The Star Clusters Young & Old Newsletter

edited by Giovanni Carraro, Martin Netopil, and Ernst Paunzen
https://www.univie.ac.at/scyon/
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Dear Colleagues,

With this issue we unfortunately have to announce that Giovanni Carraro stepped down as editor of SCYON. We would like to thank him for his valuable work during the last decade and wish him all the best for the future! Concluding words by him can be found in the following. As new editor for the future issues we cordially welcome Angela Adamo from the Stockholm University and Oskar Klein Centre!

> It has been a pleasure to serve as editor of the Star clusters young and old (SCYON) newsletter for more than 10 years. During this decade we tried to improve the newsletter in several ways. One major achievement is that as of 2012 it has become the official newsletter of the IAU inter-division commission H4: Stellar Clusters throughout Cosmic Space and Time. We have tried with modest success to include other features into the newsletter. In any case I believe it continues to be a reference for star cluster studies, given the reasonable number of abstracts regularly submitted. I wish all the best to Angela Adamo, and I hope that this newsletter will continue to exist as a service to our community.
>
> **Giovanni Carraro**

Furthermore, Amanda Karakas stepped down as President of the IAU H4 commission and assists as Advisor. Francesca D'Antona, the previous Vice-President, has taken over as President. With the last IAU elections Florent Renaud is now the current Vice-President. The remaining new Organizing Commitee consists of: Randa Asa'd, Angela Bragaglia, Andrea Dupree, Ignacio Negueruela, Eric Peng, and Andrés Piatti.

We wish the new Organizing Committee all the best!

Unfortunately, the COVID-19 pandemic still does not allow conventional conferences on a larger scale, which are probably eagerly awaited by most of us. Most switched to online meetings or were again postponed to the next year. We hope that then finally a get-together will be possible.

The SCYON editor team:
Giovanni Carraro, Martin Netopil, and Ernst Paunzen

Ivan Robert King (1927-2021)

Ivan Robert King, one of the preeminent astronomers of his generation, passed away on August 31, 2021. His work led to a deeper understanding of globular star clusters, their structure, dynamics, evolution, and their stellar content. He also played an important early role in the development of the Hubble Space Telescope.

Over the course of his more than sixty-year career, King made fundamental contributions to our understanding of and built the Faint Object Camera (FOC) on board HST. He used the FOC to study individual stars in the dense cores of globular star clusters and even discovered the double nucleus in our sister galaxy, M31.

Among his colleagues he was known for his encyclopedic knowledge, deep scientific insights, a sharp intelligence, and an even sharper wit. He maintained the highest standards of scholarship and scientific integrity and instilled them in his students and collaborators.

He was active in the American Astronomical Society, serving as a Counsellor (1963-1966), Chairman of the Dynamical Astronomy Division (1972-1973), and as President (1978-1980). He was also an active member of the International Astronomical Union, where he was Chair of the Commission on Star Clusters (1973-1976). His public service also includes roles in several other professional groups and committees in astronomy.

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About the Newsletter

SCYON publishes abstracts from any area in astronomy, which are relevant to research on star clusters. We welcome all kinds of submitted contributions (abstracts of refereed papers or conference proceedings, PhD summaries, and general announcements of e.g. conferences, databases, tools, etc.)

The mission of this newsletter is to help all the researchers in the field with a quick and efficient link to the scientific activity in the field. We encourage everybody to contribute to the new releases! New abstracts can be submitted *at any time* using the **webform** on the SCYON homepage.

https://www.univie.ac.at/scyon

Star Forming Regions

A kinematic perspective on the formation process of the stellar groups in the Rosette Nebula

