The Star Clusters Young & Old Newsletter

edited by Giovanni Carraro, Martin Netopil, and Ernst Paunzen
http://www.univie.ac.at/scyon/
email: scyon@univie.ac.at

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Dear Colleagues,

For the next issues we will invite various researchers to outline their view about future prospects of star cluster research. The input for the current editorial was kindly provided by **Mark Gieles** (University of Surrey, UK).

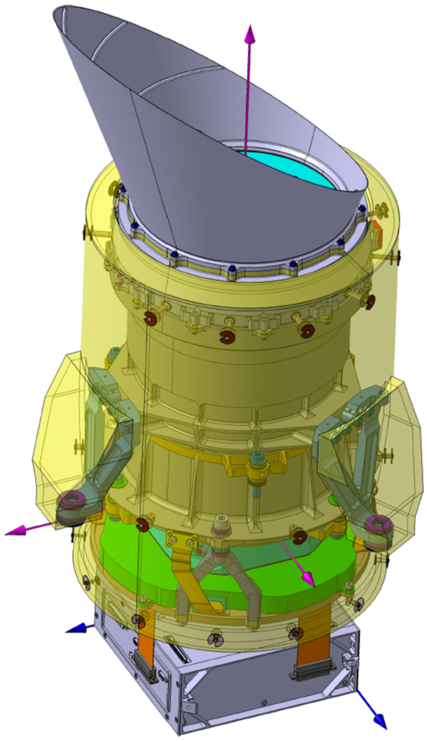
We would like to draw your attention on one promising future avenue in star cluster research. One of the next generation ESA mission is Plato. The main science driver of the Plato mission is to provide accurate parameters of large sample of planets. It does this with precise, time-resolved photometry, over a large field of view (>2000 deg^2) over a large magnitude range (4–16 mag). The impact on star clusters' science is huge. In fact it will provide invaluable legacy in the area of eclipsing binaries. Additionally, for the brightest stars (4–11 mag), asteroseismology will be performed which – combined with follow-up spectroscopy – gives unprecedented stellar ages and masses. For globular clusters (GCs), the asteroseismology is out of range (the tip of the red giant branch in the nearest GC Messier 4 is at V $\sim$ 11 mag), but the exquisite photometry will provide a wealth of information about binary properties in GCs. In particular in the largely unexplored outer parts, for which membership will be obtained with Gaia DR2. Follow-up spectroscopy will enable chemical tagging of stars in the halo that originated from GCs, based on their anomalous abundances (i.e. enhanced N, Na and Al and depleted, C, O and Mg). For open clusters, asteroseismology will allow the determination of stellar rotation rates and orientation of the spin axis, which can constrain theories of star and star cluster formation. Finally, the binary properties of runaway O and B stars in the solar neighbourhood will help us to understand whether runaways are mainly the result of dynamical ejections, or the result of the binary supernova ejection channel.

This SCYON issue includes a variety of paper abstracts, announcements of upcoming conferences, a job announcement and the PhD thesis summary by Laia Casamiquela Floriach (University of Barcelona). We want to congratulate her for this work and wish her all the best for the future career!

We kindly remind all subscribers to provide the current email-address in case of an affiliation change.

The SCYON editor team

Giovanni Carraro, Martin Netopil, and Ernst Paunzen



PLATO factsheet

Mission type: ESA Cosmic Vision (M3)
Targeted launch date: 2026
Mission duration: 4 years, nominal
26 cameras (à 12 cm)
Array of 4 CCDs per camera (à 4510 px^2, 18μm)
FOV: ~2250 deg^2 per pointing
Sky coverage: 10–50 %, depending on strategy
Read-out cadence: 2.5 s / 25 s
Photometry in white light (500–950 nm)
Orbit around Sun-Earth Lagrangian point L2

http://sci.esa.int/plato/
http://www.plato-mission.eu

Schematic figure of one of the cameras of the PLATO spacecraft (© PLATO Mission Consortium)

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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.

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

Star Forming Regions

The Structure of the Young Star Cluster NGC 6231. I. Stellar Population

M. A. Kuhn [1,2], N. Medina [1,2], K. V. Getman [3], and 4 co-authors

([1]) Millennium Institute of Astrophysics, Santiago, Chile; ([2]) Instituto de Fisica y Astronomía, Universidad de Valparaíso, Valparaíso, Chile; ([3]) Dep. of Astronomy & Astrophysics, Pennsylvania State University, PA 16802, USA

NGC 6231 is a young cluster (age ∼2–7 Myr) dominating the Sco OB1 association (d ∼1.59 kpc) with ∼100 O and B stars and a large pre–main-sequence (PMS) stellar population. We combine a reanalysis of archival *Chandra* X-ray data with multi-epoch NIR photometry from the VVV survey and published optical catalogs to obtain a catalog of 2148 probable cluster members. This catalog is 70% larger than previous censuses of probable cluster members in NGC 6231, and it includes many low-mass stars detected in the NIR but not in the optical and some B-stars without previously noted X-ray counterparts. In addition, we identify 295 NIR variables, about half of which are expected to be PMS stars. With the more-complete sample, we estimate a total population in the *Chandra* field of 5700–7500 cluster members down to 0.08 $M_\odot$ (assuming a universal IMF) with a completeness limit at 0.5 $M_\odot$. A decrease in stellar X-ray luminosities is noted relative to other younger clusters. However, within the cluster, there is little variation in the distribution of X-ray luminosities for ages less than 5 Myr. X-ray spectral hardness for B stars may be useful for distinguishing between early-B stars with X-rays generated in stellar winds and B-star systems with X-rays from PMS companions (>35% of B stars). A small fraction of catalog members have unusually high X-ray median energies or reddened near-infrared colors, which might be explained by absorption from thick or edge-on disks or being background field stars.

