The Milky Way Revealed by Gaia: The Next Frontier

Tuesday, 5 September 2023 - Thursday, 7 September 2023

Institute of Cosmos Sciences (ICCUB-IEEC)

Book of Abstracts

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Welcome and WG4: Gaia Fundamentals: Space and Time (I). Chair: Nick Walton / 106

Report WG4: Gaia Fundamentals: Space and Time

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Welcome and WG4: Gaia Fundamentals: Space and Time (I). Chair: Nick Walton / 98

Close stellar interactions from Gaia (invited talk)

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A great fraction of stars are born in binary or multiple systems. For a given stellar population, about a third would be products of binary interaction: stripped stellar companions, semi-detached systems, or stellar mergers. A particularly important phase in the life of a binary is the phase of common envelope, which is responsible for the formation of compact binary systems, such as gravitational wave sources, or supernova progenitors. During this phase, the unstable mass transfer from one star to its companion leads to the formation of a shared, non-coronating gaseous layer, called the common envelope. The quick spiral in of the companion inside this layer transfers the orbital angular momentum into the envelope, which can be fully or partially ejected. The final system will be a compact binary, or a stellar merger remnant, respectively. The high-precision astrometry, spectro-photometry, and time-domain capabilities of Gaia have allowed us to explore close stellar interactions in two different ways: on the one hand, it has allowed us to directly study the transients, called Luminous Red Novae, caused by the ejection of the common envelope; on the other hand, the DR3 catalogue has provided new ways to identify new interacting binary systems. In my talk, I will present the results of ongoing work aimed to better understand these two types of close stellar interactions.

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Dynamical formation of Gaia BH1 in a young star cluster

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Gaia BH1, the first quiescent black hole detected using data from the Gaia mission presents a challenge to existing binary evolution models due to its unusual characteristics, such as a mass ratio of

approximately 0.1 and an orbital period that does not align with typical post-common envelope or non-interacting binary systems.
To investigate its formation, we explore the hypothesis that Gaia BH1 originated from dynamical interactions within a young star cluster (YSC). We use direct *N*-body simulations coupled with binary population synthesis, considering YSCs with initial masses ranging from 300 to 3 × 10^4 solar masses at Solar metallicity.
We find that BH-MS systems that form via dynamical exchanges populate the region corresponding to the main orbital properties of Gaia BH1 (period, eccentricity, and masses). In contrast, none of our isolated binary systems matches the orbital period and MS mass of *Gaia* BH1. Our best matching *Gaia* BH1–like system forms via repeated dynamical exchanges and collisions involving the BH progenitor star, before it undergoes core collapse. YSCs are at least two orders of magnitude more efficient in forming *Gaia* BH1–like systems than isolated binaries

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Young Star Clusters Dominate the Production of Detached Black Hole-Star Binaries

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The recent discovery of two detached black hole-star (BH-star) binaries from Gaia's third data release has sparkled interest in understanding the formation mechanisms of these systems. We investigate the formation of these systems by dynamical processes in young open star clusters (SCs) and via isolated binary (IB) evolution, using a combination of direct N-body models and population synthesis simulations. By comparing dynamical and isolated systems created using the same model of binary stellar evolution, we find that dynamical formation in SCs is nearly 40 times as efficient, per unit of star formation at producing BH-star binaries as isolated binary evolution. We expand this analysis to the full MW using the star-formation history of a MW-mass hydrodynamical simulation (from the FIRE-2 suite of simulations) as a guide. Even assuming that only 10% of star formation produces SCs with masses $> 1000\ \mathrm{M}_{\odot}$, we find that the MW contains $\sim 2 \times 10^5$ black hole-star systems, with approximately 4 out of every 5 systems systems being formed dynamically. Many of these dynamically-formed systems have larger orbital periods, eccentricities, and black hole masses than their isolated counterparts, and we show that any system with $e > 0.5$ or $M_{\mathrm{BH}} > 10\,\mathrm{M}_{\odot}$ can only be formed through dynamical processes. Taking into account the detectability of systems in the current and future Gaia data releases, our MW model predicts between 61 and 210 detections from the complete DR4 Gaia catalog, with the majority of systems being dynamically formed in a massive and metal-rich SC. Finally, we compare our populations to the recently discovered Gaia BH1 and Gaia BH2, and we conclude that the dynamical scenario is the most favorable formation pathway for both of them, and especially for gaia BH2.

WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 33

Unveiling black holes in open clusters

Author: Stefano Torniamenti[1]

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Open clusters are the place where a large fraction of massive stars form, evolve, and eventually die, giving birth to stellar-mass black holes. If a significant fraction of black holes receives low (⊠ km /s) kicks at birth, even open clusters with low escape velocities can efficiently retain them. Thanks to the exquisite astrometric and photometric measurement by *Gaia*, we have now the opportunity to

infer the presence of these black holes from the imprints they leave on the observable properties of the host cluster.

In my contribution, I will present the very first attempt to search for signatures of black holes in the nearest open cluster to the Sun, the Hyades. I will compare the stellar mass distributions from direct N–body models to those derived from the high-precision data by Gaia. Specifically, I will quantify the impact of black holes on the mass and kinematic profiles of the stars, and on the structure of the tidal tails. By this comparison, I will estimate whether a central black hole component is required to match the observed stellar distributions.

My results indicate that, at the present day, the radial mass distribution of stars provides the most effective tracer to find signatures of black holes in open clusters. For the Hyades, the observations are best reproduced by models with 2–3 black holes at present. Models that have never possessed black holes have an half-mass radius ~ 30% smaller than the observed value, while those where the last black holes were ejected ▯ 150 Myr ago can still reproduce the density profile. Thus, the Hyades present-day structure requires a significant fraction of black holes to form with low kicks (< 3 km/s) to match the observations.

WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 37

Natal Kicks on Compact Objects: Insights from Gaia's Precision Astrometry

Author: Yue Zhao[1]

Co-authors: Poshak Gandhi [1]; Cordelia Dashwood Brown [1]; Christian Knigge [1]; Phil Charles [1]; Thomas Maccarone [2]; Pornisara Nuchvanichakul [3]

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The death of massive stars can impart an impulse to the remnant black holes (BHs) and neutron stars (NSs) during supernova explosions. This impulse, also known as a natal kick (NK), can propel the compact objects to substantial space velocities. Understanding the motions perturbed by NKs not only sheds light on the underlying supernova physics but also plays a crucial role in the evolution of compact object binary which are potential gravitational wave sources. This presentation will focus on our recent investigation on systemic peculiar velocities ($v_{\rm pec}$) in an extended sample of binaries hosting NSs or BHs. Our analysis finds no clear difference in $v_{\rm pec}$ distributions between binaries hosting BHs and NSs. However, it uncovers a significant difference between binaries hosting low-mass (LM) and high-mass (HM) non-degenerate companions. HM binaries are constrained to$v_{\rm pec}$ lower than 100 km/s while LM binaries exhibit a more extensive distribution, reaching about 400 km/s. We further found a significant anti-correlation of $v_{\rm pec}$ with binary mass, which is consistent with our expectation that heavier binaries are more resistant to acceleration by NKs. This presentation will also present a related discussion based on an already-developed kinematic framework.

WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 99

Follow-up studies of Gaia transients with small and medium-sized telescopes: recent results and findings (poster pitch)

Author: Vira Godunova[1]

Co-authors: A. Simon [2]; E. Pavlenko [3]; I. Izviekova [1]; M. Chupira [2]; V. Reshetnyk [2]; V. Taradii [1]; V. Troianskyi [4]; Y. Markus [1]

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We report on optical observations of transient objects detected by ESA Gaia, DPAC and the Photometric Science Alerts Team (http://gsaweb.ast.cam.ac.uk/alerts). Ground-based observations contribute significantly to achieving advances in studies of these objects, especially in their classifying. In 2016, we started to observe Gaia transients using the telescopes with diameters up to 2 m. Our research activities are highly focused on BVRI photometry of sources with unusual brightness variations; a lot of them have been continuously observed over the years. These datasets allowed us to reveal physical characteristics of many objects, as well as to classify a number of transients.

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Potential of Gaia BP/RP spectra and LDS sky surveys for study of high z Universe (poster pitch)

Author: Rene Hudec[1]

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Gaia Blue (BP) and Red (RP) Photometer low-resolution spectral data is one of the exciting new products in Gaia Data Release 3 (Gaia DR3). However, analogous LDS (low dispersive spectral data) data also available in numerous historical photographic sky surveys (access after digitization).
My estimate is more than 100 mil LDS star spectra covering time period of more than 60 years in these databases. These LDS photographic sky surveys have the potential of adding historical epochs to Gaia LDS spectra. This may allow to study prominent spectral variations with time … field so far little exploited. Both Gaia BP/RP and archival LDS data have excellent potential for recent astrophysics e.g searches for high z objects and optical counterparts of gamma ray bursts (GRBs).

WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 64

Characterisation of Gaia alerts using the Virtual Observatory (poster pitch, online)

Author: Enrique Solano[1]

Co-authors: Alessandro Ederoclite [2]; Almudena Velasco [1]

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Transients can be defined as astrophysical phenomena whose duration is significantly lower than the typical timescale of the stellar and galactic evolution (from seconds to years in contrast to millions or billions of years). Supernovae, novae, gamma-ray burst,…, are some examples of transient events. In most cases, a fast, multiwavelength characterisation is required to properly understand the true nature of the transient. Follow-up observations made by both professional and amateur astronomers using ground- and space-based facilities are key to achieve this goal.

In this poster we propose an alternative and complementary approach using the existing information in astronomical archives and benefiting from the advantages that the Virtual Observatory (VO) offers in terms of discovery, access and analysis of astronomical data. Using VO tools and services (STILTS, VOSA, SVO DiscTool) we will describe an automated workflow to validate and characterise candidate Cataclysmic Variables identified by the Gaia Science Alerts project.

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Report WG2: The Life and Death of Stars (online)

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WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 103

Gaia RVS spectroscopy (invited talk)

Author: Alejandra Recio-Blanco[None]

In June 2022, the Gaia Data Release 3, completing the previous EDR3, made possible a 3D kinematical and dynamical analysis of 33 million stars in the Milky Way and its satellites. In addition, Gaia DR3 has opened a new era of all-sky chemo-physical analysis of stellar populations thanks to the nearly 5.6 million stars observed by the Radial Velocity Spectrometer and parameterized by the GSP-Spec module. This all-sky Gaia chemo-dynamical cartography allows a powerful and precise view of the Milky Way with unprecedented spatial coverage, statistical robustness and spectral fidelity. The RVS spectrographe, with a resolution of 11 500, is enabling a stellar parametrization of quality comparable to ground-based surveys of higher spectral resolution and wavelength coverage. In this talk I will discuss the reasons of the Gaia RVS spectral fidelity, unexpected for a large part of the scientific community, and the different advantages of a space spectroscopic survey like Gaia. In addition, the RVS performances in chemo-physical parametrization will be presented through several scientific examples, including heavy element abundances, comparisons with asteroseismic surveys, the detailed characterization of stellar evolutionary phases and Milky Way astrophysics. The Gaia chemical constraints on our understanding of Milky Way's nature and nurture evolution, will be particularly highlighted.

