SCYON

The Star Clusters Young & Old Newsletter

edited by Holger Baumgardt, Ernst Paunzen and Thomas Puzia

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

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EDITORIAL

This is the 56th issue of the SCYON newsletter. With todays issue we welcome Thomas Puzia on the editorial board. Thomas will help me with the editing of the newsletter and will also maintain a SCYON mirror site in Santiago. Todays issue features 21 abstracts from refereed publications and conference proceedings. We also have an announcement for the Black Hole Fingerprints conference in Utah in March next year.

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

Holger Baumgardt, Ernst Paunzen and Thomas Puzia

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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

Do all stars in the solar neighbourhood form in clusters? A cautionary note on the use of the distribution of surface densities

Mark Gieles, Nick Moeckel, Cathie J. Clarke
Institute of Astronomy, Cambridge

Bressert et al. recently showed that the surface density distribution of low-mass, young stellar objects in the solar neighbourhood is approximately lognormal. The authors conclude that the star formation process is hierarchical and that only a small fraction of stars form in dense star clusters. Here we show that the peak and the width of the density distribution is also what follows if all stars form in bound clusters which are not significantly affected by the presence of gas and expand by two-body relaxation. The peak of the surface density distribution is simply obtained from the typical ages (few Myrs) and cluster membership number (few hundred) typifying nearby star forming regions. This result depends weakly on initial cluster sizes, provided that they are sufficiently dense (initial half mass radius of ≤ 0.3 pc) for dynamical evolution to be important at an age of a few Myrs. We conclude that the degeneracy of the YSO surface density distribution complicates its use as a diagnostic of the stellar formation environment.

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For preprints, contact `mgieles@ast.cam.ac.uk`
Also available from the URL `http://arxiv.org/abs/1207.2059`
or by anonymous ftp at `ftp://`

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The mass function and dynamical mass of young star clusters: Why their initial crossing-time matters crucially

Geneviève Parmentier ([1,2,3]), Holger Baumgardt ([4])
[1] ARI, Heidelberg University, [2] MPIfR, Bonn, [3] AIfA, Bonn University, [4] School of Mathematics and Physics, University of Queensland

We highlight the impact of cluster-mass-dependent evolutionary rates upon the evolution of the cluster mass function during violent relaxation, that is, while clusters dynamically respond to the expulsion of their residual star-forming gas. Mass-dependent evolutionary rates arise when the mean volume density of cluster-forming regions is mass-dependent. In that case, even if the initial conditions are such that the cluster mass function at the end of violent relaxation has the same shape as the embedded-cluster mass function (i.e. infant weight-loss is mass-independent), the shape of the cluster mass function does change transiently *during* violent relaxation. In contrast, for cluster-forming regions of constant mean volume density, the cluster mass function shape is preserved all through violent relaxation since all clusters then evolve at the same mass-independent rate.

On the scale of individual clusters, we model the evolution of the ratio between the dynamical mass and luminous mass of a cluster after gas expulsion. Specifically, we map the radial dependence of the time-scale for a star cluster to return to equilibrium. We stress that fields-of-view a few pc in size only, typical of compact clusters with rapid evolutionary rates, are likely to reveal cluster regions which have returned to equilibrium even if the cluster experienced a major gas expulsion episode a few Myr earlier. We provide models with the aperture and time expressed in units of the initial half-mass radius and initial crossing-time, respectively, so that our results can be applied to clusters with initial densities, sizes, and apertures different from ours.

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Also available from the URL `http://xxx.lanl.gov/abs/1209.0766`
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Modes of clustered star formation

S. Pfalzner([1]) T. Kaczmarek([1]), C. Olczak([2,3,4])

([1])Max-Planck-Institut fuer Radioastronomie, Auf dem Huegel 69, 53121 Bonn, Germany ([2])Astronomisches Rechen-Institut (ARI), Zentrum fuer Astronomie Universitaet Heidelberg, Moenchhofstrasse 12-14, 69120 Heidelberg, Germany ([3])Max-Planck-Institut fuer Astronomie (MPIA), Koenigstuhl 17, 69117 Heidelberg, Germany ([4])National Astronomical Observatories of China, Chinese Academy of Sciences (NAOC/CAS), 20A Datun Lu, Chaoyang District, Beijing 100012, China

