SCYON

The Star Clusters Young & Old Newsletter

edited by Holger Baumgardt and Ernst Paunzen

SCYON can be found at URL:
`http://www.univie.ac.at/scyon/`

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EDITORIAL

Dear Subscribers,

This is the 52nd issue of the SCYON newsletter. Today we have again a large newsletter with 29 abstracts from refereed publications. We also have the first announcement for a summer workshop in Aspen on the formation of the Milky Way in May/June of 2012.

As usual, we would like to thank all who sent us their contributions.

Holger Baumgardt and Ernst Paunzen

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SCYON POLICY

The SCYON Newsletter publishes abstracts from any area in astronomy which are relevant to research on star clusters. We welcome all contributions. Topics to be covered include

1. Abstracts from refereed articles
2. Abstracts from conference proceedings
3. PhD summaries
4. General announcements : Conferences, new databases, and the likes.

Concerning possible infringements to copyright laws, we understand that the authors themselves are taking responsibility for the material they send us. We make no claim whatsoever to owning the material that is posted at our url or circulated by email. The newsletter SCYON is a free service. It does not substitute for our personal opinions, nor does it reflect in any way the views of our respective institutes of affiliations.

SCYON will be published initially once every two months. If the number of contributions justifies monthly installments, we will move toward more frequent issues in order to keep the newsletter relatively short, manageable for us, and up-to-date.

Conference and journal abstracts can be submitted at any time either by web download, or failing this, we also accept abstracts typeset using the latest latex abstract template (available from the SCYON webpage). We much prefer contributors to use the direct download form, since it is mostly automated. Abstracts will normally appear on the website as soon as they are submitted to us. Other contributions, such as PhD summaries, should be sent to us using the LaTeX template. *Please do not submit postscript files, nor encoded abstracts as e-mail attachments.*

All abstracts/contributions will be processed, but we reserve the right to not post abstracts submitted in the wrong format or which do not compile. If you experience any sort of problems accessing the web site, or with the LaTeX template, please write to us at scyon@univie.ac.at.

A "Call for abstracts" is sent out approximately one week before the next issue of the newsletter is finalised. This call contains the deadline for abstract submissions for that coming issue and the LaTeX abstract template.
Depending on circumstances, the editors might actively solicit contributions, usually those spotted on a preprint server, but they do not publish abstracts without the author's consent.

We implicitly encourage further dissemination of the letter to institutes and astronomers who may benefit from it.

The editors

SCYON Mirrors

The official Scyon mirror site in Australia is hosted at the Centre for Astrophysics & Supercomputing of the University of Swinburne by Duncan Forbes and his team :
HTTP://ASTRONOMY.SWIN.EDU.AU/SCYON/)

1. Star Forming Regions

FEEDBACK REGULATED STAR FORMATION: IMPLICATIONS FOR THE KENNICUTT-SCHMIDT LAW

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We derive a metallicity dependent relation between the surface density of the star formation rate (Σ_{SFR}) and the gas surface density (Σ_g) in a feedback regulated model of star formation in galactic disks. In this model, star formation occurs in gravitationally bound protocluster clumps embedded in larger giant molecular clouds with the protocluster clump mass function following a power law function with a slope of -2. Metallicity dependent feedback is generated by the winds of OB stars ($M > 5$ $M_{\odot}$) that form in the clumps. The quenching of star formation in clumps of decreasing metallicity occurs at later epochs due to weaker wind luminosities, thus resulting in higher final star formation efficiencies (SFE_{exp}). By combining SFE_{exp} with the timescales on which gas expulsion occurs, we derive the metallicity dependent star formation rate per unit time in this model as a function of Σ_g. This is combined with the molecular gas fraction in order to derive the global dependence of Σ_{SFR} on Σ_g. The model reproduces very well the observed star formation laws extending from low gas surface densities up to the starburst regime. Furthermore, our results show a dependence of Σ_{SFR} on metallicity over the entire range of gas surface densities in contrast to other models, and can also explain part of the scatter in the observations. We provide a tabulated form of the star formation laws that can be easily incorporated into numerical simulations or semi-analytical models of galaxy formation and evolution.

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Pre-Main-Sequence stellar populations across Shapley Constellation III. I. Photometric Analysis and Identification

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We present our investigation of pre–main-sequence (PMS) stellar populations in the Large Magellanic Cloud (LMC) from imaging with Hubble Space Telescope WFPC2 camera. Our targets of interest are four star-forming regions located at the periphery of the super-giant shell LMC 4 (Shapley Constellation III). The PMS stellar content of the regions is revealed through the differential Hess diagrams and the observed color-magnitude diagrams (CMDs). Further statistical analysis of stellar distributions along cross-sections of the faint part of the CMDs allowed the quantitative assessment of the PMS stars census, and the isolation of faint PMS stars as the true low-mass stellar members of the regions. These distributions are found to be well represented by a double Gaussian function, the first component of which represents the main-sequence field stars and the second the native PMS stars of each region. Based on this result, a cluster membership probability was assigned to each PMS star according to its CMD position. The higher extinction in the region LH 88 did not allow the unambiguous identification of its native stellar population. The CMD distributions of the PMS stars with the highest membership probability in the regions LH 60, LH 63 and LH 72 exhibit an extraordinary similarity among the regions, suggesting that these stars share common characteristics, as well as common recent star formation history. Considering that the regions are located at different areas of the edge of LMC 4, this finding suggests that star formation along the super-giant shell may have occurred almost simultaneously.

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An obscured cluster associated with the HII region RCW173

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Context. The discovery of several clusters of red supergiants towards l = 24 deg - 30 deg has triggered interest in this area of the Galactic plane, where lines of sight are very complex and previous explorations of the stellar content were very preliminary.

Aims. We attempt to characterise the stellar population associated with the HII region RCW 173 (=Sh2-60), located at l = 25.3 deg, as previous studies have suggested that this population could be beyond the Sagittarius arm.

