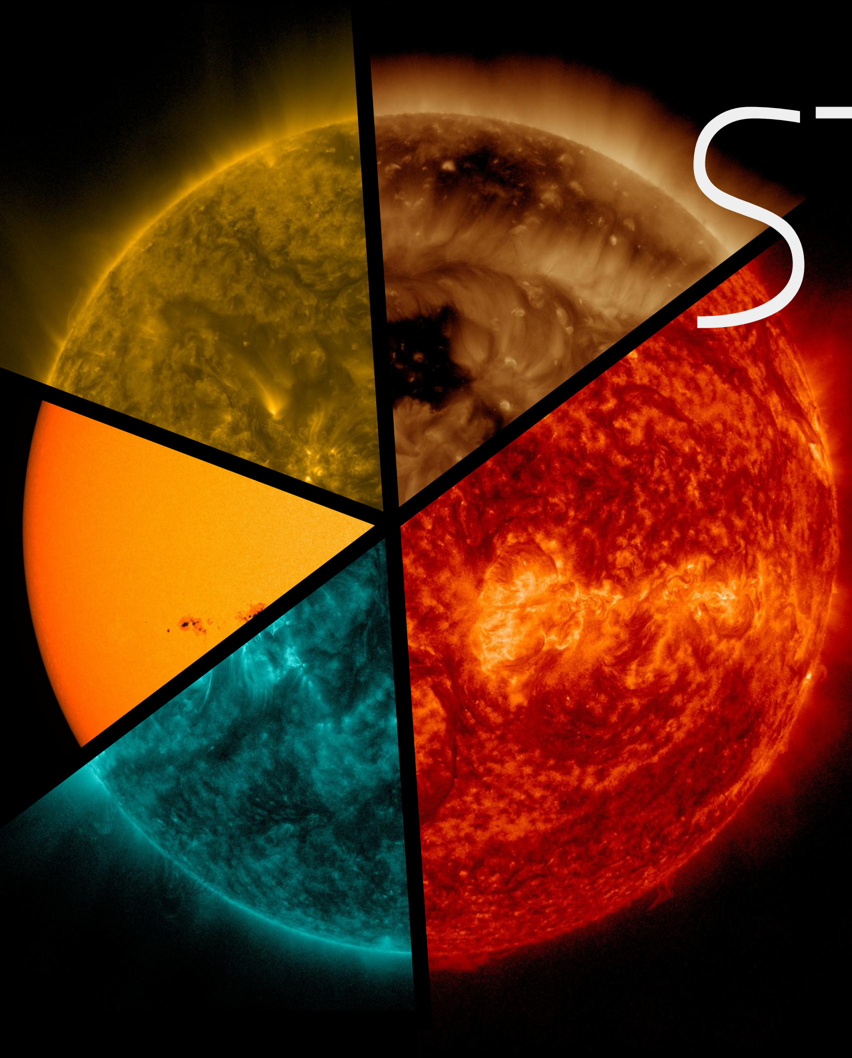

STARS II

current challenges, upcoming solutions

JUNE 16-20, 2025

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Book of Abstracts

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Session: Chemistry of Resolved Stellar Populations

Monday 16th June

Cartography of the Galaxy: an overview of upcoming Stellar Surveys - Invited talk

Sara Lucatello
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Session: Chemistry of resolved stellar populations

The Ba puzzle, an (un-)solved puzzle

Martina Baratella
European Southern Observatory, Chile

In recent years, the spectroscopic analysis of stars in Galactic open clusters showed a peculiar behaviour regarding the slow neutron capture processes. Clusters younger than 200 Myr display an unexpected over-abundance of Ba, reaching values up to $\sim$0.7 dex over solar at 30 Myr. Instead, regarding the other s-process elements, there is a general disagreement in the literature. Some authors claim that La and Ce, in particular, are found solar at all ages, while others instead claim they show a slight increase in abundance with age. This anomalous time evolution of the s-process elements is called the Ba puzzle. In this talk, I will present the latest results revealed by the spectroscopic analysis of FGK dwarf stars belonging to six open clusters observed within the Gaia-ESO large spectroscopic survey. From our deep investigation we found that stellar activity (more intense at these ages) might be responsible for the Ba enrichment. Nevertheless, the hypothesis of a nucleosynthesis origin (activation of the intermediate process) cannot be discarded, yet.

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Session: Chemistry of resolved stellar populations

High-resolution spectroscopy of metal-poor stars in the Small Magellanic Cloud

Lorenzo Santarelli
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Metal-poor stars are the oldest objects populating the local Universe and they offer a unique per- spective to explore early star formation and stellar nucleosynthesis in different galaxies. However, our knowledge of the early stages of chemical enrichment of the Magellanic Clouds, the closest Milky Way satellites, is still incomplete. In the talk I will discuss the results of the chemical analysis of seven metal-poor ([Fe/H] $\sim$ −2.0 dex) RGB stars of the Small Magellanic Cloud (SMC) using wide coverage, high-resolution and high SNR UVES@VLT spectra. This is the first analysis of SMC metal-poor stars based on high-quality spectra, providing a first glimpse into the early stages of the chemical evolution of this galaxy. The analysed stars likely formed in the first Gyr of the SMC evolution and exhibit relevant differences with respect to the Milky Way stars of similar [Fe/H].

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Session: Chemistry of resolved stellar populations

CERES survey: chemical abundances of light neutron capture elements

Linda Lombardo
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Metal-poor stars play a key role in understanding the nucleosynthesis of heavy elements in the early Universe, as their chemical abundances reflect the composition of the gas in which they formed. High-resolution spectra show that very metal-poor stars are characterised by a broad range of heavy elements'abundances, but they have consistent relative chemical abundance patterns among elements in the lanthanide region (56<Z<72). However, this robustness in the abundance patterns is not observed for the light neutron-capture elements (30<Z<50). These abundance pattern variations suggest the presence of an additional process to the main r-process, that contributes to the production of light neutron capture elements (e.g. Sr, Y, Zr) but not the heavy ones in the early Galaxy. The nucleosynthesis processes and astrophysical sites associated with the production of light neutron capture elements are still a matter of debate, as several processes could be involved (e.g. weak r-process, weak s-process, …). In this talk, I will present the abundances of heavy elements, including the poorly studied Mo, Ru, Pd and Ag, for a sample of 52 very metal-poor stars. The talk will focus on exploring the impact of different neutron-capture processes that synthesise heavy elements at low metallicity, comparing the observed chemical abundances with those predicted by theoretical models.

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Session: Chemistry of resolved stellar populations

The Bulge Cluster Origin (BulCO) survey: first results in Liller 1

Lan Chiappino
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A variety of stellar systems are expected to populate galaxy bulges: genuine in-situ and accreted globular clusters (GCs), the relics of nuclear star clusters of cannibalized galaxies, and even the fossil remnants of the proto-bulge formation process (the so-called "bulge fossil fragments"). The Galactic bulge is the only spheroid where individual stars can be observed in detail, and the signatures of its origin and evolution are imprinted in the kinematic, photometric, and chemical properties of its stellar systems. In particular, chemical tagging is a very powerful tool, since specific abundance patterns provide authentic "chemical DNA tests"univocally tracing the enrichment process, hence the environment, where the stellar population formed. The Bulge Cluster Origin (BulCO) survey has been designed to perform a comprehensive and unprecedented chemical screening of a representative sample of stellar systems orbiting the Milky Way bulge, with CRIRES+ at the ESO-VLT. The abundances of iron and iron-peak elements, CNO, alpha-, other light elements (such as Al, Na, K) and a few neutron-capture elements are used to identify the polluters and the enrichment timescales of each system, providing crucial information on their nature and origin. In this talk I will present an overview of the BulCO survey, and the first results obtained for Liller 1, one of the most extincted systems of the Galactic Bulge, which is suspected to be a bulge fossil fragment.