The recent realization that most stars form in clusters, immediately raises the question of whether star and planet formation are influenced by the cluster environment. The stellar density in the most prevalent clusters is the key factor here. Whether dominant modes of clustered star formation exist is a fundamental question. Using near-neighbour searches in young clusters, Bressert and collaborators claim this not to be the case. They conclude that - at least in the solar neighbourhood - star formation is continuous from isolated to densely clustered environments and that the environment plays a minor role in star and planet formation. We investigate under which conditions near-neighbour searches in young clusters can distinguish between different modes of clustered star formation. Model star clusters with different memberships and density distributions are set up and near-neighbour searches are performed. We investigate the influence of the combination of different cluster modes, observational biases, and types of diagnostic on the results. We find that the specific cluster density profile, the relative sample sizes, the limitations of the observation and the choice of diagnostic method decide whether modelled modes of clustered star formation are detected by near-neighbour searches. For density distributions that are centrally concentrated but span a wide density range (for example, King profiles), separate cluster modes are only detectable under ideal conditions (sample selection, completeness) if the mean density of the individual clusters differs by at least a factor of approx. 65. Introducing a central cut-off can lead to an underestimate of the mean density by more than a factor of ten especially in high density regions. Similarly, the environmental effect on star and planet formation is underestimated for half of the population in dense systems. Local surface-density distributions are a very useful tool for single cluster analyses, but only for high-resolution data. However, in a simultaneous analysis of a sample of cluster environments effects of superposition suppress characteristic features very efficiently and thus promotes erroneous conclusions. While multiple peaks in the distribution of the local surface density in star forming regions imply the existence of different modes of star formation, the converse conclusion is impossible. Equally, a smooth distribution is no proof of continuous star formation, because such a shape can easily hide modes of clustered star formation.

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Spectral classification and HR diagram of pre-main sequence stars in NGC6530

L. Prisinzano([1]), G. Micela([1]), S. Sciortino([1]), L. Affer([1]) and F. Damiani([1])
([1])INAF - Osservatorio Astronomico di Palermo, Piazza del Parlamento 1, 90134 Palermo

Mechanisms involved in the star formation process and in particular the duration of the different phases of the cloud contraction are not yet fully understood. Photometric data alone suggest that objects coexist in the young cluster NGC6530 with ages from 1 Myr up to 10 Myrs. We want to derive accurate stellar parameters and, in particular, stellar ages to be able to constrain a possible age spread in the star-forming region NGC6530. We used low-resolution spectra taken with VIMOS@VLT and literature spectra of standard stars to derive spectral types of a subsample of 94 candidate members of this cluster. We assign spectral types to 86 of the 88 confirmed cluster members and derive individual reddenings. Our data are better fitted by the anomalous reddening law with R_V=5. We confirm the presence of strong differential reddening in this region. We derive fundamental stellar parameters, such as effective temperatures, photospheric colors, luminosities, masses, and ages for 78 members, while for the remaining 8 YSOs we cannot determine the interstellar absorption, since they are likely accretors, and their V-I colors are bluer than their intrinsic colors. The cluster members studied in this work have masses between 0.4 and 4 $M_\odot$ and ages between 1-2 Myrs and 6-7 Myrs. We find that the SE region is the most recent site of star formation, while the older YSOs are loosely clustered in the N and W regions. The presence of two distint generations of YSOs with different spatial distribution allows us to conclude that in this region there is an age spread of 6-7 Myrs. This is consistent with the scenario of sequential star formation suggested in literature.

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2. Galactic Open Clusters

Global survey of star clusters in the Milky Way I. The pipeline and fundamental parameters in the second quadrant

N.V. Kharchenko[1,2,3]; A.E. Piskunov[1,2,4]; E. Schilbach[2]; S. Röser[2]; R.-D. Scholz[1]

Leibniz-Institut für Astrophysik Potsdam (AIP), An der Sternwarte 16, D–14482 Potsdam, Germany; Astronomisches Rechen-Institut, Zentrum für Astronomie der Universität Heidelberg, Mönchhofstraße 12-14, D–69120 Heidelberg, Germany; Main Astronomical Observatory, 27 Academica Zabolotnogo Str., 03680 Kiev, Ukraine; Institute of Astronomy of the Russian Acad. Sci., 48 Pyatnitskaya Str., 109017 Moscow, Russia

Aims: On the basis of the PPMXL star catalogue we performed a survey of star clusters in the 2nd quadrant of the Milky Way.

Methods: From the PPMXL catalogue of positions and proper motions we took the subset of stars with near-infrared photometry from 2MASS and added the remaining 2MASS stars without proper motions (called 2MAst, i.e. 2MASS with astrometry). We developed a data processing pipeline **including interactive human control of a standardised set of multi-dimensional diagrams** to determine kinematic and photometric membership probabilities for stars in a cluster region. The pipeline simultaneously produced the astrophysical parameters of a cluster. From literature we compiled a target list of presently known open and globular clusters, cluster candidates, associations and moving groups. From established member stars we derived spatial parameters (coordinates of centres and radii of the main morphological parts of clusters) and cluster kinematics (average proper motions and sometimes radial velocities). For distance, reddening, and age determination we used specific sets of theoretical isochrones. Tidal parameters were obtained by a fit of 3-parameter King profiles to the observed density distributions of members.