Accepted by : Astronomical Journal

http://adsabs.harvard.edu/abs/2017AJ....154...87K

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The Structure of the Young Star Cluster NGC 6231. II. Structure, Formation, and Fate

M. A. Kuhn [1,2], K. V. Getman [3], E. D. Feigelson [3,1], and 5 co-authors

([1]) Millennium Institute of Astrophysics, Santiago, Chile; ([2]) Instituto de Fisica y Astronomía, Universidad de Valparaíso, Valparaíso, Chile; ([3]) Dep. of Astronomy & Astrophysics, Pennsylvania State University, PA 16802, USA

The young cluster NGC 6231 (stellar ages ∼2–7 Myr) is observed shortly after star-formation activity has ceased. Using the catalog of 2148 probable cluster members obtained from *Chandra*, VVV, and optical surveys (Paper I), we examine the cluster's spatial structure and dynamical state. The spatial distribution of stars is remarkably well fit by an isothermal sphere with moderate elongation, while other commonly used models like Plummer spheres, multivariate normal distributions, or power-law models are poor fits. The cluster has a core radius of 1.2 ± 0.1 pc and a central density of ∼200 stars pc^{-3}. The distribution of stars is mildly mass segregated. However, there is no radial stratification of the stars by age. Although most of the stars belong to a single cluster, a small subcluster of stars is found superimposed on the main cluster, and there are clumpy non-isotropic distributions of stars outside ∼4 core radii. When the size, mass, and age of NGC 6231 are compared to other young star clusters and subclusters in nearby active star-forming regions, it lies at the high-mass end of the distribution but along the same trend line. This could result from similar formation processes, possibly hierarchical cluster assembly. We argue that NGC 6231 has expanded from its initial size but that it remains gravitationally bound.

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http://adsabs.harvard.edu/abs/2017AJ....154..214K

Galactic Open Clusters

New atlas of open star clusters

A. F. Seleznev, E. Avvakumova, M. Kulesh, and 3 co-authors
Ural Federal University, Yekaterinburg, Russian Federation

Due to numerous new discoveries of open star clusters in the last two decades, astronomers need an easy to use resource to get visual information on the relative position of clusters in the sky. Therefore we propose a new atlas of open star clusters. It is based on a table compiled from the largest modern cluster catalogues. The atlas shows the positions and sizes of 3291 clusters and associations, and consists of two parts. The first contains 108 maps of 12 by 12 degrees with an overlapping of 2 degrees in three strips along the Galactic equator. The second one is an online web application, which shows a square field of an arbitrary size, either in equatorial coordinates or in galactic coordinates by request. The atlas is proposed for the sampling of clusters and cluster stars for further investigation. Another use is the identification of clusters among overdensities in stellar density maps or among stellar groups in images of the sky. The online atlas is accessible at the address http://astro.ins.urfu.ru/atlas. You will need to register in order to get an access. Choice of an object by its name had changed as compared to the paper for greater convenience. You can enter either the full cluster name (NGC 1912, Collinder 31), or the shortened name in accordance with Table 2 of the paper, but without the underlined symbol. Please send your remarks to e-mail address. We would be very grateful for your response and for your reference to the atlas paper if the atlas will help in your work. We plan to supplement the atlas with new data on clusters regularly.

Accepted by : Open Astronomy
https://doi.org/10.1515/astro-2017-0023

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Structure and mass segregation in Galactic stellar clusters

S. Dib [1,2], S. Schmeja [3,4], and R. J. Parker [5]
([1]) Universidad de Atacama, Copiapo, Chile; ([2]) Niels Bohr International Academy, Niels Bohr Institute, Copenhagen, Denmark; ([3]) Technische Informationsbibliothek, Hannover, Germany; ([4]) Astronomisches Rechen-Institut, ZAH, Heidelberg, Germany; ([5]) The University of Sheffield, Sheffield, United Kingdom

We quantify the structure of a very large number of Galactic open clusters and look for evidence of mass segregation for the most massive stars in the clusters. We characterise the structure and mass segregation ratios of 1276 clusters in the Milky Way Stellar Cluster (MWSC) catalogue containing each at least 40 stars and that are located at a distance of up to ≈ 2 kpc from the Sun. We use an approach based on the calculation of the minimum spanning tree of the clusters, and for each one of them, we calculate the structure parameter Q and the mass segregation ratio $\Lambda_{\rm MSR}$. Our findings indicate that most clusters possess a Q parameter that falls in the range 0.7-0.8 and are thus neither strongly concentrated nor do they show significant substructure. Only 27% can be considered centrally concentrated with Q values > 0.8. Of the 1276 clusters, only 14% show indication of significant mass segregation ($\Lambda_{\rm MSR} > 1.5$). Furthermore, no correlation is found between the structure of the clusters or the degree of mass segregation with their position in the Galaxy. A comparison of the measured Q values for the young open clusters in the MWSC to N-body numerical simulations that follow the evolution of the Q parameter over the first 10 Myrs of the clusters life suggests that the young clusters found in the MWSC catalogue initially possessed local mean volume densities of $\rho_* \approx 10 - 100$ $M_\odot$ pc^{-3}.