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Stellar kinematics is a powerful tool for understanding the formation process of stellar associations. Here, we present a kinematic study of the young stellar population in the Rosette nebula using the recent Gaia data and high-resolution spectra. We first isolate member candidates using the published mid-infrared photometric data and the list of X-ray sources. A total of 403 stars with similar parallaxes and proper motions are finally selected as members. The spatial distribution of the members shows that this star-forming region is highly substructured. The young open cluster NGC 2244 in the center of the nebula has a pattern of radial expansion and rotation. We discuss its implication on the cluster formation, e.g., monolithic cold collapse or hierarchical assembly. On the other hand, we also investigate three groups located around the border of the H II bubble. The western group seems to be spatially correlated with the adjacent gas structure, but their kinematics is not associated with that of the gas. The southern group does not show any systematic motion relative to NGC 2244. These two groups might be spontaneously formed in filaments of a turbulent cloud. The eastern group is spatially and kinematically associated with the gas pillar receding away from NGC 2244. This group might be formed by feedback from massive stars in NGC 2244. Our results suggest that the stellar population in the Rosette Nebula may form through three different processes: the expansion of stellar clusters, hierarchical star formation in turbulent clouds, and feedback-driven star formation.

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https://arxiv.org/abs/2105.03698

Galactic Open Clusters

A study of the Czernik 2 and NGC 7654 open clusters using CCD UBV photometric and Gaia EDR3 data

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We analysed the open clusters Czernik 2 and NGC 7654 using CCD UBV photometric and Gaia Early Data Release 3 (EDR3) photometric and astrometric data. Structural parameters of the two clusters were derived, including the physical sizes of Czernik 2 being r=5 and NGC 7654 as 8 min. We calculated membership probabilities of stars based on their proper motion components as released in the Gaia EDR3. To identify member stars of the clusters, we used these membership probabilities taking into account location and the impact of binarity on main-sequence stars. We used membership probabilities higher than $P = 0.5$ to identify 28 member stars for Czernik 2 and 369 for NGC 7654. We estimated colour-excesses and metallicities separately using two-colour diagrams to derive homogeneously determined parameters. The derived $E(B-V)$ colour excess is 0.46(0.02) mag for Czernik 2 and 0.57(0.04) mag for NGC 7654. Metallicities were obtained for the first time for both clusters, -0.08(0.02) dex for Czernik 2 and -0.05(0.01) dex for NGC 7654. Keeping the reddening and metallicity as constant quantities, we fitted PARSEC models using colour-magnitude diagrams, resulting in estimated distance moduli and ages of the two clusters. We obtained the distance modulus for Czernik 2 as 12.80(0.07) mag and for NGC 7654 as 13.20(0.16) mag, which coincide with ages of 1.2(0.2) Gyr and 120(20) Myr, respectively. The distances to the clusters were calculated using the Gaia EDR3 trigonometric parallaxes and compared with the literature. We found good agreement between the distances obtained in this study and the literature. Present day mass function slopes for both clusters are comparable with the value of Salpeter (1955), being X=-1.37(0.24) for Czernik 2 and X=-1.39(0.19) for NGC 7654.

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https://ui.adsabs.harvard.edu/abs/2021arXiv210703462A/abstract

A massive open cluster hiding in full sight

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Obscuration and confusion conspire to limit our knowledge of the inner Milky Way. Even at moderate distances, the identification of stellar systems becomes compounded by the extremely high density of background sources. Here we provide a very revealing example of these complications by unveiling a large, massive, young cluster in the Sagittarius arm that has escaped detection until now despite containing more than 30 stars brighter than $G = 13$. By combining Gaia DR2 astrometry, Gaia and 2MASS photometry and optical spectroscopy, we find that the new cluster, which we name Valparaiso 1, located at ~ 2.3 kpc, is about 75 Ma old and includes a large complement of evolved stars, among which we highlight the 4 d classical Cepheid CM Sct and an M-type giant that probably represents the first detection of an AGB star in a Galactic young open cluster. Although strong differential reddening renders accurate parameter determination unfeasible with the current dataset, direct comparison to clusters of similar age suggests that Valparaiso 1 was born as one of the most massive clusters in the Solar Neighbourhood, with an initial mass close to $10^4 M_\odot$.

