The Star Clusters Young & Old Newsletter

edited by Giovanni Carraro, Martin Netopil, and Ernst Paunzen
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The official Newsletter of
the IAU Commission H4.

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Dear Colleagues,

The new issue includes an announcement by the Organising Committee for IAU Commission H4 (please see next page). Furthermore, the issue includes 26 abstracts in total and several conference announcements. The COVID-19 pandemic unfortunately still does not allow conventional international meetings, thus the upcoming ones are on a virtual basis only. We encourage you to actively participate and thank all organizers for their efforts in these difficult times. We hope that a physical get-together will be possible soon again.

Finally, the issue also includes the PhD thesis abstract by Marta Reina-Campos. We want to congratulate her for the thesis and wish her all the best for the future career.

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.

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

Dear all,

We are pleased to inform you that our commission H4 will continue for the next 6 years. We will continue to be an inter-division commission, sitting under Divisions G-H-J, with Division H being our governing Division. After discussions within the Organising Committee we are thinking of shortening our name to simply "Star Clusters" since "Stellar Clusters throughout Cosmic Space and Time" is rather lengthy. Please let me know if you have any major objections to this proposal.

We would like to ask our members to encourage their colleagues and collaborators who work in Star Cluster science to join Commission H4. While the deadline of January 29, 2021 for joining new commissions using the registration form has passed, it is still possible to join by contacting the IAU Secretariat.

Remember that the IAU Working Rules indicate that any Individual or Junior Member can belong to no more than 3 Commissions, allowing membership of a 4th Commission only when it belongs to Division B or C. Also note that for the existing Commissions you may join or leave a Commission at any time.

You may have heard that the IAU General Assembly has been postponed to 2022. This is best given the current pandemic, however there will still be virtual elections in August 2021 for the structure of Commissions and Divisions.

In August 2021, I will step down as President of H4 and our current Vice-President, Francesca D'Antona will take over as President. There will be opportunities for members to join the Organising Committee or to become Vice-President. We will have open:

- Minimum 3 positions on the Organising Committee
- The position of Vice-President. We require a minimum of 2 names for the election and we currently have one nomination.

Please contact Franca or myself if you are interested in nominating for any of these opportunities.

Best regards,

Amanda and Franca

On behalf of the Organising Committee for Commission H4

See the Commission H4 webpage for contact details:
https://www.iau.org/science/scientific_bodies/commissions/H4/

Star Forming Regions

Testing the role of environmental effects on the Initial Mass Function of low mass stars

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In star formation process, the vital role of environmental factors such as feedback from massive stars and stellar density on the form of the Initial Mass Function (IMF) at low-mass end is yet to be understood. Hence a systematic, high sensitive observational analysis of a sample of regions under diverse environmental conditions is essential. We analyse the IMF of eight young clusters (<5 Myr) namely IC1848-West, IC1848-East, NGC1893, NGC2244, NGC2362, NGC6611, Stock8 and Cygnus OB2 which are located at the Galactocentric distance (R_g) range ∼6-12 kpc along with nearby cluster IC348 using deep near-IR photometry and Gaia-DR2. These clusters are embedded in massive stellar environments of radiation strength $log(L_{FUV}/L_{\odot})$ ∼2.6 to 6.8, $log(L_{EUV})$ ∼42.2 to 50.85 photons/s, with stellar density in the range of ∼170 - 1220 stars/pc^2. After structural analysis and field decontamination we obtain an unbiased, uniformly sensitive sample of Pre-Main Sequence members of the clusters down to brown-dwarf regime. The log-normal fit to the IMF of nine clusters gives the mean characteristic mass (m_c) and σ of 0.32±0.02 $M_{\odot}$ and 0.47±0.02, respectively. We compare the IMF with that of low and high mass clusters across the Milky Way. We also check for any systematic variation with respect to the radiation field strength, stellar density as well with R_g. We conclude that there is no strong evidence for environmental effect in the underlying form of IMF of these clusters.

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https://ui.adsabs.harvard.edu/abs/2021arXiv210108804D/abstract

Galactic Open Clusters

UOCS. III. UVIT catalogue of open clusters with machine learning based membership using *Gaia* EDR3 astrometry

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We present a study of six open clusters (Berkeley 67, King 2, NGC 2420, NGC 2477, NGC 2682 and NGC 6940) using the Ultra Violet Imaging Telescope (UVIT) aboard *ASTROSAT* and *Gaia* EDR3. We used combinations of astrometric, photometric and systematic parameters to train and supervise a machine learning algorithm along with a Gaussian mixture model for the determination of cluster membership. This technique is robust, reproducible and versatile in various cluster environments. In this study, the *Gaia* EDR3 membership catalogues are provided along with classification of the stars as `members, candidates` and `field` in the six clusters. We could detect 200–2500 additional members using our method with respect to previous studies, which helped estimate mean space velocities, distances, number of members and core radii. UVIT photometric catalogues, which include blue stragglers, main-sequence and red giants are also provided. From UV–Optical colour-magnitude diagrams, we found that majority of the sources in NGC 2682 and a few in NGC 2420, NGC 2477 and NGC 6940 showed excess UV flux. NGC 2682 images have ten white dwarf detection in far-UV. The far-UV and near-UV images of the massive cluster NGC 2477 have 92 and 576 `members` respectively, which will be useful to study the UV properties of stars in the extended turn-off and in various evolutionary stages from main-sequence to red clump. Future studies will carry out panchromatic and spectroscopic analysis of noteworthy members detected in this study.