Methods. We obtained UBV photometry of a stellar field to the south of the brightest part of RCW 173, as well as spectroscopy of about twenty stars in the area. We combined our new data with archival 2MASS near-infrared photometry and Spitzer/GLIMPSE imaging and photometry, to achieve more accurate characterisation of the stellar sources and the associated cloud.

Results. We find a significant population of early-type stars located at d = 3.0 kpc, in good agreement with the "near" dynamical distance to the HII region. This population should be located at the near intersection of the Scutum-Crux arm. A luminous O7 II star is likely to be the main source of ionisation. Many stars are concentrated around the bright nebulosity, where GLIMPSE images in the mid infrared show the presence of a bubble of excited material surrounding a cavity that coincides spatially with a number of B0-1V stars. We interpret this as an emerging cluster, perhaps triggered by the nearby O7 II star. We also find a number of B-type giants. Some of them are located at approximately the same distance, and may be part of an older population in the same area, characterised by much lower reddening. A few have shorter distance moduli and are likely to be located in the Sagittarius arm.

Conclusions. The line of sight in this direction is very complex. Optically visible tracers delineate two spiral arms, but seem to be absent beyond $d \approx 3$ kpc. Several HII regions in this area suggest that the Scutum-Crux arm contains thick clouds actively forming stars. All these populations are projected on top of the major stellar complex signposted by the clusters of red supergiants.

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Also available from the URL `http://astro.ua.es/download/rcw173.pdf`
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Volume Density Thresholds for Overall Star Formation imply Mass-Size Thresholds for Massive Star Formation

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We aim at understanding the massive star formation (MSF) limit $m(r) = 870M_{\odot}(r/pc)^{1.33}$ in the mass-size space of molecular structures recently proposed by Kauffmann & Pillai (2010). As a first step, we build on the hypothesis of a volume density threshold for overall star formation and the model of Parmentier (2011) to establish the mass-radius relations of molecular clumps containing given masses of star-forming gas. Specifically, we relate the mass m_{clump}, radius r_{clump} and density profile slope $-p$ of molecular clumps which contain a mass m_{th} of gas denser than a volume density threshold ρ_{th}. In a second step, we use the relation between the mass of embedded-clusters and the mass of their most-massive star to estimate the minimum mass of star-forming gas needed to form a $10\,M_{\odot}$ star. Assuming a star formation efficiency of $SFE \simeq 0.30$, this gives $m_{th,crit} \simeq 150M_{\odot}$. In a third step, we demonstrate that, for sensible choices of the clump density index ($p \simeq 1.7$) and of the cluster formation density threshold ($n_{th} \simeq 10^4\,cm^{-3}$), the line of constant $m_{th,crit} \simeq 150M_{\odot}$ in the mass-radius space of molecular structures equates with the MSF limit for spatial scales larger than 0.3 pc. Hence, the observationally inferred MSF limit of Kauffmann & Pillai is consistent with a threshold in star-forming gas mass beyond which the star-forming gas reservoir is large enough to allow the formation of massive stars. For radii smaller than 0.3 pc, the MSF limit is shown to be consistent with the formation of a $10\,M_{\odot}$ star out of its individual pre-stellar core of density threshold $n_{th} \simeq 10^5\,cm^{-3}$. The inferred density thresholds for the formation of star clusters and individual stars within star clusters match those previously suggested in the literature.

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2. Galactic Open Clusters

A UBVI and uvbyCaHbeta Analysis of the Intermediate-Age Open Cluster, NGC 5822

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NGC 5822 is a richly populated, moderately nearby, intermediate-age open cluster covering an area larger than the full moon on the sky. A CCD survey of the cluster on the UBVI and uvbyCaHbeta systems shows that the cluster is superposed upon a heavily reddened field of background stars with E(B-V) $>$ 0.35 mag, while the cluster has small and uniform reddening at E(b-y) = 0.075 ± 0.008 mag or E(B-V) = 0.103 ± 0.011 mag, based upon 48 and 61 probable A and F dwarf single-star members, respectively. The errors quoted include both internal photometric precision and external photometric uncertainties. The metallicity derived from 61 probable single F-star members is [Fe/H] = -0.058 ± 0.027 (sem) from m_1 and 0.010 ± 0.020 (sem) from hk, for a weighted average of [Fe/H] = -0.019 ± 0.023, where the errors refer to the internal errors from the photometry alone. With reddening and metallicity fixed, the cluster age and apparent distance modulus are obtained through a comparison to appropriate isochrones in both VI and BV, producing 0.9 ± 0.1 Gyr and 9.85 ± 0.15, respectively. The giant branch remains dominated by two distinct clumps of stars, though the brighter clump seems a better match to the core-He-burning phase while the fainter clump straddles the first-ascent red giant branch. Four potential new clump members have been identified, equally split between the two groups. Reanalysis of the UBV two-color data extending well down the main sequence shows it to be optimally matched by reddening near E(B-V) = 0.10 rather than the older value of 0.15, leading to [Fe/H] between -0.16 and 0.00 from the ultraviolet excess of the unevolved dwarfs. The impact of the lower reddening and younger age of the cluster on previous analyses of the cluster is discussed.

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About the nature of Mercer 14

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University of Kent

We used UKIRT near infrared (NIR) broad band JHK photometry, narrow band imaging of the 1-0S(1) molecular hydrogen emission line and mid infrared Spitzer IRAC data to investigate the nature of the young cluster Mercer14. Foreground star counts in decontaminated NIR photometry and a comparison with the Besancon Galaxy Model are performed to estimate the cluster distance. This method yields a distance of 2.5kpc with an uncertainty of about 10% and can be applied to other young and embedded clusters. Mercer 14 shows clear signs of ongoing star formation with several detected molecular hydrogen outflows, a high fraction of infrared excess sources and an association to a small gas and dust cloud. Hence, the cluster is less than 4 Myrs old and has a line of sight extinction of A_K=0.8mag. Based on the most massive cluster members we find that Mercer 14 is an intermediate mass cluster with about 500 $M_{\odot}$.