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https://ui.adsabs.harvard.edu/abs/2021MNRAS.505.1618N/abstract

Multicolour photometry and Gaia EDR3 astrometry of two couples of binary clusters (NGC 5617 and Trumpler 22) and (NGC 3293 and NGC 3324)

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This paper presents a comprehensive analysis of two pairs of binary clusters (NGC 5617 and Trumpler 22) and (NGC 3293 and NGC 3324) located in the fourth quadrant of our Galaxy. For this purpose, we use different data taken from VVV survey, WISE, VPHAS, APASS, and GLIMPSE along with Gaia EDR3 astrometric data. We identified 584, 429, 692, and 273 most probable cluster members with membership probability higher than 80 per cent towards the region of the clusters NGC 5617, Trumpler 22, NGC 3293, and NGC 3324. We estimated the value of R = Av/E(BV) as $\sim$3.1 for the clusters NGC 5617 and Trumpler 22, which indicates the normal extinction law. The values of R $\sim$ 3.8 and $\sim$1.9 represent the abnormal extinction law towards the clusters NGC 3293 and NGC 3324. Our kinematical analysis shows that all these clusters have circular orbits. Ages are found to be 90$\pm$10 and 12$\pm$3 Myr for the cluster pairs (NGC 5617 and Trumpler 22) and (NGC 3293 and NGC 3324), respectively. The distances of 2.43$\pm$0.08, 2.64$\pm$0.07, 2.59$\pm$0.1, and 2.80$\pm$0.2 kpc estimated using parallax are consistent with the values calculated by using the distance modulus. We have also identified 18 and 44 young stellar object candidates present in NGC 5617 and Trumpler 22, respectively. Mass function slopes are found to be in fair agreement with the Salpeter's value. The dynamical study of these objects shows a lack of faint stars in their inner regions, which leads to the mass-segregation effect. Our study indicates that NGC 5617 and Trumpler 22 are dynamically relaxed but the other pair of clusters are not. Orbital along with the physical parameters show that the clusters in both pairs are physically connected.

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https://ui.adsabs.harvard.edu/abs/2021MNRAS.503.5929B/abstract

Galactic Globular Clusters

The surroundings of the Milky Way globular cluster NGC 6809

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We study the outer regions of the Milky Way globular cluster NGC6809 based on Dark Energy Camera (DECam) observations, which reach nearly 6 mag below the cluster main sequence (MS) turnoff. In order to unveil its fainter outermost structure, we built stellar density maps using cluster MS stars, once the contamination of field stars was removed from the cluster color-magnitude diagram. We found that only the resulting stellar density map for the lightest stars exhibits some excesses of stars at opposite sides from the cluster centre that diminish soon thereafter at 0.32o. Studied globular clusters with apogalactic distances smaller than that of NGC6809 (5.5 kpc) do not have observed tidal tails. The lack of detection of tidal tails in the studied inner globular cluster sample could be due to the reduced diffusion time of tidal tails by the kinematically chaotic nature of the orbits of these globular clusters, thus shortening the time interval during which the tidal tails can be detected. Further investigations with an enlarged cluster sample are needed to confirm whether chaotic and non-chaotic orbits are responsible for the existence of globular clusters with tidal tails and those with extra-tidal features that are different from tidal tails or without any signatures of extended stellar density profiles.

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https://arxiv.org/pdf/2105.11289.pdf

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A supra-massive population of stellar-mass black holes in the globular cluster Palomar 5

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Palomar 5 is one of the sparsest star clusters in the Galactic halo and is best-known for its spectacular tidal tails, spanning over 20 degrees across the sky. With N-body simulations we show that both distinguishing features can result from a stellar-mass black hole population, comprising $\sim$20% of the present-day cluster mass. In this scenario, Palomar 5 formed with a 'normal' black hole mass fraction of a few per cent, but stars were lost at a higher rate than black holes, such that the black hole fraction gradually increased. This inflated the cluster, enhancing tidal stripping and tail formation. A gigayear from now, the cluster will dissolve as a 100

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Accurate distances to Galactic globular clusters through a combination of Gaia EDR3, HST, and literature data

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We have derived accurate distances to Galactic globular clusters by combining data from the Gaia Early Data Release 3 (EDR3) with distances based on Hubble Space Telescope (HST) data and literature-based distances. We determine distances either directly from the Gaia EDR3 parallaxes, or kinematically by combining line-of-sight velocity dispersion profiles with Gaia EDR3 and HST-based proper motion velocity dispersion profiles. We furthermore calculate cluster distances from fitting nearby subdwarfs, whose absolute luminosities we determine from their Gaia EDR3 parallaxes, to globular cluster main sequences. We finally use HST-based stellar number counts to determine distances. We find good agreement in the average distances derived from the different methods down to a level of about 2 per cent. Combining all available data, we are able to derive distances to 162 Galactic globular clusters, with the distances to about 20 nearby globular clusters determined with an accuracy of 1 per cent or better. We finally discuss the implications of our distances for the value of the local Hubble constant.

