The Star Clusters Young & Old Newsletter

edited by Giovanni Carraro, Martin Netopil, and Ernst Paunzen

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Dear colleagues,

With this issue we would like to draw your attention on the recent contribution of the old Commission 37 to the special issue of the IAU Transaction A, called Legacy volume, announced by Thierry Montmerle, IAU secretary for the term 2012–15. The motivation for this was to provide the astronomical community with a special volume that reflects the significant changes the IAU underwent very recently.

This contribution has been edited by the organising committee of Commission 37, and prepared by leading scientists members of the star cluster commission (now called H4). It summarises the main results of research in our field in the last decade. Ignacio Negueruela presented highlights on massive star clusters and star forming regions in the Milky Way, while Elena Glushkova summarised results obtained for Galactic open clusters. Eugenio Carretta and Angela Bragaglia write on globular clusters and photometric and spectroscopic signatures of multiple populations. Finally, Tom Richtler reports about extra-galactic star clusters. We recently posted it at <http://arxiv.org/abs/1511.00835>. We expect this contribution to be an inspiring reference for the star cluster community. Please help us to disseminate it!

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About the Newsletter

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

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

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Star Forming Regions

The grey extinction of the ionizing cluster in NGC 3603 from ultraviolet to optical wavelengths

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We use photometry in the F220W, F250W, F330W, F435W filters from the High Resolution Channel of the Advanced Camera for Surveys and photometry in the F555W, F675W, and F814W filters from the Wide Field and Planetary Camera 2 aboard the Hubble Space Telescope to derive individual stellar reddenings and extinctions for stars in the HD 97950 cluster in the giant HII region NGC 3603. The mean line-of-sight reddening for about a hundred main-sequence member stars inside the cluster is $E(F435W - F555W) = 1.33 \pm 0.12$ mag. After correcting for foreground reddening, the total to selective extinction ratio is $R_{F555W} = 3.75 \pm 0.87$ in the cluster. Within the standard deviation associated with $E(\lambda - \mathrm{F555W})/\mathrm{E(F435W - F555W)}$ in each filter, the cluster extinction curve at ultraviolet wavelengths tends to be greyer than the average Galactic extinction laws from Cardelli et al. (1989) and Fitzpatrick et al. (1999). It is closer to the extinction law derived by Calzetti et al. (2000) for starburst galaxies, where the 0.2175 μm bump is absent. This indicates an anomalous extinction in the HD 97950 cluster, which may due to the clumpy dust distribution within the cluster, and the size of dust grains being larger than the average Galactic ISM.

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Sejong open cluster survey (SOS) - V. The active star forming region SH 2-255 – 257

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There is much observational evidence that active star formation is taking place in the HII regions Sh 2-255 – 257. We present a photometric study of this star forming region (SFR) using imaging data obtained in passbands from the optical to the mid-infrared in order to study the star formation process. A total of 218 members were identified using various selection criteria based on their observational properties. The SFR is reddened by at least $E(B - V) = 0.8$ mag, and the reddening law toward the region is normal ($R_V = 3.1$). From the zero-age main sequence fitting method it is confirmed that the SFR is 2.1 $\pm$ 0.3 kpc from the Sun. The median age of the identified members is estimated to be about 1.3 Myr from comparison of the Hertzsprung-Russell diagram (HRD) with stellar evolutionary models. The initial mass function (IMF) is derived from the HRD and the near-infrared $(J, J - H)$ color-magnitude diagram. The slope of the IMF is about Gamma = -1.6 ± 0.1 which is slightly steeper than that of the Salpeter/Kroupa IMF. It implies that low-mass star formation is dominant in the SFR. The sum of the masses of all the identified members provides the lower limit of the cluster mass ($169 M_\odot$). We also analyzed the spectral energy distribution (SED) of pre-main sequence stars using the SED fitting tool of Robitaille et al. and confirmed that there is a significant discrepancy between stellar mass and age obtained from two different methods based on the SED fitting tool and the HRD.

