From star clusters to field populations: survived, destroyed and migrated clusters

Report of Contributions

https://indico.ict.inaf.it/e/2472

Contribution ID: **1** Type: **not specified**

The longevity of the oldest open clusters

Open clusters'dynamical evolution is driven by stellar evolution, internal dynamics and external forces, which according to dynamical simulations, will evaporate them in a timescale of about 1 Gyr. However, about 10% of the known open clusters are older. They are special systems whose detailed properties are related to the dynamical evolution of clusters and the balance between mechanisms of cluster formation and dissolution. In this talk, I will present the results of our study of the spatial distribution and structural parameters of six of the oldest open clusters in the Milky Way in order to constraint their dynamical evolution and longevity. Moreover, I will discuss how the ongoing and forthcoming Galactic spectroscopic surveys such as WEAVE or 4 MOST will contribute to study the internal kinematics of open clusters, and in particular, the oldest ones with the final goal of understanding the reasons of their longevity.

Primary author: CARRERA, Ricardo Jesus (Istituto Nazionale di Astrofisica (INAF))

Presenter: CARRERA, Ricardo Jesus (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **2** Type: **not specified**

Vertical phase diagram of young open clusters: a linear relationship and a simple model

The spiral shape of the vertical phase diagram found by Antoja and collaborators is one of the most conspicuous of the many results provided by Gaia. This structure is observed over a wide range of galactocentric radii for disk stars with ages greater than 1 Ga. Alfaro et al. chose a sample of star clusters with ages less than 30 Ma finding a linear relationship between Vz and Z. We have modeled the kinematics of young disk objects subjected to simple mass density-dependent galactic potential in the solar neighborhood.
We have obtained vertical phase diagrams for different age intervals with data from Gaia open clusters. The simulations reproduce the obtained results except for objects with ages close to 100 Ma, where the largest discrepancy is found.
This simple model represents an interesting starting point to explain the structure of the vertical phase diagram without resorting to other input-hoc.

Primary author: Dr ALFARO, Emilio J. (Instituto de Astrofísica de Andalucía, CSIC)

Co-authors: Dr ELMEGREEN, Bruce (IBM Research Center, New York, USA); Dr SÁNCHEZ-GIL, Mª Carmen (Universidad de Cádz)

Presenter: Dr ALFARO, Emilio J. (Instituto de Astrofísica de Andalucía, CSIC)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **3** Type: **not specified**

Open and Young clusters in WEAVE and 4MOST

Monday, 20 November 2023 15:50 (25 minutes)

The study of open clusters is 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. For this reason they have been targeted by all the recent spectroscopic surveys, providing radial velocities and chemical abundances. In the coming future, a number of spectroscopic surveys such as WEAVE and 4MOST will have dedicated open cluster surveys. In this talk I will briefly revise the current status of knowledge on chemical abundances and radial velocities from large spectroscopic surveys. I will focus on the WEAVE and 4MOST open and young cluster survey, providing updates on the status of the projects.

Primary author: VALLENARI, Antonella (Istituto Nazionale di Astrofisica (INAF))

Presenter: VALLENARI, Antonella (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **4** Type: **not specified**

Quantifying the boundness of star clusters with Gaia data

Wednesday, 22 November 2023 09:15 (25 minutes)

In just five years, Gaia has revolutionised the census of star clusters in the Milky Way - including allowing for the detection of thousands of new clusters. However, many of these clusters are much smaller and more dispersed than canonical open clusters like the Pleiades, and it is not clear how many of these clusters are actually gravitationally bound. This presents critical challenges when trying to interpret the results of cluster detection algorithms.

In practice, measuring the boundness of a star cluster observationally is challenging, and dynamical studies of star clusters have so far been limited to analysing no more than a few dozen reliable objects at a time. In this talk, I will present the results of a study quantifying the boundness of around 7000 clusters in the recent catalogue of Hunt & Reffert 2023. I will overview the methods I used, including how masses and dispersions were measured for these objects. I will also discuss which physical theories (such as the virial theorem) were the most useful in measuring the boundness of star clusters, as well as discussing their caveats and areas that require more work in the future. Finally, I will present the overall results of this work, which show that at least 21% of the clusters in Hunt & Reffert 2023 are not gravitationally bound clusters, with most of these unbound clusters being within a few hundred parsecs of the Sun. The methods developed in this work should have wide applications to other studies of the boundness of star clusters in the Gaia era.

Primary author: HUNT, Emily (Landessternwarte, Center for Astronomy of Heidelberg University)

Presenter: HUNT, Emily (Landessternwarte, Center for Astronomy of Heidelberg University)

Session Classification: Cluster properties

Track Classification: Session 3

Contribution ID: **5** Type: **not specified**

The tidal arms of open star clusters uncovered with Gaia are much longer than thought

Wednesday, 22 November 2023 15:05 (25 minutes)

The tidal tails of stellar clusters are an important tool for studying the clusters'birth conditions, their evolution, coupling, and interaction with the Galactic potential, and to understand how field stars populate the Milky Way. Thanks to Gaia, much progress has been accomplished in finding tails of open clusters. I will show here that such tidal tails are much longer than previously observed, and that their identification requires not only a sophisticated analysis of the Gaia catalogue, using the convergent point method and clustering algorithms, but ideally, the use of N-body simulations and the new compact convergent point method. I will highlight recent results about the tails of several open clusters, which extend over several hundreds of parsecs.