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Session: Chemistry of resolved stellar populations

Advances in Galactic Chemical Evolution: Unveiling the Enrichment History of the Cosmos - Invited talk

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Session: Chemistry of resolved stellar populations

Europium, do we have a problem? Modelling r-process enrichment across Local Group galaxies

Marco Palla
INAF-OAS Bologna

The origin of heavy elements in the periodic table remains one of the most compelling and debated topics in Galactic Archaeology. Europium (Eu), a nearly pure product of the rapid neutron-capture process (r-process), serves as a crucial tracer for understanding the astrophysical sites of this process. While the chemical evolution of Eu in the Milky Way has been extensively studied, providing valuable constraints on r-process mechanisms, the diverse star formation histories of Local Group galaxies offer a unique, yet almost unexploited, opportunity to break the degeneracies still present in this field. In this talk, I will present a deep investigation into Eu enrichment across Local Group galaxies, employing detailed chemical evolution models. Building upon an r-process enrichment framework that successfully reproduces observed abundance patterns and event rates in the Milky Way, we extend this framework to models for Sagittarius, Fornax, and Sculptor dwarf spheroidal galaxies. Our results reveal that models aligning with the Galaxy Eu pattern significantly underestimate Eu levels observed in Local Group dwarf spheroidals. To address this "missing Eu"problem, we explore potential additional contributions from both prompt (i.e., core-collapse supernova like) and delayed (i.e., neutron star merger) sources and asses their compatibility with the Milky Way observables.

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Session: Chemistry of resolved stellar populations

Unveiling the Chemical Enrichment with CRIMSONS

Martina Rossi
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The process of chemical evolution is a universal phenomenon that has shaped the Universe from its earliest epochs to the present day. This intricate process is governed by the interplay of several factors, such as the nature of chemical pollutants, the mass distribution of stars and feedback mechanisms. Among these, the Initial Mass Function (IMF) plays a pivotal role in determining the expected chemical enrichment of different environments, as it regulates the relative fractions of low- and high-mass stars of a stellar population. In systems with low star formation rates (SFR$< 10^{-1}\mathrm{M}_\odot$ yr^{-1}), it has been shown that the theoretical IMF is never fully sampled. This critical yet often-overlooked factor has a profound influence on the process of chemical enrichment. Yet, incorporating this stochastic component into theoretical models and simulations, significantly increases the complexity of modelling chemical evolution, highlighting the need for advanced tools that can accurately account for these nuances. In this talk, I will introduce CRIMSONS, the first online tool with a user friendly interface, specifically designed to study chemical enrichment while incorporating the stochastic sampling of the IMF. CRIMSONS provides unparalleled flexibility, allowing users to explore the effects of varying IMFs, stellar population metallicities and masses, and different stellar yield sets. The tool follow the chemical evolution of individual stars and it tracks 30 chemical elements (from H to Zn), while assessing the contributions of key enrichment sources, including SNe, AGB stars, and Type Ia SNe. Exploiting CRIMSONS, I will demonstrate how stochastic IMF sampling fundamentally alters chemical enrichment predictions by comparing the enrichment outcomes of poorly- and fully-sampled IMF. Then, I will illustrate the sensitivity of predicted chemical abundance patterns using different stellar yield sets and I will identify the chemical elements that remain robust and reliable across varying stellar yield models. Finally, I will highlight the crucial role of pre-enrichment driven by primordial (Pop III) stars in shaping the chemical composition of the interstellar medium (ISM). I will compare models that include Pop III-driven pre-enrichment with those that rely exclusively on enrichment from later-generation (Pop II) stars, assuming a metallicity floor. This comparison will underscore how the early contributions of Pop III stars influence the abundance patterns and chemical evolution, offering insights into the initial conditions that govern subsequent star formation and evolution.

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Session: Chemistry of resolved stellar populations

Unravelling the chemical abundance patterns of the Milky Way building blocks

Alice Mori
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In the hierarchical mass assembly framework, the accretion history of the Milky Way (MW) is crucial to understand its evolution. Previous works have shown that the integrals of motion quantities are not necessarily conserved when massive merger events are concerned, but rather they spread their stars throughout the dynamical spaces. Additionally, part of the in-situ disc component itself becomes kinematically heated and acquires halo-like orbits as a result of the merger. Consequently, even if minor mergers are supposed to preserve a higher degree of phase-space coherence - given the lower dynamical friction effect, we expect their kinematic-defined samples to be anyway contaminated by both the massive merger(s) and the thick disc stars, thus hiding different populations. The main objective of this work is to quantify both these types of contamination within the accreted halo substructure known in literature by means of a chemistry-only analysis, to uncover their specific chemical patterns. We constructed the kinematic samples using Gaia EDR3 and APOGEE DR17 data. We adopted a Gaussian Mixture Model (GMM) approach, taking into account several chemical elements (Fe, Mg, Si, Ca, Mn, Al, C). This method incorporates the analysis of various abundances that probe different nucleosynthetic pathways, providing a percentage of global chemical compatibility. At the same time it allows to perform a comprehensive comparison between two samples of the overall trend of a given element [x/Fe] vs. [Fe/H]. In particular, it guards information about the eventual hidden different populations traced by the trend and potentially lost when computing averages. We show that a number of halo substructures feature high fraction of chemically-compatible stars w.r.t. the most massive merger of the MW (i.e., Gaia Sausage-Enceladus), in a few cases pointing towards a shared origin or at least to a very similar chemical evolution history. Once their samples are cleaned from this contamination and from that due to the thick disc, we derive the specific chemical patterns of the known accreted halo substructures.

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Session: Chemistry of resolved stellar populations

Homogenous chemical characterisation of accreted streams in the local stellar halo

Emma Dodd
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Galaxies stellar haloes, including their globular cluster populations, are known to build up through the accretion of smaller systems. With Gaia DR3 kinematic data we uncovered several new small substructures in the local stellar halo, namely the ED-2, 3, 4, 5 and 6; the ED streams. I will present the chemical follow up of these streams, using targeted high-resolution UVES spectroscopy to unveil their nature. With the exception of ED-2, all of the streams present a significant spread in [Fe/H] and the chemical signatures of an accreted origin. ED-3 and ED-4 exhibit lower [α/Fe] compared to homogeneously derived abundances of local Gaia Enceladus (GE) stars. In many elements, ED-3 and ED-4 are more similar to the lower mass accreted dwarfs; Sequoia and Helmi Streams. ED-5 and ED-6 are consistent with the GE chemical track and could be high-energy tails of GE that were lost earlier in the accretion process. The new elemental abundances of 5 ED-2 stars are in line with the picture that ED-2 is a disrupted ancient star cluster. I will present these elements, including for the Gaia BH3 33 $M_{\odot}$ black hole companion star that is associated with this stream. Our results demonstrate that obtaining high-precision and homogeneous chemical abundances are crucial for disentangling distinct accretion events that have deposited debris in the local halo.

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Session: Chemistry of resolved stellar populations

Tracing the evolution of the Milky Way through high-resolution spectroscopy

Edoardo Ceccarelli
University of Bologna

The stellar halo of our Galaxy harbors remnants from ancient accretion events, but disentangling the contributions of different accreted dwarf galaxies to the assembly of the Milky Way is a significant challenge due to the overlapping distributions of their debris in dynamical spaces. Previous works based on large spectroscopic surveys (e.g., APOGEE, GALAH) have hinted at distinct chemical patterns for stars associated with different halo substructures. Yet, the dissimilarity and non-homogeneity of these studies pose limitations. To address this complex context, in this talk I will show how high-resolution spectroscopy of either field stars and globular clusters (GCs) confirms the effectiveness of chemical tagging as an essential tool to complement dynamical information. First, I will present the 'A Walk on the Retograde Side (WRS)' project, a small spectroscopic survey that aims at investigating the retrograde portion of the halo by leveraging homogenous and detailed chemical abundances within the dynamical substructures using proprietary high-resolution spectra from UVES@VLT and PEPSI@LBT for 400+ stars in the retrograde halo (RH). Our findings reveal that

two recently discovered structures in the RH, L-RL64/Antaeus and ED-3, exhibit identical chemical patterns, suggesting a shared origin from a common merging event. Moreover, the abundance patterns of this unified system differ from those observed in Gaia-Sausage-Enceladus (GSE), indicating distinct chemical enrichment histories. Furthermore, our investigation demonstrates that Sequoia displays chemistry similar to that of GSE, albeit with subtle differences, while Thamnos exhibits unique chemical patterns that are incompatible with any known accreted substructure, potentially pointing to a distinct evolutionary history. Second, I will discuss abundances of six GCs dynamically tagged as either Galactic or accreted from distinct disrupted galaxies in the metallicity regime where abundance patterns of field stars with different origin effectively separate ([Fe/H] $= -1.2$ dex), showing that when high precision is achieved, the abundances of certain chemical elements (e.g., the alpha-elements, Zn, Eu) can not only efficiently separate in situ from accreted GCs, but can also distinguish among GCs born in different progenitor galaxies.

