2020 SPRING SYMPOSIUM:

THE LOCAL GROUP

Assembly and Evolution

8/31 – 9/4/2020

STScI

Scientific Rationale:

The universe evolves hierarchically with small structures merging and falling in to form bigger ones. The Local Group is the best place to study these hierarchical processes in action as evidenced by numerous substructures found in and around the Milky Way and M31. The Local Group can therefore be considered the perfect laboratory for testing various aspects of galaxy formation and cosmological theories.

Thanks to the advancements in both observational and theoretical grounds, our understanding about how the Local Group has assembled and evolved has made significant progress in the last decade. Wide-field photometric/astrometric surveys such as the Pan-STARRS, DES, and Gaia, as well as deep HST imaging and proper motions continue to provide unprecedented views of the stellar systems in the Local Group. Spectroscopic surveys such as APOGEE now allows chemical tagging of stars that belong to multiple structural components. Facilities coming up in the close future such as JWST and LSST will further advance our knowledge of the processes leading to galaxy formation. At the same time, computing resources have become powerful enough to provide detailed studies of simulated galaxies and how they evolve even in the faint end of the luminosity function.

In this symposium, we will bring together researchers studying the assembly and evolution of the Local Group and its components. The main goal is to review and discuss the current status of the field and future opportunities. Some of the key questions we will address throughout this meeting are listed below:

1. How did the Milky Way system assemble and form?
2. How similar/different are the Milky Way and M31?
3. What mechanisms are involved in the formation and evolution of the Local Group and its constituent galaxies?
4. What can we learn about the Local Group by studying other groups/clusters in the local universe?

Agenda

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2020 SYMPOSIUM PROGRAM

Monday, August 31, 2020

		SESSION 1
11:00-11:15	WELCOME	Ken Sembach,Director
11:15-11:30		Welcome and Introduction from the Organizers
11:30-12:00	Dante Minniti	New Globular Clusters in the Galactic Bulge
12:00-12:15	Pawel Pietrukowicz	Structure and Formation of the Milky Way Disk and Bulge According to OGLE RR Lyrae Stars
12:15-12:30	Alejandra Recio-Blanco	The Falling Sky and the Revolving Discs: Building Up the Primordial Milky Way
12:30-13:10	BREAK	
		SESSION 2
	Giacomo Cordoni	Gaia View of the Kinematics of Stellar Populations in the Anomalous Globular Clusters ωCen and M22
13:10-13:30	Stefano Souza	Self- consistent Analysis of Globular Clusters: Simple and Multiple Stellar Populations
	Andreia Carrillo	The Detailed Chemical Abundance Patterns of Accreted Halo Stars
13:30-13:45	Nicolas Martin	Unveiling the Proto-Milky Way with Extremely Metal-poor Stars
13:45 - 14:00	Diane Feuillet	The SkyMapper View of the Sausage, Sequoia, and Splash
14:00 - 14:15	Jianhui Lian	Revealing the Milky Way's Star Formation History: A Recent Gas-rich Merger?
14:15 - 14:30	Jason Hunt	Resonance & Phase Mixing in the Galactic Disc
14:30 - 14:45	Kevin McKinnon	Chemical Properties of the Milky Way's Stellar Halo
14:45 - 15:00	Nicholas Boardman	Milky Way Analogs in the Local Universe
15:00 – 16:00	POSTER/DISCUSSION SESSION	

Tuesday, September 1, 2020

		SESSION 3
11:00 - 11:30	Ana Bonaca	What are the Stellar Streams Telling Us?
11:30-11:45	Meghan Hughes	Using Surviving and Disrupted Globular Clusters to Infer the Formation History of Milky Way-mass Galaxies
11:45 - 12:00	Carme Gallart	The Evolutionary History of the Milky Way Disk(s) and Halo from Gaia DR2 Color-magnitude Diagram Fitting.
12:00 - 12:15	Ian Roederer	Chemically Tagging Accreted Ultra-Faint Dwarf Galaxies Using r-process-enhanced Stars
12:15-12:30	Nora Shipp	Dynamical Modeling of Stellar Streams in the Southern Sky
12:30-13:10	BREAK	
		SESSION 4
	Helmer Koppelman	Insights into the Assembly History of the Milky Way from Data, Simulations and Theory
13:10-13:30	Nilanjan Banik	Stellar Streams: A Novel Probe on the Particle Nature of Dark Matter
	Alberto Manuel Martínez García	Disentangling the 3D Internal Kinematics of the Sculptor dSph Galaxy
13:30-14:00	David Nidever	The Evolution of the Magellanic Clouds and their Impact on the Milky Way
14:00:14:15	Andrew Fox	The Magellanic Stream: Gas Transfer in the Local Group
14:15-14:30	Yanbin Yang	Toward A Complete Understanding of the Magellanic Stream and the Clouds
14:30-14:45	Paul Zivick	Deciphering the Kinematic Structure of the Small Magellanic Cloud in the Age of HST and Gaia
14:45-15:00	Clare Higgs	Isolated Dwarfs in the Local Group with the Solo Survey
15:00-16:00	POSTER/DISCUSSION SESSION	

