Monday 10 June

Invited Talk: Massive Globular Clusters
Giampaolo Piotto
Padova

Terzan 5: a fossil remnant of the Galactic Bulge
Francesco Ferraro
Dipartimento di Fisica e Astronomia, Università di Bologna

Terzan 5 is a stellar system commonly catalogued as a globular cluster (GC), located in the inner Bulge of our Galaxy, at a distance of 5.9 Kpc from Earth. Two distinct sub-populations have been recently discovered in this system (Ferraro et al. 2009, Nature, 462, 483). They define two well separated (by $\sim 0.3$ mag) red clumps in the (K, J-K) colour-magnitude diagram (CMD) and show very different iron content: Fe $\sim 0.5$ dex (such a large difference in iron abundance has been found only in another GC-like stellar system, omega Centauri, in the Halo of the Galaxy). Moreover, the abundance of light elements measured in both sub-populations has been found not to follow the typical anti-correlations observed in genuine GCs and the overall chemical patterns appear strikingly similar to those of Bulge stars (Origlia et al. 2011, ApJ 726, L20). These observational results demonstrate that Terzan 5 is not a genuine GC, but a stellar system that experienced complex star formation and chemical enrichment histories. The strong chemical link with the Bulge, together with the location in the inner region of it, suggest that Terzan 5 (at odds with omega Centauri) is not the nucleus of an accreted dwarf galaxy, but possibly the relic of one of the pristine fragments that contributed to form the Bulge itself.

Formation and Dynamical Evolution of Multiple Stellar Populations in Globular Clusters
Enrico Vesperini
Indiana University

An increasing number of photometric and spectroscopic observational studies are providing strong evidence that many globular clusters host multiple stellar populations. This discovery raises numerous theoretical questions concerning the formation and dynamical evolution of globular clusters. I will present the results of our studies on the formation of multiple populations in globular clusters, the dynamical evolution of their structural and kinematical properties and the implications of the structural properties of multiple population clusters for the evolution and disruption of cluster binary stars. The link between multiple populations in globular clusters and the possible contribution of globular clusters to the assembly of the Galactic halo will also be discussed.

Discrete dynamical modelling of Local Group stellar systems
Laura Watkins
MPIA

Dynamical modelling of nearby galaxies with unresolved integral-field spectroscopy data has been carried out very successfully and makes excellent use of the data available. The same cannot be said for objects in the Local Group; we are in the fortunate position of having discrete, resolved datasets - often of both high quality and high quantity - yet the dynamical modelling techniques employed typically degrade
the data by spatially binning, are often overly simplified, and make assumptions that are not always (astro)physically justified. To address these issues, we are developing discrete dynamical modelling tools that use maximum-likelihood analysis to fully exploit the resolved nature of the data. Such an approach avoids the loss of information due to spatial binning and allows contaminant populations to be included directly in the models for better membership identification. With these models, we hope to better constrain the dark matter content of dwarf galaxies and address the question of the presence of intermediate-mass black holes and dark matter in globular clusters. The work I will describe is some of the steps we have taken towards this goal. This includes the application to the globular cluster Omega Centauri, which is a calibration object for HST/WFC3 and, as such, has a wealth of high-quality data available.

The most metal-poor, C-rich and C-normal, populations of the Galaxy’s Halo and Ultrafaint Dwarf Satellites
John Norris
RSAA, ANU

The carbon-normal and carbon-rich metal-poor stars with \([\text{Fe/H}] > -3.0\) hold a key to an understanding of the formation and nature of the first stars, while the relationship between the Milky Way Galaxy’s ultrafaint dwarf galaxy satellites and its outer halo provides further information on the manner in which larger galaxies assemble. The case will be presented, based on high-resolution, high S/N, chemical abundance analyses, that at lowest iron abundance the C-rich and C-normal halo stars represent two distinct star formation channels at the earliest times. High quality chemical abundances of red giants in the Bootes I and Segue 1 ultrafaint dwarf galaxies will be discussed, which suggest that similar populations exist in these systems as well. The comparison supports the growing consensus that low mass dwarf galaxies played an important role in the formation of the Galaxy’s halo.

The NGC 5253 star cluster system: infrared excess and the effects of stochasticity
Richard de Grijs
Kavli Institute for Astronomy and Astrophysics, Peking University

Using high-resolution Hubble Space Telescope data, we reexamine the fundamental properties (ages, masses and extinction values) of the rich star cluster population in the dwarf starburst galaxy NGC 5253. The gain in resolution compared to previous studies is of order a factor of two in both spatial dimensions, while our accessible wavelength range transcends previous studies by incorporation of both near-ultraviolet and near-infrared (IR) passbands. We apply spectral synthesis treatments based on two different simple stellar population model suites to our set of medium-/broad-band (and H-alpha) images, taking into account the updated effects of nebular emission and improved physical understanding of the IR-excess flux found for a subset of young clusters (30 of 149), while also explicitly addressing stochasticity in the stellar mass function. The NGC 5253 cluster population is dominated by a significant number of relatively low-mass \(M_{cl} > 10^4 \text{ Msun}\) objects with ages ranging from a few \(10^6\) to a few \(10^7\) yr, which is in excellent agreement with the starburst age of the host galaxy. The IR-excess clusters are almost all found in this young age range and have masses of up to a few \(10^4\) Msun. The IR excess in the relatively low-mass NGC 5253 clusters is most likely caused by a combination of stochastic sampling effects and colour variations due to the presence of either red supergiant or pre-main-sequence stars. We also find a small number of intermediate-age (\(~1\) Gyr-old), \(\sim 10^5\) Msun clusters, as well as up to a dozen massive, \(~10\) Gyr-old globular clusters. Their presence supports the notion that NGC 5253 is a very active galaxy that has undergone multiple episodes of star cluster formation.
Black Holes in Globular Clusters
Jay Strader
Michigan State University

I will discuss recent multi-wavelength observational and theoretical work on the presence of stellar-mass and intermediate-mass black holes in globular clusters.

The Enigma of NGC 2419, an extreme outer halo globular cluster
Judith Cohen
Caltech

Although NGC 2419 is among the most distant and luminous globular clusters in the Milky Way, it was considered chemically ordinary until very recently. We have established that NGC 2419 harbors a population of stars, comprising about one third of its mass, that is depleted in Mg by a factor of 8 and enhanced in K by a factor of 6 with respect to the Mg-normal population. Although the majority, Mg-normal population appears to have a chemical abundance pattern indistinguishable from ordinary, inner halo globular clusters, the Mg-poor population exhibits dispersions of several elements. The abundances of K and Sc are strongly anti-correlated with Mg, and some other elements (Si and Ca among others) are weakly anti-correlated with Mg. These abundance patterns suggest that the different populations of NGC 2419 sample the ejecta of diverse supernovae in addition to AGB ejecta. However, the abundances of Fe-peak elements except Sc show no star-to-star variation. We find no nucleosynthetic source that satisfactorily explains all of the abundance variations in this cluster. We discuss very recent attempts in the literature by Ventura et al to explain all this via super AGB stars with very hot bottom burning. With luck and good weather (and this cannot be guaranteed at present) we will present new evidence which can refute or support this hypothesis.

Bootes III: Disrupting Before our Eyes?
Carl Grillmair
California Institute of Technology

I discuss Bootes III, the presumed remnant of a dwarf galaxy. If bound, its measured velocity dispersion suggests a very high dark matter content. The object may or may not be the progenitor of the Styx stellar stream. If so, then its dark matter content should have been stripped away long ago. Yet if unbound, BooIII should have dispersed on a time scale of just $10^4$ years. Whether bound or disrupting, a more detailed dynamical study of BooIII may yield new insights into the distribution of dark matter and/or the workings of gravity at very low accelerations.
Hot Question Discussion: Bimodality

Suk-Jin Yoon
Yonsei University

Michele Cantiello
INAF Osservatorio Astronomico di Teramo

Christopher Usher
Swinburne University of Technology

Ana Chies-Santos
University of Nottingham

Jay Strader
Michigan State University
Tuesday 11 June

Invited Talk: Globular Cluster Systems
Jean Brodie  
UCSC

The metallicity bimodality of globular cluster systems: a test of galaxy assembly and of the evolution of the galaxy mass-metallicity relation

Chiara Tonini  
Swinburne University of Technology

We build a theoretical model to study the origin of the globular cluster metallicity bimodality in the hierarchical galaxy assembly scenario. The model is based on empirical relations such as the galaxy mass-metallicity relation \([O/H]-M(\text{star})\) as a function of redshift, and on the observed galaxy stellar mass function up to redshift \(z \sim 4\). We make use of the theoretical merger rates as a function of mass and redshift from the Millennium simulation to build galaxy merger trees. We derive a new galaxy \([\text{Fe/H}]-M(\text{star})\) relation as a function of redshift, and by assuming that globular clusters share the metallicity of their original parent galaxy at the time of their formation, we populate the merger tree with globular clusters. We perform a series of Monte-Carlo simulations of the galaxy hierarchical assembly, and study the properties of the final globular cluster population as a function of galaxy mass, assembly and star formation history, and under different assumptions for the evolution of the galaxy mass-metallicity relation. The main results and predictions of the model are the following. 1) The hierarchical clustering scenario naturally predicts a metallicity bimodality in the galaxy globular cluster population, where the metal-rich subpopulation is composed of globular clusters formed in the galaxy main progenitor around redshift \(z \sim 2\), and the metal-poor subpopulation is composed of clusters accreted from satellites, and formed at redshifts \(z \sim 3-4\). 2) The model reproduces the observed relations by Peng et al. (2006) for the metallicities of the metal-rich and metal-poor globular cluster subpopulations as a function of galaxy mass; the positions of the metal-poor and metal-rich peaks depend exclusively on the evolution of the galaxy mass-metallicity relation and the \([O/Fe]\), both of which can be constrained by this method. In particular, we find that the galaxy \([O/Fe]\) evolves linearly with redshift from a value of \(\sim 0.5\) at redshift \(z \sim 4\) to a value of \(\sim 0.1\) at \(z = 0.3\). 3) For a given galaxy mass, the relative strenght of the metal-rich and metal-poor peaks depends exclusively on the galaxy assembly and star formation history, where galaxies living in denser environments and/or early types galaxies show a larger fraction of metal-poor clusters, while galaxies with a sparse merger history and/or late type galaxies are dominated by metal-rich clusters. 4) The globular cluster metallicity bimodality disappears for galaxy masses around and below \(M(\text{star}) \sim 1 \times 10^{9} \, M(\text{sun})\), and for redshifts \(z > 2\).

