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Report on the Workshop

Stellar Populations in Stellar Clusters and Dwarf Galaxies — New Astronomical and Astrophysical Challenges

held at ESO Vitacura, Santiago, Chile, 2–3 March 2017

Bruno Dias[1]
Ivo Saviane[1]

[1] ESO

Chile hosts many world-leading expert groups working on stellar populations and stellar clusters. This field has undergone something of a revolution during the last decade with the advent of large photometric and spectroscopic surveys, and preparations for relevant new facilities are underway. A Chilean meeting on stellar populations and star clusters was therefore timely. The goal was to bring together experts in the field for discussion and to encourage collaboration. The workshop was open to all astronomers and advanced students, especially those in Chilean institutes, limited to a maximum of 50 participants in order to foster discussion.

A significant fraction of the Chilean astronomical community is involved in the investigation of stellar populations in star clusters and dwarf galaxies, and in the last few years this research field has witnessed many developments. So in late 2016 we felt there was a need to discuss the new results in a national meeting, which took place in March this year.

Particular topics we wanted to discuss were, for example: the high-precision photometric and spectroscopic observations revealing multiple stellar generations in young and old Galactic and extragalactic massive clusters; the large surveys that are amassing impressive datasets on the Milky Way and Local Group galaxies (such as VISTA Variables in the *Via Lactea* [VVV[1]], Gaia-ESO[2], the Sloan Digital Sky Survey [SDSS], the Apache Point Observatory Galactic Evolution Experiment [APOGEE[3]], the GlObular clusTer Homogeneous Abundance Measurements survey [GOTHAM], etc.); and the associated theoretical efforts that are attempting to make sense of all this information. Observers and theoreticians are together trying to solve the puzzle of how star clusters form and evolve, and how this is connected with the history of their host galaxy.

Key questions that we wanted to address during the two days of the conference were: Are massive young clusters the prototypes of future globular clusters? What is missing in stellar evolution models, in particular concerning evolved stars, such as those in the asymptotic giant branch (AGB) and horizontal branch (HB) phases? What is the relationship between stars in clusters and dwarf galaxies, and stars in the Galactic halo and bulge? What are the fractions of Galactic clusters formed in situ and those that formed in dwarf galaxies captured by the Milky Way? What are the differences and similarities between star clusters in the Milky Way and Local Group galaxies? How can star clusters be used as tracers of the chemical and dynamical evolution history of their host galaxy? What is the best complement of instruments that is needed to answer these questions?

In order to promote focused discussions, the workshop was divided into five sessions: The Milky Way; The Magellanic Clouds; Dynamics and models; Extragalactic stellar populations; and a special session dedicated to the VVV survey. Each session was followed by a half-hour discussion where everyone had the opportunity to express their opinions and make plans for collaborations on topics triggered by the chair. The full programme can be found on the workshop webpage[4].

Some highlights from the various sessions are presented.

The Milky Way

Two sub-sessions were dedicated to this vast topic. We started with an invited talk by Patricia Tissera who discussed the chemical evolution of Milky Way-type galaxies. The results from the simulations show that the outer halo was mostly accreted, while the inner halo has a mix of histories (see for example, Scannapieco et al., 2011). The Disc was formed more recently and the Bulge was mostly formed *in situ* with a fraction accreted at high redshift. These stars contribute to the spheroidal, dispersion-dominated component while most of the stars formed *in situ* make up the bar structure. Patricia showed that a good way to disentangle populations formed *in situ* from those that have been accreted is to look at the [α/Fe] vs. [Fe/H] plot, thanks to its sensitivity to star formation efficiency (Tissera et al., in prep.).