Primary author: BOFFIN, Henri (ESO)

Co-authors: Dr BECCARI, Giacomo (ESO); Dr JERABKOVA, Tereza (ESO)

Presenter: BOFFIN, Henri (ESO)

Session Classification: Cluster perturbations

Track Classification: Session 4

Contribution ID: **6** Type: **not specified**

FILAMENTARY RELICTS OF STAR FORMATION DISCOVERED BY GAIA

Tuesday, 21 November 2023 16:40 (25 minutes)

Young clusters are a formidable tool to study star formation, stellar evolution, binary stars, as well as the formation and evolution of clusters themselves. The availability of data from Gaia, coupled with additional ground-based data and clustering analysis methods, allow us for the first time to discover and study a wide range of clusters with unprecedented details. In the region around Gamma Vel, we have identified a 260pc long filamentary structure of coeval stars that connects several 30 Myr old associations and known clusters, possible relict of the formation of stars along a more that 100 pc-long filament. Similarly, we identified a long (90pc), thin (about 10pc width), co-eval (10Myr) stellar structure in the Orion star-forming region which is likely a relic of star formation along a molecular cloud filament, naming it the Orion relic filament. In both cases, we exclude that such populations originates by the same mechanism responsible to create tidal streams around older clusters. We are instead observing a constellations of young and coeval star clusters and associations few million years after their formation, bridged on a more than 100pc scale by a filament of coeval stars. Such structures are likely the outcome of a mechanism of filamentary star formation in a Giant Molecular Clouds. Clearly, thanks to Gaia, the study of young stellar clusters on a galactic scale is undergoing a complete revolution.

Primary authors: BECCARI, Giacomo (ESO); Dr BOFFIN, Henri (ESO); Dr JERABKOVA, Tereza (ESO)

Presenter: BECCARI, Giacomo (ESO)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **7** Type: **not specified**

Star Cluster Formation is Messy and Should Not be Simplified

Tuesday, 21 November 2023 09:15 (25 minutes)

Stars are primarily formed in clustered environments in giant molecular clouds. Stars are also primarily found in binary or higher order multiple systems. Therefore, there is a time during the formation of star clusters when both stellar dynamics and hydrodynamics are needed to describe the dominant populations, and we probably also need to care about radiation, chemistry, dust physics, and magnetic fields at some level too. In this talk, I will describe some recent simulations of star cluster formation and show how a more complete treatment of stellar and gas physics, and their interaction, are necessary to properly model star cluster formation, and can lead to "common sense" solutions to some of the puzzles that remain about the properties of star clusters.

Primary author: SILLS, Alison (McMaster University)

Presenter: SILLS, Alison (McMaster University)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **8** Type: **not specified**

On the effects of unresolved binaries on the deduced total mass and stellar mass function of stellar clusters

Wednesday, 22 November 2023 10:05 (25 minutes)

Deducing the masses and mass functions of stellar clusters (SCs) is an important step to understanding their formation and evolution and to comprehending the formation of the Galaxy. This contribution explores, how unresolved binaries affect not only the deduction of these parameters for SCs, but also for their tails. If the binaries in SCs and their tails cannot be resolved, their masses are expected to be underestimated by up to 25%, while the power law index of the deduced mass function is underestimated by about 0.2. It is also found that since the Galactic field stars were born in SCs, populations of stars with large velocity dispersions would be expected to host larger binary fractions. However, the large scatter in the velocity dispersions makes it hard to observe this effect.

Primary author: WIRTH, Henriette

Presenter: WIRTH, Henriette

Session Classification: Cluster properties

Track Classification: Session 3

Contribution ID: **9** Type: **not specified**

Open Clusters as Windows into Galactic Disk Fluorine Evolution

Wednesday, 22 November 2023 11:00 (25 minutes)

Fluorine remains an enigmatic element in galactic archaeology, with a scarcity that camouflages its importance in understanding chemical and stellar evolution. Various astrophysical sites, including massive stars, AGB stars, Wolf-Rayet stars, and Novae, have been proposed as fluorine producers, yet the element's origins remain a subject of debate. To shed light on this, we have initiated a specialized project that leverages the capabilities of the GIANO-B instrument at the TNG telescope to study fluorine's chemical evolution in the Galactic disk using open clusters as key tracers. Our research will uniquely provide fluorine abundance data as a function of both galactocentric distance and cluster age, a feat not achievable with current or forthcoming stellar surveys. By doing so, we aim to offer critical observational constraints to models of stellar and galactic chemical evolution. This project is poised to become the most exhaustive database on fluorine abundances in open clusters to date.

Primary author: D'ORAZI, Valentina (University of Rome Tor Vergata / INAF OAPd)

Presenter: D'ORAZI, Valentina (University of Rome Tor Vergata / INAF OAPd)

Session Classification: Cluster properties

Track Classification: Session 3

Contribution ID: **11** Type: **not specified**

High resolution spectroscopy of open clusters: results from the SPA LP @TNG

Monday, 20 November 2023 16:45 (25 minutes)

To study stellar clusters and be able to effectively use them to understand how stars and clusters form and evolve and to link this to the Galactic evolution, we need not only large samples, such as those provided by the spectroscopic surveys, but also high resolution and detailed analysis.
As part of the SPA (Stellar Population Astrophysics) Large Programme at the TNG, we observed a large sample of open clusters with GIARPS (GIANO+HARPS-N), obtaining a few to a few tens of stars in each of them. I will present the aims, some highlights of our work, some work in progress and will underline how such project may be very useful also in a large-survey era.