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Deep Infrared ZAMS Fits to Benchmark Open Clusters Hosting delta Scuti Stars

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This research aims to secure precise distances for cluster delta Scutis in order to investigate their properties via a VI Wesenheit framework. Deep JHKs colour-colour and ZAMS relations derived from $\sim$ 700 unreddened stars featuring 2MASS photometry and precise HIP parallaxes ($d<25$ pc) are applied to establish distances to several benchmark open clusters that host delta Scutis: Hyades, Pleiades, Praesepe, alpha Per, and M67 ($d = 47\pm2,138\pm6,183\pm8,171\pm8,815\pm40$ pc). That analysis provided constraints on the delta Sct sample's absolute Wesenheit magnitudes (W_{VI},0), evolutionary status, and pulsation modes (order, n). The reliability of JHKs established cluster parameters is demonstrated via a comparison with van Leeuwen 2009 revised HIP results. Distances for 7 of 9 nearby ($d<250$ pc) clusters agree, and the discrepant cases (Pleiades & Blanco 1) are unrelated to (insignificant) Te/J-Ks variations with cluster age or [Fe/H]. JHKs photometry is tabulated for $\sim 3{\cdot}10^3$ probable cluster members on the basis of proper motions (NOMAD). The deep JHKs photometry extends into the low mass regime ($\sim$ 0.4 Msun) and ensures precise ($<$ 5%) ZAMS fits. Pulsation modes inferred for the cluster delta Scutis from VI Wesenheit and independent analyses are comparable ($\pm$n), and the methods are consistent in identifying higher order pulsators. Most small-amplitude cluster delta Scutis lie on VI Wesenheit loci characterizing $n \geq 1$ pulsators. A distance established to NGC 1817 from delta Scutis ($d\sim 1.7$ kpc) via a universal VI Wesenheit template agrees with estimates in the literature, assuming the variables delineate the n $\geq$ 1 boundary. Small statistics in tandem with other factors presently encumber the use of mmag delta Scutis as viable distance indicators to intermediate-age open clusters, yet a VI Wesenheit approach is a pertinent means for studying delta Scutis in harmony with other methods.

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A spectroscopic investigation of early-type stars in the young open cluster Westerlund 2

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The distance of the very young open cluster Westerlund 2, which contains the very massive binary system WR 20a and is likely associated with a TeV source, has been the subject of much debate. We attempt a joint analysis of spectroscopic and photometric data of eclipsing binaries in the cluster to constrain its distance. A sample of 15 stars, including three eclipsing binaries (MSP 44, MSP 96, and MSP 223) was monitored with the FLAMES multi-object spectrograph. The spectroscopic data are analysed together with existing B V photometry. The analysis of the three eclipsing binaries clearly supports the larger values of the distance, around 8 kpc, and rules out values of about 2.4 - 2.8 kpc that have been suggested in the literature. Furthermore, our spectroscopic monitoring reveals no clear signature of binarity with periods shorter than 50 days in either the WN6ha star WR 20b, the early O-type stars MSP 18, MSP 171, MSP 182, MSP 183, MSP 199, and MSP 203, or three previously unknown mid O-type stars. The only newly identified candidate binary system is MSP 167. The absence of a binary signature is especially surprising for WR 20b and MSP 18, which were previously found to be bright X-ray sources. The distance of Westerlund 2 is confirmed to be around 8 kpc as previously suggested based on the spectrophotometry of its population of O-type stars and the analysis of the light curve of WR 20a. Our results suggest that short-period binary systems are not likely to be common, at least not among the population of O-type stars in the cluster.

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WR 38/38a and the ratio of total-to-selective extinction in Carina

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A reanalysis of the (seemingly very distant) open cluster Shorlin 1, the group of stars associated with WR 38 and WR 38a, is made on the basis of existing UBV and JHKs observations for cluster members. The 2MASS observations, in particular, imply a mean cluster reddening of E(B-V)=1.45+-0.07 and a distance of 2.94+-0.12 kpc. The reddening agrees with the UBV results provided that the local reddening slope is described by E(U-B)/E(B-V)=0.64+-0.01, but the distance estimates in the 2MASS and UBV systems agree only if the ratio of total-to-selective extinction for the associated dust is R=Av/E(B-V)=4.0+-0.1. Both results are similar to what has been obtained for adjacent clusters in the Eta Carinae region by similar analyses, which suggests that 'anomalous' dust extinction is widespread through the region, particularly for groups reddened by relatively nearby dust. Dust associated with the Eta Carinae complex itself appears to exhibit more 'normal' qualities. The results have direct implications for the interpretation of distances to optical spiral arm indicators for the Galaxy at l=287-291 degrees, in particular the Carina arm here is probably little more than 2 kpc distant, rather than 2.5-3 kpc distant as implied in previous studies. Newly-derived intrinsic parameters for the two cluster Wolf-Rayet stars WR 38 (WC4) and WR 38a (WN5) are in good agreement with what is found for other WR stars in Galactic open clusters, which was not the case previously.

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3. Galactic Globular Clusters

Outer density profiles of Galactic globular clusters

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Using deep photometric data from WFC@INT and WFI@ESO2.2m we measure the outer number density profiles of 19 stellar clusters located in the inner region of the Milky Way halo (within a Galactocentric distance range of 10–30 kpc) in order to assess the impact of internal and external dynamical processes on the spatial distribution of stars. Adopting power-law fitting templates, with index $-\gamma$ in the outer region, we find that the clusters in our sample can be divided in two groups: a group of massive clusters ($\geq 10^5\,M_\odot$) that has relatively flat profiles with $2.5 < \gamma < 4$ and a group of low-mass clusters ($\leq 10^5\,M_\odot$), with steep profiles ($\gamma > 4$) and clear signatures of interaction with the Galactic tidal field. We refer to these two groups as 'tidally unaffected' and 'tidally affected', respectively. Our results also show a clear trend between the slope of the outer parts and the half-mass density of these systems, which suggests that the outer density profiles may retain key information on the dominant processes driving the dynamical evolution of Globular Clusters.