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Galactic Open Clusters

Properties of the open cluster Tombaugh 1 from high resolution spectroscopy and uvbyCaHβ photometry

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Open clusters can be the key to deepen our knowledge on various issues involving the structure and evolution of the Galactic disk and details of stellar evolution because a cluster's properties are applicable to all its members. However the number of open clusters with detailed analysis from high resolution spectroscopy and/or precision photometry imposes severe limitation on studies of these objects. To expand the number of open clusters with well-defined chemical abundances and fundamental parameters, we investigate the poorly studied, anticenter open cluster Tombaugh 1. Using precision uvbyCaHβ photometry and high resolution spectroscopy, we derive the cluster's properties and, for the first time, present detailed abundance analysis of 10 potential cluster stars. Using radial position from the cluster center and multiple color indices, we have isolated a sample of unevolved probable, single-star members of Tombaugh 1. The weighted photometric metallicity from m1 and hk is [Fe/H] = -0.10 ± 0.02, while a match to the Victoria-Regina Strömgren isochrones leads to an age of 0.95 ± 0.10 Gyr and an apparent modulus of (m$-$M) = 13.10 ± 0.10. Radial velocities identify 6 giants as probable cluster members and the elemental abundances of Fe, Na, Mg, Al, Si, Ca, Ti, Cr, Ni, Y,Ba, Ce, and Nd have been derived for both the cluster and the field stars. Tombaugh 1 appears to be a typical inner thin disk, intermediate-age open cluster of slightly subsolar metallicity, located just beyond the solar circle, with solar elemental abundance ratios except for the heavy s-process elements, which are a factor of two above solar. Its metallicity is consistent with a steep metallicity gradient in the galactocentric region between 9.5 and 12 kpc. Our study also shows that Cepheid XZ CMa is not a member of Tombaugh 1, and reveals that this Cepheid presents signs of barium enrichment.

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Open cluster Dolidze 25: Stellar parameters and the metallicity in the Galactic Anticentre

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The young open cluster Dolidze 25, in the direction of the Galactic Anticentre, has been attributed a very low metallicity, with typical abundances between -0.5 and -0.7 dex below solar. We intend to derive accurate cluster parameters and accurate stellar abundances for some of its members. We have obtained a large sample of intermediate- and high-resolution spectra for stars in and around Dolidze 25. We used the FASTWIND code to generate stellar atmosphere models to fit the observed spectra. We derive stellar parameters for a large number of OB stars in the area, and abundances of oxygen and silicon for a number of stars with spectral types around B0. We measure low abundances in stars of Dolidze 25. For the three stars with spectral types around B0, we find 0.3 dex (Si) and 0.5 dex (O) below the values typical in the solar neighbourhood. These values, even though not as low as those given previously, confirm Dolidze 25 and the surrounding H II region Sh2-284 as the most metal-poor star-forming environment known in the Milky Way. We derive a distance 4.5 ± 0.3 kpc to the cluster

($r_G \sim 12.3$ kpc). The cluster cannot be older than $\sim$ 3 Myr, and likely is not much younger. One star in its immediate vicinity, sharing the same distance, has Si and O abundances at most 0.15 dex below solar. The low abundances measured in Dolidze 25 are compatible with currently accepted values for the slope of the Galactic metallicity gradient, if we take into account that variations of at least ±0.15 dex are observed at a given radius. The area traditionally identified as Dolidze 25 is only a small part of a much larger star-forming region that comprises the whole dust shell associated with Sh2-284 and very likely several other smaller H ii regions in its vicinity.

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Chemical composition of intermediate mass stars members of the M6 (NGC 6405) open cluster

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We present here the first abundance analysis of 44 late B, A and F-type members of the young open cluster M6 (NGC 6405, age about 75 Myrs). Low and medium resolution spectra, covering the 4500 to 5800 Angs. wavelength range, were obtained using the FLAMES/GIRAFFE spectrograph attached to the ESO Very Large Telescopes (VLT). We determined the atmospheric parameters using calibrations of the Geneva photometry and by adjusting the H-beta profiles to synthetic ones. The abundances of up to 20 chemical elements, from helium to mercury, were derived for 19 late B, 16 A and 9 F stars by iteratively adjusting synthetic spectra to the observations. We also derived a mean cluster metallicity of [Fe/H]=0.07 ± 0.03 dex from the iron abundances of the F-type stars. We find that, for most chemical elements, the normal late B and A-type stars exhibit larger star-to-star abundance variations than the F-type stars do probably because of the faster rotation of the B and A stars. The abundances of C, O, Mg, Si and Sc appear to be anticorrelated to that of Fe, while the opposite holds for the abundances of Ca, Ti, Cr, Mn, Ni, Y, and Ba about as expected if radiative diffusion is efficient in the envelopes of these stars. In the course of this analysis, we discovered five new peculiar stars: one mild-Am, one Am, and one Fm star (HD 318091, CD-32 13109, GSC 07380-01211), one HgMn star (HD 318126), and one He-weak P-rich (HD 318101) star. We also discovered a new spectroscopic binary, most likely a SB2. We performed a detailed modelling of HD 318101,the new He-weak P-rich CP star, using the Montreal stellar evolution code XEVOL which treats self-consistently all particle transport processes. Although the overall abundance pattern of this star is properly reproduced, we find that detailed abundances (in particular the high P excess) resisted modelling attempts even when a range of turbulence profiles and mass loss rates were considered. Solutions are proposed, which are still under investigation.

