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.

SCYON Issue No. 76 July 8^{th}, 2018

Dear Colleagues,

Recently, the election results for the new Organising Committee of the IAU Commission H4 were announced. Amanda Karakas (Monash University, Australia) will lead the star cluster activities as new Commission President during a three-year term, supported by Francesca D'Antona (Italy) as vice president. We wish them all the best, and also big thanks to Richard de Grijs for the activities as past president!
Beyond doubt, the Gaia Data Release 2 provides a big step forward in cluster research. Even within the short time since its release, the current SCYON issue already includes some papers making use of the data, e.g. combined with APOGEE (Kounkel et al.) or the confirmation of new clusters (Camargo or Castro-Ginard et al.). The next issues will certainly include many more results.
This issue also includes the PhD thesis summaries by Javier Alonso Santiago (University of Alicante, Spain) and Romas Smilgys (University of St. Andrews, UK). We congratulate them for their final degree and wish them all the best for their future career.
We also want to draw your attention to the SCYON webpage, which obtained a new layout. We kindly ask for some input if you notice problems, in particular with the handling of the new submission forms.

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.

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

Star Forming Regions

Low mass star formation and subclustering in the HII regions RCW 32, 33 and 27 of the Vela Molecular Ridge. A photometric diagnostics to identify M-type stars

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Most stars are born in clusters, and recent results suggest that star formation (SF) preferentially occurs in subclusters. Studying the morphology and SF history of young clusters is crucial for understanding early cluster formation processes. We aim to identify the embedded population of young stellar objects (YSOs) down to the low-mass stars in the M-type regime in the three HII regions RCW33, RCW32, and RCW27, which are located in the northwestern region of the Vela Molecular Ridge. Our aim is to characterize their properties, such as morphology and extent of the clusters in the three HII regions, derive stellar ages, and determine the connection of the SF history with the environment. Through public photometric surveys such as Gaia, VPHAS, 2MASS, and Spitzer/GLIMPSE, we identify YSOs with classical techniques aimed at detecting IR, Hα, and UV excesses as signatures of circumstellar disks and accretion. In addition, we implement a method for distinguishing main-sequence (MS) stars and giants in the M-type regime by comparing the reddening derived in several optical/IR color-color diagrams, assuming suitable theoretical models. Since this diagnostic is sensitive to stellar gravity, the procedure allows us to also identify pre-MS (PMS) stars. Using the classical membership criteria, we find that a large population of YSOs shows signatures of circumstellar disks with or without accretion. In addition, with the new technique of M-type star selection, we find a rich population of young M-type stars whose spatial distribution strongly correlates with the more massive population. We find evidence of three young clusters, with different morphology, for which we estimate the individual distances using TGAS Gaia data of the brighter subsample. In addition, we identify field stars falling in the same region by securely classifying them as giants and foreground MS stars. We identify the embedded population of YSOs down to about $0.1 M_\odot$ that is associated with the three HII regions RCW33, RCW32, and RCW27 and the three clusters Vela T2, Cr197, and Vela T1, respectively. All the three clusters are located at a similar distance, but they have very different morphologies. Our results suggest a decreasing SF rate in Vela T2 and triggered SF in Cr197 and Vela T1.

Accepted by: Astronomy & Astrophysics

https://arxiv.org/abs/1806.06625

The APOGEE-2 Survey of the Orion Star Forming Complex II: Six-dimensional structure

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We present an analysis of spectrosopic and astrometric data from APOGEE-2 and Gaia DR2 to identify structures towards the Orion Complex. By applying a hierarchical clustering algorithm to the 6-dimensional stellar data, we identify spatially and/or kinematically distinct groups of young stellar objects with ages ranging from 1 to 12 Myr. We also investigate the star forming history within the Orion Complex, and identify peculiar sub-clusters. With this method we reconstruct the older populations in the regions that are presently largely devoid of molecular gas, such as Orion C (which includes the Ori cluster), and Orion D (the population that traces Ori OB1a, OB1b, and Orion X). We report on the distances, kinematics, and ages of the groups within the Complex. The Orion D groups is in the process of expanding. On the other hand, Orion B is still in the process of contraction. In Ori the proper motions are consistent with a radial expansion due to an explosion from a supernova; the traceback age from the expansion exceeds the age of the youngest stars formed near the outer edges of the region, and their formation would have been triggered when they were half-way from the cluster center to their current positions. We also present a comparison between the parallax and proper motion solutions obtained by Gaia DR2, and those obtained towards star-forming regions by Very Long Baseline Array.

