Report on the Workshop

Resolved and Unresolved Stellar PopUlaTIoNs (RASPUTIN)

held at ESO Headquarters, Garching, Germany, 13–17 October 2014

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The workshop aimed at sharing and discussing observations and diagnostics, together with models and simulations, of the resolved and unresolved stellar populations in galaxies from the Milky Way to the distant Universe. Special attention was paid to recent results concerning galaxy formation and evolution, fostering the exchange of ideas and techniques in dealing with nearby stellar populations. There will be no published proceedings, but presentations are available for download from the workshop web page (www.eso.org/sci/meetings/2014/rasputin2014).

Stellar populations are among the most important observables required to constrain galaxy formation and evolution. Quantitative analyses of the stellar content of stellar systems pave the way to converting the information carried by starlight into physical quantities, such as stellar masses, chemical abundances and star formation rates, and to trace back in time the evolution and chemical enrichment history of galaxies.

Historically, stellar population studies have followed two parallel paths. Observations and analyses of individual stars belonging to **resolved** stellar populations have enabled us to understand the fundamental physics of stellar evolution, through a detailed comparison between theory (isochrones, luminosity functions) and observations (photometry, spectroscopy); a path that has also allowed us to reconstruct the star formation history of the Milky Way and nearby Local Group galaxies. Secondly, knowledge of the evolutionary properties of nearby stellar populations has, in turn, helped to constrain the nature of **unresolved** stellar populations and galaxy evolution back to the dawn of time.

Strangely enough, despite their tight connection, the resolved and the unresolved approaches have made progress almost independently, with a marginal overlap between the two communities. We felt that the time was ripe for a new synergy between these two communities. The advent of the latest generation of ground- and space-based telescopes has had a profound impact on the field of stellar populations. For instance, multiple populations have been recently observed in globular clusters, which used to be considered as the template for simple stellar populations (same age, same chemical composition). On the other hand, secondary kinematic features have been recently discovered in nearby dwarf spheroidal galaxies, which used to be considered relaxed stellar systems, indicating that they experienced multiple star formation events with no evidence of rotation.

Moreover, the wealth of information on the metallicity (α-, *r*- and *s*-elements, CNO) and kinematics of thousands of stars in the Milky Way are enabling us to compare our own Galaxy with external systems, thus providing a unique opportunity for understanding the mechanisms of galaxy evolution. Finally, unresolved studies of nearby and high-redshift objects can now provide unprecedented constraints on resolved stellar population studies, as clearly indicated by the recent claims of a non-universal initial mass function (IMF) in external galaxies.

Thus, with the era of the Extremely Large Telescopes (ELTs) approaching, it is more important than ever to ensure that both resolved and unresolved stellar population studies share similar ingredients, compare and validate homogeneously their specific tools. The workshop was therefore organised with the goal of reviewing the state of the art in both fields, as well as in the framework of future ELT facilities, and to foster synergies between the two stellar communities.

More than a hundred participants from Europe, North and South America and Asia gathered for the RASPUTIN meeting held at ESO Headquarters. The five-day workshop featured 63 talks, 18 of which were invited reviews, and two panel discussions. Additionally, on the second and the fourth days of the meeting, we held poster pop-up sessions, giving a chance to those who had applied for a poster to present their most important results in five minutes (37 poster presentations). The formula was broadly appreciated, and it fostered very lively discussions, both among the younger and the more senior researchers.

Science sessions

Forty-five contributed talks were selected by the Scientific Organising Committee (SOC), out of a pool of nearly a hundred proposals received during workshop registration. The selected talks, as well as the invited reviews, covered quite large research areas, from star formation in the nearby Universe, stellar populations (observations and theory) in the Galaxy and in the Local Universe, to stellar populations in late-type galaxies and into the European Extremely Large Telescope (E-ELT) era. In order to promote and develop new collaborations, the exchange of ideas and plans between the two communities, the talks in the different sessions were intentionally mixed, rather than scheduled according to their research topic.

In the following paragraphs, we only mention the content of relatively few contributions. The summary mirrors our opinions and attitudes. We urge the reader to check the remaining presentations posted on the web page of the meeting[1].

