here.

The radial velocity dispersions within each cluster are found between \( 0.3 - 1.7 \text{ km s}^{-1} \). The quoted dispersions are the result of (a) the precision that we have in our radial velocity determinations (Table 6), which is computed as the line-by-line radial velocity variance found by DAOSPEC, (b) a fraction of undetected binaries, and (c) the intrinsic internal dispersion of each cluster. In most of the cases the dispersions in Table 7 are at the level of the quoted precisions. Only, the dispersion for NGC 6705 is very well above the uncertainties (\( 1.7 \text{ km s}^{-1} \)). This can be indicative that either this cluster has a larger fraction of undetected binaries, or that this is indeed the intrinsic radial velocity dispersion, and that this OC is kinematically hot. Given that the star by star comparison of this cluster with the literature is coherent within the uncertainties (Fig. 7, Table 6), we tend to think that this is the intrinsic velocity dispersion. Moreover, this OC is the most massive and youngest cluster in the sample. Cantat-Gaudin et al. (2014b) selected bona-fide members and found a mean radial velocity of \( 34.1 \pm 1.5 \text{ km s}^{-1} \) from 21 stars (UVES targets), and 35.9 \( \pm 2.8 \text{ km s}^{-1} \) from 536 stars (GIRAFFE targets). Our result confirms the high intrinsic velocity dispersion of this cluster.

### 3.4 Comparison with literature

We compared our final values for each star (column 12 of Table 6), with previous measurements in the literature, when available (column 13 of Table 6). Since in most cases our individual exposures are taken during the same night, this external comparison is also useful to identify potential spectroscopic binaries.

Calculated differences with each author are shown in Table 6 (column 14) and illustrated in Fig. 7. We exclude
from this comparison the confirmed spectroscopic binaries already described in Sec. 3.3.3 (NGC 6819 W0333, NGC 2539 W233 and NGC 2682 W224). The mean differences with each author are shown in Table 8.

We find good agreement with literature except for five stars:

(i) IC 4756 W0081: we find a difference of 4.8 km s$^{-1}$ with Valitova et al. (1990), and a difference of only 0.1 km s$^{-1}$ with Mermilliod et al. (2008). Given the small differences of the other stars in common with Valitova et al. (1990), we consider this case an outlier in this comparison and we exclude it to calculate the mean difference with these authors (Table 8). Our three individual measurements are taken within the same night (Table 5), so we cannot know if this star is a spectroscopic binary. A large set of measurements from Mermilliod et al. (2008) do not show variability.

(ii) NGC 1907 W0062: we find a difference of 4.68 km s$^{-1}$ with Glushkova & Rastorguev (1991). We have three other stars from the cluster NGC 1907 in common with these authors, with differences of: 0.53, 2.98, 1.35 km s$^{-1}$. Their uncertainties are of the order of 1 km s$^{-1}$. The mean difference with these authors is large (2.4 ± 1.6 km s$^{-1}$), even if we consider the star W0062 as outlier (1.6 ± 1.0 km s$^{-1}$). Glushkova & Rastorguev (1991) reported large uncertainties in their final values due to large errors in the observational data.

(iii) NGC 6819 W0333: there is a discrepancy of -2.11 km s$^{-1}$ with Bragaglia et al. (2001), of 0.43 km s$^{-1}$ with Milliman et al. (2014), and 8.8 km s$^{-1}$ with Alam et al. (2015), which is the Data Release 12 (DR12) of APOGEE. We find a difference of only 0.7 km s$^{-1}$ with Mészáros et al. (2013), which is the Data Release 10 (DR10). This star is reported to have “high persistence” in the APOGEE detector by Alam et al. (2015). Given the low differences of the other stars in common, this effect could be the explanation for the discrepancy. From a set of 5 measurements Milliman et al. (2014) identify this star as single member.

(iv) NGC 6819 W0978: there is a difference of -4.76 km s$^{-1}$ with Bragaglia et al. (2001), and a small difference with both APOGEE DR10 and DR12, -0.4 and -0.1 km s$^{-1}$, respectively. Also we see a small difference of 0.41 km s$^{-1}$ with Milliman et al. (2014), which identify this star as single member. Bragaglia et al. (2001) have used a spectral resolution of $R = 40,000$. They do not specify their errors, but they report that they were not interested in obtaining precise radial velocities.