Accepted by: Astronomical Journal

http://adsabs.harvard.edu/abs/2018arXiv180504649K

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Is stellar multiplicity universal? Tight stellar binaries in the Orion Nebula Cluster

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We present a survey for the tightest visual binaries among 0.3-2 Msun members the Orion Nebula Cluster (ONC). Among 42 targets, we discovered 13 new 0.025-0.15" companions. Accounting for the Branch bias, we find a companion star fraction (CSF) in the 10-60 au range of 21^{+8}_{-5}%, consistent with that observed in other star-forming regions (SFRs) and twice as high as among field stars; this excess is found with a high level of confidence. Since our sample is dominated by disk-bearing targets, this indicates that disk disruption by close binaries is inefficient, or has not yet taken place, in the ONC. The resulting separation distribution in the ONC drops sharply outside 60 au. These findings are consistent with a scenario in which the initial multiplicity properties, set by the star formation process itself, are identical in the ONC and in other SFRs and subsequently altered by the cluster's dynamical evolution. This implies that the fragmentation process does not depend on the global properties of a molecular cloud, but on the local properties of prestellar cores, and that the latter are self-regulated to be nearly identical in a wide range of environments. These results, however, raise anew the question of the origin of field stars as the tight binaries we have discovered will not be destroyed as the ONC dissolves into the galactic field. It thus appears that most field stars formed in regions differ from well-studied SFRs in the Solar neighborhood, possibly due to changes in core fragmentation on Gyr timescales.

Accepted by : Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.478.1825D

Unbound Young Stellar Systems: Star Formation on the Loose

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Unbound young stellar systems, the loose ensembles of physically related young bright stars, trace the typical regions of recent star formation in galaxies. Their morphologies vary from small few pc-size associations of newly formed stars to enormous few kpc-size complexes composed of stars few 100 Myr old. These stellar conglomerations are located within the disks and along the spiral arms and rings of star-forming disk galaxies, and they are the active star-forming centers of dwarf and starburst galaxies. Being associated with star-forming regions of various sizes, these stellar structures trace the regions where stars form at various length- and timescales, from compact clusters to whole galactic disks. Stellar associations, the prototypical unbound young systems, and their larger counterparts, stellar aggregates, and stellar complexes, have been the focus of several studies for quite a few decades, with special interest on their demographics, classification, and structural morphology. The compiled surveys of these loose young stellar systems demonstrate that the clear distinction of these systems into well-defined classes is not as straightforward as for stellar clusters, due to their low densities, asymmetric shapes and variety in structural parameters. These surveys also illustrate that unbound stellar structures follow a clear hierarchical pattern in the clustering of their stars across various scales. Stellar associations are characterized by significant sub-structure with bound stellar clusters being their most compact parts, while associations themselves are the brighter denser parts of larger stellar aggregates and stellar complexes, which are members of larger super-structures up to the scale of a whole star-forming galaxy. This structural pattern, which is usually characterized as self-similar or fractal, appears to be identical to that of star-forming giant molecular clouds and interstellar gas, driven mainly by turbulence cascade. In this short review, I make a concise compilation of our understanding of unbound young stellar systems across various environments in the local universe, as it is developed during the last 60 years. I present a factual assessment of the clustering behavior of star formation, as revealed from the assembling pattern of stars across loose stellar structures and its relation to the interstellar medium and the environmental conditions. I also provide a consistent account of the processes that possibly play important role in the formation of unbound stellar systems, compiled from both theoretical and observational investigations on the field.

Accepted by : Publication of the Astronomical Society of the Pacific

http://adsabs.harvard.edu/abs/2018PASP..130g2001G

Galactic Open Clusters

A new method for unveiling Open Clusters in Gaia: new nearby Open Clusters confirmed by DR2

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The publication of the Gaia Data Release 2 (Gaia DR2) opens a new era in Astronomy. It includes precise astrometric data (positions, proper motions and parallaxes) for more than 1.3 billion sources, mostly stars. To analyse such a vast amount of new data, the use of data mining techniques and machine learning algorithms are mandatory. The search for Open Clusters, groups of stars that were born and move together, located in the disk, is a great example for the application of these techniques. Our aim is to develop a method to automatically explore the data space, requiring minimal manual intervention. We explore the performance of a density based clustering algorithm, DBSCAN, to find clusters in the data together with a supervised learning method such as an Artificial Neural Network (ANN) to automatically distinguish between real Open Clusters and statistical clusters. The development and implementation of this method to a 5-Dimensional space (l, b, ϖ, μ_{α^*}, μ_δ) to the Tycho-Gaia Astrometric Solution (TGAS) data, and a posterior validation using Gaia DR2 data, lead to the proposal of a set of new nearby Open Clusters. We have developed a method to find OCs in astrometric data, designed to be applied to the full Gaia DR2 archive.