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The little-studied cluster Berkeley 90. II. The foreground ISM

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Nearly one century after their discovery, the carrier(s) of Diffuse Interstellar Bands is/are still unknown and there are few sightlines studied in detail for a large number of DIBs. We want to study the ISM sightlines towards LS III +46 11 and LS III +46 12, two early-O-type stellar systems, and LS III +46 11 B, a mid-B-type star. The three targets are located in the stellar cluster Berkeley 90 and have a high extinction. We use the multi-epoch high-S/N optical spectra presented in paper I (Maíz Apellániz et al. 2015), the extinction results derived there, and additional spectra. We have measured equivalent widths, velocities, and FWHMs for a large number of absorption lines in the rich ISM spectrum in front of Berkeley 90. The absorbing ISM has at least two clouds at different velocities, one with a lower column density (thinner) in the K I lines located away from Berkeley 90 and another one with a higher column density (thicker) associated with the cluster. The first cloud has similar properties for both O-star sightlines but the second one is thicker for LS III +46 11. The comparison between species indicate that the cloud with a higher column density has a denser core, allowing us to classify the DIBs in a sigma-zeta scale, some of them for the first time. The LS III +46 12 sightline also has a high-velocity redshifted component.

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A color-period diagram for the open cluster M 48 (NGC 2548), and its rotational age

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Rotation periods are increasingly being used to derive ages for cool single field stars. Such ages are based on an empirical understanding of how cool stars spin down, acquired by constructing color-period diagrams (CPDs) for a series of open clusters. Our main aims here are to construct a CPD for M 48, to compare this with other clusters of similar age to check for consistency, and to derive a rotational age for M 48 using gyrochronology. We monitored M 48 photometrically for over 2 months with AIP's STELLA I 1.2 m telescope and the WiFSIP 4K imager in Tenerife. Light curves with 3 mmag precision for bright (V $\sim$ 14 mag) stars were produced and then analysed to provide rotation periods. A cluster CPD has then been constructed. We report 62 rotation periods for cool stars in M 48. The CPD displays a clear slow/I-sequence of rotating stars, similar to those seen in the 625 Myr-old Hyades and 590 Myr-old Praesepe clusters, and below both, confirming that M 48 is younger. A similar comparison with the 250 Myr-old M 34 cluster shows that M 48 is older and does not possess any fast/C-sequence G or early K stars like those in M 34, although relatively fast rotators do seem to be present among the late-K and M stars. A more detailed comparison of the CPD with rotational evolution models shows that the cluster stars have a mean age of 450 Myr, and its (rotating) stars can be individually dated to $\pm$ 117 Myr (26%). Much of this uncertainty stems from intrinsic astrophysical spread in initial periods, and almost all stars are consistent with a single age of 450 Myr. The gyro-age of M 48 as a whole is 450 $\pm$ 50 Myr, in agreement with the previously determined isochrone age of 400 $\pm$ 100 Myr.

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Photometric and spectroscopic study of the intermediate-age open cluster NGC 2355

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In this paper we analyse the evolutionary status and properties of the old open cluster NGC 2355, located in the Galactic anticentre direction, as a part of the long term programme BOCCE. NGC 2355 was observed with LBC@LBT using the Bessel B, V, and Ic filters. The cluster parameters have been obtained using the synthetic colour-magnitude diagram (CMD) method, as done in other papers of this series. Additional spectroscopic observations with FIES@NOT of three giant stars were used to determine the chemical properties of the cluster. Our analysis shows that NGC 2355 has metallicity slightly less than solar, with [Fe/H]=−0.06 dex, age between 0.8 and 1 Gyr, reddening $E(B-V)$ in the range 0.14 and 0.19 mag, and distance modulus $(\mathrm{m{-}M})_0$ of about 11 mag. We also investigated the abundances of O, Na, Al, alpha, iron-peak, and neutron capture elements, showing that NGC 2355 falls within the abundance distribution of similar clusters (same age and metallicity). The Galactocentric distance of NGC 2355 places it at the border between two regimes of metallicity distribution; this makes it an important cluster for the study of the chemical properties and evolution of the disc.