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Fundamental parameters for 45 open clusters with Gaia DR2, an improved extinction correction and a metallicity gradient prior

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Reliable fundamental parameters of open clusters (OCs) such as distance, age, and extinction are key to our understanding of Galactic structure and stellar evolution. In this work, we use Gaia Data Release 2 (DR2) to investigate 45 OCs listed in the New catalogue of optically visible open clusters and candidates (DAML) but with no previous astrometric membership estimation based on Gaia DR2. In the process of selecting targets for this study, we found that some clusters reported as new discoveries in recent papers based on Gaia DR2 were already known clusters listed in DAML. Cluster memberships were determined using a maximum likelihood method applied to Gaia DR2 astrometry. This has allowed us to estimate mean proper motions and mean parallaxes for all investigated clusters. Mean radial velocities were also determined for 12 clusters, 7 of which had no previous published values. We have improved our isochrone fitting code to account for interstellar extinction using an updated extinction polynomial for the Gaia DR2 photometric bandpasses and the Galactic abundance gradient as a prior for metallicity. The updated procedure was validated with a sample of clusters with high-quality [Fe/H] determinations. We then did a critical review of the literature and verified that our cluster parameter determinations represent a substantial improvement over previous values.

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https://ui.adsabs.harvard.edu/abs/2020MNRAS.499.1874M/abstract

The VVV Open Cluster Project. Near-infrared sequences of NGC 6067, NGC 6259, NGC 4815, Pismis 18, Trumpler 23, and Trumpler 20.

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Open clusters are central elements of our understanding of the Galactic disk evolution, as an accurate determination of their parameters leads to an unbiased picture of our Galaxy's structure. Extending the analysis towards fainter magnitudes in cluster sequences has a significant impact on the derived fundamental parameters, such as extinction and total mass. We perform a homogeneous analysis of six open stellar clusters in the Galactic disk using kinematic and photometric information from the Gaia DR2 and VVV surveys: NGC 6067, NGC 6259, NGC 4815, Pismis 18, Trumpler 23, and Trumpler 20. We implement two coarse-to-fine characterization methods: first, we employ Gaussian mixture models to tag fields around each open cluster in the proper motion space, and then we apply an unsupervised machine learning method to make the membership assignment to each cluster. For the studied clusters, with ages in the 120-1900 Myr range, we report an increase of ∼45% new member candidates on average in our sample. The data-driven selection approach of cluster members makes our catalog a valuable resource for testing stellar evolutionary models and for assessing the cluster low-to-intermediate mass populations. This study is the first of a series intended to homogeneously reveal open cluster near-infrared sequences.

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https://ui.adsabs.harvard.edu/abs/2021arXiv210204303P/abstract

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A Study of Open Clusters Frolov 1 and NGC 7510 using CCD UBV Photometry and Gaia DR2 Astrometry

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We present reddening, photometric metallicity, age and distance estimates for the Frolov 1 and NGC 7510 open clusters based on CCD UBV photometric and Gaia data. Photometric observations were collected using the 1-m telescope of the TÜBİTAK National Observatory. Gaia DR2 proper motion data in the direction of two groupings were used to identify cluster membership. We determined mean proper motion values $(\mu_\alpha \cos\delta, \mu_\delta) = (-3.02\pm0.10, -1.75\pm0.08)$ and $(-3.66\pm0.07, -2.17\pm0.06)$ mas yr^{-1} for Frolov 1 and NGC 7510, respectively. We used two-colour diagrams to obtain $E(B-V)$ colour excesses for Frolov 1 and NGC 7510 as 0.65 ± 0.06 and 1.05 ± 0.05 mag, respectively. We derived the photometric metallicity of Frolov 1 as [Fe/H] = 0.03 ± 0.03 dex and adopted a solar metallicity for NGC 7510. Based on these reddening and metallicities we determined the distance moduli and ages of the clusters via fitting PARSEC isochrones to the cluster colour-magnitude diagrams. Isochrone fitting distances for Frolov 1 and NGC 7510 are 2864 ± 254 and 2818 ± 247 pc, respectively, which correspond to the ages 35 ± 10 Myr and 18 ± 6 Myr. We also calculated mean Gaia distances and compared them with those given in the literature and in this study, concluding that our results are in good agreement with previous work. Finally, we calculated the mass function slopes as being $X = -1.21 \pm 0.18$ for Frolov 1 and $X = -1.42 \pm 0.27$ for NGC 7510.