This review was followed by a series of talks on multiple populations in globular and open clusters. The applicability of the sodium-oxygen anticorrelation as a default characteristic of Milky Way globular clusters was explored (see review by Gratton et al., 2012). Some young

Figure 1. The workshop participants, mostly from all regions in Chile with others from Argentina, Australia and Spain, photographed in the ESO Vitacura garden.

massive clusters (for example, Geisler et al., 2012; Schultheis et al., in prep.), and extragalactic clusters (Niederhofer et al., 2017; Salgado et al., in prep.) also show the anticorrelation. Dynamics and black holes were then discussed for the case of ω Centauri. To better understand the origin of multiple stellar populations, the search is on for special cases with a single stellar population. Different surveys of Milky Way populations were presented: APOGEE, GOTHAM, Gaia-ESO for spectroscopy, and Hubble Space Telescope (HST) for photometry of Bulge clusters. In particular, the GOTHAM survey has defined a new metallicity scale for Milky Way globular clusters (Dias et al., 2016a, b) and has established a non-linear calibration for Ca II triplet strength with metallicity (Vasquez et al., in prep.), essentially confirming the results of Saviane et al. (2012).

The Magellanic Clouds

The invited talk by Celeste Parisi reviewed the chemical evolution of the Magellanic Clouds. Recent studies argue in favour of a first close passage of the Clouds into the Milky Way neighbourhood, which contrasts with the classical scenario in which the Clouds are orbiting the Milky Way (for example, Besla et al., 2007; Diaz & Bekki, 2011). It is possible that the Clouds are the largest members of a group of dwarf galaxies that came into the Milky Way halo at late times. The peculiar metallicity gradients in the Clouds inspired discussion. This invited talk was followed by one on the VIsible photometric survey on SOAR star Clusters from tApii Coxi HuguA (VISCACHA) and the first results on the Small Magellanic Cloud (SMC). This survey reveals four components of star clusters, three of them related to the tidal history. All external regions present peculiar age and metallicity gradients, and each component seems to have a specific age-metallicity relation (Dias et al., 2016c).

The star formation region of 30 Doradus was discussed in the light of the findings of sequential star formation during the last two million years. The case of light element abundance variations in globular clusters was discussed with respect to Magellanic Cloud clusters, in particular for CN, CH and Na abundances (Salgado et al., in prep.). Finally, a different point of view was presented for the abundance spread in the subgiant branch, which is usually thought to explain the photometric evidence of multiple populations in clusters. The claim is that stellar variability plays an important role in this regard and the presence of multiple populations is only one of the possible interpretations (Salinas et al., 2016).

Dynamics and models

This was a short and intense session led by the invited speaker Michael Fellhauer, who stated that there is no accepted model for globular cluster formation. Models which focus on dynamics cannot explain the observations concerning the chemistry of stellar populations, as discussed above, but they certainly constrain the relation between globular clusters and dwarf galaxies, for example. He also discussed the formation of ultra-compact dwarf (UCD) galaxies, which either originated as threshed nucleated dwarfs after getting rid of dark matter (Bekki et al., 2001) or are merger products from intense starbursts forming many star clusters in a small confined area (Fellhauer & Kroupa, 2002). Dwarf spheroidal (dSph) galaxies could have formed from tidally disrupted discs, either through interactions with a major galaxy (ram-pressure and tidal stripping) or through dwarf-dwarf interactions (resonant stripping), or in isolation through merging and dissolution of star clusters inside a dark matter halo. In the first two formation scenarios, the basic building blocks in the Universe are dwarf discs, while in the last they are in fact the dSph galaxies.

There was also a talk on young stellar cluster formation and one on the possibility that gas filaments eject protostars. The effect of binaries was also addressed.

VVV

Dante Minniti discussed globular clusters in the VVV survey using data from the past six years, and announced the extension of the survey for the next few years, the VVVX ESO Public Survey (see Arnaboldi et al. p. 15). There could be thousands of young clusters and up to 100 globular clusters hidden in the infrared imaging data (Ivanov et al., 2017). Challenging Bulge clusters were analysed in a following talk, the conclusion of which was that dust must be studied in different environments. Another talk on young star clusters showed evidence of 120 $M_{\odot}$ stars in small clusters. There were also two talks on the characterisation of variable sources from within the survey.