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Session: Chemistry of resolved stellar populations

A Sequoia Candidate with Exceptionally High Be and Li Abundances: Hypernova or Planetary Engulfment?

Lorenzo Monaco
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We report the discovery of a metal-poor dwarf star exhibiting exceptionally high Be and Li abundances. The star is a potential member of the Sequoia/Thamnos accreted galaxy, and its chemical anomalies extend to several other elements. We explore the possible origins of this peculiar chemical signature. The elevated Li and Be abundances could have arisen from synthesis in the environment of a hypernova or, alternatively, from the engulfment of rocky planets enriched in spallation-produced Li and Be.

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Session: Chemistry of resolved stellar populations

Icarus Revisited: An Ancient, Metal-poor Accreted Stellar Stream in the Disk of the Milky Way

Paola Re Fiorentin
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The search for accreted satellites in the Galactic disk is a challenging task, to which Gaia plays a crucial role in synergy with ground-based spectroscopic surveys. In 2021, P. Re Fiorentin et al. discovered five substructures with disk kinematics including

Icarus. To gain more insight into the origin of Icarus as a remnant of a dwarf galaxy rather than a signature of secular processes of disk formation, we complement astrometric Gaia DR3 data with spectroscopy from APOGEE DR17 and GALAH DR3, and explore the chemodynamical distributions within 3 kpc of the Sun. We select 622 stars in the accreted/unevolved regions of [Mg/Mn]–[Al/Fe] and [Mg/Fe]–[Fe/H], where we identify 81 and 376 stars with $-2 <$ [Fe/H] < -0.7 belonging to Icarus and Gaia-Sausage-Enceladus (GSE), respectively. The revised properties of Icarus are: ⟨V + V_{LSR} ⟩≃ 171 km/s, $\sigma_V \simeq$ 37 km/s, ⟨e⟩≃ 0.36, ⟨[Fe/H]⟩≃−1.35, ⟨[Mg/Fe]⟩≃ $+0.27$, ⟨[Al/Fe]⟩ ≃ −0.13, and ⟨[Mn/Fe]⟩≃ -0.39. From the color–magnitude diagram of its members, Icarus appears older than 12 Gyr. Such age and dynamical properties are reminiscent of the metal-weak thick disk. However, detailed chemical analysis in the diagnostic spaces [Ni/Fe]–[(C+N)/O], [Y/Eu]–[Fe/H], [Eu/Mg]–[Fe/H], [Ba/Y]–[Fe/H], and [Ba/Mg]–[Mg/H] evidences that Icarus and GSE occupy the accreted region, well separated from the bulk of in situ disk stars. Updated comparisons with N -body simulations confirm that Icarus's stars are consistent with the debris of a dwarf galaxy with a stellar mass of $10^9 M_{\odot}$ accreted onto a primordial disk on an initial prograde low-inclination orbit.

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Session: Chemistry of resolved stellar populations

Session: Milky Way and Local Group

Tuesday 17th June

Resolved stellar systems: from Globular Clusters to the Milky Way

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Thanks to the Gaia mission, new windows have opened for the study of stellar systems. Precise astrometry of these systems have allowed studies of their internal dynamics, from the bulk rotation of globular clusters to the precise mapping of the global kinematics of the Large Magellanic Cloud. Mean proper motion determinations of the globular clusters and nearby dwarf galaxies have allowed a determination of their orbits and informed our understanding of the merging history of our Galaxy. Meanwhile, considering the Milky Way as the largest of the currently known resolved stellar systems, Gaia has allowed a mapping of the bulk kinematics over a significant portion of the Galactic disk. With still two more planned data releases from Gaia, we consider the open questions that may be addressed in the future.

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Session: Milky Way and Local Group

Myths and challenges behind the formation of the Galactic disc

Matthew Orkney
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The local stellar disc of the Milky Way (MW) exhibits a bimodal distribution in the chemical abundances of its alpha-process elements, forming two distinct sequences: the high and low-alpha discs. Numerous hypotheses have been proposed to explain the origin of this bimodality, including the 'two-infall'model, which suggests two distinct epochs of gas accretion. This model is favoured by the discovery of an ancient and massive Galactic merger, the Gaia-Sausage Enceladus (GSE), which could have contributed the metal-poor gas needed to fuel the formation of the low-alpha sequence. In this talk I will analyse the Auriga simulations, which have been shown to feature GSE-like mergers and chemical distributions comparable to the high and low-alpha discs. I will demonstrate that a chemical bimodality can arise through different scenarios, independent of a MW-like accretion history or GSE-like merger event. I will examine the role of gas-rich mergers in the formation of the low-alpha sequence, finding that it is highly unlikely for a GSE-like merger to provide sufficient low-metallicity fuel. Finally, I argue that the timing of the MW disc 'spin-up'could be more closely linked to the GSE merger than to the early formation of the disc itself.

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Session: Milky Way and Local Group

Exploring the history of the Milky Way halo: Integrating chemistry and kinematics for clustering analysis

Leda Berni
University of Florence

The hierarchical process of structure formation predicted by the Λ-CDM model implies that the Milky Way (MW) halo is composed of smaller accreted structures (Cooper et al. 2010). The identification of these structures is fundamental in order to understand the history of formation and evolution of the MW. The search for stellar structures in the MW halo, such as stellar streams or merger remnants, is typically executed using the kinematics of stars that compose them (Das et al. 2020, Carrillo et al. 2022). However, this approach has limitations due to gravitational interactions such as tidal forces caused by the Milky Way, potential star escape, or passages through the galactic plane. These effects may lead to the loss of part of the stars or even the complete disruption of the structure, preventing the identification of their members only through their kinematics. We demonstrate that the combined use of chemistry and kinematics, implemented through a system of neural networks, helps in the development of a clustering method to find accreted structures in the MW halo. We applied the method to MW halo stars from the APOGEE dataset. We addressed the challenges of large-scale stellar datasets by employing machine learning techniques. We developed a combined use of Siamese Neural Networks (SNN), Graph Neural Networks (GNN), Autoencoders, and the OPTICS algorithm to provide a full procedure, named the CREEK, used to uncover stellar structures in the Galactic halo. The CREEK is first trained on known globular clusters and then applied to the dataset to recognise stellar streams. The CREEK allowed us to recover 80% of the GCs in the APOGEE dataset. It successfully re- identified some of the known streams present within it, and identified a possible new one. The CREEK creates thus an objective and data-driven method for the selection of stars belonging to streams and to stellar structures in general. In very populated stellar structures it also manages to identify some substructures with different chemistry and energy.

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Session: Milky Way and Local Group

Orbit integration with an updated potential model: insights into the globular cluster populations of the Milky Way and resonances induced by the bar

Michele De Leo
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The data releases of Gaia opened up the possibility for an unprecedented level of detail in studies of the Milky Way (MW) stellar populations. To fully exploit such a wealth of data, it is necessary to develop the tools we use to analyse and characterise them. I' ll present a new orbital integration tool with an up-to-date MW potential model and the results of its application to stars and globular clusters (GCs). By taking into account a more realistic and precise modeling of the bulge component, I'll show how the tool is able to recover accurate orbital parameters for the GC population of the MW. This expands our knowledge on the Galaxy's assembly history by allowing to assign progenitor accretion events to recently discovered GCs and to some well established GCs with unknown or debated ancestry. I'll also show how properly accounting for the MW rotating bar during the recovery of the orbital parameters leads to uncovering the signature features of resonances in the parameter space.

