The Star Clusters Young & Old Newsletter

edited by Giovanni Carraro, Martin Netopil, and Ernst Paunzen
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Dear Colleagues,

In total, we received 40 abstracts, thanks very much. It shows how vital the star cluster community is.

Virtually any star cluster paper states in the introduction that they are key stellar structure and evolution test-benches. We want in this editorial to highlight one of them in particular, accepted for A&A (arXiv:2007.09153) recently. The paper uses high quality Gaia ESO spectra of the old open cluster NGC 2420 and performs a detailed, physically sounded 3D NLTE analysis using modern stellar evolution tools to stress the limitations of the routinely employed 1D atmosphere models. This tandem of good observations and sophisticated theory allow the authors to achieve quite a number of interesting results. Among them, chemical differences in the atmospheres of stars in different evolutionary phases in the same cluster, and a simple solution of the cosmological Li problem. This is made possible by recognising the crucial role that star interiors' small scale physics plays.

The investigation of star clusters never stops providing very important insights for stellar structure studies!

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

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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.

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Star Forming Regions

The origin of a distributed stellar population in th star-forming region W4

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Stellar kinematics provides the key to understanding the formation process and dynamical evolution of stellar systems. Here, we present a kinematic study of the massive star-forming region W4 in the Cassiopeia OB6 association using the Gaia Data Release 2 and high-resolution optical spectra. This star-forming region is composed of a core cluster (IC 1805) and a stellar population distributed over 20 pc, which is a typical structural feature found in many OB associations. According to a classical model, this structural feature can be understood in the context of the dynamical evolution of a star cluster. The core-extended structure exhibits internally different kinematic properties. Stars in the core have an almost isotropic motion, and they appear to reach virial equilibrium given their velocity dispersion (0.9 ± 0.3 km s^{-1}) comparable to that in a virial state ($\sim$0.8 km s^{-1}). On the other hand, the distributed population shows a clear pattern of radial expansion. From the N-body simulation for the dynamical evolution of a model cluster in subvirial state, we reproduce the observed structure and kinematics of stars. This model cluster experiences collapse for the first 2 Myr. Some members begin to radially escape from the cluster after the initial collapse, eventually forming a distributed population. The internal structure and kinematics of the model cluster appear similar to those of W4. Our results support the idea that the stellar population distributed over 20 pc in W4 originate from the dynamical evolution of IC 1805.

Accepted by: Astrophysical Journal

https://ui.adsabs.harvard.edu/abs/2020arXiv200615262L/abstract

The Formation of a Stellar Association in the NGC 7000/IC 5070 Complex: Results from Kinematic Analysis of Stars and Gas

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We examine the clustering and kinematics of young stellar objects (YSOs) in the North America/Pelican Nebulae, as revealed by *Gaia* astrometry, in relation to the structure and motions of the molecular gas, as indicated in molecular line maps. The *Gaia* parallaxes and proper motions allow us to significantly refine previously published lists of YSOs, demonstrating that many of the objects previously thought to form a distributed population turn out to be non-members. The members are subdivided into at least 6 spatio-kinematic groups, each of which is associated with its own molecular cloud component or components. Three of the groups are expanding, with velocity gradients of 0.3–0.5 km s^{-1} pc^{-1}, up to maximum velocities of $\sim$8 km s^{-1} away from the groups' centers. The two known O-type stars associated with the region, 2MASS J20555125+4352246 and HD 199579, are rapidly escaping one of these groups, following the same position–velocity relation as the low-mass stars. We calculate that a combination of gas expulsion and tidal forces from the clumpy distribution of molecular gas could impart the observed velocity gradients within the groups. However, on a global scale, the relative motions of the groups do not appear either divergent or convergent. The velocity dispersion of the whole system is consistent with the kinetic energy gained due to gravitational collapse of the complex. Most of the stellar population has ages similar to the free-fall timescales for the natal clouds. Thus, we suggest the nearly free-fall collapse of a turbulent molecular cloud as the most likely scenario for star formation in this complex.

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The Villafranca catalog of Galactic OB groups: I. Systems with O2-O3.5 stars

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The spectral classifications of the Galactic O-Star Spectroscopic Survey (GOSSS) and the astrometric and photometric data from Gaia have significantly improved our ability to measure distances and determine memberships of stellar groups (clusters, associations, or parts thereof) with OB stars. In the near future the situation will further improve with more Gaia data releases and new photometric and spectroscopic surveys. We have started a program to identify, measure distances, and determine the membership of Galactic stellar groups with OB stars. Given the data currently available, we start with the identification and distance determinations of groups with O stars. In this paper we concentrate on groups that contain stars with the earliest spectral subtypes. We use GOSSS to select Galactic stellar groups with O2-O3.5 stars and the method described in paper 0 of this series that combines Gaia DR2 G + G_BP + G_RP photometry, positions, proper motions, and parallaxes to assign robust memberships and measure distances. We also include Collinder 419 and NGC 2264, the clusters in that paper, to generate our first list of 16 O-type Galactic stellar groups. We derive distances, determine the membership, and analyze the structure of sixteen Galactic stellar groups with O stars, Villafranca O-001 to Villafranca O-016, including the fourteen groups with the earliest-O-type optically-accessible stars known in the Milky Way. We compare our distance with previous literature results and establish that the best consistency is with (the small number of) VLBI parallaxes and the worst is with kinematic distances. Our results indicate that very massive stars can form in relatively low-mass clusters or even in near-isolation, as is the case for the Bajamar star in the North America nebula. This lends support to the hierarchical scenario of star formation, where some stars are born in well-defined bound clusters but others are born in associations that are unbound from the beginning: groups of newborn stars come in many shapes and sizes. We propose that HD 64 568 and HD 64 315 AB could have been ejected simultaneously from Haffner 18 (Villafranca O-012 S). Our results are consistent with a difference of approx. 20 microarcseconds in the Gaia DR2 parallax zero point between bright and faint stars.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200905773M/abstract

Galactic Open Clusters

Strömgren metallicities for intermediate-age and old star clusters

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We report results that show that the straightforwardly star cluster metallicities obtained from Strömgren vby photometry is age- dependent and need to be corrected for further use. This outcome arises from the comparison of [Fe/H] values derived from Strömgren photometry with those metallicities published in the literature for 26 Large and Small Magellanic Cloud star clusters, whose ages range from approx. 1 Gyr up to the known oldest globular clusters' ages in these galaxies. While deriving mean star cluster metallicities we carried out a thorough selection of red giant branch candidates to comply with the Strömgren metallicity calibration validity regime. We paid attention to the effect of contamination by field stars, particularly of those that lie inside the star clusters' radii, distributed along the star cluster red giant branches, and with [Fe/H] values covering a similar range as that for the selected stars. We found that the measured Strömgren metallicities are systematically more metal-poor than the published ones and that a quadratically age- varying function reproduces the relative metallicity values with an overall uncertainty of approx. 0.05 dex. We finally performed a similar comparison relying on a fully independent approach, that consisted in using theoretical red giant branches of old globular clusters spanning [Fe/H] values from -2.0 up to 0.0 dex as standard ones. We then superimposed on to them the red giant branches of star clusters with ages in the range 1.0 - 12.5 Gyr and estimated by interpolation their associated metallicities. The derived theoretical relative metallicities follow a similar trend as a function of the star clusters' ages than that found from observations of star clusters.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200805270P/abstract

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Rotation of open clusters based on the GAIA data. Praesepe.