WG4 (II) & WG2: The life and death of stars (I). Chair: Mercè Romero / 35

Young, (metal-)rich ad not alone: formation of thin-disc RR Lyrae stars through binary evolution

Author: Giuliano Iorio[1]

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Despite the classical interpretation of RR Lyrae as old and metal-poor population II stars, it is well known that metal-rich (up to solar values) RR Lyrae stars exist in the solar vicinity. Thanks to the unprecedented Gaia capabilities (Gaia DR2 and Gaia DR3), we found that the metal-rich RR Lyrae stars are present all over the Galactic disc, well beyond the Solar neighbourhood. The kinematics of these stars is consistent with a young (less than 5 Gyr) thin-disc population. An age of only a few Gyrs would be very difficult to reconcile with the conventional scenarios of the RR Lyrae formation. At the same time, assuming that they are instead truly old implies that they are tracing one of the oldest components of the Milky Way. Alternative formation channels for RR Lyrae can be called into play to solve this conundrum. In particular, I will present the results of a set of MESA binary simulations showing that is theoretically possible to produce a population of metal-rich RR Lyrae with ages consistent with the thin-disc populations. Such stars are formed after an episode of Roche-Lobe overflow mass transfer that ends with a partial envelope stripping of the donor star.

WG2. The Life and Death of Stars (II). Chair: Ivanka Stateva / 43

A Multi-wavelength Study of the Galactic Point Sources in the MeerKAT Galactic Plane Survey with GAIA DR3

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The MeerKAT Galactic Plane Survey is a radio continuum survey conducted in the L band (~1.4 GHz) in the Galactic plane, covering a wide range of galactic longitudes, spanning from 0 to 60 degrees and 250 to 360 degrees and mostly within a latitude range of |b| ≤ 1.5 degrees. The survey resulted in the detection of approximately 5×105 sources. In this study, we present our analysis of the Galactic sources by cross-matching the radio point sources with the GAIA Data Release 3 (DR3) catalog using a Bayesian cross-match approach. To refine our sample and mitigate spurious and extragalactic counterparts, we imposed a selection criterion based on GAIA parallax over error, focusing on sources with a parallax measurement accuracy of at least 10. This restriction reduced our initial crossmatch sample size to approximately 3000 sources. Leveraging the GAIA extinction measurements along the line of sight and the reddening parameter, we applied extinction corrections to the magnitudes and dereddened the colors of the selected sources. Utilizing the dereddened colors and extinction-corrected magnitudes, we constructed a color-magnitude diagram (CMD). The CMD analysis revealed a diverse population of stellar objects, ranging from massive OB stars, white dwarfs, RS CVn binaries, high-mass X-ray binaries (HMXB), YSOs and dMe flare stars. Additionally, we conducted spectroscopic observations of some of the young stars using the Mokodi instrument on the 1-m Lesedi telescope at SAAO. These observations revealed the presence of H-alpha emission, a characteristic emission associated with coronally and chromospherically active radio stars. Our findings provide valuable insights into the radio stellar populations within the Galactic plane, showcasing the diverse range of stellar objects detected in the MeerKAT Galactic Plane Survey. This study highlights the power of cross-matching radio surveys with multi-wavelength datasets, enabling comprehensive characterization of Galactic sources and advancing our understanding of stellar evolution in our galaxy.

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The problem of variability of chemically peculiar Am stars

Authors: Natalia Posiłek[1]; Ewa Niemczura[1]

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The metallic-line (Am) stars, classified as chemically peculiar A and early F stars, exhibit unique spectral characteristics with weak Ca II K and Sc lines, along with strong Fe-group features compared to their H-line spectral type. These stars are located in the classical instability zone, where pulsating delta Scuti stars lie. For many years, it was believed that classical Am stars cannot pulsate due to the gravitational settling of helium in the He II partial ionization zone, which is the driving mechanism for delta Scuti pulsations. However, subsequent studies have revealed pulsations in many Am stars (Smalley et al., 2017, MNRAS, 465, 2662). Antoci et al. (2014, ApJ, 796, 118) proposed that turbulent pressure may be the primary driving mechanism for pulsating Am stars, in contrast to the classical kappa-mechanism.

By conducting a detailed analysis of high-resolution and high signal-to-noise spectra, alongside the analysis of photometric data, we aim to study the problem of variability in chemically peculiar Am stars. We performed spectral classification on approximately 400 stars previously classified as metallic stars, revealing that only about half of them exhibit features typical of Am stars. Furthermore, we have obtained atmospheric parameters and will present the results of our spectroscopic analysis combined with pulsation information for these stars.

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Study of galactic AGB stars from Gaia and the Virtual Observatory

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Co-authors: Belén López Martí [2]; Cuán de Barra [3]; Dieter Engels [4]; Pedro García-Lario [5]

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Gaia data has revolutioned our knowledge in many fields of Astronomy. If we add the power of the Virtual Observatory (VO), we obtain a very usefull research framework. We have combined Gaia and the VO to have an insight into the Asymptotic Giant Branch (AGB) phase of stellar evolution.

From the study of AGB stars in the Magellanic Clouds, three evolutionary paths depending on the stellar masses were proposed: The lower-mass stars ($M \leq 1.5M_{\odot}$), which include classical Mira variables, are oxygen-rich; in contrast with intermediate-mass stars ($1.5M_{\odot} \leq M \leq 3M_{\odot}$), which are carbon-rich. On the higher-mass end ($M \geq 3M_{\odot}$), stars experience the so-called "Hot Bottom Burning" process, in which the temperature at the bottom of the convective envelope is enough to initiate hydrogen burning. This process destroys carbon, thus preventing the stars from becoming carbon-rich; hence high-mass AGB stars are also oxygen-rich. Variable OH/IR stars belong to this group. This scenario of chemical branching is widely accepted. However, it is far from being confirmed in our Galaxy, mainly due to the lack of reliable distances for a significantly large number of stars. Something that Gaia has now changed.

With the propose of testing this evolutive scenario in our Galaxy, we have defined three different samples of thousands of AGB stars with Gaia counterpart, corresponding to the three chemical paths. With the VO, we have built their spectral energy distributions and used the distances estimated from Gaia DR3 parallaxes to derive their absolute luminosities. Furthermore, we have analysed the Gaia DR3 light curves to characterize their variability properties.

In this talk, we will present the results of this study, with special emphasis on the comparison between the properties shown by the three samples of galactic AGB stars.

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The white dwarf population revealed by Gaia

Author: Santiago Torres Gil[1]

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The *Gaia* mission has brought an unprecedented revelation in our understanding of the white dwarf population of the Solar neighborhood. The excellent astrometry and photometry provided by DR2 and eDR3 have unveiled unexpected patterns in the Hertzsprung-Russell diagram, such as the bifurcation or the so-called Q-branch. The analysis and comprehension of such features rely on an accurate determination of the type of atmospheres of white dwarfs (dominated by hydrogen, or helium, or with traces of carbon or other metals). This fact is crucial for determining key stellar parameters, such as temperature, mass, or age of these objects. The use of powerful analysis tools such as VOSA (Virtual Observatory SED Analyzer) or automated classification techniques like Random Forest algorithm has enabled the extraction of maximum information from low-resolution spectra provided by *Gaia* DR3 for approximately 100,000 white dwarfs within 500 pc, allowing for a spectral classification that sheds light on those intriguing characteristics of the white dwarf population.

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Kinematic study of the Orion Complex in the GAIA era

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Co-authors: Jesús Hernández [1]; Ángeles Pérez-Villegas [1]

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The study of Young Stellar Clusters (YSCs) has gained relevance in modern astrophysics thanks to the role played by large scale surveys with unprecedented precision. In particular, in the solar neighborhood, multiple star-forming regions will be used to characterize YSCs in terms of kinematics, stellar masses and chemical composition, the main ingredients to understand the dynamical evolution during their early stages. With astrometric information provided by GAIA DR3, we have selected a star sample below 30 Myr in the Orion Complex to identify kinematic groups. After applying the clustering algorithm HDBScan in the 5D parameter space (sky position, proper motions, and parallax), we found between 10 and 14 big stellar groups, according to the parameters provided to HDBScan. The majority of the detected groups show expansion, contraction, or rotation, which can give us a clue about the dynamic effects the region is undergoing. Including spectroscopic data from APOGEE and GALAH, we can explore a general characterization of each cluster considering atmospheric parameters, obtaining subtle differences in metallicity and ages. After this analysis, the identified groups can be used by performing N-body simulations and evaluate statistically the likely scenarios in which the clusters formed and also will evolve. This study will allow us to create a proof of concept to extrapolate toward other star-forming regions in the Galaxy.

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Fine structure in the Sigma Orionis cluster revealed by Gaia DR3

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Sigma Orionis is an open cluster in the nearest giant star formation site - Orion. Its youth (2-4 Myr), little reddening and relative vicinity make it an important benchmark cluster to study stellar and substellar formation. I will present the first detailed kinematic study of the Sigma Orionis cluster with the Gaia DR3 data. It reveals a clear substructure of this complex region with proper motions that differ from the main cluster. This revised membership list with 72 new members will serve as the basis for the future studies of age determination, the frequency and evolution of stellar multiplicity, the presence of discs and exoplanets, and the initial mass function in the low mass/substellar regime down to planetary masses. Connections between the Gaia and the Euclid space mission for the study of this cluster will be discussed.

WG2.(II) & WG5: Impact, Inclusiveness and Outreach. Chair: Friedrich Anders / 53

Analysis and Classification of Hot Subdwarfs Using Artificial Intelligence Techniques and Gaia DR3 data (poster pitch, online)

Authors: Carlos Viscasillas Vázquez[1]; Enrique Solano[2]; Ana Ulla-Miguel[3]; Marco Antonio Álvarez González[4]; Raúl Santoveña Gómez[4]; Minia Manteiga Outeiro[4]; José Carlos Dafonte Vázquez[4]; Esther Perez-Fernández[3]; Carlos Rodrigo[5]; Alba Aller[5]; Raquel Oreiro[3]

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In this study, we present an analysis of hot subdwarf stars (hot sds) based on the catalogue provided by Solano et al. (2022). Our analysis includes the utilization of the newly available Gaia DR3 data including the treatment of BP/RP spectra using artificial intelligence (AI) techniques. The AI techniques employed in this study involve Self Organized Maps (SOM) and software tools accessible to our collaboration group. This collaboration involves researchers of the Galician Group for the Gaia satellite (GGG), from the University of A Coruña (UDC) and the University of Vigo (UVIGO), in association with the Gaia DPAC consortium, of the Spanish Virtual Observatory (SVO) and of the University of Vilnius (Lithuania).

Our current work focuses on the development of a novel classification method for hot subdwarfs in binary systems, employing supervised machine learning (ML) techniques. Subsequently, we calculate the distribution of binary probabilities. For training purposes, we selected samples from Solano et al. (2022) and Drilling et al. (2013), and we applied our methodes to a larger catalogue of over 39,000 blue candidates as presented in Geier et al. (2019). We plan to compare our results with the outcomes derived from SOM techniques and also in the context of Virtual Observatory (VO) techniques as explored in Solano et al. (2022). These analyses aim to contribute to a better understanding of hot subdwarfs evolution and to enhance our knowledge of binary systems within this class, using advanced AI and data mining methodologies.

This abstract is framed within a Short-Term Scientific Mission (STSM), as part of a research exchange between members of the GGG consortium, the SVO and a visitor (presenting author) from the University of Vilnius, aiming to strengthen scientific collaboration and to advance the field of hot subdwarf classification using artificial intelligence techniques.

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Geier, S. ; Raddi, R.; Gentile Fusillo, N. P. ; Marsh, T. R. (2019). A&A, 621, A38.
Solano, E. ; Ulla, A. ; Pérez-Fernández, E. et al. (2022). MNRAS 514, 3.