Primary author: BRAGAGLIA, Angela (Istituto Nazionale di Astrofisica (INAF))

Presenter: BRAGAGLIA, Angela (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **12** Type: **not specified**

Gravitational theory and the tidal tails of open star clusters

Wednesday, 22 November 2023 14:15 (25 minutes)

The stars in a galaxy form in compact embedded star clusters which expand after removal of their residual gas. The subsequent virialisation leads to a fraction of the stars condensing into an open star cluster. The open star cluster dissolves as it orbits in the potential of the hosting galaxy through the energy equipartition process. In the Newtonian gravitational theory, the ensuing tidal tails contain about as many stars in the leading tail as in the trailing tail. In Milgromian gravitation the leading tail is predicted to contain more stars as a result of the non-linearity of this gravitational theory. The observed tidal tails of COIN-Gaia13, Coma Berenices, the Praesepe and the Hyades each contain more stars in the leading tail, implying the validity of Milgromian rather than Newtonian gravitation. I will also touch upon two new methods to assess the ages of open stars clusters using tidal tails from the gas expulsion process and the kissing instability in the interiors of M dwarf stars.

Primary author: KROUPA, Pavel (University of Bonn, Charles University)

Presenter: KROUPA, Pavel (University of Bonn, Charles University)

Session Classification: Cluster perturbations

Track Classification: Session 4

Contribution ID: **13** Type: **not specified**

Tidal tails of open clusters

Wednesday, 22 November 2023 14:40 (25 minutes)

Compared to the globular clusters and their tidal tails, open cluster tails are ~1000 smaller in terms of star counts and must be found in an environment ~1000 times denser than the halo. Hence finding stars in tidal tails of open clusters is a difficult task even in the era of Gaia. I will present a probabilistic method where we start by simulating the dissolution of a cluster, which defines a likelihood of where the tidal tails should appear in some parameter space. We then select most likely stars belonging to the tidal tails from the Gaia catalogue as well as from a simulated population of stars. Comparing the two selections of stars allows us to define properly normalized membership probabilities for Gaia stars to be part of the tidal tails of a cluster. Normalized membership probabilities have not been calculated before. They allow quantitative measure for matching models of cluster formation and dissolution to observations and open several possibilities for more complete studies of stellar populations in clusters. We used Gaia's positions, distances, and proper motions to search for tidal tails of 500 open clusters and found tails up to thousands of parsecs long. I will also show the diversity of the shapes and structures of tidal tails and discuss the numerous dynamical processes that can be inferred from it.

Primary author: KOS, Janez (Faculty of mathematics and physics, University of Ljubljana)

Presenter: KOS, Janez (Faculty of mathematics and physics, University of Ljubljana)

Session Classification: Cluster perturbations

Track Classification: Session 4

Contribution ID: **14** Type: **not specified**

The Rotational Personae of Cores and Coronae

Gaia has undoubtedly changed the way we look at the dynamics, morphology and evolution of star clusters. The exquisite spatio-kinematic dataset combined with sophisticated clustering tools allow us to observe not only the compact cores, but also extended regions beyond the tidal radius, where haloes, coronae and tails harbour an increasing fraction of the stellar mass as clusters dissolve with time. This begs the question: *how are stellar properties affected by their cluster environment?*

In this talk I compare rotation period distributions for thousands of stars across the mass spectrum, that reside in the cores and coronae of ten open clusters (aged between 30-300 Myr, within 500pc) identified by Meingast et al. (2021). Rotation periods are measured using my publicly-available TESSilator code, which I will briefly describe, along with a discussion of the effects of TESS faintness/crowding on this data sample.

These results provide observational clues about how stellar properties are affected by their environment as a function of age and mass, and can serve as a useful resource to infer physical parameters from imminent large-scale spectroscopic surveys.

Primary author: BINKS, Alexander (University of Tuebingen)

Co-authors: STELZER, Beate (Tuebingen University); GUENTHER, Hans Moritz (MIT Kavli Institute)

Presenter: BINKS, Alexander (University of Tuebingen)

Session Classification: Cluster perturbations

Track Classification: Session 4

Contribution ID: **15** Type: **not specified**

Kinematic Insights into the Survival of Milky Way Star Clusters. From Perturbations to Persistence: Star Cluster Evolution in Our Galaxy.

Thursday, 23 November 2023 09:40 (25 minutes)

Understanding the factors that influence the survival of open clusters within the Milky Way is a complex endeavor. This study delves into the role of key parameters such as mass, density, size, and the galactic environment, including the Galactic bar, spiral structures, and molecular clouds. Particular attention is given to how open clusters and field stars respond differently to perturbations, with a special focus on the longevity of the oldest clusters. Our analysis compares kinematic properties between two Gaia DR3 datasets: ~40 open clusters and a vast sample of field stars. These datasets share quality criteria, thin disc membership, a similar metallicity range and locations. Employing a statistical approach, we explore the behavior of their kinematic properties. Our findings indicate that younger clusters (< 2-3 Gyr) exhibit greater resilience to perturbations, following quasi-circular orbits. In contrast, the surviving older clusters (> 3 Gyr) display more eccentric and inclined orbits.