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Session: Milky Way and Local Group

Low-alpha, low-metallicity Milky Way disc stars at z>2

Chervin Laporte
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To a good approximation, the chemical dichotomy in the disc suggests that high-α sequence is predominantly old (with a monotonic age metallicity relation) and the low-α sequence is predominantly young (in the solar neighbourhood and outer disc). However, I will show using two different surveys (Gaia-ESO, SDSS SEGUE+APOGEE) that there is growing evidence for a population of old (τ >10 Gyr), metal-poor (-0.7 <[Fe/H]< -0.5), low-α stars in the Milky Way disc both in the solar neighbourhood as well as in the outer disc (e.g. Anticenter Stream). This suggests that the high/low-α discs may have been forming co-evally at z≥2. I will show that currently all cosmological simulations of galaxy formation struggle to explain the existence of such a population. Some idealised isolated galaxy formation models of clumpy star formation as observed in high-z galaxies seem to support such processes may have taken place in the early Milky Way.

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Session: Milky Way and Local Group

Chemical Tagging and Stellar Migration with Graph Attention Networks

Lorenzo Spina
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Understanding the structure and dynamics of the Milky Way disk is a major astrophysical challenge, complicated by stellar migration, which limits the reliability of kinematics in tracing the Galaxy's evolution and building blocks. While chemical tagging offers a way to link stars to their formation environments, it struggles in the thin disk, where stars exhibit similar chemical patterns. This talk presents an innovative use of Graph Attention Neural Networks to address these challenges. By leveraging the chemical information of stars, this method enables the re-identification of small groups of 10-20 stars from the same open cluster embedded within a dataset of 50k stars and provides insights into stellar migration.

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Session: Milky Way and Local Group

The kinematics of young stars in the Milky Way disc: first results from SDSS-V

Eleonora Zari
University of Florence

The fifth iteration of the Sloan Digital Sky Survey (SDSS-V) is surveying an unprecedented sample of ∼500 000 hot stars in the Milky Way, and obtaining multi-epoch low-resolution BOSS spectra. While the survey coverage of the Galactic plane is not yet complete, the amount of data collected so far allows for a first inspection of the kinematic properties of the sample. We employ the spectral parameters (T_{eff} , log g) and line-of-sight velocities $v_{l.o.s.}$ derived by the BOSS Net method to select stars hotter than 12,000 K and to compute their 3D velocities and actions (by combining with Gaia DR3 astrometric information). We find strong radial motions with respect to the Galactic centre, alternating inward/outward, and coherent over several kpc's. The inward motions are loosely associated with the underlying spatial density distribution of hot massive stars, which suggests a relation with the spiral arm pattern. We discuss this result in the context of current theoretical models of the Milky Way spiral structure and by comparing with numerical simulations.

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Session: Milky Way and Local Group

Chemical gradients of the thin disk from a Non Local Thermal Equilibrium spectral synthesis of Cepheids

Antonino Nunnari
INAF - Astronomical Observatory of Rome

The formation and evolution of the Milky Way pose numerous unresolved questions, such as the formation of its components and their interconnections. Abundance gradients serve as crucial diagnostics for tracing the chemical enrichment history of individual galactic components. High-resolution spectroscopy is a powerful tool for conducting chemical tagging and, thus, for reconstructing abundance gradients. We are analysing 1118 high-resolution spectra for a large sample of 356 Classical Cepheids distributed over the entire disk, with Galactocentric distances ranging from 4kpc to almost 30kpc. We aim to estabilish chemical gradients of the thin disk for elements where new Non-Local Thermal Equilibrium (NLTE) grids are available, testing and validating a novel spectral analysis method based on a NLTE approach. These grids include light elements (C, N, O, Na, Al), alpha elements (Mg, Si, Ca, Ti), iron peak elements (Mn, Fe) and neutron capture elements (Ba), making possible the reconstruction of the chemical enrichment history of the thin disk.

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Session: Milky Way and Local Group

Imaging and stellar photometry from space: current and forthcoming challenges - Invited talk

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Session: Milky Way and Local Group

The future of astrometry in space: from Gaia DR4 to GaiaNIR

Antonella Vallenari
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The ESA Gaia astrometric mission has revolutionized many fields of modern astrophysics from stellar evolution to Galaxy formation and evolution. In this talk present the content and preview of Gaia DR4 that will take place in the second half of 2026. We will provide an overview of Gaia DR5 and of the legacy archive. Finally we will present the plan for next astrometric mission, GaiaNIR. GaiaNIR was submitted to ESA in response to the call for Voyage 2050 and was recommended by the Senior Committee. Built on the Gaia principles, GaiaNIR is an astrometric mission in the near IR, to be launched around 2045. The main goals are to explore the previously inaccessible components of the Galaxy, obscured by dust, in the near-IR and to achieve a significant improvement in parallaxes and, most importantly, in proper motions by combining Gaia's epochs with new observations over a 20-year period. Finally, this will ensure a revision of the Gaia reference frame. The talk presents the science case and the challenges that the mission is facing.

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Session: Milky Way and Local Group

The chrono-dynamic structure of the Large Magellanic Cloud star cluster system

Florian Niederhofer
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Star clusters have been proven to be powerful tool in reconstructing the assembly history of a galaxy. However, detailed studies of their full 3 dimensional kinematics, in combination with the ages and chemical compositions of the clusters, have been limited to our own Galaxy so far. With the availability of deep high-precision space-based data we are now at the advent of expanding these studies to nearby dwarf galaxies. In this respect, our neighbouring galaxy, the Large Magellanic Cloud (LMC) has attracted much attention. It is currently interacting with its most prominent companion galaxy, the Small Magellanic Cloud, thus providing a unique opportunity to witness the cosmological processes of hierarchical structure formation in unparalleled detail. Studying the chemo-dynamics of the rich population of star clusters within the LMC will thus provide us with valuable clues about the formation and assembly history of the galaxy, as well as the origins of it system of star clusters. To this end we started an observational campaign using multi-epoch Hubble Space Telescope data to measure high-precision stellar proper motions within a sample of 23 massive LMC star clusters. Employing an isochrone-fitting framework, we additionally inferred homogeneous and robust estimates for the distances, ages and metallicities of the clusters. This collection of information allows us to investigate for the first time the full 3-dimensional dynamics of the clusters within the frame of the LMC in a self-consistent way. In the first part of this contribution, I will introduce the survey and demonstrate the potential and limitations of the proper motion data set, using the young cluster NGC 1850 as an example. In the second part, I will present the results of the analysis of the chromo-dynamic structure of seven old LMC clusters, where we found conclusive evidence for an ancient cluster that has been accreted by the LMC during a past merger event.

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Session: Milky Way and Local Group

Exploring the Impact of Satellite Galaxies on Milky Way Evolution

Ingrid Beloto Latini
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The Milky Way (MW) has been shaped by its interactions with satellite galaxies like the Large Magellanic Cloud (LMC) and the Sagittarius dwarf galaxy (Sgr). These interactions play a key role in the galaxy's chemo-dynamical evolution. Yet, their full impact is often missing from cosmological simulations due to the complexity of modeling realistic orbits and masses. To address this issue, we use cosmological simulations of MW-like galaxies from the Auriga suite. Our initial focus is the LMC, where we embed LMC-like satellites on calibrated orbits into cosmologically evolving MW analogs. This allows us to study the LMC's dynamical effects on the MW's disc, such as vertical and radial oscillations. We aim to contrast these results with other idealized N-body models to disentangle the contributions of the dark matter halo and other processes. The developed models will provide new insights into the interplay of secular and externally driven processes in the MW's evolution over the last 8 Gyr. These results will be instrumental in interpreting upcoming datasets from spectroscopic surveys (e.g., SDSS-V, WEAVE) and future Gaia data releases.