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https://ui.adsabs.harvard.edu/abs/2021MNRAS.505.5957B/abstract

Clusters in the Magellanic clouds

The kinematics of Small Magellanic Cloud star clusters

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We report results of proper motions of 25 known Small Magellanic Cloud (SMC) clusters (ages $\sim$ 1 - 10 Gyr old) derived from Gaia EDR3 data sets. When these mean proper motions are gathered with existent radial velocity measurements to compose the clusters' velocity vectors, we found the parameter values of a rotation disk that best resemble their observed motions, namely: central coordinates and distance, inclination and position angle of the line-of-node, proper motion in right ascension and declination and systemic velocity, rotation velocity and velocity dispersion. The SMC cluster rotation disk seems to be at some level kinematically synchronized with the rotation of field red giants recently modeled using DR2 data sets. Such a rotation disk is seen in the sky as a tilted edge-on disk, with a velocity dispersion perpendicular to it twice as big as that in the plane of the disk. Because the direction perpendicular to the disk is nearly aligned with the Magellanic Bridge, we interpret the larger velocity dispersion as a consequence of the SMC velocity stretching caused by the tidal interaction with the Large Magellanic Cloud. Rotation alone would not seem sufficient to explain the observed kinematic behaviors in the SMC.

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https://ui.adsabs.harvard.edu/abs/2021arXiv210403750P/abstract

On the Nitrogen variation in 2 Gyr old massive star clusters in the Large Magellanic Cloud

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We present ESO/VLT FORS2 low resolution spectroscopy of red giant branch stars in three massive, intermediate age ($\sim 1.7 - 2.3$ Gyr) star clusters in the Large Magellanic Cloud. We measure CH and CN index bands at 4300A, and 3883A, as well as [C/Fe] and [N/Fe] abundance ratios for 24, 21 and 12 member stars of NGC 1978, NGC 1651, NGC 1783, respectively. We find a significant intrinsic spread in CN in NGC 1978 and NGC 1651, a signal of multiple stellar populations (MPs) within the clusters. On the contrary, we report a null CN spread in NGC 1783 within our measurement precision. For NGC 1978, we separated the two populations in the CN distribution and we translated the CN spread into an internal N variation Δ[N/Fe]= 0.63 ± 0.49 dex. For NGC 1651 and NGC 1783, we put upper limits on the N abundance variations of Δ[N/Fe]$\leq 0.2, 0.4$ dex, respectively. The spectroscopic analysis confirms previous results from HST photometry, where NGC 1978 was found to host MPs in the form of N spreads, while slightly younger clusters (e.g. NGC 1783, <2 Gyr old) were not, within the limits of the uncertainties. It also confirms that intermediate age massive clusters show lower N abundance variations with respect to the ancient globular clusters, although this is in part due to the effect of the first dredge up at these stellar masses, as recently reported in the literature. We stress the importance of future studies to estimate the *initial* N abundance variations, free of stellar evolutionary mixing processes, by observing unevolved stars in young clusters.

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https://arxiv.org/pdf/2106.02054.pdf