Wednesday, September 2, 2020

		SESSION 5
11:00-11:15	Randa Asa'd	Chemical Enrichment History of Magellanic Clouds Derived from a Large Uniformly Analyzed Sample of Integrated Star Cluster Spectra
11:15-11:30	Pol Massana	SMASHing the Star Formation History of the Small Magellanic Cloud
11:30-11:45	Magda Arnaboldi	The Survey of Planetary Nebulae in Andromeda (M31). The Age-Velocity Dispersion Relation in the Disc and Constraints on the 2.5 Gyr Old Accretion Event
11:45-12:00	Emily Cunningham	Characterizing Dark Matter Wakes with Spherical Harmonic Expansion
12:00-12:15	Clara Martínez-Vázquez	Tracing the Early Chemical Evolution of Local Group Dwarf Galaxies Using RR Lyrae Stars
	Tomas Tamfal	Wakes and Global Halo Modes Triggered by Massive Satellites and their Observability with Gaia
12:15-12:30	Ethan Nadler	The Galaxy-Halo Connection Including the Impact of the LMC
	Jennifer Wojno	Elemental Abundances in M31: [Fe/H] and [α/Fe] in M31 Dwarf Galaxies Using Coadded Spectra
12:30-13:10	BREAK	
		SESSION 6
	Lara Cullinane	The Magellanic Edges Survey: Exploring Origins of Stellar Substructures in the Magellanic Periphery
13:10-13:30	Nicolas Garavito Camargo	Hunting for the Dark Matter Wake Induced by the LMC
	Yumi Choi	SMASHing the Magellanic Clouds: Imprints of Tidal Interactions between the Clouds in the Galactic Structures
13:30-14:00	Coral Wheeler	Sweating the Small Stuff: Or How I Learned to START Worrying and Love the Smallest Galaxies
14:00-14:15	Nicolas Lehner	Capturing the Dynamics of the Circumgalactic Medium of M31
14:15-14:30	Ivanna Escala	The Formation History of Andromeda from Chemical Abundances
14:30-14:45	Alexander Ji	Chemical Abundances Trace the Formation and Disruption of Ultra-faint Dwarf Galaxies
14:45-15:00	Jeff Carlin	Faint Satellites of Magellanic Analogs Beyond the Local Group: An HST Perspective
15:00-16:00	POSTER/DISCUSSION SESSION	

Thursday, September 3, 2020

		SESSION 7
11:00 - 11:30	Marla Geha	The SAGA Survey: Building a Statistical Sample of Satellite Galaxies in Milky Way-like Systems
11:30 - 11:45	Marcel S. Pawlowski	Planes of Satellites in the Local Group: Observational Evidence in Light of Gaia DR2 and Testing Proposed Solutions with Cosmological Simulations
11:45-12:00	Salvatore Taibi	Stellar Chemo-kinematics of Isolated Dwarf Galaxies
12:00-12:15	Marina Rejkuba	Centaurus A and Its Dwarf Galaxy Satellite System
12:15-12:30	Elaad Applebaum	My Hometown: A New Suite of Simulations to Interpret Local Volume Observations
12:30-13:10	BREAK	
		SESSION 8
	Amanda Quirk	Kinematics of Resolved Stellar Populations in the Disk of M33
13:10-13:30	Catalina Mora Urrejola	Vertical Oscillation Patterns in MW-type Galaxies Using Hα Data
	Julio Navarro	The Fornax Globular Cluster Timing Problem
13:30-14:00	Raja GuhaThakurta	Dynamics of Resolved Stellar Populations and Rare Stars in the Local Group and Beyond
14:00-14:15	Dan Weisz*	The Star Formation Histories of M31 Satellites
14:15-14:30	Ekta Patel	Satellites of Satellites in the Local Group
14:30-14:45	Yong Zheng	Conducting Time-Resolved Metal Census in Local Group Dwarf Galaxies
	Isabel Santos-Santos	Predictions from LMC Analogs in the APOSTLE Cosmological Simulations
14:45-15:00	Alec Hirschauer	Discovery of a Massive, Young, Embedded Star-Forming Region in NGC 6822
	Scott Carlsten	Dwarf Satellite Systems in the Local Volume: New Perspectives on the Satellites of the Milky Way
15:00-16:00	POSTER/DISCUSSION SESSION	

* Talk cancelled.

Friday, September 4, 2020

		SESSION 9
11:00-11:15	Andrew Pace	Chemodynamic Stellar Populations in Dwarf Spheroidal Galaxies
11:15-11:30	Lea Hagen	Unleashing the BEAST: Modeling the Stellar and Dust Parameters toward Millions of Stars in the Local Group
11:30-11:45	Alessandro Savino	The Oldest Stellar Population in the Galaxy
11:45-12:00	Charlie Conroy	Mapping the Stellar Halo with the H3 Survey
12:00-12:15	Antonela Monachesi	Insights from Stellar Halos and Bulges of MW-like Galaxies: Assembly History of M31 and the MW into Context
12:15-12:30	Alex Drlica-Wagner	Studies of the Galactic Halo with DES, MagLiteS, and DELVE
12:30-13:10	BREAK	
		SESSION 10
	Adam Wheeler	Abundances in the Milky Way across Five Nucleosynthetic Channels from 4 Million LAMOST Stars
	Adam Smercina	The Satellite Populations and Stellar Halos of MW-mass Galaxies
13:10-13:35	Kathy Vivas	The Giant Satellite Galaxy Crater II
	Martin Rey	How Diverse Are Ultra-faint Dwarf Galaxies?
13:35-14:05	Roeland van der Marel	Local Group Dynamics: Improved Understanding from Future Facilities
14:05-14:20	Michael Siegel	Swift/UVOT Surveys of the Local Group
14:20-14:35	Andrew Wetzel	Simulating the Formation of the Local Group
14:35-15:05	Rosemary Wyse	Summary and Concluding Remarks
15:05-15:20	Conclusion	Concluding Remarks from Organizers

Talk Abstracts

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Elaad Applebaum (Rutgers University)