Accepted by : Monthly Notices of the Royal Astronomical Society
http://adsabs.harvard.edu/abs/2018MNRAS.473..849D

The Gaia-ESO Survey: open clusters in Gaia-DR1 - a way forward to stellar age calibration

S. Randich [1], E. Tognelli [2,3], R. Jackson [4] and 42 co-authors

([1]) INAF-Osservatorio Astrofisico di Arcetri, Firenze, Italy; ([2]) Department of Physics 'E.Fermi', University of Pisa, Pisa, Italy; ([3]) INFN, Section of Pisa, Pisa, Italy; ([4]) Astrophysics Group, University of Keele, Keele, UK

Determination and calibration of the ages of stars, which heavily rely on stellar evolutionary models, are very challenging, while representing a crucial aspect in many astrophysical areas. We describe the methodologies that, taking advantage of Gaia-DR1 and the Gaia-ESO Survey data, enable the comparison of observed open star cluster sequences with stellar evolutionary models. The final, long-term goal is the exploitation of open clusters as age calibrators. We perform a homogeneous analysis of eight open clusters using the Gaia-DR1 TGAS catalogue for bright members and information from the Gaia-ESO Survey for fainter stars. Cluster membership probabilities for the Gaia-ESO Survey targets are derived based on several spectroscopic tracers. The Gaia-ESO Survey also provides the cluster chemical composition. We obtain cluster parallaxes using two methods. The first one relies on the astrometric selection of a sample of bona fide members, while the other one fits the parallax distribution of a larger sample of TGAS sources. Ages and reddening values are recovered through a Bayesian analysis using the 2MASS magnitudes and three sets of standard models. Lithium depletion boundary (LDB) ages are also determined using literature observations and the same models employed for the Bayesian analysis. For all but one cluster, parallaxes derived by us agree with those presented in Gaia Collaboration et al. (2017), while a discrepancy is found for NGC 2516; we provide evidence supporting our own determination. Inferred cluster ages are robust against models and are generally consistent with literature values. The systematic parallax errors inherent in the Gaia DR1 data presently limit the precision of our results. Nevertheless, we have been able to place these eight clusters onto the same age scale for the first time, with good agreement between isochronal and LDB ages where there is overlap. Our approach appears promising and demonstrates the potential of combining Gaia and ground-based spectroscopic datasets.

Accepted by : Astronomy & Astrophysics

http://adsabs.harvard.edu/abs/2017arXiv171107699R

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Why is the Main Sequence of NGC 2482 So Fat?

K. Krisciunas, N.B. Suntzeff, D.Q. Nagasawa, and 3 co-authors

Texas A. & M. University, Department of Physics and Astronomy, College Station, TX 77843-4242, USA

We present the results of high resolution spectra of seven stars in the field of NGC 2482, an open star cluster of age 447 Myr. We confirm the previously published values of the radial velocity and metallicity of one giant star. This gives us confidence that another giant star is a bona fide cluster member, and that three stars significantly above the main sequence in a color-magnitude diagram are not members, on the basis of discordant radial velocities. Another star $\sim$1.7 mag above the main sequence may or may not be a member. Its [Fe/H] value is $\sim$0.1 dex more positive than two giant stars studied, and its radial velocity is 3–4 km/s less than that of the two giant stars, which is a significant difference if the velocity dispersion of the cluster is less than ± 1 km s^{-1}. To a large extent the width of the main sequence seems to be due to the presence of foreground and background stars in the same general direction, stars that masquerade as main sequence stars in the cluster.

Accepted by : Research Notes of the American Astronomical Society

http://adsabs.harvard.edu/abs/2017RNAAS...1...19K

Galactic Globular Clusters

Milky Way globular cluster metallicity and low-mass X-ray binaries: the red giant influence

N. Vulic, P. Barmby, and S. C. Gallagher
Department of Physics & Astronomy, Western University, London, ON, Canada

Galactic and extragalactic studies have shown that metal-rich globular clusters (GCs) are approximately three times more likely to host bright low-mass X-ray binaries (LMXBs) than metal-poor GCs. There is no satisfactory explanation for this metallicity effect. We tested the hypothesis that the number density of red giant branch (RGB) stars is larger in metal-rich GCs, and thus potentially the cause of the metallicity effect. Using Hubble Space Telescope photometry for 109 unique Milky Way GCs, we investigated whether RGB star density was correlated with GC metallicity. Isochrone fitting was used to calculate the number of RGB stars, which were normalized by the GC mass and fraction of observed GC luminosity, and determined density using the volume at the half-light radius (r_h). The RGB star number density was weakly correlated with metallicity [Fe/H], giving Spearman and Kendall Rank test p-values of 0.00016 and 0.00021 and coefficients $r_s = 0.35$ and $\tau = 0.24$, respectively. This correlation may be biased by a possible dependence of r_h on [Fe/H], although studies have shown that r_h is correlated with Galactocentric distance and independent of [Fe/H]. The dynamical origin of the r_h-metallicity correlation (tidal stripping) suggests that metal-rich GCs may have had more active dynamical histories, which would promote LMXB formation. No correlation between the RGB star number density and metallicity was found when using only the GCs that hosted quiescent LMXBs. A complete census of quiescent LMXBs in our Galaxy is needed to further probe the metallicity effect, which will be possible with the upcoming launch of eROSITA.

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http://adsabs.harvard.edu/abs/2018MNRAS.473.4900V

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M13 multiple stellar populations seen with the eyes of Strömgren photometry

A. Savino [1,2], D. Massari [2,3], A. Bragaglia [4], E. Dalessandro [4], and E. Tolstoy [2]
([1]) Astrophysics Research Institute, Liverpool John Moores University, Liverpool, UK; ([2]) Kapteyn Astronomical Institute, University of Groningen, Groningen, The Netherlands; ([3]) Leiden Observatory, University of Leiden, Leiden, The Netherlands; ([4]) INAF – Osservatorio Astronomico di Bologna, Bologna, Italy

We present a photometric study of M13 multiple stellar populations over a wide field of view, covering approximately 6.5 half-light radii, using archival Isaac Newton Telescope observations to build an accurate multi-band Strömgren catalogue. The use of the Strömgren index cy permits us to separate the multiple populations of M13 on the basis of their position on the red giant branch. The comparison with medium and high resolution spectroscopic analysis confirms the robustness of our selection criterion. To determine the radial distribution of stars in M13, we complemented our dataset with Hubble Space Telescope observations of the cluster core, to compensate for the effect of incompleteness affecting the most crowded regions. From the analysis of the radial distributions we do not find any significant evidence of spatial segregation. Some residuals may be present in the external regions where we observe only a small number of stars. This finding is compatible with the short dynamical timescale of M13 and represents, to date, one of the few examples of fully spatially mixed multiple populations in a massive globular cluster.