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Session: Milky Way and Local Group

Status and challenges for dark matter inferences in Local Group dwarf galaxies

Giuseppina Battaglia
Instituto de Astrofisica de Canarias - IAC

Dwarf galaxies are widely regarded as some of the best systems to learn about the nature of dark matter and about how the properties of dark matter haloes might be affected by baryonic processes. The particular interest in studying these galaxies within the Local Group has multiple reasons, mainly related to their relative vicinity: it is for these nearby dwarf galaxies that we can gather the best data-sets on which dark matter inferences can be made and that we can probe a range of stellar-to-halo mass ratios and star formation histories where the influence of baryonic processes is expected to vary from null or mild to strong. In this talk I will give an overview on where we stand in terms of dark matter halo inferences for Local Group dwarf galaxies and an outlook on the road ahead for assembling the desirable data-sets and identifying "clean" test-cases.

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Session: Milky Way and Local Group

Tracing the Local Group evolution with resolved stellar populations

Matteo Monelli
INAF - Osservatorio Astronomico di Roma

Local Group dwarf galaxies provide valuable information about the early Universe through the detailed study of their resolved stellar populations. In this talk I will present our latest results on few galaxies (Leo II, Draco, CVnI), focusing on the synergies between different techniques applied to resolved stellar population studies. In particular, different approaches such as the star formation history derivation from the deep colour-magnitude diagrams combined with the properties of variable stars can provide interesting insight on the host galaxy evolution, chemical evolution, and accretion history.

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Session: Milky Way and Local Group

Dwarf-dwarf mergers and the hierarchical build-up of galaxies at the smallest scales

Francesca Annibali
INAF-OAS Bologna

Although interactions and mergers are a fundamental component of the commonly accepted Lambda CDM paradigm, direct observational evidence of accretion events around otherwise isolated dwarf galaxies is still very poor. In this talk I will present the results of a project aimed at characterizing streams and tidal features around dwarf galaxies in order to understand how they build-up from hierarchical merging of smaller units. The project builds on a program at the Large Binocular Telescope providing wide-field, deep imaging for 45 nearby (D<10 Mpc) dwarf galaxies with the aim of identifying tidal features down to unprecedented low surface brightness limits. From these data, convincing signatures of recent interaction with smaller companions have been found in six systems. Deep, follow-up HST observations have then been acquired for the interacting dwarfs in order to infer their star formation histories (SFHs) in detail through resolved-star color-magnitude diagram modeling. In the end, the derived SFHs will provide, together with the galaxies'kinematical and morphological properties, crucial constraints for N-body hydrodynamical simulations aimed at reconstructing the host satellite merging histories. I will conclude my talk discussing future perspectives opened up by the recently started Euclid mission in the framework of merging phenomena in low mass galaxies.

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Session: Milky Way and Local Group

Unveiling nearby young stars from planet search surveys

Silvano Desidera
INAF

Nearby young stars are precious targets for the search for planets at early ages and the understading of their evolution, but typically after the dispersal of the parent cloud and departure from the birth site become quite elusive. I will present the methods and results on the identification and characterization of young stars performed as part of long-term planet search projects such as the SPHERE GTO survey and the GAPS program and the key information for the determination of the stellar properties that are provided from the data taken with the primary purpose of planet search, related to e.g. rotation, magnetic activity, chemical abundances, kinematics, multiplicity. I will also highlight the identification of stars mistakenly classified as young because of the occurrence of recent accretion on angular momentum from a companion formerly on the AGB phase or for other reasons.

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Session: Milky Way and Local Group

Using a Deep Neural Network to Estimate Effective Temperatures and Derive Stellar Ages in Star-Forming Regions

Loredana Prisinzano
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Determining the timescales and physical mechanisms driving star formation (SF) from giant molecular clouds is crucial for advancing SF theories and reconstructing the SF history of Galactic Star-Forming Regions (SFRs). Such timescales can be observationally constrained by deriving the age and age spread of stars in recently formed clusters. The main challenge lies in accurately estimating fundamental astrophysical parameters - such as effective temperatures, luminosities and stellar ages - for large samples of young stellar objects (YSO). In the era of Gaia and other extensive optical/NIR photometric surveys, YSOs in SFRs can be reliably identified; however, accurately characterising them remains challenging in the absence of spectroscopic data. In this talk, we present a model based on a deep neural network that can predict the effective temperatures of YSOs in the range 3000-7000 K. This machine learning approach leverages both spectroscopic and photometric variables as input features for the training set, with data from the Gaia-ESO (GES), Gaia DR3, and 2MASS surveys. We apply this model to an all-sky catalog of low-mass YSOs to predict their effective temperatures. Using standard astrophysical techniques and novel theoretical models, we derive the stellar ages of these objects. A preliminary statistical analysis of the age distributions of Galactic SFRs will be presented and discussed.

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Session: Milky Way and Local Group

Session: Stellar variability and Star Clusters

Wednesday 18th June

Invited talk

Giuseppe Bono
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Session: Stellar variability and Star clusters

The stellar age distribution of the Galactic bulge

Annalisa Calamida
Space Telescope Science Institute

The presence of an extended age range for the Galactic bulge stellar populations has been a hot debated topic in the last decade. A study based on spectra of microlensed bulge stars showed evidence for the presence of very young, up to ∼2 Gyr old, stars in the Galactic bulge. On the other hand, proper motion (PM) cleaned Color-Magnitude Diagrams (CMDs) of the Galactic bulge based on Hubble Space Telescope (HST) data and reaching a few magnitudes below the main sequence turn-off (MSTO), show a lack of young stars in the bulge. However, these studies focus on a very small field of view (FoV, 3x3 square arcmin) towards the bulge, and are based on small statistics (less than 50,000 stars). In this talk, I will present PM-cleaned CMDs in different optical and near-infrared filters for a much larger FoV (1x1 square degree) towards the bulge Baade's window, based on DECam and VISTA observations for ∼1 million stars. PMs were estimated with a novel algorithm that corrects for the geometric distorsion of the wide-field camera and have a better precision compared to Gaia DR3 at magnitudes fainter than r ∼17 mag. Therefore, we were able to use DECam PMs to separate disk and bulge stars down to 1 mag below the MSTO. We built a luminosity function of the MSTO region and comfirmed the lack of stars younger than 2 Gyr. This study is preparatory for similar ones that the LSST/Rubin and Roman Space Telescope surveys of the Galactic bulge will enable for most of its stellar populations. In my talk I will further elaborate on these future projects.

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Session: Stellar variability and Star clusters

Novae as Galactic lithium factories: indications from optical and gamma-ray observations

Luca Izzo
INAF - Osservatorio di Capodimonte

Classical Novae have been suggested as a primary source of lithium production in our Galaxy. In this presentation, I will provide additional evidence supporting the existence of lithium in classical novae ejecta through a multi-wavelength analysis of several bright events. The lithium yields inferred from these observations, while approximately an order of magnitude higher than theoretical predictions, strongly support the notion that novae play a pivotal role in lithium enrichment within the Milky Way and possibly throughout the Universe.

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Session: Stellar variability and Star clusters

Metallicity dependence of Classical Cepheids Period-Luminosity relations

Vincenzo Ripepi
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Classical Cepheids (DCEPs) are the most important primary indicators of the extragalactic distance scale thanks to the tight Period-Luminosity relations that held for these stars. However, despite many efforts over the past years, there is still no consensus on the detailed calibration of such PL relations, especially regarding their dependence on metallicity. In this context, we started the project "Cepheid metallicity in the Leavitt law"(C-MetaLL) with the immediate goal of obtaining homogeneous high-resolution spectroscopy and near-infrared time-series photometry for a sample of more than 350 DCEPs with the explicit purpose of significantly extending the DCEP sample metallicity towards the metal-poor regime. In our previous works, we used a large sample of about 900 DCEPs, comprising metallicities from both literature and C-MetaLL, combined with Gaia parallaxes to determine metallicity-dependent PL relations for various photometric bands. We found a large negative metallicity term (the so-called gamma coefficient) for all the PL relations investigated so far with typical values of gamma $\sim -0.4 : -0.5$ mag/dex, which is larger than most of the recent determinations present in the literature. In this talk, I present the latest results from the C-MetaLL project, based on a sample of approximately 300 DCEPs for which we have obtained metallicity homogeneously from our spectra. More- over, our sample encompasses with an even number of pulsators a range of more than 1 dex in [Fe/H]. We discuss the resulting metallicity dependence of the DCEPs PL relations in the context of the extragalactic distance scale.