Acknowledgments:
CVV and AUM acknowledge the MW-Gaia COST Action CA18104.

WG2.(II) & WG5: Impact, Inclusiveness and Outreach. Chair: Friedrich Anders / 57

Symbiotic stars in Gaia DR3 (poster pitch, online)

Author: Jaroslav Merc[1]

Co-authors: Rudolf Gális [2]; Marek Wolf [1]; Lionel Mulato [3]

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Symbiotic stars are interacting binary systems consisting of a red giant and a hot companion, typically a white dwarf or, in some cases, a neutron star. They constitute unique astrophysical laboratories for the study of various phenomena, including mass transfer and accretion, stellar winds and their collision, formation and collimation of jets, production and destruction of dust, stellar pulsations, or thermonuclear outbursts. These systems also play an important role in stellar and binary evolution and have been proposed as possible progenitors of supernovae Ia.

Despite their significance, many questions regarding the parameters of symbiotic components or evolutionary channels leading to the symbiotic phenomenon remain unanswered. In this contribution, we explore various aspects of Gaia DR3 in the study of symbiotic stars. We focus on the astrometric, photometric, spectroscopic, and astrophysical data presented for known symbiotic systems and compare them with the parameters presented in the literature and collected in our New Online Database of Symbiotic Variables. Additionally, we present the first results of the effort aimed at classifying new symbiotic candidates identified in the Gaia DR3 and introduce a novel method to search for new objects of this class using Gaia observations, supplemented by the data from various other surveys.

WG2.(II) & WG5: Impact, Inclusiveness and Outreach. Chair: Friedrich Anders / 70

Exploring chemical tagging limitations and feasibility with Gaia-ESO Survey (poster pitch)

Author: Helio Perottoni[1]

Co-authors: Rodolfo Smiljanic [1]; Maria Luiza Dantas [1]

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Chemical tagging is a promising technique for studying and reconstruct the history of our Galaxy by grouping stars based on their similar chemical compositions. To investigate the feasibility and effectiveness of this technique, we utilized high-resolution observations from the Gaia-ESO Survey with Gaia DR3 data to select open clusters and field stars, obtaining additional information on ages and distances from the StarHorse code. Our preliminary results focus on analyzing the importance of heavy elements in the chemical tagging process, as well as exploring the impact of abundance errors, the recovery fraction of open cluster members, and addressing the contamination from field stars. Through these investigations, our aim is to advance our understanding of implementing chemical tagging, which could provide valuable constraints for future models on mixing and chemical enrichment.

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Spectral Classification of Gaia White Dwarfs within 500 pc using a Random Forest Algorithm (poster pitch)

Author: Enrique Miguel García Zamora[1]

Co-authors: Santiago Torres [1]; Alberto Rebassa-Mansergas [1]; Francisco M. Jiménez-Esteban [2]; Raquel Murillo-Ojeda [2]; Patricia Cruz [2]; Enrique Solano [2]

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The third Gaia data release has provided low resolution BP/RP spectra for nearly 100,000 white dwarfs, the most common stellar remnant. The sheer magnitude of this quantity of data precludes the possibility of performing spectral analysis and type determination by human inspection. However, the current development of machine learning techniques allows us to tackle this issue in a satisfactory manner. In this contribution we use a Random Forest algorithm for extracting the maximum information locked in the Gaia spectra coefficients. We aim to classify the white dwarf population into its different atmospheric spectral types; a key feature for accurately deriving stellar parameters of these stars such as their masses, temperatures or ages. Our results are first validated using a sample of white dwarfs within 100 pc from the Sun, achieving an overall accuracy of 90%. We then apply our Random Forest algorithm for spectral classification to the 500-pc white dwarf sample, which comprises over 95% of all known white dwarfs with available Gaia spectra.

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Population synthesis study of the Gaia single and binary white dwarf population within 100 pc (poster pitch)

Author: Alejandro Santos García[1]

Co-authors: Alberto Rebassa-Mansergas [1]; Santiago Torres [1]

[1] *Universitat Politècnica de Catalunya*

White dwarfs and binary stars can provide a wealth of information about the origin and evolution of the Galaxy and its constituents. Thanks to Gaia, we now have astrometric and photometric data from an immense number of white dwarfs previously unknown, and the number of binary systems has also increased exponentially. Moreover, the completeness of such systems to a distance of 100 pc is higher than 95%. To understand their physics, we are simulating the different Galactic populations of binary systems that contain at least one white dwarf. To that end we use a Monte Carlo code together with a stellar evolutionary code conveniently adapted to cover a wide range of stars from all ages, masses and metallicities. Different physical processes such as mass transfer, common envelope evolution, collisions or tidal interactions are considered, which can give us a hint about the formation history and evolution of the observed stars. The ultimate end is to compare the outcome of the simulations with the nearly complete observed Gaia samples in the Solar Neighborhood to constrain current evolutionary models.

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White dwarfs with infrared excess: Gaia and the Virtual Observatory (poster pitch)

Author: Raquel Murillo-Ojeda[1]

Co-authors: Francisco M. Jiménez-Esteban [2]; Enrique Solano [2]; Alberto Rebassa-Mansergas [3]; Santiago Torres [3]

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White dwarfs (WDs) are one of the most common objects in the universe. They are stellar remnants of low and intermediate mass stars, such as the Sun. WDs are compact objects, with typical masses around half a solar mass and planetary sizes. The superb astrometric data provided by Gaia has

been a revolution in the field, like the discovery of several cooling branches in the Gaia Hertzsprung-Russell diagram which were unpredicted by the models and which still remain not fully explained. In addition, thanks to Gaia the number of known WDs in the Galaxy has increased tenfold, allowing us to perform more detailed studies of peculiar types of WDs, such as WDs with infrared excesses that may be due to debris disks or substellar companions. They are key sources in the understanding of the composition and evolution of exoplanetary material around intermediate mass stars in their late stages of evolution.
In this poster we describe the work aimed at identifying nearby (< 100 pc) WDs with infrared excess. Starting from the so far most complete volume-limited WD sample built from Gaia-DR3 data (Jiménez-Esteban et al. 2023MNRAS.518.5106J), we use Gaia DR3 spectra and the GaiaXPy tool to obtain J-PAS photometry. With the help of VOSA, a Virtual Observatory tool, the J-PAS photometry is complemented with photometry in the infrared and used to build the spectral energy distribution (SED). In a second step, SEDs are compared to model atmospheres to identify flux excess at infrared wavelengths.
Once we have got rid of the potential sources of contamination, the origin of the excess can be attributed to two causes: The presence of a low mass companion or the existence of a circumstellar dust disk. Spectroscopic observations are required to discern between the two possible scenarios. This is why we started a follow-up program of the most promising candidates using the X-Shooter instrument at the Very Large Telescope. In this poster, we will show the first results obtained in this analysis.

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The Gaia color-magnitude diagram revealing the physics of white dwarfs (poster pitch)

Authors: Alberto Rebassa-Mansergas[1]; Maria Camisassa[1]; Roberto Raddi[1]; Santiago Torres Gil[1]

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White dwarf stars are the most common end-point of stellar evolution. Therefore, these numerous, old and compact objects provide valuable information on the late stages of stellar evolution, and the structure and evolution of our Galaxy. The ESA Gaia space mission has revolutionized this research field, revealing unexpected features on the color-magnitude diagram for white dwarf stars, and raising new questions on the nature of these stars. Namely, the white dwarf cooling sequence is divided into three main branches: A, B and Q. On the basis of detailed theoretical evolutionary models and population synthesis studies, we have analyzed these branches providing possible explanations for them. We found that the Q branch can be reproduced if the energy released by crystallization and sedimentation of minor species is included, and that the B branch can be explained by a hidden population of white dwarfs with "invisible" atmospheric carbon traces.

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Reactive collisions of electrons with molecular cations of astrophysical interest: effects to H2+, HD+, H3+ (poster pitch)

Authors: Felix Iacob[1]; Ioan Schneider[2]; Kalyan Chakrabarti[3]; M. D. Epée Epée[4]; Nicolina Pop[5]; Ousmanou Motapon[6]; Zsolt Janos Mezei[7]

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The dissociative recombination (DR) together with the competing reactions – ro-vibrational excitation/de-excitation of the hydrogen molecular ion plays a decisive role in astrophysical ionized media: stars and interstellar molecular clouds, early Universe.
Using a stepwise method based on Multichannel Quantum Defect Theory (MQDT) [1], cross sections and rate coefficients have been obtained for reactions induced on HD+[2], H2+ [3] and D2+ [6] .
For H2+, the full rotational computations improved considerably, the accuracy of the resulting dissociative recombination cross sections and Maxwell isotropic rate coefficients [5]. The different mechanisms taken into account for H2+, i.e. direct vs indirect and rotational vs non-rotational processes are presented.
An analytic three-channel model was developed for the description of simultaneous direct and indirect DR cross sections of H3+ [4].
For these analyzed systems the results is in good agreement with the CRYRING (Stockholm) and TSR (Heidelberg) magnetic storage ring results.

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Peculiar radial velocities and action values of red supergiant stars in RSGC4 (poster pitch)

Author: Sang-Hyun Chun[1]

Co-authors: Gyu-Choel Myeong [2]; Jae-Joon Lee [1]; Heeyoung Oh [1]

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Young massive clusters are excellent laboratories to study the star formation process and structures of galaxies as well as massive stellar evolution. Six red supergiant clusters (RSGCs) recently found in the Scutum-Crux arm can provide insights into starburst history and chemical enrichment in the region. We report that RSGs in RSGC4 (Alicante 8) show peculiar radial velocities and action values. Combining the radial velocities measured from high resolution (R~45,000) near-infrared spectra of IGRINS and Gaia proper motion, we find that RSGs in RSGC4 do not exhibit disk-like motion, unlike the other clusters. We additionally find that RSGs in RSGC1 show significant vertical motion characterized by large inclinations and eccentricities. From photometry, action values, and spectroscopy data, we carefully raise the possibility that RSGC4 is not a genuine star cluster but rather a composite of stars (RSG and AGB) along the line of sight.

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New O and Be runaways stars found with Gaia DR3 (poster pitch)

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Co-author: Marc Ribó [2]

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A relevant fraction of massive stars are runaway stars, moving with a significant peculiar velocity with respect to their environment. The runaway origin can be explained by kicks produced in supernova explosions or by dynamical ejection of stars from clusters. Runaway stars can be detected using accurate proper motions and parallaxes such as the ones provided by Gaia. We present here a 2-dimensional method in the velocity space to discover runaway stars among GOSC and BeSS catalogs using Gaia DR3 data. We found 106 O runaway stars, 42 of them with no previous identification as runaways, and 69 Be runaway stars, 47 of them with no previous identification as runaways. We further characterize their velocity dispersion, spatial distribution and runaway percentage as a function of the spectral type. The percentage of runaways is 25.4% for O-type stars and decreases to 5.2% for Be-type stars. The higher percentages and larger velocities found for O-type runaways compared to Be-type ones reinforce the dominance of the dynamical ejection scenario versus the binary supernova one. Our results open the door to identify new high-energy systems or stellar bow shocks among our runaways by conducting detailed studies.

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Report WG5: Impact, Inclusiveness and Outreach

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The billion ways of using Gaia data (invited talk)

Author: Tineke Roegiers[1]

[1] *ESA*

Gaia data is used in many ways by many scientists and the diversity of the research topics is dazzling, making it sometimes seem like there could be a billion ways of using Gaia data. While Gaia's impact mapping the Milky Way might be obvious, Gaia's data has been used closer to home as well, and further out beyond the Milky Way. A full overview of the many results Gaia data helped with is impossible to make, but a taste of the diversity of topics affected by Gaia is aimed at here. Starting from the Sun we will move out into the Solar System, further out into the Milky Way, and then beyond, all the while exploring the different ways Gaia data has been used so far and pointing to existing outreach resources to learn more about these topics.