My Hometown: A New Suite of Simulations to Interpret Local Volume Observations

Dwarf galaxies of the Local Group span a wide array of environments, ranging from satellites of massive galaxies like the Milky Way to extremely isolated galaxies like Aquarius. Our most detailed knowledge of the faintest galaxies comes from our immediate neighborhood, and it remains an open question whether those results apply to distant field dwarfs. It has long been a challenge to simulate the faintest dwarf galaxies across a broad array of cosmological environments. In this talk, I present results from two sets of simulations designed to address this challenge. These simulations are run at some of the highest resolutions ever achieved (i.e., star particles born with only 400 Msun), allowing us to resolve galaxies down into the ultra-faint range. Importantly, the simulations are run with the same physics and at comparable resolution, but cover different environments. The MARVEL-ous dwarf simulations capture large volumes containing dozens of field dwarf galaxies that are located from a few Mpc to ~10 Mpc from a Milky Way, representative of galaxies in the Local Volume. The DC Justice League simulations capture Milky Way-mass galaxies and their environments out to several virial radii, again resolving down into the ultra-faint dwarf scale, making them the highest resolution Milky Way-mass galaxies ever simulated. I will discuss first results from these simulations, and show that we are able to model realistic dwarf galaxies across all luminosities, morphologies, and environments. I will also show preliminary results that there are systematic differences in galaxies as a function of environment, including HI gas mass (down to ultra-faints), star formation histories, and stellar mass at a given halo mass.

Magda Arnaboldi (ESO)

The Survey of Planetary Nebulae in Andromeda (M31). The Age-Velocity Dispersion Relation in the Disc and Constraints on the 2.5 Gyr Old Accretion Event

We use planetary nebulae (PNe) from the most extended (50 deg^2), deep (sensitivity down to 1.5 x 10^-16 erg cm2 sec-1) narrow band survey of M31 to obtain the age-velocity dispersion relation in different radial bins (RGC = 14-17 and 17-20 kpc) of the M31 disc. We separate the observed PN sample based on their extinction values into two distinct age populations in the M31 disc, for the 2.5 and˜4.5 Gyr age bins, respectively. At RGC = 17-20 kpc, which is the equivalent distance in disc scale lengths of the Sun in the Milky Way disc, we obtain σφ,2.5 Gyr = 61 ± 14 km s-1 and σφ,4.5 Gyr = 101 ± 13 km s-1. The high- and low-extinction PNe are associated with the young thin and old thicker disc of M31, whose velocity dispersion values increase with age. These values are almost twice and three times that of the Milky Way disc stellar population of corresponding ages. From comparison with simulations of merging galaxies, we find that the age-velocity dispersion relation in the M 31 disc measured using PNe is indicative of a single major merger that occurred 2.5-4.5 Gyr ago with an estimated merger mass ratio ≈1:5. Such single major merger event perturbed the pre-existing disc in Andromeda and added ex-situ stars to its inner halo. Using the PN multi dimension space - radius RGC, azimuthal angle φ, line-of sight velocity vLOS, and [OIII] 5007 Å flux - these substructures are identified, mapped to the corresponding in-situ and ex-situ components, and can thus be compared with predictions from cosmological simulations of M31-like discs.

Randa Asa'd (American University of Sharjah)

Chemical Enrichment History of Magellanic Clouds Derived from a Large Uniformly Analyzed Sample of Integrated Star Cluster Spectra

The star formation and chemical enrichment histories of Local Group galaxies are traditionally studied by analyzing their resolved stellar populations. The integrated light of star clusters however, can be studied using ground-based telescopes to much larger distances. They represent snapshots of the chemical evolution of their host galaxy at different ages. In our initial study (Chilingarian & Asa'd 2018) we presented an analytical chemical evolution framework that separately traces chemical enrichment by iron and alpha-elements. We demonstrated that ages and chemical composition ([Fe/H], [alpha/Fe]) of 15 star-clusters derived from the fitting of their integrated optical spectra reliably trace the chemical enrichment history of the Large Magellanic Cloud derived from the star formation history estimated from resolved stellar population analysis. We also showed that the present-day total gas mass of the LMC estimated by our chemical model matches within uncertainties the observed HI mass corrected for the presence of molecular gas. Motivated by these results, we expand the study using high-quality integrated spectra of over 50 star clusters in the Large and Small Magelanic Clouds recently observed with Magellan and SOAR telescopes. We perform the uniform analysis using NBursts, a full spectrum fitting technique in order to derive consistent ages, metallicities, and alpha-enhancements for this large sample of clusters. It allows us to perform sophisticated analysis and test detailed models of chemical evolution such as detecting potential spread/bi-modality of metallicities at a fixed age as a result of a past merger or accretion event in the LMC.

Nilanjan Banik (Texas A&M University)

Stellar Streams: A Novel Probe on the Particle Nature of Dark Matter

Stellar streams are elongated, almost one-dimensional collection of stars that originate from the tidal disruption of globular clusters or dwarf galaxies merging into the Milky Way. Gravitational encounters between a stellar stream and dark matter subhalos will leave imprints in the stellar stream density which can be statistically analyzed to predict the properties of the impacting subhalos as well as the dark matter micro-physics, both of which are intimately related. Using recent data from Gaia and PanSTARRS on the GD-1 stream and CFHT data on the Pal 5 stream I constrain the overall abundance of subhalos within a Galactocentric radius of 20 kpc. Furthermore, in the case of dark matter being a thermal relic, I will show that by combining stellar stream constraints and dwarf satellite counts the dark matter particle mass should be > 6.3 keV at 95% confidence.

Nicholas Boardman (University of Utah)

Milky Way Analogs in the Local Universe

Our Milky Way Galaxy provides an ideal opportunity for us to study galaxy evolution on small scales, due to our position within the Milky Way's disk. However, this position makes it difficult to connect the Milky Way to the wider galaxy population. Milky Way analogs allow us to consider how the Milky Way might appear to an external observer, and so in turn allow us to bridge this divide.

He, we present a sample of 62 galaxies identified as Milky Way analogs and observed as part of the MaNGA spectroscopic survey. We showcase the properties of the analogs' ionised gas and stellar components, with comparisons made to our knowledge of our own Milky Way. We discuss the implications of the analogs' properties for understanding the Milky Way's uniqueness, as well as for understanding the Milky Way's position in the wider galaxy population.

