Workshop

The Early Life of Stellar Clusters: Formation and Dynamics

Book of Abstracts

Session I: Star cluster formation, observations

Prof. Kelsey Johnson
University of Virginia, USA

Title: Probing the Physical Conditions of Massive Star Cluster Formation with ALMA

Abstract: Observationally constraining the physical conditions that give rise to massive star clusters has been a long-standing challenge. Our team's ALMA observations of the Antennae Galaxies confirm and characterize a potential proto-globular cluster molecular cloud. This CO has no associated Paβ or thermal radio emission, indicating that star formation has not yet begun – this allows us to assess the physical conditions before the onset of star formation. The observed CO(3-2) intensity and size of the cloud imply a mass of at least 10^7 M_sun. The observed properties indicate that this cloud appears to be subject to remarkable external pressure (potentially as high as P/k ~10^8 K cm^-3). A comparison with ALMA CO(2-1) science verification observations and non-LTE analysis yields an excitation temperature of ~25K; an equilibrium state would require significant internal nonthermal pressure. I will give an overview of the ALMA observations, discuss the properties of this extraordinary source, and put these results in the context with other molecular clouds in the local universe.

Prof. Frederique Motte
CEA, Saclay, France

Title: Mini-starburst ridges and instantaneous star formation efficiency

Abstract: The Herschel/HOBYS key program (Motte et al. 2010, 2012) revealed thousands of burgeoning YSOs in the Galactic regions forming OB-type stars at distances less than 3 kpc. Counting Herschel protostars and measuring their envelope mass gives a direct measure of the mass of stars forming in a period of ~10^5 yrs. We call these measures the instantaneous or present-day star formation efficiency (SFE) and rate (SFR) (Nguyen Luong et al. 2011; Louvet et al. 2014), as opposed to the integrated or past SFE and SFR measured from counting ~10^6 yrs T Tauri stars detected with Spitzer (e.g. Heiderman et al. 2010). The instantaneous SFE concept is crucial for high-mass star-forming regions which probably do not have a constant SFR over the ~10^6 yrs typically used to integrate the past SFR. We have measured the instantaneous SFRs in the DR21 and W43 ridges, which are high-density, dominating cloud filaments of several pc^2 (Hill et al. 2011; Hennemann et al. 2012; Nguyen Luong et al. 2013). The cloud ridges have mass densities and star formation activities unusually high in the Milky Way but reminiscent of starburst galaxies (e.g. Nguyen-Luong et al. 2011; Louvet et al. 2014). Called mini-starburst ridges, they could be seen as "miniature and instant models" of starburst galaxies.

Dr Timea Csengeri
MPIfR, Bonn, Germany

Title: The ATLASGAL survey: a view on the earliest stages of high-mass star and cluster formation

Abstract: The ATLASGAL survey is one of the most sensitive and extensive ground-based survey of the inner Galaxy at sub-millimeter wavelengths providing an unprecedented view on all stages of massive star-formation. With over 10 000 compact sources identified, it provides a statistically significant sample of massive star-forming clumps, many of them have been previously not known. Cross-correlation with ancillary data from the radio to the mid-IR wavelengths was used to pin down potential sites of high-mass star-formation in the earliest stages and therefore a sample of massive clumps with extreme youth have been identified. I will present recent results from the ATLASGAL survey with particular focus on the youngest clumps, where intensive outflows associated with potentially young, Class 0 like embedded protostars have been confirmed. Such a Galactic scale sample complemented with spectroscopic follow-up observations is the first step to characterize the initial conditions of high-mass star and cluster formation.

Dr Fumitaka Nakamura
NAOJ, Mitaka, Japan

Title: Revealing Initial Condition of Star Cluster Formation: The Case of Serpens South

Abstract: Serpens South is an embedded cluster discovered by Spitzer. Its unique characterictic is the high fraction of Class 0/I objects, indicating that this cluster is just formed within 0.5Myr. Thus, serpens south is an ideal object to study early phase of cluster formation. Based on our multiple molecular line data(N2H+, NH3,CCS,...), we propose that cluster formation triggered by collisions of three filaments whose dynamics is controlled by globally ordered magnetic field.

Dr Arjan Bik
Stockholm Observatory, Sweden

Title: The star formation history of embedded clusters

Abstract: Massive stars are typically observed to form in clustered environments, with morphologies ranging from very dense, centrally concentrated starburst clusters to loose associations. These associations and clusters are morphologically and dynamically different. It is not clear if these differences arise from different initial conditions in the star formation process or environmental effects, like feedback. I will present the results on a large, ongoing observational campaign aiming at deriving the star formation history of a sample of the most massive embedded clusters. Near-infrared spectroscopy from VLT/SINFONI and LBT/LUCI allows us to characterize the stellar content and estimate cluster ages and search for age spreads. Combined with a large suite of multi-wavelength observations we obtain a detailed picture of the stellar clusters and their stellar populations. The near-infrared visible stellar population is typically a few Myr old, but mid-IR and (sub) mm data reveal more deeply embedded and younger star forming regions in the vincinity. Different stellar populations are found in many embedded clusters, suggesting that the star formation history is much more complex than a single star formation event.

Dr. Dimitrios Gouliermis
Institute for Theoretical Astrophysics, U. of Heidelberg, Germany

Title: Exploring the topology of clustered star formation

Abstract: Stars are born in groups of diverse forms, sizes and degree of self-gravity ("boundness"). Different types of stellar systems, such as compact dense clusters, or extended stellar associations, do not seem to be independent stellar ensembles,but manifestations of the same hierarchy in the star formation process. This is supported from observations of resolved star-forming complexes, where compact stellar clusters seem to represent the centers of recent star formation within larger loose stellar structures of older or comparable ages. We discuss the spatial distribution of newly-born stars, and discuss methods for its depiction, in order to comprehend the scale-free formation of stellar structures in terms of the initial physical conditions in molecular clouds. We use as templates typical star-forming complexes in the Magellanic Clouds, observed with the

Hubble Space Telescope, allowing for the complete stellar sampling across length-scales of molecular clouds. We interpret these observations with the use of simulated stellar distributions to characterize stellar clustering and its hierarchical behavior, in an attempt to disentangle the star formation conditions in such magnificent stellar structures.

Dr Maria Messineo
Institution:MPIfR, Bonn, Germany

Title: Massive stars/clusters in the giant molecular cloud G23.3-0.3

Abstract: Massive stars/clusters in the giant molecular cloud G23.3-0.3 Recent observations and advanced technique of analysis have shown that massive stars do not necessarily form in dense environments. I would like to illustrate/discuss with you the case of G23.3-0.3. This giant molecular cloud is more than 2 degrees wide and hosts a large number of HII regions and supernova remnants. Our spectroscopic survey has unveiled a dozen massive O stars, several red supergiants, and a candidate luminous blue variable (in isolation). The detected stars provide evidence for two epochs of star formation (6-8 Myrs ago and 20-30 Myrs ago). One cluster is detected, wich belongs to the first epoch.