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High–precision trigonometric parallaxes, proper motions, and radial velocities of the GAIA DR2 catalogue allow us to investigate the problem of open clusters rotation. Such a study could naturally be started with the clusters closest to the Sun, so wechose Praesepe as an object of our study. We selected 908 probable cluster members up to the apparent magnitude G=19 mag based on their trigonometric parallaxes and proper motions, within 10° distance from the cluster centre. We estimated the cluster distance modulus to be 6.36 mag and 6.02 mag using the trigonometric parallaxes of the probable cluster members and by fitting the theoretical isochrone to the cluster HR diagram, respectively. The cluster rotation velocity was estimated to be 0.4 km s^{-1} at the periphery of the cluster, using three different methods. In future, we will continue the study of clusters rotation, with several nearby open clusters.

Accepted by: Astronomische Nachrichten

Leveraging HST with MUSE: II. Na-abundance variations in intermediate age star clusters

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Ancient (>10 Gyr) globular clusters (GCs) show chemical abundance variations in the form of patterns among certain elements, e.g. N correlates with Na and anti-correlates with O. Recently, N abundance spreads have also been observed in massive star clusters that are significantly younger than old GCs, down to an age of ∼2 Gyr. However, as so far N has been the only element found to vary in such young objects. We report here the presence of Na abundance variations in the intermediate age massive star clusters NGC 416 (∼6.5 Gyr old) and Lindsay 1 (∼7.5 Gyr old) in the Small Magellanic Cloud, by combining HST and ESO-VLT MUSE observations. Using HST photometry we were able to construct "chromosome maps" and separate sub-populations with different N content, in the red giant branch of each cluster. MUSE spectra of individual stars belonging to each population were combined, resulting in high signal-to-noise spectra representative of each population, which were compared to search for mean differences in Na. We find a mean abundance variation of Δ[Na/Fe]$= 0.18 \pm 0.04$ dex for NGC 416 and Δ[Na/Fe]$= 0.24 \pm 0.05$ dex for Lindsay 1. In both clusters we find that the population that is enhanced in N is also enhanced in Na, which is the same pattern to the one observed in ancient GCs. Furthermore, we detect a bimodal distribution of core-helium burning Red Clump (RC) giants in the UV colour magnitude diagram of NGC 416. A comparison of the stacked MUSE spectra of the two RCs shows the same mean Na abundance difference between the two populations. The results reported in this work are a crucial hint that star clusters of a large age range share the same origin: they are the same types of objects, but only separated in age.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200910023M/abstract

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The Relation of the Alpha Persei Star Cluster with the Nearby Stellar Stream

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A map of 100° on a side extracted from Gaia DR2 and centered on Alpha Persei reveals two distinct structures—the Alpha Persei star cluster and a conspicuous stellar stream, as widely documented in recent literature. In this work we employ DBSCAN to assess individual stars' membership and attempt at separating stars belonging to the cluster and to the stream from the general field. In turn, we characterize the stream and investigate its relation with the cluster. The stream population turned out to be significantly older (5 ± 1 Gyr) than the cluster, and to be positioned approx. 90 pc away from the cluster, in its background. The stream exhibits a sizeable thickness of ∼180 pc in the direction of the line of view. Finally, the stream harbors a prominent population of white dwarf stars. We estimated an upper limit of the stream mass of $\sim 6000 M_{\odot}$. The stream would therefore be the leftover of a relatively massive old cluster. The surface density map of Alpha Persei indicates the presence of tidal tails. While it is tempting to ascribe their presence to the interaction with the disrupting old star cluster, we prefer to believe, conservatively, they are of Galactic origin.

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https://ui.adsabs.harvard.edu/abs/2020AJ....160..142N/abstract

Three open clusters containing Cepheids: NGC 6649, NGC 6664 & Berkeley 55

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Classical Cepheids in open clusters play an important role in benchmarking stellar evolution models, anchoring the cosmic distance scale, and invariably securing the Hubble constant. NGC 6649, NGC 6664 and Berkeley 55 are three pertinent clusters that host classical Cepheids and red (super)giants, and an analysis was consequently initiated to assess newly acquired spectra (≈50), archival photometry, and *Gaia* DR2 data. Importantly, for the first time chemical abundances are determined for the evolved members of NGC 6649 and NGC 6664. We find that they are slightly metal-poor relative to the mean Galactic gradient, and an overabundance of Ba is observed. Those clusters likely belong to the thin disc, and the latter finding supports D'Orazi et al. (2009) "*s*-enhanced" scenario. NGC 6664 and Berkeley 55 exhibit radial velocities consistent with Galactic rotation, while NGC 6649 displays a peculiar velocity. The resulting age estimates for the clusters (≈70 Ma) imply masses for the (super)giant demographic of ≈6 $M_{\odot}$. Lastly, the observed yellow-to-red (super)giant ratio is lower than expected, and the overall differences relative to models reflect outstanding theoretical uncertainties.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200912418A/abstract

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Analysis of Red-Supergiants in VdBH-222

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Recent surveys uncovered new Young Massive Clusters (YMCs) that host dozens of Red Supergiants (RSGs) in the inner Milky Way. These clusters are ideal for studying the most recent and violent star formation events in the inner Galaxy. However, due to the high extinction that affects the Galactic plane, they need to be studied through infrared (IR) spectroscopy. IR spectra of RSGs have proven to be powerful tools for obtaining chemical abundances. We present the first [Fe/H] measurement (−0.07±0.02) for the YMC VdBH-222 through analysis of its RSGs using VLT/X-Shooter spectra. As expected for YMCs younger than 2 Gyr, we find no evidence for star-to-star chemical variations in light-element abundances in this cluster, contrary to what is routinely observed in older massive clusters.