A review talk on the Galactic Bulge (by M. Zoccali) summarised the latest results in this field. A very complex picture is emerging of its stellar populations from detailed spectroscopic and photometric observation. The Bulge of the Milky Way is a boxy/peanut structure, traced by red clump stars. However, several independent observations suggest the presence of two stellar components: the oldest ($\gtrsim$ 10 Gyr) and metal-poor component, traced by RR Lyrae stars, is a spheroidal component; whereas the younger (8–10 Gyr) metal-rich component, traced by red clump stars, is a boxy/peanut bar. The presence of a significantly younger component (1–6 Gyr), as suggested by the spectroscopic campaign of microlensed dwarfs, is still an open question. The presence in the outer Bulge of a metallicity gradient

following the boxy/peanut structure, but with lack of significant evidence for this metallicity gradient in the inner Bulge, represents a real challenge for dynamical models.

Additional results on the Galactic Bulge stellar population were presented in several other talks, such as the first detection of the white dwarf cooling sequence (A. Calamida), the largest photometric infrared database collected through the ESO Public Survey VISTA Variables in the *Via Lactea* (VVV; talk by D. Minniti), and the cylindrical rotation confirmed by the recent spectroscopic survey — the GIRAFFE Inner Bulge Survey (GIBS: presentation by E. Valenti).

Preliminary results of the Gaia–ESO survey on the iron and α-element distribution across the Galactic spheroid (Halo, thick and thin Disc) were also widely discussed. In particular the role which the different approaches to data reduction and analysis play in constraining the systematics affecting individual abundance measurements, was discussed. Interestingly enough, we also discussed the role which the sociology of large collaborations plays in planning and running large surveys (G. Gilmore).

The properties of the stellar component in the innermost Galactic region (within ~ 300 pc of the Centre) were reviewed by N. Matsunaga, using variable stars, in particular Cepheids, as tracers. In this context, infrared spectra represent a unique diagnostic for studying the kinematics and chemical content of this hidden population in the Galaxy. Since they are good distance indicators and tracers of old and young populations, different types of variables stars can be used to construct 3D maps and the star formation history of various Galactic structures. As a tracer of old stellar populations, RR Lyrae variables have also been used to explore and discuss the role of ultra-faint dwarf spheroidal galaxies in the formation of the Galactic Halo (G. Fiorentino). The comparison of RR Lyrae properties in the Halo and in dwarf galaxies suggests that — under very extreme assumptions — no more than 50 % of the Halo population can be made from dwarfs. Additionally, it has been suggested that high-amplitude, short-

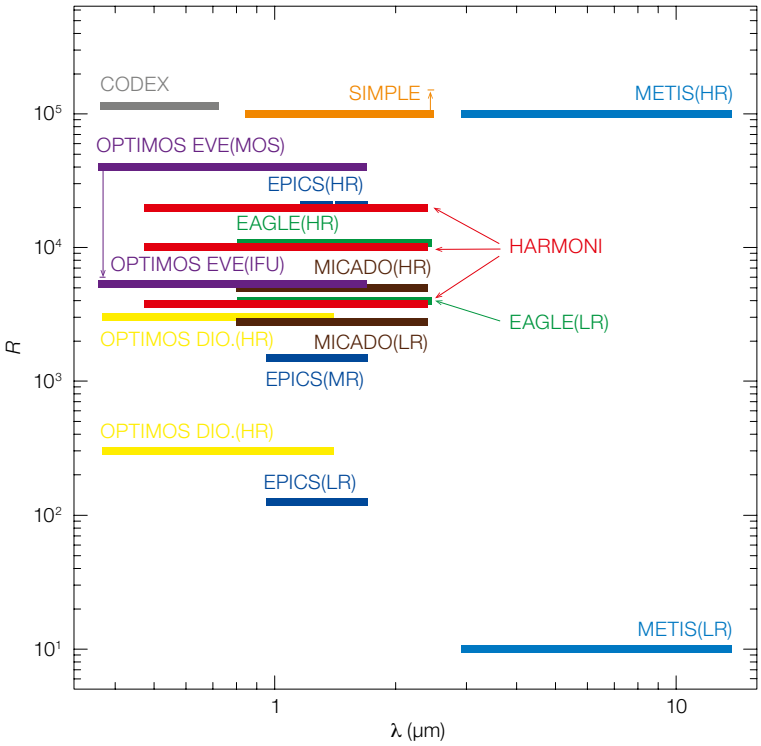

Figure 1. Spectral resolution and wavelength coverage of the proposed/planned new instrumentation at E-ELT.

period, fundamental RR Lyrae stars could represent a powerful tool with which to constrain the metallicity of the old stellar population in much more distant galaxies.