Dr Ignacio Negueruela
University of Alicante, Spain

Title: High-mass star formation in the Outer Milky Way

Abstract: Open clusters in the Outer Milky Way are excellent laboratories to study star formation, because they suffer from low foreground extinction and negligible background contamination. I will present a spectroscopic survey of very young clusters towards the Galactic Anticentre (with Galactocentric distances > 10 kpc). Together with wide-field optical and IR imaging, these data provide evidence for high-mass star formation in a fashion very different from typical assumptions about massive clusters. All clusters present evidence for spatially-extended, sequential (likely triggered) small bursts of star formation. In most cases, the most massive star in the cluster is located away from the obvious "core" of the cluster, suggesting that it has formed separately from, and likely before, the main body of massive and intermediate-mass stars. In some cases, very massive stars are present in very small stellar concentrations, suggesting either stochastic sampling of the IMF or a very efficient mechanism to expel moderately massive stars.

Dr Sacha Hony
Institute of Theoretical Astrophysics, U. of Heidelberg, Germany

Title: Contrasting the gas and stellar distributions in N66: the most active star forming region in the SMC

Abstract: We present a direct comparison of the way the young stars and the dust and gas are distributed around N66, the most active star-formation site in the Small Magellanic Cloud. This comparison allows us to estimate the star-formation efficiency and the effects of stellar dynamics for decoupling the newly formed stars from the "parent" ISM from which they were born. N66 is of particularly interest, since it hosts a range of different environments including a rich clustered environment with over 2000 possible members and a more dispersed component extending over ~100 pc radius

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Dr Aina Palau
CRyA/UNAM, Morelia, Mexico

Title: Fragmentation of massive dense cores down to ~1000 AU: relation between fragmentation, density structure and turbulence.

Abstract: We present an observational project aimed at studying the fragmentation of massive dense cores, which constitute the first stages of cluster formation and the cradles where high-mass stars are born. We used the Plateau de Bure Interferometer in its most extended configuration, providing subarcsecond angular resolution, to observe the 1.3 mm continuum and CO(2-1) emission of four massive dense cores. This allowed us to study protoclusters down to mass sensitivities (~0.3 Msun) and spatial resolutions (~1000 AU) comparable to infrared/optical studies of clusters. We built, in combination with additional cores from the literature observed at similar mass sensitivity and spatial resolution, a sample of 19 protoclusters with luminosities spanning three orders of magnitude. Among the 19 regions, 30% show no signs of fragmentation, while 50% split up into >~ 4 millimeter sources. We inferred the density structure of the 19 cores through a simultaneous fit of the radial intensity profiles at 450 and 850 micron and the spectral energy distribution, and find a trend of fragmentation increasing with density within a given radius. Finally, we study the relation of turbulence and fragmentation level and found no signs of a possible trend. On the contrary, the best correlations are found for the case of pure `thermal' Jeans fragmentation. Our work suggests that gravity, rather than turbulence, is the key ingredient in determining the fragmentation level of massive dense cores.

Mr Robert Czanik
North Western University, Potchefstroom, South Africa

Title: A very interesting high mass star forming region RCW 34

Abstract: The high mass star forming region RCW 34 located in Vela presented a high number of deeply embedded low-mass members. In an initial deep study the NIR colours of these low-mass members let them cluster above the T Tauri locus, which is not common in other star forming regions. An extended study was performed at the beginning of 2014 on a larger field, determining how far the embedded low-mass members extends and if any of them presents variability. The results of the recent extended study will be presented and discussed.

Mr Shiwei Wu
MPIA, Heidelberg

Title: The Massive Stellar Population of W49: a Spectroscopic Survey

Abstract: As a part of the LOBSTAR project (Luci OBservations of STARburst regions), which aims at understanding the stellar content of some of the most massive star-forming regions, we present our first result on the high-mass stellar content of W49. K-band spectra of the candidate massive stars from VLT/ISAAC and LBT/LUCI provide us with reliable spectral types of dozens of massive stars in this HII region. The first results show that this region hosts several of the most massive stars in our galaxy. We identify the brightest star in the core of the central cluster in W49 as a very massive stars (M > 100 solar masses). The K-band spectrum is classified as a O2-3.5If* supergiant. After comparison to the Geneva evolutionary models, the mass range of W49nr1 was estimated to be between ~100 M⊙ and ~180 M⊙. Four other stars are classified as O3V-O5V stars with estimated masse masses around 50 - 60 M⊙. With the results from photometry and spectroscopy together of these and the lower-mass OB stars, we derived the stellar masses as long as the ages for the cluster members. This will give us a clue on understanding the formation history and the way massive star formation progresses in the star-forming region W49.

Session II: The dynamics of stars in (young) clusters: observations

Prof. Rob Jeffries
Keele University, UK

Title: The dynamics of young clusters from the Gaia-ESO survey

Abstract: I will briefly describe the ongoing Gaia-ESO spectroscopic survey, which amongst other things, includes measurements of large numbers of low-mass stars in young clusters and star forming regions, with a radial velocity precision of about 0.3 km/s. I will discuss some early results from the survey, which is able to resolve kinematic structure and determine the dynamical state of these young, nearby clusters

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Dr Vasilii Gvaramadze
Sternberg Astronomical Institute, Lomonosov Moscow State University, Russia

Title: Runaway massive (and less massive) stars

Abstract: A majority of massive stars form as binary systems in compact star clusters and then find themselves in the field due to two main processes: few-body dynamical encounters and binary-supernova explosions. In this talk I'll review the origin of high-velocity population of the field stars (the so-called runaway stars), the methods for their detection, and the role they play in constraining early dynamical evolution of star clusters.

Dr Vincent Henault-Brunet
University of Surrey

Title: Supernova ejection dominates the massive runaway star production of 30 Doradus

Abstract: Massive runaway stars can travel large distances from their birthplace during their lifetime, so that they can inject energy and processed chemical elements deep into the interstellar medium. Two distinct mechanisms have been proposed to explain their origin: dynamical interaction in a dense star cluster, or release from a close binary system when the companion explodes as a supernova. Understanding these mechanisms and their relative contribution is pivotal to quantify the feedback from massive stars in the broader context of reionization and the chemical enrichment of galaxies. In this contribution, we use data from the VLT-FLAMES Tarantula Survey (VFTS) to show that the overall runaway production of the archetypal young massive starburst 30 Doradus in the Large Magellanic Cloud is largely dominated by supernova ejection, with only a handful (10-20% of today's population), though spectacular, runaway stars produced by dynamical interactions. We discuss the implications of this relative scarcity of dynamically ejected runaways for cluster formation theories and the early life of 30 Doradus.