Results: We investigated all 871 objects in the 2nd Galactic quadrant, of which we successfully treated 642 open clusters, 2 globular clusters, and 8 stellar associations. 219 groups (24%) were recognised by us to be nonexistent clusters, duplicate entries, or clusters too faint for 2MAst. We found that our sample is complete in the 2nd quadrant up to a distance of 2 kpc, where the average surface density is 94 clusters per kpc^2. Compared with literature values we found good agreement in spatial and kinematic data, as well as for optical distances and reddening. Small, but systematic offsets were detected in the age determination.

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Red supergiants around the obscured open cluster Stephenson 2

I. Negueruela ([1]), A. Marco ([1]), C. González-Fernández ([1]), F. Jiménez-Esteban ([2]), J.S. Clark ([3]), M. Garcia ([4]), E. Solano ([2])

([1]) Universidad de Alicante, Spain; ([2]) Spanish Virtual Observatory and CAB-CSIC; ([3]) Open University; ([4]) IAC

Several clusters of red supergiants have been discovered in a small region of the Milky Way close to the base of the Scutum-Crux Arm and the tip of the Long Bar. Population synthesis models indicate that they must be very massive to harbour so many supergiants. Among them, Stephenson 2, with a core grouping of 26 RSGs, is a strong candidate to be the most massive cluster in the Galaxy. It is located close to a region where a strong over-density of RSGs had been found. We explore the actual cluster size and its possible connection to this over-density. We have performed a cross-match between DENIS, USNO-B1 and 2MASS to identify candidate obscured luminous red stars around Ste 2, and in a control nearby region, finding > 600 candidates. More than 400 are sufficiently bright in I to allow observation with a 4-m class telescope. We have observed a subsample of $\sim$250 stars, using AF2 on the WHT telescope in La Palma, obtaining intermediate-resolution spectroscopy in the 7500–9000A range. We derive spectral types and luminosity classes for all these objects and measure their radial velocities. Our targets are G and K supergiants, late ($\geq$ M4) M giants, and M-type bright giants (luminosity class II) and supergiants. We find $\sim$35 RSGs with radial velocities similar to Ste 2 members, spread over the two areas surveyed. In addition, we find $\sim$40 RSGs with radial velocities incompatible in principle with a physical association. Our results show that Ste 2 is not an isolated cluster, but part of a huge structure likely containing hundreds of RSGs, with radial velocities compatible with the terminal velocity at this Galactic longitude (and a distance $\sim$6 kpc). In addition, we find evidence of several populations of massive stars at different distances along this line of sight [ABRIDGED].

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Also available from the URL `http://arxiv.org/abs/1208.3282`
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High resolution elemental abundances analysis of the open cluster IC 4756

Ting, Yuan-Sen ([1,2]); De Silva, Gayandhi ([3]); Freeman, Ken([1]); Parker, Stacey-Jo ([4])

[1]. Research School of Astronomy & Astrophysics, The Australian National University, Cotter Road, Weston Creek, ACT 2611, Australia [2]. Harvard-Smithsonian Center for Astrophysics, 60 Garden Street, Cambridge, Massachusetts 02139, USA [3]. Australian Astronomical Observatory, PO Box 296, NSW 1710, Australia [4]. Institute of Astronomy, University of Cambridge, UK

We present detailed elemental abundances of 12 subgiants in the open cluster IC 4756 including Na, Al, Mg, Si, Ca, Ti, Cr, Ni, Fe, Zn, Ba. We measure the cluster to have [Fe/H] = -0.01 +/- 0.10. Most of the measured star-to-star [X/H] abundance variation is below sigma < 0.03, as expected from a coeval stellar population preserving natal abundance patterns, supporting the use of elemental abundances as a probe to reconstruct dispersed clusters. We find discrepancies between Cr I and Cr II abundances as well as Ti I and Ti II abundances, where the ionized abundances are larger by about 0.2 dex. This follows other such studies which demonstrate the effects of overionization in cool stars. IC 4756 are super-solar in Mg, Si, Na, Al, but are solar in the other elements. The fact that IC 4756 is super-solar in some alpha-elements (Mg, Si) but solar in the others (Ca, Ti) suggests that the production of alpha-elements is not simply one dimensional and could be exploited for chemical tagging.

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Also available from the URL `http://arxiv.org/abs/1207.7076`
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3. Galactic Globular Clusters

The Tidal Tails of 47 Tucanae

Richard R. Lane[1], Andreas H.W. Küpper[2,3] and Douglas C. Heggie[4]
[1]Departamento de Astronomía, Universidad de Concepción, Casilla 160 C, Concepción, Chile
[2]Argelander-Institut für Astronomie (AIfA), Auf dem Hügel 71, 53121 Bonn, Germany
[3]European Southern Observatory, Alonso de Cordova 3107, Vitacura, Santiago, Chile
[4]University of Edinburgh, School of Mathematics and Maxwell Institute for Mathematical Sciences, King's Buildings, Edinburgh EH9 3JZ, U.K.