(v) NGC 2682 W286 we find significant differences of 8.1 km s$^{-1}$ and -5.1 km s$^{-1}$ with Mermilliod et al. (2008) and Pancino et al. (2010), respectively. Since we find differences smaller than 1 km s$^{-1}$ for the same star with six other authors (Pasquini et al. 2011; Jacobson et al. 2011b; Pasquini et al. 2012; Alam et al. 2015; Mészáros et al. 2013; Mathieu et al. 1986), we consider this case as outlier, and we exclude it to calculate the mean difference with Mermilliod et al. (2008) and Pancino et al. (2010) in Table 8.

We can state that large differences are found for few specific authors and stars. Given that for the same stars

\[ \Delta v = v_r - v_{r,\text{lit}} \]

\[ \Delta v_r \]

\[ v_{r,\text{lit}} \]

\[ v_r \]

\[ v_{r,\text{lit}} \]

| Cluster | $v_r$(km s$^{-1}$) | $v_{r,\text{lit}}$(km s$^{-1}$) | $\Delta v_r$(km s$^{-1}$) | Reference |
|---------|------------------|------------------|------------------|----------|
| IC 4756 | -24.7 ± 0.7 (7)  | -25.0 ± 0.2 (15) | 0.3              | Valitova et al. (1990) |
| NGC 752 | 5.6 ± 0.4 (7)    | 5.04 ± 0.08 (16) | 0.56             | Mermilliod et al. (2008) |
| NGC 1907| 2.3 ± 0.5 (5)    | 0.1 ± 1.8 (4)    | 2.2              | Glushkova & Rastorguev (1991) |
| NGC 2682| 33.9 ± 0.5 (7)   | 33.52 ± 0.29 (23)| 0.38             | Mermilliod et al. (2008) |
| NGC 6633| -28.6 ± 0.3 (4)  | -28.95 ± 0.09 (6)| 0.35             | Mermilliod et al. (2008) |
| NGC 6705| 34.5 ± 1.7 (7)   | 35.98 ± 0.32 (15)| -0.58            | Mermilliod et al. (2008) |
| NGC 6818| 3.0 ± 0.5 (5)    | 2.45 ± 1.02 (566)| 0.55             | Milliman et al. (2014) |
| NGC 6991| -12.3 ± 0.6 (6)  | -               | -               | -        |
| NGC 7762| -45.7 ± 0.3 (5)  | -               | -               | -        |
| NGC 7789| -53.6 ± 0.6 (7)  | -54.9 ± 0.9 (50) | 1.3              | Gim et al. (1998) |
|          |                  | -54.7 ± 1.3 (26) | 1.1              | Jacobson et al. (2011b) |
|          |                  | -54.6 ± 1.0 (29) | 1.0              | Overbeek et al. (2015) |
we find compatible values with other authors, we do not interpret these discrepancies as due to binarity but some spurious measurements in the literature. For all these stars mentioned above we make use of our radial velocities.

Arcturus and μ-Leo are compared with the values given by Blanco-Cuaresma et al. (2014) for the Gaia Benchmark stars. These are two stars with very precise determination of the radial velocity because they are taken as standard stars for the Gaia mission wavelength calibration. We find a difference of 0.19 and 0.37 km s\(^{-1}\), respectively. We also compare with the results for the APOGEE DR12, which are -0.28 and 0.19 km s\(^{-1}\), respectively. All differences are lower than our quoted uncertainties.

We compare the 6 stars in common with GES for the cluster NGC 6705 with Cantat-Gaudin et al. (2014b) (21 stars analyzed), finding a mean offset of 0.95 ± 0.21 km s\(^{-1}\). However, comparison of individual stars agree within the quoted uncertainties.

### Table 8. Mean offsets and dispersions calculated for each author from the values in Table 6. Offsets (second column) are in the direction OCCASO-litterature, the number of stars for each paper is listed in the third column.