The most distant clusters

Globular cluster candidates in the Sagittarius dwarf galaxy

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Recently, new Sagittarius (Sgr) dwarf galaxy globular clusters were discovered, which opens the question on the actual size of the Sgr globular cluster population, and therefore on our understanding of the Sgr galaxy formation and accretion history onto the Milky Way. Based on *Gaia* EDR3 and SDSS IV DR16 (APOGEE-2) data sets, we performed an analysis of the color-magnitude diagrams (CMDs) of the eight new Sgr globular clusters found by Minniti et al(2021) from a sound cleaning of the contamination of Milky Way and Sgr field stars, complemented by available kinematic and metal abundance information. The cleaned CMDs and spatial stellar distibutions reveal the presence of stars with a wide range of cluster membership probabilities. Minni 332 turned out to be a younger ($<$ 9 Gyr) and more metal-rich ([M/H] -1.0 dex) globular cluster than M54, the nuclear Sgr globular cluster, as could also be the case of Minni 342, 348, and 349, although their results are less convincing. Minni 341 could be an open cluster candidate (age $<$ 1 Gyr, [M/H] $\sim$ -0.3 dex), while the analyses of Minni 335, 343, and 344 did not allow us to confirm their physical reality. We also built the Sgr cluster frequency (CF) using available ages of the Sgr globular clusters and compared it with that obtained from the Sgr star formation history. Both CFs are in excellent agreement. However, the addition of eight new globular clusters with ages and metallicities distributed according to the Sgr age-metallicity relationship turns out in a remarkably different CF.

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Dynamical evolution - Simulations

Binary-driven stellar rotation evolution at the main-sequence turn-off in star clusters

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The impact of stellar rotation on the morphology of star cluster colour-magnitude diagrams is widely acknowledged. However, the physics driving the distribution of the equatorial rotation velocities of main-sequence turn-off (MSTO) stars is as yet poorly understood. Using Gaia Data Release 2 photometry and new Southern African Large Telescope medium-resolution spectroscopy, we analyse the intermediate-age (1Gyr-old) Galactic open clusters NGC 3960, NGC 6134 and IC 4756 and develop a novel method to derive their stellar rotation distributions based on SYCLIST stellar rotation models. Combined with literature data for the open clusters NGC 5822 and NGC 2818, we find a tight correlation between the number ratio of slow rotators and the clusters' binary fractions. The blue-main-sequence stars in at least two of our clusters are more centrally concentrated than their red-main-sequence counterparts. The origin of the equatorial stellar rotation distribution and its evolution remains as yet unidentified. However, the observed correlation in our open cluster sample suggests a binary-driven formation mechanism.

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Impact of initial mass functions on the dynamical channel of gravitational wave sources

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Dynamically formed black hole (BH) binaries (BBHs) are important sources of gravitational waves (GWs). Globular clusters (GCs) are one of the major environments to produce such BBHs, but the total mass of the known GCs is small compared to that in the Galaxy, thus the fraction of BBHs formed in GCs is also small. However, this assumes that GCs contain a canonical initial mass function like that in the field stars. This might not be true because several studies suggest that extreme dense and metal-poor environment can result in top-heavy IMFs, where GCs may come from. Although GCs with top-heavy IMFs were easily disrupted or have become dark clusters, the contribution to the GW sources can be significant. Using a high-performance and accurate N-body code, PeTar, we investigate the effect of varying IMFs by carrying out four star-by-star simulations of dense GCs with the initial mass of $5 \times 10^5 M_\odot$ and the half-mass radius of 2 pc. We find that the BBH merger rate does not monotonically correlate with the slope of IMFs. Due to a rapid expansion, top-heavy IMFs lead to less efficient formation of merging BBHs. The formation rate continuously decreases as the cluster expands due to the dynamical heating caused by BHs. However, in star clusters with a top-heavier IMF, the total number of BHs is larger, and therefore the final contribution to merging BBHs can still be more than clusters with the standard IMF, if the initial cluster mass and density is higher than the model we used.

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https://arxiv.org/abs/2101.09283v1

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Central dynamics of multimass rotating star clusters

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We investigate the evolutionary nexus between the morphology and internal kinematics of the central regions of collisional, rotating, multimass stellar systems, with special attention to the spatial characterization of the process of mass segregation. We report results from idealized, purely N-body simulations that show multimass, rotating, and spherical systems rapidly form an oblate, spheroidal massive core, unlike single-mass rotating, or multimass non-rotating configurations with otherwise identical initial properties, indicating that this evolution is a result of the interplay between the presence of a mass spectrum and angular momentum. This feature appears to be long-lasting, preserving itself for several relaxation times. The degree of flattening experienced by the systems is directly proportional to the initial degree of internal rotation. In addition, this morphological effect has a clear characterization in terms of orbital architecture, as it lowers the inclination of the orbits of massive stars. We offer an idealized dynamical interpretation that could explain the mechanism underpinning this effect and we highlight possible useful implications, from kinematic hysteresis to spatial distribution of dark remnants in dense stellar systems.