Accepted by: Astronomy & Astrophysics

http://adsabs.harvard.edu/abs/2018arXiv180503045C

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The Gaia-ESO Survey: evidence of atomic diffusion in M67?

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Investigating the chemical homogeneity of stars born from the same molecular cloud at virtually the same time is very important for our understanding of the chemical enrichment of the interstellar medium and with it the chemical evolution of the Galaxy. One major cause of inhomogeneities in the abundances of open clusters is stellar evolution of the cluster members. In this work, we investigate variations in the surface chemical composition of member stars of the old open cluster M67 as a possible consequence of atomic diffusion effects taking place during the main-sequence phase. The abundances used are obtained from high-resolution UVES/FLAMES spectra within the framework of the Gaia-ESO Survey. We find that the surface abundances of stars on the main sequence decrease with increasing mass reaching a minimum at the turn-off. After deepening of the convective envelope in subgiant branch stars, the initial surface abundances are restored. We found the measured abundances to be consistent with the predictions of stellar evolutionary models for a cluster with the age and metallicity of M67. Our findings indicate that atomic diffusion poses a non-negligible constraint on the achievable precision of chemical tagging methods.

Accepted by: Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.478..425B

CCD UBV photometric study of five open clusters - Dolidze 36, NGC 6728, NGC 6800, NGC 7209 and Platais 1

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In this study, we present CCD UBV photometry of poorly studied open star clusters, Dolidze 36, NGC 6728, NGC 6800, NGC 7209, and Platais 1, located in the first and second Galactic quadrants. Observations were obtained with T100, the 1-m telescope of the TUBITAK National Observatory. Using photometric data, we determined several astrophysical parameters such as reddening, distance, metallicity and ages and from them, initial mass functions, integrated magnitudes and colours. We took into account the proper motions of the observed stars to calculate the membership probabilities. The colour excesses and metallicities were determined independently using two-colour diagrams. After obtaining the colour excesses of the clusters Dolidze 36, NGC 6728, NGC 6800, NGC 7209, and Platais 1 as 0.19 ± 0.06, 0.15 ± 0.05, 0.32 ± 0.05, 0.12 ± 0.04, and 0.43 ± 0.06 mag, respectively, the metallicities are found to be 0.00 ± 0.09, 0.02 ± 0.11, 0.03 ± 0.07, 0.01 ± 0.08, and 0.01 ± 0.08 dex, respectively. Furthermore, using these parameters, distance moduli and age of the clusters were also calculated from colour-magnitude diagrams simultaneously using PARSEC theoretical models. The distances to the clusters Dolidze 36, NGC 6728, NGC 6800, NGC 7209, and Platais 1 are 1050 ± 90, 1610 ± 190, 1210 ± 150, 1060 ± 90, and 1710 ± 250 pc, respectively, while corresponding ages are 400 ± 100, 750 ± 150, 400 ± 100, 600 ± 100, and 175 ± 50 Myr, respectively. Our results are compatible with those found in previous studies. The mass function of each cluster is derived. The slopes of the mass functions of the open clusters range from 1.31 to 1.58, which are in agreement with Salpeter's initial mass function. We also found integrated absolute magnitudes varying from -4.08 to -3.40 for the clusters.

Accepted by: Astrophysics & Space Science

http://adsabs.harvard.edu/abs/2018Ap%26SS.363..143B

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NGC 3105: a young open cluster with low metallicity