Primary author: VISCASILLAS VÁZQUEZ, Carlos (Vilnius University)

Presenter: VISCASILLAS VÁZQUEZ, Carlos (Vilnius University)

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **16** Type: **not specified**

Star cluster formation, stellar properties, and cluster dispersal

Thursday, 23 November 2023 09:15 (25 minutes)

I will discuss the results from numerical simulations of star cluster formation and evolution. I will review what has been learnt from numerical simulations regarding how the properties of low-mass stellar clusters and their stars depend on initial conditions, such as metallicity, molecular cloud density, magnetic fields, and turbulence. I will also discuss how these clusters may be expected to disperse into the galactic population of field stars, and possible kinematic signatures of dispersing stellar populations.

Primary author: Prof. BATE, Matthew (University of Exeter, UK)

Presenter: Prof. BATE, Matthew (University of Exeter, UK)

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **17** Type: **not specified**

A new observable for probing star formation and dispersion with stellar clocks

Tuesday, 21 November 2023 15:20 (25 minutes)

Star formation is a fundamental process that impacts many fields of astrophysics, from the formation and evolution of planets to galaxies. The interaction between the natal cloud and the newborn stars is one of the least understood star formation processes and has an important impact on the final star-formation efficiency and cluster dynamics. I will present an innovative methodology to measure the timescale of the gas-embedded phase by comparing stellar ages derived with two independent methods: dynamical tracebacks and isochrone fitting. In this new framework, the dynamical-traceback "clock"initiates when a stellar cluster or association begins to expand after expelling most of the gas, while the isochronal "clock"initiates earlier when most stars form. Measuring this difference accurately and understanding its variations across different environments provides new information on the impact of local conditions and stellar feedback on the formation and dispersal of stellar clusters.

Primary author: MIRET ROIG, Núria (University of Vienna)

Presenter: MIRET ROIG, Núria (University of Vienna)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **18** Type: **not specified**

A morphological, kinematical and chemical analysis of the disrupting open cluster UBC274

Thursday, 23 November 2023 10:05 (25 minutes)

The wealth and homogeneity of Gaia data have allowed the discovery of several open clusters with signs of disruption.
We do a morphological, kinematic and chemical analysis of the disrupting cluster UBC 274 (2.5 Gyr, d = 1778 pc), with the objective of studying its global properties.
A new membership study up to 50 pc from its center and un to magnitude G=19 using GaiaEDR3 data, shows that the cluster has a highly eccentric (0.93) component, tilted 10 deg with respect to the plane of the Galaxy, which is morphologically compatible with the result of a test-particle simulation of a disrupting cluster.
We find a significant sign of mass segregation where the most massive stars appear 1.5 times more concentrated than other stars.
We obtained high resolution and high signal-to-noise spectra of 6 giants and subgiants. Our abundance analysis shows that the cluster has a slightly subsolar metallicity of [Fe=H] = -0.08\pm0.02. Its chemical pattern is compatible with that of Ruprecht 147, of similar age but located closer to the Sun, with the remarkable exception of neutron-capture elements which present an overabundance.

Primary author: CASAMIQUELA, Laia (GEPI Observatoire de Paris)

Presenter: CASAMIQUELA, Laia (GEPI Observatoire de Paris)

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **19** Type: **not specified**

The dynamical history of M67

Thursday, 23 November 2023 11:00 (25 minutes)

M67 is a cornerstone open cluster for stellar astrophysicists. It is the same age and metallicity as the Sun - indeed its stars are so similar to the Sun that some have speculated that the Sun may have been born there. Furthermore its location - relatively close to use but well above the plane of the Milky Way - makes it easy to distinguish from the background field population. However this poses a question - how did M67 reach its present-day Galactic orbit? I will describe our investigations into different dynamical processes that affect cluster orbits in the Milky Way, how they could have acted to take M67 onto its present orbit, and the present-day orbits of the stars lost along the way. Our conclusion is that dynamics alone does not prevent a solar origin in M67, but makes it rather unlikely. Finally, I will briefly mention an interesting side-effect of M67's age and metallicity - the low mass of its surface convection zone - which makes it uniquely valuable as a place to study the ingestion of planets into stellar photospheres.

Primary author: CHURCH, Ross (Lund University)

Presenter: CHURCH, Ross (Lund University)

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **20** Type: **not specified**

Mapping the Galactic disc with field stars and open clusters

Monday, 20 November 2023 14:10 (25 minutes)

Galactic studies are currently undergoing a renaissance, thanks to the wealth of data from the Gaia satellite and ground-based surveys. Previously unknown portions of the Galactic disc have been mapped, triggering new interest and questions into the physical mechanisms regulating the evolution of the Galaxy. Recent works based on field stars and open clusters revealed: (i) the segments of the nearest spiral arms out to 5 kpc in heliocentric distance; (ii) substructures in velocity space; (iii) spatially-dependent chemical substructures. In this talk, I will compare the spatial, kinematic and chemical properties of field stars and open clusters, to investigate whether the evolutionary processes that led to their current configuration acted in a similar way.