Modeling Self Enrichment in Globular Clusters

Jeremy Bailin  
University of Alabama

I present a theoretical model to describe self-enrichment in globular clusters. Our model assumes that the highest mass stars formed, evolved, and exploded as supernovae while the lower-mass stars visible today were still forming, seeding the protocluster cloud with metals while also gravitationally unbinding some of the gas. A mass-metallicity relationship naturally arises in this model, which provides a good match to the "blue tilt" of GCs around massive elliptical galaxies and predicts a milder "red tilt" at higher luminosities. I also present our recent calibration of the metallicity-colour relation in the HST/ACS filter system, which is required to test these models.
Scaling relations of small stellar systems
Duncan Forbes
Swinburne University of Technology

The distinction between massive globular clusters, ultra compact dwarfs and dwarf galaxies has become increasingly blurred. Here I present recent examples of individual small stellar systems and place them on scaling relations to explore the connections across a range of mass. I examine size, luminosity (stellar mass) and when possible internal velocities (dynamical mass). Finally, I speculate on the origin of small stellar systems.

The leverage of globular cluster systems: a kinematic perspective
Vincenzo Pota
Swinburne University of Technology

I will present some results from an extended spectro-photometric survey of a dozen never-before studied GC systems, with particular emphasis to their kinematics. These were obtained from the synergy between the Subaru/Suprime-Cam wide-field imager and the Keck/DEIMOS multi-object spectrograph. The kinematics for each GC system and for their metal-rich and metal-poor subpopulations will be discussed in terms of: (i) origin and evolution of GC systems, (ii) connection with supermassive black holes and (iii) galaxy dark matter halos modelling.

Detailed Abundances of GCs in NGC 5128, M31, and the Local Group Dwarfs
Rebecca Bernstein
University of California, Santa Cruz

Using the method that we have developed for measuring detailed chemical abundances of extragalactic Globular Clusters (GCs), we have obtained abundances for 20 elements (including Fe, alpha-elements, r- and s-process elements, and light elements) in over 30 GCs in M31, 11 GCs in NGC 5128, and more than 15 GCs in Local Group Dwarf galaxies. We present those abundances here. Differences are evident in the alpha and heavy element abundance ratios between galaxies, particularly at the high [Fe/H] regime. Light element abundances show the presence of the Na-O and Mg-Al abundance anti-correlations, which are well known in Milky Way GCs. We will discuss the patterns in these abundance ratios as a function of GC mass, age, galaxy type, and environment, and the clues those patterns provide into the formation scenarios of GCs and the parent galaxies. We also discuss the horizontal branch morphology of extragalactic GCs that can be constrained using the full optical wavelength coverage of our high resolution integrated light spectra. These constraints are used to investigate the second parameter effect through the [Fe/H] vs. HB morphology relation of other galaxies.
Discovery of unusually large globular clusters or unusually compact ultra compact dwarfs
Caroline Foster
ESO - Chile

We present the details of the discovery of three interesting objects around the elliptical galaxy NGC 4494. These objects share some characteristics of both globular clusters and ultra-compact dwarfs. Hence, they could be transitional objects between the two types of star clusters.

The Rich Globular Cluster System in Abell 1689 and Variations in Formation Efficiency
John Blakeslee
NRC Herzberg Institute of Astrophysics

We present new results on the extremely rich globular cluster (GC) system at z=0.18 in the center of Abell 1689, one of the most powerful gravitational lensing clusters known. At 28 orbits, this is the deepest single-pointing HST/ACS observation in F814W (broad I-band), and we reach $I_{814} > 29$ mag with 90% completeness. Assuming a standard GC luminosity function, we estimate a total population of 160,000 GCs within a projected radius of 400 kpc. The statistical error is small, and the main uncertainty results from the GCLF parameters. However, with a lower limit exceeding 100,000 GCs, the system is unprecedentedly large. The specific GC frequency $S_N$ rises outward from the central cD galaxy, and although the $S_N$ is high, it is not anomalous for the centers of massive galaxy clusters. We compare the radial distributions of the GCs, galaxy light, X-ray intensity, and total lensing-derived mass. The Abell 1689 GCs appear intermediate between the galaxy light and cluster mass distributions. We discuss implications for cluster evolution arising from this extremely rich data set. Finally, we present recent results on intracluster GCs from the Next Generation Virgo Cluster Survey.

UCDs in the Perseus Cluster core: evidence for multiple formation mechanisms
Samantha Penny
Monash University

Deep Hubble Space Telescope imaging has made it possible to study the cores of nearby rich galaxy clusters in incredible detail, including their compact stellar systems. Using HST, we have uncovered a large population of UCDs around NGC 1275, the brightest galaxy in the Perseus Cluster. I will present evidence of multiple formation channels for these UCDs. While the majority of UCDs in this region follow an extrapolation of the red sequence of Perseus dEs to fainter magnitudes, three UCDs in the complex star forming filaments surrounding NGC 1275 have remarkably blue colours of $(B-R) < 0.6$. These UCDs must therefore have ceased star formation at recent times ($< 100$ Myr), with GCs and UCDs likely forming in NGC 1275 at the present time. I will also show that a subset of UCDs in Perseus originate as stripped dEs, with Keck-DEIMOS spectroscopy revealing a remarkably high internal velocity dispersion ($> 30$ km/s) for the most massive UCD in our sample ($r_e = 57$ pc). Finally, a fraction of Perseus UCDs follow the same colour trends as the globular cluster population of NGC 1275. These results suggest that UCDs in Perseus originate both as massive star clusters and tidally stripped galaxies.
Invited Talk: Ultra-compact dwarfs: what we know about them 15 years after their discovery
Michael Hilker
European Southern Observatory - Germany

I propose to give a review on the properties of UCDs, small stellar systems at the interface between star clusters and dwarf galaxies. After a brief overall summary, I will focus in particular on two aspects. 1. The specific frequencies of UCDs - a recently introduced quantity that allows to test whether the luminosity distribution of UCDs follows the bright tail of the globular cluster luminosity function. Can all UCDs be explained as bright star clusters? 2. The elevated dynamical M/L ratios of UCDs. How massive would central black holes in UCDs have to be to explain them? Where are UCDs located in the M-sigma plane with respect to bulges, nuclei, GCs, assuming that their elevated M/L ratios are caused by central black holes?

Hot Question Discussion: UCD origin

Claudia Bruens
Argelander-Institut fuer Astronomie, Universitaet Bonn

Sean Farrell
The University of Sydney

Steffen Mieske
ESO

Hongxin Zhang
Peking University

Holger Baumgardt
University of Queensland

Kristin Chiboucas
Gemini Observatory

Changze Liu
Shanghai Jiao Tong University
Wednesday 12 June

Invited Talk: Globular clusters as tracers of galaxy assembly
Oleg Gnedin
University of Michigan

On the origin of correlated populations of dwarf galaxies in the Local Group
Marcel Pawlowski
Argelander Institute for Astronomy, University of Bonn

The Milky Way is surrounded by numerous satellite objects: dwarf galaxies, globular clusters and streams of disrupted systems. I will show that these are part of, and mostly co-orbit within, a vast polar structure (VPOS), a thin plane spreading to Galactocentric distances as large as 250 kpc. In addition, about half of the satellite galaxies of Andromeda define and mostly co-orbit in a thin plane. The discovery of similar, co-rotating structures in the two only satellite galaxy systems for which 3D positions are known emphasizes the need to develop an understanding of their origin. Formation scenarios which interpret the satellite galaxies as tracers of dark matter sub-halos, often based on their accretion along cosmic filaments, fail to deliver a satisfactory explanation. As an alternative origin I suggest the formation of tidal dwarf galaxies (TDGs) in the phase-space correlated debris of interacting galaxies. I will discuss the consistencies between this dwarf galaxy origin and the observed Local Group, which offers several scenarios for TDG formation. However, a TDG-origin has far-reaching consequences. If the satellite galaxies are ancient TDGs, spuriously interpreting them to trace the dark matter sub-structure gives rise to inconsistencies with cosmological predictions, artificially attenuates the missing satellites problem and therefore seriously affects current (near-field) cosmology.

The effects of cosmic reionization on the early Star Formation History of dwarf galaxies
Antonio Aparicio
University of La Laguna & Instituto de Astrofísica de Canarias

We present results of the LCID (Local Cosmology from Isolated Dwarfs) project. The main purpose of the project is to obtain the star formation histories (SFHs) of a sample of dwarf galaxies with three objectives: (i) searching for signatures of cosmic reionization and local feed-back on the star formation history (SFH); (ii) searching for any SFH-morphological type relation, and (iii) searching for stellar population gradients and their temporal evolutions as signature of the galactic evolution. Six isolated dwarfs have been observed during 133 orbits with the ACS@HST. The SFHs of all them have been derived from the on-set of the star formation, more than 13 Gyr ago, with a precision better than 1 Gyr for the whole history and within a few hundred million years for relative ages even for the oldest populations. In this way, the effects of UV-background due to cosmic reionization on the early SFH of these systems can be studied. Here we present and discuss this topic and the consequences that our results may have on the standard scenario of galaxy formation.
Invited Talk: Early Type Dwarfs
Thorsten Lisker
Zentrum fuer Astronomie, University of Heidelberg

Observations have revealed that early-type dwarf galaxies are a complex population. They comprise objects with young and old stellar populations, slow and fast rotation, single- and multi-component structure, as well as faint and bright stellar nuclei. Given that these characteristics show correlations with environmental density, early-type dwarfs may hold a fossil record of how environment affected galaxy evolution over time. In addition to reviewing observational progress, I will attempt to reconcile the proposed formation mechanisms of early-type dwarfs with the early and continuous environmental influence predicted by cosmological simulations. I will discuss whether the characteristics of today’s late-type galaxies are at all representative for the progenitors of today’s early-type dwarfs, thereby also emphasizing the observed diversity of late types. To understand the present-day dwarf population, we need to model the time evolution not only of individual galaxies, but of the entire sequence of galaxy types, and of the environments themselves.