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Stellar Population Astrophysics (SPA) with TNG. The old open clusters Collinder 350, Gulliver 51, NGC 7044, and Ruprecht 171

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Open clusters are excellent tracers of the chemical evolution of the Galactic disc. The spatial distribution of their elemental abundances, through the analysis of high-quality and high-resolution spectra, provides insight into the chemical evolution and mechanisms of element nucleosynthesis in regions characterised by different conditions (e.g. star formation efficiency and metallicity). In the framework of the Stellar Population Astrophysics (SPA) project, we present new observations and spectral analysis of four sparsely studied open clusters located in the solar neighbourhood, namely Collinder 350, Gulliver 51, NGC 7044, and Ruprecht 171. We exploit the HARPS-N spectrograph at the TNG telescope to acquire high-resolution optical spectra for 15 member stars of four clusters. We derive stellar parameters ($T_{\rm eff}$, log g, [Fe/H] and ξ) using both the equivalent width (EW) analysis and the spectral fitting technique. We compute elemental abundances for light, α-, iron-peak, and n-capture elements using the EW measurement approach. We investigate the origin of the correlation between metallicity and stellar parameters derived with the EW method for the coolest stars of the sample ($T_{\rm eff} < 4300$ K). The correlation is likely due to the challenging continuum setting and to a general inaccuracy of model atmospheres used to reproduce the conditions of very cool giant stars. We locate the properties of our clusters in the radial distributions of metallicity and abundance ratios, comparing our results with clusters from the Gaia-ESO and APOGEE surveys. We present the [X/Fe]-[Fe/H] and [X/Fe]-$R_{\rm GC}$ trends for elements in common between the two surveys. Finally, we derive the C and Li abundances as a function of the evolutionary phase and compare them with theoretical models. The SPA survey, with its high-resolution spectra, allows us to fully characterise the chemistry of nearby clusters. With a single set of spectra, we provide chemical abundances for a variety of chemical elements, which are comparable to those obtained in two of the largest surveys combined. The metallicities and abundance ratios of our clusters fit very well in the radial distributions defined by the recent literature, reinforcing the importance of star clusters to outline the spatial distribution of abundances in our Galaxy. Moreover, the abundances of C and Li, modified by stellar evolution during the giant phase, agree with evolutionary prescriptions (rotation-induced mixing) for their masses and metallicities.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200906695C/abstract

The Gaia-ESO Survey: Calibrating the lithium-age relation with open clusters and associations. I. Cluster age range and initial membership selections

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Previous studies of open clusters have shown that lithium depletion is not only strongly age dependent but also shows a complex pattern with other parameters that is not yet understood. For pre- and main-sequence late-type stars, these parameters include metallicity, mixing mechanisms, convection structure, rotation, and magnetic activity. We perform a thorough membership analysis for a large number of stars observed within the Gaia-ESO survey (GES) in the field of 20 open clusters, ranging in age from young clusters and associations, to intermediate-age and old open clusters. Based on the parameters derived from the GES spectroscopic observations, we obtained lists of candidate members for each of the clusters in the sample by deriving RV distributions and studying the position of the kinematic selections in the EW(Li) versus Teff plane to obtain lithium members. We used gravity indicators to discard field contaminants and studied [Fe/H] metallicity to further confirm the membership of the candidates. We also made use of studies using recent data from the Gaia DR1 and DR2 releases to assess our member selections. We identified likely member candidates for the sample of 20 clusters observed in GES (iDR4) with UVES and GIRAFFE, and conducted a comparative study that allowed us to characterize the properties of these members, as well as identify field contaminant stars, both lithium-rich giants and non-giant outliers. This work is the first step towards the calibration of the lithium-age relation and its dependence on other GES parameters. During this project we aim to use this relation to infer the ages of GES field stars, and identify their potential membership to young associations and stellar kinematic groups of different ages.

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Galactic Globular Clusters

On the absence of symbiotic stars in globular clusters

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Even though plenty of symbiotic stars (SySts) have been found in the Galactic field and nearby galaxies, not a single one has ever been confirmed in a Galactic globular cluster (GC). We investigate the lack of such systems in GCs for the first time by analysing 144 GC models evolved with the MOCCA code, which have different initial properties and are roughly representative of the Galactic GC population. We focus here on SySts formed through the wind-accretion channel, which can be consistently modelled in binary population synthesis codes. We found that the orbital periods of the majority of such SySts are sufficiently long ($\gtrsim 10^3$ d) so that, for very dense GC models, dynamical interactions play an important role in destroying their progenitors before the present day ($\sim 11 - 12$ Gyr). In less dense GC models, some SySts are still predicted to exist. However, these systems tend to be located far from the central parts ($\gtrsim 70$ per cent are far beyond the half-light radius) and are sufficiently rare ($\lesssim 1$ per GC per Myr), which makes their identification rather difficult in observational campaigns. We propose that future searches for SySts in GCs should be performed in the outskirts of nearby low-density GCs with sufficiently long half-mass relaxation times and relatively large Galactocentric distances. Finally, we obtained spectra of the candidate proposed in ω Cen (SOPS IV e-94) and showed that this object is most likely not a SySt.

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https://ui.adsabs.harvard.edu/abs/2020MNRAS.496.3436B/abstract

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Properties of Cataclysmic Variables in Globular Clusters

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The study of star clusters plays an important role in our understanding of the Universe since these systems are natural laboratories for testing theories of stellar dynamics and evolution. Particularly, globular clusters (GCs) are one of the most important objects for studying the formation and the physical nature of exotic systems which in turn provide basic information and tools that can help us to understand the formation and evolution processes of star clusters themselves, galaxies and, in general, the young Universe. Among the most interesting objects in GCs are the cataclysmic variables (CVs), which are interacting binaries harboring a white dwarf accreting from a low-mass companion. Since GC densities are sufficiently high that dynamical encounters involving binaries should be common, CV progenitors are expected to be affected by dynamics in some way in the early stages. In this article we review the formation channels and the influence of dynamics on the CV population in GCs. In particular, we review recent progress in numerical simulations. Furthermore, we discuss observational properties of CVs in GCs and the techniques used to identify and study them. We focus the discussion on the multi-wavelength observations carried out with HST and Chandra on the best-studied GCs NGC 6397, NGC 6752, 47 Tucanae and ω Centauri; on the recent spectroscopic findings with MUSE, and on updates regarding the correlation between the number of faint X-ray sources and the cluster stellar encounter rate. Finally, we discuss some observational prospects that might potentially help future investigations.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200812772B/abstract

The elusive tidal tails of the Milky Way globular cluster NGC 7099

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We present results on the extra-tidal features of the Milky Way globular cluster NGC 7099, using deep gr photometry obtained with the Dark Energy Camera (DECam). We reached nearly 6 mag below the cluster Main Sequence (MS) turnoff, so that we dealt with the most suitable candidates to trace any stellar structure located beyond the cluster tidal radius. From star-by-star reddening corrected color-magnitude diagrams (CMDs) we defined four adjacent strips along the MS, for which we built the respective stellar density maps, once the contamination by field stars was properly removed. The resulting field star cleaned stellar density maps show a short tidal tail and some scattered debris. Such extra-tidal features are hardly detected when much shallower Gaia DR2 data sets are used and the same CMD field star cleaning procedure is applied. Indeed, by using 2.5 magnitudes below the cluster MS turnoff as the faintest limit ($G < 20.5$ mag), cluster members turned out to be distributed within the cluster's tidal radius, and some hints for field star density variations are found across a circle of radius 3.5deg centered on the cluster and with similar CMD features as cluster stars. The proper motion distribution of these stars is distinguishable from that of the cluster, with some superposition, which resembles that of stars located beyond 3.5deg from the cluster center.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200904290P/abstract

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Absolute V-band magnitudes and mass-to-light ratios of Galactic globular clusters

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We have used HST and ground-based photometry to determine total V-band magnitudes and mass-to-light ratios of more than 150 Galactic globular clusters. We do this by summing up the magnitudes of their individual member stars, using color-magnitude information, Gaia DR2 proper motions and radial velocities to distinguish cluster stars from background stars. Our new magnitudes confirm literature estimates for bright clusters with V<8, but can deviate by up to two magnitudes from literature values for fainter clusters. They lead to absolute mass-to-light ratios that are confined to a narrow range between 1.4 and 2.5, significantly smaller than what was found before. We also find a correlation between a cluster's M/L_V value and its age, in agreement with theoretical predictions. The M/L_V ratios of globular clusters are also in good agreement with those predicted by stellar isochrones, arguing against a significant amount of dark matter inside globular clusters. We finally find that, in agreement with what has been seen in M31, the magnitude distribution of outer halo globular clusters has a tail towards faint clusters that is absent in the inner parts of the Milky Way.