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http://adsabs.harvard.edu/abs/2017arXiv171201284S

Mass models of NGC 6624 without an intermediate-mass black hole

M. Gieles, E. Balbinot, R. I. S. M. Yaaqib, and 4 co-authors
Department of Physics, University of Surrey, Guildford, UK

An intermediate-mass black hole (IMBH) was recently reported to reside in the centre of the Galactic globular cluster (GC) NGC 6624, based on timing observations of a millisecond pulsar (MSP) located near the cluster centre in projection. We present dynamical models with multiple mass components of NGC 6624 - without an IMBH - which successfully describe the surface brightness profile and proper motion kinematics from the Hubble Space Telescope (HST) and the stellar-mass function at different distances from the cluster centre. The maximum line-of-sight acceleration at the position of the MSP accommodates the inferred acceleration of the MSP, as derived from its first period derivative. With discrete realizations of the models we show that the higher-order period derivatives - which were previously used to derive the IMBH mass - are due to passing stars and stellar remnants, as previously shown analytically in literature. We conclude that there is no need for an IMBH to explain the timing observations of this MSP.

Accepted by : Monthly Notices of the Royal Astronomical Society
http://adsabs.harvard.edu/abs/2018MNRAS.473.4832G

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Multiple Stellar Populations in Globular Clusters

N. Bastian [1] and C. Lardo [1,2]
([1]) Astrophysics Research Institute, Liverpool John Moores University, Liverpool, UK; ([2]) Laboratoire d'astrophysique, École Polytechnique Fédérale de Lausanne (EPFL), Versoix, Switzerland

Globular Clusters (GCs) exhibit star-to-star variations in specific elements (e.g., He, C, N, O, Na, Al) that bare the hallmark of high temperature H burning. These abundance variations can be observed spectroscopically and also photometrically, with the appropriate choice of filters, due to the changing of spectral features within the band pass. This phenomenon is observed in nearly all of the ancient GCs, although, to date, has not been found in any massive cluster younger than 2 Gyr. Many scenarios have been suggested to explain this phenomenon, with most invoking multiple epochs of star-formation within the cluster, however all have failed to reproduce various key observations, in particular when a global view of the GC population is taken. We review the state of current observations, and outline the successes and failures of each of the main proposed models. The traditional idea of using the stellar ejecta from a 1st generation of stars to form a 2nd generation of stars, while conceptually straight forward, has failed to reproduce an increasing number of observational constraints. We conclude that the puzzle of multiple populations remains unsolved, hence alternative theories are needed.

Accepted by : Annual Reviews of Astronomy and Astrophysics
http://adsabs.harvard.edu/abs/2017arXiv171201286B

Clusters in the Magellanic clouds

Age as a Major Factor in the Onset of Multiple Populations in Stellar Clusters

S. Martocchia [1], I. Cabrera-Ziri [2], C. Lardo [1,3], and 16 co-authors

([1]) Astrophysics Research Institute, Liverpool John Moores University, Liverpool, UK; ([2]) Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA; ([3]) Laboratoire d'astrophysique, École Polytechnique Fédérale de Lausanne (EPFL), Versoix, Switzerland

It is now well established that globular clusters (GCs) exhibit star-to-star light-element abundance variations (known as multiple stellar populations, MPs). Such chemical anomalies have been found in (nearly) all the ancient GCs (more than 10 Gyr old) of our Galaxy and its close companions, but so far no model for the origin of MPs is able to reproduce all the relevant observations. To gain new insights into this phenomenon, we have undertaken a photometric Hubble Space Telescope survey to study clusters with masses comparable to that of old GCs, where MPs have been identified, but with significantly younger ages. Nine clusters in the Magellanic Clouds with ages between $\sim$ 1.5-11 Gyr have been targeted in this survey. We confirm the presence of multiple populations in all clusters older than 6 Gyr and we add NGC 1978 to the group of clusters for which MPs have been identified. With an age of $\sim$ 2 Gyr, NGC 1978 is the youngest cluster known to host chemical abundance spreads found to date. We do not detect evident star-to-star variations for slightly younger massive clusters ($\sim$ 1.7 Gyr), thus pointing towards an unexpected age dependence for the onset of multiple populations. This discovery suggests that the formation of MPs is not restricted to the early Universe and that GCs and young massive clusters share common formation and evolutionary processes.

Accepted by : Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.473.2688M

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Not-so-simple stellar populations in nearby, resolved massive star clusters

R. de Grijs [1,2] and C. Li [3]

([1]) Kavli Institute for Astronomy & Astrophysics and Department of Astronomy, Peking University, Beijing, China; ([2]) International Space Science Institute-Beijing, Beijing, China; ([3]) Department of Physics and Astronomy, Macquarie University, North Ryde, NSW 2109, Australia

Around the turn of the last century, star clusters of all kinds were considered "simple" stellar populations. Over the past decade, this situation has changed dramatically. At the same time, star clusters are among the brightest stellar population components and, as such, they are visible out to much greater distances than individual stars, even the brightest, so that understanding the intricacies of star cluster composition and their evolution is imperative for understanding stellar populations and the evolution of galaxies as a whole. In this review of where the field has moved to in recent years, we place particular emphasis on the properties and importance of binary systems, the effects of rapid stellar rotation, and the presence of multiple populations in Magellanic Cloud star clusters across the full age range. Our most recent results imply a reverse paradigm shift, back to the old simple stellar population picture for at least some intermediate-age ($\sim$1–3 Gyr-old) star clusters, opening up exciting avenues for future research efforts.