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Impact, Inclusiveness and Outreach: Outputs from the MW-Gaia WG5 School

Author: Dionysios Gakis[1]

[1] *University of Patras*

The main goal of MW-Gaia is to enhance the scientific exploration of the Gaia satellite results across the community in Europe and beyond. WG5 working group is devoted to impact, inclusiveness and

outreach, and one of the workshops organized towards this plan is the WG5 School. The program includes four sessions, workshops, hands-on activities covering topics such as public engagement, practical skills for engaging with diverse audiences, and training in social innovation. As a selected participant for the school, we will present the outputs of this event, such as ideas and initiatives to improve inclusion and impact, reinforcing the importance of equity, diversity, and inclusion commitment in research. Lastly, this poster will present the highlights from the participants' assigned projects, showcasing the ideas developed during the school.

WG2. The Life and Death of Stars (III). Chair: André Moithino. / **86**

The bright future of open clusters

Author: Antonella Vallenari[1]

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Open clusters are an ideal laboratory to understand star formation and evolution. Open clusters provide an important contribution to the overall mass budget and stellar population properties of the disk, making their study a crucial element in the understanding of the processes that led to the formation of the disk in the Milky Way and in general in spiral galaxies. Gaia Data Releases have brought an unprecedented renaissance in the open cluster exploration making them an increasingly central topic. Further development in the field is expected from the next Gaia Data Releases and from the upcoming spectroscopic surveys, WEAVE@WHT and 4MOST@VISTA where dedicated surveys will provide large homogenous databases of chemical abundances and radial velocities. In this talk we will discuss what is expected from the upcoming Gaia Data Releases. We will present the open cluster surveys with WEAVE and 4MOST, discussing the synergies and the impact of the different observational strategies on the science cases.

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Detection of open cluster rotation fields from Gaia DR3 proper motions

Author: André Moitinho[1]

Co-author: Alberto Krone-Martins [2]

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Most stars from in groups which with time disperse, building the field population of their host galaxy. In the Milky Way, open clusters have been continuously forming in the disk up to the present time, providing it with stars spanning a broad range of ages and masses. Observations of the details of cluster dissolution are, however, scarce. One of the main difficulties is obtaining a detailed characterization of the internal cluster kinematics, which requires very high quality proper motions. For open clusters, which are typically loose groups with some tens to hundreds of members, there is the additional difficulty of inferring kinematic structures from sparse and irregular distributions of stars.

In this work, we seek to map the internal stellar kinematics of open clusters, and identify rotation, expansion or contraction patterns. To this end, we use Gaia (early) Data Release 3 (eDR3) astrometry and Integrated Nested Laplace Approximations to perform vector-field inference and create spatio-kinematic maps of 1237 open clusters with available lists of members.

We report the detection of rotation patterns in a 8 open clusters, with some additional clusters display possible rotation signs. We also observe 14 expanding clusters, with over 10 other objects showing

possible expansion patterns. Contraction is identified in 2 clusters, with 1 additional cluster presenting a more uncertain detection. In total, 53 clusters are found to display kinematic structures. Within these, elongated spatial distributions suggesting tidal tails are found in 5 clusters.

These results indicate that the approach developed here can recover kinematic patterns from noisy vector fields, as those from astrometric measurements of open clusters or other stellar or galactic populations, thus offering a promising probe for exploring the internal kinematics and dynamics of these types of objects.

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Mass loss in open clusters

Authors: Duarte Almeida[1]; André Moitinho[1]

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Most stars are thought to be born in groups which later dissolve into the field population of their host galaxy. This dissolution and integration into the field population has long been a topic of interest. For example, Lamers et al (2005) explored this process using the open cluster (OC) age distribution derived from the Kharchenko et al. (2005) OC catalogue. With the advent of the Gaia mission, we have an exceptional opportunity to revisit and enhance these studies using high-quality data.

Given the absence of large scale, high-quality mass determinations for OCs, we have determined the luminous masses for 1724 OCs using the Dias et al. (2021) catalogue of cluster parameters and stellar memberships. In the process, we have also determined the cluster radii through King profile fits. We discuss the effect of the radii uncertainties on the derived masses.

We have implemented a model for the build-up and mass evolution of a population of OCs, following Lamers et al. (2005). By comparing our simulations with the observational data, we reproduced the disruption timescale and mass dependency parameters previously obtained in the literature. However, while there is a reasonable agreement for the age distribution, the simulated mass distribution does not match the observations for any combination of the parameters. We note that in the previous studies only age distributions had been considered. Not mass distributions.

We found, however that the mass distribution of young clusters does not follow the typically assumed power-law for the Cluster Initial Mass Function (CIMF); instead, it exhibits a log-normal behaviour. This motivated modifying accordingly the CIMF used in the model, which significantly improved the agreement between simulations and the observed mass distribution. These findings suggest that the mass distribution for non-embedded clusters, at the moment they emerge from their parent molecular clouds, may differ from the commonly adopted power-law CIMF, which is derived from embedded clusters. Moreover, our results also suggest a previously unexplored mass dependence associated with the disruption arising from cluster emergence from molecular clouds. These new insights pave the way for further investigations, offering valuable perspectives on the formation and evolution of stellar systems within the context of the Gaia mission.

References:
Dias et al. (2021)
Kharchenko et al. (2005)
Lamers et al (2005)

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The new detection of blue straggler stars in 50 open clusters using Gaia DR3

Author: ChuanYan Li[1]

Co-authors: Jing Zhong [1]; Li Chen [1]; Songmei Qin [1]

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The particularly abundant presence of blue straggler stars (BSS) in Galactic open clusters offers favorable conditions for detailed studies on the statistical properties and the origin of the blue straggler population. With the help of Gaia DR3, the number of identified open clusters continuously increases, and the determination of star cluster members is more reliable. We performed a homogeneous and more thorough search for BSS in newly found open clusters by implementing a uniform membership determination for over one thousand newly identified open clusters with larger sky coverage based on the Gaia DR3 astrometric and photometric data. The membership probabilities of stars were assigned by the pyUPMASK algorithm. Then we estimated the physical parameters of these clusters by isochrone fitting on their CMDs and picked out BSS in the specific region of these CMDs. As a result, we identified 138 BSS that had not been reported before in 50 open clusters. Compared with the latest catalogs that present a total of about 1500 BSS in 339 open clusters, our new catalog increased the number of BSS in Galactic open clusters by about 10%, and the number of open clusters with BSS by nearly 17%. In the future, more accurate abundance measurements are anticipated to better probe the formation pathways of BSS in open clusters.

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Evolution of the Vertical Distribution of Open Clusters in the Milky Way

Authors: Sandro Moreira[1]; André Moitinho[1]

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The scale height of the spatial distribution of open clusters in the Milky Way exhibits a well known increase with age. This increase is usually attributed, in a vague way, to disc heating mechanisms similar to those that act on individual stars. In this contribution, we address the evolution of the scale height of open clusters from a different angle, as an effect of the disruption of clusters due to disc phenomena such as encounters with giant molecular clouds. We present a dynamical model that follows the orbits of open clusters and includes their disruption due to interactions with the disc. We show how the model reproduces the observed evolution of the open cluster vertical distribution remarkably well.

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On the determination of stellar mass and binary fraction of open clusters within 500 pc (poster pitch)

Author: Jinliang HOU[1]

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We investigated the stellar mass function and the binary fraction of 114 nearby (within 500pc) open clusters (OCs) using the high-precision photometric data from Gaia DR3. We estimate the mass of member stars by using ridge lines (RL) that are better in line with the observed CMD, thus obtaining more reasonable stellar mass and the binary mass ratio at the low mass region. By analyzing the present-day mass function (PDMF) of star clusters, we found that most of them follow a two-stage power law distribution. Adopting the visual inspection, we determined the segmentation point of a high and low mass segment for each cluster and fitted the gamma values of different mass segments separately. For our cluster sample, the median values of Gamma_H and Gamma_1 are 1.37 and 0.28,

respectively, which are roughly consistent with the IMF results provided by Kroupa (2001). In order to quantify the mass segregation effect of different star clusters, we calculated the cumulative radial distribution function of stars with different masses and used their area difference A+ to characterize the mass segregation degree of OCs. It is shown that there is a significant correlation between A+ and the dynamical evolution stage of OCs: the longer the dynamical evolution, the more obvious the mass segregation effect. We also estimate the binary fraction of OCs (q ≥ 0.5), varying from 6% to 34% with a median of 17%. Finally, we provided a catalog of 114 nearby cluster properties, including the total mass, the binary fraction, the PDMF, and the dynamical state.

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Taking the census of star clusters in the Milky Way (poster pitch)

Authors: Ariana Dias[1]; André Moitinho[1]; Márcia Barros[2]

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With the advent of Gaia and its all-sky accurate astrometry and photometry for almost two billion sources, a broad interest in open clusters (OCs) has resurged, having become the subject of active research.

While in pre-Gaia times, there were two main reference catalogues of open clusters (Dias et al. 2002, and Kharchenko et al. 2013), the wealth of Gaia data together with recent developments in machine learning techniques, availability of open source software, compute power, and a new generation of researchers trained in these methods has brought an explosion of reported OC discoveries. These reported discoveries are usually published in catalogues, in which the cross-identification with previously known OCs is done with various degrees of rigour, leading to "discoveries" of clusters that were in fact known and other situations illustrated in this contribution.

Indeed, it is a delicate task to cross-identify OCs, which are often sparse and discrete stellar groups with irregular shapes, different sizes, and without clear boundaries. The universally employed method of relying on a reported cluster centre and (highly uncertain) radius for cross-identification is clearly not producing high-quality compilations of OCs. Moreover, nowadays when hardly a month passes without the publication of a new catalogue of reported discoveries, it has become extremely hard to veto and integrate new discoveries into a carefully curated compilation of all known OCs.

To address the issues above, we present a framework being developed for cross-identifying OCs and for building a master list of the known OCs and candidates. Noting that OCs are defined by their members, we develop member-based approaches for cross-identification instead of employing cluster coordinates and radii-based matches. To support the storage and analysis of the growing number of catalogues, we have built a system of two databases. The first is a data warehouse with the original tables of clusters and/or members from the literature (most of which are automatically retrieved from the CDS), and whose formats, fields and other descriptors are quite heterogeneous. The other one is our primary analysis database where cluster identifiers, parameters and stellar memberships are stored in a structured and homogeneous way, allowing an easy integration and analysis of new catalogues as they arrive. In addition to the generated master list, statistical reports are generated which can be used for tuning the matching criteria. Finally, the framework supports optional filters for validating/checking the reality of catalogued OCs.

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Calibrating APs of Gaia DR3 with Open Clusters (poster pitch)

Author: Tong(⊠) Tang(⊠)[1]

Co-authors: Jing(⊠) Zhong(⊠) [1]; Songmei(⊠⊠) Qin(⊠) [1]; Li(⊠) Chen(⊠) [1]

[1] *Shanghai Astronomical Observatory, CAS*

We calibrated the atmospheric parameters provided by the GSP-Phot module from Gaia DR3 using a deliberately selected sample of open clusters in the solar neighborhood. We used Padova isochrone models to estimate the theoretical atmospheric parameters of cluster members and obtained the calibration expression by fitting the deviation between observed and theoretical values. Our results show that for stars with intrinsic colors (BP-RP) in the range of [0.4, 3.4], the $T_{\rm eff}$ provided by Gaia DR3 is underestimated at the blue end and overestimated at the red end, while the log g is generally underestimated but overestimated at the reddest end. We also discussed a degeneracy between the atmospheric parameters and the extinction from the GSP-Phot module.