Primary author: POGGIO, Eloisa (CNRS - Observatoire de la Côte d'Azur / INAF - Osservatorio Astrofisico di Torino)

Presenter: POGGIO, Eloisa (CNRS - Observatoire de la Côte d'Azur / INAF - Osservatorio Astrofisico di Torino)

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **21** Type: **not specified**

Distruption of star clusters in galactic potentials in Newtonian and MOND gravities: stochastic N-body simulations

Thursday, 23 November 2023 11:25 (25 minutes)

Numerical and analytical evidences that collisionless and collisional relaxation processes work differently in Newtonian and modified Newtonian dynamics (MOND) theories of gravitation imply that processes such as the disruption of satellites falling onto the parent galaxy should, in principle, behave differently in the two scenarios. In particular, it is not clear whether a stronger (barionic) dynamical friction in MOND systems could compensate or not the absence of the contribution of dark matter with respect to the parent (equivalent) Newtonian system.
Aiming at shedding some light on this issue, here we present some preliminary simulations with a hybrid stochastic-N-body method where the the internal dynamics of the stellar cluster is solved with a standard direct N-body scheme, while the effect of host galaxy is modelled, in both Newtonian and MOND gravities, with a smooth potential plus noise and dynamical friction (accounting for the discreteness effects) implemented via a Langevin-like method.

Primary author: DI CINTIO, Pierfrancesco (Consiglio Nazionale delle Ricerche (CNR) & INAF OAA)

Presenter: DI CINTIO, Pierfrancesco (Consiglio Nazionale delle Ricerche (CNR) & INAF OAA)

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **22** Type: **not specified**

The formation of clusters and associations in spiral galaxies

Tuesday, 21 November 2023 11:50 (25 minutes)

We perform simulations of cluster formation in regions taken from galaxy scale simulations, including photoionization and supernovae feedback. We simulate regions with different densities, and from different galactic environments. In all our simulations, clusters undergo mergers and splits during their formation. More massive clusters form in regions of spiral arms with stronger converging flows, and in bars and inner spiral arm regions. In inter-arm or outer galaxy regions, we tend to see looser groups more characteristic of associations. In all simulations, the most massive clusters are formed by mergers. Feedback has a greater impact on cluster formation at lower densities, where star formation occurs over a longer timescale. In our lowest density case, the resulting clusters (in terms of number, mass) are very different with and without feedback, and one of our simulations forms an association which has a similar size, mass and morphology to the Orion OB1 association. We also show that photoionizing feedback is necessary to produce clusters with the observed cluster mass relation. Initial results with magnetic fields show that magnetic fields can have a strong impact on cluster formation, depending on field strength. Lastly, we place our simulated clusters into the GAIA catalogue and try to re-identify them. We find that the spatial properties of clusters are surprisingly robust even at relatively large distances and when relatively few members of the original cluster are observed. However dynamical measurements tend to be much less reliable.

Primary author: Prof. DOBBS, clare (university of Exeter)

Presenter: Prof. DOBBS, clare (university of Exeter)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **23** Type: **not specified**

Gaia, extinction, and the Galactic mid-plane

Monday, 20 November 2023 15:00 (25 minutes)

Gaia has revolutionised our ability to identify clusters and to use them as tracers of the Galactic structure. Our view is however severely limited when looking towards the inner regions of the Milky Way, where the clusters we do see are very young and very massive. The differences between the inner and outer disc are in part due to observational biases, but could also indicate that different environments lead to different preferential modes of star formation. Upcoming mid-infrared astrometric missions such as JASMINE and GaiaNIR will allow us to probe the inner disc and shed light on the processes driving cluster formation and dispersal.

Primary author: CANTAT-GAUDIN, Tristan (MPIA Heidelberg)

Presenter: CANTAT-GAUDIN, Tristan (MPIA Heidelberg)

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **24** Type: **not specified**

Young Stellar Clusters as gamma-ray sources

Tuesday, 21 November 2023 10:05 (25 minutes)

In the last ~10 yrs, several young stellar clusters have been associated to diffuse gamma-ray emission in the energy range from ~1 GeV up to ~100 TeV. In particular in the region close to the association Cygnus OB2 photons up to the incredible energy od 1.4 PeV have been detected by LHAASO. The orginin of the non-thermal particles responsible for the gamma-ray emission is not completely clear. Here we present a model based on particle acceleration at the wind termination shock of the collective wind generated by massive stars in the cluster. This model requires as an imput the wind kinetic power, which depends on the IMF and age of the clusters. We will critically discuss those aspects.

Primary author: MORLINO, Giovanni (Istituto Nazionale di Astrofisica (INAF))

Presenter: MORLINO, Giovanni (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **25** Type: **not specified**

Impacts of spiral arms on the kinematics of the young stars

Wednesday, 22 November 2023 16:00 (25 minutes)

We study the kinematics of the young stars around the spiral arms in the Milky Way, using Gaia DR3. We first demonstrate that we can measure the circular velocity at the position of the Sun in the Milky Way using the young OB stars, but there is a clear sign of the impact of the Local arm. From the kinematics of these stars and also of old stars, we find that the Local arm is not a minor arm, but a significant major spiral arm. In addition, the stellar kinematics indicates that the Local arm is a transient dynamic arm, and it is likely to be a growing phase. We also discuss the kinematics of the young stars around the Perseus and Outer arms. The kinematics of the young star clusters are likely to be also affected by the spiral arms in similar way to these young stars, and they will be a great chemo-dynamical tracer to further study of the nature of the spiral arm. Finally, we also briefly discuss the potential impact of the Local arm on the nearby star clusters.