Accepted by : Physica Scripta (invited review article)

http://adsabs.harvard.edu/abs/2017arXiv171106079D

The most distant clusters

The young star cluster population of M51 with LEGUS – I. A comprehensive study of cluster formation and evolution

M. Messa, A. Adamo, G. Östlin, and 34 co-authors
Department of Astronomy, The Oskar Klein Centre, Stockholm University, Stockholm, Sweden

Recently acquired WFC3 UV (F275W and F336W) imaging mosaics under the Legacy Extragalactic UV Survey (LEGUS), combined with archival ACS data of M51, are used to study the young star cluster (YSC) population of this interacting system. Our newly extracted source catalogue contains 2834 cluster candidates, morphologically classified to be compact and uniform in colour, for which ages, masses and extinction are derived. In this first work we study the main properties of the YSC population of the whole galaxy, considering a mass-limited sample. Both luminosity and mass functions follow a power-law shape with slope -2, but at high luminosities and masses a dearth of sources is observed. The analysis of the mass function suggests that it is best fitted by a Schechter function with slope -2 and a truncation mass at $1.00 \pm 0.12 \times 10^5$ $M_\odot$. Through Monte Carlo simulations, we confirm this result and link the shape of the luminosity function to the presence of a truncation in the mass function. A mass limited age function analysis, between 10 and 200 Myr, suggests that the cluster population is undergoing only moderate disruption. We observe little variation in the shape of the mass function at masses above 1×10^4 $M_\odot$ over this age range. The fraction of star formation happening in the form of bound clusters in M51 is $\sim 20\%$ in the age range 10–100 Myr and little variation is observed over the whole range from 1 to 200 Myr.

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http://adsabs.harvard.edu/abs/2018MNRAS.473..996M

Dynamical evolution - Simulations

Gas expulsion in MOND: the possible origin of diffuse globular clusters and ultra-faint dwarf galaxies

X. Wu [1,2] and P. Kroupa [3]

([1]) CAS Key Laboratory for Research in Galaxies and Cosmology, Department of Astronomy, University of Science and Technology of China, Hefei, China; ([2]) School of Astronomy and Space Science, University of Science and Technology of China, Hefei, China; ([3]) Helmholtz-Institut für Strahlen- und Kernphysik, Universität Bonn, Bonn, Germany

We study the evolution of star clusters located in the outer regions of a galaxy undergoing a sudden mass loss through gas expulsion in the framework of Milgromian dynamics (MOND) by means of N-body simulations. We find that, to leave a bound star cluster, the star formation efficiency (SFE) of an embedded cluster dominated by deep MOND gravity can be reduced down to 2.5%. For a given SFE, the star clusters that survive in MOND can bind a larger fraction of mass compared to the Newtonian dynamics. Moreover, the more diffuse the embedded cluster is, the less substantial the size expansion of the final star cluster is. The density profiles of a surviving star cluster are more cuspy in the centre for more massive embedded clusters, and the central density profiles are flatter for less massive embedded clusters or for lower SFE. This work may help to understand the low concentration and extension of the distant low-density globular clusters (GCs) and ultra-faint and diffuse satellite galaxies around the Milky Way.

Accepted by : Astrophysical Journal

http://adsabs.harvard.edu/abs/2017arXiv171202354W

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The Evolution of Kicked Stellar-Mass Black Holes in Star Cluster Environments

J. J. Webb [1] , N. W. C. Leigh [2], A. Singh [1], and 3 co-authors

([1]) Department of Astronomy, Indiana University, IN 47405 Bloomington, USA; ([2]) Department of Astrophysics, American Museum of Natural History, New York, NY 10024, USA

We consider how dynamical friction acts on black holes that receive a velocity kick while located at the center of a gravitational potential, analogous to a star cluster, due to either a natal kick or the anisotropic emission of gravitational waves during a black hole-black hole merger. Our investigation specifically focuses on how well various Chandrasekhar-based dynamical friction models can predict the orbital decay of kicked black holes with $m_{bh} \lesssim 100$ $M_\odot$ due to an inhomogeneous background stellar field. In general, the orbital evolution of a kicked black hole follows that of a damped oscillator where two-body encounters and dynamical friction serve as sources of damping. However, we find models for approximating the effects of dynamical friction do not accurately predict the amount of energy lost by the black hole if the initial kick velocity v_k is greater than the stellar velocity dispersion σ. For all kick velocities, we also find that two-body encounters with nearby stars can cause the energy evolution of a kicked BH to stray significantly from standard dynamical friction theory as encounters can sometimes lead to an energy gain. For larger kick velocities, we find the orbital decay of a black hole departs from classical theory completely as the black hole's orbital amplitude decays linearly with time as opposed to exponentially. Therefore, we have developed a linear decay formalism which scales linearly with black hole mass and $\frac{v_k}{\sigma}$ in order to account for the variations in the local gravitational potential.