The Galactic globular cluster 47 Tucanae (47 Tuc) shows a rare increase in its velocity dispersion profile at large radii, indicative of energetic, yet bound, stars at large radii dominating the velocity dispersion and, potentially, of ongoing evaporation. Escaping stars will form tidal tails, as seen with several Galactic globular clusters, however, the tidal tails of 47 Tuc are yet to be uncovered. We model these tails of 47 Tuc using the most accurate input data available, with the specific aim of determining their locations, as well as the densities of the epicyclic overdensities within the tails. The overdensities from our models show an increase of 3-4% above the Galactic background and, therefore, should be easily detectable using matched filtering techniques. We find that the most influential parameter with regard to both the locations and densities of the epicyclic overdensities is the Heliocentric distance to the cluster. Hence, uncovering these tidal features observationally will contribute greatly to the ongoing problem of determining the distance to 47 Tuc, tightly constraining the distance of the cluster independent of other methods. Using our streakline method for determining the locations of the tidal tails and their overdensities, we show how, in principle, the shape and extent of the tidal tails of any Galactic globular cluster can be determined without resorting to computationally expensive N-body simulations.

Accepted by: MNRAS
For preprints, contact rlane@astro-udec.cl
Also available from the URL http://de.arxiv.org/abs/1204.2549

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The Impact of Contaminated RR Lyrae/Globular Cluster Photometry on the Distance Scale

D. Majaess (1), D. G. Turner (1), W. Gieren (2), D. J. Lane (1)

(1) Saint Mary's University, Halifax, Nova Scotia, Canada (2) Universidad de Concepcion, Concepcion, Chile

RR Lyrae variables and the stellar constituents of globular clusters are employed to establish the cosmic distance scale and age of the universe. However, photometry for RR Lyrae variables in the globular clusters M3, M15, M54, M92, NGC2419, and NGC6441 exhibit a dependence on the clustercentric distance. For example, variables and stars positioned near the crowded high-surface brightness cores of the clusters may suffer from photometric contamination, which invariably affects a suite of inferred parameters (e.g., distance, color excess, absolute magnitude, etc.). The impetus for this study is to mitigate the propagation of systematic uncertainties by increasing awareness of the pernicious impact of contaminated and radial-dependent photometry.

To appear in : ApJL

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Also available from the URL `http://iopscience.iop.org/2041-8205/752/1/L10/`

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4. Galactic Center Clusters

Spin Evolution of Supermassive Black Holes and Galactic Nuclei

David Merritt, Eugene Vasiliev
RIT

The spin angular momentum S of a supermassive black hole (SBH) precesses due to torques from orbiting stars, and the stellar orbits precess due to dragging of inertial frames by the spinning hole. We solve the coupled post-Newtonian equations describing the joint evolution of S and the stellar angular momenta Lj, j = 1...N in spherical, rotating nuclear star clusters. In the absence of gravitational interactions between the stars, two evolutionary modes are found: (1) nearly uniform precession of S about the total angular momentum vector of the system; (2) damped precession, leading, in less than one precessional period, to alignment of S with the angular momentum of the rotating cluster. Beyond a certain distance from the SBH, the time scale for angular momentum changes due to gravitational encounters between the stars is shorter than spin-orbit precession times. We present a model, based on the Ornstein-Uhlenbeck equation, for the stochastic evolution of star clusters due to gravitational encounters and use it to evaluate the evolution of S in nuclei where changes in the Lj are due to frame dragging close to the SBH and to encounters farther out. Long-term evolution in this case is well described as uniform precession of the SBH about the cluster's rotational axis, with an increasingly important stochastic contribution when SBH masses are small. Spin precessional periods are predicted to be strongly dependent on nuclear properties, but typical values are 10-100 Myr for low-mass SBHs in dense nuclei, 100 Myr - 10 Gyr for intermediate mass SBHs, and $>$ 10 Gyr for the most massive SBHs. We compare the evolution of SBH spins in stellar nuclei to the case of torquing by an inclined, gaseous accretion disk.