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3D kinematics and age distribution of the open cluster population

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Open clusters (OCs) trace the evolution of the Galactic disc with great accuracy. Gaia and large ground-based spectroscopic surveys make it possible to determine their properties and study their kinematics with unprecedented precision. We study the kinematical behaviour of the OC population over time. We take advantage of the latest age determinations of OCs to investigate the correlations of the 6D phase-space coordinates and orbital properties with age. The phase-space distribution, age-velocity relation, and action distribution are compared to those of field stars. We also investigate the rotation curve of the Milky Way traced by OCs, and we compare it to that of other observational or theoretical studies. We gathered nearly 30 000 radial velocity (RV) measurements of OC members from both Gaia-RVS data and ground-based surveys and catalogues. We computed the weighted mean RV, Galactic velocities, and orbital parameters of 1 382 OCs. We investigated their distributions as a function of age and by comparison to field stars. We provide the largest RV catalogue available for OCs, half of it based on at least three members. Compared to field stars, we note that OCs are not on exactly the same arches in the radial-azimuthal velocity plane, while they seem to follow the same diagonal ridges in the Galactic radial distribution of azimuthal velocities. Velocity ellipsoids in different age bins all show a clear anisotropy. The heating rate of the OC population is similar to that of field stars for the radial and azimuthal components, but it is significantly lower for the vertical component. The rotation curve drawn by our sample of clusters shows several dips that match the wiggles derived from nonaxisymmetric models of the Galaxy. From the computation of orbits, we obtain a clear dependence of the maximum height and eccentricity on age. Finally, the orbital characteristics of the sample of clusters as shown by the action variables follow the distribution of field stars. The additional age information of the clusters indicates some (weak) age dependence of the known moving groups.

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The Blue Straggler Population of the Open Clusters Trumpler 5, Trumpler 20, and NGC 2477

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We present a study based on Gaia DR2 of the population of blue straggler stars in the open clusters Trumpler 5, Trumpler 20, and NGC 2477. According to their position in the colour-magnitude diagram, all candidates were selected, their proper motion components, and their parallax. We also looked for yellow stragglers, i.e., possible evolved blue stragglers. We found that Trumpler 5 hosts a large blue straggler star population, which allowed us to analyze their radial distribution as a probe of the cluster's dynamical status. The blue straggler star distribution was compared with that of red giant branch stars to evaluate mass segregation. Our results indicate that blue straggler stars are not more centrally concentrated than red giant branch stars in any clusters. The radial distribution of blue straggler stars in Trumpler 5 is flat. Additionally, using a multi-epoch radial velocity survey conducted with the high-resolution spectrograph FLAMES/GIRAFFE at the Very Large Telescope, we measured the radial velocities on a sample of stragglers to compare with the mean radial velocity and the velocity dispersion of the clusters. We roughly classified these stars as possible close or long-period binaries based on the radial velocity variations for different epochs.

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https://ui.adsabs.harvard.edu/abs/2021AJ....161...37R/abstract

Galactic Globular Clusters

Excess of Ca (and Sc) produced in globular cluster multiple populations: a first census in 77 Galactic globular clusters

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Multiple stellar populations in globular clusters (GCs) are distinct by their different abundances of light elements. The abundance anti-correlations point towards a nucleosynthesis origin due to high-temperature H burning, but it remains to be assessed which type of stars altered primordial abundances in GCs. In particular, the regime at very high temperature that shapes the variations in potassium as well as calcium and scandium, which has been detected in a few notable cases such as NGC 2419 and NGC 2808, is still poorly explored. We started a systematic search for excess of Ca (and Sc) in GC stars with respect to the level of unmodified field stars. This method has recently been proven to be highly efficient in revealing the outcome of the proton-capture reactions at very high temperatures. Statistically robust evidence of such excess was found in a small number of GCs (NGC 4833, NGC 6715, NGC 6402, NGC 5986, NGC 5824, and NGC 5139/ω Centauri) that join the previously known two clusters. For the first time we show that NGC 4833 is likely to host anti-correlated K and Mg abundances. All these GCs are among the most massive ones in the Galaxy. We found that the fraction of stars with Ca enhancement at 3σ above the field star distribution is a multivariate function of the GC mass and metallicity, as in other manifestations of the multiple population phenomenon in GCs. We argue that these alterations in only a few GCs can be reproduced by two different channels: either a class of ordinary stars, that is common to all GCs, acts only in particular environments, or an on-off mechanism is generated by the occurrence of a peculiar type of stars (or lack of such stars). Hot bottom-burning in asymptotic giant branch stars in the low-metallicity regime is a good candidate for the first class. Alternatively, a metallicity dependence is also expected for supermassive stars, which are predicted to preferentially form in massive GCs.