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NGC 3105 is a young open cluster hosting blue, yellow and red supergiants. This rare combination makes it an excellent laboratory to constrain evolutionary models of high-mass stars. It is poorly studied and fundamental parameters such as its age or distance are not well defined. We intend to characterize in an accurate way the cluster as well as its evolved stars, for which we derive for the first time atmospheric parameters and chemical abundances. We identify 126 B-type likely members within a radius of 2.7±0.6 arcmin, which implies an initial mass, $M_{cl} \approx 4100$ M$_{\odot}$. We find a distance of 7.2±0.7 kpc for NGC 3105, placing it at R_{GC}=10.0±1.2 kpc. Isochrone fitting supports an age of 28±6 Ma, implying masses around 9.5 M$_{\odot}$ for the supergiants. A high fraction of Be stars (≈25 spectral type b3. From the spectral analysis we estimate for the cluster a v_{rad}=+46.9±0.9 km s^{-1} and a low metallicity, [Fe/H]=-0.29±0.22. We also have determined, for the first time, chemical abundances for Li, O, Na, Mg, Si, Ca, Ti, Ni, Rb, Y, and Ba for the evolved stars. The chemical composition of the cluster is consistent with that of the Galactic thin disc. An overabundance of Ba is found, supporting the enhanced *s*-process. NGC 3105 has a low metallicity for its Galactocentric distance, comparable to typical LMC stars. It is a valuable spiral tracer in a very distant region of the Carina-Sagittarius spiral arm, a poorly known part of the Galaxy. As one of the few Galactic clusters containing blue,

yellow and red supergiants, it is massive enough to serve as a testbed for theoretical evolutionary models close to the boundary between intermediate and high-mass stars.

Accepted by : Astronomy & Astrophysics
http://adsabs.harvard.edu/abs/2018arXiv180500507A

Galactic Globular Clusters

The most metal-poor Galactic globular cluster: the first spectroscopic observations of ESO280-SC06

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We present the first spectroscopic observations of the very metal-poor Milky Way globular cluster ESO280-SC06. Using spectra acquired with the 2dF/AAOmega spectrograph on the Anglo-Australian Telescope, we have identified 13 members of the cluster, and estimate from their infrared calcium triplet lines that the cluster has a metallicity of $[Fe/H] = -2.48^{+0.06}_{-0.11}$. This would make it the most metal-poor globular cluster known in the Milky Way. This result was verified with comparisons to three other metal-poor globular clusters that had been observed and analyzed in the same manner. We also present new photometry of the cluster from EFOSC2 and SkyMapper and confirm that the cluster is located 22.9 ± 2.1 kpc from the Sun and 15.2 ± 2.1 kpc from the Galactic centre, and has a radial velocity of $92.5^{+2.4}_{-1.6}$ km s^{-1}. These new data finds the cluster to have a radius about half that previously estimated, and we find that the cluster has a dynamical mass of the cluster of $(12 \pm 2) \times 10^3$ solar masses. Unfortunately, we lack reliable proper motions to fully characterize its orbit about the Galaxy. Intriguingly, the photometry suggests that the cluster lacks a well-populated horizontal branch, something that has not been observed in a cluster so ancient or metal-poor.

Accepted by: Monthly Notices of the Royal Astronomical Society
http://adsabs.harvard.edu/abs/2018MNRAS.477.4565S

On the physical nature of globular cluster candidates in the Milky Way bulge

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We present results from 2MASS JK_s photometry on the physical reality of recently reported globular cluster (GC) candidates in the Milky Way (MW) bulge. We relied our analysis on photometric membership probabilities that allowed us to distinguish real stellar aggregates from the composite field star population. When building colour-magnitude diagrams and stellar density maps for stars at different membership probability levels, the genuine GC candidate populations are clearly highlighted. We then used the tip of the red giant branch (RGB) as distance estimator, resulting heliocentric distances that place many of the objects in regions near of the MW bulge where no GC had been previously recognised. Some few GC candidates resulted to be MW halo/disc objects. Metallicities estimated from the standard RGB method are in agreement with the values expected according to the position of the GC candidates in the Galaxy. Finally, we derived from the first time their structural parameters. We found that the studied objects have core, half-light and tidal radii in the ranges spanned by the population of known MW GCs. Their internal dynamical evolutionary stages will be described properly when their masses are estimated.

Accepted by : Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.477.2164P

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Five New Globular Clusters Discovered in the Galactic Bulge

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This Letter reports the discovery of five new globular clusters (GCs) in the Galactic bulge (Camargo 1102, 1103, 1104, 1105, and 1106) using Wide-field Infrared Survey Explorer (WISE) images. Their natures are established by using 2MASS and Gaia second data release (DR2) photometry. The new findings are old and metal-poor GCs located less than 4 kpc from the Galactic center. Camargo 1102 seems to be located over the Galactic bar on the far side of the Milky Way and at a vertical distance lower than 1 kpc. The other four clusters lie even closer to the Milky Way mid-plane. The old ages and low metallicities suggest that the newly discovered GCs may have the potential of providing important clues on the early inner Galaxy formation and its subsequent evolution, as well as the current bulge structure and kinematics.