To appear in : Submitted to PRD
For preprints, contact merritt@astro.rit.edu
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5. Extragalactic Clusters

The VLT-FLAMES Tarantula Survey. VII. A low velocity dispersion for the young massive cluster R136

V. Henault-Brunet ([1]), C. J. Evans, H. Sana, M. Gieles, N. Bastian, J. Maiz Apellaniz, N. Markova, W. D. Taylor, E. Bressert, P.A. Crowther, J. Th. van Loon

([1]) Scottish Universities Physics Alliance (SUPA), Institute for Astronomy, University of Edinburgh

Detailed studies of resolved young massive star clusters are necessary to determine their dynamical state and evaluate the importance of gas expulsion and early cluster evolution. In an effort to gain insight into the dynamical state of the young massive cluster R136 and obtain the first measurement of its velocity dispersion, we analyse multi-epoch spectroscopic data of the inner regions of 30 Doradus in the Large Magellanic Cloud (LMC) obtained as part of the VLT-FLAMES Tarantula Survey. Following a quantitative assessment of the variability, we use the radial velocities of non-variable sources to place an upper limit of 6 km/s on the line-of-sight velocity dispersion of stars within a projected distance of 5 pc from the centre of the cluster. After accounting for the contributions of undetected binaries and measurement errors through Monte Carlo simulations, we conclude that the true velocity dispersion is likely between 4 and 5 km/s given a range of standard assumptions about the binary distribution. This result is consistent with what is expected if the cluster is in virial equilibrium, suggesting that gas expulsion has not altered its dynamics. We find that the velocity dispersion would be $\sim$25 km/s if binaries were not identified and rejected, confirming the importance of the multi-epoch strategy and the risk of interpreting velocity dispersion measurements of unresolved extragalactic young massive clusters.

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Also available from the URL http://arxiv.org/abs/1208.0825

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The VLT-FLAMES Tarantula Survey. VI. Evidence for rotation of the young massive cluster R136

V. Henault-Brunet ([1]), M. Gieles, C. J. Evans, H. Sana, N. Bastian, J. Maiz Apellaniz, W. D. Taylor, N. Markova, E. Bressert, A. de Koter, J. Th. van Loon

([1]) Scottish Universities Physics Alliance (SUPA), Institute for Astronomy, University of Edinburgh

Although it has important ramifications for both the formation of star clusters and their subsequent dynamical evolution, rotation remains a largely unexplored characteristic of young star clusters (few Myr). Using multi-epoch spectroscopic data of the inner regions of 30 Doradus in the Large Magellanic Cloud (LMC) obtained as part of the VLT-FLAMES Tarantula Survey, we search for rotation of the young massive cluster R136. From the radial velocities of 36 apparently single O-type stars within a projected radius of 10 pc from the centre of the cluster, we find evidence, at the 95% confidence level, for rotation of the cluster as a whole. We use a maximum likelihood method to fit simple rotation curves to our data and find a typical rotational velocity of ~3 km/s. When compared to the low velocity dispersion of R136, our result suggests that star clusters may form with at least ~20% of the kinetic energy in rotation.

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Also available from the URL http://arxiv.org/abs/1207.7071

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6. Dynamical evolution - Simulations

The emergence of super-canonical stars in R136-type star-burst clusters

Sambaran Banerjee, Pavel Kroupa, Seungkyung Oh
Argelander-Institut für Astronomie, Auf dem Hügel 71, D-53121, Bonn, Germany

Among the most remarkable features of the stellar population of R136, the central, young, massive star cluster in the 30 Doradus complex of the Large Magellanic Cloud, are the single stars whose masses substantially exceed the canonical stellar upper mass limit of 150 $M_\odot$. A recent study by us, viz., that of Banerjee, Kroupa & Oh (2012; Paper I), which involves realistic N-body computations of star clusters mimicking R136, indicates that such "super-canonical" (SC) stars can be formed out of a dense stellar population with a canonical initial mass function (IMF) through dynamically induced mergers of the most massive binaries. Here we study the formation of SC stars in the R136 models of Paper I in detail. To avoid forming extraneous SC stars from initially highly eccentric primordial binaries as in Paper I, we compute additional models with only initially circular primordial binaries. We also take into account the mass-evolution of the SC stars using detailed stellar evolutionary models that incorporate updated treatments of stellar winds. We find that SC stars begin to form via dynamical mergers of massive binaries from approx. 1 Myr cluster age. We obtain SC stars with initial masses up to approx. 250 $M_\odot$ from these computations. Multiple SC stars are found to remain bound to the cluster simultaneously within a SC-lifetime. These properties of the dynamically formed SC stars are consistent with those observed in R136. In fact, the stellar evolutionary models of SC stars imply that had they formed primordially along with the rest of the R136 cluster, i.e., violating the canonical upper limit, they would have evolved below the canonical 150 $M_\odot$ limit by approx. 3 Myr, the likely age of R136, and would not have been observable as SC stars at the present time in R136. This strongly supports the dynamical formation scenario of the observed SC stars in R136.

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Also available from the URL http://arxiv.org/abs/1208.0826
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Planets in Open Clusters Detectable by Kepler

Sourav Chatterjee[1], Eric B. Ford[1], Aaron M. Geller[2], and Frederic A. Rasio[2]
[1]Department of Astronomy, University of Florida, Gainesville, FL 32611,
and
[2]Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) and
Dept. of Physics & Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA.