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Globular clusters in the outer Galactic halo: new HST/ACS imaging of 6 globular clusters and the Galactic globular cluster age-metallicity relation

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Color-magnitude diagrams (CMDs) derived from Hubble Space Telescope (HST) Advanced Camera for Surveys F606W,F814W photometry of 6 globular clusters (GCs) are presented. The six GCs form two loose groupings in Galactocentric distance (R_{gc}): IC 4499, NGC 6426, and Ruprecht 106 at $\sim 15-20$ kpc and NGC 7006, Palomar 15, and Pyxis at ~ 40 kpc. The CMDs allow the ages to be estimated from the main sequence turnoff in every case. In addition, the age of Palomar 5 ($R_{gc} \sim 18$ kpc) is estimated using archival HST Wide Field Planetary Camera 2 V,I photometry. The age analysis reveals the following: IC 4499, Ruprecht 106, and Pyxis are 1-2 Gyr younger than inner halo GCs with similar metallicities; NGC 7006 and Palomar 5 are marginally younger than their inner halo counterparts; NGC 6426 and Palomar 15, the two most metal-poor GCs in the sample, are coeval with all the other metal-poor GCs within the uncertainties. Combined with our previous efforts, the current sample provides strong evidence that the Galactic GC age-metallicity relation consists of two distinct branches. One suggests a rapid chemical enrichment in the inner Galaxy while the other suggests prolonged GC formation in the outer halo. The latter is consistent with the outer halo GCs forming in dwarf galaxies and later being accreted by the Milky Way.

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On the reliability of proxies for globular cluster collision rates

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A variety of different proxies for the stellar collision rates in globular clusters is used in the literature, depending on the quality of data available. We present com- parisons between these proxies and the full integrated collision rate for different King models. The most commonly used proxy, Γ, defined to be $\rho_0^{3/2} r_c^2$, where ρ_0 is the central cluster density, and r_c is the core radius based on the 1966 King model, is an accurate representation of the collision rate from the King model to within about 25% for all but the least concentrated globular clusters. By integrating over King models with a range of parameters, we show that Γ_h, defined to be $\rho_h^{3/2} r_h^2$, where ρ_h is the average density within the half-light radius, and r_h is the half-light radius, is only marginally better correlated with the full King model collision rate than is the cluster luminosity. The two galaxies where results of King model fitting have been reported in detail show a dearth of core-collapsed clusters relative to that seen in the Milky Way, indicating that the core radii of the most concentrated clusters are probably slightly overestimated, even with excellent data. Recent work has suggested that shallower than linear relations exist between proxies for Γ and the probability that a cluster will contain an X-ray source; we show that there is a similarly shallower than linear relationship between Γ and Γ_h that can explain the relationship where Γ_h is used; we also show that reasonable measurement errors are likely to produce a shallower than linear relationship even when Γ itself is used. We thus conclude that the existing evidence is all consistent with the idea that X-ray binary formation rates are linearly proportional to cluster collision rates. We also find, through comparison with Gunn- Griffin models (sometimes referred to as multi-mass King models) suggestive evidence that the retention fractions of neutron stars in globular clusters may be related to the present day concentration parameters, which would imply that the most concentrated clusters today were the most concentrated clusters at the time of their supernovae.

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Empirical determination of the integrated red giant and horizontal branch stellar mass loss in omega Centauri

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We herein determine the average integrated mass loss from stars stars belonging to the dominant metal-poor population ([Fe/H] $\sim$ -1.7) of the Galactic globular cluster omega Centauri (NGC 5139) during their red giant and horizontal branch evolution. Masses are empirically calculated from spectroscopic measurements of surface gravity and photometric measurements of temperature and luminosity. Systematic uncertainties prevent an absolute measurement of masses at a phase of evolution. However, the relative masses of early asymptotic giant branch stars and central red giant branch stars can be measured, and used to derive the mass loss between these two phases. This can then be used as a physical check of models of horizontal branch (HB) stars. For omega Cen, the average difference is found to be $26 \pm 4\%$. Assuming initial and final masses of 0.83 and 0.53 solar masses, we determine that 0.21 ± 0.03 solar masses is lost on the RGB and 0.09 ± 0.05 solar masses is lost on the AGB. The implied HB stellar mass of 0.62 ± 0.04 solar masses is commensurate with literature determinations of the masses of the cluster's HB stars. The accuracy of this measurement can be improved through better selection of stars and spectral coverage, and applied to other clusters where horizontal branch models do not currently agree.

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Kinematic signature of an intermediate-mass black hole in the globular cluster NGC 6388

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Intermediate-mass black holes (IMBHs) are of interest in a wide range of astrophysical fields. In particular, the possibility of finding them at the centers of globular clusters has recently drawn attention. IMBHs became detectable since the quality of observational data sets, particularly those obtained with HST and with high resolution ground based spectrographs, advanced to the point where it is possible to measure velocity dispersions at a spatial resolution comparable to the size of the gravitational sphere of influence for plausible IMBH masses. We present results from ground based VLT/FLAMES spectroscopy in combination with HST data for the globular cluster NGC 6388. The aim of this work is to probe whether this massive cluster hosts an intermediate-mass black hole at its center and to compare the results with the expected value predicted by the $M_\bullet - \sigma$ scaling relation. The spectroscopic data, containing integral field unit measurements, provide kinematic signatures in the center of the cluster while the photometric data give information of the stellar density. Together, these data sets are compared to dynamical models and present evidence of an additional compact dark mass at the center: a black hole. Using analytical Jeans models in combination with various Monte Carlo simulations to estimate the errors, we derive (with 68% confidence limits) a best fit black-hole mass of $(17 \pm 9) \times 10^3 M_\odot$ and a global mass-to-light ratio of $M/L_V = (1.6 \pm 0.3)\ M_\odot/L_\odot$.

