spend additional time on writing a separate conference paper. With this Zenodo solution, presentation slides and posters presented at conferences are preserved and made available to the community promptly, in a professional way, and are available for reuse and redistribution by other researchers.

References

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Links

1 Scanned versions of selected volumes of ESO Conference and Workshop Proceedings are accessible through the ESO Library catalogue: https://eso.koha-ptfs.eu/cgi-bin/koha/opac-search.pl?q=ccl=se%2Cphr%3A%22ESO%20Conference%20and%20Workshop%20Proceedings%22&offset=0&sort_by=pubdate_dsc
2 Papers published in ESO Conference and Workshop Proceedings are available at the NASA ADS: http://adsabs.harvard.edu/cgi-bin/nph-abs_connect?sort=BIBCODE&bibstem=ESOC
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Report on the ESO Workshop

A Revolution in Stellar Physics with Gaia and Large Surveys

held at the Warsaw University Library, Warsaw, Poland, 3–7 September 2018

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The exquisite astrometry and photometry of ESA's Gaia satellite combined with data from other large photometric, spectroscopic, and asteroseismic stellar surveys are enabling a revolution in our understanding of stellar physics. The goal of this workshop was to bring together a diverse community working on or making use of various aspects of stellar physics. The discussions covered both recent advances in the field and expectations for when new data and surveys become available.

Taking place a few months after the second data release (DR2) of Gaia, the workshop was ideally timed to allow the presentation of the first results to come out from those data. The topics covered included both theory and observations of: low- and high-mass stars; evolutionary stages ranging from the pre-main sequence to white dwarfs and black holes; stellar ages; stellar clusters; and stellar populations.

This workshop was co-organised by ESO and the Nicolaus Copernicus Astronomical Center, a research institute of the Polish Academy of Sciences. Poland became the 15th ESO member state in mid-2015. Hosting the workshop in Warsaw facilitated and encouraged the participation of the local community, helping to strengthen the links between Polish astronomers and the wider ESO community — of the 117 participants, 21 had Polish affiliation. The programme comprised 16 invited talks, 43 contributed talks and 40 posters. Details of the programme can be found via the workshop webpage[1]. Each talk was followed by a five-minute session dedicated to questions and discussions. It was very pleasing to note that the level of participation during these sessions was very high and that the number of questions was certainly above average. Poster viewing took place during all coffee breaks and was particularly encouraged during one dedicated long break of 50 minutes.

Setting the stage for the rest of the week, the first talk of the workshop was a review of Gaia DR2 by Elena Pancino. The talk highlighted the impressive numbers associated with Gaia, which includes positions and *G* magnitudes for more than 1.6×10^9 stars, astrometry and colours for more than 1.3×10^9 stars, radial velocities for more than 7×10^6 stars, and effective temperatures for more than 160×10^6 stars. At the faint end ($G > 14$ magnitudes), the astrometry of Gaia DR2 already reached the expected performance for the end of mission. The uncertainties and caveats associated with the released data were also discussed, stressing the need for users of Gaia data to familiarise themselves with the DR2 publications and documentation.

Stellar physics and models

Three invited talks reviewed the state-of-the-art stellar models, one focussing on low-mass stars, another on high-mass

Figure 1. Workshop participants on the steps inside the impressive Warsaw University Library.

stars, and the third on internal transport processes. Low-mass stellar models have many difficulties in accurately describing the pre-main sequence phase and the reasons are not entirely clear. Magnetic fields, starspots, problems with the description of convection and/or problems in the opacities all might play a role, and getting masses for more eclipsing binaries would help to disentangle these effects. For high-mass stellar models before the supernova stage, the main physical uncertainties include core overshooting, rotation, mass loss, and semi-convection. Mechanisms that transport chemicals inside stars, such as atomic diffusion, rotation, and thermoline mixing were also discussed, with particular emphasis on the impact of these processes on surface abundances used to study stellar populations.