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While hundreds of planets have been discovered around field stars, only a few are known in star clusters. To explain the lack of short-period giant planets in globular clusters (GC), such as 47 Tucane and ω Centauri, it has been suggested that their low metallicities may have prevented planet formation. Alternatively, the high rates of close stellar encounters in these clusters may have influenced the formation and subsequent evolution of planetary systems. How common are planets in clusters around normal main-sequence stars? Here we consider whether this question can be addressed using data from the Kepler mission. The Kepler field of view contains 4 low-density (relative to GCs) open clusters where the metallicities are about solar (or even higher) and stellar encounters are much less frequent than in typical GCs. We provide detailed N-body models and show that most planets in Kepler-detectable orbits are not significantly perturbed by stellar encounters in these open clusters. We focus on the most massive cluster, NGC 6791, which has super-solar metallicity, and find that if planets formed in this cluster at the same frequency as observed in the field, Kepler could detect 1 – 20 transiting planets depending on the planet-size distribution and the duration of data collection. Due to the large distance to NGC 6791 Kepler will have to search relatively faint ($K_p < 20$) stars for the full extended mission to achieve such a yield.
For preprints, contact s.chatterjee@astro.ufl.edu
Also available from the URL http://adsabs.harvard.edu/abs/2012arXiv1207.3545C

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Understanding the Dynamical State of Globular Clusters: Core-Collapsed vs Non Core-Collapsed

Sourav Chatterjee, Stefan Umbreit, John M. Fregeau, Frederic A. Rasio

Department of Astronomy, University of Florida, Gainesville, 32611 Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) and Dept. of Physics & Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA, Institute for Defense Analyses, 4850 Mark Center Dr, Alexandria, VA 22311, Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) and Dept. of Physics & Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA

We study the dynamical evolution of globular clusters using our Hénon-type Monte Carlo code for stellar dynamics including all relevant physics such as two-body relaxation, single and binary stellar evolution, Galactic tidal stripping, and strong interactions such as physical collisions and binary mediated scattering. We compute a large database of several hundred models starting from broad ranges of initial conditions guided by observations of young and massive star clusters. We show that these initial conditions very naturally lead to present day clusters with properties including the central density, core radius, half-light radius, and cluster mass, that match well with those of the old Galactic globular clusters. In particular, we can naturally reproduce the bimodal distribution in observed core radii separating the "core-collapsed" vs the "non core-collapsed" clusters. We see that the core-collapsed clusters are those that have reached or are about to reach the equilibrium "binary burning" phase. The non core collapsed clusters are still undergoing gravo-thermal contraction.

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For preprints, contact `s.chatterjee@astro.ufl.edu`
Also available from the URL `http://`
or by anonymous ftp at `ftp://`

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A Parallel Monte Carlo Code for Simulating Collisional N-body Systems

Pattabiraman, Bharath; Umbreit, Stefan; Liao, Wei-Keng; Choudhary, Alok; Kalogera, Vassiliki; Memik, Gokhan; Rasio, Frederic A.

Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) & Dept. of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA.

We present a new parallel code for computing the dynamical evolution of collisional N-body systems with up to $N \sim 10^7$ particles. Our code is based on the the Henon Monte Carlo method for solving the Fokker-Planck equation, and makes assumptions of spherical symmetry and dynamical equilibrium. The principal algorithmic developments involve optimizing data structures, and the introduction of a parallel random number generation scheme, as well as a parallel sorting algorithm, required to find nearest neighbors for interactions and to compute the gravitational potential. The new algorithms we introduce along with our choice of decomposition scheme minimize communication costs and ensure optimal distribution of data and workload among the processing units. The implementation uses the Message Passing Interface (MPI) library for communication, which makes it portable to many different supercomputing architectures. We validate the code by calculating the evolution of clusters with initial Plummer distribution functions up to core collapse with the number of stars, N, spanning three orders of magnitude, from 10^5 to 10^7. We find that our results are in good agreement with self-similar core-collapse solutions, and the core collapse times generally agree with expectations from the literature. Also, we observe good total energy conservation, within less than 1% throughout all simulations. We analyze the performance of the code, and demonstrate near-linear scaling of the runtime with the number of processors up to 64 processors for $N = 10^5$, 128 for $N = 10^6$ and 256 for $N = 10^7$. The runtime reaches a saturation with the addition of more processors beyond these limits which is a characteristic of the parallel sorting algorithm. The resulting maximum speedups we achieve are approximately 60x, 100x, and 220x, respectively.

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For preprints, contact Bharath Pattabiraman <bharath@u.northwestern.edu>
Also available from the URL http://arxiv.org/abs/1206.5878
or by anonymous ftp at ftp://

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Constraining Intermediate-Mass Black Holes in Globular Clusters

Umbreit, Stefan Rasio, Frederic A

Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) & Dept. of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA.