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UVIT study of UV bright stars in the globular cluster NGC 4147

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We present far ultraviolet (FUV) observations of globular cluster NGC 4147 using three FUV filters, BaF2 (F154W), Sapphire (F169M), and Silica (F172M) of Ultra-Violet Imaging Telescope (UVIT) on-board the *AstroSat* satellite. We confirmed the cluster membership of the UVIT observed sources using proper motions from Gaia data release 2 (GAIA DR2). We identified 37 blue horizontal branch stars (BHBs), one blue straggler star (BSS) and 15 variable stars using UV-optical color magnitude diagrams (CMDs). We find that all the FUV bright BHBs are second generation population stars. Using UV-optical CMDs, we identify two sub-populations, BHB1 and BHB2, among the UV-bright BHBs in the cluster with stars count ratio of 24:13 for BHB1 and BHB2. The effective temperatures (T_{eff}) of BHB1 and BHB2 were derived using color-temperature relation of BaSTI-IAC zero-age horizontal branch (ZAHB). We found that BHB1 stars are more centrally concentrated than BHB2 stars. We also derive physical parameters of the detected FUV bright BSS by fitting younger age BaSTI-IAC isochrones on optical and UV-optical CMDs.

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https://ui.adsabs.harvard.edu/abs/2020arXiv201207318K/abstract

Ultraviolet Imaging Telescope (UVIT) observation of the Galactic Globular Cluster NGC 7492

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We present detailed photometric observations of the Galactic globular cluster NGC 7492 using the data obtained with two far-ultraviolet (FUV: 1300 - 1800 Å) and three near-ultraviolet (NUV: 2000 - 3000 Å) filters of Ultraviolet Imaging Telescope (UVIT) on-board the AstroSat satellite. We confirmed the cluster membership of the extracted sources using GAIA data release 2 (Gaia DR2) proper motion data. We have used color-magnitude diagrams (CMDs) using UVIT and GAIA filters to separate out different evolutionary stages of the stars present in the cluster. We have identified a new extreme horizontal branch (EHB) star at the core of the cluster using UV and UV-optical CMDs. The estimated distance-modulus of the cluster is 16.95 ± 0.05 obtained by fitting BaSTI isochrones with cluster parameters, [Fe/H] = −1.8 dex and age = 12.0 Gyr on the V − I vs V CMD. Interestingly, only the EHB star and blue horizontal branch stars (BHBs) among the UV-bright hot sources are detected in FUV filters of UVIT. We have derived the effective temperature of BHBs using color-temperature relation and spectral energy distributions (SEDs) of multi-band filters, which are in the range from 8,000 K to 10,500 K. We find a variation of He abundance of BHBs by fitting the BaSTI ZAHB. The range in the He abundance of the BHBs corresponding to the best fit isochrones is 0.247 to 0.350. We have estimated various physical parameters of the newly identified EHB star in the cluster using SED fit and post-HB evolutionary tracks. We have studied the radial distribution of all the sources of the cluster detected in UVIT. The sources detected in FUV filters extend beyond the half light radius (1.15′) of the cluster, whereas the sources detected in NUV filters extend beyond the tidal radius (9.2′) of the cluster.

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https://ui.adsabs.harvard.edu/abs/2021MNRAS.tmp...38K/abstract

Signatures of tidal disruption in the Milky Way globular cluster NGC 6981 (M72)

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We study the outer regions of the Milky Way globular cluster NGC6981 from publicly available BV photometry and new Dark Energy Camera (DECam) observations, both reaching nearly 4 mag below the cluster main sequence (MS) turnoff. While the BV data sets reveal the present of extra-tidal features around the cluster, the much larger field of view of DECam observations allowed us to identify some other tidal features, which extend from the cluster toward the opposite direction to the Milky Way center. These cluster structural features arise from stellar density maps built using MS stars, once the cluster color-magnitude diagram was cleaned from the contamination of field stars. We also performed N-body simulations in order to help us to understand the spatial distribution of the extra-tidal debris. The outcomes reveal the presence of long trailing and leading tails mostly parallel to the direction of the cluster velocity vector. We found that the cluster has lost most of its mass by tidal disruption during its perigalactic passages, that lasted nearly 20 Myr each. Hence, a decrease in the density of escaping stars near the cluster is expected from our N-body simulations, which in turn means that stronger extra-tidal features could be found out by exploring much larger areas around NGC6891.