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http://adsabs.harvard.edu/abs/2017arXiv171109100W

Modelling the observed stellar mass function and its radial variation in galactic globular clusters

J. J. Webb [1], E. Vesperini [1], E. Dalessandro [2,3], and 3 co-authors

([1]) Department of Astronomy, Indiana University, Swain West, IN 47405 Bloomington, USA; ([2]) INAF Osservatorio Astronomico di Bologna, Bologna, Italy; ([3]) Dept. of Physics and Astronomy, University of Bologna, Bologna, Italy

We measure how the slope α of the stellar mass function (MF) changes as a function of clustercentric distance r in five Galactic globular clusters and compare α(r) to predictions from direct N-body star cluster simulations. Theoretical studies predict that α(r) (which traces the degree of mass segregation in a cluster) should steepen with time as a cluster undergoes two-body relaxation and that the amount by which the global MF can evolve from its initial state due to stellar escape is directly linked to α(r). We find that the amount of mass segregation in M10, NGC 6218, and NGC 6981 is consistent with their dynamical ages, but only the global MF of M10 is consistent with its degree of mass segregation as well. NGC 5466 and NGC 6101 on the other hand appear to be less segregated than their dynamical ages would indicate. Furthermore, despite the fact that the escape rate of stars in non-segregated clusters is independent of stellar mass, both NGC 5466 and NGC 6101 have near-flat MFs. We discuss various mechanisms which could produce non-segregated clusters with near-flat MFs, including higher mass-loss rates and black hole retention, but argue that for some clusters (NGC 5466 and NGC 6101) explaining the present-day properties might require either a non-universal initial mass function or a much more complex dynamical history.

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http://adsabs.harvard.edu/abs/2017MNRAS.471.3845W

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A clustered origin for isolated massive stars

W. Lucas [1], M. Rybak [1,2], I. Bonnell [1], and M. Gieles [3]

([1]) Scottish Universities Physics Alliance (SUPA), School of Physics and Astronomy, University of St Andrews, North Haugh, St Andrews, UK; ([2]) Leiden Observatory, Leiden University, Leiden, the Netherlands; ([3]) Department of Physics, University of Surrey, Guildford, UK

High-mass stars are commonly found in stellar clusters promoting the idea that their formation occurs due to the physical processes linked with a young stellar cluster. It has recently been reported that isolated high-mass stars are present in the Large Magellanic Cloud. Due to their low velocities it has been argued that these are high-mass stars which formed without a surrounding stellar cluster. In this paper we present an alternative explanation for the origin of these stars in which they formed in a cluster environment but are subsequently dispersed into the field as their natal cluster is tidally disrupted in a merger with a higher-mass cluster. They escape the merged cluster with relatively low velocities typical of the cluster interaction and thus of the larger scale velocity dispersion, similarly to the observed stars. N-body simulations of cluster mergers predict a sizeable population of low velocity (≤ 20 km s^{-1}), high-mass stars at distances of > 20 pc from the cluster. High-mass clusters in which gas poor mergers are frequent would be expected to commonly have halos of young stars, including high-mass stars, that were actually formed in a cluster environment.

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The E-MOSAICS Project: simulating the formation and co-evolution of galaxies and their star cluster populations

J. Pfeffer [1], J. M. D. Kruijssen [2], R. A. Crain [1], and N. Bastian [1]

([1]) Astrophysics Research Institute, Liverpool John Moores University, Liverpool, UK; ([2]) Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Heidelberg, Germany

We introduce the MOdelling Star cluster population Assembly In Cosmological Simulations within EAGLE (E-MOSAICS) project. E-MOSAICS incorporates models describing the formation, evolution and disruption of star clusters into the EAGLE galaxy formation simulations, enabling the examination of the co-evolution of star clusters and their host galaxies in a fully cosmological context. A fraction of the star formation rate of dense gas is assumed to yield a cluster population; this fraction, and the population's initial properties, are governed by the physical properties of the natal gas. The subsequent evolution and disruption of the entire cluster population is followed accounting for two-body relaxation, stellar evolution, and gravitational shocks induced by the local tidal field. This introductory paper presents a detailed description of the model and initial results from a suite of 10 simulations of $\sim L^{\star}$ galaxies with disc-like morphologies at $z = 0$. The simulations broadly reproduce key observed characteristics of young star clusters and globular clusters (GCs), without invoking separate formation mechanisms for each population. The simulated GCs are the surviving population of massive clusters formed at early epochs ($z \gtrsim 1 - 2$), when the characteristic pressures and surface densities of star-forming gas were significantly higher than observed in local galaxies. We examine the influence of the star formation and assembly histories of galaxies on their cluster populations, finding that (at similar present-day mass) earlier-forming galaxies foster a more massive and disruption-resilient cluster population, while galaxies with late mergers are capable of forming massive clusters even at late cosmic epochs. We find that the phenomenological treatment of interstellar gas in EAGLE precludes the accurate modelling of cluster disruption in low-density environments, but infer that simulations incorporating an explicitly-modelled cold interstellar gas phase will overcome this shortcoming.

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Probing dark matter with star clusters: a dark matter core in the ultra-faint dwarf Eridanus II

F. Contenta, E. Balbinot, J. A. Petts, and 6 co-authors

Department of Physics, University of Surrey, Guildford, UK

We present a new technique to probe the central dark matter (DM) density profile of galaxies that harnesses both the survival and observed properties of star clusters. As a first application, we apply our method to the 'ultra-faint' dwarf Eridanus II (Eri II) that has a lone star cluster ∼45 pc from its centre. Using a grid of collisional N-body simulations, incorporating the effects of stellar evolution, external tides and dynamical friction, we show that a DM core for Eri II naturally reproduces the size and the projected position of its star cluster. By contrast, a dense cusped galaxy requires the cluster to lie implausibly far from the centre of Eri II (>1 kpc), with a high inclination orbit that must be observed at a particular orbital phase. Our results imply that either a cold DM cusp was 'heated up' at the centre of Eri II by bursty star formation, or we are seeing an evidence for physics beyond cold DM.