Finally, a nice example of the tight interplay between the study of resolved and unresolved stellar populations was shown by E. D’Alessandro’s results on the ultraviolet colours of Galactic and extragalactic globular clusters. He presented a new approach to the analysis of the horizontal branch (HB) stars in globular clusters, based on a detailed comparison between the observed and synthetic HB, which takes into account the strong impact of the He content in shaping the HB of old stellar populations. By using a combination of Hubble Space Telescope (HST) ultraviolet (UV) and the GALaxy Evolution eXplorer (GALEX) data, they have observed a general correlation between the UV colours of globular clusters and the mass of the host galaxies: the UV colours of the globulars get bluer with increasing host galaxy mass.

There were extensive reviews of the different aspects of the spectroscopic diagnostics of giants and supergiants, including advances of atomic data, model atmospheres and synthetic spectra, as well as their consequences for the science of Galactic and extragalactic observations. In particular, the impact which non-local thermodynamic equilibrium effects have in providing precise heavy element abundances was discussed (M. Bergemann). We also discussed the potential of the planned instruments at the E-ELT (see Figure 1) to provide different stellar information with a new generations of models, such as the quality of chemical abundances in stars.

The metallicity of red supergiants can be obtained from quantitative spectroscopy down to a resolution of ~ 3000 in the *J*-band, where several α-elements (Ti, Mg, Si) and Fe lines can be used for abundance analysis (see Figure 2). Red supergiants, the brightest stars at infrared wavelengths, are therefore the ideal targets for measuring the metallicity of star-forming galaxies out to 7–10 Mpc and up to ten times further by observing the integrated light of unresolved super star-clusters. By using the *K*-band Multi

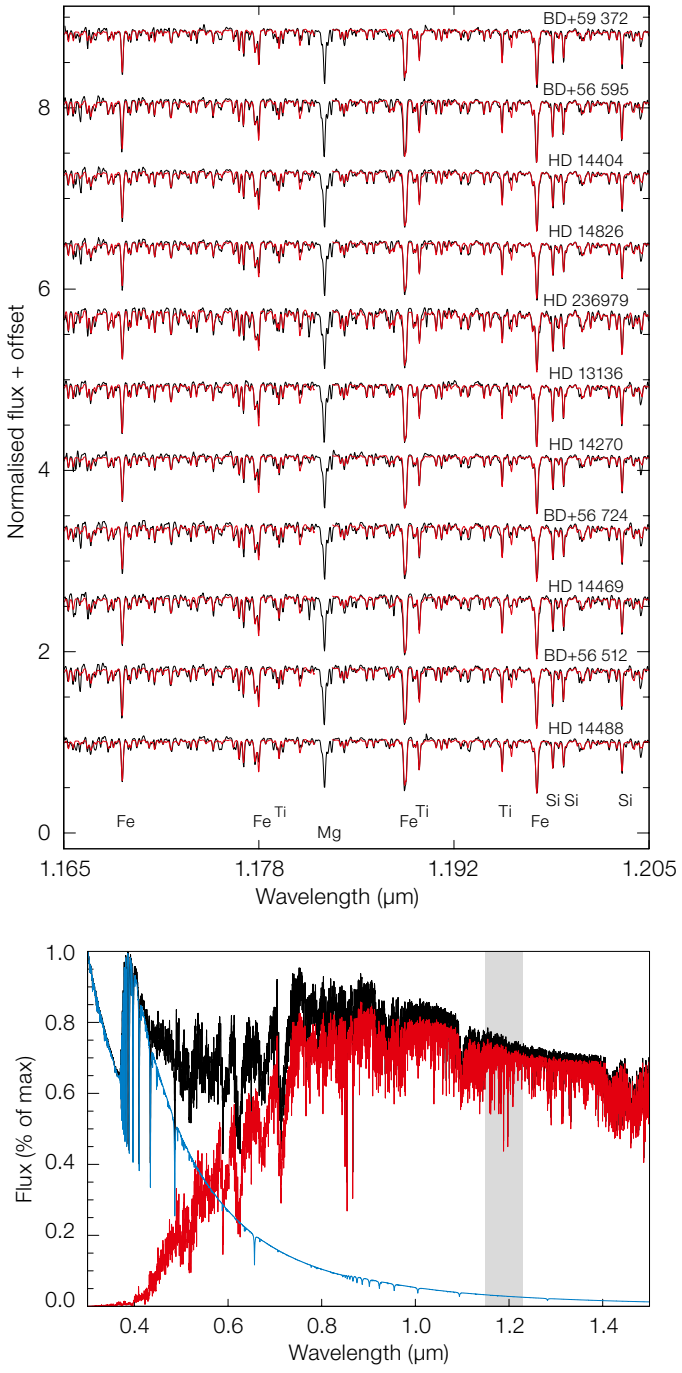

Figure 2. Upper: Spectral library of red supergiants observed at high resolution and then degraded to R = 3000. The main diagnostic atomic lines are labelled. Red lines refer to the best fitting non-local thermodynamic equilibrium models (Gazak et al., 2014a).