Accepted by: The Astrophysical Journal Letters

http://adsabs.harvard.edu/abs/2018ApJ...860L..27C

Light element variations in globular clusters via nucleosynthesis in black hole accretion discs

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Ancient globular clusters contain multiple stellar populations identified by variations in light element (e.g., C, N, O, Na). Though many scenarios have been suggested to explain this phenomenon, all are faced with challenges when compared with all the observational evidence. In this Letter, we propose a new scenario in which light element variations are determined by nucleosynthesis in accretion discs around black holes. Since the black holes form after a few Myrs, the cluster is expected to still be embedded in a gas rich environment. By using a simplified accretion model which assumes virial temperatures, we show that the correct light element anti-correlations could be produced in accretion flows around stellar-mass black holes. Assuming a Kroupa IMF, each black hole would only have to process $\approx 300 M_{\odot}$ of material in order to produce multiple populations; over a period of 1Myr this corresponds $\sim 10^{-4} M_{\odot} yr^{-1}$, which is within the range of values typically assumed for the formation of massive stars.

Submitted to: Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018arXiv180408877B

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A catalogue of masses, structural parameters and velocity dispersion profiles of 112 Milky Way globular clusters

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We have determined masses, stellar mass functions and structural parameters of 112 Milky Way globular clusters by fitting a large set of N-body simulations to their velocity dispersion and surface density profiles. The velocity dispersion profiles were calculated based on a combination of more than 15,000 high-precision radial velocities which we derived from archival ESO/VLT and Keck spectra together with 20,000 published radial velocities from the literature. Our fits also include the stellar mass functions of the globular clusters, which are available for 47 clusters in our sample, allowing us to self-consistently take the effects of mass segregation and ongoing cluster dissolution into account. We confirm the strong correlation between the global mass functions of globular clusters and their relaxation times recently found by Sollima & Baumgardt (2017). We also find a correlation of the escape velocity from the centre of a globular cluster and the fraction of first generation stars (FG) in the cluster recently derived for 57 globular clusters by Milone et al. (2017), but no correlation between the FG star fraction and the global mass function of a globular cluster. This could indicate that the ability of a globular cluster to keep the wind ejecta from the polluting star(s) is the crucial parameter determining the presence and fraction of second generation stars and not its later dynamical mass loss.

Accepted by: Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.478.1520B

Clusters in the Magellanic clouds

Blue straggler stars beyond the Milky Way. II. A binary origin for blue straggler stars in Magellanic Cloud clusters

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We have analyzed populations of blue straggler stars (BSSs) in 24 Magellanic Cloud star clusters using multi-passband Hubble Space Telescope images. We compiled a homogeneous BSS database, containing both traditional and evolved BSSs. We uncovered a sub-linear correlation between the number of BSSs in the cluster cores and the clusters' core masses, characterized by a power-law index of 0.51 ± 0.07. For low stellar collision rates, the mass-normalized number of BSSs depends only weakly (or perhaps not at all) on the collision rate, implying that the binary-driven BSS formation channel dominates. Comparison with simulations suggests that stellar collisions contribute less than 20% to the total number of BSSs formed. Further tests, including analysis of the BSS specific frequencies and their population numbers at larger cluster radii, suggest that binary interactions may be their main formation channel, hinting at an anti-correlation between a cluster's binary fraction and its core mass.

Accepted by: Astrophysical Journal

http://adsabs.harvard.edu/abs/2018arXiv180604805S

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The search for multiple populations in Magellanic Cloud Clusters IV: Coeval multiple stellar populations in the young star cluster NGC 1978

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We have recently shown that the $\sim$2 Gyr old Large Magellanic Cloud star cluster NGC 1978 hosts multiple populations in terms of star-to-star abundance variations in [N/Fe]. These can be seen as a splitting or spread in the sub-giant and red giant branches (SGB and RGB) when certain photometric filter combinations are used. Due to its relative youth, NGC 1978 can be used to place stringent limits on whether multiple bursts of star-formation have taken place within the cluster, as predicted by some models for the origin of multiple populations. We carry out two distinct analyses to test whether multiple star-formation epochs have occurred within NGC 1978. First, we use UV CMDs to select stars from the first and second population along the SGB, and then compare their positions in optical CMDs, where the morphology is dominantly controlled by age as opposed to multiple population effects. We find that the two populations are indistinguishable, with age differences of 1 ± 20 Myr between them. This is in tension with predictions from the AGB scenario for the origin of multiple populations. Second, we estimate the broadness of the main sequence turnoff (MSTO) of NGC 1978 and we report that it is consistent with the observational errors. We find an upper limit of $\sim$65 Myr on the age spread in the MSTO of NGC 1978. This finding is in conflict with the age spread scenario

as origin of the extendend MSTO in intermediate age clusters, while it fully supports predictions from the stellar rotation model.