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`http://adsabs.harvard.edu/abs/2015MNRAS.453.4185D`

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The complex stellar populations in the lines of sight to open clusters in the third Galactic quadrant

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Multi-color photometry of the stellar populations in five fields in the third Galactic quadrant centred on the clusters NGC 2215, NGC 2354, Haffner 22, Ruprecht 11, and ESO489SC01 is interpreted in terms of a warped and flared Galactic disk, without resort to an external entity such as the popular Monoceros or Canis Major overdensities. Except for NGC 2215, the clusters are poorly or unstudied previously. The data generate basic parameters for each cluster, including the distribution of stars along the line of sight. We use star counts and photometric analysis, without recourse to Galactic-model-based predictions or interpretations, and confirms earlier results for NGC 2215 and NGC 2354. ESO489SC01 is not a real cluster, while Haffner 22 is an overlooked cluster aged about 2.5 Gyr. Conclusions for Ruprecht 11 are preliminary, evidence for a cluster being marginal. Fields surrounding the clusters show signatures of young and intermediate-age stellar populations. The young population background to NGC 2354 and Ruprecht 11 lies 8–9 kpc from the Sun and ∼1 kpc below the formal Galactic plane, tracing a portion of the Norma-Cygnus arm, challenging Galactic models that adopt a sharp cut-off of the disk 12–14 kpc from the Galactic center. The old population is metal poor with an age of 2–3 Gyr, resembling star clusters like Tombaugh 2 or NGC 2158. It has a large color spread and is difficult to locate precisely. Young and old populations follow a pattern that depends critically on the vertical location of the thin and/or thick disk, and whether or not a particular line of sight intersects one, both, or none.

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Galactic Globular Clusters

ALMA reveals sunburn: CO dissociation around AGB stars in the globular cluster 47 Tucanae

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ALMA observations show a non-detection of carbon monoxide around the four most luminous asymptotic giant branch (AGB) stars in the globular cluster 47 Tucanae. Stellar evolution models and star counts show that the mass-loss rates from these stars should be $\sim$1.2-3.5 $\times$ 10^{-7} solar masses per year. We would naively expect such stars to be detectable at this distance (4.5 kpc). By modelling the ultraviolet radiation field from post-AGB stars and white dwarfs in 47 Tuc, we conclude CO should be dissociated abnormally close to the stars. We estimate that the CO envelopes will be truncated at a few hundred stellar radii from their host stars and that the line intensities are about two orders of magnitude below our current detection limits. The truncation of CO envelopes should be important for AGB stars in dense clusters. Observing the CO (3-2) and higher transitions and targeting stars far from the centres of clusters should result in the detections needed to measure the outflow velocities from these stars.

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Strömgren uvby photometry of the peculiar globular cluster NGC 2419

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NGC 2419 is a peculiar Galactic globular cluster offset from the others in the size-luminosity diagram, and showing several chemical abundance anomalies. Here, we present Strömgren uvby photometry of the cluster. Using the gravity- and metallicity-sensitive c1 and m1 indices, we identify a sample of likely cluster members extending well beyond the formal tidal radius. The estimated contamination by cluster non-members is only one per cent, making our catalogue ideally suited for spectroscopic follow-up. We derive photometric [Fe/H] of red giants, and depending on which metallicity calibration from the literature we use, we find reasonable to excellent agreement with spectroscopic [Fe/H], both for the cluster mean metallicity and for individual stars. We demonstrate explicitly that the photometric uncertainties are not Gaussian and this must be accounted for in any analysis of the metallicity distribution function. Using a realistic, non-Gaussian model for the photometric uncertainties, we find a formal internal [Fe/H] spread of sigma=0.11+0.02/$-$0.01 dex. This is an upper limit to the clusters true [Fe/H] spread and may partially, and possibly entirely, reflect the limited precision of the photometric metallicity estimation and systematic effects. The lack of correlation between spectroscopic and photometric [Fe/H] of individual stars is further evidence against a [Fe/H] spread on the 0.1 dex level. Finally, the CN-sensitive delta4, among other colour indices, anti-correlates strongly with magnesium abundance, indicating that the second-generation stars are nitrogen enriched. The absence of similar correlations in some other CN-sensitive indices supports the second generation being enriched in He, which in these indices approximately compensates the shift due to CN. Compared to a single continuous distribution with finite dispersion, the observed delta4 distribution of red giants is slightly better fit by two distinct populations with no internal spread, with the nitrogen-enhanced second generation accounting for 53±5 per cent of stars. Despite its known peculiarities, NGC 2419 appears to be very similar to other metal-poor Galactic globular clusters with a similarly nitrogen-enhanced second generation and little or no variation in [Fe/H], which sets it apart from other suspected accreted nuclei such as omegaCen.