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https://ui.adsabs.harvard.edu/abs/2021MNRAS.506.4488T/abstract

Modeling Dense Star Clusters in the Milky Way and Beyond with the Cluster Monte Carlo Code

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We describe the public release of the Cluster Monte Carlo Code (CMC) a parallel, star-by-star N-body code for modeling dense star clusters. CMC treats collisional stellar dynamics using Hénon's method, where the cumulative effect of many two-body encounters is statistically reproduced as a single effective encounter between nearest-neighbor particles on a relaxation timescale. The star-by-star approach allows for the inclusion of additional physics, including strong gravitational three- and four-body encounters, two-body tidal and gravitational-wave captures, mass loss in arbitrary galactic tidal fields, and stellar evolution for both single and binary stars. The public release of CMC is pinned directly to the COSMIC population synthesis code, allowing dynamical star cluster simulations and population synthesis studies to be performed using identical assumptions about the stellar physics and initial conditions. As a demonstration, we present two examples of star cluster modeling: first, we perform the largest ($N = 10^8$) star-by-star N-body simulation of a Plummer sphere evolving to core collapse, reproducing the expected self-similar density profile over more than 15 orders of magnitude; second, we generate realistic models for typical globular clusters, and we show that their dynamical evolution can produce significant numbers of black hole mergers with masses greater than those produced from isolated binary evolution (such as GW190521, a recently reported merger with component masses in the pulsational pair-instability mass gap).

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https://arxiv.org/abs/2106.02643

Early dynamics and violent relaxation of multi-mass rotating star clusters

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We present the results of a study aimed at exploring, by means of N-body simulations, the evolution of rotating multi-mass star clusters during the violent relaxation phase, in the presence of a weak external tidal field. We study the implications of the initial rotation and the presence of a mass spectrum for the violent relaxation dynamics and the final properties of the equilibria emerging at the end of this stage. Our simulations show a clear manifestation of the evolution towards spatial mass segregation and evolution towards energy equipartition during and at the end of the violent relaxation phase. We study the final rotational kinematics and show that massive stars tend to rotate more rapidly than low-mass stars around the axis of cluster rotation. Our analysis also reveals that during the violent relaxation phase, massive stars tend to preferentially segregate into orbits with angular momentum aligned with the cluster's angular momentum, an effect previously found in the context of the long-term evolution of star clusters driven by two-body relaxation.

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Miscellaneous

On the precision of full-spectrum fitting of simple stellar populations - II. The dependence on star cluster mass in the wavelength range 0.3-5.0 μm

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In this second paper of a series on the accuracy and precision of the determination of age and metallicity of simple stellar populations (SSPs) by means of the full spectrum fitting technique, we study the influence of star cluster mass through stochastic fluctuations of the number of stars near the top of the stellar mass function, which dominate the flux in certain wavelength regimes depending on the age. We consider SSP models based on the Padova isochrones, spanning the age range $7.0 \leq \log(\text{age/yr}) \leq 10.1$. Simulated spectra of star clusters in the mass range $10^4 \leq M/M_\odot < 10^6$ are compared with SSP model spectra to determine best-fit ages and metallicities using a full-spectrum fitting routine in four wavelength regimes: the blue optical ($0.35 - 0.70$ μm), the red optical ($0.6 - 1.0$ μm), the near-IR ($1.0 - 2.5$ μm), and the mid-IR ($2.5 - 5.0$ μm). We compare the power of each wavelength regime in terms of both the overall precision of age and metallicity determination, and of its dependence on cluster mass. We also study the relevance of spectral resolution in this context by utilizing two different spectral libraries (BaSeL and BT-Settl). We highlight the power of the mid-IR regime in terms of identifying young massive clusters in dusty star forming regions in distant galaxies. The spectra of the simulated star clusters and SSPs are made available online to enable follow-up studies by the community.