A near-infrared census of the multi-component stellar structure of early-type dwarf galaxies in the Virgo cluster
Joachim Janz
University of Oulu/Heidelberg

Early-type dwarf galaxies, once believed to be simple systems, have recently been shown to exhibit an intriguing diversity in structure and stellar content. To analyze this further, we started the SMAKCED project, and obtained deep H-band images for over \( \sim 120 \) early-type dwarf galaxies in the Virgo cluster in a brightness range of \( 19 < M_r < 16 \) mag, typically reaching a signal-to-noise of 1 per pixel of \( \sim 0.25'' \times 0.25'' \) at surface brightnesses \( \sim 22.5 \) mag arcsec\(^2\) in the H-band. Here we present the decompositions of their two-dimensional light distributions. This is the first study dedicated to early-type dwarf galaxies using the two-dimensional multi-component decomposition approach, which has been proven to be important for giant galaxies. Armed with this new technique, we find more structural components than previous studies: less than a third of the galaxies fall into the simplest group, namely those represented by a single Sersic function, optionally with a nucleus. Furthermore, we find a bar fraction of 14%. We detect also a similar fraction of lenses which appear as shallow structures with sharp outer edges. The fraction of simple galaxies we find to be strongly dependent on galaxy brightness, and explore through several comparisons to what degree these multi-component structures can arise from (external) secular evolution.
Thursday 13 June

Invited Talk: Origin of dSphs and ultra-faint dwarfs
Lucio Mayer
University of Zurich

Ongoing destruction of dwarf galaxies in Virgo cluster.
Sanjaya Paudel
CEA, Saclay

Well-known cosmological idea of galaxy formation and evolution predicts that the small galaxies have to be formed first and hierarchical merging of these small primordial objects gradually build up the large galaxies. Thus a major mass assembly process in galactic evolution actually happen by accretion of their small counterparts such as cannibalization of dwarf galaxies by the giant one. Such accretion process is not smooth, tidal force produced by differential gravitational acceleration first affects the dynamics of content of small satellite as they orbit the main host galaxy. As a result, dwarf galaxies get stretched and its stellar body takes gradually the shapes of stream and filaments, and as time passes it destroyed completely. We have undertaken a systematic search of such stellar debris, i.e filaments, arcs, plumes and shells in NGVS (Next Generation Virgo Cluster Survey) images. As one of the prominent result of this search, we made a detail study of dwarf galaxy destruction around host giant galaxy NGC 4216. We found several filaments, plumes structure around it and also several ongoing destruction of dwarf galaxy. We report that, at least four dwarf galaxies (some of them are already catalogued in VCC catalogue) are being accreted and disrupted by tidal field of NGC 4216. We discuss time scale and possible future evolution of these dwarf galaxies in our recently submitted publication. I will present the analysis of this system and some of similarly interesting systems that we have discovered in SDSS images.

3D view on Virgo and field dwarf ellipticals: late-type origin, environmental transformations, and relation to giant early-type galaxies
Agnieszka Rys
Instituto de Astrofísica de Canarias

Dwarf elliptical galaxies (dEs) are the most common galaxy class in dense environments. They are also a surprisingly inhomogeneous class, which has made it challenging both to relate different dE subtypes to each other, as well as place the whole class in the larger context of galaxy assembly and (trans)formation processes. In our contribution we will show the effects of environmental evolution on Virgo Cluster and field dEs, presenting the first large-scale integral-field spectroscopic (SAURON) data for this galaxy class. Our sample consists of 12 galaxies and no two of them are alike. We find that the level of rotation is not tied to flattening; we observe kinematic twists; we discover large-scale kinematically-decoupled components; we see varying gradients in line-strength maps. This great variety of morphological, kinematic, and stellar population parameters supports the claim that dEs are defunct dwarf spiral/irregular* galaxies and points to a formation scenario that allows for a stochastic shaping of galaxy properties. The combined influence of ram-pressure stripping and harassment fulfills these requirements, still, the exact impact of the two is not yet understood. We further investigate the properties of our sample by performing a detailed comprehensive analysis of its kinematic, dynamical, and stellar population properties. We infer the total (dark and baryonic) matter distribution by fitting the observed stellar velocity and velocity dispersion with the solutions of the Jeans equations. We obtain 2D age, metallicity, and enrichment information from line-strength and full-spectrum fitting analysis. We then tie these results to the galaxies’ intrinsic (i.e. deprojected) locations in the cluster with the use of surface-brightness fluctuation distances. This step is essential to providing unbiased correlations.
with the local environment density. We show that the dark matter fraction, unlike the level of rotational support, appears to correlate with the clustrocentric distance, and we discuss how the uncertainties in the virial mass scaling factor prohibit us from applying it to previously published data and call for studies of larger 3D samples to confirm the above trends. Also, our results indicate that dEs have kinematic properties similar to those of fast-rotating giant early-type galaxies, but they are more dark matter dominated than the latter, based on the analysis of \((M/L)_{\text{dyn}}\) - velocity dispersion relation, shown here for the first time on a homogeneous sample of dwarf and giant early-type galaxies.

**Satellites of Satellites: Globular Cluster Systems as Tracers of Environmental Effects on Early-Type Virgo Dwarfs**
Ruben Sanchez-Janssen
*Herzberg Institute of Astrophysics, Canada*

I will present an overview of our recent efforts to constrain the evolutionary history of early-type dwarf galaxies (dEs) in the Virgo cluster by means of their globular cluster systems (GCSs). Through a detailed comparison between observations and both basic theoretical arguments and numerical simulations, I will show that the majority of luminous dEs have properties - including the high mass specific frequencies of their GCSs and their concentrated spatial distribution within Virgo incompatible with a recent, environmentally driven evolution. Our analysis does not favour violent evolutionary mechanisms that result in significant stellar mass losses, but more gentle processes involving gas removal by a combination of internal and external factors - and highlights the relevant role of initial conditions. Finally, our numerical experiments indicate that, even though the dynamical behaviour of the GCS is strongly influenced by the fraction of bound dark matter remaining in the galaxy, the kinematics of the GCS can still be used to accurately measure the true enclosed mass. In this context, I will finish by presenting our ongoing observing programmes aimed at deriving robust kinematical measurements for the GCSs of half a dozen Virgo dEs.

**Kinematic Properties and Dark Matter Halos of Dwarf Early-Type Galaxies in the Virgo Cluster**
Elisa Toloba
*UCO/Lick and Carnegie Observatories*

The physical mechanisms involved in the formation and evolution of dwarf early-type galaxies (dEs) are not well understood yet. In the last few years, it has been proved that the study of the kinematic properties of dEs is a powerful tool to distinguish between different formation scenarios. In our works, Toloba et al. (2009, 2011) we found that dEs are likely low luminosity spiral galaxies that were transformed through environmental processes. These previous works were biased towards the most luminous dwarf members of the Virgo cluster, so we have extended them to less luminous dEs, and now we have coherently analysed a sample of 40 dEs in Virgo. The dark matter content of these galaxies is another property, inferred from their kinematics, that provides important information about their formation processes. We have used the Fundamental Plane to learn that dEs have around 40% more dark matter than massive elliptical galaxies. This measurement is done within the half-light radius \((R_e)\), while the dark matter halos of these systems should extend beyond that. To test this idea we have used Keck/DEIMOS to observe a sample of 300 globular cluster (GC) candidates around 21 dEs in the Virgo cluster, targeted using the Next Generation Virgo Survey. These GCs, used as tracers of the potential well of the dEs, provide information of the kinematics and the dark matter halo of these systems up to 15\(R_e\), the farthest away ever explored. In this conference, I will summarize our latest findings regarding the kinematic profiles and the associated dark matter content of dEs in the Virgo cluster.
Do dwarf galaxies house intermediate mass black holes?
Alister Graham  
Swinburne University of Technology

Graham (2012, ApJ, 746, 113) and Graham & Scott (2013, ApJ, in press: arXiv:1211.3199) have re-defined the highly popular/useful scaling relation between a galaxy’s mass and that of its central black hole. The new results suggest that dwarf galaxies, and similarly-sized bulges in disc galaxies, may house the much looked for but currently missing population of ‘intermediate mass black holes’. Many of these are expected to reside in dense, nuclear star clusters. Potential target galaxies will also be discussed.

PAndAS: A comprehensive view of the Andromeda’s dwarf galaxy system
Nicolas Martin  
Strasbourg Obs./MPIA Heidelberg

I will present the comprehensive view of the Andromeda satellite system provided by the now complete Pan-Andromeda Archaeological Survey (PAndAS). In particular, I will review the final search for Andromeda’s dwarf galaxies in the complete survey through the development of new, optimized search techniques; the ensuing luminosity function of M31’s dwarf galaxies; the study of differences and similarities with the Milky Way’s satellite system; the discovery of a strong anisotropy in the satellite distribution in the form of a vast rotating plane hosting half of Andromeda’s satellites. I will conclude with the impact the PAndAS’ view of the M31 dwarf galaxy system has on Local Group cosmology.

Tidally disrupted dwarf galaxies in the Local Universe
Andreas Koch  
Landessternwarte/ZAH, Universitaet Heidelberg

Tidal sculpting and the disruption of satellites is a major source for the hierarchical build-up of Galaxy halos. A clearly visible consequence is a significant variation of a system’s characteristic radius. Here, we present the discovery of tidal tails at very low-surface brightness around dwarf galaxies, out to large distances of $\sim 50$ Mpc. One example (HCC-087) is peculiar in that it lacks an obvious parent to the disruption. We also discuss the importance of null-detections of tidal features when assessing a system’s radius.