The contributed talks in this session included the presentation of a new set of evolutionary tracks and isochrones from the PAdova and TRieste Stellar Evolution Code (PARSEC), computed with a new convective overshooting calibration which improves the position of the red giant branch bump in 47 Tuc. New empirical relations for the estimation of stellar masses and radii were presented. The relations which have a precision and accuracy better than 10%, were derived using data from asteroseismology, eclipsing binaries and interferometry. Another talk described an effort to improve the modelling of core-helium-burning stars combining different types of observational data with modern fluid-dynamics simulations in 3D. An effort to use eclipsing binaries to provide an improved calibration of convective overshooting, one of the major weaknesses in stellar models, was also presented.

From star formation to the main sequence

An invited talk summarised the impact of Gaia in the studies of star formation and pre-main sequence stars. Gaia data for stars in young clusters help to define cluster membership, to probe the internal kinematics of several clusters (revealing that some are expanding), and to study stellar and circumstellar properties. This is providing new insights into how star formation takes place and the evolution of discs and angular momentum in young stellar systems, as well as identification of eclipsing binaries in the Upper Sco star-forming cluster.

Contributed talks included a study of intermediate-mass pre-main sequence stars combining Gaia DR2 data with infrared photometry and spectroscopy. The differences in variability seen in Herbig Ae and Herbig Be systems suggest that the discs surrounding these stars have different properties. A series of contributions showed work that combines Gaia data with other photometric and spectroscopic surveys to study populations down to M stars for several star-forming regions, moving groups, and young open clusters. A careful analysis of the chemical composition of stars in the Pleiades suggests that inhomogeneities at the 0.04 dex level are present. It was suggested that these chemical differences might be related to planetary material being engulfed.

Post-main sequence evolution

One invited talk covered the asymptotic giant branch (AGB) and post-AGB phases of low- and intermediate-mass stars. Besides the complexities typical of these stages (for example, thermal pulses and envelope ejection), the models inherit the uncertainties from the earlier phases (regarding, for example, rotation, deep mixing and magnetic fields). Gaia itself has had little impact on these stars so far,

but the Atacama Large Millimeter/submillimeter Array (ALMA) has been particularly important in unveiling their circumstellar environments.

Another invited talk covered the white dwarf stage. Important progress in this field came with SDSS but Gaia DR2 has now increased the sample of known white dwarfs. White dwarf main sequence binary systems are particularly valuable as the age can be derived from the white dwarf while metallicity can be measured in the MS star companion. Some of these objects show signs of accretion of planetary material in their atmospheres, opening a window to studying the chemical composition of this material. Objects that might have survived a SNIa explosion have also been identified, giving some unique insight into these rare events. Future massive spectroscopic surveys will play an important role in advancing the field.

Contributed talks included: the report of 300 new red-clump Li-rich giants identified from spectra obtained with the Large sky Area Multi-Object fibre Spectroscopic Telescope (LAMOST); a chemical analysis of intrinsic and extrinsic S-type stars with precise positions in the Hertzsprung Russell (HR) diagram thanks to Gaia parallaxes; the presentation of a new catalogue of ~ 260 000 high-confidence white dwarfs identified with Gaia data; and the search for stellar-mass black holes using microlensing with OGLE and Gaia data. Recent progress in understanding the nature of sub-dwarf A-type stars was also presented. Some of these objects seem to be old, metal-poor halo objects, others are extremely low mass white dwarfs, but the nature of many of these objects remains a mystery.

Surveys and techniques

An invited talk reviewed the power of asteroseismology in probing stellar physics, highlighting important results such as the discovery of constant core rotation in red giants. Synergies between Gaia and asteroseismology were discussed and the need for interferometry to provide accurate stellar temperatures was stressed. This will bring further progress not only in the study of stellar physics but also in the field of exoplanets. Another invited talk highlighted the opportunities that stem from combining photometric surveys with Gaia data. They include the unveiling of new physics using calibrated colour-magnitude diagrams (CMD) for large stellar samples and time domain studies, which are important, for example, for the understanding of the evolution of stellar rotation. The Large Synoptic Survey Telescope (LSST) will expand these opportunities in the future.