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Binary Black Hole Mergers from Young Massive and Open Clusters: Comparison to GWTC-2 Gravitational Wave Data

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Several astrophysical scenarios have been proposed to explain the origin of the population of binary black hole (BBH) mergers detected in gravitational waves by the LIGO/Virgo Collaboration. Among them, BBH mergers assembled dynamically in young massive and open clusters have been shown to produce merger rate densities consistent with LIGO/Virgo estimated rates. We use the results of a suite of direct, high-precision N-body evolutionary models of young massive and open clusters and build the population of BBH mergers, by accounting for both a cosmologically motivated model for the formation of young massive and open clusters and the detection probability of LIGO/Virgo. We show that our models produce dynamically paired BBH mergers that are well consistent with the observed masses, mass ratios, effective spin parameters, and final spins of the second Gravitational Wave Transient Catalog (GWTC-2).

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Stellar-mass black holes in young massive and open stellar clusters - V. comparisons with LIGO-Virgo merger rate densities

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I study the contribution of young massive star clusters (YMCs) and open star clusters (OCs) to the present day, intrinsic merger rate density of dynamically-assembled binary black holes (BBHs). The BBH merger event rate is estimated based on a set of state-of-the-art evolutionary models of star clusters, as presented in Banerjee (2021). The merger-event rates are obtained by constructing a cluster population of the Universe, out of the models, taking into account mass distribution of clusters and cosmic star formation and enrichment histories, as per observations. The model BBH merger rate density ranges from a pessimistic to a reference value of $0.5 - 37.9$ yr^{-1}Gpc^{-3}, for a LIGO-Virgo-like detector horizon. The reference rate well accommodates the BBH merger rate densities estimated from GWTC-1 and GWTC-2 merger-event catalogues. The computed models also yield differential BBH merger rate densities that agree reasonably with those from GWTC-1 and, as well, with the much more constrained ones from GWTC-2. These results suggest that dynamical interactions in YMCs and OCs can, in principle, alone explain the BBH merger rate density and its dependence on the merging-binary properties, as inferred from to-date gravitational-wave (GW) events. The cosmic merger rate density evolution also agrees with GWTC-2. The models predict a rate of ≈ 5 yr^{-1}Gpc^{-3} for eccentric LIGO-Virgo mergers from YMCs and OCs. The improving constraints on BBH merger rate density with mounting GW events will help constraining scenarios of star cluster formation across cosmic time and as well the relative contributions of the various compact binary merger channels.

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The impact of massive stars and black holes on the fate of open star clusters and their tidal streams

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Context: To investigate how the content of massive OB stars affects the long-term evolution of young open clusters and their tidal streams, and how such an effect influences the constraint of initial conditions by looking at the present-day observations. Aims: OB stars are typically in binaries, have a strong wind mass loss during the first few Myr, and many become black holes. These affect the dynamical evolution of an open star cluster and impact its dissolution in a given Galactic potential. We investigate the correlation between the mass of OB stars and the observational properties of open clusters. Hyades-like star clusters are well represented in the Solar neighborhood and thus allow comparisons with observational data. Methods: We perform a large number of star-by-star numerical N-body simulations of Hyades-like star clusters by using the high-performance N-body code PETAR combined with GALPY. We also developed the tool to transfer the simulation data to mock observations of Gaia. Results: We find that OB stars and black holes have a major effect on star cluster evolution. Star clusters with the same initial conditions, but a different initial content of OB stars, follow very different evolutionary paths. Thus, the initial total mass and radius of an observed star cluster cannot be unambiguously determined unless the initial content of OB stars is known. We show that the stellar counts in the corresponding tidal tails, that can be identified in the Gaia data, help to resolve this issues. We thus emphasise the importance of exploring not only star-clusters, but also their corresponding tidal tails. These findings are relevant for studies of the formation of massive stars.

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Conferences

IlIuminating Galaxy Formation with Ancient Globular Star Clusters and Their Progenitors

March 13 – 18 2022
Aspen, USA
https://www.as.utexas.edu/~mbk/aspen2022/index.html

Cool Stars, Stellar Systems, and the Sun (CS21)

July 4 – 9 2022
Toulouse, France
https://coolstars21.github.io/

UV Insights to Massive Stars and Young Stellar Clusters

August 2022
Busan, Republic of Korea
https://busan2021fm4.org/

Wheel of Star Formation

September 12 – 16 2022
Prague, Czech Republic
https://janfest2020.asu.cas.cz/