Accepted by : Monthly Notices of the Royal Astronomical Society
http://adsabs.harvard.edu/abs/2018MNRAS.477.4696M

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Hubble Tarantula Treasury Project - VI. Identification of Pre-Main-Sequence Stars using Machine Learning techniques

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The Hubble Tarantula Treasury Project (HTTP) has provided an unprecedented photometric coverage of the entire star-burst region of 30 Doradus down to the half Solar mass limit. We use the deep stellar catalogue of HTTP to identify all the pre–main-sequence (PMS) stars of the region, i.e., stars that have not started their lives on the main-sequence yet. The photometric distinction of these stars from the more evolved populations is not a trivial task due to several factors that alter their colour-magnitude diagram positions. The identification of PMS stars requires, thus, sophisticated statistical methods. We employ Machine Learning Classification techniques on the HTTP survey of more than 800,000 sources to identify the PMS stellar content of the observed field. Our methodology consists of 1) carefully selecting the most probable low-mass PMS stellar population of the star-forming cluster NGC 2070, 2) using this sample to train classification algorithms to build a predictive model for PMS stars, and 3) applying this model in order to identify the most probable PMS content across the entire Tarantula Nebula. We employ Decision Tree, Random Forest and Support Vector Machine classifiers to categorise the stars as PMS and Non-PMS. The Random Forest and Support Vector Machine provided the most accurate models, predicting about 20,000 sources with a candidateship probability higher than 50 percent, and almost 10,000 PMS candidates with a probability higher than 95 percent. This is the richest and most accurate photometric catalogue of extragalactic PMS candidates across the extent of a whole star-forming complex.

Accepted by: Monthly Notices of the Royal Astronomical Society
https://arxiv.org/abs/1805.07157

The most distant clusters

The young star cluster population of M51 with LEGUS - II. Testing environmental dependences

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It has recently been established that the properties of young star clusters (YSCs) can vary as a function of the galactic environment in which they are found. We use the cluster catalogue produced by the Legacy Extragalactic UV Survey (LEGUS) collaboration to investigate cluster properties in the spiral galaxy M51. We analyse the cluster population as a function of galactocentric distance and in arm and inter-arm regions. The cluster mass function exhibits a similar shape at all radial bins, described by a power law with a slope close to -2 and an exponential truncation around 10^5 $M_\odot$. While the mass functions of the YSCs in the spiral arm and inter-arm regions have similar truncation masses, the inter-arm region mass function has a significantly steeper slope than the one in the arm region; a trend that is also observed in the giant molecular cloud mass function and predicted by simulations. The age distribution of clusters is dependent on the region considered, and is consistent with rapid disruption only in dense regions, while little disruption is observed at large galactocentric distances and in the inter-arm region. The fraction of stars forming in clusters does not show radial variations, despite the drop in the H_2 surface density measured as function of galactocentric distance. We suggest that the higher disruption rate observed in the inner part of the galaxy is likely at the origin of the observed flat cluster formation efficiency radial profile.

Accepted by: Monthly Notices of the Royal Astronomical Society

http://adsabs.harvard.edu/abs/2018MNRAS.477.1683M

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Dissolved Massive Metal-Rich Globular Clusters can cause the Range of UV Upturn Strengths found among Early-Type Galaxies

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I discuss a scenario in which the ultraviolet (UV) upturn of giant early-type galaxies (ETGs) is primarily due to helium-rich stellar populations that formed in massive metal-rich globular clusters (GCs) which subsequently dissolved in the strong tidal field in the central regions of the massive host galaxy. These massive GCs are assumed to show UV upturns similar to those observed recently in M87, the central giant elliptical galaxy in the Virgo cluster of galaxies. Data taken from the literature reveals a strong correlation between the strength of the UV upturn and the specific frequency of metal-rich GCs in ETGs. Adopting a Schechter function parametrization of GC mass functions, simulations of long-term dynamical evolution of GC systems show that the observed correlation between UV upturn strength and GC specific frequency can be explained by variations in the characteristic truncation mass M_c such that M_c increases with ETG luminosity in a way that is consistent with observed GC luminosity functions in ETGs. These findings suggest that the nature of the UV upturn in ETGs and the variation of its strength among ETGs are causally related to that of helium-rich populations in massive GCs, rather than intrinsic properties of field stars in massive galactic spheroids. With this in mind, I predict that future studies will find that [N/Fe] decreases with increasing galactocentric radius in massive ETGs, and that such gradients have the largest amplitudes in ETGs with the strongest UV upturns.