Dr. Nicholas Wright
CAR, University of Hertfordshire, UK

Title: Tracing the Origins of Star Clusters through their Structure and Kinematics

Abstract: I will present results from structural studies of star clusters that constrain their past dynamical evolution. For example in Cygnus OB2 we showed that the lack of mass segregation and considerable physical substructure shows that the association can not be an expanded star cluster. This suggests that the massive stars in Cygnus OB2 did not form in a dense star cluster by mechanisms such as competitive accretion or stellar

mergers that require high densities. I will also present results from a 3D kinematical survey of Cygnus OB2, combining radial velocities and proper motions to expose its current dynamical state and history. The kinematics do not exhibit the expanding motions that would be expected if the association were a disrupted star cluster undergoing infant mortality (disruption via residual gas expulsion). Instead the kinematics reveal considerable substructure showing that the association is not dynamically evolved and possibly reveal the primordial structures present during the star formation process.

Session III: The IMF & binarity: theory, statistics, and observations

Prof. Adam Kraus
University of Texas, Austin, USA

Title: Observations of Stellar Multiplicity in Star-Forming Regions and Young Clusters

Abstract: I will describe the current state of observational research into stellar multiplicity in star-forming regions and young clusters. Observational advances, driven by both high-resolution imaging and multiplexed spectroscopy, now offer the first complete and unbiased census of stellar multiplicity across a wide range of masses, ages, and environments. In particular, I will discuss the lessons for binary formation physics, the signatures of early dynamical evolution, and the final distributions of binary properties that should constitute the "initial conditions" for star clusters and the Milky Way field population.

Prof. Patrick Hennebelle
CEA, Saclay, France

Title: Analytical models of the initial mass function

Abstract: I will discuss the various models, which have been proposed to explain the IMF

Dr Sami Dib
NBIA & Starplan, Copenhagen, Denmark

Title: A non universal IMF in Galactic stellar clusters

Abstract: I will present results from a Bayesian statistics study of the IMF of young Galactic stellar clusters and argue that the IMF is not described by universal set of parameters.

Dr Morten Andersen
Laboratoire d'Astrophysique de Marseille

Title: The low-mass initial mass function and dynamical state of Westerlund 1

Abstract: Westerlund 1 is the most massive young star cluster known in the Galaxy and is as such a prime template to study massive clusters in their infancy in detail. Other super-massive star clusters are either extra-galactic and hence to distant to study in detail. We present results on the low-mass stellar initial mass function in the cluster reaching down to 0.15 Msun and whether it is similar to the field. This is tied with measurements of the clusters velocity dispersion to provide estimates on the fate of the cluster and whether it will remain bound.

Dr Francisco Maia
IPAG, Grenoble, France

Title: Near infrared study of the fainter stellar populations in Cygnus OB2

Abstract: The Cygnus X area is one of the richest star forming regions known in the Galaxy. It presents an extended structure to which are associated numerous optical, infrared and radio objects, scattered along 9 OB associations. However, the large extinction towards this region hampers most studies of its fainter, embedded stellar population. Previous studies in this region relied largely on 2MASS, being able to sample only its higher mass stellar content (> 5Mo). To address this issue, we have acquired deep CFHT/WIRCam exposures of an embedded cluster complex in the northeast region of the Cygnus OB2 association, sampling its stellar population down to the sub-solar mass regime. Stellar density maps, extinction maps, radial density profiles, color-magnitude/color-color diagrams and mass functions were employed to locate and characterise the stellar clusters in the area, focusing on their fainter population. These will provide a unprecedented view of the stellar formation history of this region.

Mr Peter Zeidler
Astronomisches rechen Institute, Heidelberg, Germany

Title: A Hubble Space Telescope multi-band survey with WFC3 and ACS of the young massive star cluster Westerlund 2

Abstract: Westerlund 2 is one of the most massive compact young Galactic star clusters. It is the central ionizing cluster of the giant HII region RCW 49. The winds and energetic radiation of its more than eighty O-type stars have created a cavity around the cluster and are eroding the surrounding giant molecular cloud, creating complex structure of pillars and bright-rimmed filaments whose tails point away from Westerlund 2. We recently obtained deep broad- and narrowband Hubble Space Telescope ACS and WFC3 images of Westerlund 2 to explore the evolutionary history of the starburst cluster and its surroundings. Our spatially resolved extinction maps permit us to obtain color-magnitude diagrams with indvidual stellar dereddening, allowing us to infer the distance, age, and age spread of Westerlund 2 with unprecedented accuracy and to constrain the anomalous extinction in the region. We trace the prominent pre-main-sequence population of Westerlund 2 across a mass range of ~0.5-11 solar masses. Some of those stars, including massive Herbig Ae/Be stars, exhibit considerable H alpha excess. The broad turn-on region towards the main sequence suggests an age spread of up to three Myr in Westerlund 2. Moreover, subclustering is visible in the region, and the data suggest a core-halo age gradient as found in other young clusters. We also analyze the mass function of Westerlund 2 and note that, just as in other similarly young massive compact clusters, mass segregation is already noticeable

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Session IV: Theoretical and numerical models of star formation

Prof. Matthew Bate
University of Exeter, UK

Title: The dependence of star cluster formation on initial conditions

Abstract: I will discuss the results from radiation hydrodynamical simulations of star cluster formation, and how the outcomes depend on initial conditions such as cloud density and metallicity

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Prof. Shantanu Basu
University of Western Ontario, London, Canada

Title: The Effect of Magnetic Fields on Fragmentation and the Core Mass Function

Abstract: Non-ideal MHD simulations of molecular cloud fragmentation reveal a very sensitive dependence of preferred fragment size on the ambient mass-to-flux ratio. Since the mass-to-flux ratio of a molecular cloud is not expected to be uniform, this provides a natural way to generate a very broad core mass function. I show quantitative results of this process. Furthermore, the change of magnetic field coupling as some parts of a molecular cloud are highly ionized by UV starlight and other parts only by cosmic rays means that a two-stage fragmentation process can occur. I present numerical simulations of this process.

Dr Troels Haugbolle
StarPlan & NBI

Title: Turbulent fragmentation and the IMF

Abstract: TBD

Dr. Seyit Hocuk
MPE, Garching, Germany

Title: Understanding the role of small and large scale physics in numerical sudies of star formation

Abstract: Star-forming gas clouds undergo many physical processes during their evolution from diffuse clouds to dense cores. During this time, large scale physics, such as gravity, turbulence, feedback, and magnetic fields, play a major role in the kinematics and the thermodynamics of collapsing clouds. This inevitably influences the efficiency in forming stars, the eventual masses of stars, as well as the mass distribution at stellar birth. While recent discoveries are shifting the paradigm of a universal initial mass distribution (IMF) to a non-universal one at the low-mass end, the high-mass end still seems to follow a Salpeter slope in the Milky Way. To understand this behaviour and the shape of the IMF, small scale physics, such as gas-phase and grain surface chemistry, may offer a solution. Linking physics that act on microscopic scales with the ones acting on macroscopic scales is unprecedented in simulations of star formation. In this review, I will try to enlighted the impact of different physics on star formation and, in the end, present the most recent studies in combining small and large scales to an ultimate theory of star formation.