A new formation scenario for dSph galaxies
Michael Fellhauer  
Departamento de Astronomia, Universidad de Concepcion

Previous formation scenarios for dSph galaxies involve interactions between dwarf galaxies and other objects (i.e. other dwarfs or the infall into major galaxies). In our scenario the dSph galaxies form as we see them now in isolation. The only ingredient we need are stars forming in dissolving star clusters, i.e. star clusters which do not survive infant mortality. Our scenario is able to explain all the observed features of the dwarfs and makes predictions for future high resolution observations.
Invited Talk: The Universal Mass-Metallicity Relation for Dwarf Galaxies
Evan Kirby
University of California Irvine

Photometric average metallicities of dwarf galaxies in the Local Group indicated that dIrrs and dSphs follow separate mass-metallicity relationships (Grebel, Gallagher & Harbeck 2003). I will present evidence from Keck/DEIMOS spectroscopy of many Local Group galaxies that there is no dichotomy in the metallicities of dIrrs and dSphs. Instead, nearly all galaxies—from the ultra-faint dwarfs to massive ellipticals—obey the same unbroken relationship between stellar mass and average metallicity. However, the metallicity distributions of dIrrs conform to the closed box model of chemical evolution, whereas the metallicity distributions of dSphs do not. I will interpret the mass-metallicity relation and the metallicity distributions in terms of gas flows during star formation.

The Extended Star Formation Histories of the Least Luminous Milky Way Companions
Daniel Zucker
Macquarie University

We present the star formation histories (SFHs) of four low luminosity Milky Way dwarf satellites (Canes Venatici I, Canes Venatici II, Hercules, and Leo IV), based on Hubble Space Telescope imaging that extends below the oldest main sequence turnoff in each galaxy. We find that each of these galaxies formed most of its stellar mass prior to 10 Gyr ago, but that 10-20% of the total stellar mass formed 8-10 Gyr ago, a result that is robust to the choice of stellar evolution model used in the SFH derivation process (Padova, Dartmouth, or BaSTI). These results suggest that extremely low mass galaxies are not necessarily simple stellar populations, and are instead capable of retaining gas and forming stars over extended periods. We compare fundamental parameters (e.g., half-light radii, luminosity, distance from Milky Way) and star formation truncation ages of these galaxies and "classical" Milky Way satellites, and find no significant differences between the populations, suggesting that the early type dwarfs of the Local Group trace out a continuum, one which is obfuscated by the commonly-used "ultra-faint" and "classical" groupings.

Dwarf spheroidal challenges
Jorge Penarrubia
University of Edinburgh

Dwarf spheroidal galaxies are the faintest galaxies in the Universe and as such play a fundamental role in galaxy formation models. In addition, their internal kinematics suggest the presence of large amounts of non-baryonic matter, making these objects excellent laboratories to test cosmological predictions on the smallest scales. In cosmological models where dark matter consists of exotic particles formed shortly after the Big Bang, the high phase-space densities inferred in dwarf galaxies puts strong constraints on the mass and cross section of particle candidates. It is thus remarkable that none of the existing models appear to successfully reproduce the observed properties of the bright Milky Way dwarfs. In this talk I will give an overview of the current conflicts between theory and observations, as well as the on-going efforts to solve the challenges posed by the dwarf spheroidals.
Friday 14 June

Invited Talk: The UCD/cE Divide: Aiming to Bridge the Gap
Mark Norris
MPIA, Heidelberg

Compact elliptical galaxies in clusters, groups, and in the field
Igor Chilingarian
Smithsonian Astrophysical Observatory

Compact elliptical galaxies have recently been transformed from the unique rare type of a stellar system in nearby clusters. They are thought to form through tidal threshing of more massive progenitors by giant galaxies and/or cDs. Here we present a sample of a hundred new compact elliptical galaxies discovered in a joint dataset from SDSS and GALEX photometric surveys in nearby Universe (z<0.08).

Now we find galaxies in all types of environment: clusters, groups, and field. We used a set of criteria to find cE candidates from photometry and then put additional constraints from their stellar population and internal kinematics made by analysing their SDSS DR7 spectra. We found at least one case where a cE is projected on to a central region of a galaxy cluster but its radial velocity suggests it to be gravitationally unbound from the cluster. This might have happened as a result of a three-body interaction when one of the galaxies got ejected, which is predicted by numerical simulations. It also explains the existence of field cEs under the tidal stripping scenario of their formation.

Comparative study of compact elliptical galaxies in nearby clusters
Analia Smith Castelli
Instituto de Astrofísica de La Plata, UNLP-CONICET, Argentina

Smith Castelli A., Faifer F., Gonzalez N., Forte J. C., Cellone S. We present a comparative study of compact elliptical (cE) galaxies identified in different nearby clusters. We aim at giving clues about the origin of this peculiar systems by performing a photometric study of cEs detected in the Virgo cluster (Smith Castelli et al., ApJ, submitted) and in the NGC 7626 group (Faifer et al., in preparation). We will compare their properties with those displayed by cE galaxies previously studied in the literature, such as M32 and those identified in the Antlia cluster (Smith Castelli et al. 2008, 2012). Our study is based on ACS-HST F475W and F850LP images, as well as on g’, r’, i’ frames obtained with GMOS-Gemini North. We will analyze their color maps, brightness and color profiles, isophotal ellipticity and position angle variations, as well as their location in photometric diagrams such as the color–magnitude and mean-effective-surface-brightness–luminosity ones.

Investigating the earliest phases of star formation in classical dwarf galaxies
Else Starkenburg
University of Victoria, Canada

The lowest metallicity stars that still exist today probably carry the imprint of very few generations of supernovae. A comparison of these stars in the Milky Way and surrounding dwarf galaxies can teach us about the earliest phases of star formation and its dependence on environment and the mass of the
Nuclear star clusters in Coma cluster dwarf ellipticals
Mark Den Brok
University of Utah

In this talk, I will present results on nuclear star clusters in early-type dwarf galaxies in the Coma cluster from the Coma HST/ACS Treasury Survey. Our data confirm that the properties of nuclear star clusters are closely related to those of their host galaxies. A non-negligible number of star clusters are resolved, even at the distance of Coma. The sizes of these star clusters are consistent with those of Ultra-Compact Dwarf galaxies. We confirm the previously found colour-magnitude relation for nuclear star clusters, which extends to much fainter magnitudes. This relation is surprisingly tight at the faint end, and flattens below $M_I > -11$. A viable explanation of this relation is self-enrichment during the formation of the star cluster. We find a picture emerging where a nuclear star cluster is different from just a central dynamically hot object. Even though the objects are still 'compact', some of them are resolved, and may show features of discs. The colours of large star clusters appear to be inconsistent with formation by inspiraling globular clusters. Instead, we find evidence that nuclear star clusters form secularly and in situ and are able to set their metallicity according to their mass.

Formation of Nearby Nuclear Star Clusters
Anil Seth
University of Utah

Nuclear star clusters are massive $10^6 - 8$ Msol systems found at the centers of most nearby galaxies. Using Hubble Space Telescope data, optical spectroscopy, and adaptive optics enhanced NIR spectroscopy, we analyze the morphology, kinematics and stellar populations of a sample of the 13 nearest nuclear star clusters. This sample includes both early and late type galaxies. These data reveal that the mechanism for nuclear star cluster formation varies significantly from galaxy to galaxy, with secular accretion, minor mergers, and stellar winds all appearing to play a role in different galaxies.

Identifying Tidal Dwarf Galaxies in the extragalactic zoo
Pierre-Alain Duc
AIM Paris-Saclay

Among the variety of stellar objects in the Universe, Tidal Dwarf Galaxies (TDGs), made out of recycled galactic matter, have a special status: they have the mass and properties of regular dwarf galaxies (stellar and ISM content, SFRs), but are dark matter poor, raising questions on the very definition of galaxies. Their contribution in number to the extragalactic zoo has been a matter of strong debate.
in the recent years, especially after the discovery of intriguing alignments of satellites around our own Milky Way and the Andromeda galaxies, that might be consistent with a tidal origin for at least some of the Local Group dwarfs. The uncertainty on the real number of TDGs is largely due to the difficulty to distinguish these objects among others once they became independent and lost their umbilical cord linking them to their merging parent galaxies. I will present criteria to help identifying objects of tidal origin (structural properties, stellar populations, metallicity), discuss the predictions of numerical simulations on the evolution of TDGs, and finally review the various on-going surveys of old TDGs. In particular, I will show our recent discovery of very promising old TDG candidates in an extremely deep optical survey of the environment of massive early-type galaxies.

**Dwarf elliptical galaxies as ancient tidal dwarf galaxies**

Joerg Dabringhausen  
*Argelander Institute for Astronomy, University of Bonn*

The formation of tidal dwarf galaxies (TDGs) is triggered by the encounters of already existing galaxies. Their existence is predicted from numerical calculations of encountering galaxies and is also well documented with observations. The numerical calculations on the formation of TDGs furthermore predict that TDGs cannot contain significant amounts of non-baryonic dark matter. Comparing the objects in an exhaustive sample of TDG-candidates from observations and numerical calculations with old dwarf elliptical galaxies (dEs) shows a possible connection between TDGs and dEs. The young TDG-candidates in the sample are gas-rich at the present, but they will probably evolve into gas-poor objects that are indistinguishable from dEs based on their masses and radii. Indeed, known gas-poor TDGs appear as normal dEs. According to the currently prevailing cosmological paradigm, there should also be a population of primordial galaxies that formed within haloes of dark matter in the same mass range. Due to their different composition and origin, it would be expected that objects belonging to that population would have a different structure than TDGs and would thus be distinguishable from them, but such a population cannot be identified from their masses and radii. Moreover, long-lived TDGs could indeed be numerous enough to account for all dEs in the Universe. Downsizing, i.e. that less massive galaxies tend to be younger, would then be a natural consequence of the origin of the dEs. If these claims can be kept up in the light of future observations, the presently prevailing understanding of galaxy formation would need to be revised.