Primary author: KAWATA, Daisuke (MSSL, UCL)

Presenter: KAWATA, Daisuke (MSSL, UCL)

Session Classification: Cluster perturbations

Track Classification: Session 4

Contribution ID: **27** Type: **not specified**

Phase space densities of star-forming regions

Tuesday, 21 November 2023 10:30 (25 minutes)

The initial conditions of star-forming regions will dictate if they will disperse into the field or survive as bound open clusters. Methods have been developed to characterise star-forming regions and infer the initial conditions of them (i.e. initial density, degree of substructure and virial state). These methods have been used to quantify the spatial clustering of stars within star-forming regions and the overall morphologies of such regions. One such method is the Mahalanobis density, which for stars quantifies a 6D (position-velocity) phase space density, which has been used to infer the initial formation conditions of exoplanet host stars. I have applied the Mahalanobis density to simulations with different initial conditions and find that it is unable to reliably infer the initial conditions of these regions when used by itself. I will show that using multiple methods together enables the initial conditions of star-forming regions to be better constrained.

Primary author: BLAYLOCK-SQUIBBS, George (University of Sheffield)

Presenter: BLAYLOCK-SQUIBBS, George (University of Sheffield)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **28** Type: **not specified**

Revealing the star formation history of nearby star-forming regions in 3D space and time with Gaia

Tuesday, 21 November 2023 11:25 (25 minutes)

In our quest to gain a deeper understanding of our Solar Neighborhood, Gaia has proven instrumental in elucidating the 3D spatial structure of the local interstellar medium (ISM) and the distribution of young stellar clusters. However, to unravel the origin and evolution of nearby young structures, a crucial dimension is the measurement of their 3D space motions. These motions allow us to trace back the orbits of stellar clusters and molecular clouds within our Galaxy, and investigate the relative space motions within single complexes.
To address these challenges, we have recently developed a machine learning-based clustering tool (SigMA) tailored for the selection of stellar clusters in the 5D phase space as provided by Gaia. This innovative approach was initially applied to the Scorpio-Centaurus complex, leading to the identification of previously unnoticed substructures and richer stellar populations than earlier established. Combined with updated cluster ages, this framework enables a more comprehensive investigation of the history of this nearby region, including the evolution of velocity dispersion within a single complex and the propagation of star formation influenced by feedback from massive stars.
To achieve this we analyze the 6D phase-space of individual entities such as clusters and clouds, utilizing Gaia DR3 data in combination with ancillary radial velocity (RV) data. This approach allows us to reconstruct the formation history of star-forming complexes, also shedding light on past feedback processes. Consequently, we can study the interaction of stars with the ISM and the formation and evolution of feedback-driven bubbles, (e.g., Orion-Eridanus Superbubble, Local Bubble). Hence, our research provides a quantifiable assessment of the impact of feedback from massive stars on nearby regions, contributing to a more comprehensive understanding of star formation in the Milky Way.

Primary author: GROSZSCHEDL, Josefa (Universität zu Köln)

Co-authors: Prof. ALVES, João (Universität Wien); Dr RATZENBÖCK, Sebastian (Universität Wien)

Presenter: GROSZSCHEDL, Josefa (Universität zu Köln)

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **29** Type: **not specified**

Simulating the population of young massive stellar clusters in the Milky Way.

Wednesday, 22 November 2023 11:25 (25 minutes)

The recent detection of large diffuse γ-ray halos in coincidence with a dozen young massive stellar clusters (YMSCs) has strengthened the hypothesis of stellar clusters as cosmic ray factories and γ-ray sources. Noticeably, the observed γ-ray emission is, on average, remarkably extended (~1-3°) and of the same size as the dimension of the superbubble developed by YMSCs. Such a large diffuse emission, characterized by a low surface brightness, suggests that non-resolved YMSCs could significantly contribute to the diffuse γ-ray emission observed along the Galactic plane. To estimate this contribution, a robust modeling of both the galactic population of YMSCs and the feedback from stellar winds in terms of wind power and mass loss rate is required.
In this work, we present a novel method for simulating a synthetic population of galactic YMSCs based on observations of local stellar clusters. We additionally estimate the power of stellar wind and mass loss rate by building a mock stellar population for every cluster and empirically modeling the stellar wind physics.

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Presenter: MENCHIARI, Stefano (INAF - Osservatorio Astrofisico di Arcetri)

Session Classification: Cluster properties

Track Classification: Session 3

Contribution ID: **30** Type: **not specified**

Investigating the formation and dispersion of star clusters with the multi-object spectrographs MOONS and 4MOST

Monday, 20 November 2023 15:25 (25 minutes)

The combination of photometric and astrometric data from Gaia with parameters derived by spectroscopic surveys, like Gaia-ESO, improved our knowledge of the properties of young star clusters and our understanding of the processes leading the cluster evolution until its dispersion.
However, current datasets suffer of two main shortcomings: they are mostly based on optical observations, so we are not able to investigate the earliest stages of cluster life, when they are still embedded in molecular clouds, and spectroscopic data coming from multi-object spectrographs are usually limited to the inner and most dense part of the cluster. In this talk, I will present two spectroscopic surveys that will be carried out with the new multi-object spectrographs MOONS at the VLT and 4MOST at VISTA.
The first will gather infrared spectra of about 10 embedded young clusters to investigate their structural and kinematic properties at their earliest stages. While the 4MOST survey will observe ~100,000 candidate young stars within 500 pc selected independently from their position and kinematic to investigate the properties of young unbound stellar populations.