Decades after the first predictions of intermediate-mass black holes (IMBHs) in globular clusters (GCs) there is still no unambiguous observational evidence for their existence. The most promising signatures for IMBHs are found in the cores of GCs, where the evidence now comes from the stellar velocity distribution, the surface density profile, and, for very deep observations, the mass-segregation profile near the cluster center. However, interpretation of the data, and, in particular, constraints on central IMBH masses, require the use of detailed cluster dynamical models. Here we present results from Monte Carlo cluster simulations of GCs that harbor IMBHs. As an example of application, we compare velocity dispersion, surface brightness and mass-segregation profiles with observations of the GC M10, and constrain the mass of a possible central IMBH in this cluster. We find that, although M10 does not seem to possess a cuspy surface density profile, the presence of an IMBH with a mass up to 0.75% of the total cluster mass, corresponding to about 600 Msun, cannot be excluded. This is also in agreement with the surface brightness profile, although we find it to be less constraining, as it is dominated by the light of giants, causing it to fluctuate significantly. We also find that the mass-segregation profile cannot be used to discriminate between models with and without IMBH. The reason is that M10 is not yet dynamically evolved enough for the quenching of mass segregation to take effect. Finally, detecting a velocity dispersion cusp in clusters with central densities as low as in M10 is extremely challenging, and has to rely on only 20-40 bright stars. It is only when stars with masses down to 0.3 Msun are included that the velocity cusp is sampled close enough to the IMBH for a significant increase above the core velocity dispersion to become detectable.

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For preprints, contact `Stefan Umbreit <s-umbreit@northwestern.edu>`

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or by anonymous ftp at `ftp://`

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Monte Carlo Simulations of Globular Cluster Evolution. VI. The Influence of an Intermediate-mass Black Hole

Stefan Umbreit, John M. Fregeau, Sourav Chatterjee, Frederic A. Rasio

Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) & Dept. of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA, Kavli Institute of Theoretical Physics, University of California, Santa Barbara, CA 93106, USA Chandra Fellow

We present results from a series of Monte Carlo (MC) simulations investigating the imprint of a central intermediate-mass black hole (IMBH) on the structure of a globular cluster. We investigate the three-dimensional and projected density profiles, and stellar disruption rates for idealized as well as realistic cluster models, taking into account a stellar mass spectrum and stellar evolution, and allowing for a larger, more realistic number of stars than was previously possible with direct N-body methods. We compare our results to other N-body and Fokker-Planck simulations published previously. We find, in general, very good agreement for the overall cluster structure and dynamical evolution between direct N-body simulations and our MC simulations. Significant differences exist in the number of stars that are tidally disrupted by the IMBH, and this is most likely caused by the wandering motion of the IMBH, not included in the MC scheme. These differences, however, are negligible for the final IMBH masses in realistic cluster models, as the disruption rates are generally much lower than for single-mass clusters. As a direct comparison to observations we construct a detailed model for the cluster NGC 5694, which is known to possess a central surface brightness cusp consistent with the presence of an IMBH. We find that not only the inner slope but also the outer part of the surface brightness profile agree well with observations. However, there is only a slight preference for models harboring an IMBH compared to models without.

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For preprints, contact Stefan Umbreit <s-umbreit@northwestern.edu>
Also available from the URL http://iopscience.iop.org/0004-637X/750/1/31/
or by anonymous ftp at ftp://

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Formation of Massive Black Holes in Dense Star Clusters. II. Initial Mass Function and Primordial Mass Segregation

Sanghamitra Goswami, Stefan Umbreit, Matt Bierbaum, and Frederic A. Rasio
Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) & Dept. of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA

A promising mechanism to form intermediate-mass black holes is the runaway merger in dense star clusters, where main-sequence stars collide and form a very massive star (VMS), which then collapses to a black hole (BH). In this paper, we study the effects of primordial mass segregation and the importance of the stellar initial mass function (IMF) on the runaway growth of VMSs using a dynamical Monte Carlo code for N-body systems with N as high as 106 stars. Our code now includes an explicit treatment of all stellar collisions. We place special emphasis on the possibility of top-heavy IMFs, as observed in some very young massive clusters. We find that both primordial mass segregation and the shape of the IMF affect the rate of core collapse of star clusters and thus the time of the runaway. When we include primordial mass segregation, we generally see a decrease in core-collapse time (tcc). Although for smaller degrees of primordial mass segregation this decrease in tcc is mostly due to the change in the density profile of the cluster, for highly mass-segregated (primordial) clusters, it is the increase in the average mass in the core which reduces the central relaxation time decreasing tcc. The final mass of the VMS formed is always close to $\sim 10^{-3}$ of the total cluster mass, in agreement with previous studies and is reminiscent of the observed correlation between the central BH mass and the bulge mass of the galaxies. As the degree of primordial mass segregation is increased, the mass of the VMS increases at most by a factor of three. Flatter IMFs generally increase the average mass in the whole cluster, which increases tcc. For the range of IMFs investigated in this paper, this increase in tcc is to some degree balanced by stellar collisions, which accelerate core collapse. Thus, there is no significant change in tcc for the somewhat flatter global IMFs observed in very young massive clusters.