Extragalactic populations

The last session of the two days covered globular cluster systems in other galaxies and the Milky Way neighbourhood. The first topic was addressed in the invited review by Thomas Puzia. He came back to the formation of globular clusters, offering at least three channels: *in situ* via mergers; as a leftover from stripped dwarfs; or formed in primordial dark matter halos. He showed evidence that most globular clusters are found in luminous and low-metallicity galaxies (see review by Brodie & Strader, 2006).

Galactic neighbours are increasing in number, as more than 40 new dwarfs and 20 globular clusters were discovered in the past few years (see, for example, Bechtol et al., 2015; Koposov et al., 2015). More tidal streams around globular clusters have been characterised, supporting the disruption scenario for dwarf galaxies and globular clusters in the Milky Way halo. Moreover, the effect of different star formation histories on the mass-to-light ratio was discussed. This effect directly impacts on the stellar mass estimation of dwarf galaxies.

Take-home messages

From two intense days of discussions with 50 participants, we can safely say that the meeting was rather successful, thanks to a few key factors:
– We chose a topic which is very popular among the Chilean community (and beyond);
– The short, two-day span focused the talks and discussions;

– The chairs did an excellent job of moderating the discussions and launching interesting themes at the end of each session.

While it is not possible to convey here the full range of the discussions, a few main topics emerged during the workshop:

1. Many new results about multiple stellar populations in globular clusters were presented, but there is no theoretical model that can explain all the evidence. This is in no small part due to the sheer computational power that is required to simulate physical processes from the stellar to the galactic scale, and over long time scales;
2. Spectroscopic tagging of stellar populations is becoming one of the key tools to uncover the past evolution of the Milky Way and its sub-components;
3. More and more, the spectroscopic data are delivered by large surveys (such as, VVV(X), APOGEE, Gaia-ESO, GOTHAM, etc.);
4. Surveys are revealing that we lack basic data for many Galactic components, even after decades of research efforts (such as for globular clusters). Perhaps hundreds of young clusters and globular clusters are hidden in the highly extincted regions of the Milky Way;
5. Variable stars are a powerful tool to find those hidden clusters and other structures, so many results can be expected as the detection and characterisation of variables progresses;
6. The accumulation of large spectroscopic datasets is both a blessing and a challenge for the simulations of galaxy evolution that need to reproduce them;
7. Nevertheless, simulations of Milky Way-type galaxies are reaching significant maturity, and we can expect an ever-improving match to observations in the near future;
8. Both known Milky Way streams, and the search for new ones with wide-field imaging surveys, were discussed. In agreement with recent observational results, simulations predict that outer galactic halos are mostly formed by accretion;
9. Photometric and spectroscopic surveys are helping to disentangle the complex evolution history of the Magellanic Clouds. Stellar populations from external regions (star clusters in particular) are useful tools to characterise the tidal interaction history of both galaxies.

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Links

[1] Variables in the *Via Lactea* survey: https://vvvsurvey.org/
[2] Gaia-ESO survey: https://www.gaia-eso.eu/
[3] SDSS APOGEE survey: http://www.sdss3.org/surveys/apogee.php
[4] Workshop web pages: http://www.eso.org/CG2017

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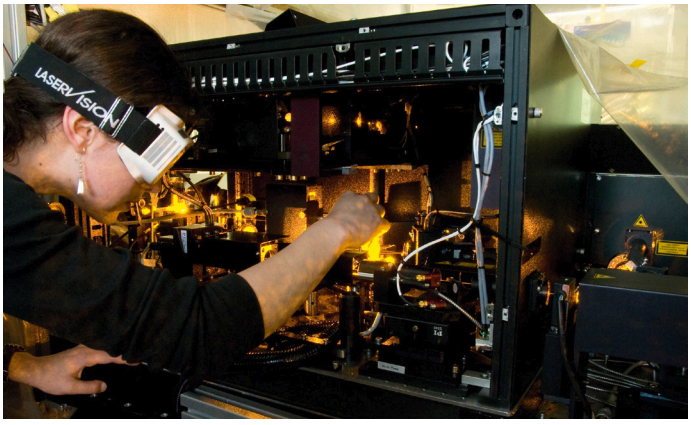

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