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Presenter: SACCO, Giuseppe Germano (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **31** Type: **not specified**

Open cluster mass functions and tidal masses from Gaia DR3

Wednesday, 22 November 2023 09:40 (25 minutes)

Accurate mass determinations for open clusters (OCs) are essential for studying star formation as well as OC dissolution processes. Using the Gaia DR3 OC catalogue of Hunt & Reffert (2023), we construct an extensive sample of OC mass estimates. We analyze more than 2000 OCs within 2 kpc, estimating their tidal masses and fitting their mass functions where possible (including the effect of unresolved binaries). Our analysis is in general agreement with previous Gaia studies of smaller samples, and indicates that the mass function break shifts towards higher masses as the cluster ages. We also show that the complex selection function of the Gaia DR3 OC census is the main missing ingredient for tighter measurements of the cluster formation and destruction rates in the solar vicinity.

Primary author: ANDERS, Friedrich (ICCUB)

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Presenter: ANDERS, Friedrich (ICCUB)

Session Classification: Cluster properties

Track Classification: Session 3

Contribution ID: **32** Type: **not specified**

Stellar Clusters in 4MOST

I will discuss the upcoming survey that will make use of 4MOST at the VISTA ESO telescope. By exploiting the characteristics of such instrument, the survey will provide the most comprehensive characterization of the chemistry and kinematics of stellar clusters collected to date. It will target essentially all the Galactic Globular and Open Clusters and Star Forming Regions accessible 4MOST, for a total of ~75K stars in LRS and ~50K in HRS.
This will allow: to shed light on how clusters form, evolve, dissolve, and populate the Milky Way; calibrate complex physics that affect stellar evolution, on which our ability to measure ages ultimately stands; measure the contribution of star clusters to the formation and evolution of the individual Galactic components with unparalleled statistics.

Primary author: LUCATELLO, Sara (Istituto Nazionale di Astrofisica (INAF))

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Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **33** Type: **not specified**

Dynamical evolution of open star clusters in Milgrom-law-dynamics

Thursday, 23 November 2023 11:50 (25 minutes)

The sun is located at a Galactocentric distance where the transition from Newtonian to MoNDian dynamics is expected to occur. Due to their proximity solar neighbourhood open star clusters are ideal kinematical laboratories to discriminate between the validity of Newtonian or MoNDian dynamics. Direct MoNDian N-body integrations of open star clusters embedded in an external field are performed by the application of Milgrom's law. The evolution of open star clusters in Newtonian and MoNDian dynamics show three main differences: i) The tidal tails are populated asymmetrically in MoND. The leading tail hosts more members than the trailing arm, whereas in Newton the tidal arms are populated nearly symmetrically. ii) Open star clusters dissolve approximately 30% faster in MoNDian dynamics than in Newtonian dynamics. iii) Open star cluster appear slightly super-virial when their internal kinematics is interpreted in Newtonian dynamics.

Primary author: Dr PFLAMM-ALTENBURG, Jan (Helmholtz-Institute of Radiation and Nuclear Physics (HISKP))

Presenter: Dr PFLAMM-ALTENBURG, Jan (Helmholtz-Institute of Radiation and Nuclear Physics (HISKP))

Session Classification: Cluster Survival

Track Classification: Session 5

Contribution ID: **34** Type: **not specified**

Parameter Estimation for Open Clusters using an Artificial Neural Network with a QuadTree-based Feature Extractor

Monday, 20 November 2023 14:35 (25 minutes)

With the unprecedented increase of known star clusters, quick and modern tools are needed for their analysis. In this work, we develop an artificial neural network trained on synthetic clusters to estimate the age, metallicity, extinction, and distance of *Gaia* open clusters. We implement a novel technique to extract features from the colour-magnitude diagram of clusters by means of the QuadTree tool and we adopt a multi-band approach. We obtain reliable parameters for ~5400 clusters. We demonstrate the effectiveness of our methodology in accurately determining crucial parameters of *Gaia* open clusters by performing a comprehensive scientific validation. In particular, with the parameters produced by our neural network, we obtain a Galactic metallicity gradient in agreement with the observed ones thus it demonstrates that our method reliably extracts information on metallicity from color-magnitude diagrams (CMDs) of stellar clusters. For the sample of clusters studied, we find an intriguing systematic older age compared to previous analyses present in the literature. This work introduces a novel approach to feature extraction using a QuadTree algorithm, effectively tracing sequences in CMDs despite photometric errors and outliers. The adoption of ANNs, rather than Convolutional Neural Networks, maintains the full positional information and improves performance, while also demonstrating the potential for deriving clusters' parameters from simultaneous analysis of multiple photometric bands, beneficial for upcoming telescopes like the Vera Rubin Observatory. The implementation of ANN tools with robust isochrone fit techniques could provide further improvements in the quest for open clusters' parameters.