**The evolution of smooth Blue Compact Dwarfs from observations and simulations**

Mina Koleva  
*Ghent University*

We study the evolution history of BCD galaxies and the possible evolutionary link between BCDs and dEs. For this purpose we selected 4 smooth, symmetric BCDs with $M_B$ between -16 and -17 mag for which we obtained high quality VLT/FORS2 near-IR long-slit spectra along major and minor axes and B, I, J, and K band images with FORS2 and ISAAC. High-quality 21cm observations could be taken from the literature, providing us with information on both the old and young stellar populations, and the neutral and ionized gas. These smooth BCDs have structural parameters similar to those of dEs so once the starburst is over, these systems may become classifiable as true dEs. With the aid of a state-of-the-art full spectrum fitting technique we derive their stellar population properties, stellar and gaseous kinematics, and coarse-binned star-formation histories. We discuss the occurrence of metallicity gradients in these systems and how this relates with their dynamical properties (i.e. mass, angular momentum, solid body versus differential rotation). For this, we compare the properties of the observed
BCDs with a suite of numerical simulations of star-bursting dwarfs created by us. By comparing with bursty simulated dwarfs that have similar present-day properties, we made an estimate of the observed BCDs’ future evolution and classification. Moreover, we present preliminary results from dwarf/dwarf and dwarf/gas cloud merger simulations in an attempt to induce strong star-formation bursts in dwarf galaxies. We discuss the future evolution of these systems, with and without external influences such as ram-pressure stripping.

Evidence for a Bottom-Heavy Initial Mass Function in Giant Elliptical Galaxies from the Colors of their Massive Globular Clusters
Paul Goudfrooij
Space Telescope Science Institute

We report a systematic and statistically significant offset between the optical (B-I or g-z) colors of seven massive elliptical galaxies and the mean colors of their associated massive metal-rich globular clusters (GCs) in the sense that the parent galaxies are redder by 0.12-0.20 mag at a given galactocentric distance. However, spectroscopic Lick indices indicate that the luminosity-weighted ages and metallicities of such galaxies are equal to that of their averaged massive metal-rich GCs at a given galactocentric distance, to within small uncertainties. We show that the observed color differences between the metal-rich GC systems and their parent galaxies cannot be explained by the presence of multiple stellar generations in massive metal-rich GCs. However, we show that this paradox can be explained if the stellar initial mass function (IMF) in these massive elliptical galaxies was significantly steeper at subsolar masses than Kroupa or Chabrier IMFs, with the GC colors having become bluer due to dynamical evolution, causing a significant flattening of the stellar MF of the average surviving GC. Finally, we present the significant impact of such a bottom-heavy IMF to the interpretation of the color-magnitude relation among GCs, putting the so-called ‘blue tilt’ seen in metal-poor GC systems in a new light.

Challenges to the standard gravitational scenario from small stellar systems
Xavier Hernandez
Instituto de Astronomia, UNAM

Over the past year a number of results regarding the structural and dynamical configurations of a variety of small stellar systems have appeared, which challenge the standard scale invariant plus dark matter gravitational paradigm. Galactic globular clusters at large radii exhibit flat (dispersion) velocity curves, which intriguingly, comply with the Tully-Fisher scaling between mass and velocity seen in large galaxies. The smallest of the small stellar systems, wide binary stars, also show relative velocities which appear in conflict with standard expectations. The largest of the faint stellar systems, the tenuous stellar halos surrounding galaxies, show density profiles in accordance with equilibrium solutions under MONDian gravity. I will review a number of the above cases, and show that while explanations under standard gravity are sometimes contrived or unlikely, under MONDian schemes, the most straightforward first order solutions quite naturally account for the observational situation.
What can we learn about compact systems from high-z observations?
Christopher Conselice
University of Nottingham

While most of this conference will be on talks focused on nearby objects and on simulations of their formation, there is still perhaps surprisingly much we can learn about compact and dwarf galaxies from high redshift objects that is just now beginning to be explored. I will present several perhaps related issues that can shed important light on the formation of compact stellar systems. The first is the observation that even the most massive galaxies at high redshift have very compact sizes \( \lesssim 1 \) kpc and have stellar densities similar to global clusters. Why this is and how these systems may related to early formation modes of systems will be discussed. Furthermore, we are now probing down to the dwarf galaxy regime in deep survey fields such as the GOODS NICMOS Survey (GNS) and CANDELS fields. This allows us to examine features such as the strongly evolving faint end of the mass function, the star formation rate of forming dwarfs, as well as their structures and morphologies. Since this is an emerging area, I will discuss the basic observations and provide them in context of lower redshift compact stellar system.
Posters

Are globular cluster sizes standard rulers?
Poul Alexander
*Institute of Astronomy, University of Cambridge*

Recent work on extra-galactic cluster populations has shown that globular cluster (GC) half-light radii can be used as standard rulers for distances. To understand why GC radii and radius distributions (RDs) are so universal across galaxies, we present a series of models of (synthetic) GC populations. We consider various cluster initial mass functions and initial cluster radii, and evolve GCs for a Hubble time with a simple prescription for their life-cycle. We show that the only scenario in which the RD has properties that can be used as a standard ruler is a model whereby the majority of clusters form Roche-lobe under-filling, and with a relatively flat cluster mass function similar to that observed today. The shape of the RD in this model provides an excellent match to the RD of Milky Way GCs. Finally, we present a fast code for accurately evolving GCs that can substantially aid future studies of this nature.

High-precision proper motions of globular clusters with HST
Andrea Bellini
*STScI*

The stable environment of space makes HST an excellent astrometric tool. Its diffraction-limited resolution allows it to distinguish and measure positions and fluxes for stars all the way to the center of most globular clusters. Apart from small changes due to breathing, its PSFs and geometric distortion have been extremely stable over its 20-year lifetime. There are now over 20 globular clusters for which there exist two or more well-separated epochs in the archive, spanning up to 8+ years. Our photometric and astrometric techniques allow us to measure thousands of stars within one arcmin from the cluster, with typical proper-motion errors of 0.2 mas/yr, which translates to 2 km/s for a typical cluster. These high-quality measurements are crucial in order to detect the possible presence of the central IMBH, and put constraints on its mass. In addition, they will provide a direct measurement of the cluster anisotropy and equipartition. I will present our preliminary results in these areas, and will discuss them in the context of what is already known from other techniques.

On the efficiency of galaxy harassment on different orbits
Daniel Bialas
*Astronomisches Recheninstitut Heidelberg (Germany) (ARI/ZAH)*

Harassment of galaxies has been proposed as one potential explanation of the morphology-density-relation and the Butcher-Oemler effect. Former studies have shown that galaxy harassment is a suitable mechanism to induce a morphological transformation from late-type to early-type galaxies. The efficiency of harassment is expected to depend strongly on the orbit of a galaxy across the galaxy cluster, which determines the strength of tidal forces and the probability of a flyby encounter. We have used a combination of N-body simulation and Monte Carlo Method to study the efficiency of galaxy harassment on different orbits through a galaxy cluster. Galaxies which pass through a cluster on large orbits (apocenter : pericenter = 1.5Mpc : 0.3 Mpc) are only weakly affected (stellar losses ≥ 6%), whereas galaxies on inner orbits (0.5Mpc : 0.3 Mpc) were transformed efficiently (stellar losses up to 50%). Furthermore we found that compact galaxies, which lie well inside their own potential, were hardly affected by harassment (stellar losses ≥ 2%). Additionally we probed how the transformation is influenced by a tilt of the disk to the orbital plane. Such a tilt leads to stronger thickening of the disk.
We conclude that harassment is a suitable mechanism to explain the transformation of galaxies inside of galaxy clusters, but the efficiency of harassment depends on many parameters. Therefore it needs further studies of the efficiency of harassment to clarify its overall significance.

**Uncovering the accreted vs. in-situ origin of Milky Way globular clusters**

**Paolo Bianchini**

*Max Planck Institute for Astronomy, Heidelberg, Germany*

Authors: Bianchini P., Norris M., van de Ven G., Schinnerer E. Galactic globular clusters (GCs) are believed to have formed in two different ways: an old population of GCs is thought to have formed in-situ, while a younger population is suspected to have originated in accreted dwarf galaxies. However, no diagnostics are yet available to robustly discriminate between both formation processes. Henceforth, we plan to use LUCI at the LBT to obtain Near Infrared (NIR) imaging as well as red-giant-star spectra of a sample of Milky Way GCs out to 2-3 half-light radii. The combination of the deepest NIR photometry yet available and a few km/s accuracy radial velocity measurements will be used to carry out a systematic search for stellar population and kinematic diagnostics of an accreted vs. in-situ origin of GCs. We carefully selected the sample to include objects on retrograde orbit suspected of an accreted origin and objects with an old population thought to have formed in-situ. We will show how axisymmetric self-consistent differentially-rotating models combined with photometry and stellar kinematics are a powerful tool to investigate the internal dynamics of quasi-relaxed stellar systems. Indeed, the application of these models to three well-studied GCs shows that a good description is provided for "ordinary" well-relaxed systems (47 Tuc and M15), while significant discrepancies are found for omega Cen, which is believed to be a stripped dwarf galaxy’s nucleus. We are thus able to identify through this modeling unusual kinematic and morphological signatures, such as high degree of internal rotation, enhanced tangential anisotropy, and high degree of flattening, that can directly reveal an accreted origin for GCs.

**Using Globular Clusters to map galaxy interaction in a galaxy group**

**Christina Blom**

*Swinburne University of Technology*

I will present results of a study where we were able to identify tidal stripping of a galaxy 23 Mpc away, from analysis of spatial overdensities in its globular cluster distribution. The tidal interaction is occurring in the W’ group, between NGC 4365 and NGC 4342. We have compared the globular cluster tidal feature with very deep imaging of the stellar component and have obtained follow up spectroscopy with the Keck II telescope. Bogdan et al. (2012b) rule out tidal stripping of NGC 4342. Our results contradict theirs. I will also discuss how the W’ group interaction challenges our understanding of the fundamental principle of tidal stripping. This new technique could allow the efficient identification of intra-group interaction for comparison with theoretical predictions and current studies of galaxy properties.

**Survivability of dSph in Cluster Environments.**

**Mia Bovill**

*PUC-DAA*

We present the results from a set of N-body simulations designed to study the survival rate of dSph galaxies in dense cluster environments (eg. Fornax, Virgo, Coma). We explore how disruption of
low surface brightness dwarf stellar systems varies with cluster centric radius, level of harrassment by substructure as given by the lambda CDM power spectrum index.

**Formation of star clusters in dwarf spheroidals: a clue from light elements**
Angela Bragaglia
*INAF-Osservatorio Astronomico di Bologna*

We present a comparison of several properties of stellar clusters of similar present-day (small) mass associated to the Milky Way and to its dwarf satellites. We focus on the chemical abundances to highlight similarities and main differences, to discriminate the formation mechanism of stellar clusters in different environments.