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Testing Photometric Diagnostics for the Dynamical State and Possible IMBH presence in Globular Clusters

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Surface photometry is a necessary tool to establish the dynamical state of stars clusters. We produce realistic HST-like images from N-body models of star clusters with and without central intermediate-mass black holes (IMBHs) in order to measure their surface brightness profiles. The models contain ∼600,000 individual stars, black holes of various masses between 0% to 2% of the total mass, and are evolved for a Hubble time. We measure surface brightness and star count profiles for every constructed image in order to test the effect of intermediate mass black holes on the central logarithmic slope, the core radius, and the half-light radius. We use these quantities to test diagnostic tools for the presence of central black holes using photometry. We find that the the only models that show central shallow cusps with logarithmic slopes between -0.1 and -0.4 are those containing central black holes. Thus, the central logarithmic slope seems to be a good way to choose clusters suspect of containing intermediate-mass black holes. Clusters with steep central cusps can definitely be ruled out to host an IMBH. The measured r_c/r_h ratio has similar values for clusters that have not undergone core-collapse, and those containing a central black hole. We notice that observed Galactic globular clusters have a larger span of values for central slope and r_c/r_h than our modeled clusters, and suggest possible reasons that could account for this and contribute to improve future models.

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Some Systematics of Galactic Globular Clusters

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The global properties of all known Galactic globular clusters are examined. The relationship between the luminosities and the metallicities of Galactic globular clusters is found to be complex. Among luminous clusters there is a correlation in the sense that the oldest clusters are slightly more metal deficient than are younger clusters. However, no such clear-cut relationship is found among the faintest globular clusters. The central concentration index C of globular clusters is seen to be independent of metallicity. The dependence of the half-light radii of globular clusters on their Galactocentric distances can be approximated by the relation $R_h \alpha R_{gc}^{2/3}$. Clusters with collapsed cores are mostly situated close to the Galactic nucleus. For $R_{gc} < 10$ kpc the luminosities and the radii of clusters appear to be uncorrelated. The Galaxy differs from the LMC and the SMC in that it appears to lack highly flattened luminous clusters. Galactic globular clusters with ages $\geq$ 13.0 Gyr are all of Oosterhoff type II, whereas almost all of those with ages < 13.0 Gyr have been assigned to Oosterhoff type I. Globular clusters with ages <11.5 Gyr are all located in the outer Galactic halo, have below-average luminosities and above-average radii. On the other hand the very old globular cluster NGC 6522 is situated close to the Galactic nucleus.

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4. Galactic Center Clusters

Dynamical Friction around Supermassive Black Holes

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The density of stars in galactic bulges is often observed to be flat or slowly rising inside the influence radius of the supermassive black hole (SMBH). Chandrasekhar's dynamical friction formula predicts little or no frictional force on a test body in such a core, regardless of its density, due to the absence of stars moving more slowly than the local circular velocity. We have tested this prediction using large-scale N-body experiments. The rate of orbital decay never drops precisely to zero, because stars moving faster than the test body also contribute to the frictional force. When the contribution from the fast-moving stars is included in the expression for the dynamical friction force, and the changes induced by the massive body on the stellar distribution are taken into account, Chandrasekhar's theory is found to reproduce the rate of orbital decay remarkably well. However, this rate is still substantially smaller than the rate predicted by Chandrasekhar's formula! in its most widely-used forms, implying longer time scales for inspiral. Motivated by recent observations that suggest a parsec-scale core around the Galactic center SMBH, we investigate the evolution of a population of stellar-mass black holes (BHs) as they spiral in to the center of the Galaxy. After 10 Gyr, we find that the density of BHs can remain substantially less than the density in stars at all radii; we conclude that it would be unjustified to assume that the spatial distribution of BHs at the Galactic center is well described by steady-state models. One consequence is that rates of capture of BHs by the SMBH at the Galactic center (EMRIs) may be much lower than in standard models. When capture occurs, inspiraling BHs often reach the gravitational-radiation-dominated regime while on orbits that are still highly eccentric; even after the semi-major axis has decreased to values small enough for detection by space-based interferometers, eccentricities can be large enough that the efficient analysis of gravitational wave signals would require the use of eccentric templates.

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For preprints, contact antonini@astro.rit.edu
Also available from the URL http://arxiv.org/abs/1108.1163
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Long-term evolution of massive black hole binaries. IV. Mergers of galaxies with collisionally relaxed nuclei

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We simulate mergers between galaxies containing collisionally-relaxed nuclei around massive black holes (BHs). Our galaxies contain four mass groups, rep- resentative of old stellar populations; a primary goal is to understand the distri- bution of stellar-mass BHs after the merger. Mergers are followed using direct- summation N-body simulations, assuming a mass ratio of 1:3 and two different orbits. Evolution of the massive BH binary is followed until its separation has shrunk by a factor of 20 below the hard-binary separation. During the galaxy merger, large cores are carved out in the stellar distribution, with radii several times the influence radius of the massive BH. Much of the pre-existing mass segre- gation is erased during this phase. We follow the evolution of the merged galaxies for approximately three, central relaxation times after coalescence of the massive binary; both standard, and top-heavy, mass functions are considered. The cores that were formed in the stellar distribution persist, and the distribution of the stellar-mass black holes evolves against this essentially fixed background. Even after three central relaxation times, these models look very different from the relaxed, multi-mass models that are often assumed to describe the distribution of stars and stellar remnants near a massive BH; in particular, the density of stellar BHs is much smaller than in those models. We discuss the implications of our results for the EMRI problem and for the existence of Bahcall-Wolf cusps.