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Hunting for Neighboring Open Clusters with Gaia DR3: 101 New Open Clusters within 500 pc (poster pitch)

Author: Songmei(⊠⊠) Qin(⊠)[1]

Co-authors: Jing(⊠) Zhong(⊠) [1]; Li Chen ; Tong(⊠) Tang(⊠) [1]

[1] *Shanghai Astronomical Observatory, CAS*

We systematically searched for open clusters in the solar neighborhood within 500 pc using pyUPMASK and HDBSCAN clustering algorithms based on Gaia DR3. Taking into consideration that the physical size for most open clusters is less than 50 pc, we adopted a slicing approach for different distance shells and identified 324 neighboring open clusters, including 223 reported open clusters and 101 newly discovered open clusters (named as OCSN, Open Cluster of Solar Neighborhood). Our discovery has increased the number of open clusters in the solar neighborhood by about 45%. In this work, larger spatial extents and more member stars were attained for our cluster sample. We performed membership determination with the pyUPMASK algorithm and then derived the mean position, proper motion, radial velocity, parallax and structural parameters for each cluster. Through isochrone fitting we obtained ages, distance modulus and reddening parameters for the clusters. The cluster catalog and the list of member stars with membership probabilities greater than 0.5 have been made publicly available. For our hunted OC samples, more detailed analyses are needed to further investigate their properties, such as the mass function and the dynamical states. Especially more spectroscopic data for the member stars will be of prime importance to determine the dynamical and chemical evolution of these clusters.

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Gaps in the Main-Sequence of Star Cluster HR Diagrams (poster pitch)

Author: Priya Shah[1]

[1] *Maulana Azad National Urdu University, Hyderabad*

The presence of gaps or regions of small numbers of stars in the main sequence of the Hertzsprung Russell Diagram (HRD) of star clusters has been reported in literature. This is interesting and significant as it could be related to star formation and/or rapid evolution or instabilities. In this paper, using Gaia DR3 photometry and confirmed membership data, we explore the HRD of nine open clusters with reported gaps, identify them and assess their importance and spectral types.

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Building the largest sample of open cluster masses with Gaia DR3 (poster pitch)

Author: Andrija Zupic[1]

Co-authors: Alfred Castro-Ginard [2]; Friedrich Anders [1]

[1] *Universitat de Barcelona*

[2] *Leiden Observatory*

Open clusters (OCs) play a fundamental role in understanding star formation, evolution, and the Milky Way's structure. The ESA space-based mission Gaia has significantly improved our knowledge of OCs and the Milky Way through precise astrometric and photometric data. The main objective of this research is to construct an extensive sample of estimated OC masses using Gaia DR3. We analyze 2880 OCs within 2 kpc, estimating masses using different methodologies depending the OC distance and on the number of member stars. Our analysis reveals that the mass function's break varies with cluster distance, suggesting an observational bias. The break of the function also shifts towards higher masses as the cluster ages. Older clusters exhibit a less steep high mass slope. Moreover, for clusters older than log t = 9.3, high-mass clusters become scarce, while low-mass clusters prevail. The spatial distribution of cluster masses in the Galactic disk indicates fewer high-mass OCs at bigger vertical distances abs(z) from the Galactic plane, with only low-mass OCs observed at the biggest z-values. Clusters in sparse regions exhibit higher mean tidal mass compared to those in spiral arms. Upon evaluating the completeness of our sample, we have identified a discrepancy in our cluster age function compared to the one derived using completeness-corrected Gaia DR2, highlighting the need for completeness corrections.

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Metallicity determination in open star clusters by exploring Gaia–J-PLUS synergy (poster pitch, online)

Author: Eduardo Machado Pereira[1]

[1] *Observatório Nacional*

Under various initial conditions, open star clusters serve as valuable laboratories for studying stellar evolution and its outcomes. The Gaia mission has significantly advanced our understanding of the Milky Way through precise astrometric data, while the Javalambre-Photometric Local Universe Survey (J-PLUS) offers extensive multiband photometric information. In this study, we investigate a list of 24 open star clusters, including 13 recently discovered ones, by combining the precise astrometric measurements from Gaia with data from J-PLUS. By utilizing machine learning algorithms, we trained models using Gaia and J-PLUS data to determine atmospheric parameters for members individually, in particular yielding metallicities estimates for these clusters. Importantly, this methodology can be readily extended to other multiband photometric surveys, providing a direct pathway to explore the metallicity properties of other various clusters.

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Report WG3: Planetary Systems Near and Far (online)

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Gaia DR3 and colors of the Solar System

Author: Dagmara Oszkiewicz[1]

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The Gaia third data release (DR3) includes the mean reflectance spectra of 60 518 asteroids at visible wavelengths (0.374−1.05 μm), which is a 10-fold increase in the number of known asteroid spectra (Galluccio et al. 2022). This huge increase in the number of available asteroid spectra provides more detailed distributions of various taxonomies across the Solar System and thus expands our undestanding of the formation of the Solar System.

The Gaia spectral data are acquired by the blue and red photometers (BP/RP) (Gaia Collaboration 2016; Prusti et al. 2016). For each object, average spectra sampled at 16 wavelengths (in the range between 0.374 and 1.034 μm every 0.044 μm) together with 16 quality flags are provided. These spectra are the result of averaging typically more than 20 individual epoch spectra for each object (Galluccio et al. 2022). One epoch corresponds to a single transit of an asteroid in the Gaia focal plane. Thus each average spectra is composed of individual spectra taken at different phase angles - different phase reddening. The Gaia DR3 asteroid spectra is also burdened with systematic and random errors which are more complex for moving objects.

We focused on clasification of basaltic asteroids with various machine learning methods. These asteroids are thought to be parts of crust of differentiated planetesimals - that is planetary embroys that existed 4 bilion years ago. Their multiplicity, distribution, and physical characteristics are crucial for providing context for and constraining the theoretical evolution models of the Solar system and terestial planets. We were able to identify ~2000 new basaltic asteroids, out of which ~350 pass our validation criteria. We found great diversity of spectral parameters amoung these objects. Furthermore, a few asteroids exhibited peculiar spectra that warrant ground-based follow-up observations.

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Estimating the Shapes and Spins of Asteroids from GAIA DR3 Photometry (online)

Author: Eric MacLennan[1]

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Photometric inversion is a technique that has been used for several decades to infer the shape and spin properties of asteroids [1]. Inversion methods have extensively been applied to ground- based observations of asteroids [2], but the high- precision data provided by the Gaia mission has enabled more detailed studies of these objects.
Previous data releases have demonstrated the usefulness of Gaia photometry, which represent a sparse-in-time dataset. The recent Data Release 3 (DR3) of the Gaia space observatory contains photometric observations of 150,000 asteroids [3]. Here, we use the DR3 dataset to estimate shape and spin parameters for over 22,000 asteroids that have at least 25 Gaia photometric observations. We

use ellipsoid and general convex shapes to estimate the rotational periods, spin axes, and photometric slopes of the asteroids in our sample. The results are used to assess trends in the general population.

We first fit triaxial ellipsoid shapes as described by the semimajor axes for which □ ≥ □ ≥ □. A Lommel-Seeliger surface scattering model is employed, for which the integrated brightness can be computed analytically [5]. Convex shapes are described by the Gaussian surface density. In this scheme, the proportion of surface areas are described by spherical harmonics coefficients. We characterize the probability distribution of each parameter by using a Markov chain Monte Carlo (MCMC) approach [6].

Comparing the shape parameters obtained from ellipsoids and convex shapes, we find an improvement in the uncertainty estimates when using the latter. Generally speaking, shapes are not well constrained along the c axis, arising from viewing aspects of the observations. We investigate the b/a distributions for different sizes (Figure 1) and rotation periods. Spin pole latitudes are more robustly constrained compared to longitudes, but both are susceptible to having erroneous mirror solutions. Interestingly, we find an excess of retrograde rotators in our sample which is dominated by asteroids in the Main Belt. We also find a small population of super- slow rotators (rotation periods exceeding 1000 hr) at small sizes (H ~ 14 mag, and smaller), which demand for further investigation. Further results and analyses will be presented at the conference and included in two manuscripts currently in preparation [7,8].

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WG3: Planetary Systems Near and Far. Chair: Anthony Brown / 85

The Photocenter-Barycenter Effect in Gaia astrometry and its Impact on Asteroid Orbit Determination

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The recent advancement of observational capabilities, particularly with the addition of Gaia observations, has brought significant improvements in the determination of orbital parameters for Small Solar System bodies. In this study, we investigate the impact of incorporating Gaia Data Release 3 (DR3) into the orbit determination process, with a specific focus on the photocenter-barycenter effect.

By combining ground-based and satellite observations obtained from the Minor Planet Center (MPC) with available radar data, we compare the results obtained with and without the utilization of Gaia DR3. Figure 1 presents the relationship between the semimajor axes and their associated uncertainties for 446 Near Earth asteroids in Gaia. The green data points represent semimajor axis values determined solely using ground-based and satellite observations available in the MPC, along with radar observations, if available. The blue data points depict semimajor axis values obtained when Gaia DR3 data is incorporated. We further analyze the covariance confidence ellipses to assess the impact of Gaia DR3 on the overall precision of the orbit determination. The green ellipsoids represent the confidence ellipses calculated solely using MPC data, while the blue ellipsoids include Gaia DR3 data. The inclusion of Gaia observations results in more tightly constrained confidence ellipses, validating the enhanced precision achieved through Gaia data. Gaia DR3 significantly reduces uncertainties for the semimajor axes and other orbital parameters.

To obtain the best possible orbital fit and minimize observation residuals, we integrate the photocenter-barycenter effect into Gaia observations for selected objects. This offset represents the difference between the measured photocenter and the true center of mass of an object. The magnitude of the photocenter-barycenter offset can be significant, reaching up to 10-20% of the asteroid's apparent diameter. By accounting for this offset, we further enhance the precision and reliability of Gaia astrometric measurements, contributing to the improved accuracy of orbital parameters.

This study highlights the substantial contributions of Gaia observations in improving the determination of orbital parameters, with a specific focus on the photocenter-barycenter effect.

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Shape modelling and spectral classification of asteroids using data from the AS Vidojevica and Gaia DR3

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We present the physical models of asteroids, their shapes, sense of rotation, and spectral classes using Gaia DR3. The shape models were determined using the lightcurve inversion method with the combination of dense photometric data from the Astronomical Station Vidojevica in Serbia and sparse data from the Gaia mission.

For obtaining asteroid low-resolution shapes, using sparse data decreases the amount of required observational time for obtaining the lightcurves at different geometrical circumstances. The GAIA DR3 spectra of our targets are compared to the mean reflectance spectra of all asteroid spectral classes from the Bus-DeMeo taxonomy. For asteroids with known taxonomy, we made comparisons with Gaia-determined spectral classes, and for unclassified asteroids, we made spectral classification.