Ana Bonaca (Harvard University ITC)

What Are the Stellar Streams Telling Us?

To date, more than 50 stellar streams have been discovered in the Milky Way's halo. Formed through tidal disruption and evaporation of globular clusters and dwarf galaxies, these streams are excellent tracers of the underlying gravitational potential. Mean positions and velocities of individual streams encode information on the gravitational acceleration at their current position in the Galaxy, so modeling the entire population of streams provides an opportunity for detailed mapping of dark matter on global scales. In addition, n-body models have predicted that thin and kinematically cold streams preserve a historical record of gravitational perturbations on small scales, such as encounters with low-mass dark-matter subhalos. Excitingly, the latest photometric and astrometric observations uncovered variations in the width and density of several streams -- the expected signatures of dynamical perturbation. The data are so exquisite that ongoing modeling efforts aim to not only discover the origin of these perturbations, but also identify individual substructures and their orbits in the halo. With even more comprehensive and precise surveys scheduled in the coming decade, we are witnessing the dawn of an era where complex morphologies of stellar streams reveal the dynamical history of the Milky Way and the nature of dark matter.

Jeff Carlin (LSST)

Faint Satellites of Magellanic Analogs Beyond the Local Group: An HST Perspective

The Magellanic Analogs' Dwarf Companions and Stellar Halos (MADCASH) survey targets the extended halos of Local Volume (~2-4 Mpc) Magellanic Cloud-mass galaxies to search for their faint satellites. We present the first results from this search, which is enabled by the advent of wide-field imagers on large-aperture telescopes and has already yielded detections of the two faintest dwarf satellites around Magellanic-mass hosts. In order to (a) confirm the nature of the first two faint satellites discovered in MADCASH, and (b) to measure their structural and stellar population properties, we have obtained deep Hubble Space Telescope (HST) imaging follow-up, which we discuss here. Extending the satellite census beyond the Local Group, and to lower-mass hosts than the Milky Way and M31, allows us to assess the variation of satellite populations with environment and host mass, providing context for interpreting observations both in the Local Group and beyond.

Scott Carlsten (Princeton University)

Dwarf Satellite Systems in the Local Volume: New Perspectives on the Satellites of the Milky Way

The satellite systems of the Milky Way (MW) and M31 have long been at the forefront of small-scale tests of LCDM. In order to gain a better statistical understanding of dwarf satellite systems, we present the satellite systems of 6 hosts within 12 Mpc ranging from 0.5 to ~10 times the mass of the MW. Satellites are discovered in deep, wide-field imaging and confirmed with distances measured via surface brightness fluctuations. The satellite systems are complete to most classical-like satellites (M*≳3e5 Msun) within the survey footprints. With this expanded sample of satellite systems, we can explore the host-to-host scatter and how the properties of satellites depend on host properties, including stellar mass and environment. We highlight three results of this survey. First, we show that the luminosity functions of the satellites systems can be easily reproduced in cosmological simulations combined with standard abundance matching relations. Critically, the host-to-host scatter in the simulations closely agrees with the scatter between the observed systems. Second, we find that the observed satellite systems are significantly more radially concentrated compared to both large volume cosmological simulations and high-resolution zoom simulations. We discuss possible causes of this trend, including biases in the observations and resolution effects in the simulations. Finally, we explore the satellite quenched fraction as a function of both satellite and host mass in order to better understand the satellite quenching processes at work in MW-analogs.

Andreia Carrillo (University of Texas-Austin)

The Detailed Chemical Abundance Patterns of Accreted Halo Stars

The Gaia-Enceladus (or Gaia-Sausage) system is a theorized progenitor of a significant merger event in the Milky Way's history, which has contributed to the assembly of the stellar halo. I will focus on our recent effort to characterize this progenitor satellite's chemical evolution. Specifically, I will present stellar parameters and detailed chemical abundances for a sample of stars identified to potentially be a part of the Gaia-Enceladus system, derived from high resolution optical spectra from the McDonald Observatory and Magellan Telescope. We have selected these targets using APOGEE data, where these stars appear to be chemically distinct in the [Mg/Mn] vs [Al/Fe] plane because of their different star formation history from the Milky Way thin disk and thick disk (Hawkins et al. 2015). I will show results on >20 chemical abundances derived using the BACCHUS code (Masseron et al. 2015) as well as results on the comparison of stellar parameters derived from the optical and the infrared spectra. This project ultimately aims to understand how similar Gaia-Enceladus is to disrupted and undisrupted Milky Way satellites, what its chemical evolution and star formation history was like, and how our interaction with it has shaped and changed the evolution of our Galaxy, all through the lens of detailed chemical abundances.

Yumi Choi (Space Telescope Science Institute)

SMASHing the Magellanic Clouds: Imprints of Tidal Interactions between the Clouds in the Galactic Structures

The Large and Small Magellanic Clouds (LMC and SMC) are the closest interacting pair of dwarf galaxies at 50kpc and 60kpc, respectively. In cosmological context, LMC-mass galaxies with their own satellites are the fundamental building block of an MW-size galaxies. Although, Magellanic-type galaxies are ubiquitous in the local universe, none of them are found around a large disk galaxy like Milky Way at this proximity. Thus, the Magellanic Clouds (MCs) provide a unique opportunity to learn about the evolution of interacting dwarf galaxies falling into its larger host galaxies in great detail. The large field of view of the Dark Energy Camera allowed us to image very extended structures of the MCs including their main bodies in ugriz bands. I will present the recently discovered MCs' galactic structures that are likely induced by repeated tidal encounters between the LMC-SMC, and discuss the implications for their recent dynamical interactions with each other and with the Milky Way.