On the spectroscopic side, one invited talk presented a summary of three high-resolution large surveys: the Apache Point Observatory Galactic Evolution Experiment (APOGEE); Gaia-ESO; and Galactic Archaeology with HERMES (GALAH). Surveys such as these are providing chemical abundances that are important data for stellar physics studies. Another invited talk discussed recent progress in modelling stellar photospheres, which are important tools for the determination of chemical abundances. Results based on 3D non-local thermodynamic equilibrium (NLTE) models suggest changes in abundances that might significantly impact our understanding of stellar physics and stellar populations.

Contributed talks included a study of the rotation curve of the Milky Way and the description of a search for extremely metal-poor stars with the Pristine photometric survey and Gaia. Follow-up spectroscopy has revealed a high efficiency in identifying stars with [Fe/H] < –3.0 dex. Such stars offer an opportunity to study early star formation and the first supernovae. Another talk presented a study of spectroscopic and astrometric radial velocities (RVs) using stars in the Hyades. The study demonstrates that spectroscopic RVs with accuracy of 20–30 m s^{-1} are possible. Moreover, the internal velocity dispersion of the cluster, the rotation gradient and the gravitational redshift have been determined.

Binaries and multiple stars

An invited talk reviewed the evolution of stellar binaries and triples, focusing on the comparison between observed properties and models that take into account stellar interaction. Unstable mass transfer in common-envelope evolution is an important source of uncertainties in binary evolution. Gaia will be important in extending the size of the samples available for study. It was stressed that the evolution of stars in triple systems enhances the occurrence rate of mass transfer, the merger rate of compact objects, and the formation of compact binaries.

One contributed talk discussed cataclysmic variables and how Gaia is helping to constrain the surface gravity of the white dwarf companions and their space density. Another talk discussed the discrepancy between evolutionary, spectroscopic, and dynamical mass estimates, stressing the need to combine multiple observables in solving the problem. A discussion of the properties of short-period binaries identified in the GALAH survey was also presented.

Another talk presented a study of binary disruption that shows that, in most cases, the ejected star moves slowly. The observed runaway fraction of O-type stars exceeds by a factor of 10 that predicted by models. On a similar topic, another talk discussed how Gaia is helping to exclude and select between the likely ejection mechanisms that can explain the presence of hypervelocity stars. The detection of spectroscopic binaries in the Gaia-ESO Survey was also presented, confirming that the frequency of single-lined binaries (SB1) decreases with metallicity and that the frequency of both single- and double-lined binaries (SB2) increases with spectral type. Hot subdwarfs were discussed in another talk, a field where Gaia is helping with the identification of large volume-limited samples and with parallaxes to constrain the stellar masses.

Stellar variability

One invited talk highlighted the impact of Gaia on variability studies. Gaia is repeatedly scanning the sky over many years and providing nearly simultaneous photometry and spectroscopy for all the different types of variable stars. With Gaia data it is possible to position these stars accurately in the HR diagram and to

add to that the time axis, allowing the observation of how the pulsating stars move in the diagram through their variability cycles.

Another invited talk described mainly the results of the Optical Gravitational Lensing Experiment (OGLE), a time domain survey aiming to identify microlensing events that also provides light curves for billion of stars. Amongst other achievements, OGLE has discovered extrasolar planets and new types of variables like blue large-amplitude pulsators. The observed fields include the Galactic disc and bulge as well as the Magellanic Clouds. Other surveys like the All Sky Automated Survey (ASAS), BRIght Target Explorer (BRITE), Solaris and Pi of the Sky were also mentioned.