Dr Dimitris Stamatellos
UCLAN, UK

Title: The binary properties of low-mass stars and brown dwarfs

Abstract: The binary properties of brown dwarfs (and low-mass stars) hide important information about their formation mechanism, and may be used to distinguish between different models. We use (i) hydrodynamic (SPH), and (ii) pure N-Body simulations, to determine the binary properties of brown dwarfs, low-mass stars, and planetary mass objects produced by disc fragmentation. We will present the predictions of this model regarding the distribution of semi-major axes, mass ratios and eccentricities of brown dwarf binaries, and compare these with observations. We will show that interactions of brown dwarfs with the gas in the disc, early after their formation, play a crucial role on how they pair with each other and on determining their final properties.

Prof. Paolo Padoan
ICREA & ICC, University of Barcelona, Spain

Title: Protostellar accretion and luminosity function

Abstract: We investigate the role of mass infall in the formation and evolution of protostars. To avoid ad hoc initial and boundary conditions, we consider the infall resulting self-consistently from modeling the formation of stellar clusters in turbulent molecular clouds. We show that infall rates in turbulent clouds are comparable to accretion rates inferred from protostellar luminosities or measured in pre-main-sequence stars. They should not be neglected in modeling the luminosity of protostars and the evolution of disks, even after the embedded protostellar phase. We find large variations of infall rates from protostar to protostar, and large fluctuations during the evolution of individual protostars. In most cases, the infall rate is initially of order 10^{-5}\msun\ yr^{-1}, and may either decay rapidly in the formation of low-mass stars, or remain relatively large when more massive stars are formed. The simulation reproduces well the observed characteristic values and scatter of protostellar luminosities and matches the observed protostellar luminosity function. The luminosity problem is therefore solved once realistic protostellar infall histories are accounted for, with no need for extreme accretion episodes. These results are based on a simulation of randomly-driven magneto-hydrodynamic turbulence on a scale of 4pc, including self-gravity, adaptive-mesh refinement to a resolution of 50AU, and accreting sink particles. The simulation yields a low star formation rate, consistent with the observations, and a mass distribution of sink particles consistent with the observed stellar initial mass function during the whole duration of the simulation, forming nearly 1,300 sink particles over 3.2 Myr.

Dr. Nicole Bailey
Max Planck Institute for Extraterrestrial Physics, Garching, Germany

Title: Two-Stage Fragmentation for Cluster Formation

Abstract: Linear analysis of the formation of protostellar cores in planar magnetic interstellar clouds has shown that the fragmentation length and time scales can undergo a dramatic drop across the column density boundary that separates the ultraviolet and cosmic ray dominated ionisation regimes. This drop can allow for a two-stage cluster formation process of clumps and cores within molecular clouds. Two dimensional, thin disk, non-ideal MHD simulations with partial ionisation reveal the necessary conditions for such a two-stage formation process to occur. I will discuss the linear analysis results and corresponding simulations, with focus on these conditions and velocity signatures.

Dr Tommaso Grassi
Starplan & NBI, Copenhagen, Denmark

Title: microphysics modelling with KROME.

Abstract: Herschel and ALMA are revolutionizing observational star formation, resolving for the first time the intricate structure of filaments that feed the pre-stellar envelopes. Interpreting these observations will require accurate modelling of protostellar regions using ground-breaking computational simulations that include advanced numerical techniques and detailed chemistry and microphysics. In order to make quantitative predictions from state-of-the-art magneto-hydrodynamical (MHD) simulations of protoplanetary environments one needs to have an accurate model of the micro-physics. Microphysics includes a large number of complex physical processes (cooling, heating, dust, opacity, and many others) and it is also tightly related to the chemical evolution, which is poorly understood in realistic models, and represents one of the critical computational bottle-necks of current simulations. To this aim I have recently developed an open-source code called KROME (http://kromepackage.org), which embeds most of the relevant physics for a large set of astrophysical environments (see Grassi et al. 2014). KROME is a state-of-the-art code to treat microphysics, and is uniquely flexible in the way it interfaces to other computational codes. KROME has successfully been employed in 3D simulations of the very first generation of primordial stars by coupling it to the cosmological fluid dynamics code Enzo.

Mr Soeren Frimann
Niels Bohr Institute & Starplan

Title: Bridging the Gap between Large-Scale Simulations and Observations of Star Forming Cores

Abstract: Bridging the gap between large-scale simulations and observations of star forming cores Numerical simulations and observations of star forming cores are topics which both see a lot of progress these years. MHD simulations of molecular clouds have reached a level, where it is possible to evolve the cloud on parsec scale, while simultaneously resolving the neighbourhood around the individual protostars on AU scale. At the same time interferometers such as ALMA, with its increased sensitivity and resolving capabilities, are making it possible to zoom in on the protostellar cores in their earliest stages and map their gas and dust content. The advances in simulations and observations also open the possibility of comparing the two directly to one another. The poster synthetic observations of a large number of protostellar cores, created from the high resolution numerical simulations of Padoan, Haugbølle & NordLund 2012 and Haugbølle et al. in prep. The synthetic observations are compared directly to real observations obtained from a range of different submm telescopes. The motivation for comparing real and synthetic observations is twofold. First it enables us to test the validity of the simulations by ensuring that the synthetic observations agree with the real ones, and in the cases where they differ to identify the issues. Second through the simulations we are able to gain additional insight into the physics behind the observations.