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Clusters in the Magellanic clouds

Runaway OB Stars in the Small Magellanic Cloud: Dynamical Versus Supernova Ejections

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Runaway OB stars are ejected from their parent clusters via two mechanisms, both involving multiple stars: the dynamical ejection scenario (DES) and the binary supernova scenario (BSS). We constrain the relative contributions from these two ejection mechanisms in the Small Magellanic Cloud (SMC) using data for 304 field OB stars from the spatially complete, Runaways and Isolated O-Type Star Spectroscopic Survey of the SMC (RIOTS4). We obtain stellar masses and projected rotational velocities $v_r \sin i$ for the sample using RIOTS4 spectra, and use transverse velocities $v_{\rm loc}$ from *Gaia* DR2 proper motions. Kinematic analyses of the masses, $v_r \sin i$, non-compact binaries, high-mass X-ray binaries, and Oe/Be stars largely support predictions for the statistical properties of the DES and BSS populations. We find that dynamical ejections dominate over supernova ejections by a factor of $\sim 2-3$ in the SMC, and our results suggest a high frequency of DES runaways and binary ejections. Objects seen as BSS runaways also include two-step ejections of binaries that are reaccelerated by SN kicks. We find that two-step runaways likely dominate the BSS runaway population. Our results further imply that any contribution from *in-situ* field OB star formation is small. Finally, our data strongly support the post-mass-transfer model for the origin of classical Oe/Be stars, providing a simple explanation for the bimodality in the $v_r \sin i$ distribution and high, near-critical, Oe/Be rotation velocities. The close correspondence of Oe/Be stars with BSS predictions implies that the emission-line disks are long-lived.

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Revisiting newly Large Magellanic Cloud age gap star clusters

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Recently, a noticeable number of new star clusters was identified in the outskirts of the Large Magellanic Cloud (LMC) populating the so-called star cluster age gap, a space of time ($\sim$ 4-12 Gyr) where the only known star cluster is up-to-date ESO121-SC03. We used Survey of the Magellanic Stellar History (SMASH) DR2 data sets, as well as those employed to identify these star cluster candidates, to produce relatively deep color-magnitude diagrams (CMDs) of 17 out of 20 discovered age gap star clusters with the aim of investigating them in detail. Our analysis relies on a thorough CMD cleaning procedure of the field star contamination, which presents variations in its stellar density and astrophysical properties, such as luminosity and effective temperature, around the star cluster fields. We built star cluster CMDs from stars with membership probabilities assigned from the cleaning procedure. These CMDs and their respective spatial distribution maps favor the existence of LMC star field density fluctuations rather than age gap star clusters, although a definitive assessment on them will be possible from further deeper photometry.

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On the structure of Small Magellanic Cloud star clusters

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It has been recently shown from observational data sets the variation of structural parameters and internal dynamical evolution of star clusters in the Milky Way and in the Large Magellanic Cloud (LMC), caused by the different gravitational field strengths that they experience. We report here some hints for such a differential tidal effects in structural parameters of star clusters in the Small Magellanic Cloud (SMC), which is nearly 10 times less massive than the LMC. A key contribution to this study is the consideration of the SMC as a triaxial spheroid, from which we estimate the deprojected distances to the SMC center of the statistically significant sample of star clusters analyzed. By adopting a 3D geometry of the SMC, we avoid the spurious effects caused by considering that a star cluster observed along the line-of-sight is close to the galaxy center. When inspecting the relationships between the star cluster sizes (represented by the 90% light radii), their eccentricities, masses and ages with the deprojected distances, we find: (i) the star cluster sizes are not visibly affected by tidal effects, because relatively small and large objects are spread through the SMC body. (ii) Star clusters with large eccentricities (≥ 0.4) are preferentially found located at deprojected distances smaller than $\sim$ 7-8 kpc, although many star clusters with smaller eccentricities are also found occupying a similar volume. (iii) Star clusters more massive than $\log(M\ /\ M_{\odot}) \sim 4.0$ are among the oldest star clusters, generally placed in the outermost SMC region and with a relative small level of flattening. These findings contrast with the more elongated, generally younger, less massive and innermost star clusters.

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Multiple populations of Hβ emission line stars in the Large Magellanic Cloud cluster NGC 1971

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We revisited the young Large Magellanic Cloud star cluster NGC1971 with the aim of providing additional clues to our understanding of its observed extended Main Sequence turnoff (eMSTO), a feature common seen in young stars clusters, which was recently argued to be caused by a real age spread similar to the cluster age ($\sim$160 Myr). We combined accurate Washington and Stromgren photometry of high membership probability stars to explore the nature of such an eMSTO. From different ad hoc defined pseudo colors we found that bluer and redder stars distributed throughout the eMSTO do not show any inhomogeneities of light and heavy-element abundances. These 'blue' and 'red' stars split into two clearly different groups only when the Washington M magnitudes are employed, which delimites the number of spectral features responsible for the appearance of the eMSTO. We speculate that Be stars populate the eMSTO of NGC1971 because: i) Hβ contributes to the M passband; ii) Hβ emissions are common features of Be stars and; iii) Washington M and T1 magnitudes show a tight correlation; the latter measuring the observed contribution of Halpha emission line in Be stars, which in turn correlates with Hβ emissions. As far as we are aware, this is the first observational result pointing to Hβ emissions as the origin of eMSTOs observed in young star clusters. The presence outcome will certainly open new possibilities of studying eMSTO from photometric systems with passbands centered at features commonly seen in Be stars.