A series of contributed talks discussed Cepheids. Discussions included the use of Cepheids as standard candles, their use in constraining models of the evolution of intermediate-mass stars, and how measuring masses of Cepheids in binary systems is important to constrain period-mass-radius relations. Another contributed talk described the use of Cepheids and RR Lyrae observed with OGLE to study the structure of the Magellanic Clouds. These stellar tracers suggest no evident connection between the clouds. A discussion of dynamical phenomena in RR Lyrae using K2 light curves was also presented, revealing how Gaia DR2 has enabled the discovery of many more RR Lyrae systems in the original Kepler field. Another talk presented the combination of the ASAS-SN photometric survey with APOGEE spectroscopy to study variable stars.

Stellar ages

An invited talk described the determination of stellar ages using stellar models and colour-magnitude diagrams from Gaia. General applications to pre-main sequence stars, open clusters, and single stars were also discussed and the need to use robust statistical techniques was highlighted. Models do not always fit the observations, which emphasises that there is missing physics in the models, particularly for M stars. A lack of metallicity and extinction measurements can also limit the accuracy of the results themselves, particularly in star forming regions.

Contributed talks included a report on the determination of ages for the Gaia benchmark stars, a series of stars used as references for Gaia and many spectroscopic surveys. Gyrochronology was discussed in another talk where new models that take into account magnetism and stellar winds were described. The lack of — and need for — information on slowly rotating old M stars was highlighted. Gaia is providing crucial data on cluster membership, masses, absolute magnitudes, and rotation periods that are going to help gyrochronology to improve the accuracy of stellar age estimates.

The use of chemical abundance ratios as stellar clocks was discussed in one talk. A Bayesian tool called the Unified tool to estimate Distances, Ages and Masses (of stars) (UniDAM) was the topic of another talk. This tool has been used to provide ages for about 5.5×10^6 stars observed by many spectroscopic surveys. One talk presented the combined use of Gaia and LAMOST to derive ages to be used in studies of Galactic archaeology.

Stellar populations

An invited talk discussed the needs of Galactic archaeology in terms of reliable ages, which are needed to complement information on chemistry, masses, and evolutionary stages coming from spectroscopic and asteroseismic surveys. It was stressed that, for giants in particular, isochrone fitting is the main way to obtain ages but that models suffer from key uncertainties. Significant improvements are coming from the study of the secondary red clump in clusters, as well as double-lined eclipsing binaries, and from asteroseismic data.

Galactic archaeology using spectroscopic surveys like APOGEE, the Gaia-ESO Public Spectroscopic Survey and GALAH, were discussed in a series of talks, also including smaller samples of stars. The topics covered the understanding of the disc populations, radial and vertical gradients, and the evolution of metallicity and other chemical abundances with time. The use of Gaia parallaxes to improve spectroscopic analysis in the context of the GALAH survey was discussed in another talk. The last talk discussed Galactic chemical evolution models and their comparison with abundances from the APOGEE and the AMBRE project.

Several themes recurred throughout the workshop, including the need to combine several types of data to uncover the limitations of current stellar models. The requirement for higher quality chemical abundances from spectroscopic surveys was also stressed many times. The community is working hard to use the data that are currently available but it is also looking forward to future Gaia data releases, new missions like NASA's Transiting Exoplanet Survey Satellite (TESS) and LSST, and new massive spectroscopic surveys like the 4-metre Multi-Object Spectrograph Telescope (4MOST) and the WHT Enhanced Area Velocity Explorer (WEAVE). It is an exciting era for studies of stellar physics, and many participants already expressed the wish to meet again for a similar workshop after the release of Gaia DR3.

Demographics

The gender balance among the speakers reflected the 1:3 (female:male) distribution of the participants, though the SOC had a corresponding ratio of 4:7 (female: male). The speakers constituted a mix of early career researchers (students and postdocs) as well as more senior staff.

Acknowledgements

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Links

[1] The workshop webpage includes links to the presentations that speakers have uploaded: https://indico.camk.edu.pl/e/revolution