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GAIA mission: the true time saver for asteroids shape modeling and spectral classification

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Our work aims to determine the shape models of a few asteroids, derived by using a combination of our dense photometric data with the sparse data provided by the database AstDys and as well as by the GAIA mission. These sparse data help us in gaining additional information for the asteroids with a small number of lightcurves and are in favor of the required observational time. Unlike the low-accuracy sparse photometric data from ground-based telescopes, GAIA provides us with sparse

data with much higher accuracy. Using GAIA DR3, we managed to give complex solutions for the asteroid's physical model, including its shapes, sense of rotation, and spectral class. The dense data in our work was collected from long-term observations done at NAO Rozhen, Bulgaria.
Additionally, the GAIA mean,sigma-clipped16-bands spectra of our targets are compared to the mean reflectance spectra of all asteroids' spectral classes from the Bus-DeMeo taxonomy. We assigned the most plausible taxonomy for the asteroids that were unclassified before. The objects with a pre-obtained taxonomy, from our observations, were compared with the GAIA-determined spectral class. GAIA and upcoming surveys will be used in our future work in addition to our dense photometric and spectroscopic observations for enriching the number of asteroids with known physical parameters.

WG1: The Milky Way as a Galaxy (I). Chair: Teresa Antoja / 110

Report WG1: The Milky Way as a Galaxy

Author: Despina Hatzidimitriou[None]

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Chemodynamical models of the Milky Way (invited talk)

Author: Eugene Vasiliev[None]

I present a framework for constructing self-consistent dynamical models of our Galaxy described by distribution functions in action space, and its extension to the chemical space (metallicity and alpha). The models are fitted to the data from Gaia DR3 and APOGEE DR17, and contain several disc components with varying chemodynamical properties, as well as the stellar and dark haloes. The models qualitatively recover salient features of the Galactic disc, such as the transition from alpha-enhanced to alpha-poor populations in the geometrically thick disc, which occurs roughly at the Solar radius, but do not match the extensive available data in every detail, despite having over 100 tunable parameters. I outline the pathways for future improvements on the modelling side and how they could benefit from the upcoming observational advancements.

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Possible confirmation of the spiral density-wave structure in the solar neighborhood using about 650000 Gaia EDR3 stars

Author: Evgeny Griv[1]

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More than fifty years ago, Lin & Shu (1964), Lin & Shu (1966), Lin et al. (1969), and Shu (1970), published their basic, asymptotic theory of spiral sound-like density waves (or a breathing mode of collective oscillations'), developing in the disk of a rotationally flattened galaxy, by solving both gas-dynamic and Vlasov-Poisson equations for a 2D mass distribution. The theoretical concept of adensity-wave theory' was born, and was greatly refined in the coming years by the work of Bertin & Lau (1978), Lin & Lau (1979), Morozov (1980), and many others by considering the second-order effects.
Griv & Gedalin (2012) extended the theory by considering a 3D mass distribution. In this work, a sample of selected $\sim 500\,000$ stars from a total of 656\,161 sources of the system at distances $r < 3$ kpc from the Galactic Centre and $|z| < 300$ pc from the mid-plane identified in the {\it Gaia} EDR3 is leveraged. The parameters of solar peculiar motion and Galactic differential rotation corrected

for the effects of small-amplitude 3D density waves, and the radial, transverse, and vertical components of streaming motion of stars due to the spiral arms as well as the geometrical and dynamical parameters of the waves are estimated from the measured line-of-sight velocities of objects. Two scales of periodic compression/rarefaction irregularity of the velocity field with the radial and vertical wavelengths of about 1.9 kpc in the form of a spiral density wave propagating in the disk are also revealed. We find that the velocity fields depart significantly from an axisymmetric model. These departures indicate the possible presence of local sound-like perturbations in the Galactic disk. We identify two features that are present in both planar and vertical velocities. These features appear to be associated with the Local and Scutum-Centaurus Spiral Arms.

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Spiral-like features in the disc revealed by Gaia DR3 radial actions

Author: Pedro Alonso Palicio[1]

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The so-called action variables are specific functions of the positions and velocities that remain constant along the stellar orbit. The astrometry provided by Gaia Early Data Release 3 (EDR3), combined with the velocities inferred from the Radial Velocity Spectrograph (RVS) spectra of Gaia DR3, allows for the estimation of the actions and orbital parameters for the largest volume of stars to date (33.6 million sources). In Palicio et al. (2023, published in A&A), we computed these quantities and explored them with the aim of locating structures in the Galactic disc. Using Gaia DR3 photometric data, we selected a subset of giant stars with better astrometry as a control sample.
We found that the maps of the percentiles of the radial action J_R reveal arc-like segments. In particular, we found three arc-shape regions dominated by circular orbits at inner radii, whose location and shape suggest a connection with the spiral arms. The spatial distribution of the control sample, moreover, shows overdensities similar to those interpreted as spiral arms using upper main sequence stars (Poggio et al. 2021). For Galactic coordinates (X, Y, Z), we found good agreement with the literature in the innermost region for the Scutum-Sagittarius spiral arms. At larger radii, a low J_R structure tracks the Local arm at negative X, while for the Perseus arm, the agreement is restricted to the X<2 kpc region, with a displacement with respect to the literature at more negative longitudes. We detected a high J_R area at a Galactocentric radii of 10.5 kpc, consistent with some estimations of the outer Lindblad resonance location. We conclude that the pattern in the dynamics of the old stars is consistent in several places with the spatial distribution of the spiral arms traced by young populations, with small potential contributions from the moving groups.

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Radial Wave in the Galactic Disk: New Clues to discriminate different Perturbations

Author: Chengye Cao[1]

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Decoding the key dynamical processes that shape the Galactic disk structure is crucial for reconstructing the Milky Way's evolution history. The second Gaia data release uncovers a new wave pattern in the L_Z-V_R space accompanied by a richness of phase space substructures, signifying the Galactic disk in dynamical disequilibrium. However, its formation mechanism remains elusive due to the complexity of involved perturbations and the challenges in disentangling their effects. Utilizing the latest Gaia DR3 data, we find that the wave systematically shifts towards lower L_Z for dynamically hotter stars. The amplitude of this phase shift between stars of different dynamical hotness increases with decreasing L_Z within the range of L_Z larger than 2000 km*kpc/s but stays approximately constant at a small value in the lower L_Z part of the wave. To investigate the role of different perturbations separately, we set up three test particle simulations in which a satellite galaxy, spiral, and bar act as the sole perturber by turn. The former trend is consistent with the waves induced by satellite impact, which we interpret in the context of a toy model of radial phase mixing. While corotating transient spiral arms do not produce a systematic phase shift pattern, a steadily rotating bar could generate a wave with phase alignment at higher L_Z extrema and phase shift at lower L_Z extrema at the locations of Lindblad resonances. Our results suggest that the formation of L_Z-V_R wave may arise from a complex interplay between internal and external perturbations. Moreover, the dependence of disk response on dynamical hotness could provide insights for discriminating between perturbations of different types.

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Modeling the evolution of the Milky Way from Gaia DR3

Author: Annie Robin[1]

Co-authors: Olivier Bienaymé ; Francesca Figueras ; Marc del Alcázar i Julià ; Roger Mor

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Galactic stellar populations are good tracers of the history of the Milky Way. Their study via Gaia astrometric and photometric data should allow to pinpoint the star formation history (SFH) in the disc and halo in a self-consistent dynamical model. Population synthesis models are efficient tools to measure the SFH from the distribution of the stars in the Hess diagram, thanks to different locations of stars according to their age and metallicity. We present the iterative strategy planned to fit the IMF and the SFH of the thin disk using the BGMFast scheme (del Alcazar et al., see poster) based on approximate bayesian computation (ABC) performed with HPC tools and, at the same time, the attempt to keep the self-consistent dynamical model by fitting the gravitational potential of the Milky Way to the stellar kinematics and densities from Gaia data (Robin et al., 2022).

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Improving Galactic Disk simulations with Gaia

Author: Alessandro Mazzi[1]

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The *Gaia* mission has produced an extraordinary amount of high quality photometric data for the whole sky and has contributed dramatically to advancing our understanding of the Milky Way. In particular, its data can be used to calibrate population synthesis models of our galaxy, aiming to reduce the gap between simulations and observations.

We present here a study of the star formation rate (SFR) of the Galactic disc based on data from the third data release of the *Gaia* mission. We select a sample of stars within a cylinder of the extended Solar Neighborhood with radius 200 pc and spanning 1.3 kpc above and below the midplane of the Galaxy. We split the sample in 28 slices located at different heights from the Plane and we build

synthetic color-magnitude diagrams in 16 age bins for each slice with the TRILEGAL population synthesis model, which includes state-of-the-art stellar models and a detailed treatment of interacting binaries. Using the Bayesian color-magnitude diagram fitting tool we developed, we determine simultaneously the SFR in all age bins and all slices, and we compute the scale heights of the Galactic disc in each age bin. We find that our results are compatible with previous ones, although we achieve a better age resolution. Most importantly, we obtain a clear picture of the increase with age of the scale heights, from about 50 pc in the youngest age bins to about 500 pc in the oldest ones.

These results will be included in the geometric model of the Galaxy implemented in TRILEGAL, leading to a significant improvement in the simulated Galactic disc structure.

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GASTRO library: studying substructures of the Milky Way stellar halo with SPH + N-body single merger models

Authors: Chervin Laporte[1]; João Antônio Silveira do Amarante[1]; Leandro Beraldo e Silva[2]; Victor Debattista[3]

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The Milky Way (MW) experienced several merger events which left their imprints on the stellar halo. In particular, it is known that a major merger happened during the Galaxy's first Gyrs. In order to fully understand the effects of such an event, we need to know the chemical and dynamical characteristics of the young MW, i.e. before the major merger event, and the accreted satellite. For this purpose, we developed the Gaia-EncelAdus-Sausage Timing, chemistRy and Orbit (GASTRO) library: a suite of SPH + N-body models to explore formation scenarios of MW-like galaxies that went through similar accretion events. Such idealized models enable us to control the initial conditions of the merger and which physical processes are included, therefore understanding them better. In this short talk, I present a subset of the GASTRO library and explore the chemodynamical properties of the accreted stars. I show that single merger events spread over a large range in the energy-angular momentum plane and also have a rich chemical signature in the dynamical space. I also show that clustering algorithms, such as HDSBSCAN, can identify multiple clusters in this single merger event. Finally, I discuss the results and how to reconcile some substructures in the MW's stellar halo to a single merger event.

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Studying Jeans Equations in the Milky Way disk

Author: Orlin Koop[1]

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Determining the circular velocity curve of a galaxy is a powerful tool for studying its overall properties. One can fit a potential and determine the dark matter distribution and density and the virial mass of the system.
One way of determining the rotation curve is through Jeans equations (Eilers et al. 2019, Ou et al. 2023). However, when using Jeans equations one needs to assume axisymmetry and time-independence. In this talk, I will show how the components in Jeans equations behave in different

regions in the Milky Way disk, determined with Gaia DR3 data. I will talk about how well the aforementioned assumptions hold up, and show what the uncertainty in our conclusions can be if they don't.
I will also show results from cosmological and N-body simulations of Milky-Way like systems to show the effectiveness of Jeans equations.