**Dwarf galaxy merger trees**
Annelies Cloet-Osselaer
*Ghent University*

As all galaxies, dwarfs have grown through a process of hierarchical merging. We have simulated the evolution of a set of dwarf galaxies, covering a wide range of masses, through a series of mergers with cosmologically motivated initial conditions. The dwarfs’ merger trees are constructed using the Monte Carlo algorithm from Parkinson et al. (2008), which is based on the Extended Press-Schechter theory, sampling their orbital parameters from the probability distributions of Benson (2005). This novel approach has the important advantage that we achieve the required high resolution to reliably predict the kinematical and chemical properties of dwarf galaxies. Moreover, we take into account the dwarfs’ merger histories without the necessity of running numerically very costly cosmological simulations. We use a modified version of Gadget2 which includes gas dynamics, star formation, stellar feedback, radiative cooling and metal enrichment. We discuss how hierarchical merging affects the evolution of dwarf galaxies by comparing these simulations with similar simulations of isolated dwarfs. More importantly, we show that the properties of the simulated galaxies are in good agreement with the kinematic and photometric scaling relations of observed dwarf galaxies.

**Assessing the dynamics and abundances of Andromeda’s dwarf spheroidal galaxies**
Michelle Collins
*MPIA*

Over the past few years, we have been conducting a systematic survey of the dwarf spheroidal galaxies of M31 using the Keck II DEIMOS spectrograph as part of the Pan Andromeda Archaeological Survey (PAndAS) project. This has allowed our group to measure systemic velocities, central masses and average metallicities for 21 of the 28 M31 dSphs. In this talk I will present this homogeneous dataset and highlight some of our more unusual findings. These include the curiously low mass objects, Andromeda’s XIX, XXI and XXV, and the tidally disrupting Andromeda XXVII. In addition, I will discuss the results of our new pilot program to map the chemical abundances of individual stars in the Andromeda II dSph using the LBT MODS spectrograph.
Globular Clusters, Planetary Nebulae and Starlight kinematics in the S0 galaxy NGC 2768
Arianna Cortesi
Osservatorio Astronomico di Capodimonte

We compare the kinematics and distribution of globular clusters (GCs) in the S0 galaxy NGC 2768 to those of stars and planetary nebulae (PNe). This is a pilot project aimed at understanding the origin of GCs in S0 galaxies. GCs are divided into blue and red subpopulations, depending on their color, which is related to their metal content. We find that: (i) the red subpopulation of GCs and a subpopulation of PNe follow the same radial surface density profile as the bulge component of the galaxy starlight; (ii) a distinct, and presumably younger PNe subpopulation is associated with the galaxy disk; and (iii) the radially extended kinematics of GCs, PNe and starlight out to 4 Re are in good agreement with each other. From the study of these kinematic tracers we also learn clues on the origin of the galaxy itself. In fact, NGC 2768 presents a disk kinematics similar to that of spiral galaxies, with rotation velocity dominating over random motions at large radii. On the other hand, the ratio between ordered and random motions is higher than in spiral galaxies, implying that something more than a simple gas stripping is responsible for the creation of this S0. This pilot study on NGC 2768 demonstrates the power of the comparative analysis of stars, PNe, and GCs in understanding the formation of galaxies.

Lithium Abundances in the globular clusters NGC 6218 and NGC 3201
Valentina D’Orazi
Macquarie

Old stellar systems in UV: resolved and integrated properties
Emanuele Dalessandro
Dipartimento di Fisica e Astronomia - Universitádi Bologna

We present ultraviolet (UV) resolved and integrated photometry obtained with both HST and GALEX for more than 50 Galactic globular clusters (GGCs). Taking advantage of the fact that individual stars are resolved in GGCs, we use these data to understand how the hot stellar populations (primarily horizontal branch (HB) stars and their progeny) characterize the observed UV emission, thus to get a deeper knowledge of unresolved systems in distant galaxies. We introduce a new HB classification particularly sensitive to its hot extension. We show how this new classification, coupled with detailed HB modeling, is able to give new insights into the so-called HB "second parameter problem". We also investigate how the UV colours vary with parameters like metallicity, age, helium abundance and concentration. We find for the first time that GCs associated with the Sagittarius dwarf galaxy have UV colours systematically redder than GGCs with the same metallicity. Finally, we speculate about the presence of an interesting trend, suggesting that the UV colour of GCs may be correlated with the mass of the host galaxy, in the sense that more massive galaxies host bluer clusters.
Metallicities and Alpha-to-Iron Ratios in Globular Clusters Stars - Search for Multiple Populations
Bruno Dias
IAG-USP/Brasil & ESO/Chile

We are carrying out a survey of 51 poorly studied Milky Way globular clusters, by means of spectroscopy of ∼20 red giants per cluster. Optical spectra (4600-5800 Å) were obtained with the FORS2@VLT/ESO, at a resolution Delta lambda ∼ 2.5 Å. We are using ETOILE code to derive [Fe/H], Teff, log g, and [Mg/Fe] for each star, by finding the best fitting spectrum among a grid of observed stars of ELODIE and MILES libraries. These parameters represent the initial guesses for HALO, which finds [Mg/Fe] values by comparing the observed spectrum to a grid of 4000 synthetic spectra. The main contributions of this work are: to provide a homogeneous scale of [Fe/H], [Mg/Fe], and radial velocities for the 51 clusters – in particular for the 29 distant and/or highly reddened ones – to provide a catalogue of confirmed member stars for each cluster, as well as to find interesting cases for follow-up with high resolution (like the massive clusters M 22, and NGC 5824, for which we found a spread in [Fe/H]).

Globular cluster systems in groups of galaxies
Favio Faifer
Facultad de ciencias Astronomicas y Geofísicas, UNLP. IALP-CONICET

From mosaics built from deep g', r', i' images obtained with the GMOS cameras of Gemini-North and Gemini-South, we developed a photometric study of globular cluster systems (GCs) belonging to the central regions of three groups of galaxies: NGC 5044, Pegasus I and HCG 44. These groups present very different properties and their GCs are poorly studied. NGC 5044 is dominated by the giant elliptical galaxy NGC 5044 while Pegasus I is dominated by two elliptical galaxies (NGC 7619 and NGC 7626). In addition, HGC 44 is a Hickson Compact Groups that contains late-type galaxies. We analyze and compare their total population of GCs, spatial distribution, luminosity functions, the presence of GC sub-populations showing differences in color and/or luminosity, the existence of a ”blue-tilt”, UCDs, etc. In addition, as in the literature additional analysis with the same instrumental and photometric system are found, we compare our results with them. We aim at obtaining clues about the evolutive history of the galaxies of these groups.

Globular Clusters in the UV: A HST WFC3 view of the globular cluster population in nearby ellipticals
Alyson Ford
National Radio Astronomy Observatory

Globular clusters are the closest things to simple stellar populations (SSPs - a group of stars with the same age and composition). As models of complex stellar populations are built by combining SSPs, it is crucial that the SSPs be anchored observationally. When a mystery presents itself in the SED of a complex stellar population, such as the UV properties of elliptical galaxies that are predominantly comprised of old stars, a key ingredient in the solution is the UV properties of the SSPs that dominate the complex population, i.e., the UV properties of globular clusters. This is particularly important when analyzing high-z galaxies, since the rest-frame UV gets redshifted into the observed optical bands, requiring inferences based on the poorly-understood rest-frame UV properties. As such, we present HST WFC3 UVIS observations of the globular cluster systems of four nearby elliptical galaxies, which we have used to both constrain the UV properties of globular clusters and to compare with their optical properties.
Massive clusters in late-type dwarf galaxies
Iskren Georgiev
ESA
We will present our recent analysis of properties of massive globular clusters based on VLT/VIMOS-BVI imaging in a sample of 10 Magellanic-type dwarf galaxies in the Fornax/Eridanus galaxy clusters. Interestingly, we find that 8 out of 10 dwarf galaxies have a bright (massive) cluster in their nucleus. We will discuss on the possible evolutionary connection between such nuclear clusters and other massive compact stellar systems (bright wCen-type GCs, UCDs).

Challenges and results of the applications of fuzzy logic in the dwarf galaxies’ classifications
Rafael Girola
Universidad Nacional de Tres de febrero (UNTREF) Buenos Aires Argentina
The fuzzy logic is a branch of the artificial intelligence founded on the concept that everything is a matter of degree. It intends to create mathematical approximations on the resolution of certain types of problems. In addition, it aims to produce exact results obtained from imprecise data, for which it is particularly useful for electronic and computer applications. This enables it to handle vague or unspecific information when certain parts of a system are unknown or ambiguous and cannot be measured in a reliable manner. Also when the variation of a variable can produce an alteration on the others. The purpose of this paper is to show the importance of these techniques formulated from a theoretical analysis on its application on ambiguous situations in the field of the dwarf galaxies’ classification. In order to show its applicability, the chosen scenario is the one concerning the early and late dwarf galaxies, as they do not form homogeneous families. The first ones are constituted by at least two structurally different groups. On the other hand, the second ones show at the same time variety in their characteristics. Also, it is not clear that every elliptic galaxy is spheroidal, for which the distribution of the dE and dI galaxies becomes vague in some cases. This may be connected with a diversity of beginnings for different dwarf galaxies and with the evolutionary relationship between the distinct types and subtypes. From this context, the application of the fuzzy logic techniques approximates the solution of the mathematical models in abstractions about the dwarf galaxies’ physical properties in order to solve the obscurities which must be confronted by an investigation group in order to make a decision. A particular example used to demonstrate the extent of this technique is the case of the luminosity relationship between the dE and the dI, which is obscure, as well as in the case of galaxies of the early kind that follows a well-defined color-magnitude relationship (CMR) ranged from the most luminous E to the dE.dSph; also whether the gradient and the dispersion prevailed or not from the luminous E to the dE.