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Astrophysical properties of newly discovered Magellanic Cloud star clusters

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New star cluster candidates projected toward the Large and Small Magellanic Clouds (L/SMC) have been recently discovered from relatively deep imaging surveys. We here conduct a sound analysis of 24 star cluster candidates located in the outer regions of the L/SMC using PSF photometry produced by the Survey of the Magellanic Stellar History. With only one exception, the studied objects resulted to be genuine stellar aggregates. We conclude on their physical reality once their observed color-magnitude diagrams (CMDs) were statistically decontaminated by the presence of field stars, and the resulting cleaned CMDs for stars with assigned membership probabilities higher than 50% were compared with synthetic CMDs generated for thousand combinations of ages, distances, metallicities, star cluster mass and binary fractions. The parameter of the best-matched synthetic CMDs obtained from a likelihood approach were adopted as the star cluster astrophysical properties. The present star cluster sample spans a wide range of distances, from those star clusters located in front of the LMC, to those along the onset of the Magellanic Bridge, up to those behind the SMC. Their ages reveal different formation episodes that took place along the galaxy formation and others as a consequence of the galaxy interactions. From their estimated metallicities and ages, we speculate with the possibility that relatively metal-deficient gaseous flows have existed between these galaxies during nearly the last one Gyr ($\log(\mathrm{age/yr}) \approx 9.0$), that made possible the formation of young star clusters in the galaxy peripheries. Despide the L/SMC interactions, the studied star clusters are similar or more massive than their counterparts in the Milky Way, which suggests that tidal effects are relatively more important in our Galaxy.

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The most distant clusters

StarcNet: Machine Learning for Star Cluster Identification

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We present a machine learning (ML) pipeline to identify star clusters in the multi-color images of nearby galaxies, from observations obtained with the Hubble Space Telescope as part of the Treasury Project LEGUS (Legacy ExtraGalactic Ultraviolet Survey). StarcNet (STAR Cluster classification NETwork) is a multi-scale convolutional neural network (CNN) which achieves an accuracy of 68.6% (4 classes)/86.0% (2 classes: cluster/non-cluster) for star cluster classification in the images of the LEGUS galaxies, nearly matching human expert performance. We test the performance of StarcNet by applying pre-trained CNN model to galaxies not included in the training set, finding accuracies similar to the reference one. We test the effect of StarcNet predictions on the inferred cluster properties by comparing multi-color luminosity functions and mass-age plots from catalogs produced by StarcNet and by human-labeling; distributions in luminosity, color, and physical characteristics of star clusters are similar for the human and ML classified samples. There are two advantages to the ML approach: (1) reproducibility of the classifications: the ML algorithm's biases are fixed and can be measured for subsequent analysis; and (2) speed of classification: the algorithm requires minutes for tasks that humans require weeks to months to perform. By achieving comparable accuracy to human classifiers, StarcNet will enable extending classifications to a larger number of candidate samples than currently available, thus increasing significantly the statistics for cluster studies.

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The initial properties of young star clusters in M83

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The initial sizes and masses of massive star clusters provide information about the cluster formation process and also determine how cluster populations are modified and destroyed, which have implications for using clusters as tracers of galaxy assembly. Young massive cluster populations are often assumed to be unchanged since cluster formation, and therefore their distribution of masses and radii are used as the initial values. However, the first few hundred million years of cluster evolution does change both cluster mass and cluster radius, through both internal and external processes. In this paper, we use a large suite of N-body cluster simulations in an appropriate tidal field to determine the best initial mass and initial size distributions of young clusters in the nearby galaxy M83. We find that the initial masses follow a power-law distribution with a slope of -2.7 ± 0.4, and the half-mass radii follow a log-normal distribution with a mean of 2.57 ± 0.04 pc and a dispersion of 1.59 ± 0.01 pc. The corresponding initial projected half-light radius function has a mean of 2.7 ± 0.3 pc and a dispersion of 1.7 ± 0.2 pc. The evolution of the initial mass and size distribution functions are consistent with mass loss and expansion due to stellar evolution, independent of the external tidal field and the cluster's initial density profile. Observed cluster sizes and masses should not be used as the initial values, even when clusters are only a few hundred million years old.

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Dynamical evolution - Simulations

The Lifetimes of Star Clusters Born with a Top-heavy IMF

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Several observational and theoretical indications suggest that the initial mass function (IMF) becomes increasingly top-heavy (i.e., overabundant in high-mass stars with mass $m > 1M_{\odot}$) with decreasing metallicity and increasing gas density of the forming object. This affects the evolution of globular clusters (GCs) owing to the different mass-loss rates and the number of black holes formed. Previous numerical modeling of GCs usually assumed an invariant canonical IMF. Using the state-of-the-art NBODY6 code, we perform a comprehensive series of direct N-body simulations to study the evolution of star clusters, starting with a top-heavy IMF and undergoing early gas expulsion. Utilizing the embedded cluster mass-radius relation of Marks & Kroupa (2012) for initializing the models, and by varying the degree of top-heaviness, we calculate the minimum cluster mass needed for the cluster to survive longer than 12 Gyr. We document how the evolution of different characteristics of star clusters such as the total mass, the final size, the density, the mass-to-light ratio, the population of stellar remnants and the survival of GCs are influenced by the degree of top-heaviness. We find that the lifetimes of clusters with different IMFs moving on the same orbit are proportional to the relaxation time to a power of x which is in the range 0.8 to 1. The observed correlation between concentration and the mass function slope in Galactic GCs can be accounted for excellently in models starting with a top heavy IMF and undergoing an early phase of rapid gas expulsion.