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Session: Stellar variability and Star clusters

The dynamical evolution of the stellar clumps in the Sparkler galaxy

Eric Giunchi
University of Bologna

The formation and evolution of globular clusters (GCs) is still a key open question of modern astrophysics. Recent JWST observations detected a system of stellar clumps around the gravitationally lensed Sparkler galaxy at z=1.4, with ages and metallicities compatible with GC-progenitors. However, the masses and effective radii of such clumps are about 10 times those of the Milky Way (MW) GCs. I will present N-body simulations of the clump dynamical evolution to z=0, under the effects of dynamical friction and tidal stripping, aimed at assessing whether these clumps can evolve into GC-like objects. Since the Sparkler morphology is poorly constrained, we explored two scenarios, in which the galaxy is either a spheroid or has a prominent stellar disk. Independently of the galactic morphology, we find that dynamical friction is quite inefficient on clumps with mass <1e7 Msun (the "surviving"clumps), while the massive ones sink to the galaxy central regions, possibly contributing to the bulge growth.

Tidal stripping is important only in presence of the disk, which triggers shocks able to strip considerable mass from low-mass clumps and shifts the peak of the mass distribution of the surviving clumps to 2-3e6 Msun, which is compatible with the high-mass end of the MW GC mass distribution, even though the clump effective radii remain larger than those of GCs even if large fractions of mass are stripped

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Session: Stellar variability and Star clusters

Morphology and dynamics of open clusters with tidal tails

Anna Parul
Observatoire de Paris

Unprecedented quality of Gaia data has led to recent discoveries of extended stellar coronae and tidal tails around nearby open clusters. These elongated structures form through complex dynamical interactions between cluster stars and the Galactic environment, and are crucial for understanding the processes involved in clusters disruptions and their associated timescales. For a sample of recently discovered open clusters with tidal tails, we re-evaluate their membership completeness taking into account Gaia selection function with *GaiaUnlimited* tools, quantify their morphological structure with Gaussian Mixture models, and assess their mass segregation degree. We proceed with running N-body simulations in galactic potential to follow the formation of tidal tails and compare their shapes, directions and densities with observational data.

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Session: Stellar variability and Star clusters

A 3D view of multiple populations' kinematics: clues on globular clusters formation and early evolution

Emanuele Dalessandro
INAF-OAS Bologna

Globular clusters are key benchmarks in many fields of Astrophysics, ranging form stellar evolution and dynamics, to star and galaxy formation and assembly. However, their use as standard templates strongly relies on our understanding of when, how and why star clusters form. The kinematic and structural properties of multiple stellar populations (MPs) in globular clusters differing in terms of their light-element abundances can provide new insights into the early epochs of massive clusters formation and evolution. In this context, I will present the results of the first 3D kinematic analysis of MPs in a large and representative sample of Galactic globulars based on a homogeneous combination of line-of-sight radial velocities and proper motions secured by

large spectroscopic surveys and Gaia DR3, respectively. Our analysis provides the first purely observational description of the MP kinematic properties and of the path they follow during the cluster long-term dynamical evolution. In particular, we observe evidence of differential rotation among MPs along all velocity components with the second population (SP) preferentially rotating faster than the first population (FP). The difference in the rotation strength between MPs turns out to be anti-correlated with the cluster dynamical age. We observe also that FPs are characterized by isotropic velocity distributions at any dynamical age probed by our sample. On the contrary, the velocity distribution of SP stars is found to be radially anisotropic in dynamically young clusters and isotropic at later evolutionary stages. By means of an appropriate comparison with a set of state-of-the-art numerical simulations, we show that the observational results are consistent with the long-term evolution of clusters forming with an initially more centrally concentrated and more rapidly rotating SP subsystem. In addition, we show that the present-day kinematic properties of MPs would support formation models predicting that globular clusters experience multiple events of star formation during their early phases of evolution.

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Session: Stellar variability and Star clusters

Do we really expect a metallicity spread in all stellar clusters? Not so fast, please

Angela Bragaglia
INAF-OAS Bologna

The chemical homogeneity of stellar clusters, once a staple of stellar astrophysics, is more and more challenged. This comes both from improved stellar models which take into account diffusion, mixing etc and from observational data, either spectroscopic or photometric. However, the situation is complicated. While star-to-star variations in light elements in globular clusters (GCs) are now well assessed in all Milky Way GCs, a spread in metallicity is more debated and high resolution spectroscopic studies have found metallicity variations only in a handful of GCs, sometimes with controversial results for the same GC. Furthermore, using a combination of HST filters sensitive to variations in chemical abundances, a metallicity spread has been claimed, in particular for the primordial, unpolluted component of GCs. The resulting spreads are even larger than those in dwarf galaxies and generally difficult to reconcile with spectroscopic analysis. Finally, a metallicity spread has also been proposed for some open clusters. We present here a critical examination of this issue and inconsistencies we found based on published and new data.

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Session: Stellar variability and Star clusters

Session: Stellar Evolution

Thursday 19th June

Sharpening our view on the inner workings of stars with star quakes: the current and future role of space-based observations - Invited talk

Andrea Miglio
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Session: Stellar evolution

Nitrogen-rich stars through the lens of asteroseismology

Ellie Leitinger
University of Bologna

Globular clusters (GCs) are important tracers of the early Galactic assembly process, with their stars showing distinct chemical abundance patterns. When such stars are found in the Galactic field rather than within GCs, they are considered remnant populations from clusters disrupted during the hierarchical assembly of our Milky Way. We expand the search for such chemically enriched stars in the Kepler, K2, and TESS fields, to show the potential in using asteroseismology to link seismic properties with chemical abundances. Using data from APOGEE DR17, Gaia DR3, and the Kepler, K2 and TESS asteroseismology missions, we identify primordial stars as those with chemical signatures typical of field stars, and enriched stars as those exhibiting strong Nitrogen and Aluminum enrichment, with corresponding Carbon and Oxygen depletion. We present our samples of primordial, enriched and very enriched stars selected by their chemical abundances, 3D kinematics and asteroseismology parameters. By comparing stars with primordial and enriched characteristics, we aim to uncover stellar properties that reflect the star formation environments of their origins.

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Session: Stellar evolution

JWST unveils the brown dwarf population of the most extreme star clusters of the Milky Way: Westerlund 1 and 2

Victor Almendros Abad
INAF - Osservatorio astronomico di Palermo

Brown dwarfs have been extensively studied in nearby star-forming regions (d<400 pc). However, theories suggest that high gas or stellar densities, as well as the presence of massive OB stars, may enhance brown dwarf formation relative to stars. To test this, it is crucial to study brown dwarf populations in massive young clusters, which provide dramatically different star-forming conditions. The nearest examples of such clusters are the supermassive star clusters (SSCs) Westerlund 1 and Westerlund 2, each exceeding 30000 $M_{\odot}$ in total stellar mass. As part of the EWOCS (Extended Westerlund 1 and 2 Open Clusters Survey) project, we have obtained deep JWST/NIRCam observations of these clusters. A key goal of this project is to derive their mass functions and assess whether extreme environments influence brown dwarf formation. By combining these results with studies of other massive young clusters led by members of the project, such as Trumpler 14 and RCW 38, we are placing the first robust constraints on the efficiency of brown dwarf formation in such environments. In this talk, I will present the JWST/NIRCam data products of both clusters, the (sub)stellar initial mass function of Westerlund 1, and the detection and characterization of brown dwarfs in Westerlund 2, enabled by the rich multi-wavelength filter selection. I will also discuss the implications of these results for our understanding of star formation.