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Tidal disruption rate of stars by supermassive black holes obtained by direct N-body simulations

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The disruption rate of stars by supermassive black holes (SMBHs) is calculated numerically with a modified version of Aarseth's NBODY6 code. The initial stellar distribution around the SMBH follows a Sérsic n=4 profile representing bulges and early type galaxies. In order to infer relaxation driven effects and to increase the statistical significance, a very large set of N-body integrations with different particle numbers N, ranging from 10^3 to $0.5 \cdot 10^6$ particles, is performed. Three different black hole capture radii are taken into account, enabling us to scale these results to a broad range of astrophysical systems with relaxation times shorter than one Hubble time, i.e. for SMBHs up to $M_{BH} \approx 10^7$ $M_\odot$. The computed number of disrupted stars are driven by diffusion in angular momentum space into the loss cone of the black hole and the rate scales with the total number of particles as dN/dt $\propto N^b$, where b is as large as 0.83. This is significantly steeper than the expected scaling dN/dt $\propto ln(N)$ derived from simplest energy relaxation arguments. Only a relatively modest dependence of the tidal disruption rate on the mass of the SMBH is found and we discuss our results in the context of the M_{BH}/σ relation. The number of disrupted stars contribute a significant part to the mass growth of black holes in the lower mass range as long as a significant part of the stellar mass becomes swallowed by the SMBH. This also bears direct consequences for the search and existence of IMBHs in globular clusters. For SMBHs similar to the galactic center black hole SgrA*, a tidal disruption rate of 55 ± 27 events per Myr is deduced. Finally relaxation driven stellar feeding can not account for the masses of massive black holes $M_{BH} \geq 10^7$ $M_\odot$.

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5. Extragalactic Clusters

Resolved photometry of extragalactic young massive star clusters

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We present colour-magnitude diagrams (CMDs) for a sample of seven young massive clusters in the galaxies NGC 1313, NGC 1569, NGC 1705 and NGC 5236. The clusters have ages in the range 5-50 million years and masses of 10^5 - 10^6 $M_\odot$. Although crowding prevents us from obtaining photometry in the inner regions of the clusters, we are still able to measure up to 30-100 supergiant stars in each of the richest clusters, along with the brighter main sequence stars. The resulting CMDs and luminosity functions are compared with photometry of artificially generated clusters, designed to reproduce the photometric errors and completeness as realistically as possible. In agreement with previous studies, our CMDs show no clear gap between the H-burning main sequence and the He-burning supergiant stars, contrary to predictions by common stellar isochrones. In general, the isochrones also fail to match the observed number ratios of red-to-blue supergiant stars, although the difficulty of separating blue supergiants from the main sequence complicates this comparison. In several cases we observe a large spread (1-2 mag) in the luminosities of the supergiant stars that cannot be accounted for by observational errors. This spread can be reproduced by including an age spread of 10-30 million years in the models. However, age spreads cannot fully account for the observed morphology of the CMDs and other processes, such as the evolution of interacting binary stars, may also play a role.

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Evidence for Environmentally Dependent Cluster Disruption in M83

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Using multi-wavelength imaging from the Wide Field Camera 3 on the Hubble Space Telescope we study the stellar cluster populations of two adjacent fields in the nearby face-on spiral galaxy, M83. The observations cover the galactic centre and reach out to 6 kpc, thereby spanning a large range of environmental conditions, ideal for testing empirical laws of cluster disruption. The clusters are selected by visual inspection to be centrally concentrated, symmetric, and resolved on the images. We find that a large fraction of objects detected by automated algorithms (e.g. SExtractor or Daofind) are not clusters, but rather are associations. These are likely to disperse into the field on timescales of tens of Myr due to their lower stellar densities and not due to gas expulsion (i.e. they were never gravitationally bound). We split the sample into two discrete fields (inner and outer regions of the galaxy) and search for evidence of environmentally dependent cluster disruption. Colour-colour diagrams of the clusters, when compared to simple stellar population models, already indicate that a much larger fraction of the clusters in the outer field are older by tens of Myr than in the inner field. This impression is quantified by estimating each cluster's properties (age, mass, and extinction) and comparing the age/mass distributions between the two fields. Our results are inconsistent with "universal" age and mass distributions of clusters, and instead show that the ambient environment strongly affects the observed populations.

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Also available from the URL `http://xxx.lanl.gov/abs/1106.2427`
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Stellar Clusters in M31 from PHAT: Survey Overview and First Results

L. Clifton Johnson ([1]), Anil C. Seth ([2]), Julianne J. Dalcanton ([1]), Nelson Caldwell ([2]), Dimitrios A. Gouliermis ([3]), Paul W. Hodge ([1]), Soeren S. Larsen ([4]), Knut A. G. Olsen ([5]), Izaskun San Roman ([6]), Ata Sarajedini ([6]), Daniel R. Weisz ([1]), the PHAT Collaboration

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The Panchromatic Hubble Andromeda Treasury (PHAT) is an on-going Hubble Space Telescope (HST) multi-cycle program that will image one-third of the M31 disk at high resolution, with wavelength coverage from the ultraviolet through the near-infrared. This dataset will allow for the construction of the most complete catalog of stellar clusters obtained for a spiral galaxy. Here, we provide an overview of the PHAT survey, a progress report on the status of observations and analysis, and preliminary results from the PHAT cluster program. Although only $\sim 20\%$ of the survey is complete, the superior resolution of HST has allowed us to identify hundreds of new intermediate and low mass clusters. As a result, the size of the cluster sample within the Year 1 survey footprint has grown by a factor of three relative to previous catalogs.