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https://ui.adsabs.harvard.edu/abs/2020arXiv200909611B/abstract

The Effects of Dwarf Galaxies on the Orbital Evolution of Galactic Globular Clusters

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We investigate the effect that dwarf galaxies have on the orbits, tidal histories, and assumed formation environment of Milky Way globular clusters. We determine the orbits of the Milky Way's 150 globular clusters in a gravitational potential both with and without dwarf galaxies. We find that the presence of a small number of satellite galaxies can affect the orbits of many of the globular clusters. Over 12 Gyr, we find that the semi-major axis and orbital eccentricity of individual clusters fluctuate with dispersions on the order of ∼10% and ∼4% , respectively. Outer clusters are more strongly affected by dwarf galaxies than inner clusters, with their semi-major axis and orbital eccentricities fluctuating by more than ∼15% and ∼5% , respectively. Using detailed N-body simulations of select clusters, we find that altering their orbital histories can lead to different mass loss rates and structural evolution. Furthermore, we caution against using kinematics alone to identify whether a Galactic cluster formed in-situ or was accreted during a past merger event as these values are no longer conserved. The presence of dwarf galaxies causes the orbital energies and actions of individual clusters to evolve over time, spanning a wider range than that coming from random uncertainties in a cluster's proper motions and radial velocity.

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Different Sodium enhancements among multiple populations of Milky Way globular clusters

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We searched for trails to understand the different Na abundances measured in first and second generation stars of ancient Milky Way globular clusters. For that purpose, we gathered from the recent literature the aforementioned Na abundances, orbital parameters, structural and internal dynamical properties and ages in an homogeneous scale of 28 globular clusters. We found that the intra-cluster Na enrichment, measured by the difference of Na abundances between first and second generation stars, exhibits a trend as a function of the Na abundances of first generation stars, in the sense that the more Na-poor the first generation stars, the larger the Na enrichment. By using the inclinations of the globular clusters' orbits, the analyzed Na enrichments also hinted at a boundary at ∼0.3 dex to differentiate globular clusters with an accreted or in situ origin, the accreted globular clusters having larger Na enrichments. Because relatively larger intra-cluster Na enhancements are seen in accreted globular clusters, and small Na enhancements are observed in globular clusters formed in situ (although not exclusively), we speculate with the possibility that the amplitude of the Na enrichment could be linked with the building block paradigm. Globular clusters at the time of formation of first and second generation stars would seem to keep memory of this hierarchical galaxy formation process.

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Clusters in the Magellanic clouds

The VISCACHA survey – II. Structure of star clusters in the Magellanic Clouds periphery

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We provide a homogeneous set of structural parameters of 83 star clusters located at the periphery of the Small Magellanic Cloud (SMC) and the Large Magellanic Cloud (LMC). The clusters' stellar density and surface brightness profiles were built from deep, AO assisted optical images, and uniform analysis techniques. The structural parameters were obtained from King and Elson et al. model fittings. Integrated magnitudes and masses (for a subsample) are also provided. The sample contains mostly low surface brightness clusters with distances between 4.5 and 6.5 kpc and between 1 and 6.5 kpc from the LMC and SMC centres, respectively. We analysed their spatial distribution and structural properties, comparing them with those of inner clusters. Half-light and Jacobi radii were estimated, allowing an evaluation of the Roche volume tidal filling. We found that: (i) for our sample of LMC clusters, the tidal radii are, on average, larger than those of inner clusters from previous studies; (ii) the core radii dispersion tends to be greater for LMC clusters located towards the southwest, with position angles of $\sim$200° and about $\sim$5° from the LMC centre, i.e. those LMC clusters nearer to the SMC; (iii) the core radius evolution for clusters with known age is similar to that of inner clusters; (iv) SMC clusters with galactocentric distances closer than 4 kpc are overfilling; (v) the recent Clouds collision did not leave marks on the LMC clusters' structure that our analysis could reveal.

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A Search for In-Situ Field OB Star Formation in the Small Magellanic Cloud

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Whether any OB stars form in isolation is a question central to theories of massive star formation. To address this, we search for tiny, sparse clusters around 210 field OB stars from the Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (RIOTS4), using friends-of-friends (FOF) and nearest neighbors (NN) algorithms. We also stack the target fields to evaluate the presence of an aggregate density enhancement. Using several statistical tests, we compare these observations with three random-field datasets, and we also compare the known runaways to non-runaways. We find that the local environments of non-runaways show higher aggregate central densities than for runaways, implying the presence of some "tips-of-iceberg" (TIB) clusters. We find that the frequency of these tiny clusters is low, $\sim$4-5% of our sample. This fraction is much lower than some previous estimates, but is consistent with field OB stars being almost entirely runaway and walkaway stars. The lack of TIB clusters implies that such objects either evaporate on short timescales, or do not form, implying a higher cluster lower-mass limit and consistent with a relationship between maximum stellar mass (mmax) and the mass of the cluster (Mcl). On the other hand, we also cannot rule out that some OB stars may form in highly isolated conditions. Our results set strong constraints on the formation of massive stars in relative isolation.

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The most distant clusters

The Next Generation Virgo Cluster Survey. XXXIV. Ultracompact Dwarf Galaxies in the Virgo Cluster

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We present a study of ultracompact dwarf (UCD) galaxies in the Virgo cluster based mainly on imaging from the Next Generation Virgo Cluster Survey (NGVS). Using ∼100 $\deg^2$ of ugiz imaging, we have identified more than 600 candidate UCDs, from the core of Virgo out to its virial radius. Candidates have been selected through a combination of magnitudes, ellipticities, colors, surface brightnesses, half-light radii, and, when available, radial velocities. Candidates were also visually validated from deep NGVS images. Subsamples of varying completeness and purity have been defined to explore the properties of UCDs and compare to those of globular clusters and the nuclei of dwarf galaxies with the aim of delineating the nature and origins of UCDs. From a surface density map, we find the UCDs to be mostly concentrated within Virgo's main subclusters, around its brightest galaxies. We identify several subsamples of UCDs – i.e., the brightest, largest, and those with the most pronounced and/or asymmetric envelopes – that could hold clues to the origin of UCDs and possible evolutionary links with dwarf nuclei. We find some evidence for such a connection from the existence of diffuse envelopes around some UCDs and comparisons of radial distributions of UCDs and nucleated galaxies within the cluster.