Charlie Conroy (Harvard University)

Mapping the Stellar Halo with the H3 Survey

The history of the Galaxy is encoded in the phase space distribution Modern theories of galaxy formation predict that the Galactic stellar halo was hierarchically assembled from the accretion and disruption of smaller systems. Simulations predict that the halo contains an extraordinary amount of structure in the high dimensional space (6D phase plus N dimensional abundances plus stellar ages) occupied by stars. Gaia DR2 has already revolutionized our understanding of the local stellar halo. However, Gaia will not provide radial velocities nor chemistry except for the very brightest stars, and parallaxes will be too uncertain to provide accurate distances beyond ~10 kpc. In order to remedy this shortcoming, we are undertaking a large survey with MMT/Hectochelle to obtain radial velocities, metallicities, and spectrophotometric distances for ~200,000 parallax-selected stars to r=18 over 15,000 sq. degrees in high latitude fields. I will present results from the first two years of data collection, including the metallicity distribution of the stellar halo and the identification of numerous structures in phase space.

Giacomo Cordoni (University of Padova)

Gaia View of the Kinematics of Stellar Populations in the Anomalous Globular Clusters ωCentauri and M22.

Galactic Globular Clusters are known to host multiple sequences, corresponding to different stellar populations with specific chemical composition. Their discovery revolutionized the field of Stellar Astrophysics, and in the past decades, many efforts have been made to understand their formation.

Regardless of these efforts, none of the proposed hypotheses has been able to fulfill the increasing number of observational constraints.

While the photometric and spectroscopic properties of multiple populations are well characterized, their internal kinematics is still uncharted territory. Nonetheless, theoretical works suggest that it would provide a unique window on the physical processes leading to the formation of these puzzling astrophysical systems.

Specifically, the present-day dynamics of the distinct stellar populations could still carry the imprint of their initial configuration. Its study is therefore crucial to shed light on the puzzling multi-populations phenomenon.

In my work, I have combined Gaia Data Release 2 (DR2) accurate proper motions, together with wide-field ground-based photometry to investigate multiple stellar populations in 9 Galactic Globular clusters. The analyzed sample span a wide range in cluster mass, from one of the least massive clusters with multiple populations, NGC6838, to the most massive one, ωCentauri.

We find clear evidence of dynamical differences in some of these systems. Moreover, kinematically distinct stellar populations also show a different spatial distribution on the plane of the Sky.

These results add new constraints to the evermore puzzling enigma that are Multiple Stellar populations in Globular Clusters.

Lara Cullinane (Australian National University)

The Magellanic Edges Survey: Exploring Origins of Stellar Substructures in the Magellanic Periphery

The Large and Small Magellanic Clouds (LMC/SMC), as two of the closest and most massive satellites of the Milky Way, have significant effects on the local Universe; including on the orbits of tidal streams, and on the distribution of ultra-faint satellites. However their masses, and interaction history beyond the most recent LMC/SMC close passage, remain poorly constrained. In this talk, I will discuss the Magellanic Edges Survey (MagES), which photometrically and kinematically maps the extremely low-surface-brightness periphery of the Clouds, in order to shed light on these issues. We present a contiguous, panoramic view of the Clouds' outskirts, obtained using the Dark Energy Camera, revealing significant distortions to the bodies of the Clouds; together with a wealth of stellar substructure extending to distances beyond 23 degrees from the Clouds' centres. Further, we use a combination of Gaia astrometry and spectroscopically-derived radial velocities, obtained with 2dF+AAOmega on the Anglo-Australian Telescope, to determine the first 3D kinematics for these substructures. Our initial results focus on the northern LMC, where we reveal a large substructure that, due to its discrepant kinematics relative to the LMC disk, was likely formed during a recent interaction with the Milky Way. Ultimately, our survey aims to provide a new benchmark for assessing dynamical models, in order to shed light on both the origin of Magellanic substructures, and the evolution of the Magellanic/Milky Way system.

Emily Cunningham (Flatiron Institute, CCA)

Characterizing Dark Matter Wakes with Spherical Harmonic Expansion

Using detailed N-body simulations of the infall of the Large Magellanic Cloud (LMC) into the Milky Way (MW), Garavito-Camargo et al. (2019) demonstrate that the LMC induces a density wake in the MW dark matter (DM) halo that gives rise to distinct, correlated kinematic patterns in the MW stellar halo. Spherical harmonic expansion of the perturbed velocity fields can be used to characterize the different components of the predicted wake signatures. The Transient response (i.e., the wake trailing the LMC in its orbit) results in power at $\ell=2$ in v_{ϕ}, strongest near the radius of the LMC. The Collective response (i.e., the modal response of the halo, as well as the motion of the MW disk with respect to the new orbital barycenter) results in a velocity dipole in v_R and net velocity v_{θ}, both of which increase as a function of distance, out to the virial radius of the MW. I will show how the spherical harmonic expansion coefficients depend on the kinematic state of the MW halo and the mass of the LMC. I will demonstrate how the presence of Galactic substructure might affect the angular power spectrum of the velocity field and our ability to measure wake signatures using spherical harmonic expansion. Finally, I will discuss prospects for studying these signatures observationally, and comparisons with cosmological simulations.

Alex Drlica-Wagner (Fermilab/University of Chicago)

Studies of the Galactic Halo with DES, MagLiteS, and DELVE

The Dark Energy Camera (DECam) on the 4-m Blanco Telescope at CTIO has become a valuable tool for studying resolved stellar populations in the southern hemisphere. Over the past 6 years, the Dark Energy Survey (DES) has used DECam to perform a deep, extremely well-calibrated survey of the Galactic halo in five photometric bands (grizY). Now, smaller community programs like the Magellanic Satellites Survey (MagLiteS) and the DECam Local Volume Exploration Survey (DELVE) seek to extend DECam coverage to the entire accessible high-Galactic-latitude sky. I will discuss recent results from DES, MagLiteS, and DELVE, focusing on studies of Milky Way satellite galaxies, stellar streams, and RR Lyrae.