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http://adsabs.harvard.edu/abs/2017arXiv170501820C

The signatures of the parental cluster on field planetary systems

M. X. Cai, S. Portegies Zwart, and A. van Elteren
Leiden Observatory, Leiden University, Leiden, The Netherlands

Due to the high stellar densities in young clusters, planetary systems formed in these environments are likely to have experienced perturbations from encounters with other stars. We carry out direct N-body simulations of multi-planet systems in star clusters to study the combined effects of stellar encounters and internal planetary dynamics. These planetary systems eventually become part of the Galactic field population the parental cluster dissolves, which is where most presently-known exoplanets are observed. We show that perturbations induced by stellar encounters lead to distinct signatures in the field planetary systems, most prominently, the excited orbital inclinations and eccentricities. Planetary systems that form within the cluster's half-mass radius are more prone to such perturbations. The orbital elements are most strongly excited in the outermost orbit, but the effect propagates to the entire planetary system through secular evolution. Planet ejections may occur long after a stellar encounter. The surviving planets in these reduced systems tend to have, on average, higher inclinations and larger eccentricities compared to systems that were perturbed less strongly. As soon as the parental star cluster dissolves, external perturbations stop affecting the escaped planetary systems, and further evolution proceeds on a relaxation time scale. The outer regions of these ejected planetary systems tend to relax so slowly that their state carries the memory of their last strong encounter in the star cluster. Regardless of the stellar density, we observe a robust anticorrelation between multiplicity and mean inclination/eccentricity. We speculate that the "Kepler dichotomy" observed in field planetary systems is a natural consequence of their early evolution in the parental cluster.

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Dynamical equivalence, the origin of the Galactic field stellar and binary population, and the initial radius–mass relation of embedded clusters

D. Belloni [1,2], P. Kroupa [3,4], H. J. Rocha-Pinto [5], and M. Giersz [1]
([1]) Nicolaus Copernicus Astronomical Centre, Warsaw, Poland; ([2]) CAPES Foundation, Brasilia, Brazil; ([3]) Helmholtz-Institut für Strahlen- und Kernphysik, Bonn, Germany; ([4]) Charles University in Prague, Prague, Czech Republic; ([5]) Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil

In order to allow a better understanding of the origin of Galactic field populations, dynamical equivalence of stellar-dynamical systems has been postulated by Kroupa and Belloni et al. to allow mapping of solutions of the initial conditions of embedded clusters such that they yield, after a period of dynamical processing, the Galactic field population. Dynamically equivalent systems are defined to initially and finally have the same distribution functions of periods, mass ratios and eccentricities of binary stars. Here we search for dynamically equivalent clusters using the MOCCA code. The simulations confirm that dynamically equivalent solutions indeed exist. The result is that the solution space is next to identical to the radius–mass relation of Marks & Kroupa, $(r_h/\mathrm{pc}) = 0.1^{+0.07}_{-0.04}\ (M_{\mathrm{ecl}}/\mathrm{M}_\odot)^{0.13\pm0.04}$. This relation is in good agreement with the observed density of molecular cloud clumps. According to the solutions, the time-scale to reach dynamical equivalence is about 0.5 Myr which is, interestingly, consistent with the lifetime of ultra-compact HII regions and the time-scale needed for gas expulsion to be active in observed very young clusters as based on their dynamical modelling.

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Proceedings abstracts

The ages of (the oldest) stars

M. Catelan [1,2]

([1]) Pontificia Universidad Católica de Chile, Santiago, Chile; ([2]) Millennium Institute of Astrophysics, Santiago, Chile

Much progress has been achieved in the age-dating of old stellar systems, and even of individual stars in the field, in the more than sixty years since the evolution of low-mass stars was first correctly described. In this paper, I provide an overview of some of the main methods that have been used in this context, and discuss some of the issues that still affect the determination of accurate ages for the oldest stars.

To appear in : Proceedings of the IAU Symp. 334 ("Rediscovering our Galaxy"), invited review, ed. C. Chiappini et al.

http://adsabs.harvard.edu/abs/2017arXiv170908656C

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Interpreting the complex CMDs of the Magellanic Clouds clusters

I. Cabrera-Ziri [1], **S. Martocchia** [2], **K. Hollyhead** [3], **and N. Bastian** [2]

([1]) Harvard-Smithsonian Center for Astrophysics, Cambridge, MA 02138, USA; ([2]) Astrophysics Research Institute, Liverpool John Moores University, Liverpool UK; ([3]) Department of Astronomy, Oskar Klein Centre, Stockholm University, Stockholm, Sweden

The Magellanic Clouds host a large population of massive ($> 10^4\,M_\odot$) star clusters with ages ranging from a few Myr to 12 Gyr. In nearly all cases, close inspection of their CMDs reveals features that deviate from expectations of a classic isochrone. Young (< 2 Gyr) clusters show extended main sequence turnoffs and in some cases split/dual main sequences. Clusters older than ~ 2 Gyr show splitting in the red giant branches when viewed in UV filters that are sensitive to abundance variations (in particular nitrogen). A distribution of stellar rotation rates appears to be the cause of the complex features observed in the young and intermediate age clusters, while above ~ 2 Gyr the features seem to be the same light-element abundance variations as observed in the ancient Galactic globular clusters, a.k.a. "multiple populations". Here, we provide an overview of current observations and their interpretations and summarise possible links between all the classes of complexities, regardless of age.

To appear in : Proceedings of "Star cluster formation history in the Magellanic Clouds", EWASS 2017

http://adsabs.harvard.edu/abs/2017arXiv171101121C

Ph.D. (dissertation) summaries

Chemical and dynamical analysis of Open Clusters in the context of the Milky Way disc

Laia Casamiquela Floriach

Departament de Física Quàntica i Astrofísica, Universitat de Barcelona, ICCUB-IEEC

This thesis has as a main purpose the determination of the chemical composition of Open Clusters for the study of the chemical gradients in the Galactic disc with: Galactocentric radius, position above the plane, and age.