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Is Fornax 4 the nuclear star cluster of the Fornax dwarf spheroidal galaxy?

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Fornax 4 is the most distinctive globular cluster in the Fornax dwarf spheroidal. Located close to the centre of the galaxy, more metal-rich and potentially younger than its four companions (namely, Fornax clusters number 1, 2, 3, and 5), it has been suggested to have experienced a different formation than the other clusters in the galaxy. Here, we use Hubble Space Telescope/WFC3 photometry to characterize the stellar population content of this system and shed new light on its nature. By means of a detailed comparison of synthetic horizontal branch and red giant branch with the observed colour–magnitude diagrams, we find that this system likely hosts stellar sub-populations characterized by a significant iron spread up to Δ[Fe/H] ~ 0.4 dex and possibly by also some degree of He abundance variations $\Delta Y \sim 0.03$. We argue that this purely observational evidence, combined with the other peculiarities characterizing this system, supports the possibility that Fornax 4 is the nuclear star cluster of the Fornax dwarf spheroidal galaxy. A spectroscopic follow-up for a large number of resolved member stars is needed to confirm this interesting result and to study in detail the formation and early evolution of this system and more in general the process of galaxy nucleation.

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The Next Generation Virgo Cluster Survey (NGVS). XXX. Ultra-diffuse Galaxies and Their Globular Cluster Systems

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We present a study of ultra-diffuse galaxies (UDGs) in the Virgo Cluster based on deep imaging from the Next Generation Virgo Cluster Survey. Applying a new definition for the UDG class based on galaxy scaling relations, we define samples of 44 and 26 UDGs using expansive and restrictive selection criteria, respectively. Our UDG sample includes objects that are significantly fainter than previously known UDGs: i.e., more than half are fainter than $\langle\mu\rangle_e \sim 27.5$ mag arcsec^{-2}. The UDGs in Virgo's core region show some evidence for being structurally distinct from "normal" dwarf galaxies, but this separation disappears when considering the full sample of galaxies throughout the cluster. UDGs are more centrally concentrated in their spatial distribution than other Virgo galaxies of similar luminosity, while their morphologies demonstrate that at least some UDGs owe their diffuse nature to physical processes—such as tidal interactions or low-mass mergers—that are at play within the cluster environment. The globular cluster (GC) systems of Virgo UDGs have a wide range in specific frequency (S_N), with a higher mean S_N than "normal" Virgo dwarfs, but a lower mean S_N than Coma UDGs at fixed luminosity. Their GCs are predominantly blue, with a small contribution from red clusters in the more massive UDGs. The combined GC luminosity function is consistent with those observed in dwarf galaxies, showing no evidence of being anomalously luminous. The diversity in their morphologies and their GC properties suggests no single process has given rise to all objects within the UDG class. Based on the available evidence, we conclude that UDGs are simply those systems that occupy the extended tails of the galaxy size and surface brightness distributions.

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Star cluster formation in the most extreme environments: Insights from the HiPEEC survey

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We present the Hubble imaging Probe of Extreme Environments and Clusters (HiPEEC) survey. We fit HST NUV to NIR broadband and Hα fluxes, to derive star cluster ages, masses, extinctions and determine the star formation rate (SFR) of 6 merging galaxies. These systems are excellent laboratories to trace cluster formation under extreme gas physical conditions, rare in the local universe, but typical for star-forming galaxies at cosmic noon. We detect clusters with ages of 1-500 Myr and masses that exceed 10^7 $M_\odot$. The recent cluster formation history and their distribution within the host galaxies suggest that systems like NGC34, NGC1614, NGC4194 are close to their final coalescing phase, while NGC3256, NGC3690, NGC6052 are at an earlier/intermediate stage. A Bayesian analysis of the cluster mass function in the age interval 1-100 Myr provides strong evidence in 4 of the 6 galaxies that an exponentially truncated power law better describes the observed mass distributions. For two galaxies, the fits are inconclusive due to low number statistics. We determine power-law slopes $\beta \sim -1.5$ to -2.0, and truncation masses, M_c, between 10^6 and a few times 10^7 $M_\odot$, among the highest values reported in the literature. Advanced mergers have higher M_c than early/intermediate merger stage galaxies, suggesting rapid changes in the dense gas conditions during the merger. We compare the total stellar mass in clusters to the SFR of the galaxy, finding that these systems are among the most efficient environments to form star clusters in the local universe.

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Dynamical evolution - Simulations

How fast do young star clusters expel their natal gas?: Estimating the upper limit of the gas expulsion time-scale

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Formation of massive stars within embedded star clusters starts a complex interplay between their feedback, inflowing gas and stellar dynamics, which often includes close stellar encounters. Hydrodynamical simulations usually resort to substantial simplifications to model embedded clusters. Here, we address the simplification which approximates the whole star cluster by a single sink particle, which completely neglects the internal stellar dynamics. In order to model the internal stellar dynamics, we implement a Hermite predictor-corrector integration scheme to the hydrodynamic code FLASH. As we illustrate by a suite of tests, this integrator significantly outperforms the current leap-frog scheme, and it is able to follow the dynamics of small compact stellar systems without the necessity to soften the gravitational potential. We find that resolving individual massive stars instead of representing the whole cluster by a single energetic source has a profound influence on the gas component: for clusters of mass less than $\approx 3 \times 10^3 M_\odot$, it slows gas expulsion by a factor of ≈ 5 to ≈ 1 Myr, and it results in substantially more complex gas structures. With increasing cluster mass (up to $\approx 3 \times 10^3 M_\odot$), the gas expulsion time-scale slightly decreases. However, more massive clusters ($\gtrsim 5 \times 10^3 M_\odot$) are unable to clear their natal gas with photoionising radiation and stellar winds only if they form with a star formation efficiency (SFE) of 1/3. This implies that the more massive clusters are either cleared with another feedback mechanism or they form with a SFE higher than 1/3.

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A new parameterization of the star formation rate-dense gas mass relation: embracing gas density gradients

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It is well-established that a gas density gradient inside molecular clouds and clumps raises their star formation rate compared to what they would experience from a gas reservoir of uniform density. This effect should be observed in the relation between dense-gas mass M_{dg} and star formation rate SFR of molecular clouds and clumps, with steeper gas density gradients yielding higher SFR/M_{dg} ratios. The content of this paper is two-fold. Firstly, we build on the notion of magnification factor introduced by Parmentier (2019) to redefine the dense-gas relation (i.e. the relation between M_{dg} and SFR). Not only does the SFR/M_{dg} ratio depend on the mean free-fall time of the gas and on its (intrinsic) star formation efficiency per free-fall time, it also depends on the logarithmic slope $-p$ of the gas density profile and on the relative extent of the constant-density region at the clump center. Secondly, we show that nearby molecular clouds follow the newly-defined dense-gas relation, provided that their dense-gas mass is defined based on a volume density criterion. We also find the same trend for the dense molecular clouds of the Central Molecular Zone (CMZ) of the Galaxy, although this one is scaled down by a factor of 10 compared to nearby clouds. The respective locii of both nearby and CMZ clouds in the $(p, SFR/M_{dg})$ parameter space is discussed.