Mr Michael Kuffmeier
Niels Bohr Institute & Starplan, Copenhagen, Denmark

Title: Zooming in on star formation

Abstract: In the context of adaptive mesh refinement simulations of the collapse from pre-stellar cores simulated as part of giant molecular clouds - to disks, I investigate in particular the role of the magnetic field and its impact on the accretion as well as the outflow processes. The simulations cover a range of nearly 9 orders of magnitude, from 40 pc to 0.015 AU, and are carried out using the adaptive-mesh-refinement code

RAMSES (Teyssier 2002, Fromang et al. 2006). The strength of large-scale magnetic fields is shown to influence the accretion process dramatically, and is furthermore key to understand the launching of jets and outflows.The magnetic field goes through a characteristic sequence of structure evolution during the accretion process, starting out with an approximate hour-glass shape in the earliest phases of evolution, then evolving into a structure that contains a central jet and a broader disk outflow. Late in the accretion process the magnetic field is mainly oriented along the direction of rotation. However, it remains non-stationarity, with strong fluctuations in time and space being characteristic throughout the entire process. Jets and outflows, for example, are seldom symmetric- more often one side or the other dominates, only to be replaced by the opposite sense of symmetry breaking. The results presented in this poster thus demonstrate the variability of accretion processes due to the stellar environment, and illustrate how the environment influences the formation of protoplanetary disks. Moreover, I show that accretion, jets and outflows are not distinct processes, but that they are rather tightly coupled to each other. With respect to the computational setting, an adequately large number of cells per level of refinement is crucial to be able to model the accretion process, and the jet launching semi-quantitatively. Insufficient refinement leads to lower mass disks, which are lower in mass and more homogeneous. As a consequence, the influence of turbulence is smeared out and the jets are weaker with lower speeds for under resolved disks. The latter effect is related to the lower Kepler speed induced by the lower refinement, which causes a larger launching radius for the jet.

Session V: The dynamical evolution of stellar clusters

Dr Simon Goodwin
University of Sheffield, UK

Title: Star formation and the initial conditions of star clusters

Abstract: Star formation observation and theory suggest that stars form in complex hierarchical structures. I will discuss if star clusters are 'born' or 'made'.

Dr Sambaran Banerjee
Argelander-Institut für Astronomie, University of Bonn, Germany

Title: Formation of very young massive clusters: the case of NGC 3603 young cluster

Abstract: The ways in which near-spherical, gas-free, massive star clusters of very young age come into existence is among the most widely debated topic in astronomy. Once formed, one of the widely raised issue is their dynamical implications. In the first part of this talk, I discuss the formation channels of the well observed Galactic NGC 3603 young cluster (HD 97950), based on our recent studies. I demonstrate that the classical notion of monolithic cluster formation out of dense gas clumps remarkably reproduces the HD 97950 cluster. In particular, its shape, internal motion and the mass distribution of stars, are found to follow naturally and consistently from a single model calculation undergoing approx. 70% by mass gas removal. Next, we explore the possibility of formation of the same cluster via hierarchical merging of subclusters. Unlike the above monolithic initial system that reproduces the HD 97950 very well, the same is found to be practically impossible with hierarchical assembly alone. Only those systems which assemble quickly into a single cluster (in < 1 Myr) from a close separation (all within approx. 2 pc) could reproduce the observed density profile of HD 97950 after a similar gas removal. These results therefore suggest that the NGC 3603 young cluster has formed essentially in an episodic manner followed by a substantial residual gas dispersal. In the second part, I discuss the role of the young "super" star cluster R136, in the Tarantula nebula of the LMC, in generating runaway massive stars, based on our recent studies. In particular, we show that the existence of massive "slow runaway" stars like VFTS 682, in the vicinity of R136, can be easily explained by dynamical ejections from the R136 cluster. We also quantify the general properties of runaway O-type stars from an R136-like young massive cluster.

Dr. Richard Parker
LJMU, Liverpool, UK

Title: Making sense of mass segregation in clusters (observed and simulated)

Abstract: One of the major observables in star clusters is the phenomenon of mass segregation. Until recently, mass segregation was thought to be a predominately primordial effect (i.e. an outcome of the star formation process, rather than subsequent dynamical evolution). In this contribution, I will demonstrate that different methods to find mass segregation in both observed regions and simulations can produce apparently contradictory results. I will then present an overview of recent observational searches for mass segregation in clusters, using more than one method. I will then show that hydrodynamical simulations of star formation sometimes, but not always, show mass segregation. Finally, I will present the results of N-body simulations in which I show the initial conditions and evolutionary scenarios that lead to `dynamical' mass segregation and how we can distinguish this from `primordial' mass segregation.

Dr. Inti Pelupessy
Leiden Observatory, The Netherlands

Title: Modeling early cluster evolution with AMUSE

Abstract: The major challenge in astrophysics is the intrinsically multi-physics and multi-scale character of most astronomical systems. For example, the process of star formation involves the microphysics of dust and molecule formation, as well as self-gravity, hydrodynamics and radiative transfer on large scales, as well as the assembly of stars, disks and planets on intermediate scales. For each of these domains seperately there exist well tested and optimized code packages, which have been developed over decades. Combining them is often times a tedious and non-trivial endeavour. We have developed the Astrophysical Multi-purpose Software Environment (AMUSE) to couple component codes easily and develop combined simulations efficiently. AMUSE couples a wide range of astrophysical simulation codes in a homogeneous Python-based interface. I will present AMUSE, its current status and describe our experiences building this multi-physics framework as well as applications to the evolution of young clusters.

Prof. Jihad Touma
American University of Beirut, Lebanon

Title: Stellar dynamical remedies to star formation headaches: The triple nucleus of M31 in focus

Abstract: Forming stars deep in a super-massive black hole's sphere of influence is challenging enough. Forming them with distinctive (not to say exotic) kinematic features qualifies as a conundrum. We review the rich interplay between star formation scenarios and stellar dynamical processes in galactic nuclei, highlighting progress in the case of M31's triple nucleus.

Mr Giacomo Frangione
University of Rome (La Sapienza), Italy

Title: Gravity and Thermodynamics: fundamental principles and gravothermal instability

Abstract: In the dynamical evolution of globular clusters, stellar encounters strongly contribute in phase space mixing of stellar orbits. In this scenario, thermodynamics plays a central role in the gravitational equilibrium and stability of the clusters. On the other hand, the observations of luminosity profiles suggest a unique distribution function allowing the study of the evolution as a sequence of thermodynamic transformations, keeping constant the distribution of the star velocities, like in the framework of Boltzmann statistical mechanics. Then, we can construct equilibrium models with a different approach by applying thermodynamic principles to a Boltzmann distribution function, with an Hamiltonian which contains an effective potential depending on the kinetic energy of the stars. We also obtain new relations for the thermodynamical equilibrium in presence of gravity and introduce the concept of thermodynamic and kinetic temperature and pressure. The models present regions with positive and negative specific heat, producing thermodynamic instabilities which drive the clusters towards the so called gravothermal catastrophe.