| Reference                        | \(\Delta v_{r} (\text{km s}^{-1})\) | \(N\) |
|----------------------------------|----------------------------------|------|
| Blanco-Cuaresma et al. (2014)   | 0.28 ± 0.09                     | 2    |
| Mermilliod et al. (2008)\(^1\)  | 0.21 ± 0.21                     | 40   |
| Valitova et al. (1990)\(^2\)    | 0.33 ± 0.39                     | 6    |
| Glushkova & Rastorguev (1991)   | 2.4 ± 1.6                       | 4    |
| Pancino et al. (2010)\(^3\)     | −0.88 ± 0.79                    | 4    |
| Cantat-Gaudin et al. (2014b)    | 0.95 ± 0.21                     | 6    |
| Mathieu et al. (1986)           | 0.24 ± 0.18                     | 14   |
| Bragaglia et al. (2001)         | −0.5 ± 2.0                      | 2    |
| Gim et al. (1998)               | 0.42 ± 0.49                     | 6    |
| Alam et al. (2015)\(^4\)       | 0.06 ± 0.34                     | 7    |
| Mészáros et al. (2013)          | −0.27 ± 0.25                    | 7    |
| Pasquini et al. (2011)          | 0.26 ± 0.36                     | 7    |
| Sakari et al. (2011)            | 0.00                            | 1    |
| Yadav et al. (2008)             | −0.05 ± 0.07                    | 3    |
| Pasquini et al. (2012)          | 0.12 ± 0.06                     | 7    |
| Milliman et al. (2014)          | 0.13 ± 0.06                     | 3    |
| Böcek Topcu et al. (2015)       | 0.4 ± 0.5                       | 7    |
| Geller et al. (2015)            | 0.4 ± 0.5                       | 5    |

\(^1\)excluded NGC 2682 W286
\(^2\)excluded IC 4756 W0081
\(^3\)excluded NGC 2682 W286
\(^4\)excluded NGC 6819 W0333

Besides, we have 7 stars in common with APOGEE DR12 (Alam et al. 2015), and 8 stars in common with APOGEE DR10 (Mészáros et al. 2013). To make an overall comparison we do not take into account the star NGC 2682 W224 and NGC 6819 W0333 for the reasons already discussed. We find a mean offset of 0.06 ± 0.34 km s\(^{-1}\) with Alam et al. (2015), and −0.27 ± 0.25 km s\(^{-1}\) with Mészáros et al. (2013).

All the computed mean differences with literature estimates are listed in Table 8. The largest offset is found for Glushkova & Rastorguev (1991) and is already commented above. The mean of the differences with the other authors is 0.2 ± 0.7 km s\(^{-1}\). This means that the accuracy with the overall literature is formally consistent with the quoted uncertainties.

### 3.5 Discussion: relation to the disc kinematics

As described in Sec. 2.1, Galactic disc kinematics is one of the science topics of OCCASO. This section is devoted to a preliminary analysis with the 12 OCs published here. A more detailed investigation will be carried out when all observations will be completed and Gaia proper motions will be available. Our analysis here is also limited by the small range of Galactocentric distances of the 12 OCs, mainly in the range 8–10 kpc. Most of the OCs studied here are located in the vicinity of the Local arm. Three of them in the Perseus arm, and only NGC 6705, is located in the Sagittarius arm (see Fig. 9).
3.5.1 Radial velocity with respect to the GSR and RSR

It is well known that the Galactocentric velocity of any source in the Galactic disc can be described using two components: (a) the velocity associated to a circular orbit around the Galactic center, constrained by the Galactocentric distance and defining the Regional Standard of Rest (RSR), and (b) an additional peculiar velocity, the velocity with respect to such RSR. The velocity with respect to RSR tells us how much the motion of the cluster differs from the Galactic disc rotation.

One can compute the velocity with respect to the Galactocentric Standard of Rest (GSR) by adding the spatial velocity of the Sun to the measured heliocentric velocity. This spatial velocity of the Sun is described in the same two components: its velocity with respect to the Local Standard of Rest (LSR), and the circular motion of the LSR. Considering only the line-of-sight component:

\[
 v_{\text{GSR}} = v_{\text{h}} + U_{\odot} \cos l \cos b + (\Theta_0 + V_{\odot}) \sin l \cos b + W_{\odot} \sin b
\]

where \( v_{\text{h}} \) is the heliocentric radial velocity, \((U_{\odot}, V_{\odot}, W_{\odot})\) are the components of the motion of the Sun with respect to the LSR, and \( \Theta_0 \) is the circular velocity at the Galactocentric distance of the Sun \( R_0 \).