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The role of collision speed, cloud density, and turbulence in the formation of young massive clusters via cloud-cloud collisions

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Young massive clusters (YMCs) are recently formed astronomical objects with unusually high star formation rates. We propose the collision of giant molecular clouds (GMCs) as a likely formation mechanism of YMCs, consistent with the YMC conveyor-belt formation mode concluded by other authors. We conducted smoothed particle hydrodynamical simulations of cloud-cloud collisions and explored the effect of the clouds' collision speed, initial cloud density, and the level of cloud turbulence on the global star formation rate and the properties of the clusters formed from the collision. We show that greater collision speed, greater initial cloud density and lower turbulence increase the overall star formation rate and produce clusters with greater cluster mass. In general, collisions with relative velocity $\gtrsim$ 25 km/s, initial cloud density $\gtrsim$ 250 cm^{-3}, and turbulence of $\approx$ 2.5 km/s can produce massive clusters with properties resembling the observed Milky Way YMCs.

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Demographics of neutron stars in young massive and open clusters

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Star clusters appear to be the ideal environment for the assembly of neutron star-neutron star (NS-NS) and black hole-neutron star (BH-NS) binaries. These binaries are among the most interesting astrophysical objects, being potential sources of gravitational waves (GWs) and gamma-ray bursts. We use for the first time high-precision N-body simulations of young massive and open clusters to study the origin and dynamical evolution of NSs, within clusters with different initial masses, metallicities, primordial binary fractions, and prescriptions for the compact object natal kicks at birth. We find that the radial profile of NSs is shaped by the BH content of the cluster, which partially quenches the NS segregation due to the BH-burning process. This leaves most of the NSs out of the densest cluster regions, where NS-NS and BH-NS binaries could potentially form. Due to a large velocity kick that they receive at birth, most of the NSs escape the host clusters, with the bulk of their retained population made up of NSs of $\sim 1.3 M_{\odot}$ coming from the electron-capture supernova process. The details of the primordial binary fraction and pairing can smear out this trend. Finally, we find that a subset of our models produce NS-NS mergers, leading to a rate of $\sim 0.01 - 0.1 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ in the local Universe, and compute an upper limit of $\sim 3 \times 10^{-2} - 3 \times 10^{-3} \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ for the BH-NS merger rate. Our estimates are several orders of magnitude smaller than the current empirical merger rate from LIGO/Virgo, in agreement with the recent rate estimates for old globular clusters.

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PeTar: a high-performance N-body code for modeling massive collisional stellar systems

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The numerical simulations of massive collisional stellar systems, such as globular clusters (GCs), are very time-consuming. Until now, only a few realistic million-body simulations of GCs with a small fraction of binaries (5%) have been performed by using the NBODY6++GPU code. Such models took half a year computational time on a GPU based super-computer. In this work, we develop a new N-body code, PeTar, by combining the methods of Barnes-Hut tree, Hermite integrator and slow-down algorithmic regularization (SDAR). The code can accurately handle an arbitrary fraction of multiple systems (e.g. binaries, triples) while keeping a high performance by using the hybrid parallelization methods with MPI, OpenMP, SIMD instructions and GPU. A few benchmarks indicate that PeTar and NBODY6++GPU have a very good agreement on the long-term evolution of the global structure, binary orbits and escapers. On a highly configured GPU desktop computer, the performance of a million-body simulation with all stars in binaries by using PeTar is 11 times faster than that of NBODY6++GPU. Moreover, on the Cray XC50 supercomputer, PeTar well scales when number of cores increase. The ten million-body problem, which covers the region of ultra compact dwarfs and nuclear star clusters, becomes possible to be solved.

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The Physics of Star Cluster Formation and Evolution

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Star clusters form in dense, hierarchically collapsing gas clouds. Bulk kinetic energy is transformed to turbulence with stars forming from cores fed by filaments. In the most compact regions, stellar feedback is least effective in remov- ing the gas and stars may form very efficiently. These are also the regions where, in high-mass clusters, ejecta from some kind of high-mass stars are effectively cap- tured during the formation phase of some of the low mass stars and effectively channeled into the latter to form multiple populations. Star formation epochs in star clusters are generally set by gas flows that determine the abundance of gas in the cluster. We argue that there is likely only one star formation epoch after which clusters remain essentially clear of gas by cluster winds. Collisional dynamics is important in this phase leading to core collapse, expansion and eventual disper- sion of every cluster. We review recent developments in the field with a focus on theoretical work.

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Hypercompact stellar clusters: morphological renditions and spectrophotometric models

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Numerical relativity predicts that the coalescence of a black hole (BH) binary causes the newly formed BH to recoil, and evidence for such recoils has been found in the gravitational waves observed during the merger of stellar-mass BHs. Recoiling (super)massive BHs are expected to reside in hypercompact stellar clusters (HCSCs). Simulations of galaxy assembly predict that hundreds of HCSCs should be present in the halo of a Milky Way (MW)-type galaxy, and a fraction of those around the MW should have magnitudes within the sensitivity limit of existing surveys. However, recoiling BHs and their HCSCs are still waiting to be securely identified. With the goal of enabling searches through recent and forthcoming data bases, we improve over existing literature to produce realistic renditions of HCSCs bound to BHs with a mass of 105 $M_\odot$. Including the effects of a population of blue stragglers, we simulate their appearance in Pan-STARRS and in forthcoming Euclid images. We also derive broad-band spectra and the corresponding multiwavelength colours, finding that the great majority of the simulated HCSCs fall on the colour-colour loci defined by stars and galaxies, with their spectra resembling those of giant K-type stars. We discuss the clusters properties, search strategies, and possible interlopers.