Session VI: The formation of the Solar system, planets, in stellar clusters

Dr Ross Church
Lund Observatory, Sweden

Title: The birth stellar cluster of the Solar System

Abstract: We present two investigations into the nature of the stellar cluster in which the Sun was born. First, we use N-body simulations of star cluster evolution to explore the hypothesis that short-lived radioactive isotopes found in meteorites, such as aluminium 26, were delivered to the Sun's protoplanetary disc from a supernova at the epoch of Solar system formation. We determine the number of solar type stars that are within 0.1-0.3 pc of a 25 $M_\odot$ star when it explodes as a supernova, which is the distance required to enrich the protoplanetary disc with the aluminium 26 abundances found in meteorites. We then determine how many of these G-dwarfs are unperturbed `singletons'; stars which are never in close binaries, nor suffer sub-100 au encounters, and which also do not suffer strong dynamical perturbations. We find that the initial conditions for star formation do not strongly affect the results, and that ˜1 per cent of all G-dwarfs in our simulations are enriched, unperturbed singletons. Secondly, we investigate the possibility, implied by recent chemical abundance analyses, that the Sun may have been born in the rich, old open cluster M67. At a first blush this is excluded by the very different Galactic orbits of the Sun, which is a disc object, and M67, which is several hundred pc above the plane. We investigate what mechanisms act to drive clusters such as M67 up to large Galactic lattitudes, and show that spiral arms, the Galactic Bar and giant molecular clouds all play an important role. We show that if we include all these components we can construct a self-consistent model where the Sun was born in M67 and subsequently ejected in an encounter between M67 and a giant molecular cloud.

Prof. Melvyn Davies
Lund Observatory, Sweden

Title: Close encounters in the birth environments of planetary systems

Abstract: The birth environments of planetary systems are crowded places where dynamical encounters between stars are relatively common. We consider the role played by stellar flybys and exchanges into binaries on the formation and evolution of planetary systems. For example, we show how such encounters can destabilise planetary systems, leading to the ejection of some planets whilst leaving others on eccentric orbits. We quantify the frequency of close encounters as a function of initial conditions (i.e. density of star-forming regions, the initial motions of the stars within the region, and the lumpiness of the stellar distribution). We consider the possible role played by free-floating planets within star-forming regions, including encounters between free-floating planets and discs around stars.

Dr Giovanni Rosotti
IoA, Cambridge, UK

Title: Stellar encounters and protoplanetary disc evolution

Abstract: Most stars form in a clustered environment. Therefore, it is important to assess how this environment influences the evolution of protoplanetary discs around young stars. In turn, this affects their ability to produce planets and ultimately life. I will present 3D SPH/N-body simulations that include both the hydrodynamical evolution of the discs around their natal stars, as well as the dynamics of the stars themselves. The discs are viscously evolving, accreting mass onto the central star and spreading. I find penetrating encounters to be very

destructive for the discs as in previous studies, although the frequency of such encounters is low. I also find, however, that encounters influence much more disc radii than other disc properties, including mass. The disc sizes are set by the competition between viscous spreading and the disruptive effect of encounters. As discs spread, encounters become more and more important. In the regime of rapid spreading encounters simply truncate the discs, stripping the outer portions. In the opposite regime, I find that the effect of many distant encounters is able to limit the disc size, and can cause a mass redistribution that steepens the surface density profile of the discs. Finally, the simulations predict that disc sizes are limited by encounters at stellar densities exceeding ~ 2 □ 3 × 10^3 pc□2.

Ms Kirsten Vincke
MPIfR, Bonn, Germany

Title: How the dynamics of young clusters influence the properties of forming planetary systems

Abstract: Most stars formed not in isolation, but as part of a stellar cluster. A large variety of young clusters and associations exists, differing in size as well as in mass and density. Within these clusters – at least in the centre – stellar encounters are frequent events. The question arises, to what degree such encounters influence the protoplanetary discs surrounding the young stars. Using our extensive data archive of disc sizes after encounter events, we apply these to models of different clusters. We show that, perhaps surprisingly, the final sizes of protoplanetary discs are largely determined by the properties of the cluster environment and not their natal disc size.

Session VII: The role of feedback in the evolution and disruption of stellar clusters

Prof. Devendra Ojha
Tata Institute of Fundamental Research, Mumbai, India

Title: Triggered star formation in molecular clouds

Abstract: The formation of high-mass stars (M > 8MΘ) and their subsequent evolution can significantly alter the composition and morphology of the associated natal medium, which in turn can affect the star formation in a region. The harsh radiation field from early-type stars can either disperse a molecular cloud, thus quenching further star-formation activity, or provide impetus to existing clumps leading to triggered star formation. Understanding the effect of these feedback processes has been the subject of many theoretical and observational studies. In this talk, I focus on the multiwavelength study of classical HII regions. These HII regions harbour OB stars and are at an older stage of evolution, making them apt to study any discernible effects of the OB stars. We emphasize on a multiwavelength analysis of these regions to arrive at a coherent picture of the relevant stellar activity. In particular, we find likely evidence of induced star formation at the borders of the HII regions, which could suggest radiation driven implosion, triggering due to the advancing ionization front, or sweeping-up of material leading to instability and star formation. The properties of the stellar clusters formed in such a manner are also discussed.

Dr. Mauricio Tapia
Instituto de Astronomia, UNAM, Ensenada, Mexico

Title: Evidence of sequential star formation processes involving mid-size embedded clusters. The examples of RCW 121, IRAS 12272-6240 and Trumpler 14-N4.

Abstract: We present near- to far-infrared ground-based, and satellite observations of three regions containing very young, massive embedded clusters in relatively different environments. Apart from deriving the properties of their young stellar population, we discovered the presence of younger protostars in their vicinity. These characteristics support the idea that sequential or triggered star formation is very common, not only in very large and massive molecular complexes, but also in more modest clouds. The regions for which we present evidence for such scenarios are RCW~121 (IRAS~17149-3916), G287.47-0.54 (Tr~14-N4) in the Northern Carina Nebula and IRAS 12272-6240. The data were obtained with the Baade/Magellan telescope at Las Campanas Observatory, and from the Spitzer and Herschel space observatories' archives.

Prof. Robi Banerjee
Hamburg Observatory, Germany

Title: Disc Formation and Feedback from YSOs

Abstract: TBD

Prof. Aake Nordlund
NBI & Starplan, Copenhagen, Denmark

Title: Feedback on molecular cloud scales

Abstract: TBD

Dr. James Dale
Excellence Cluster Universe, LMU, Germany

Title: Before the supernovae - effects of ionisation and winds on embedded clusters

Abstract: I will present results from a comprehensive suite of models of embedded clusters in molecular clouds ranging from 10^4 -10^6 solar masses in mass, 2.5-180pc in radius and having virial parameters between 0.7 and 2.3. I will examine the effects of photoionisation and winds from the O-stars on the clouds and clusters, in particular on star formation rates, initial mass functions and the dynamical states of the clusters.

Dr Ary Rodriguez-Gonzalez
Instituto de Ciencias Nucleares, UNAM, Mexico

Title: The dynamics of superbubbles driven by star cluster winds and a supernova explosion

Abstract: The supershells are interstellar material pushed by the mechanical energy injected by the massive stars via stellar winds and supernova explosions. The supershells have been clasified in high and low velocity. The high velocity supershells do not follow the predicted velocity by the standard model. We studied the dynamics of the supershell taking into acount the mechanical energy injected by the massive stellar winds (in early and late stages), thermal conduction, supernova explotions and the stellar distribution in the volume of the cluster. We also explored the mass cluster effects in the acceleration and/or deacceleration of their supershells. We compare our analytical and numerical results with optical observation of extragalactic supershells.