Lower: Theoretical spectra for a $10^5\ M_\odot$ super star-cluster after 15 Myr. The spectrum representing the full super star-cluster spectral energy distribution is shown in black, the main sequence and blue supergiants stars in blue, and the flux due to red supergiant members is plotted in red. The grey shaded region represents the J-band (Gazak et al., 2014b).

Object Spectrograph (KMOS) at the Very Large Telescope (VLT) with only a modest amount of time, it is now possible to probe the cosmic chemical evolution in a substantial volume of the local Universe containing hundreds of star-forming galaxies, with the ultimate goal of providing a robust measurement of the mass–metallicity relation for low-redshift galaxies (B. Davies). Low-resolution multi-object optical spectroscopy of individual blue supergiants can also be used in order to constrain the metallicity content in galaxies out to a distance of 8 Mpc, as shown by R. P. Kudritzki.

M. Monelli introduced the astrophysical and cosmological role of nearby dwarf galaxies. The presentation focussed on star formation history in early, late and transition dwarf galaxies in the nearby Universe and their correlation with the total mass. The role which accurate and deep colour–magnitude diagrams play in constraining the age and metallicity distribution of the different populations was also discussed, together with detailed elemental abundances (talks by K. Venn and M. Fabrizio).

Recent developments and findings concerning chemo-dynamical models were broadly reviewed by I. Minchev, with particular emphasis on the role played by stellar migrations and chemo-kinematic relations in constraining disc formation models. The theoretical framework for modelling galaxies, both from the analytical and numerical point of view, was thoroughly presented by J. Binney and L. Mayer. The discussion was focussed on the dynamical modelling of the different galactic components, as well as on the cosmological simulations of isolated dwarf galaxies. Special attention was paid to the implications of core formation on the early evolution of dwarf spheroidals.

Panel discussions

During the first and the third day of the meeting, we had two panel discussions, respectively focussed on Theory and Simulations (chair: R. P. Kudritzki), and Observations and Synergies between VLT and E-ELT (chairs: B. Leibundgut and J. Liske).

The panel discussion on theory and observations was considered a good chance to discuss future developments in the ongoing effort to improve the predictive power of simulations and models currently available in the literature. The discussion touched on several pending issues in the current theoretical framework. In particular, we discussed the limits in microphysics (molecular opacities, gravitational settling, radiative levitation) and in macrophysics (turbulent mixing, mass loss) affecting stellar interior models (M. Salaris, S. degl'Innocenti, P. G. Prada Moroni). We also considered the present limitations of the stellar atmospheric models, e.g., the impact that non-local thermodynamic equilibrium effects have on heavy element abundances