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Also available from the URL `http://arxiv.org/abs/1107.2668`
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6. Dynamical evolution - Simulations

Mass segregation and fractal substructure in young massive clusters: (I) the McLuster code and method calibration

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By analysing models of the young massive cluster R136 in 30 Doradus, set-up using the herewith introduced and publicly made available code McLuster, we investigate and compare different methods for detecting and quantifying mass segregation and substructure in non-seeing limited N-body data. For this purpose we generate star cluster models with different degrees of mass segregation and fractal substructure and analyse them.

We quantify mass segregation by measuring, from the projected 2d model data, the mass function slope in radial annuli, by looking for colour gradients in radial colour profiles, by measuring Allison's Λ parameter, and by determining the local stellar surface density around each star. We find that these methods for quantifying mass segregation often produce ambiguous results. Most reliable for detecting mass segregation is the mass function slope method, whereas the colour gradient method is the least practical in an R136-like configuration. The other two methods are more sensitive to low degrees of mass segregation but are computationally much more demanding. We also discuss the effect of binaries on these measures.

Moreover, we quantify substructure by looking at the projected radial stellar density profile, by comparing projected azimuthal stellar density profiles, and by determining Cartwright & Whitworth's Q parameter. We find that only high degrees of substructure affect the projected radial density profile, whereas the projected azimuthal density profile is very sensitive to substructure. The Q parameter is also sensitive to substructure but its absolute value shows a dependence on the radial density gradient of the cluster and is strongly influenced by binaries.

Thus, in terms of applicability and comparability for large sets of N-body data, the mass function slope method and the azimuthal density profile method seem to be the best choices for quantifying the degree of mass segregation and substructure, respectively. The other methods are computationally too demanding to be practically feasible for large data sets.

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The McLuster code is available from the following URL:
`www.astro.uni-bonn.de/ akuepper/mcluster/mcluster.html`
For preprints, contact `akuepper@astro.uni-bonn.de`
Also available from the URL `www.astro.uni-bonn.de/ akuepper/index.html`

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An analytical description of the evolution of binary orbital-parameter distributions in N-body computations of star clusters

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A new method is presented to describe the evolution of the orbital-parameter distributions for an initially universal binary population in star clusters by means of the currently largest existing library of N-body models. It is demonstrated that a stellar-dynamical operator, $\Omega_{\rm dyn}$, exists, which uniquely transforms an initial ($t=0$) orbital parameter distribution function for binaries, $\mathcal{D}_{\rm in}$, into a new distribution, $\mathcal{D}_{\rm fin}$, depending on the initial cluster mass, $M_{\rm ecl}$, and half-mass radius, r_h, after some time t of dynamical evolution. For $\mathcal{D}_{\rm in}$ the distribution functions derived by Kroupa (1995a,b) are used, which are consistent with constraints for pre-main sequence and Class I binary populations. Binaries with a lower energy and a higher reduced-mass are dissolved preferentially. The Ω-operator can be used to efficiently calculate and predict binary properties in clusters and whole galaxies wit! hout the need for further N-body computations. For the present set of N-body models it is found that the binary populations change their properties on a crossing time-scale such that $\Omega_{\rm dyn}$ can be well parametrized as a function of the cluster density, $\rho_{\rm in}$. Furthermore it is shown that the binary-fraction in clusters with similar initial velocity dispersions follows the same evolutionary tracks as a function of the passed number of relaxation-times. Present-day observed binary populations in star clusters put constraints on their initial stellar densities, $\rho_{\rm in}$, which are found to be in the range $10^2 \le \rho_{\rm in}(\le r_h)/M_\odot pc^3 \le 2\times10^5$ for open clusters and a few$\times10^3 \le \rho_{\rm in}(\le r_h)/M_\odot pc^3 \le 10^8$ for globular clusters, respectively.

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Evolution of star clusters in arbitrary tidal fields

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We present a novel and flexible tensor approach to computing the effect of a time-dependent tidal field acting on a stellar system. The tidal forces are recovered from the tensor by polynomial interpolation in time. The method has been implemented in a direct-summation stellar dynamics integrator (Nbody6) and test-proved through a set of reference calculations: heating, dissolution time and structural evolution of model star clusters are all recovered accurately. The tensor method is applicable to arbitrary configurations, including the important situation where the background potential is a strong function of time. This opens up new perspectives in stellar population studies reaching to the formation epoch of the host galaxy or galaxy cluster, as well as for star-burst events taking place during the merger of large galaxies. A pilot application to a star cluster in the merging galaxies NGC 4038/39 (the Antennae) is presented.
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A natural formation scenario for misaligned and short-period eccentric extrasolar planets

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Recent discoveries of strongly misaligned transiting exoplanets pose a challenge to the established planet formation theory which assumes planetary systems to form and evolve in isolation. However, the fact that the majority of stars actually do form in star clusters raises the question how isolated forming planetary systems really are. Besides radiative and tidal forces the presence of dense gas aggregates in star-forming regions are potential sources for perturbations to protoplanetary discs or systems. Here we show that subsequent capture of gas from large extended accretion envelopes onto a passing star with a typical circumstellar disc can tilt the disc plane to retrograde orientation, naturally explaining the formation of strongly inclined planetary systems. Furthermore, the inner disc regions may become denser, and thus more prone to speedy coagulation and planet formation. Pre-existing planetary systems are compressed by gas inflows leading to a natural occurrence of close-in misaligned hot Jupiters and short-period eccentric planets. The likelihood of such events mainly depends on the gas content of the cluster and is thus expected to be highest in the youngest star clusters.