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Planetary Systems in a Star Cluster II: intermediate-mass black holes and planetary systems

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Most stars form in dense stellar environments. It is speculated that some dense star clusters may host intermediate-mass black holes (IMBHs), which may have formed from runaway collisions between high-mass stars, or from the mergers of less massive black holes. Here, we numerically explore the evolution of populations of planets in star clusters with an IMBH. We study the dynamical evolution of single-planet systems and free-floating planets, over a period of 100 Myr, in star clusters without an IMBH, and in clusters with a central IMBH of mass 100 $M_{\odot}$ or 200 $M_{\odot}$. In the central region ($r \lesssim 0.2$ pc), the IMBH's tidal influence on planetary systems is typically 10 times stronger than the average neighbour star. For a star cluster with a $200 M_{\odot}$ IMBH, the region in which the IMBH's influence is stronger within the virial radius (~ 1 pc). The IMBH quenches mass segregation, and the stars in the core tend to move towards intermediate regions. The ejection rate of both stars and planets is higher when an IMBH is present. The rate at which planets are expelled from their host star rate is higher for clusters with higher IMBH masses, for $t < 0.5 t_{\rm rh}$, while remains mostly constant while the star cluster fills its Roche lobe, similar to a star cluster without an IMBH. The disruption rate of planetary systems is higher in initially denser clusters, and for wider planetary orbits, but this rate is substantially enhanced by the presence of a central IMBH

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Tidal tails of open star clusters as probes to early gas expulsion I: A semi-analytic model

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Star clusters form out of the densest parts of infrared dark clouds. The emergence of massive stars expels the residual gas, which has not formed stars yet. Gas expulsion lowers the gravitational potential of the embedded cluster, unbinding many of the cluster stars. These stars then move on their own trajectories in the external gravitational field of the Galaxy, forming a tidal tail. We investigate the formation and evolution of the tidal tail forming due to expulsion of primordial gas under various scenarios of gas expulsion to provide predictions for tidal tails around dynamically evolved (age ¿ 100 Myr) galactic star clusters, which can be possibly detected by the Gaia mission. We provide a semi-analytical model for the tail evolution. We find that tidal tails released during gas expulsion have different kinematic properties than the tails gradually forming due to evaporation. The gas expulsion tidal tail shows non-monotonic expansion with time, where longer epochs of expansion are interspersed with shorter epochs of contraction. The tail thickness and velocity dispersions strongly, but not exactly periodically, vary with time. The times of minima of tail thickness and velocity dispersions are given only by the properties of the galactic potential, and not by the properties of the cluster. The estimates provided by the (semi-)analytical model for the extent of the tail, the minima of tail thickness, and velocity dispersions are in a very good agreement with the nbody6 simulations. This implies that the semi-analytic model can be used for estimating the properties of the gas expulsion tidal tail for a cluster of a given age and orbital parameters without the necessity of performing numerical simulations. A study with a more extended parameter space of the initial conditions is performed in the follow up paper.

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Tidal tails of open star clusters as probes to early gas expulsion II: Predictions for Gaia

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We study the formation and evolution of the tidal tail released from a young star Pleiades-like cluster, due to expulsion of primordial gas in a realistic gravitational field of the Galaxy. The tidal tails (as well as clusters) are integrated from their embedded phase for 300 Myr. We vary star formation efficiencies (SFEs) from 33% to 100% and the timescales of gas expulsion as free parameters, and provide predictions for the morphology and kinematics of the evolved tail for each of the models. The resulting tail properties are intended for comparison with anticipated Gaia observations in order to constrain the poorly understood early conditions during the gas phase and gas expulsion. The simulations are performed with the code Nbody6 including a realistic external gravitational potential of the Galaxy, and an analytical approximation for the natal gaseous potential. Assuming that the Pleiades formed with rapid gas expulsion and an SFE of ≈ 30 %, the current Pleiades are surrounded by a rich tail extending from ≈ 150 to ≈ 350 pc from the cluster and containing $0.7\times$ to $2.7\times$ the number of stars in the present-day cluster. If the Pleiades formed with an SFE close to 100%, then the tail is shorter ($\lesssim 90$ pc) and substantially poorer with only $\approx 0.02\times$ the number of present-day cluster stars. If the Pleiades formed with an SFE of ≈ 30 %, but the gas expulsion was adiabatic, the tail signatures are indistinguishable from the case of the model with 100The mass function of the tail stars is close to that of the canonical mass function for the clusters including primordial gas, but it is slightly depleted of stars more massive than $\approx 1 M_\odot$ for the cluster with 100% SFE, a difference that is not likely to be observed. The model takes into account the estimated contamination due to the field stars and the Hyades-Pleiades stream, which constitutes a more limiting factor than the accuracy of the Gaia measurements.

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Demographics of neutron stars in young massive and open clusters

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Star clusters appear to be the ideal environment for the assembly of neutron star-neutron star (NS-NS) and black hole-neutron star (BH-NS) binaries. These binaries are among the most interesting astrophysical objects, being potential sources of gravitational waves (GWs) and gamma-ray bursts. We use for the first time high-precision N-body simulations of young massive and open clusters to study the origin and dynamical evolution of NSs, within clusters with different initial masses, metallicities, primordial binary fractions, and prescriptions for the compact object natal kicks at birth. We find that the radial profile of NSs is shaped by the BH content of the cluster, which partially quenches the NS segregation due to the BH-burning process. This leaves most of the NSs out of the densest cluster regions, where NS-NS and BH-NS binaries could potentially form. Due to a large velocity kick that they receive at birth, most of the NSs escape the host clusters, with the bulk of their retained population made up of NSs of $\sim 1.3 M_{\odot}$ coming from the electron-capture supernova process. The details of the primordial binary fraction and pairing can smear out this trend. Finally, we find that a subset of our models produce NS-NS mergers, leading to a rate of $\sim 0.01 - 0.1 \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ in the local Universe, and compute an upper limit of $\sim 3 \times 10^{-2} - 3 \times 10^{-3} \mathrm{Gpc}^{-3}\mathrm{yr}^{-1}$ for the BH-NS merger rate. Our estimates are several orders of magnitude smaller than the current empirical merger rate from LIGO/Virgo, in agreement with the recent rate estimates for old globular clusters.

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LISA sources from young massive and open stellar clusters

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I study the potential role of young massive (YMCs) and open star clusters (OCs) in assembling stellar-mass binary black holes (BBHs) which would be detectable as persistent gravitational-wave (GW) sources by the forthcoming LISA mission. The energetic dynamical interactions inside star clusters make them factories of assembling BBHs and other types of double-compact binaries that undergo general-relativistic (GR) inspiral and merger. The initial phase of such inspirals would, typically, sweep through the LISA GW band. Here, such LISA sources are studied from a set of evolutionary models of star clusters with masses ranging over $10^4 M_\odot - 10^5 M_\odot$ that represent YMCs and intermediate-aged OCs in metal-rich and metal-poor environments of the Local Universe. These models are evolved with long-term, direct, relativistic many-body computations incorporating state-of-the-art stellar-evolutionary and remnant-formation models. Based on models of Local Universe constructed with such model clusters, it is shown that YMCs and intermediate-aged OCs would yield several 10s to 100s of LISA BBH sources at the current cosmic epoch with GW frequency within 10^{-3} Hz $- 10^{-1}$ Hz and signal-to-noise-ratio (S/N) > 5, assuming a mission lifetime of 5 or 10 years. Such LISA BBHs would have a bimodal distribution in total mass, be generally eccentric ($\lesssim 0.7$), and typically have similar component masses although mass-asymmetric systems are possible. Intrinsically, there would be 1000s of present-day, LISA-detectable BBHs from YMCs and OCs. That way, YMCs and OCs would provide a significant and the dominant contribution to the stellar-mass BBH population detectable by LISA. A small fraction, $< 5\%$, of these BBHs would undergo GR inspiral to make it to LIGO-Virgo GW frequency band and merge, within the mission timespan; $< 15\%$ would do so within twice the timespan.