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Miscellaneous

Low-Mass and Sub-stellar Eclipsing Binaries in Stellar Clusters

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We highlight the importance of eclipsing double-line binaries in our understanding on star formation and evolution. We review the recent discoveries of low-mass and sub-stellar eclipsing binaries belonging to star-forming regions, open clusters, and globular clusters identified by ground-based surveys and space missions with high resolution spectroscopic follow-up. These discoveries provide benchmark systems with known distances, metallicities, and ages to calibrate masses and radii predicted by state-of-the-art evolutionary models to a few percent. We report their density and discuss current limitations on the accuracy of the physical parameters. We discuss future opportunities and highlight future guidelines to fill gaps in age and metallicity to improve further our knowledge of low-mass stars and brown dwarfs.

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https://ui.adsabs.harvard.edu/abs/2020rfma.book..213L/abstract

Do ultra-compact dwarf galaxies form monolithically or as merged star cluster complexes?

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Some ultra-compact dwarf galaxies (UCDs) have elevated observed dynamical V-band mass-to-light ($M/L_{\rm V}$) ratios with respect to what is expected from their stellar populations assuming a canonical initial mass function (IMF). Observations have also revealed the presence of a compact dark object in the centers of several UCDs, having a mass of a few to 15% of the present-day stellar mass of the UCD. This central mass concentration has typically been interpreted as a super-massive black hole, but can in principle also be a sub-cluster of stellar remnants. We explore the following two formation scenarios of UCDs, i) monolithic collapse and ii) mergers of star clusters in cluster complexes as are observed in massively star-bursting regions. We explore the physical properties of the UCDs at different evolutionary stages assuming different initial stellar masses of the UCDs and the IMF being either universal or changing systematically with metallicity and density according to the Integrated Galactic IMF (IGIMF) theory. While the observed elevated $M/L_{\rm V}$ ratios of the UCDs cannot be reproduced if the IMF is invariant and universal, the empirically derived IMF which varies systematically with density and metallicity shows agreement with the observations. Incorporating the UCD-mass-dependent retention fraction of dark remnants improves this agreement. In addition we apply the results of N-body simulations to young UCDs and show that the same initial conditions describing the observed $M/L_{\rm V}$ ratios reproduce the observed relation between the half-mass radii and the present-day masses of the UCDs. The findings thus suggest that the majority of UCDs that have elevated $M/L_{\rm V}$ ratios could have formed monolithically with significant remnant-mass components that are centrally concentrated, while those with small M/L_V values may be merged star-cluster complexes.

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Short period variability in the globular cluster NGC 419 and the SMC field

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Delta Scuti (δ Sct) stars have been extensively studied in our Galaxy, but far less in extragalactic systems. Here we study the population of δ Sct variables in NGC 419, an intermediate-age globular cluster of the Small Magellanic Cloud (SMC), using g,r,i Gemini-S/GMOS time series observations. Our goal is to study the role of such variables in the cluster extended main-sequence turnoff (MSTO). We report the discovery of 54 δ Sct stars and three eclipsing binaries in the NGC 419 field. We find only a handful of the δ Sct stars at the MSTO of NGC 419 while the majority is fainter, indicating that the cluster is younger ($\lesssim 1.2$ Gyr) than previously thought. Considering their radial distribution, we identify only six δ Sct stars as probable members of NGC 419 while the 48 remaining are likely δ Sct stars of the SMC field. Cluster δ Sct stars appear close to the red edge of the MSTO, supporting the idea that the extended MSTO has its origin in an age spread. The 48 field δ Sct stars represent the largest detection of δ Sct stars made in the SMC. The period distribution of these newly detected δ Sct stars ($0.04 \lesssim \mathrm{P} \lesssim 0.15$ d) is similar to that detected in other systems. The amplitude distribution ($0.05 \lesssim \Delta\,\mathrm{r} \lesssim 0.60$ mag) is likely biased because of the lack of low-amplitude stars. We finally use the δ Sct stars to calculate distances using different period-luminosity relations. The average distance moduli obtained are 18.76±0.14 mag for NGC 419 and 18.86±0.11 mag for the SMC field, which agree with previous measurements.