In 3 years and a half we have acquired high-resolution spectra of stars in 18 Open Clusters as a part of the OCCASO survey. We have used three fiber fed high-resolution spectrographs in the Observatorio del Roque de los Muchachos (La Palma, Spain) and the CAHA observatory (Almera, Spain). After a very accurate data reduction we have determined radial velocities, atmospheric parameters (effective temperature, surface gravity) and chemical abundances.

Using the derived radial velocities and proper motions from the literature we have done a kinematic study of these clusters in the context of the Galactic disc and the position near the spiral arms. We have obtained radial velocities for OC never studied before with high-resolution spectroscopy: NGC 1907 (v_r=2.3±0.5 km s^{-1}), NGC 6991 (v_r=-12.3±0.6 km s^{-1}) and NGC 7245 (v_r=−74.0±1.4 km s^{-1}). We have computed the possible orbits that the clusters have followed using two models of the Galactic potential: an axisymmetric one, and a model with a bar and spiral arms featuring those of the Milky Way. With this, we have recovered the position of the clusters at birth.

We have calculated temperatures, gravities and iron abundances using two different methodologies widely used in the literature. We have made an exhaustive comparison of the behaviour of both methods and the differences obtained among them. We obtained no systematics in effective temperature and surface gravity within the quoted errors, though with a large dispersion in surface gravity. As a sanity check we derived atmospheric parameters from BVI Johnson photometry for the stars from NGC 2420 and NGC 6791. We found systematic differences between spectroscopic and photometric determinations which change with slight variations of the assumed reddening, distance, age and metallicity to compute photometric parameters. Mean uncertainties in the final adopted in temperature and gravity are around 40 K and 0.1 dex. The comparison with literature values gives mean offsets well within uncertainties and dispersions. All these checks provide a study of the precision and accuracy of the obtained results.

We have measured abundances of iron-peak elements (Fe, Ni, Cr) and the so-called α-elements (Si, Ca, Ti, Mg, O). From member stars we derive mean Fe cluster abundances with the two methods. We do an extensive star-by-star comparison with literature, showing good agreement. We also derived mean cluster Ni, Cr, Si, Ca and Ti abundances, and its abundance ratios respect to Fe. We see that all the clusters present small dispersions in abundance. The larger ones are 0.03 ([Ni/Fe]), 0.06 ([Cr/Fe]), 0.05 ([Si/Fe]), 0.07 ([Ca/Fe]), 0.05 ([Ti/Fe]) dex, excluding NGC 6791 (for which we have larger errors)

We have compared the Galactocentric trend seen with OCCASO clusters with different theoretical models obtaining that the results for the oldest clusters favour a chemo-dynamical model instead of a pure chemical evolution model. Using OCCASO and two complementary samples (40 clusters in total), we have determined new values for the Galactocentric Fe gradient in three age bins, and the age-metallicity relation in four ranges of Galactocentric distance.

In particular we have studied NGC 6705 in detail. We have seen that this cluster presents an unexpected α-enhancement for its location in the disc and its young age. We have derived the birth location of this cluster computing the possible orbits that it could have followed in the disc using different models. It seems that its α-enhancement cannot be explained by a very different place of birth of this cluster (i.e. the inner Galaxy), which from our calculations would be at most from a radii of 6.5 kpc.

PhD thesis completed at the University of Barcelona under the supervision of C. Jordi, L. Balaguer-Núñez and R. Carrera

The thesis is available at: https://zenodo.org/record/836759#.WhgoEZ_ibrE

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Jobs

Post-doctoral position at the Department of Astronomy, Indiana University, Bloomington, USA

Applications are invited for a postdoctoral position in Theoretical and Computational Astrophysics to work with Professor Enrico Vesperini in the Department of Astronomy at Indiana University, Bloomington. Areas of research interest include formation and dynamical evolution of star clusters, multiple stellar populations in globular clusters, hydrodynamical, N-body and Fokker-Planck numerical simulations of globular cluster formation and evolution. Applications from candidates with experience in the observational study of star clusters and the comparison between theoretical models and observations are also encouraged.

The successful applicant will have access to the supercomputer facilities of Indiana University.

The initial appointment will be for two years with extension to the third year depending on availability of funding and satisfactory progress. Start date is expected to be August 2018 but is negotiable.

Minimum qualifications: Ph.D. in Astronomy or Physics by appointment start date.

Duration: 2(3) years
Best Consideration Date: January 20, 2018
Expected start Date: August 1, 2018

Contact: Prof. Enrico Vesperini, (evesperi@indiana.edu)

Details are provided at:
https://indiana.peopleadmin.com/postings/5188

Conferences

EPoS 2018 - The Early Phase of Star Formation

13–18 May, 2018
Ringberg Castle, Kreuth, Germany
http://www.mpia.de/homes/stein/EPoS/2018/2018.php

Registration deadline: 15 January, 2018

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MODEST 18
Dense stellar systems in the era of Gaia, LIGO & LISA

25–29 June, 2018
Santorini, Greece
http://sites.northwestern.edu/modest18ciera/

Pre-registration is open

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Multiple Populations in Stellar Clusters

9–13 July, 2018
Sexten, Italy
http://www.sexten-cfa.eu/en/conferences/2018/details/
104-multiple-populations-in-stellar-clusters.html

Registration opens end of January

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The formation of globular clusters at high and low redshift

16–20 July, 2018
Sexten, Italy
http://www.sexten-cfa.eu/en/conferences/2018/details/
106-the-formation-of-globular-clusters-at-high-and-low-z.html

Registration opens end of January

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ESO Workshop “A revolution in stellar physics with Gaia and large surveys”

3–7 September, 2018
Warsaw, Poland
https://indico.camk.edu.pl/event/9/

Registration: 3 January, 2018 – 15 April, 2018