Ivanna Escala (California Institute of Technology)

The Formation History of Andromeda from Chemical Abundances

Measurements of chemical abundances ([Fe/H] and [alpha/Fe]) in individual stars can probe the formation history of a galaxy. In contrast to the Milky Way (MW), relatively little is known about [alpha/Fe] of individual red giant branch (RGB) stars in M31. To make progress with existing telescopes, we have measured abundances from deep, medium- and low-resolution DEIMOS spectroscopy of individual M31 RGB stars using spectral synthesis. I will present measurements of [alpha/Fe] and [Fe/H] for over 100 M31 RGB stars across fields spanning the stellar halo, Giant Southern Stream, and outer disk. Prior to this work, only 4 stars in M31 had such measurements. I will discuss what the abundance distributions reveal about the progenitor(s) of M31's halo, including the Giant Southern Stream, and the formation of M31's stellar halo and disk. In particular, I will focus on our most recent results regarding abundance gradients across 20 kpc of the Stream and 100 kpc of the smooth stellar halo. Lastly, I will place our measurements in context via comparisons to abundances of MW and M31 dwarf galaxies, in addition to the MW stellar halo and outer disk.

Diane Feuillet (Lund University)

The SkyMapper View of the Sausage, Sequoia, and Splash

Gaia DR2 has shown the Milky Way to have several previously unknown stellar populations; notably the Enceladus/Sausage, the Splash and the Sequoia. These could only be detected thanks to Gaia's exquisite astrometry. However, the nature of these kinematic structures and their origin needs a deeper characterisation of their stars than possible with Gaia DR2 data alone. We present the SkyMapper view of these structures using 900,000 stars with photometric [Fe/H] measurements from SkyMapper and Gaia RVS measurements. We examine the kinematic properties, metallicity distribution functions, and population ages of stars possibly belonging to the Sausage, Sequoia, and the Splash. The Sausage has a mean [Fe/H] of -1.2 and is most apparent at high JR. We show that the selection of Sausage stars is quickly contaminated by disk stars below JR of 900 km/s. Using a population age analysis, we estimate the Splash to be old, with a peak older than 9 Gyr. With the full kinematic information available for such a large sample, we explore the prospects of robustly selecting stars belonging to the Sausage, Splash, and Sequoia.

Andrew Fox (Space Telescope Science Institute)

The Magellanic Stream: Gas Transfer in the Local Group

Extending for over 200 degrees across the sky, the Magellanic Stream together with its Leading Arm is the most spectacular example of a gaseous stream in the Local Group. The Stream is an interwoven tail of filaments trailing the Magellanic Clouds as they orbit the Milky Way. Thought to be created by tidal forces, ram pressure, and halo interactions, it holds many clues to the assembly history of the Milky Way. In this talk I will discuss recent progress on the Stream and Leading Arm, including their chemical composition, dynamics, ionization, total mass, origin, and fate. This will include results from UV absorption-line observations with HST/COS that have uncovered large reservoirs of diffuse ionized gas in the Stream. The chemical abundances measured in different parts of the Stream and Leading Arm have been matched up to the abundances in the LMC and SMC, allowing us to piece together the origin of the Magellanic System. Finally I will use the Stream as an example of how tidal interactions can transfer large gas masses between Local Group galaxies and drive their ongoing evolution.

Carme Gallart (Instituto de Astrofísica de Canarias {Spain})

The Evolutionary History of the Milky Way Disk(s) and Halo from Gaia DR2 Color-magnitude Diagram Fitting.

Gaia has provided distances and photometry, and thus color-magnitude diagrams in the absolute plane, for stars over an unprecedented vast volume in the Milky Way, encompassing significant fractions of the thin and thick disk, and halo. This has allowed us, for the first time, to derive unprecedentedly detailed star formation histories from direct modeling of these color-magnitude diagrams, using the same techniques that have been proven successful for external galaxies in the Local Group. Our first results for a volume of 2 Kpc radius from the Sun are extraordinarily promising. They have allowed us to date the first events involved in the formation of the inner Milky Way halo (Gallart et al. 2019) and to determine the presence of epochs of enhanced star formation well constrained in time, that can be associated to the various pericentric passages of the Sagittarius dwarf galaxy (Ruiz-Lara et al. 2019). Additionally, we have obtained results of unprecedented clarity regarding the vertical distribution of ages en the Milky Way disk (Gallart et al. 2020, in prep). I will discuss these results as well as future prospects to reach a larger Milky Way volume, and to combine chemodynamical information to this new approach to study the Milky Way evolutionary history.

Nicolas Garavito Camargo (University of Arizona)

Hunting for the Dark Matter Wake Induced by the Large Magellanic Cloud

The interaction between the Milky Way (MW) and the Large Magellanic Cloud (LMC) provides a unique opportunity to test for the existence of dark matter (DM). As a recently accreted, massive dwarf galaxy, the LMC is predicted to have induced a Wake in the outer (>40 kpc) of the MW's DM and stellar halo, as shown in Garavito-Camargo+ 2019. Consequently, interpreting the kinematics of orbiting substructures in the MW halo requires time-dependent potentials that include both the LMC and the MW's DM halo response. I will present new models built with a novel technique that analytically characterizes the time-dependent, combined MW+LMC potential from high-resolution N-body simulations. The resulting time-dependent potentials enable efficient orbit integration of stellar tracers of the MW's potential, such as Globular clusters, satellite galaxies, stellar streams, and stars. I will show how the orbits of stellar tracers of the MW are perturbed by the presence of both the LMC and the Wake and how these orbits can be used to detect the presence of the Wake. These predictions will help guide searches for the Wake with future facilities, such as JWST, WFIRST, and LSST. The detection of the DM Wake induced by the LMC will support the existence of DM and potentially constrain the identity of the DM particle itself.