Primary author: CAVALLO, Lorenzo (Università degli Studi di Padova)

Co-authors: SPINA, Lorenzo (Istituto Nazionale di Astrofisica (INAF)); CARRARO, Giovanni (Dipartimento di Fisica e Astronomia, Universitta' di Padova); MAGRINI, Laura (Istituto Nazionale di Astrofisica (INAF)); POGGIO, Eloisa (CNRS - Observatoire de la Côte d'Azur / INAF - Osservatorio Astrofisico di Torino); CANTAT-GAUDIN, Tristan (MPIA Heidelberg); LUCATELLO, Sara (Istituto Nazionale di Astrofisica (INAF))

Presenter: CAVALLO, Lorenzo (Università degli Studi di Padova)

Session Classification: Cluster demography

Track Classification: Session 1

Contribution ID: **35** Type: **not specified**

Do the majority of stars form in gravitationally unbound groups?

Tuesday, 21 November 2023 09:40 (25 minutes)

While some young stars are clustered, many other young stars are observed as dispersed, non-gravitationally bound groups, or in complete isolation. Using N-body simulations, we study dispersal of young open star clusters of a wide range of initial masses. We find that observational data are consistent with the assumption that all stars form in initially embedded star clusters, which loose most of their members at their early age as the consequence of expulsion of the residual gas. Our model predicts that the fraction of young stars (age less than 10 Myr) to be observed in gravitationally bound clusters shows only a weak dependence on the star formation rate per unit area of the galaxy. This result contrasts to the analytical work due to Kruijssen 2012, which predicts that the fraction of young stars in gravitationally bound clusters is a strong function of the star formation rate of the galaxy, and that only the galaxies with high rates of star formation form a noticeable fraction of stars in clusters.

Primary authors: Dr DINNBIER, Frantisek; KROUPA, Pavel (University of Bonn, Charles University); Dr ANDERSON, Richard (EPFL)

Presenter: Dr DINNBIER, Frantisek

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **36** Type: **not specified**

The 3D Dynamics of Young Star Clusters from Gaia DR3 and GES

Tuesday, 21 November 2023 15:45 (25 minutes)

The formation and evolution of young star clusters and OB associations is fundamental to our understanding of the star formation process, the conditions faced by young binary and planetary systems, and the formation of long-lived open and globular clusters. The Gaia-ESO Survey (GES) has spectroscopically observed 18 young star forming regions, star clusters and OB associations, providing spectroscopic indicators of youth and radial velocities to complement Gaia DR3 proper motions. We have conducted a 3D dynamical study of ~2500 young stars across the 18 young star clusters observed by GES, combining Gaia proper motions with GES radial velocities and youth indicators. This is the first large-scale and comprehensive 3D dynamical study of multiple star clusters. We measure 3D velocity dispersions, quantifying virial states, and search for evidence of (and quantify) expansion, rotation, anisotropy and energy equipartition. We compare the dynamical properties of these systems with their mass, density and age, revealing trends that hint at the formation of these systems, their dynamical evolution, and their eventual dispersal into the field.

Primary author: WRIGHT, Nick

Presenter: WRIGHT, Nick

Session Classification: Star formation and young clusters

Track Classification: Session 2

Contribution ID: **37** Type: **not specified**

Welcome

Monday, 20 November 2023 14:00 (10 minutes)

Welcome by the Director of INAF-Osservatorio di Arcetri. Brief introduction to the workshop by the organisers.

Presenters: Dr RANDICH, Maria Sofia (Istituto Nazionale di Astrofisica (INAF)); MAGRINI, Laura (Istituto Nazionale di Astrofisica (INAF)); KROUPA, Pavel (University of Bonn, Charles University)

Contribution ID: **38** Type: **not specified**

Discussion (Chair Sofia Randich)

Monday, 20 November 2023 17:10 (25 minutes)

Presenter: Dr RANDICH, Maria Sofia (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Cluster demography

Contribution ID: **39** Type: **not specified**

The EWOCS view of super massive star clusters

Tuesday, 21 November 2023 17:05 (25 minutes)

The EWOCS (Extended Westerlund 1 and 2 Open Clusters Survey) project has the objective of studying star and planet formation, and early stellar evolution, in super massive star clusters (SSCs). With a mass in excess of 10^4 solar masses, the very few SSCs known in the Milky Way represent the most accessible examples of starburst regions, which are very rare in our Galaxy today, but common in galaxies experiencing epochs of intense star formation. These regions are characterized by very high stellar density, and they are dominated by a rich and compact ensemble of massive stars that produce an environment dominated by energetic radiation and particles. With a distance of 3.87 kpc and 4.5 kpc, respectively, the Westerlund 1 and 2 clusters are the closest SSCs to the Sun, and thus the best targets to study how stars and planets form in the most energetic star forming environment known. In this talk, I will present the motivations, status and the preliminary results of the EWOCS project, which is mainly based on a 1Msec Chandra/ACIS-I Large Project and a cycle 1 JWST observation of Westerlund 1, a cycle 2 JWST observation of Westerlund 2, and other data at high spatial resolution of the two clusters."

Primary author: GUARCELLO, Mario Giuseppe (Istituto Nazionale di Astrofisica (INAF))

Presenter: GUARCELLO, Mario Giuseppe (Istituto Nazionale di Astrofisica (INAF))

Session Classification: Star formation and young clusters