Caught in the Act: The GC-like System Hydra I in the State of Tidal Disruption
Benjamin Hendricks
Landessternwarte, University of Heidelberg
In current Lambda-CDM cosmology, large-scale structures like the Milky Way are believed to have formed via continuous accretion of smaller systems. Although signs of such accretion events have been observed in form of stellar streams and, in very few cases, as currently disrupting systems, the role of
these events in the build-up of our Galaxy is still poorly understood. While stellar streams themselves are important features to constrain the potential and distribution of dark matter in the Galactic halo, the rare event of observing a stellar system in the state of disruption provides a unique tool to better understand the significance of accretion events for the distribution and characteristics of stars in the halo, as we observe it today. Here, we present radial velocity and chemical abundance measurements from moderately high-resolution (R ∼ 18000) spectra for a large number of red giants in the recently discovered, close-by (9.7 kpc) Hydra I system and its associated stellar stream. The main body of this system displays a unique, double-lobed morphology of yet unknown origin, but probably due to currently ongoing tidal disruption. Our spectra evenly cover both lobes of the body to better characterize the system with the goal to cast light on its origin and current evolutionary stage. Specifically, we will use the derived abundances of individual elements to probe, e.g., the Na–O anti-correlation, which provides a clear-cut between a globular cluster and a dwarf spheroidal galaxy as possible progenitors.

Radial gradients of stellar populations: the early evolution of dwarf galaxies.
Sebastian Hidalgo
Instituto de Astrofísica de Canarias

We present the star formation history as a function of galactocentric radius of a selection of dwarf galaxies of the Local Group observed with the HST. The sample contains galaxies of different morphological type: dSphs, dIrrs and transition galaxies (dTrs). We have obtained the star formation rate and the metallicity as a function of time and galactocentric distance using IAC-star/IAC-pop/MinnIAC algorithms. The results suggest that dSphs and dTrs galaxies may share a common ancestor. The extended star formation in the innermost regions of dTrs, which is not observed in dSphs, produces the dichotomy between both types of galaxies. Stellar populations younger than ∼3 Gyr show a single exponential profile. The change in the scale length of the outer component of the radial profile as a function of age may be related with the displacement of the star-forming regions towards the center with time, pointing to an outside-in scenario for star formation in dwarf galaxies.

The final catalogue of M31 globular clusters from the PAndAS survey
Avon Huxor
Zentrum fuer Astronomie, University of Heidelberg

I will present the final catalogue of halo globular clusters from the PAndAS survey, which was undertaken with CFHT/Megacam. We have searched the halo region of the data, which extends to a projected distance of ∼140 kpc from M31, and have found over 50 new GCs. Many of these have an extended morphology, such as those previously found in M31. We confirm and strengthen many of the tentative results noted in Huxor et al. (2011) such as: a bimodal GCLF for M31, a feature not seen in the Milky Way (MW); the presence of a population of massive, luminous GCs at large galactocentric radii (also not found in the MW); and the flattening in the radial profile of GC number surface density beyond ∼30 kpc. Finally, we will discuss the relation between the outer halo GCs and underlying M31 halo stellar substructure.
Flattened velocity dispersion profiles in Globular Clusters, a perspective from modified gravity schemes

Alejandra Jimenez

Instituto de Astronomía Universidad Nacional Autónoma de México.

Recent observations have confirmed the flattening of the radial velocity dispersion profiles for stars in various nearby globular clusters. Under Newtonian gravity, this is explained by invoking tidal heating from the overall Milky Way potential on the outer more loosely bound stars of the globular clusters in question. From the point of view of modified gravity theories, such an outer flattening is expected on crossing the critical acceleration threshold $a_0$, beyond which, a transition to MONDian dynamics is expected. From an empirical point of view, in our work, we determine Newtonian tidal radii using masses accurately calculated through stellar population modeling, and hence independent of any dynamical assumptions for a sample of globular clusters. Crucially, we find that the asymptotic values of the velocity dispersion profiles scale with the fourth root of the total masses in accordance with the galactic Tully-Fisher relation. Also, in all cases, Newtonian tidal radii at perigalacticon are larger that the radii at which the flattening in the velocity dispersion profiles occurs, which correlate with the radii where the $a_0$ threshold is crossed, as expected under modified gravity scenarios. For completeness we show that it is possible to construct gravitational equilibrium dynamical models for the globular clusters studied using a modified Newtonian force law, which reproduce all observational constraints.

Wide-field imaging of the globular cluster systems of NGC 720, NGC 1023 and NGC 2768

Sreeja Kartha

Swinburne University of Technology

We present the results from a study of globular cluster systems belonging to three early-type galaxies: NGC 720 (E5), NGC 1023 (S0) and NGC 2768 (S0). The galaxies were observed in multi-band wide-field images using the Subaru and Canada France Hawaii Telescopes. For NGC 1023 and NGC 2768, we made use of archival HST data. This work is a first time investigation of globular cluster systems to large galactocentric radii (~100 kpc) for NGC 720 and NGC 2768. The radial extent of globular cluster systems is characterised to be $68 \pm 6$ kpc for NGC 720, $20 \pm 2$ kpc for NGC 1023 and $63 \pm 3$ kpc for NGC 2768. We have determined the total number of globular clusters as $1584 \pm 190$ for NGC 720, $572 \pm 94$ for NGC 1023 and $714 \pm 162$ for NGC 2768 with values of $S_N = 5.39 \pm 0.6$, $2.12 \pm 0.2$ and $3.03 \pm 0.3$ respectively. The azimuthal distribution of globular cluster systems are investigated and found to be similar to the host galaxy properties. We have examined for globular cluster bimodality and found the three galaxies have strong blue and red subpopulations. We also present a new correlation of globular cluster system sizes and host galaxy effective radii.

X-Shooter spectroscopy of dwarf galaxies in the Centaurus Cluster

Marco Parmiggiani

INAF

We present the result of spectroscopy of 3 compact dwarfs and 3 nucleated dwarf elliptical galaxies in the nearby Centaurus Cluster (Abell 3526, z=0.0114) using X-Shooter at the ESO VLT. We have estimated their mean ages and metallicities as well as central velocity dispersions from the integrated spectra using the Ulyss code. A first analysis of their star-formation histories has also been done, indicating that the compact galaxies in this pilot study are dominated by an old and metal-rich population, while the dEs have metallicities around $[Fe/H] = -1$ and a significant intermediate-age contribution in addition to their
old population. Along with estimates of the structural parameters, these data are used to compare the integrated properties (age, metallicity, and M/L ratio) of the two classes of galaxies and discuss their origin.

**Globular cluster and stellar metallicity radial profiles in early-type galaxies**
Nicola Pastorello
Swinburne University of Technology

Here I present a chemical study of both globular clusters and stellar component for a range of early-type galaxies. From the joint analysis of the two tracers together it is possible to retrieve new information about galaxy formation. Using the near-IR CaT II absorption lines, we are able to directly probe the metallicity of the galaxy stars and globular clusters. Furthermore, I will show radial metallicity gradients up to several effective radii, reaching regions of the galaxies hardly explored in the past, despite their dramatic importance in revealing the formation history of these objects.

**Ongoing destruction of dwarf galaxies in Virgo cluster.**
Sanjaya Paudel
CEA, Saclay

Well-known cosmological idea of galaxy formation and evolution predicts that the small galaxies have to be formed first and hierarchical merging of these small primordial objects gradually build up the large galaxies. Thus a major mass assembly process in galactic evolution actually happen by accretion of their small counterparts such as cannibalization of dwarf galaxies by the giant one. Such accretion process is not smooth, tidal force produced by differential gravitational acceleration first affects the dynamics of content of small satellite as they orbit the main host galaxy. As a result, dwarf galaxies get stretched and its stellar body takes gradually the shapes of stream and filaments, and as time passes it destroyed completely. We have undertaken a systematic search of such stellar debris, i.e filaments, arcs, plumes and shells in NGVS (Next Generation Virgo Cluster Survey) images. As one of the prominent result of this search, we made a detail study of dwarf galaxy destruction around host giant galaxy NGC 4216. We found several filaments, plumes structure around it and also several ongoing destruction of dwarf galaxy. We report that, at least four dwarf galaxies (some of them are already catalogued in VCC catalogue) are being accreted and disrupted by tidal field of NGC 4216. We discuss time scale and possible future evolution of these dwarf galaxies in our recently submitted publication. I will present the analysis of this system and some of similarly interesting systems that we have discovered in SDSS images.

**On the survival of tidal dwarf galaxies**
Sylvia Ploeckinger
University of Vienna, Department of Astrophysics

We present 3D hydrodynamic simulations on the evolution of tidal dwarf galaxies. These supposedly dark matter free dwarf galaxies are not isolated objects but on orbits around the barycenter of their merging host galaxies. The simulation box is set up on this orbit and all external effects such as ram pressure stripping by the ambient hot halo gas as well as a tidal field, including accelerations caused by the centrifugal and Coriolis force and by an external gravitational potential in addition to the self-gravity of the TDG. Energy feedback and yields from Supernovae and stellar winds are included and the abun-
dances of 12 chemical species in the gaseous phase as well as the metallicity of the stellar population are traced. This setup allows to study in great detail the survival conditions for TDGs during their first star formation events as well as the long-term evolution (up to 1 Gyr) of dark matter free systems in a tidal field. In addition we provide element abundances such as [X/H] or [alpha/Fe] which can be compared to observations in order to highlight differences in the metallicities between old tidal dwarfs and classical dwarf galaxies. First simulations show ongoing star formation for at least a few hundreds of Myrs and that the TDG is not quickly destroyed by the stellar feedback.

**X-ray Sources in Globular Clusters**
David Pooley
*Sam Houston State University; Eureka Scientific*

The extreme stellar density in globular clusters results in a number of interesting dynamical effects because of the relatively high frequency of close encounters (and even mergers) between cluster members. This leads to the production of exotic close binary systems, which play a pivotal role in a cluster’s evolution. Even a modest population of binaries contains a potential reservoir of binding energy that easily exceeds the kinetic energy of all single stars in the cluster. Historically, these close binaries have been difficult to find. However, in the past decade, we have made much progress, due mainly to the Chandra X-ray Observatory, which is extremely efficient at finding large numbers of these close binary systems. To date, Chandra has observed over 80 Milky Way globular clusters, and these observations have revealed over 1500 X-ray sources. The superb angular resolution has allowed for many counterpart identifications, providing clues to the nature of this population. It is a heterogenous mix of low-mass X-ray binaries, cataclysmic variables, active main-sequence binaries, and millisecond pulsars. We have shown that the number of X-ray sources in a globular cluster correlates very well with its encounter frequency, pointing to a dynamical origin for the X-ray sources. These X-ray sources are thus excellent tracers of the complicated internal dynamics of globular clusters. The relation between the encounter frequency and the number of X-ray sources has been used to suggest that we have misunderstood the dynamical states of globular clusters.