Accepted by : Astrophysical Journal

http://adsabs.harvard.edu/abs/2018ApJ...857...16G

Connections between star cluster populations and their host galaxy nuclear rings

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Nuclear rings are excellent laboratories for probing diverse phenomena such as the formation and evolution of young massive star clusters (YMCs), nuclear starbursts, as well as the secular evolution and dynamics of their host galaxies. We have compiled a sample of 17 galaxies with nuclear rings, which are well resolved by high-resolution *Hubble* and *Spitzer Space Telescope* imaging. For each nuclear ring, we identified the ring star cluster population, along with their physical properties (ages, masses, extinction values). We also determined the integrated ring properties, including the average age, total stellar mass, and current star-formation rate (SFR). We find that Sb-type galaxies tend to have the highest ring stellar mass fraction with respect to the host galaxy, and this parameter is correlated with the ring's SFR surface density. The ring SFRs are correlated with their stellar masses, which is reminiscent of the main sequence of star-forming galaxies. There are striking correlations between star-forming properties (i.e., SFR and SFR surface density) and non-axisymmetric bar parameters, appearing to confirm previous inferences that strongly barred galaxies tend to have lower ring SFRs, although the ring star-formation histories turn out to be significantly more complicated. Nuclear rings with higher stellar masses tend to be associated with lower cluster mass fractions, but there is no such relation with the ages of the rings. The two youngest nuclear rings in our sample, NGC 1512 and NGC 4314, which have the most extreme physical properties, represent the young extremity of the nuclear ring age distribution.

Accepted by : Astrophysical Journal

http://adsabs.harvard.edu/abs/2018ApJ...857..116M

Dynamical evolution - Simulations

Concurrent formation of supermassive stars and globular clusters: implications for early self-enrichment

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We present a model for the concurrent formation of globular clusters (GCs) and supermassive stars (SMSs, $\gtrsim 10^3\,\mathrm{M}_\odot$) to address the origin of the HeCNONaMgAl abundance anomalies in GCs. GCs form in converging gas flows and accumulate low-angular momentum gas, which accretes onto protostars. This leads to an adiabatic contraction of the cluster and an increase of the stellar collision rate. A SMS can form via runaway collisions if the cluster reaches sufficiently high density before two-body relaxation halts the contraction. This condition is met if the number of stars $\gtrsim 10^6$ and the gas accretion rate $\gtrsim 10^5\,\mathrm{M}_\odot/\mathrm{Myr}$, reminiscent of GC formation in high gas-density environments, such as – but not restricted to – the early Universe. The strong SMS wind mixes with the inflowing pristine gas, such that the protostars accrete diluted hot-hydrogen burning yields of the SMS. Because of continuous rejuvenation, the amount of processed material liberated by the SMS can be an order of magnitude higher than its maximum mass. This 'conveyor-belt' production of hot-hydrogen burning products provides a solution to the mass budget problem that plagues other scenarios. Additionally, the liberated material is mildly enriched in helium and relatively rich in other hot-hydrogen burning products, in agreement with abundances of GCs today. Finally, we find a super-linear scaling between the amount of processed material and cluster mass, providing an explanation for the observed increase of the fraction of processed material with GC mass. We discuss open questions of this new GC enrichment scenario and propose observational tests.

Accepted by: Monthly Notices of the Royal Astronomical Society
http://adsabs.harvard.edu/abs/2018MNRAS.478.2461G

Ph.D. (dissertation) summaries

Clusters with K Supergiants

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The initial mass with which a star is born is the fundamental parameter that will determine the evolution and properties of the star. According to their mass, stars follow two different evolutionary branches: either the red giant or the red supergiant phase (RSG). In the first case, the red giant evolves into an AGB star and ends its life expelling its outer layers in the form of a planetary nebula, leaving as a remnant a white dwarf. In the second, the RSG suffers a core collapse which releases a large amount of energy, exploding as a supernova (SN). In this occasion, the residual object is a very compact (a neutron star or a black hole). The boundary between both scenarios would be approximately around 8–9 $M_{\odot}$, depending on models.