The line-of-sight velocity with respect to the RSR can be computed by subtracting the circular motion of the RSR projected onto the line-of-sight:

\[
 v_{\text{RSR}} = v_{\text{GSR}} - \Theta_R R_0 \sin l \cos b
\]

where \( \Theta_R \) is the circular velocity at the Galactocentric dis-
tance of the cluster $R$. In first order approximation (enough for the $R$ of our clusters) $\Theta_R$ is computed as

$$\Theta_R = \Theta_0 + \frac{d\Theta}{dR} (R - R_0)$$

(3)

Assuming the Sun motion derived by Reid et al. (2014)\(^6\) $(U_\odot, V_\odot, W_\odot) = (10.7, 15.6, 8.9)$ km s\(^{-1}\), and their values of the Galactic rotation curve, $\Theta_0 = 240$ km s\(^{-1}\), $R_0 = 8.34$ kpc and $\Theta_{RSR} = -0.2$ km s\(^{-1}\), we derive $v_{GR}$ and $\Theta_{GR}$ for each cluster. Galactocentric distances $R$ are computed from heliocentric distances in Dias et al. (2002)\(^7\) (see Table 1). Since no error estimates are given for those distances, we adopted an uncertainty of 0.2 mag in distance modulus, rather typical when determining distances from isochrone fitting. The errors in $v_{GR}$ are computed taking into account errors in $v_\gamma$, and the motion of the Sun: $\Theta_0$, $U_\odot$, $V_\odot$, and $W_\odot$. The errors in $v_{GR}$ are computed taking into account also the errors in distance modulus.

Figure 8 presents $v_{GR}$ as a function of Galactic longitude\(^8\). The values corresponding to circular orbits at different radii have been overplotted. There is a good correlation between the Galactocentric distance of each cluster and the corresponding circular orbits, meaning that line-of-sight $v_{GR}$ are small. The obtained values of $v_{GR}$ and $v_{GR}$ are listed in Table 9. The $v_{GR}$ are in the range of $-27$ to $+24.7$ km s\(^{-1}\), typical values for the disc populations. Mean $v_{GR}$ of the eight clusters located in the Local arm is $-2$ km s\(^{-1}\) with an standard deviation of $14$ km s\(^{-1}\). Again, rather typical.

We have also computed $v_{GR}$ using different assumptions for the Galactic rotation and Sun’s location taken from Antoja et al. (2011) and Soffue et al. (2009). The mean differences of $v_{GR}$ from the different assumptions are smaller than $0.4$ km s\(^{-1}\), well within uncertainties due to the errors in radial velocity and distances. Therefore, our $v_{GR}$ do not favour one or another Galactic rotation curve or location of the Sun.

### 3.5.2 Spatial velocity with respect to RSR

Cluster line-of-sight velocities were combined with proper motions to derive full spatial velocities. To do so, mean proper motions with other values in the literature and concluded that mean differences and standard deviation were among 1.4–1.7 mas yr\(^{-1}\). We have assumed uncertainties of 1.5 mas yr\(^{-1}\) in each proper motion coordinate. The velocity with respect to RSR in a cartesian Galactocentric frame, $(U_\gamma, V_\gamma, W_\gamma)$, was computed as (more details in the derivation in Reid et al. (2014)):

$$
\begin{pmatrix}
U_\gamma \\
V_\gamma + \Theta R \\
W_\gamma
\end{pmatrix} =
\begin{pmatrix}
U_\odot \\
V_\odot + \Theta_0 \\
W_\odot
\end{pmatrix} + R_s (-\beta)
\begin{pmatrix}
R_s \\
R_g (-l)
\end{pmatrix}
\begin{pmatrix}
v_\gamma \\
D_{\mu}\cos b
\end{pmatrix}
$$

(4)

where $U_\gamma$ points towards the Galactic Center, $V_\gamma$ towards Galactic rotation, and $W_\gamma$ towards the North Galactic Pole, $R_s$ and $R_g$ are rotations of a certain angle on the $z$ and $y$

---

\(^6\) Values obtained by their model $A_5$.

\(^7\) Available at http://irsa.ipac.caltech.edu

\(^8\) OCs at $b > 15$ deg (NGC 2682 and NGC 752) are not plotted since at these latitudes the line-of-sight component of the velocity is not in the Galactic plane.
axis respectively, $\beta$ is the angle formed by Sun - Galactic Center - Cluster, $\mu_l$ and $\mu_b$ are the proper motions in the $l$, $b$ directions.

The uncertainty has been derived from classical Markov chain Montecarlo simulation with 10 000 random realizations for each cluster.

Taking the values from Table 10 we find mean values and standard deviations of $\langle U_c \rangle = -6 \pm 15 \text{ km s}^{-1}$, $\langle V_c \rangle = -9 \pm 24 \text{ km s}^{-1}$, $\langle W_c \rangle = 7 \pm 23 \text{ km s}^{-1}$. Studies of velocity dispersions as a function of age such as Holmberg et al. (2009, fig. 7) indicate that for stars of ages 0.8-2.5 Gyr we expect $\sigma U$ and $\sigma V$ between 15-25 km s$^{-1}$. So, this is well verified in our sample. There are only four OCs, NGC6705, NGC6819, NGC7762 and NGC7789, with velocities with respect to their RSR larger than about 30 km s$^{-1}$ and are the ones with the larger errors. Particularly remarkable is NGC6819 with a vertical velocity of 71.73 ± 23.10 km s$^{-1}$.