Marla Geha (Yale University)

The SAGA Project: Satellite Galaxy Populations Around Milky Way-like Galaxies

The properties of the Milky Way's satellite galaxies provide critical clues to how galaxies form. However, the number of Milky Way satellites and their properties do not fully agree with well-established cosmological models. The SAGA (Satellites Around Galactic Analogs) project is a long-term program to determine complete satellite luminosity functions around 100 Milky Way analogs down to Mr = -12. I present results for 27 Milky Way analog systems with complete satellites luminosity functions.

Raja GuhaThakurta (UCO/Lick Obs., University of California, Santa Cruz)

Dynamics of Resolved Stellar Populations and Rare Stars in the Local Group and Beyond

The resolved stellar populations of Local Group galaxies, and the partially resolved stellar populations of galaxies in the immediate vicinity of the Local Group (out to a few Mpc), serve as excellent tracers of the dark matter content, accretion/interaction history, and chemical enrichment history of their host galaxies. I will present results from a few different Keck/DEIMOS spectroscopic campaigns and photometric (including time-domain) surveys of these stellar populations in the remote halo of the Milky Way (HALO7D, NGVS), disk and halo of M31 and M33 (PHAT, SPLASH), and halo and dwarf satellites of Milky-Way mass galaxies in nearby groups (PISCeS). Using the M31 and M33 galaxies as stellar evolution testbeds, I will report on the discovery of a rare population of massive evolved stars with a hitherto undetected weak CN spectral absorption feature.

Lea Hagen (Space Telescope Science Institute)

Unleashing the BEAST: Modeling the Stellar and Dust Parameters toward Millions of Stars in the Local Group

HST has been extensively used to image resolved stellar populations in the Local Group from the UV to near-IR, with programs like PHAT (M31, M33), METAL (LMC), and SMIDGE (SMC). For each of the stars in these surveys, we are using the BEAST (Bayesian Extinction And Stellar Tool) to model their SEDs and infer their stellar (age, mass, metallicity) and dust (Av, Rv, 2175A bump) parameters. We will present early results for 30 fields in the LMC, which together comprise a catalog of 600,000 sources with stellar and dust parameters. These catalogs enable a wide variety of science applications, including high resolution maps of extinction and dust grain properties, the environmental dependence of the initial mass function, and the spatially resolved star formation history.

With upcoming missions, not only will the BEAST catalogs provide complete lists of sources for spectroscopic follow up with HST, JWST, and the E-ELTs, but the BEAST algorithm will continue to be an important tool for understanding the ISM and resolved stellar populations. In particular, JWST will expand our photometric catalogs into the mid-IR, increasing our power to distinguish AGB stars and pre-main sequence stars. WFIRST will expand much of the BEAST HST science to large regions of Local Group galaxies (e.g., the entire LMC).

Clare Higgs (University of Victoria)

Isolated Dwarfs in the Local Group with the Solo Survey

Dwarf galaxies are an insightful regime in which to study galaxy evolution and the wide variety of processes that shape the galaxies we observe today. Dwarfs are intrinsically sensitive to both internal processes, like feedback from star formation, and environmental effects, like interactions with nearby galaxies. Evidence of these processes may be observed in the faint features of dwarfs. However, dwarf morphologies can be difficult to observe given their generally low surface brightnesses. Nearby dwarf galaxies are the most accessible as we can observe their resolved stellar populations.

The Solo (Solitary Local) Dwarf Galaxy Survey aims to characterize and understand the faint end of the luminosity function for isolated dwarfs, free from interactions with massive galaxies, like the Milky Way or M31. Solo is focused on dwarfs which are closer than 3 Mpc and are more than 300 kpc from the Milky Way and M31. The survey consists of wide field, g and i band, CFHT/MegaCam and Magellan/MegaCam imaging for all known dwarfs that meet this distance criteria. The proximity of the sample allows us to use resolved stellar population analysis to examine their faint, extended structure and probe their structural properties to extremely low surface brightness values (> 33 mags/sq.arcsec). Current work has focused on the 12 closest dwarfs, which all lie approximately within the zero velocity surface of the Local Group. We determine their global structures and parameterize their 1- and 2-D surface brightness profiles. We examine trends within this sample and compare their properties to the satellite dwarfs of the Milky Way and M31. These comparisons illuminate some of the environmental processes that influence the structures of low mass galaxies.

Alec Hirschauer (Space Telescope Science Institute)

Discovery of a Massive, Young, Embedded Star-Forming Region in NGC 6822

We report the discovery of a massive, young, embedded star-forming region which we refer to as Spitzer I. Bright at mid-IR wavelengths, it is located in the Local Group galaxy NGC 6822. Our analysis suggests that it contains the highest number of YSOs of any star-formation complex of NGC 6822 and is probably the youngest and most active such region. NGC 6822 is an isolated, irregular, nearby (~490 kpc) metal-poor ([Fe/H] ~ -1.2; Z ~ 30% Zsolar) gas-rich galaxy, making it an ideal laboratory for studying resolved stellar populations in an undisturbed environment and star formation in metal-poor systems comparable to the Universe at cosmic noon (z ~ 1.5-2). In an effort to better constrain the lifecycle of dust in the early Universe, and to conduct the first global survey of the properties of intermediate- to high-mass IR-bright point sources and their relation to the gas and dust distributions of NGC 6822, we have performed studies of the dusty populations of this galaxy. Two independent techniques used to identify Spitzer I are described: The first employs novel mid-IR color cuts to identify a large collection of YSO candidates in a previously overlooked region of NGC 6822. The second uses longer-wavelength color analyses and YSO SED model-fitting techniques to determine their masses and luminosities. Combined, these studies have produced an unexpected discovery of at least 90 massive YSOs inhabiting a compact region of space within the north-south-oriented stellar bar. As a potential proto-super-star cluster, Spitzer I will be observed in great detail as part of a JWST GTO program studying NGC 6822 with MIRI and NIRCam. With these data, a high-quality census of both young and evolved stars (including AGB stars and YSOs) will help shed light on the role of dust and dust production in metal-poor environments.