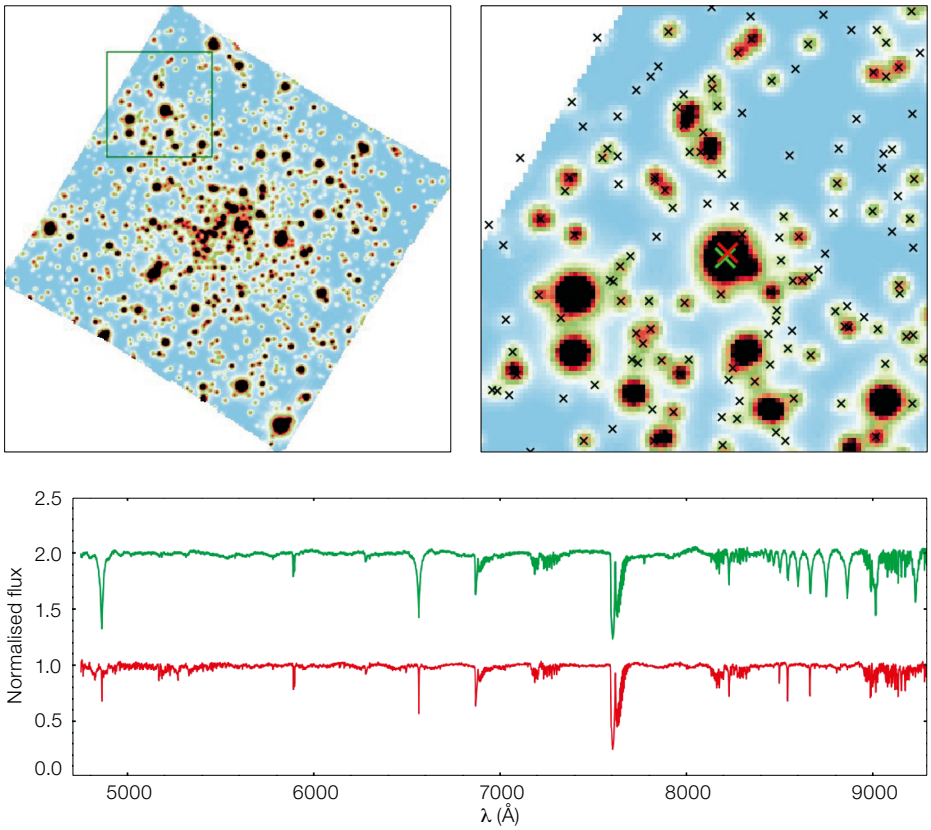

Figure 3. Observations of the central 1 by 1 arcminute region of the globular cluster NGC 6397 taken with MUSE (upper left panel); the area within the green box is shown enlarged in the upper right panel. The spectra of the two blended stars marked with red and green crosses in the upper right panel were successfully extracted using the new algorithm PampelMuse (Kamann et al., 2013). The algorithm has been specifically designed to optimise the deblending and extraction of spectra in very crowded fields by applying point spread function fitting techniques to integral field unit data.

(M. Bergemann). Moreover, we had a thorough discussion about the current limitations in handling molecular opacities (F. Alard), and its impact on late-type stars.

Furthermore, a wide-ranging debate was also devoted to optical and near-infrared (NIR) spectroscopy, and in particular, to the accuracy and precision of CNO, α-, *s*- and *r*-element abundances in the two different regimes (B. Davies, L. Origlia). The discussion concentrated also on the pros and cons of integrated spectroscopy when dealing with abundances of specific elements (Na, Mg, Fe). Participants stressed the key role that new algorithms, using synthetic and spectral libraries, are playing in modelling integrated spectra (R. Schiavon). The same outcome applies to chemo-dynamical models (I Minchev, S. de Riijcke) and to cosmological simulations (L. Mayer).

The panel discussion on observations and synergies between the VLT and the E-ELT touched on many topics. B. Leibundgut introduced the current status and the near future developments of the instrumentation available at the VLT, while J. Liske talked about the first generation of instruments planned for the E-ELT. These introductions were considered as a preamble to a discussion about the instrumentation (imaging and spectroscopy) — either available or planned — for the VLT and the E-ELT. The debate focussed on the instrumentation that is paving the road for the E-ELT. Contributors stressed the key role that low (KMOS), intermediate (X-shooter) and high spectral resolution (CRIRES) spectrographs are playing, with regard to the spectrographs planned for the E-ELT (integral field spectrograph [E-ELT-IFS], high resolution spectrograph [E-ELT-HIRES] and multi-object spectrograph [E-ELT-MOS]). The same considerations apply to NIR imaging instruments (HAWK-I and ERIS) with regard to the NIR camera for the E-ELT (MICADO).

The outcome of the discussion was that the instrumentation currently available at the VLT is much more than a stepping stone to the future. The treatment of data collected with integral field spectrographs does require new insight, not only for the quantity of spectra we are dealing with, but mainly for the algorithms adopted to perform the accurate astrometry and optimal spectral extraction of individual sources — even in very crowded environments (S. Kamann, see Figure 3). Indeed, these instruments play a strategic role, since they provide a suitable playground for training the ESO community. It was also mentioned that the currently available wide-field imagers and optical surveys might not cover the entire parameter space of the target selection for E-ELT (J. Cepa). Finally, there was a thorough analysis of the crucial role that the module(s) of adaptive optics will play for the first-light instruments (M. Tosi).

Acknowledgements

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References

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Links

[1] Workshop web page with contributions: http://http://www.eso.org/sci/meetings/2014/raputin2014/program.html