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For preprints, contact Sanghamitra Goswami <sanghamitragoswami2012@u.northwestern.edu>
Also available from the URL http://iopscience.iop.org/0004-637X/752/1/43/
or by anonymous ftp at ftp://

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The Salpeter Slope of the IMF Explained

M. S. Oey
University of Michigan

If we accept a paradigm that star formation is a self-similar, hierarchical process, then the Salpeter slope of the IMF for high-mass stars can be simply and elegantly explained as follows. If the instrinsic IMF at the smallest scales follows a simple 2 power-law slope, then the steepening to the 2.35 Salpeter value results when the most massive stars cannot form in the lowest-mass clumps of a cluster. It is stressed that this steepening MUST occur if clusters form hierarchically from clumps, and the lowest-mass clumps can form stars. This model is consistent with a variety of observations as well as theoretical simulations.

To appear in : Antfest: The Labyrinth of Star Formation, 18-22 June 2012, Crete, Greece
For preprints, contact `msoey-at-umich.edu`
Also available from the URL `http://astro.lsa.umich.edu/ msoey`
or by anonymous ftp at `ftp://`

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GPU-Accelerated Monte Carlo Simulations of Dense Stellar Systems

Pattabiraman, B.; Umbreit, S.; Liao, W. ; Rasio, F.; Kalogera, V.; Choudhary, A.
Center for Interdisciplinary Exploration and Research in Astrophysics (CIERA) & Dept. of Physics and Astronomy, Northwestern University, 2145 Sheridan Rd, Evanston, IL 60208, USA.

Computing the interactions between the stars within dense stellar clusters is a problem of fundamental importance in theoretical astrophysics. However, simulating realistic sized clusters of about 10^6 stars is computationally intensive and often takes a long time to complete. This paper presents the acceleration of a Monte Carlo algorithm for simulating stellar cluster evolution using programmable Graphics Processing Units (GPUs). This acceleration allows to explore physical regimes which were out of reach of current simulations.

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For preprints, contact Bharath Pattabiraman <bharath@u.northwestern.edu>
Also available from the URL http://aspbooks.org/custom/publications/paper/453-0329.html
or by anonymous ftp at

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Black Hole Fingerprints: Dynamics, Disruptions & Demographics

17. - 22. 3. 2013, Snowbird Ski Resort, Utah, USA

This is the first announcement for the Snowpac 2013 workshop "Black Hole Fingerprints: Dynamics, Disruptions & Demographics." The conference will be held from 17-22 March 2013 at Snowbird Ski Resort, Utah, USA. Information and registration is available at our web site:

`http://www.physics.utah.edu/snowpac/index.php/snowpac-2013`

The conference will focus on the interaction of massive black holes with the stars around them, and our ability to use stellar dynamics and tidal disruption events to understand the demographics of massive black holes. We will cover the following broad topics:

- Supermassive black hole demographics & formation
- Tidal disruption observations, signatures & rates
- Nuclear star clusters & the dynamics of dense stellar systems
- Hypervelocity stars
- Black holes in star clusters & intermediate mass black holes

Schedule & Venue Information:

The conference schedule will consist of two 3 hour sessions with a long afternoon break enabling people to ski. Two ski areas, Snowbird and Alta, are directly accessible from the conference location, providing some of the world's finest skiing. Apart from skiing, there are other winter activities possible (e.g. snowshoeing, nordic skiing), and discounted access to the Snowbird spa. The conference hotel is just 30 minutes from the Salt Lake City airport. More information available at: `http://www.snowbird.com/index.html`

Important Dates:

Abstract Submission Deadline: Nov. 15th, 2012
Registration & Hotel Deadline: Jan. 15th, 2013

Scientific Organizing Committee:

Ben Bromley (U. of Utah), Suvi Gezari (U. of Maryland), Jenny Greene (Princeton), David Merritt (Rochester Institute of Technology), Simon Portegies Zwart (Sterrewacht Leiden), Enrico Ramirez-Ruiz (U. of California, Santa Cruz), Anil Seth (U. of Utah), Roeland van der Marel (Space Telescope Science Institute), Marta Volonteri (Institut Astrophysique de Paris)

Confirmed Invited Speakers:

Aaron Barth (U. of California, Irvine), Warren Brown (Harvard-Smithsonian CfA), James Guillochon (U. of California, Santa Cruz), Kayhan Gultekin (U. of Michigan), Zoltan Haiman (Columbia

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