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Dependence of the old star clusters' dynamical clock on the host galaxy gravitational field

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I report outcomes of the analysis of the A^+ parameter, which measures the level of radial segregation of blue straggler stars in old star clusters, commonly known as the dynamical clock for the long-term internal dynamical evolution. I used A^+ values available in the literature for 48 Milky Way globular clusters. I found that the relationship of A^+ and the number of central relaxation times which have elapsed (N_{relax}) shows a non negligible dependence on the strength of the host galaxy gravitational potential, in addition to depending on the two-body relaxation mechanism. Indeed, a measured A^+ value corresponds to relatively smaller or larger N_{relax} values for star clusters located farther or closer to the galaxy center. From an observational point of view, this finding reveals the possibility of disentangling for the first time the dynamical evolutionary stage due to two-body relaxation and tidal effect, that affect the whole star clusters' body concurrently.

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https://ui.adsabs.harvard.edu/abs/2020arXiv201209628P/abstract

White dwarf-open cluster associations based on Gaia DR2

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Fundamental parameters and physical processes leading to the formation of white dwarfs (WDs) may be constrained and refined by discovering WDs in open clusters (OCs). Cluster membership can be utilized to establish the precise distances, luminosities, ages, and progenitor masses of such WDs. We compile a list of probable WDs that are OC members in order to facilitate WD studies that are impractical or difficult to conduct for Galactic field WDs. We use recent catalogs of WDs and OCs that are based on the second data release of the Gaia satellite mission (GDR2) to identify WDs that are OC members. This crossmatch is facilitated by the astrometric and photometric data contained in GDR2 and the derived catalogs. Assuming that most of the WD members are of the DA type, we estimate the WD masses, cooling ages, and progenitor masses. We have detected several new likely WD members and reassessed the membership of the literature WDs that had been previously associated with the studied OCs. Several of the recovered WDs fall into the recently reported discontinuity in the initial-final mass relation (IFMR) around $M_i \sim 2.0$ $M_\odot$, which allows for tighter constrains on the IFMR in this regime.

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https://ui.adsabs.harvard.edu/abs/2021A%26A...645A..13P/abstract

Ph.D. (dissertation) summaries

Formation and evolution of globular clusters in a cosmological context

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Stellar clusters are observed in a variety of galactic environments, from their current formation sites like the disks of the Antennae galaxies to the old globular cluster populations which in the Milky Way mostly reside in the halo. This suggests that the evolution of these puzzling objects may be linked to that of their host galaxy. This thesis explores the formation and evolution of stellar clusters in a cosmological context. For that, analytical models are developed to describe the role of the galactic environment in shaping their demographics. A suite of cosmological, hydrodynamical simulations of Milky Way-mass galaxies from the E-MOSAICS project are used to study when stellar clusters form and how they evolve over cosmic history. These simulations are also employed to estimate the contribution of stellar clusters to the build-up of stellar haloes. Finally, the EMP-Pathfinder simulations are presented, which represent the next generation of simulations of the co-formation and evolution of stellar clusters alongside their host galaxies in a cold, dense cosmic environment. The conclusion drawn from these studies is that stellar clusters are tightly linked to their host cosmic environments. This leads to exciting new future directions that are briefly discussed.

PhD thesis completed at the University Heidelberg under the supervision of Diederik Kruijssen.
http://archiv.ub.uni-heidelberg.de/volltextserver/29004/

Books

Non-stationarity of Open Star Clusters

Vladimir M. Danilov

The monograph poses issues related to the study of the non-stationarity of open star clusters (OSCs), starting with an analysis of the properties of the trajectories of individual stars to the study of collective motion of stars. A discussion of the dynamics of correlations and wave processes in such clusters is presented. The mechanisms of the dynamic evolution of OSCs, the gravitational instability of OSC nuclei, the spectra of frequencies and wavenumbers for oscillations of numerical models of OSCs, astrophysical applications of the results of studies of the dynamics of OSCs are considered. We address the monograph to academic researchers (astronomers and physicists) who are interested in astrophysics, the dynamics of stellar systems, and PhD and senior students of relevant specialities.

Ekaterinburg, Ural University Press 2021, ISBN 978-5-7996-3173-4, Translation from Russian by E. Shabalina and A. F. Seleznev (free available as pdf)
http://hdl.handle.net/10995/95118

Conferences

DELVE: Death-throes of Evolved stars, a Virtual Encounter

12–16 April, 2021
virtual
https://fys.kuleuven.be/ster/events/conferences/2021/delve

ISM 2021 - Structure, characteristic scales, and star formation

11–14 May, 2021
virtual
https://sites.google.com/view/ism2021

EAS 2021: Extragalactic Globular Clusters with upcoming wide-field space-based surveys

29 June, 2021
virtual
https://eas.unige.ch/EAS2021/session.jsp?id=SS10

EAS 2021: Star clusters to the next scale: reading the local and high-z Universe with new giant eyes

29–30 June, 2021
virtual
https://eas.unige.ch/EAS2021/session.jsp?id=SS33

Wheel of Star Formation

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

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

July 5 – 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/