**The fate of heavy elements in dwarf galaxies - the role of mass and geometry**
Simone Recchi
*Institute for Astrophysics, Vienna University*

Energetic feedback from Supernovae and stellar winds can drive galactic winds. Dwarf galaxies, due to their shallower potential wells, are assumed to be more vulnerable to this phenomenon. Metal loss through galactic winds is also commonly invoked to explain the low metal content of dwarf galaxies. My main aim in this presentation is to show that galactic mass cannot be the only parameter determining the fraction of metals lost by a galaxy. In particular, the distribution of gas must play an equally important role. I perform 2-D chemo-dynamical simulations of galaxies characterized by different gas distributions, masses and gas fractions. The gas distribution can change the fraction of lost metals through galactic winds by up to one order of magnitude. In particular, disk-like galaxies tend to loose metals more easily than roundish ones. Consequently, also the final metallicities attained by models with the same mass but with different gas distributions can vary by up to one dex. Confirming previous studies, I also show that the fate of gas and freshly produced metals strongly depends on the mass of the galaxy. Smaller galaxies (with shallower potential wells) more easily develop large-scale outflows, therefore the fraction of lost metals tends to be higher.
Chemical evolution of Local Group dwarf galaxies in a cosmological context
Donatella Romano
INAF, Osservatorio Astronomico di Bologna

We present a new approach for chemical evolution modelling, specifically designed to investigate the chemical properties of dwarf galaxies in a full cosmological framework. In particular, we focus on the Sculptor dwarf spheroidal galaxy as a test bed for our model. We select four Sculptor-like model galaxies from the catalogue of Milky Way satellites generated by the implementation of the Munich semi-analytic model of galaxy formation on the high-resolution Aquarius cosmological simulations (Starkenburg et al. 2012). We adopt the predicted mass assembly and star formation histories of these four model galaxies and compute the detailed chemical properties of such objects. Through the comparison of the model results with the relevant observations (namely, the stellar metallicity distribution and the trends of several abundance ratios with metallicity), we are able to discriminate among different cosmologically motivated models. In particular, one model is found that provides a good fit to the main chemical properties of real Sculptor’s stars. The strengths and shortcomings of our approach are discussed, as well as prospects for improvements and future work.

The lack of stellar migration and the survival of metallicity gradients in simulated dwarf galaxies
Joeri Schroyen
Ghent University

We present a detailed analysis of the formation, evolution, and possible longevity of metallicity gradients in simulated dwarf galaxies. Specifically, we investigate the role of radial stellar migration in shaping these gradients. We also consider the influence of the star formation scheme, investigating both the low density star formation threshold of 0.1 amu cm$^{-3}$, which has been in general use in the field, and the much higher threshold of 100 cm$^{-3}$, which, together with an extension of the cooling curves below 104 K and and increase of the feedback efficiency, has been argued to represent a much more realistic description of star forming regions. The Nbody-SPH models that we use to self-consistently form and evolve dwarf galaxies in isolation show that, in the absence of significant angular momentum, metallicity gradients are gradually built up during the evolution of the dwarf galaxy, by ever more centrally concentrated star formation adding to the overall gradient. We furthermore find that gradients, once formed, are robust and can easily survive in the absence of external disturbances, with their strength hardly declining over several Gyr. The underlying radial migration of stars is quite limited in our models, being of the order of only fractions of the half light radius over time-spans of 5 to 10 Gyr in all star formation schemes. This is contrary to the strong radial migration found in massive disc galaxies, which is caused by scattering of stars off the corotation resonance of large-scale spiral structure — a feature that is lacking in the dwarf regime. The density threshold, while having profound influences on the star formation mode of the models, has only an minor influence on the evolution of metallicity gradients. Increasing the threshold 1000-fold only produces slightly stronger stellar migration due to the increased turbulent gas motions and the scattering of stars off dense gas clouds.
Multiple stellar-mass black holes in globular clusters: theoretical confirmation
Anna Sippel
Swinburne/ESO

While tens or hundreds of stellar-remnant black holes are expected to form in globular star clusters, it is still unclear how many of those will be retained upon formation, and how many will be ejected through subsequent dynamical interactions. No such black holes have been found in any Milky Way globular cluster until the recent discovery of stellar-mass black holes in the globular cluster M22 (NGC 6656) with now an estimated population of 5-100 black holes. We present a direct N-body model of a star cluster of the same absolute and dynamical age as M22. Imposing an initial retention fraction of approx. 10% for black holes, 16 stellar-remnant black holes are retained at a cluster age of 12 Gyr, in agreement with the estimate for M22. Of those 16 BHs, two are in a binary system with a main sequence star each while also one pure black hole binary is present. We argue that multiple black holes can be present in any Milky Way cluster with an extended core radius, such as M22 or the model presented here.

Dynamics of Local Group Galaxies with HST Proper Motions
Tony Sohn
Space Telescope Science Institute

The Local Group has been the benchmark for testing and calibrating many aspects of cosmological and galaxy formation theories including e.g., dark halo profiles and shapes, substructure and the missing satellite problem, and the minimum mass for galaxy formation. Thanks to the advancements in both observational and theoretical areas, our understanding about the galaxy formation and evolution in the Local Group has greatly improved in the last decade. Nonetheless, many fundamental parameters (e.g., shape and extent of the dark halo of the Milky Way) still remain uncertain mostly due to the limited information on the transverse motions of galaxies in the Local Group. To resolve this issue, accurate proper motion measurements are required for the objects of interest. We have recently developed a technique to measure absolute proper motions of resolved stellar systems using multi-epoch HST data by comparing the average shift of stars with respect to the numerous background galaxies in the same fields. This technique has been successfully used to measure the proper motion of M31 for the first time. In this talk, I will present our HST projects for measuring absolute proper motions of small stellar systems to improve our understanding of the dynamics of the Local Group galaxies. The proper motion measurement technique will be discussed, and I will describe how we are using this technique to provide answers to some of the most fundamental questions in astrophysics.

Tidal dwarf galaxy candidates in gas-rich groups
Sarah Sweet
University of Queensland

We have uncovered an interesting population of star-forming dwarf galaxies in Local Group-like groups of galaxies. The dwarf galaxies in these groups have very high Halpha equivalent widths, are quite compact, and are mostly not obviously attached to a host galaxy. Integral field spectroscopy with WiFeS reveals that these dwarfs have a wide range of metallicity, some significantly above that expected for their small size. Many also have strong signs of rotation and low mass-to-light ratios measured within 1.5 effective radii. Such observations indicate that these particular dwarfs are not newly forming in their own cold dark matter haloes, because we would then expect them to have low metallicities and high mass-to-light ratios. Rather, they appear to have formed in clumps of pre-enriched tidal debris flung
off of interacting giant galaxies. We are undertaking DEIMOS multi-object spectroscopy to measure rotation curves of the more likely candidates, out to 3 effective radii. Observations of falling rotation curves and low mass-to-light ratios will indicate that these are indeed tidal dwarf galaxies.

Galactic Archaeology in the Ultra-Faint Dwarf Galaxies
Luis Vargas
Yale University

The ultra-faint dwarf galaxies (UFDs, \(10^3 < \mathcal{L} < 10^7\) Lsun) contain some of the most metal-poor, oldest stars known. They are thus unique probes of low mass galaxy evolution at high redshift. We present Keck/DEIMOS alpha abundance measurements for 61 red giant branch stars across eight UFDs. With the possible exception of Segue 1 and Ursa Major II, the individual UFDs show on average lower alpha abundances at higher metallicities, consistent with enrichment from Type Ia supernovae. Together with recent photometric studies, this suggests that star formation in the UFDs was not a single burst, but instead lasted at least as much as the minimum time delay of the onset of Type Ia supernovae (\( \sim 100\) Myr) and less than \( \sim 1\) Gyr. Thus, we show that even the faintest galaxies have undergone at least a limited level of chemical self-enrichment.

Mapping the past environmental influence on present-day satellite galaxies
Karina Voggel
Zentrum fuer Astronomie, University of Heidelberg

Environmental influences on satellite galaxies of clusters have been proposed to play a major role in explaining the morphology-density relation. Galaxy environment is often defined as the local galaxy density or the distance to the cluster center at present time. But are these parameters really representing what happened to a satellite during its evolution? To study this question in detail, we use data from the Millennium II cosmological simulation, as well as a state-of-the-art semi-analytic model for the baryonic component of galaxies. To estimate how the environment influences satellite evolution, the tidal forces and the ram pressure that a satellite experiences are integrated over the whole simulation time. Our results show to what extent these integrated environmental effects correlate with present-day satellite properties. We discuss the implications for observational studies that attempt to select different populations of satellite galaxies and trace their formation history.

Observationally and Theoretically Determining the Size of Star Clusters
Jeremy Webb
McMaster University

We make use of observations and simulations to explore the true nature of star cluster size as a function of orbital radius and eccentricity, with a focus on how size can differ from conventional tidal theory. N-body simulations of star clusters in a spherically symmetric smooth potential over a range of orbital eccentricities and initial half-mass radii were performed to examine how cluster orbit influences the removal of stars via tidal stripping. The results indicate that basic tidal theory is only applicable to clusters on circular orbits. When a cluster has an eccentric orbit, the historical assumption that limiting radii are imposed at perigalacticon breaks down, and the limiting radius more accurately traces the
cluster’s instantaneous tidal radius instead. The influence of a non-spherically symmetric potential will also be discussed. Observationally, we explore the influence of orbital eccentricity on the observed globular cluster population of M87 in order to explain the observed relationship between cluster size and galactocentric distance. This is done by comparing new Hubble Space Telescope observations to simulated globular cluster populations with different degrees of orbital anisotropy.