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Deep near-IR observations of the Globular Cluster M4: Hunting for Brown Dwarfs

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We present an analysis of deep HST/WFC3 near-IR (NIR) imaging data of the globular cluster M4. The best-photometry NIR colour-magnitude diagram (CMD) clearly shows the main sequence extending towards the expected end of the Hydrogen-burning limit and going beyond this point towards fainter sources. The white dwarf sequence can be identified. As such, this is the deepest NIR CMD of a globular cluster to date. Archival HST optical data were used for proper-motion cleaning of the CMD and for distinguishing the white dwarfs (WDs) from brown dwarf (BD) candidates. Detection limits in the NIR are around F110W approx 26.5 mag and F160W approx 27 mag, and in the optical around F775W approx 28 mag. Comparing our observed CMDs with theoretical models, we conclude that we have reached beyond the H-burning limit in our NIR CMD and are probably just above or around this limit in our optical-NIR CMDs. Thus, any faint NIR sources that have no optical counterpart are potential BD candidates, since the optical data are not deep enough to detect them. We visually inspected the positions of NIR sources which are fainter than the H-burning limit in F110W and for which the optical photometry did not return a counterpart. We found in total five sources for which we did not get an optical measurement. For four of these five sources, a faint optical counterpart could be visually identified, and an upper optical magnitude was estimated. Based on these upper optical magnitude limits, we conclude that one source is likely a WD, one source could either be a WD or BD candidate, and the remaining two sources agree with being BD candidates. For only one source no optical counterpart could be detected, which makes this source a good BD candidate. We conclude that we found in total four good BD candidates.

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The most distant clusters

The star cluster mass–galactocentric radius relation: Implications for cluster formation

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Whether or not the initial star cluster mass function is established through a universal, galactocentric-distance-independent stochastic process, on the scales of individual galaxies, remains an unsolved problem. This debate has recently gained new impetus through the publication of a study that concluded that the maximum cluster mass in a given population is not solely determined by size-of-sample effects. Here, we revisit the evidence in favor and against stochastic cluster formation by examining the young ($\lesssim$ a few $\times 10^8$ yr-old) star cluster mass–galactocentric radius relation in M33, M51, M83, and the Large Magellanic Cloud. To eliminate size-of-sample effects, we first adopt radial bin sizes containing constant numbers of clusters, which we use to quantify the radial distribution of the first- to fifth-ranked most massive clusters using ordinary least-squares fitting. We supplement this analysis with an application of quantile regression, a binless approach to rank-based regression taking an absolute-value-distance penalty. Both methods yield, within the 1σ to 3σ uncertainties, near-zero slopes in the diagnostic plane, largely irrespective of the maximum age or minimum mass imposed on our sample selection, or of the radial bin size adopted. We conclude that, at least in our four well-studied sample galaxies, star cluster formation does not necessarily require an environment-dependent cluster formation scenario, which thus supports the notion of stochastic star cluster formation as the dominant star cluster-formation process within a given galaxy.

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Dynamical evolution - Simulations

The DRAGON simulations: globular cluster evolution with a million stars

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Introducing the DRAGON simulation project, we present direct N-body simulations of four massive globular clusters (GCs) with 10^6 stars and 5% primordial binaries at a high level of accuracy and realism. The GC evolution is computed with NBODY6++GPU and follows the dynamical and stellar evolution of individual stars and binaries, kicks of neutron stars and black holes, and the effect of a tidal field. We investigate the evolution of the luminous (stellar) and dark (faint stars and stellar remnants) GC components and create mock observations of the simulations (i.e. photometry, color-magnitude diagrams, surface brightness and velocity dispersion profiles). Connecting internal processes to observable features we highlight the formation of a long-lived 'dark' nuclear sub-system made of black holes (BHs), which results in a two-component structure. The inner core is dominated by the BH subsystem and experiences a core collapse phase within the first Gyr. It can be detected in the stellar (luminous) line-of-sight velocity dispersion profiles. The outer extended core – commonly observed in the (luminous) surface brightness profiles – shows no collapse features and is continuously expanding. We demonstrate how a King (1966) model to observed clusters might help identifying the presence of post core-collapse BH subsystems. For global observable like core and half-mass radii the direct simulations agree well with Monte-Carlo models (MOCCA-code). Variations in the initial mass function can result in significantly different GC properties (e.g. density distributions) driven by varying amounts of early mass loss and the number of forming BHs.