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Session: Stellar evolution

The nucleosythesis of massive stars: a bridge between stellar modelling and galactic archaeology

Federico Rizzuti

Massive stars play a crucial role in the chemical evolution of galaxies, enriching the interstellar medium with both light and heavy elements. However, our understanding of the nucleosynthesis and evolution of massive stars is limited by numerous uncertainties arising from the complex multi-dimensional processes occurring in stellar interiors. Three-dimensional hydrodynamic models of stars can enhance our understanding of these mechanisms by studying realistic multi-D processes over a limited time range. In turn, Galactic chemical evolution models can constrain the physical properties of massive stars as production sites for various elements, thanks to the large amount of recent observations. In this talk, I will present results from 3D stellar simulations that include an explicit network for nuclear burning, reproducing different phases of advanced massive stars. I will also show how chemical evolution models and observations can be used to constrain the structure, evolution, and nucleosynthesis of these massive stars.

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Session: Stellar evolution

High-Precision Ages and Abundances: Unlocking the Milky Way's History

Giada Casali
The Australian National University

Chemical clocks, defined by abundance ratios between s-process and alpha-elements, are powerful tools for estimating stellar ages in spectroscopic surveys. I present a detailed spectroscopic analysis of 68 Kepler red giants, combining high-precision chemical abundances with asteroseismic ages (precision $< 10\%$) to calibrate chemical clock-age relations. These high-precision abundances and stellar ages are crucial for exploiting chemical clocks as reliable tools to estimate stellar ages across large samples of stars. Using these relations, I derive "chemical ages" for $\sim$270,000 stars in the APOGEE and Gaia-ESO surveys, uncovering key trends in stellar populations, such as the age distinction of low- and high-alpha sequences, the age-metallicity relation, disc flaring, and the presence of old metal-rich stars. I further explore the [C/N] ratio as a complementary chemical clock sensitive to mixing processes during the RGB phase. By calibrating [C/N]-age relations using thousands Kepler red giants, with APOGEE chemical abundances, and comparing observed trends with stellar evolutionary models, I apply mixing corrections to infer birth-[C/N] abundances, offering insights into both Galactic evolution and theoretical models of stellar mixing. This work highlights the synergy between asteroseismology, spectroscopy, and stellar evolution, providing new tools to decode the Milky Way's formation history.

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Session: Stellar evolution

Simulating the populations of binaries and products of binary interactions in the Kepler's field

Alessandro Mazzi
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Binary stars are a common occurrence in the Milky Way and interest in these systems has been re-ignited by the discovery of peculiar kinds of stars that cannot be explained only by the single star scenario and instead require evolution in a binary, such as undermassive stars in clusters and young alpha rich stars in the Galactic thick disk. The identification and characterization of binaries and products of binary interaction can be a difficult task. In this context, asteroseismology is a powerful tool that can fill the gaps left by other techniques. Focusing only on the "solar-like" oscillators, the analysis of the power spectrum derived from a star's light curve can provide accurate mass and radius estimates, as well as additional properties such as the evolutionary state and core mass, and therefore find products of non-single star evolution. In addition, unresolved binaries with two solar-like oscillators that did not undergo significant events of mass transfer have the chance to be identified if the two sets of oscillations can be detected in the power spectrum, and are then labeled "asteroseismic binaries". In this work, we use the TRILEGAL population synthesis model to simulate the stellar populations in Kepler's field, analyzing in detail the kinds of binary stars and binary products

that can be found, and take particular care in accounting for the probability to detect oscillations in both single stars and binary systems. While we adopt the Moe & Di Stefano (2017) model for generating the initial parameters of binary stars, such as mass ratio and orbital period, we also make a comparison with the results obtained using the Eggleton (2006) model, and find significant differences in the fraction of detectable binaries and binary products. This kind of analysis can also be used to understand the expected contents of other surveys, such as TESS and Plato.

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Session: Stellar evolution

Semi-analytical models of core-helium-burning stars: Structural glitches near the core

Massimiliano Matteuzzi
University of Bologna

Understanding the internal structure of core helium burning (CHeB) stars is essential for evaluating transport processes in regions where nuclear reactions occur, which are crucial for predicting yields used in chemical evolution models of galaxies, and for developing accurate models of stellar populations. However, key aspects of these stars, such as the temperature and chemical composition stratification in the convective boundary layer and the number and location of helium-flashes, remain not well constrained both theoretically and observationally. Asteroseismology offers a promising tool to address these uncertainties. By analysing oscillation modes, we can probe structural variations in the inner radiative regions near the convective core of CHeB stars. However, these variations are challenging to detect and interpret in asteroseimic data, and their impact on observed eigenfrequencies has not been thoroughly explored in the context of CHeB stars. This study aims to fill this gap by investigating how structural gradients influence the oscillation modes of low-mass CHeB stars. Using semi-analytical models calibrated with advanced stellar evolution codes—BaSTI-IAC, CLES, and MESA—we explore how density discontinuities and associated structural variations affect the oscillation pattern of these stars. These codes, selected for their distinct physical prescriptions, allow us to identify common features for calibration while maintaining realistic stellar representations. This approach enables systematic control over the type of structural variations introduced, minimising detectable numerical noise. Our results demonstrate that oscillation modes are effective tools for inferring the position and amplitude of sharp structural variations within CHeB stars. By comparing models with smooth transitions to those featuring jump discontinuities in density, we identify differences in oscillation patterns and mode trapping that help constrain the sharpness of structural variations. Additionally, simulations using four years of Kepler data show that our models produce oscillation frequencies that closely match the observed power spectral density. This validation not only supports our theoretical framework but also opens promising avenues for interpreting oscillation signatures in high-quality asteroseismic data from other space missions such as TESS and the upcoming PLATO.

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Session: Stellar evolution

ÆSOPUS 2.1: low-temperature gas opacities library and its application in stellar models

Diego Bossini
Università degli studi di Padova

We present ÆSOPUS 2.1, a publicly-available tool designed to compute low-temperature gas opacities. The tool covers temperatures from 100 K to 30000 K, and allows user-customized chemical composition, counting 92 elements in addition to the most used solar mixtures from literature (including the more recent Magg et. al 2022). The code is originally designed for computing Rosseland mean opacity tables taking into account over 800 atomic species including atoms, ions, molecules and solid grains,and is now updated with molecular absorption expanded to include 80 species. The table covers an interval of temperature and density particularly suitable for describing the outer parts and atmospheres of cool stars, including red giants and other solar-like oscillators. We will show the effect of our opacity calculations on the outer layers using the stellar evolution code PARSEC, which is essential for proper modelling stars. The impact of our tables on the surface layers will also affect asteroseismic calculations of the mode frequencies, enabling the derivation of more precise stellar properties.

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Session: Stellar evolution

Current challenges for stellar modelling - Invited talk

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Session: Stellar evolution

Testing the asteroseismic estimates of stellar radii with surface brightness-colour relations and Gaia DR3 parallaxes

Pier Giorgio Prada Moroni
University of Pisa

Accurate knowledge of the radii of stars is crucial for constraining models of stellar structure and evolution. In this presentation, I will compare stellar radii derived from asteroseismic scaling relations with those estimated using two independent surface

brightness-color relations (SBCRs) and Gaia DR3 parallaxes. In the first part, I will focus on a comparison using a set of over 6,400 Red Giant Branch (RGB) and Red Clump (RC) stars from the APO-K2 catalog. This catalog was merged with the TESS Input Catalog v8.2 to obtain precise V-band magnitudes and E(B-V) color excesses. Overall, the SBCR and asteroseismic radii exhibit good agreement, with a typical difference of 2% to 4%. However, some intriguing trends emerge when considering [α/Fe] and asteroseismically estimated mass. In the second part, I will shift to a comparison using the Kepler end-of-mission catalog, encompassing over 12,000 RGB and RC stars. The improved precision of the Kepler data leads to a more robust agreement between asteroseismic and SBCR radii, typically within 1-2%. Notably, the trends observed in the K2 data analysis are not apparent when using the Kepler data. This might suggest the presence of potential systematic errors within the K2 dataset. Given the good agreement and the significantly lower demands in terms of observational time and equipment, SBCR radii represent an attractive alternative to those obtained with asteroseismology.