Dr Pascal Tremblin
University of Exeter, UK

Title: Impact of ionization compression on turbulent molecular clouds, and dating of OB associations

Abstract: The expansion of hot ionized gas from an Hii region into a turbulent molecular cloud compresses the material and leads to the formation of dense continuous layers as well as pillars and globules in the interaction zone. This feedback should also impact the probability distribution function (PDF) of the column density around the ionized gas. We aim to quantify this effect and investigate its link to the Initial Mass Function (IMF) using Herschel column density maps and 3D simulations with the HERACLES code. The double-peaked/enlarged shape of the PDF in high-mass star-forming regions could impact the gravo-turbulent scenario used to derive the CMF supposed to be at the origin of the IMF. We derived also an analytical solution that follows the expansion of the region in a turbulent medium and test is against 1D and 3D simulations. From the corresponding 1D simulations, we computed a grid of models that can be used to estimate the age of large sample of OB associations. We applied the method to the HRDS survey and tested it on well- known regions. This method could also be used for the dating of extra-galactic Hii regions.

Mr. Troels Frost Morgensen
Starplan & NBI, Copenhagen, Denmark

Title: Ray Tracing Radiative Transfer with Ramses

Abstract: Using ray tracing radiative transfer in the context of an adaptive mesh refinement magnetohydrodynamics simulation of star formation, the thermal structure of the environment around a forming star can be studied in details. I present a new such radiative transfer method, and describe how it performs and

how it may be coupled with a non-equilibrium chemistry model to study the thermodynamics of the proto-stellar disk.

Mr Antonio Castellanos
Instituto de Ciencias Nucleares, UNAM, Mexico

Title: The soft and hard X rays thermal emission into massive stellar cluster winds with a supernova explosion

Abstract: Massive young stellar clusters contain dozens or hundreds of massive stars that inject mechanical energy in the form of stellar winds and supernova explosions, producing an outflow which expands into the surrounding ISM and forms superbubbles. Shocked material from the stellar winds and the supernovae fills in the internal part of the bubble, and the swept-up surrounding ISM forms an exterior shell. The regions of shocked gas have temperatures that exceed 10^6 K, mainly emitting in thermal X-rays (soft and hard). Both the X-ray emission and the dynamical characteristics of these objects are strongly affected by the presence of thermal conduction and by the metallicity of the gas injected by the massive stars. In this talk we will show three-dimensional numerical simulations exploring the effects of thermal conduction and of the metallicity of the stellar winds and the supernova explosions. The resulting, strong effects on the thermal, soft and hard X-ray luminosity (produced by the cluster outflows) will be discussed.

Dr Paolo Persi
IAPS/INAF, Rome, Italy

Title: The complex star forming region IRAS15507-5359

Abstract: Three massive star forming cores (here named I,II, and III) were found by Herschel observations in a field of approximately 2’X2’ around IRAS15507-5359. We present here sub-arcsec resolution broad-band and narrow-bands near-IR images of this region. Our images were compared with IRAC/Spitzer and Herschel images from 70 to 500 micr. Masses and temperatures are derived for the three dense cores that appears at very different evolutionary stages. In the dense core II in which is present an HII region, we have detected a young stellar cluster, while the dense core I associated with a dark cloud , is a starless cores. Finally the dense core II is characterized by the presence of a red filamentary structure observed in the near and mid-IR.

Session VIII: Star formation, stellar populations, and feedback on galactic scales

Prof. Ian Bonnell
University of St. Andrews, UK

Title: Galactic flows and the formation of stellar clusters

Abstract: We will present ongoing work on how galactic scale flows due to spiral arms can lead to the formation of dense molecular clouds and star formation. These simulations show that the origin of stellar clusters comes from flows over 10 pc in size. The formation itself is due to a combination of the large scale convergent flows coupled with self-gravity once the gas reaches higher densities. The large scale flows naturally result in longer time span for star formation and hence significant age dispersions. We will also discuss ongoing accretion and feedback in the contact of forming stellar clusters and the initial mass function.

Prof. Pavel Kroupa
Helmholtz-Institut fuer Strahlen- und Kernphysik, University of Bonn, Germany

Title: The stellar populations of galaxies from their fundamental building blocks

Abstract: Observations of binary stars in the Galactic field and in star-forming regions as well as surveys of star-formation in nearby molecular clouds have shown stars to form in embedded clusters. These are the "fundamental building blocks" of galaxies. They form very compact and rapidly expell the majority of the original gas mass. Their stellar populations have systematically varying properties. A particularly important property is that they disrupt binaries to a varying degree, and that extreme cases have top-heavy stellar IMFs. I will show that many properties of dwarf to massive galaxies can be derived with this notion by summing up all fresh stellar populations in the embedded clusters. An important result is dynamical population synthesis which allows predictions of binary star populations in different types of galaxies. Another important result is the prediction of a systematically varying galaxy-wide IMF. According to this IGIMF theory dwarf galaxies have top-light galaxy-wide IMFs, while galaxies with high star formation rates have top-heavy IMFs, as is observed.

Dr. Michael Butler
University of Zurich, Switzerland

Title: Kiloparsec-Scale Simulations of Star Formation in Disk Galaxies: Structure and Dynamics of Filaments and Clumps in Giant Molecular Clouds

Abstract: We present hydrodynamic simulations of self-gravitating dense gas in a galactic disk, exploring scales ranging from 1 kpc down to ~0.1 pc. Our primary goal is to understand how dense filaments, clumps and cores form in Giant Molecular Clouds (GMCs). These structures are thought to be the precursors to massive stars and star clusters, so their formation may be the rate limiting step controlling global star formation rates in galactic systems as described by the Kennicutt-Schmidt relation. Our study follows on from Van Loo et al. (2013, Paper I), which carried out simulations to 0.5 pc resolution and examined global aspects of the formation of dense gas clumps and the resulting star formation rate. Here, using our higher resolution, we examine the detailed structural properties of dense filaments and clumps, including the mass per unit length along filaments and its dispersion, transverse density profiles, filament fragmentation and column density probability distribution functions. We also study kinematic properties of line of sight velocity distributions, gradients in velocity centroids and infall motions to and along the filaments. Finally we consider the dynamical state of the clouds via the filamentary virial theorem. These properties are then compared to observations of dense clumps

and filaments within Galactic GMCs, in particular via studies of Infrared Dark Clouds (IRDCs). While a number of the properties of the simulated clouds are similar to observed systems, the overall densities and star formation rates in the simulation are much higher. Also the kinematics of the simulated structures are much more disturbed, with large velocities and velocity gradients produced during global collapse.