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Velocity anisotropy in tidally limited star clusters

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We explore the long-term evolution of the anisotropy in the velocity space of star clusters starting with different structural and kinematical properties. We show that the evolution of the radial anisotropy strength and its radial variation within a cluster contain distinct imprints of the cluster initial structural properties, dynamical history, and of the external tidal field of its host galaxy. Initially isotropic and compact clusters with small initial values of the ratio of the half-mass to Jacobi radius, r_h/r_J, develop a strong radial anisotropy during their long-term dynamical evolution. Many clusters, if formed with small values of r_h/r_J, should now be characterized by a significant radial anisotropy increasing with the distance from the cluster centre, reaching its maximum at a distance between 0.2 r_J and 0.4 r_J, and then becoming more isotropic or mildly tangentially anisotropic in the outermost regions. A similar radial variation of the anisotropy can also result from an early violent

relaxation phase. In both cases, as a cluster continues its evolution and loses mass, the anisotropy eventually starts to decrease and the system evolves toward an isotropic velocity distribution. However, in order to completely erase the strong anisotropy developed by these compact systems during their evolution, they must be in the advanced stages of their evolution and lose a large fraction of their initial mass. Clusters that are initially isotropic and characterized by larger initial values of r_h/r_J, on the other hand, never develop a significant radial anisotropy.

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The initial conditions of observed star clusters - I. Method description and validation

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We have coupled a fast, parametrized star cluster evolution code to a Markov Chain Monte Carlo code to determine the distribution of probable initial conditions of observed star clusters, that may serve as a starting point for future N-body calculations. In this paper, we validate our method by applying it to a set of star clusters which have been studied in detail numerically with N-body simulations and Monte Carlo methods: the Galactic globular clusters M4, 47 Tucanae, NGC 6397, M22, ω Centauri, Palomar 14 and Palomar 4, the Galactic open cluster M67, and the M31 globular cluster G1. For each cluster, we derive a distribution of initial conditions that, after evolution up to the cluster's current age, evolves to the currently observed conditions. We find that there is a connection between the morphology of the distribution of initial conditions and the dynamical age of a cluster and that a degeneracy in the initial half-mass radius towards small radii is present for clusters that have undergone a core collapse during their evolution. We find that the results of our method are in agreement with N-body and Monte Carlo studies for the majority of clusters. We conclude that our method is able to find reliable posteriors for the determined initial mass and half-mass radius for observed star clusters, and thus forms an suitable starting point for modelling an observed cluster's evolution.

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http://adsabs.harvard.edu/abs/2015MNRAS.453..605P

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GalevNB: a conversion from N-BODY simulations to observations

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We present GalevNB (Galev for N-body simulations), an utility that converts fundamental stellar properties of N-body simulations into observational properties using the GALEV (GAlaxy EVolutionary synthesis models) package, and thus allowing direct comparisons between observations and N-body simulations. It works by converting fundamental stellar properties, such as stellar mass, temperature, luminosity and metallicity into observational magnitudes for a variety of filters of mainstream instruments/telescopes, such as HST, ESO, SDSS, 2MASS, etc.), and into spectra that spans from far-UV (90 Å) to near-IR (160 μm). As an application, we use GalevNB to investigate the secular evolution of spectral energy distribution (SED) and color-magnitude diagram (CMD) of a simulated star cluster

over a few hundred million years. With the results given by GalevNB we discover an UV-excess in the SED of the cluster over the whole simulation time. We also identify four candidates that contribute to the FUV peak, core helium burning stars, thermal pulsing asymptotic giant branch (TPAGB) stars, white dwarfs and naked helium stars.

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http://arxiv.org/abs/1509.05864

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The Dynamics of Multiple Populations in NGC 6362

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We investigate how the Milky Way tidal field can affect the spatial mixing of multiple stellar populations in the globular cluster NGC 6362. We use N-body simulations of multiple-population clusters on the orbit of this cluster around the Milky Way. Models of the formation of multiple populations in globular clusters predict that the second population should initially be more centrally concentrated than the first. However, NGC 6362 is comprised of two chemically distinct stellar populations having the same radial distribution. We show that the high mass-loss rate experienced on this cluster's orbit significantly accelerates the spatial mixing of the two populations expected from two-body relaxation. We also find that for a range of initial second-population concentrations, cluster masses, tidal filling factors and fraction of first-population stars, a cluster with two populations should be mixed when it has lost 70–80 per cent of its initial mass. These results fully account for the complete spatial mixing of NGC 6362, since, based on its shallow present-day mass function, independent studies estimate that the cluster has lost 85 per cent of its initial mass.