In recent years, several programmes for the search of SNe progenitors have been carried out. Their results are questioning the classical paradigm which explains the origin of these objects. The minimum mass to produce a SN explosion might be up to two solar masses below the limit traditionally accepted: stars of only 6–7 $M_{\odot}$ could become a SN in low-metallicity environments and binary systems.

The main goal of this thesis is to provide for the first time a series of observational evidences that may serve to constrain theoretical models. To do this, we have studied a sample of evolved stars contained in young clusters, ideal laboratories to study the stellar evolution of their members. We performed a literature search for young open clusters with ages between 30–100 Ma, which cover the mass transition for a SN explosion (6–9 $M_{\odot}$) according to recent works. We found that clusters in this age range have on average only two red (super)giants. Nevertheless, for our sample we selected the clusters statistically more significant, those containing at least five evolved stars, namely: NGC 2345, NGC 3105, NGC 6067, NGC 6649, NGC 6664 and Trumpler 35. In total, they host half a hundred of (super)giants, most of them red although we also found some blue and yellow ones.

On the one hand, we carried out a study of every cluster in a consistent way by combining photometry (our own or achival) and low- or moderate-resolution spectroscopy. In this manner, besides the characterisation of the cluster itself, we obtain the age and mass of its evolved stars. Most of these stars have spectral types K, hence the name of the thesis. On the other hand, from high-resolution spectroscopy (R = 48 000) we characterised these stars by calculating both their atmospheric stellar parameters and chemical abundances for some elements (Li, O, Na, Mg, Si, Ca, Ti, Ni, Rb, Y and Ba). The instrument used was FEROS, which is mounted on the 2.2-m telescope at the La Silla Observatory (Chile).

In this thesis we performed the most complete study to date of the clusters contained in our sample. For the first time, a detailed spectroscopic analysis was carried out on stars of NGC 3105, NGC 6649, NGC 6664 and Trumpler 35. For the other two clusters, NGC 2345 and NGC 6067, the number of objects studied here is higher than that reported in the only paper previously published in each case. In this age range, our sample represents half the clusters observed spectroscopically and 87% of evolved stars analysed.

For these clusters, using as a proxy the iron abundance, we obtained metallicities compatible with the Galactic gradient derived from Cepheids, although our values are systematically somewhat lower. Chemical abundances are also compatible with the Galactic trend observed in the thin disc as well as the theoretical scenario which describes the chemical evolution of the Milky Way. Particularly noteworthy is the overabundance of [Ba/Fe] found in our sample, which supports the enhanced *s*-process suggested to explain the enrichment of Ba in young open clusters.

Finally, we have covered a range of masses between 5.5–9.5 $M_\odot$. We have not found any significant trend in the chemical composition from red luminous giants to supergiants. We have not spotted any super-AGB star either. From an observational point of view, the transition of the spectral types observed in our sample, from medium- or late-K II/Ib to early-M Ib, might be related to the AGB/RSG mass boundary at solar metallicity.

PhD thesis completed at the University of Alicante under the supervision of Ignacio Negueruela and Amparo Marco.

`The thesis is available at:` http://hdl.handle.net/10045/74527

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Formation of stars and stellar clusters in galactic environment

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Star and stellar cluster formation in spiral galaxies is one of the biggest questions of astrophysics. In this thesis, I study how star formation, and the formation of stellar clusters, proceeds using SPH simulations. These simulations model a region of 400 pc and 10^7 solar masses. Star formation is modelled through the use of sink particles which represent small groups of stars. Star formation occurs in high density regions, created by galactic spiral arm passage. The spiral shock compresses the gas and generates high density regions. Once these regions attain sufficiently high density, self-gravity becomes dominant and drives collapse and star formation. The regions fragment hierarchically, forming local small groups of stars. These fall together to form clusters, which grow through subsequent mergers and large scale gas infall. As the individual star formation occurs over large distances before forming a stellar cluster, this process can result in significant age spreads of 1–2 Myrs. One protocluster is found to fail to merge due to the large scale tidal forces from the nearby regions, and instead expands forming a dispersed population of young stars such as an OB association.

PhD thesis completed at the University of St. Andrews under the supervision of Ian A. Bonnell.

`The thesis is available at:`

https://research-repository.st-andrews.ac.uk/handle/10023/13229

Conferences

Survival of Dense Star Clusters in the Milky Way System

19–23 November, 2018
Heidelberg, Germany
http://www.mpia.de/~mwstreams/

Registration not yet open