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Gaia DR3 determination of the Galactic bar pattern speed

Authors: Merce Romero-Gomez[None]; Laurent Chemin[1]; Jason Hunt[2]; Ron Drimmel[3]; Shourya Khanna[3]; Eloisa Poggio[4]; Pau Ramos[5]

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New 3D kinematic maps are derived based on Gaia DR3 proper motions and line-of-sight velocities for red giant branch stars, but now, unlike those published in Gaia Collaboration, Drimmel, Romero-Gómez+2022, taking into account the correlations between the proper motions, which contribute to the correlations between the derived kinematic variables. The large-scale correlations between the planar and vertical motions are studied, highlighting the impact of the bar and spiral perturbations on the stellar dynamics. Additionally, and taking advantage of the homogeneity of Gaia DR3 data, these maps are used to apply the recent version of the Tremaine-Weinberg method to compute the pattern speed of the Galactic bar (Bovy+2019, Leung+2021). The robustness and possible systematics of the method are tested using a set of test particle simulations of different bar pattern speeds and taking into account the expected observational errors. The value recovered using the Tremaine-Weinberg method is compatible with the one found in the Gaia Collaboration paper and previous works.

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Unveiling the structure and kinematics of the Milky Way disk with A stars

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A-type stars are intrinsically bright, moderately numerous and kinetically warm. They trace the Galactic disk evolution at intermediate ages (0.3-1.0 Gyr), so they fill the gap between younger OB stars and older red giants. We present a catalogue of A-type stars selected in the northern Galactic plane (30°≤l≤215° and |b|≤5°) using photometry from the INT Galactic Plane Survey (IGAPS). It contains over 3.5 million sources up to magnitude r≤19 mag. We use *Gaia* Data Release 3 parallaxes, proper motions and line-of-sight velocities of these A-type stars to analyse the large-scale structure of the Milky Way disc and their kinematic distribution up to 6 kpc from the Sun.

We find stellar overdensities associated with the Local and the Perseus spiral arms, as well as with the Cygnus region. We also detect the Galactic warp towards the anticentre starting at Galactocentric radius R≈12 kpc and having a median vertical motion of ~7-8 km/s at R=14 kpc. This onset radius supports that the warp begins at larger radii on younger stellar tracers than on older ones. We also detect a region with downward motion extending beyond 2 kpc from the Sun towards 60°≤l≤75° that can be associated with a compression breathing mode. Furthermore, A-type stars reveal very clumpy inhomogeneities and asymmetries in the V_Z-V_φ velocity space plane.

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Measuring the Milky Way Potential with the Phase Snail in a Model Independent Way (poster pitch)

Author: Rui Guo[1]

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The vertical phase-space spiral (snail) is a direct sign of dis-equilibrium of Milky Way's disc. Nevertheless, the wrapping of the phase snail contains the information of the vertical potential. We propose a novel method to measure the vertical potential utilizing the intersections between the snail and z/V_z axes, for which we know the maximum vertical heights (Z_{max}) or the maximum vertical velocities ($V_{z,max}$) of the oscillating stars. Using a refined linear interpolation method, we directly obtain ($Z_{max},\ \frac{1}{2}V_{z,max}^2$) for these snail intersections to constrain the vertical potential profile empirically. Our method is model independent since no assumptions about the shape of the phase snail or the vertical potential have been made. We find the snail binned by the guiding center radius (R_g) stands for a vertical potential shallower than that of the snail binned by a same Galactocentric radius (R). We apply an empirical method to correct this difference. We measure the snail intersections in several R_g bins within $7.5 < R_g < 11.0$ kpc for Gaia DR3, and apply the interpolation method to obtain potential measurements at several vertical heights. The potential at the snail intersections, as well as the following mass modeling are consistent with the popular Milky Way potentials in the literature. For the R_g-binned phase snail in the Solar neighborhood, the mass modeling indicates a local dark matter density of $\rho_{\rm dm} = 0.0150 \pm 0.0031\ {\rm M_\odot\ pc^{-3}}$, consistent with previous works. Our method could be applied to larger radial ranges in future works, to provide independent and stronger constraints on the Milky Way's potential.

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The star formation history of the Galactic disk from Gaia DR3 and the BGM FASt Galaxy model (poster pitch)

Authors: Marc del Alcázar i Julià[1]; Francesca Figueras[2]; Annie Robin[3]; Roger Mor[4]; Olivier Bienaymé[5]; Sergi Bartolomé[6]; Jordi Portell[6]

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We use the Besançon Galaxy Model Fast Approximate Simulations (BGM FASt) framework together with the Approximate Bayesian Computation (ABC) algorithm to derive the posterior probability distribution function of the parameters defining the initial mass function (IMF) and the star formation history (SFH) in the solar neighbourhood. We propose new strategies to unveil the influence of some BGM model ingredients from the Poissonian distance metric and the posterior distribution of the ratio between pseudo-simulation and data in the Hess diagrams.

Gaia DR3 up to G=13 and a set of consolidated executions of the BGM Fast + ABC code on a Cloud Environment, using both different mother simulations and priors, allow us to confirm the existence of the star formation burst in the Galactic disk 2-4 years ago proposed by Mor et al., 2019. Furthermore, for the composite IMF, we obtain the slopes of α_2 and α_3 constrained to the range [1.7, 2.8] and [1.8, 2.4] respectively, in agreement with recent values from the literature. The wide range of values obtained for the total stellar surface mass density of the thin disk at the solar neighbourhood, between 30-50 $M_{\odot}/pc^2$demonstrates that, before to conclude on the set of best ingredients for the Galactic stellar population model, we shall loop the process to fit again the Galactic potential (Robin et al. 2022) using the BGM Fast inferred parameters.

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Precise stellar ages for Galactic archaeology through machine learning (poster pitch)

Author: Friedrich Anders[1]

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Age is arguably the stellar fundamental parameters that is most difficult to obtain for most stars. Over the last few years, many studies have found empirical relationships between the abundance of a star and its isochrone age, known as chemical clocks. We present a new catalogue of spectroscopic stellar ages for 180,000 red-giant stars observed by the APOGEE survey with a median statistical uncertainty of 16%, obtained using the supervised machine learning technique XGBoost, trained on a high-quality dataset of 3200 stars with asteroseismic ages from Kepler. These age estimates are then used to present new and much less spatially biased measurements of the Galactic radial metallicity gradient as a function of age, and the age-velocity dispersion relation over a large portion of the Galactic disc.

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Angular momentum of the Classical Cepheids and the spiral structure of the Milky Way

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The classical Cepheids are variable stars with relatively young ages (<300 Myr). Their tight period-luminosity relation provides highly accurate distance estimates. By combining recent measurements of proper motions from Gaia EDR3, radial velocities from Gaia DR3, and Cepheid distances, it is possible to study the details of the phase space distribution of this population. In my talk, I will discuss how the recently discovered gap in the angular momentum of Cepheids can be attributed to the spatial separation of adjacent spiral arms in the Milky Way.

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Structure, kinematics and time evolution of the Galactic Warp revealed by Classical Cepheids (online)

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The warp is a well-known undulation of the Milky Way disc. Its structure has been widely studied, but only since Gaia DR2 has it been possible to reveal its kinematic signature beyond the solar neighbourhood. In this work we will present an analysis of the warp's structure by means of a Fourier decomposition in vertical high (Z) and vertical velocity (V_z) traced by Cepheids. We find a clear but complex signal that in both variables reveals an asymmetrical warp. In Z we find the warp to be almost symmetric in amplitude at the disc's outskirts but with the two extremes never being diametrically opposed at any radius and the line of nodes presenting a twist in the direction of stellar rotation for $R > 11$ kpc. In V_z an $m = 2$ mode is needed to represent the kinematic signal of the warp, reflecting its azimuthal asymmetry. We also find that the line of maximum vertical velocity is similarly twisted but does not overlap with the line of nodes, it trails behind by ≈ 25 deg. We will show how the twisted line of maximum V_z creates "arches" in the mean V_z as a function of radii, a signature of global warp kinematics that has been observed with other tracers with less azimuthal coverage of the disc. Finally, a joint analysis of the Fourier decompositions in Z and V_z allows us to develop a new model-independent formalism to derive the pattern speed and change in amplitude of each mode at each radii. By applying it to our results for the Cepheids we find, for the $m = 1$ mode, a constant pattern speed in the direction of stellar rotation of 9.18 km/s/kpc, a constant amplitude up to $R \approx 14$ kpc and a slight increase in amplitude at larger radii, in agreement with previous works.

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The Outer Arm of the Milky Way from red clump stars

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Understanding the structure and formation of our Milky Way galaxy is one of the key goals in the field of Galactic astronomy. The study of disk morphology provides valuable insights into the processes that have shaped our galaxy over time. While our location within the disc allows for detailed observations of stars, this position also limits our ability to gain a clearer view of its structure. Many pioneering works have been done to understand the disc structure of our Galaxy. Currently, we know that our Galaxy has spiral arms but the finer details like the number of arms, their position, and extent are still uncertain. We carried out a systematic study to trace the structure of the Galactic disc from red clump (RC) stars, an indicator of the intermediate-to-old age population. The largest sample of red clump stars (~8.8 Million stars) is extracted utilizing the 2MASS and Gaia data in the Galactic disc covering $40^\circ \leq \ell \leq 340^\circ$ and $-10^\circ \leq b \leq +10^\circ$. Gaia Data plays a crucial role in selecting the pure RC sample by eliminating the foreground dwarf contamination. The resulting distribution of red clump stars in the Galactic plane detected the poorly constrained Outer arm of

the Galaxy beyond the previous notion of its extent, providing new insights into the Galactic morphology. Our study also gave observational evidence of the warping of the spiral arms of the Galaxy as depicted by red clump stars.

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Beyond Gaia DR3: tracing the [α/M] – [M/H] bimodality from the Inner to the outer Milky Way disc with Gaia RVS and Convolutional Neural-Networks

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Gaia DR3 provided the community with one million RVS spectra covering the CaII triplet region, similarly to the RAVE spectra. One third of the spectra have a signal-to-noise ratio from 15 to 25 per pixel. Gaia also provides XP spectra/coefficients in DR3. We aim to leverage versatility/capabilities of machine learning techniques for combining
the full set of Gaia products for supercharged stellar parametrization. We developed a hybrid Convolutional Neural-Network (CNN)to derive atmospheric parameters (Teff, log(g), and [M/H]) and chemical abundances ([Fe/H] and [α/M]). Our CNN is designed to effectively combine the Gaia DR3 RVS spectra, photometry (G, Bp, Rp), parallaxes, and XP coefficients and is able to extract formation from non-spectral inputs to supplement the limited spectral coverage of the RVS spectrum. We trained CNN with high-quality training sample based on APOGEE DR17 labels. The atmospheric parameters we provide thanks to CNN out-perform the spectroscopic ones provided by the Gaia Collaboration both in terms of uncertainties and comparison with external high-quality data-sets. CNN is extremely robust to noise in RVS data, and very precise labels are derived down to S/N = 15. We provide atmospheric parameters and abundances for 841 300 stars homogeneous being the first machine-learning catalog to combine such diverse datasets.
We managed to characterize the [α/M] – [M/H] bimodality from the inner regions to the outer part of the Milky Way, which has never been characterized using RVS spectra or similar datasets. This study set the path for the machine-learning analysis of Gaia-RVS spectra for the next data releases. Large high-quality datasets and archives can be ideally combined thanks to CNN,releasing the full power of spectroscopy, astrometry, and photometry.

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Testing the Milky Way's age-metallicity-velocity dispersion relation and the low-mass star age-rotation-activity relation using white dwarf ages

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Stellar ages are of utmost importance for understanding the chemical and dynamical evolution of the Milky (the so called age-metallicity and age-velocity dispersion relations, respectively) as well as to understand the physical properties of its stellar members (e.g. the age-rotation-activity relation of low-mass main sequence stars). However, estimating the ages of stars is a difficult endeavour. In this contribution we take advantage of the analysis of white dwarfs in binary systems with main sequence companions identified within the DR3 of Gaia to derive accurate main sequence companion ages. These ages, together with the main sequence observable parameters ([Fe/H] abundances, radial and rotational velocities, activity indexes) are used to test the aforementioned age relations obtained via standard methods.