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Miscellaneous

On the Precision of Full-spectrum Fitting of Simple Stellar Populations. I. Well-sampled Populations.

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We investigate the precision of the ages and metallicities of 21,000 mock simple stellar populations (SSPs) determined through full-spectrum fitting. The mock SSPs cover an age range of $6.8 < \log$ (age/yr) < 10.2, for three wavelength ranges in the optical regime, using both Padova and MIST isochrone models. Random noise is added to the model spectra to achieve S/N ratios between 10 to 100 per wavelength pixel. We find that for S/N ≥ 50, this technique can yield ages of SSPs to an overall precision of $\Delta \log(\text{age/yr}) \sim 0.1$ for ages in the ranges $7.0 \leq \log$ (age/yr) ≤ 8.3 and $8.9 \leq \log$ (age/yr) ≤ 9.4. For the age ranges of $8.3 \leq \log$ (age/yr) ≤ 8.9 and $\log$ (age/yr) ≥ 9.5, which have significant flux contributions from asymptotic giant branch (AGB) and red giant branch (RGB) stars, respectively, the age uncertainty rises to about ± 0.3 dex. The precision of age and metallicity estimation using this method depends significantly on the S/N and the wavelength range used in the fitting. We quantify the systematic differences in age predicted by the MIST and Padova isochrone models, due to their different assumptions about stellar physics in various important (i.e., luminous) phases of stellar evolution, which needs to be taken in consideration when comparing ages of star clusters obtained using these popular models. Knowing the strengths and limitations of this technique is crucial in interpreting the results obtained for real star clusters and for deciding the optimal instrument setup before performing the observations.

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Star Clusters Near and Far; Tracing Star Formation Across Cosmic Time

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Star clusters are fundamental units of stellar feedback and unique tracers of their host galactic properties. In this review, we will first focus on their constituents, i.e. detailed insight into their stellar populations and their surrounding ionised, warm, neutral, and molecular gas. We, then, move beyond the Local Group to review star cluster populations at various evolutionary stages, and in diverse galactic environmental conditions accessible in the local Universe. At high redshift, where conditions for cluster formation and evolution are more extreme, we are only able to observe the integrated light of a handful of objects that we believe will become globular clusters. We therefore discuss how numerical and analytical methods, informed by the observed properties of cluster populations in the local Universe, are used to develop sophisticated simulations potentially capable of disentangling the genetic map of galaxy formation and assembly that is carried by globular cluster populations.

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Formation of low-spinning $100M_\odot$ black holes

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It is speculated that a merger of two massive stellar-origin BHs in a dense stellar environment may lead to the formation of a massive BH in the pair-instability mass gap ($\sim 50 - 135M_\odot$). Such a merger-formed BH is expected to typically have a high spin ($a \sim 0.7$). If such a massive BH acquires another BH it may lead to another merger detectable by LIGO/Virgo in gravitational waves. Acquiring a companion may be hindered by gravitational-wave kick/recoil, which accompanies the first merger and may quickly remove the massive BH from its parent globular or nuclear cluster. We test whether it is possible for a massive merger-formed BH in the pair-instability gap to be retained in its parent cluster and have low spin. Such a BH would be indistinguishable from a primordial BH. We employed results from numerical relativity calculations of black hole mergers to explore the range of gravitational-wave recoil velocities for various combinations of merging BH masses and spins. We compared merger-formed massive BH speeds with typical escape velocities from globular and nuclear clusters. We show that a globular cluster is highly unlikely to form and retain a 100 Msun BH if the spin of the BH is low ($a \lesssim 0.3$) as such BHs acquire high recoil speeds ($\gtrsim 200$ km/s) that exceed typical escape speeds from globular clusters (~ 50 km/s). However, a very low-spinning ($a \sim 0.1$) and massive ($\sim 100M_\odot$) BH could be formed and retained in a galactic nuclear star cluster. Even though such massive merger-formed BHs with such low spins acquire high speeds during formation (~ 400 km/s), they may avoid ejection since massive nuclear clusters have high escape velocities ($\sim 300 - 500$ km/s). A future detection of a massive BH in the pair-instability mass gap with low spin would therefore not be proof of the existence of primordial BHs, which are sometimes claimed to have low spins and arbitrarily high masses.

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The structure and characteristic scales of molecular clouds

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The structure of molecular clouds holds important clues on the physical processes that lead to their formation and subsequent dynamical evolution. While it is well established that turbulence imprints a self-similar structure to the clouds, other processes, such as gravity and stellar feedback, can break their scale-free nature. The break of self-similarity can manifest itself in the existence of characteristic scales that stand out from the underlying structure generated by turbulent motions. In this work, we investigate the structure of the Cygnus-X North and the Polaris Flare molecular clouds which represent two extremes in terms of their star formation activity. We characterize the structure of the clouds using the delta-variance (Δ-variance) spectrum. In the Polaris Flare, the structure of the cloud is self-similar over more than one order of magnitude in spatial scales. In contrast, the Δ-variance spectrum of Cygnus-X North exhibits an excess and a plateau on physical scales of $\approx 0.5 - 1.2$ pc. In order to explain the observations for Cygnus-X North, we use synthetic maps in which we overlay populations of discrete structures on top of a fractal Brownian motion (fBm) image. The properties of these structures such as their major axis sizes, aspect ratios, and column density contrasts with the fBm image are randomly drawn from parameterized distribution functions. We are able to show that under plausible assumptions, it is possible to reproduce a Δ-variance spectrum that resembles the one of the Cygnus-X North region. We also use a "reverse engineering" approach in which we extract the compact structures in the Cygnus-X North cloud and re-inject them on an fBm map. The calculated Δ-variance spectrum using this approach deviates from the observations and is an indication that the range of characteristic scales ($\approx 0.5 - 1.2$ pc) observed in Cygnus-X North is not only due to the existence of compact sources, but is a signature of the whole population of structures that exist in the cloud, including more extended and elongated structures

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Proceedings abstracts

The lithium-rotation connection in young stars

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Lithium is a sensitive probe to mixing processes operating in stellar interiors. For many years, a connection has been suspected to exist between lithium abundances and stellar rotation, presumably the result of rotationally-induced internal mixing. In recent years, several studies have confirmed and refined this relationship for low-mass young stars. In various star forming regions and young open clusters, rapidly rotating K dwarfs are found to be lithium-rich compared to their more slowly rotating siblings. While this lithium-rotation correlation is contrary to naive expectations, several models have been put forward to account for it. We review here recent observational results, and briefly discuss proposed interpretations.

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Conferences

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

July 5 – 9 2021
Toulouse, France
https://coolstars21.github.io/

UV Insights to Massive Stars and Young Stellar Clusters

August 16 – 27 2021
Busan, Republic of Korea
https://busan2021fm4.org/

Wheel of Star Formation

September 20 – 24 2021
Prague, Czech Republic
https://janfest2020.asu.cas.cz/