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7. Miscellaneous

Testing Stellar Population Synthesis Models with Sloan Digital Sky Survey Colors of M31's Globular Clusters

Mark Peacock[1], Stephen Zepf[1], Thomas Maccarone[2], Arunav Kundu[3]
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Accurate stellar population synthesis models are vital in understanding the properties and formation histories of galaxies. In order to calibrate and test the reliability of these models, they are often compared with observations of star clusters. However, relatively little work has compared these models in the ugriz filters, despite the recent widespread use of this filter set. In this paper, we compare the integrated colors of globular clusters in the Sloan Digital Sky Survey (SDSS) with those predicted from commonly used simple stellar population (SSP) models. The colors are based on SDSS observations of M31's clusters and provide the largest population of star clusters with accurate photometry available from the survey. As such, it is a unique sample with which to compare SSP models with SDSS observations. From this work, we identify a significant offset between the SSP models and the clusters' g-r colors, with the models predicting colors which are too red by g-r $\sim$ 0.1. This finding is consistent with previous observations of luminous red galaxies in the SDSS, which show a similar discrepancy. The identification of this offset in globular clusters suggests that it is very unlikely to be due to a minority population of young stars. The recently updated SSP model of Maraston & Strömbäck better represents the observed g-r colors. This model is based on the empirical MILES stellar library, rather than theoretical libraries, suggesting an explanation for the g-r discrepancy.

Based on photometry available from:
`http://vizier.u-strasbg.fr/viz-bin/VizieR?-source=J%2FMNRAS%2F402%2F803`

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Birth, evolution and death of stellar clusters

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Using our recently improved understanding of star cluster physics, we are now within reach of answering a number of fundamental questions in contemporary astrophysics. Star cluster physics has immediate bearing on questions ranging from the physical basis of the stellar initial mass function – Do any O-type stars form in isolation? What is the relative importance of stochastic (random) star formation versus competitive accretion? – to the build-up of the most massive clusters - Does the cluster mass function differ in different types of galaxies? How and why do the most massive star clusters form in small dwarf galaxies and what does that imply for the build-up of larger cluster samples? What are the main observables one could (or should) use to try and distinguish among the various star- and cluster-formation scenarios? Newly emerging theoretical insights, novel high-quality observational data and the advent of the next generation of observational facilities offer significant promise to reach satisfactory and robust answers to the key outstanding questions in this field.

To appear in : Summary of a lively open discussion ("tertulia"), "Stellar Clusters and Associations – A RIA workshop on Gaia", 23–27 May 2011, Granada, Spain
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Also available from the URL `http://arxiv.org/abs/1107.0800`
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Probing the Microscopic with the Macroscopic: from Properties of Star Cluster Systems to Properties of Cluster-Forming Regions

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To understand how systems of star clusters have reached their presently observed properties constitutes a powerful probe into the physics of cluster formation, without needing to resort to high spatial resolution observations of individual cluster-forming regions (CFRg) in distant galaxies. In this contribution I focus on the mass-radius relation of CFRgs, how it can be uncovered by studying the gas expulsion phase of forming star clusters, and what the implications are. I demonstrate that, through the tidal field impact upon exposed star clusters, the CFRg mass-radius relation rules cluster infant weight-loss in dependence of cluster mass. The observational constraint of a time-invariant slope for the power-law young cluster mass function is robustly satisfied by CFRgs with a constant mean volume density. In contrast, a constant mean surface density would be conducive to the preferential destruction of high-mass clusters. A purely dynamical line-of-reasoning leads therefore to a conclusion consistent with star formation a process driven by a volume density threshold. Developing this concept further, properties of molecular clumps and CFRgs naturally get dissociated. This allows to understand: (i) why the star cluster mass function is steeper than the molecular cloud (clump) mass function; (ii) the massive star formation limit in the mass-size space of molecular structures.

To appear in: Proceedings of "Star Clusters and Associations: A RIA Workshop on Gaia", Granada, 23-27 May 2011

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A window to the formation of the Milky Way

Dynamics, observational and numerical astrophysics of dense stellar systems

Aspen Meeting Summer 2012, May 20 - June 9

Scientific Rationale

Dense stellar systems such as galactic nuclei and massive stellar clusters, like globular or starburst clusters are unique laboratories for astrophysics. The high stellar densities that are found in their centers are at least a million times higher than in the solar neighbourhood. Therefore, the interaction among stars plays a dominant role in the global evolution of such systems. These systems are the breeding grounds of stellar collisions and of tidal disruptions of stars. In galactic nuclei, such processes may contribute significantly to the mass of the central massive black-hole. Also, the formation of compact object binaries is a very promising source of gravitational radiation for ground- and future space-based detectors. The complexity of these systems is such that, in spite of the huge theoretical and numerical efforts, there are still a large number of open key questions. The precise astrometric observations that we will be able to make in the near future in our own galaxy of stars and their motions contain crucial information on the star formation history, the origin, and the evolution of the Milky Way, its nucleus and the globular clusters. Since most stars form in clusters, we can use observations of individual stars to constrain models of the building blocks of the stellar populations in galaxies. In order to develop a single narrative of the formation of galaxies such as the Milky Way and to understand the intricate dynamics of dense clusters, it is important for theorists, observers, and people working on astrophysical simulations to work together to develop strategies to piece together this picture.

Application Process

Admission to the workshop is granted not by the workshop organizers, but by the Admissions Committee of the Center (with only limited input from the workshop organizers). The Admissions Committee will endeavor to accommodate as many applicants to the workshop as possible, but because of the constraints imposed by the rest of the Aspen Center for Physics program, they may not be able to admit everyone who applies. Note that the Center strongly encourages (and prefers) participation for the full duration of the workshop.

The application is now ready at the ACP web page:

`http://www.aspenphys.org/documents/program/summerworkshops2012.html`

Further Information

For more information about participating in an Aspen Center workshop, see

`http://www.aspenphys.org/participant.html`

Everyone who wishes to participate in this workshop **must apply before January 31, 2012.** The Admissions Committee will be in late February and determine the participant list, which will be distributed in March.