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Session: Stellar evolution

Physics for stellar interiors, recent advancements

Oscar Straniero

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Trivially speaking, reliable stellar models require reliable input physics. The issue severely affects the advanced phases of stellar evolution, those most relevant for understanding the chemical evolution of the MW and of the other galaxies, as well as the final fates of stellar evolution (from compact remnants to the various supernova events). The state of the art will be presented; it includes recent advancements in nuclear physics, atomic physics and quantum field theory, all impacting on our skill as stellar modellers.

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Session: Stellar evolution

The impact of stellar evolution uncertainties on binaries

Erika Korb

Università di Padova

Most massive stars are born in binaries and are expected to interact through mass transfer processes. The duration and stability of mass transfer exchanges have a strong influence on the final binary properties and the internal structure of the stars, thus on their final fates. In my work, I demonstrate that caution must be taken when different mass transfer models are compared. Changes in the input stellar physics or in the mass transfer prescriptions can have similar effects in selecting the final binary properties

and formation channels. Being able to disentangle between stellar evolution and mass transfer effects is crucial to correctly make predictions and compare current models against X-ray observations of interacting binaries and Gaia detections of astrometric detached binaries.

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Session: Stellar evolution

New sets of PARSEC v2.0 stellar model for low-metallicity

Chi Thanh Nguyen
University of Trieste

The previous release of rotating PARSEC v2.0 models for six set of metallicities around the solar value were presented to the comunity in Nguyen et al. (2022). Recently, we are preparing to update the database for the other six sets of metallicity. The goal of this work is to provide to the community stellar model and isochrones covering a large range of rotation rate (ω_i = 0.00 - 0.99) and metallicity (Z = 0.0001 - 0.02). New results and outcomes will be presented at the conference. Besides that, we also made a first step in investigating the effect of thermohaline mixing in low-metallicity red-giant stars of the GC NGC 6397, and the calibration of envelope overshooting parameter to the GC M4 by using the seismic scaling-relations. The results of this work will also be presented.

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Session: Stellar evolution

New grids of PARSEC evolutionary tracks, with final fates, ejecta, and ionizing photons from intermediate-mass to very massive stars

Guglielmo Costa
University of Padova

Stellar models play a crucial role in interpreting and analyzing the ever-growing volume of astrophysical data. Therefore, it is essential to continuously update and release state-of-the-art, homogeneous sets of stellar tracks and make them available to the research community. In this presentation, I will introduce our new stellar evolutionary models, which have been computed with the updated PARSEC v2.0 code. These models cover a comprehensive and homogeneous grid of metallicities and initial masses, encompassing thirteen initial metallicities that range from metal-free to super-solar values, with masses from 2 to 2000 solar masses. I will describe the properties of these tracks, including their final fates, the ejecta produced, and the ionizing photons released. Additionally, I will present examples that compare our findings with obser-

vational data and other evolutionary models. All the grids and tables produced are publicly available.

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Session: Stellar evolution

The Milky Way traced by pulsating stars: theory versus observations

Marcella Marconi
INAF - Osservatorio Astronomico di Capodimonte

Pulsating stars are useful distance indicators and stellar populations tracers. In the Milky Way, the investigation of the pulsation properties of different classes of pulsating stars allows us to derive information on their 3D structure and age distribution in the various galactic components. In this context, extensive sets of nonlinear convective pulsation models have been developed for a wide range of stellar parameters in order to predict all the relevant pulsation observables. From these results, accurate relations have been derived and tools have been developed to provide theoretical calibrations of the distance scales associated to the various classes of pulsating stars and infer their intrinsic properties through the comparison with the data. In particular, model results are discussed to the light of current and future astrometric, photometric and spectroscopic surveys.

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Session: Stellar evolution

Unveiling Carbon Stars Properties in the Milky Way and the Magellanic Clouds

Alessio Liberatori
National and Kapodistrian University of Athens

In recent decades, numerous studies have used spectral energy distribution (SED) fitting with multi-band photometry in optical and IR bands to determine the properties of carbon-rich Asymptotic Giant Branch (AGB) stars. These stars are key contributors to the chemical evolution of galaxies, enriching the interstellar medium with molecules and dust through stellar winds. They also appear to play a role in extragalactic distance estimation, particularly through the J-AGB method. Past studies have estimated mass-loss rates, dust properties, luminosities, and effective temperatures for these stars, focusing predominantly on the Magellanic Clouds (MCs). Studying carbon stars in the Galaxy is challenging due to the need for accurate distances and reddening values, which can significantly affect the derivation of the properties of this class of stars. Recently, the Gaia collaboration published the Gaia Golden Sample of Carbon Stars (GGSCS), consisting of 15,740 carbon star candidates in both the Milky Way (MW) and the MCs, offering new opportunities for detailed analysis. In this work, we provide

a homogeneous and internally consistent analysis of stellar and dust properties for the GGSCS. Thanks to the advent of Gaia, we are able to determine distances and reddening values for this sample of stars with sufficiently high accuracy. We compare photometric data obtained from optical and infrared missions, i.e. SDSS, Gaia, WISE, and others with a wide grid of synthetic SED models, created using DUSTY combined with the COMARCS models. Through this analysis, we have accurately determined key parameters for these stars, including effective temperature, mass-loss rates, and additional physical properties. This work represents the first extensive and homogeneous study of carbon star properties spanning both the MW and the MCs, providing a comprehensive view of their stellar and dust characteristics.

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Session: Stellar evolution

Session: Machine Learning

Friday 20th June

Invited talk

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Session: Machine learning

Deep Learning-driven MCMC for fast and accurate stellar spectroscopy

Cristiano Fanelli
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The increasing volume of data from large-scale stellar spectroscopic surveys calls for innovative methodologies that accelerate and optimize data analysis and interpretation. In this work, we introduce a novel framework that leverages deep learning techniques for spectral synthesis and possibly direct analysis of stellar spectra. This approach significantly reduces computational time and enhances the efficiency of extracting key physical and chemical parameters, such as effective temperature, surface gravity, iron content and chemical abundances. It also enables high-quality synthetic spectra generation, making these tools readily accessible to early-career scientists and researchers with limited computational resources, as well as to those without expertise in spectral synthesis. Specifically, our research focuses on developing and integrating an

Artificial Neural Network, capable of generating synthetic spectra, as the likelihood function within a Markov Chain Monte Carlo (MCMC) algorithm. This hybrid strategy accelerates the inference phase and offers robust, automated uncertainty quantification, paving the way for comprehensive exploration of complex and expansive parameter spaces. In addition, generating synthetic spectra with a neural network requires less than one ten-thousandth of the time needed by traditional spectral synthesis codes, a benefit that becomes even more significant as the spectrum size increases. It also takes only about a tenth of the time required to read the same spectrum from a file. Moreover, using this approach within the MCMC framework drastically reduces memory allocation issues commonly encountered in other conventional methods. Finally, we will showcase potential applications, including initial results obtained from high-resolution red giants spectra collected with the ESO-VLT CRIRES+ spectrograph as part of the "The Bulge Cluster Origin" (BulCO) survey, demonstrating the practical benefits of this approach in addressing contemporary challenges in stellar spectroscopy.

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Session: Machine learning

1-DREAM and model based ML techniques for low-dimensional structure identification in the MW halo

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Low dimensional tidal features in the MW halo carry a tremendous amount of information about the structures that originated them and their environment. Streams and tidal tails of globular clusters are natural examples of these dynamical features and are ubiquitous in the galactic halo. It is then crucial to have a numerical representation of stellar streams, in order to enable further investigation. However, their detection and characterization is often hampered by instrumental noise and contamination from background and foreground stars. Taking advantage of nature inspired optimization algorithms, 1-DREAM is a collection of machine learning techniques aimed at enhancing the contrast between overdense, locally aligned structures and the "uninformative" contaminants. It then recovers a coherent, model-based, representation of their core and its noisy distribution by building a constrained probabilistic model of the full structure. The natural explainability of model based techniques and their trivial extension to higher dimensions make them the ideal candidates for the inspection of stellar, low-dimensional structures. We present the application of 1-DREAM and its extensions to the detection and modelling of stream-like structures in data from GAIA.

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Session: Machine learning