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The Dynamical Evolution of Accreted Star Clusters in the Milky Way

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We perform N-body simulations of star clusters in time-dependant galactic potentials. Since the Milky Way was built-up through mergers with dwarf galaxies, its globular cluster population is made up of clusters formed both during the initial collapse of the Galaxy and in dwarf galaxies that were later accreted. Throughout a dwarf-Milky Way merger, dwarf galaxy clusters are subject to a changing galactic potential. Building on our previous work, we investigate how this changing galactic potential affects the evolution of a cluster's half mass radius. In particular, we simulate clusters on circular orbits around a dwarf galaxy that either falls into the Milky Way or evaporates as it orbits the Milky Way. We find that the dynamical evolution of a star cluster is determined by whichever galaxy has the strongest tidal field at the position of the cluster. Thus, clusters entering the Milky Way undergo changes in size as the Milky Way tidal field becomes stronger and that of the dwarf diminishes. We find that ultimately accreted clusters quickly become the same size as a cluster born in the Milky Way on the same orbit. Assuming their initial sizes are similar, clusters born in the Galaxy and those that are accreted cannot be separated based on their current size alone.

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Possible smoking-gun evidence for initial mass segregation in re-virialized post-gas expulsion globular clusters

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We perform a series of direct N-body calculations to investigate the effect of residual gas expulsion from the gas-embedded progenitors of present-day globular clusters (GCs) on the stellar mass function (MF). Our models start either tidally filling or underfilling, and either with or without primordial mass segregation. We cover 100 Myr of the evolution of modelled clusters and show that the expulsion of residual gas from initially mass-segregated clusters leads to a significantly shallower slope of the stellar MF in the low- ($m \leq 0.50$ M$_\odot$) and intermediate-mass ($\simeq 0.50$–0.85 M$_\odot$) regime. Therefore, the imprint of residual gas expulsion and primordial mass segregation might be visible in the present-day MF. We find that the strength of the external tidal field, as an essential parameter, influences the degree of flattening, such that a primordially mass-segregated tidally filling cluster with $r_h/r_t \geq 0.1$ shows a strongly depleted MF in the intermediate stellar mass range. Therefore, the shape of the present-day stellar MF in this mass range probes the birth place of clusters in the Galactic environment. We furthermore find that this flattening agrees with the observed correlation between the concentration of a cluster and its MF slope, as found by de Marchi et al.. We show that if the expansion through the residual gas expulsion in primordial mass segregated clusters is the reason for this correlation then GCs most probably formed in strongly fluctuating local tidal fields in the early proto-Milky Way potential, supporting the recent conclusion by Marks & Kroupa.

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Evolution of star clusters on eccentric orbits

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We study the evolution of star clusters on circular and eccentric orbits using direct N-body simulations. We model clusters with initially N = 8k and N = 16k single stars of the same mass, orbiting around a point-mass galaxy. For each orbital eccentricity that we consider, we find the apogalactic radius at which the cluster has the same lifetime as the cluster with the same N on a circular orbit. We show that then, the evolution of bound particle number and half-mass radius is approximately independent of eccentricity. Secondly, when we scale our results to orbits with the same semi-major axis, we find that the lifetimes are, to first order, independent of eccentricity. When the results of Baumgardt and Makino for a singular isothermal halo are scaled in the same way, the lifetime is again independent of eccentricity to first order, suggesting that this result is independent of the Galactic mass profile. From both sets of simulations we empirically derive the higher order dependence of the lifetime on eccentricity. Our results serve as benchmark for theoretical studies of the escape rate from clusters on eccentric orbits. Finally, our results can be useful for generative models for cold streams and cluster evolution models that are confined to spherical symmetry and/or time-independent tides, such as Fokker-Planck models, Monte Carlo models, and (fast) semi-analytic models.

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Miscellaneous

Characterizing star cluster formation with WISE: 652 newly found star clusters and candidates

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We report the discovery of 652 star clusters, stellar groups and candidates in the Milky Way with WISE. Most of the objects are projected close to Galactic Plane and are embedded clusters. The present sample complements a similar study (Paper I) which provided 437 star clusters and alike. We find evidence that star formation processes span a wide range of sizes, from populous dense clusters to small compact embedded ones, sparse stellar groups or in relative isolation. The present list indicates multiple stellar generations during the embedded phase, with giant molecular clouds collapsing into several clumps composing an embedded cluster aggregate. We investigate the field star decontaminated Colour Magnitude Diagrams and Radial Density Profiles of 9 cluster candidates in the list, and derive their parameters, confirming them as embedded clusters.