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The chemodynamical properties of the Galactic bulge

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We present a chemodynamical analysis of a large sample across the whole disk selected from Gaia-XP-spectra-derived dataset. When dividing the sample into a subsequent of annuluses, a universal chemodynamical trend exists from the disk to the bulge in the row normalized density map in the azimuthal velocity V_ϕ and metallicity [M/H] space is found, that is, a V-shaped structure stacked with a vertical band shows up in all radial bins, which are considered to refledt the thin, thick disk and the Splash respectively. The median behaviour of the universal trend exhibits a regulated transition with radius all the way into the inner Galaxy, thus implying a disk origiin for the majority of bulge stars. Further split the bulge population in the V_ϕ and [M/H] plane into 5x5 grids and study the kinematical properties of those divided populations, we found a well defined boundary that separates the bulge stars into relatively hot and cold groups, the populations in the cold groups all show the V_R butterfly pattern in the x-y plane and cylindrical rotation that are strong evidence of bar, while all the populations in the hot group does not show butterfly pattern but some of them still exhibit cylindrical rotation, which implies that the cylindrical rotation is not an unique feature of bar that used to be thought as unique in literature. We perform a N-body simulation with an initially non-rotating spherical structured placed, which turns out to be that this non-rotating component would be spun up in a cylindrical way by the later formed bar that is disk-originated, and the spherical structure do not involved in the bar formation since it does not exhibit the V_R butterfly pattern, which explains the phenomenon seen in observation.

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Precise abundances of Mg and neutron-capture elements in the Milky Way: chemodynamical relations using Gaia data and chemical evolution models

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The abundance of alpha and neutron-capture elements provide an important fossil signature in Galactic archaeology for tracing the chemical evolution of the Milky Way stellar populations. The combination with the astrometry and photometry from the Gaia data releases allow us to build an accurate time evolving chemodynamical picture of the Galaxy with unprecedented detail. We employ the automated abundance estimation procedure GAUGUIN, developed in the Gaia/RVS analysis pipeline, for deriving precise Mg, Eu and Sr abundances for stars observed by the ESO spectrographs HARPS (R ~ 115000), FEROS (R ~ 48000) and UVES (R ~ 40000), and parametrised within the AMBRE Project. With respect to the precise Mg abundances, we interpret the Galactic disc evolution by using Gaia astrometric measurements and estimating ages and dynamical properties for 366 main sequence turn-off (MSTO) stars in the solar neighbourhood. We measure a steeper [Mg/Fe] gradient compared to literature values, and observe the appearance of a second chemical sequence in the outer

disc, 10-12 Gyr ago, populating the metal-poor low-[Mg/Fe] tail, leading to a chemical discontinuity. Our data favour the rapid formation of an early disc that settled in the inner regions, followed by the accretion of external metal-poor gas -probably related to a major accretion event such as the Gaia-Enceladus/Sausage one- that may have triggered the formation of the thin disc population and steepened the abundance gradient in the early disc. A direct comparison with chemical evolution models also indicate that the infall in the inner Galactic regions was chemically enriched whereas a primordial infall should have formed the outer regions. On the other hand, we derive heavy element abundances (r-/s- process elements as Sr and Eu) for a sample of 778 Milky Way stars, homogeneously characterised using Gaia data, to chemically and dynamically identify potential accreted stellar populations and study their different signatures with respect to the in-situ population in the Galaxy.

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Who is In, and Who is Not? Determining the Gaia Survey Selection Function

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What is the probability that an astronomical object of certain properties enters the Gaia catalogue (or not)? The GaiaUnlimited project aims to enable the full potential of Gaia by characterising its survey selection function, as well as for different subsamples of the data, which are key ingredients in most statistical studies of the Milky Way. By comparing Gaia with deeper imaging from the Dark Energy Camera Plane Survey (DECaPS), we have developed an empirical model of the completeness in the Gaia pipeline, as a function only of the observed G magnitude and position over the sky, which accounts for both the effects of crowding and the complex Gaia scanning law. We also demonstrate the recipe to estimate the selection function of the stars present in a subsample of Gaia data, given that the subsample is completely contained in the Gaia parent catalogue, and how it can be extended to include the selection functions of other surveys (e.g. WEAVE, GALAH). Finally, we demonstrate the use of these selection functions by showing that the asymmetry in the Gaia-Sausage/Enceladus debris is merely due to selection effects.

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The mass-loss history of the Sagittarius dwarf galaxy

Authors: Chervin Laporte[1]; Joao Amarante[1]; Teresa Antoja[2]

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Despite its discovery almost 30 years ago and its subsequent mapping of its core and tidal tails, the progenitor mass of Sagittarius is still highly uncertain/debated, spanning almost two orders of magnitudes!

On the one hand, recent observations of the chemo-dynamical structure of Sgr's stellar stream and structure of the outer disc favour a massive progenitor with $> 6 \times 10^{10}\ \mathrm{M}_{\odot}$, while detailed stream fitting of the put the current mass of Sgr at a few times $10^{8}\mathrm{M}_{\odot}$ on the brink of total destruction. How can these different lines of evidence be reconciled? This poses an interesting problem for studying the mass loss of Sagittarius for which I will present recent results from live N-body models of Sagittarius and its interaction with the Milky Way and what they can tell us about its dark matter profile.

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The Large Magellanic Cloud dynamics with high resolution glasses

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The Large Magellanic Cloud (LMC) turns out to be a unique and impressive test laboratory thanks to the latest Gaia Data Release 3. Being the closest galaxy in the Local Group, Gaia proper motions and line-of-sight velocities allow it to make 3D velocity maps for the first time (Jiménez-Arranz+23) and endeavour dynamical studies in detail, such as the determination of the LMC bar pattern speed using different methods (Jiménez-Arranz+23, to be submitted). The results highlight the evidence of the need of high resolution simulations to provide a dynamical interpretation of the information shown by the data. In this talk, we introduce KRATOS, a suite of 24 N-body simulations of the Magellanic System, and a review of the planned scientific exploitation of these data.

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Multiple phase spirals suggest multiple origins in Gaia DR3 (on-line)

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Gaia Data Release 2 revealed that the Milky Way contains significant indications of departures from equilibrium in the form of asymmetric features in the phase space density of stars in the Solar neighbourhood. One such feature is the z-vz phase spiral, interpreted as the response of the disc to the influence of a perturbation perpendicular to the disc plane, which could be external (e.g. a satellite) or internal (e.g. the bar or spiral arms). In this work, we use Gaia Data Release 3 to dissect the phase spiral by dividing the local data set into groups with similar azimuthal actions, $J\phi$, and conjugate angles, $\theta\phi$, which selects stars on similar orbits and at similar orbital phases, thus having experienced similar perturbations in the past. The separation improves the clarity of the z-vz phase spiral and exposes changes to its morphology across the different action-angle groups. In particular, we discover a transition to two armed 'breathing spirals' in the inner Milky Way. We conclude that the local data contain signatures of not one, but multiple perturbations which we can explain as a transition between internal and external perturbations.

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The Milky Way disc radial abundance gradient from planetary nebulae reveled by Gaia (poster pitch, online)

Author: Oscar Cavichia[1]

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Radial abundance gradients in the Galactic disc are one of the most important observational constraints to study the chemical evolution of the Milky Way galaxy and also other galaxies in the universe. The radial gradient is the result of many physical processes that occur since the formation of the Galaxy, as e.g. the infalling gas to form the disc, the star formation history, radial gas flows and the radial migration of stars. Planetary nebulae (PNe) are the offspring of low and intermediate-mass stars consisting of an expanding, glowing shell of ionised gas ejected from red giant stars late in their lives. They have very intense optical emission lines and some elements observed in PNe are not modified during the progenitor star evolution, making then important tools to probe the Galactic chemical evolution. However, PNe distances are subject of great uncertainties, since, unlike main sequence stars, these objects do not have a physical parameter that is direct dependent of the distance. In this work, we have used Gaia DR3 database in order to derive reliable distances for a sample of 294 Galactic PNe. The radial gradient from the O, S, Ar and Ne are computed using the new distances in the radial range from 3 to 15 kpc. The results are consistent with a flatter gradient than previously found and with a change of the slope around 8 kpc, which coincides with the Milky Way corotation radius.

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Chemical footprints of the Galactic spiral arms revealed by Gaia DR3 (poster pitch, online)

Authors: Eloisa Poggio[None]; Alejandra Recio-Blanco[None]; Pedro Alonso Palicio[None]; Paola Re Fiorentin[None]; Patrik de Laverny[None]; Ronald Drimmel[None]; Georges Kordopatis[None]; Mario G. Lattanzi[None]; Mathias Schultheis[None]; Alessandro Spagna[None]; Emanuele Spitoni[None]

We map chemical inhomogeneities in the Milky Way's disc out to a distance of ~4 kpc from the Sun, using different samples of bright giant stars in Gaia Data Release 3. The samples are selected using effective temperatures and surface gravities from the GSP-Spec module, and they are expected to trace stellar populations of a different typical age. The cool (old) giants exhibit a relatively smooth radial metallicity gradient, whose slope has an azimuthal dependence. On the other hand, the relatively hotter (and younger) giants present remarkable chemical inhomogeneities in the Galactic disc, which are apparent as three (possibly four) metal-rich elongated features in correspondence with the spiral arms' locations. When projected onto the Galactic radius, those features manifest themselves as statistically significant bumps on top of the observed radial metallicity gradients with amplitudes up to 0.05-0.1 dex, making the assumption of a linear radial decrease not applicable for this sample. The strong correlation between the spiral structure of the Galaxy and the observed chemical pattern in the young sample indicates that the spiral arms might be at the origin of the detected chemical inhomogeneities. In this scenario, the spiral arms would leave a strong signature in the younger stars which progressively disappears when cooler (and older) giants are considered.

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Where's Waldo? Unveiling a metal-poor extension of the Milky Way thin disc with Pristine-Gaia- synthetic (poster pitch)

Author: Isaure Gonzalez Rivera[1]

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Our understanding of the Milky Way's formation history can be refined by analyzing the information encoded in its oldest stellar populations, typically their chemical composition and orbital motion. Having access to such properties is valuable to depict a larger picture of the earliest stages of galactic formation. With the rise of Gaia, an orbital characterization of the different components of our Galaxy has been built over the years, leading to the discovery of various substructures questioning the formation processes at stake.
In that context, following previous work (Fernández-Alvar et al. 2021), we studied the presence of a metal-poor extension of the thin disc, using photometric metallicities from the Pristine survey (Starkenburg et al. 2017). Combining Gaia astrometry with Pristine photometry, we recovered two stellar populations at -2 < [Fe/H] < -1.5 : one slow-rotating (halo-like) and one fast-rotating (thin disc-like) in the MW anticentre using Gaussian mixture models coupled with a Markov-Chain-Monte-Carlo approach. We pursued our investigation with the upcoming Pristine-Gaia-synthetic catalog (Martin et al. 2023, in prep.), which gathers 1.7 million metal-poor stars with metallicities inferred from BP/RP spectrophotometry.
Our aim is to make use of this statistically significant catalog to characterize the kinematic behavior of the metal-poor MW population in a larger field of view. In this talk, I will present some preliminary results investigating the rotating metal-poor Milky Way using 3D kinematics of this all-sky sample.

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Final remarks