Prof. Andres Escala
Institution: Univesidad de Chile

Title: Formation of Massive Stellar Clusters in Galaxy Mergers.

Absract: Using high resolution SPH numerical simulations, we study the formation of massive star clusters on galactic mergers. We specifically setup merger simulations, to study the physical conditions for the formation of super-GMCs during the merger and the regions more favorable for massive cluster formation. We also compare our results against simple analytical estimates from gravitational instability.

Ms Diana Estrella
Instituto de Astronomia, UNAM, Mexico

Title: Models of cold low velocity clouds

Abstract: We propose a method to measure distances to Cold Low Velocity Clouds. The CLVC are HI clouds characterized by having an angular size in the range of 4 and 12 arcsec, |VLSR| < 90 km s-1, Tb between 0.3 and 1.8 K, as well as a columnar density NHII from 2.5 x10^18 to 14.2 x10^18 cm-2, and linewidths Δv <15 km s-1. The distances are largely unknown. The large number of positive-velocity cold LVCs requires some process to eject them away from the disc, be it the buoyancy of the gas or feedback from star formation in the disc. Two possible origins of the cold LVCs are a Galactic fountain process or cooling disc-halo interface gas. In a Galactic fountain model, gas is expelled out of the plane of the Galaxy by some energetic process and then rains back down out of the halo (Shapiro & Field 1976). From simple, analytic considerations we derive a method for determining the position on the Galactic disc in which the individual clouds have originated. We apply this method to observations from the Galactic Arecibo L-Band Feed Array Survey Data Release One.

Session IX: Globular clusters

Prof. Corinne Charbonnel
University of Geneva, Switzerland & CNRS, France

Title: The turbulent dawn of globular clusters

Abstract: Globular clusters are fascinating objects nearly as old as the Universe that give insight on a wide variety of astrophysical and cosmological issues. A major paradigm shift has recently occurred that has revolutionised our picture of these objects that were long thought to be simple systems of coeval stars born out of homogeneous material. Indeed, detailed abundance studies of GC long-lived low-mass stars, made possible with 8-10m class telescopes, together with high-precision photometry of Galactic GCs performed with HST, have revealed that individual GCs do actually host multiple stellar populations. Those manifest themselves through their different chemical properties and by the appearance of multimodal sequences in the colour-magnitude diagrams. This new paradigm has a severe impact on our understanding of the formation and early evolution of these objects, on the role played by massive stars in the GC infancy, as well as on the estimate of the fraction of Galactic halo stars that may have originated in massive star clusters. In this talk I will focus on the importance of the physics of the intra-cluster medium in the scenarii that have developed in the literature in order to explain the “self-enrichment” of the infant GCs. I will explore the implications for the formation of second-generation stars and I will propose a detailed timeline for the 40Myrs in the lifetime of a typical GC.

Prof. Søren Larsen
IMAPP, Nijmegen, The Netherlands

Title: Observational constraints on globular cluster formation scenarios

Abstract: It is well established that globular clusters (GCs) exhibit large star-to-star variations in their abundances of light elements, with a large fraction of the stars in GCs having abundance patterns that are not observed in field stars. Various scenarios have been proposed to account for these observations, including formation of a second generation of stars out of polluted ejecta from AGB stars or massive main sequence stars, or by accretion of ejecta from massive interacting binaries onto discs around low-mass stars. I will discuss recent observational tests of these scenarios, including 1) constraints on the amount of mass loss from GCs via observations of GCs in dwarf galaxies, 2) the spatial distribution of stellar populations within GCs, and 3) the (lack of) evidence for an ISM or on-going star formation in young massive cluster

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Dr Akram Hassani Zonoozi
IASBS, Zanjan, Iran

Title: Dynamical models for the remote halo globular clusters Pal 4 and Pal 14

Abstract: Star clusters can undergo significant changes not only at birth but also during the course of their dynamical evolutions. It is therefore essential to specify to what extent the present-day properties of a globular cluster, are imprinted by early evolution and the formation processes, and to what extent they are the outcome of long-term dynamical evolution. One of the important quantity that has to be taken into account in the modelling of star clusters is the initial mass function (IMF, which is an empirical function that describes the distribution of initial masses for a population of stars). Previous publications of our group (Zonoozi et al 2011, 2014), have studied the dynamical evolution of two specific GCs, Palomar 14 and Palomar 4. We showed that

dynamical mass segregation alone cannot explain the mass function flattening in the cluster centre when starting from Kroupa IMF, and that a very high degree of primordial mass segregation would be necessary to explain this discrepancy. Alternatively, since star clusters lose more mass during pericentric passages on eccentric orbits, and undergo stronger expansion due to the weaker tidal fields at larger Galactic radii, an eccentric cluster orbit might have had an important influence on Pal 4's evolution, as it could have had a much smaller initial size and significantly higher mass. In the rest of my presentation I will give the more recent results of eccentric orbits for these clusters. We showed that even extreme eccentric orbit alone can not reproduce such amount of flattening in Pal 4 and Pal 14, and a large amount of degree of primordial segregation is still needed.

Dr Hosein Haghi
IASBS, Zanjan, Iran

Title: How does the gas expulsion phase affect the initial conditions of star clusters ?

Abstract: The study of stellar clusters has played an important rule in developing of our knowledge about the universe. Since most stars in the galactic disc may originate in star clusters, these systems can therefore be investigated as the fundamental building blocks of galaxies to understand the origins of the properties of the galactic stellar population, such as the galactic stellar mass function. Detailed knowledge of the initial condition of globular clusters, is necessary to understand the evolution of stellar system including all physical processes that may happen during their evolution. Zonoozi et al. (2011, 2014), have been found that dynamical mass segregation alone cannot explain the mass function flattening in the cluster centre when starting from a canonical Kroupa IMF, and that a very high degree of primordial mass segregation would be necessary to explain this discrepancy. We concluded that such initial conditions for Pal 14 and Pal 4 might be obtained by a violent early gas-expulsion phase from an embedded cluster born with mass segregation and a canonical IMF for low-mass stars. After modelling some realistic Galactic clusters and finding the initial conditions, as a next stage we need to understand how this connects to what we know of star formation. So the t=0 condition which we constrained is the state of the cluster after re-virialisation and after gas expulsion. But how does the prior phase work, and what are the possible birth configurations, given the t=0 boundary condition? Which birth conditions do gas-expulsion computations covering the first 100 Myr of a Pal 14/4 type cluster require for the post-gas expulsion re-virialised cluster to match up with the initial conditions found for Pal 14/4? Did gas expulsion even play a dynamical role for Pal 14/4? This work would require many more stars in the N-body models, but covers a much shorter time, and would be done without binaries (as a first step). In my talk I therefore try to answer these questions.