IC 4756 and NGC 6633, both in the Local arm, are located close together and have similar age and spatial non-circular velocity. Taken together, this may indicate some relationship in their formation. Better uncertainties in proper motions like the ones that Gaia will provide, and comparison of chemical abundances, (which is the main purpose of OCCASO) will clarify this issue.

Finally, in Fig. 9 we have plotted the spatial distribution of the 12 OCs in the Galactic plane. The location of the spiral arms, as derived by Reid et al. (2014), and the $(U_c, V_c)$ components for each cluster have been overplotted. High-mass star forming regions (HMSFR) studied by Reid et al. (2014) are also included. We have calculated mean values and dispersions of the HMSFR $(U_s)$, $(V_s)$, $(W_s)$ in each arm. And we have computed differences with the computed components and these mean values (see last three columns in Table 10), to see if there exists a hint of dynamical relationship between our OCs and the arms. In general, the differences fall inside the $3\sigma$ margin except for the clusters NGC 7789 (Perseus arm), NGC 7762 and NGC 6819 (Local arm), and NGC 6705 (Saggitarius arm). We do not find correlations with age, but our sample is limited in number. Again, precise proper motions of Gaia will help on the interpretation of the kinematics of the studied clusters.

4 SUMMARY

The OCCASO survey has been designed to obtain radial velocities and homogeneous abundances for more than 20 chemical species for RC stars in a sample of 25 Northern OCs with ages $\geq$0.3 Gyr. These data will allow us to properly analyze the existence of trends with $R_{GC}$, $z$ and age, in the Galactic disc. Moreover, our sample of OCs is complementary to GES-UVES observations of intermediate-age and old Southern OCs. For this reason we include OCs in common with GES to guarantee homogeneity between both surveys. At the end of both surveys, an homogeneous sample of chemical abundances for around 50 OCs will be available.

We have collected observational data from high-resolution spectroscopy during 53 nights of observation using the fiber-fed echelle spectrographs FIES and HERMES at the ORM, and CAFE at CAHA. We have done a comparison among the results from the three instruments used, obtaining a good agreement within the uncertainties.

The radial velocity analysis has been performed for 77 stars in 12 OCs. We have derived radial velocities from 401 individual exposures. With these values we have found a new possible spectroscopic binary NGC 6819 W983, which has never been identified as a multiple system. We have derived radial velocities from the combined spectra with SNR $\geq$ 70, obtaining uncertainties of $0.5 - 0.9$ km s$^{-1}$. We have used these values of the radial velocities to confirm or discard membership from our sample of stars and compute a median radial velocity for each OC. In particular, we have obtained radial velocities for OCs never studied before with high-resolution spectroscopy: NGC 1907 ($v_r = 2.3 \pm 0.5$ km s$^{-1}$), NGC 6991 ($v_r = -12.3 \pm 0.6$ km s$^{-1}$) and NGC 7762 ($v_r = -45.7 \pm 0.3$ km s$^{-1}$).

The radial velocities obtained in this paper agree with the values from previous authors within the uncertainties, except for few cases. We have compared the stars in common with other two large spectroscopic surveys: GES, 6 stars in common with an average difference of $\Delta v_r = 0.95 \pm 0.21$ km s$^{-1}$; and APOGEE, 7 stars in common with Mészáros et al. (2013, DR10) a mean difference $\Delta v_r = -0.27 \pm 0.25$ km s$^{-1}$, and 7 stars in common with Alam et al. (2015, DR12) a mean difference of $\Delta v_r = 0.06 \pm 0.34$ km s$^{-1}$.

Median radial velocities for each OC have been used to study their kinematics in relation to the disc and the spiral arms. It is shown that all of the studied clusters follow the
expected rotation of the Milky Way assuming the rotation curve derived by Reid et al. (2014).

Adding information of proper motions from Dias et al. (2002) we have derived full spatial velocities, and we have compared the non-circular velocities among them. There seems to be no clear relation of the peculiar velocities among the OCs from the same spiral arm (except for IC 4756 and NGC 6633), nor with the peculiar velocities of the high-mass star-forming regions (Reid et al. 2014) from the same arms. From our sample we calculate the dispersion in the two components of the plane velocity: $\sigma_U$ and $\sigma_V = 15$ and 24 km s$^{-1}$, which is expected for a population of ages 0.8–2.5 Gyr as seen in Holmberg et al. (2009).