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Proceedings abstracts

The Initial Mass Function of Young Open Clusters in the Galaxy: A Preliminary Result

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The initial mass function (IMF) is an essential tool with which to study star formation processes. We have initiated the photometric survey of young open clusters in the Galaxy, from which the stellar IMFs are obtained in a homogeneous way. A total of 16 famous young open clusters have preferentially been studied up to now. These clusters have a wide range of surface densities (log $\sigma = -1$ to 3 [stars pc^{-2}] for stars with mass larger than 5M$_\odot$) and cluster masses (M$_{cl}$ = 165 to 50,000M$_\odot$), and also are distributed in five different spiral arms in the Galaxy. It is possible to test the dependence of star formation processes on the global properties of individual clusters or environmental conditions. We present a preliminary result on the variation of the IMF in this paper.

To appear in : To appear in the proceedings of IAU Symposium 316, "Formation, evolution and survival of massive star clusters", 2015, C. Charbonnel and A. Nota eds

`http://arxiv.org/abs/1511.01118`

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The dynamical importance of binary systems in young massive star clusters

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Characterization of the binary fractions in star clusters is of fundamental importance for many fields in astrophysics. Observations indicate that the majority of stars are found in binary systems, while most stars with masses greater than $0.5 M_\odot$ are formed in star clusters. In addition, since binaries are on average more massive than single stars, in resolved star clusters these systems are thought to be good tracers of (dynamical) mass segregation. Over time, dynamical evolution through two-body relaxation will cause the most massive objects to migrate to the cluster center, while the relatively lower-mass objects remain in or migrate to orbits at greater radii. This process will globally dominate a cluster's stellar distribution. However, close encounters involving binary systems may disrupt 'soft' binaries. This process will occur more frequently in a cluster's central, dense region than in its periphery, which may mask the effects of mass segregation. Using high resolution *Hubble Space Telescope* observations, combined with sophisticated N-body simulations, we investigate the radial distributions of the main-sequence binary fractions in massive young Large Magellanic Cloud star clusters. We show that binary disruption may play an important role on very short timescales, depending on the environmental conditions in the cluster cores. This may lead to radial binary fractions that initially decline in the cluster centers, which is contrary to the effects expected from dynamical mass segregation.

To appear in : Proc. IAU Symp. 316 (invited review)

`http://arxiv.org/abs/1510.00099`

IAU commission 37 Legacy Report

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It is widely accepted that stars do not form in isolation but result from the fragmentation of molecular clouds, which in turn leads to star cluster formation. Over time, clusters dissolve or are destroyed by interactions with molecular clouds or tidal stripping, and their members become part of the general field population. Star clusters are thus among the basic building blocks of galaxies. In turn, star cluster populations, from young associations and open clusters to old globulars, are powerful tracers of the formation, assembly, and evolutionary history of their parent galaxies. Although their importance (e.g., in mapping out the Milky Way) had been recognised for decades, major progress in this area has only become possible in recent years, both for Galactic and extragalactic cluster populations. Star clusters are the observational foundation for stellar astrophysics and evolution, provide essential tracers of galactic structure, and are unique stellar dynamical environments. Star formation, stellar structure, stellar evolution, and stellar nucleosynthesis continue to benefit and improve tremendously from the study of these systems. Additionally, fundamental quantities such as the initial mass function can be successfully derived from modelling either the Hertzsprung−Russell diagrams or the integrated velocity structures of, respectively, resolved and unresolved clusters and cluster populations. Star cluster studies thus span the fields of Galactic and extragalactic astrophysics, while heavily affecting our detailed understanding of the process of star formation in dense environments. This report highlights science results of the last decade in the major fields covered by IAU Commission 37: Star clusters and associations. Instead of focusing on the business meeting - the out-going president presentation can be found here: `www.sc.eso.org/~gcarraro/splinter2015.pdf` - this legacy report contains highlights of the most important scientific achievements in the Commission science area, compiled by 5 well expert members.

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`http://arxiv.org/abs/1511.00835`

Conferences

Globular Clusters and Galaxy Halos

22–26 February, 2016
Leiden, NL
http://www.lorentzcenter.nl/lc/web/2016/756/info.php3?wsid=756&venue=Oort

registration procedure closed, contact the local workshop coordinator

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From Stars to Massive Stars - Connecting our understanding of massive star & star cluster formation through the universe

6–9 April, 2016
Gainesville, FL, USA
http://conference.astro.ufl.edu/STARSTOMASSIVE/STM/Home.html

abstract submission deadline: 1st December!

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COSMIC-LAB: Star Clusters as Cosmic Laboratories for Astrophysics, Dynamics and Fundamental Physics (MODEST 16)

18–22 April, 2016
Bologna, Italy
http://www.cosmic-lab.eu/Cosmic-Lab/The_Conference.html