**REFERENCES**

Ahadi M. G., Navarro J. F., Steinmetz M., Eke V. R., 2003, ApJ, 597, 21
Aceituno J., et al., 2013, A&A, 552, A31
Adibekyan V. Z., Sousa S. G., Santos N. C., Delgado Mena E., González Hernández J. I., Israeliam G., Mayor M., Khachatrian G., 2012, A&A, 545, A32
Ahumada A. V., Cignoni M., Bragaglia A., Donati P., Tosi M., Marconi G., 2013, MNRAS, 430, 221
Alam S., et al., 2015, preprint, (arXiv:1501.00963)
Alcaino G., 1965, Lowell Observatory Bulletin, 6, 167
Andriesvksy S. M., Lépine J. R. D., Korotin S. A., Luck R. E., Kovytyukh V. V., Maciel W. J., 2013, MNRAS, 428, 2352
Antoja T., Figueras F., Romero-Gómez M., Pichardo B., Valenzuela O., Moreno E., 2011, MNRAS, 418, 1423
Balser D. S., Rood R. T., Bania T. M., Anderson L. D., 2011, ApJ, 738, 27
Beasley M. A., San Roman L, Gallart C., Sarajedini A., Aparicio A., 2015, MNRAS, 451, 3400
Bedin L. R., Piotto G., Carraro G., King I. R., Anderson J., 2006, A&A, 460, L27
Bird J. C., Kazantzidis S., Weinberg D. H., Guedes J., Callegari S., Mayer L., Madau P., 2013, ApJ, 773, 43
Blanco-Cuaresma S., Souhrier C., Jofré P., Heiter U., 2014, A&A, 566, A98
Böcek Topcu G., Afsar M., Schautable M., Suenen C., 2015, MNRAS, 446, 3562
Bonatto C., Bica E., 2003, A&A, 405, 525
Bovy J., Rix H.-W., Hogg D. W., 2012, ApJ, 751, 131
Bragaglia A., Tosi M., 2006, A&AS, 171, 1544
Bragaglia A., et al., 2001, ApJ, 121, 327
Cantat-Gaudin T., et al., 2014a, A&A, 562, A10
Cantat-Gaudin T., et al., 2014b, A&A, 569, A17
Carlberg J. K., 2014, AJ, 147, 138
Carraro G., Villanova S., Demarque P., McSwain M. V., Piotto G., Bedin L. R., 2006, ApJ, 643, 1151
Carrera R., 2012a, A&A, 544, A109
Carrera R., 2012b, ApJ, 758, 110
Carrera R., Pancino E., 2011, A&A, 535, A30
Carrera R., Gallart C., Aparicio A., Hardy E., 2011, AJ, 142, 61
Carrera R., Casamiquela L., Ospina N., Balaguer-Núñez L., Jordi C., Monteagudo L., 2015, A&A, 578, A27
Cheng J. Y., et al., 2012, ApJ, 746, 149
Choo K. J., et al., 2003, A&A, 399, 99
Conrad C., et al., 2014, A&A, 562, A54
Cunha K., et al., 2015, ApJ, 798, L41
Daflon S., Cunha K., de La Reza R., Holtzman J., Chiappini C., 2009, AJ, 138, 1577
Dalton G., et al., 2012, in Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. p. 0, doi:10.1117/12.929505
Davenport J. R. A., Sandquist E. L., 2010, ApJ, 711, 559
De Silva G. M., et al., 2015, MNRAS, 449, 2604
Dias W. S., Alessi B. S., Moitinho A., Lépine J. R. D., 2009, AJ, 138, 1577
Dias W. S., Monteiro H., Caetano T.C., Lépine J. R. D., Assafin M., Oliveira A. F., 2014, A&A, 564, A79
Donati P., Cocozza G., Bragaglia A., Pancino E., Cantat-Gaudin T., Carrera R., Tosi M., 2015, MNRAS, 446, 1411
Eggen O. J., Lynden-Bell D., Sandage A. R., 1962, ApJ, 136, 748
Friet E. D., 1995, ARA&A, 33, 381
Friet E. D., Janes K. A., Tavarez M., Scott J., Katsanis R., Lotz J., Hong L., Miller N., 2002a, AJ, 124, 2693
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