Meghan Hughes (Liverpool John Moores University)

Using Surviving and Disrupted Globular Clusters to Infer the Formation History of Milky Way-mass Galaxies

The age and chemistry of the globular cluster (GC) and field star populations of galaxies encode information about the formation of the galaxy. We use the E-MOSAICS suite of 25 cosmological zoom-in simulations of Milky Way-mass galaxies and their GC populations to investigate what the GC population can uncover about the formation of the galaxy.

Firstly, we try to understand how GCs associated with stellar streams can be used to estimate the mass and the infall time of their parent galaxy. We find that more massive accreted galaxies typically contribute younger and more metal rich GCs than less massive ones, due to a more extended GC formation history. In addition, at fixed stellar mass, galaxies that are accreted later host younger clusters, because they can continue to form GCs without being subjected to environmental influences for longer.

Using the age of the GCs associated with the Sagittarius dwarf, we place constraints on its infall time. We also investigate the alpha abundances of GCs associated with stellar streams and find that they host GCs with lower alpha abundances than those not on streams and therefore conclude that we may be able to identify a recently accreted GC this way and use it as a signpost for a disrupting dwarf galaxy.

Secondly, we calculate the contribution of disrupted GCs to the bulge component of the 25 simulated galaxies and find values between 0.3-14 per cent, where this fraction correlates with the galaxy's formation time. The upper range of these fractions is compatible with observationally-inferred measurements for the Milky Way, suggesting that in this respect the Milky Way is not typical of L* galaxies, having experienced a phase of unusually rapid growth at early times.

Jason Hunt (Centre for Computational Astrophysics, Flatiron Institute)

Resonance & Phase Mixing in the Galactic Disc

Gaia DR2 has provided an unprecedented wealth of information about the kinematics of stars in the Solar neighbourhood, and has highlighted the degree of features in the Galactic disc. We confront the data with a range of bar and spiral models in both action-angle space, and the R–v_ϕ plane. We find that the phase mixing induced by transient spiral structure creates ridges and arches in the local kinematics which are consistent with the Gaia data. We are able to produce a qualitatively good match to the data when combined with a bar with a variety of pattern speeds, and show that it is non-trivial to decouple the effects of the bar and the spiral structure. This is further complicated by the Milky Way's interaction with satellite galaxies such as Sagittarius & the LMC, which also induce significant perturbations in the disc kinematics.

Alexander Ji (Carnegie Observatories)

Chemical Abundances Trace the Formation and Disruption of Ultra-faint Dwarf Galaxies

Ultra-faint dwarf galaxies (UFDs, with stellar mass < 10^5 Msun) are relics of the first galaxies, providing a large population of local objects that can be connected to theoretical predictions of high-redshift star and galaxy formation. Interpreting the observed chemical abundances of UFD stars is one of the most important ways to advance our understanding of their formation. I will review the current status of chemical abundances in UFD galaxies, focusing on recent observations that point towards physical ingredients that should be included in simulations in order to productively compare with the abundance data. The unique abundance trends observed in UFDs also enable chemical tagging of some Milky Way halo stars as originating from disrupted UFDs. I will show how such chemical tags provide a means to measure the contribution of disrupted UFD galaxies to the stellar halo, and discuss requirements for upcoming spectroscopic surveys to make this measurement.

Helmer Koppelman (Kapteyn Astronomical Institute)

Insights into the Assembly History of the Milky Way from Data, Simulations and Theory

The Gaia mission is currently enabling the study of the formation history of the Milky Way in great and exquisite detail. The emerging picture is that most of the accreted stars in the solar neighbourhood originate in a single, massive dwarf galaxy: Gaia-Enceladus (or Gaia-Sausage). A detailed understanding of the accretion process of this dwarf galaxy is lacking. One open question is whether and how other recently discovered substructures in the retrograde halo may or may not be related to Gaia-Enceladus (e.g. Sequoia, Thamnos). I will present insights from simulations and spectroscopic data on their possible link and on their role in the assembly history of the Milky Way. These analyses reveal the importance of simultaneous modelling of the chemical and dynamical evolution of merger debris as well as large samples of stars with detailed chemical abundance information.

Nicolas Lehner (University of Notre Dame)

Capturing the Dynamics of the Circumgalactic Medium of M31

UV absorption-line studies of single sight lines through an ensemble of galaxy halos have shown that the circumgalactic medium (CGM) plays a major role in galaxy evolution. However, these observations fail to capture accurately the radial-azimuthal dependence of the CGM properties, which has significant diagnostic power for zoom simulations. Project AMIGA is a large HST program, which has assembled a sample of 44 QSOs observed with COS. These QSOs pierce the CGM of M31 from R=25 to 569 kpc, 25 of them probing gas from 25 kpc to about the virial radius (~300 kpc) of M31. Our large sample provides an unparalleled look on how the metals and physical conditions are distributed in the CGM of a single galaxy using ions that probe a wide range of gas-phases. I will discuss the major findings from Project AMIGA including that Si III (cool ionized gas) and O VI (warm-hot ionized gas) have near unity covering factor maintained all the way out to 330 and 569 kpc, respectively. I will show that several properties (ionization, surface densities, kinematics) are strongly varying with radius, demonstrating in particular that the inner regions of the CGM of M31 are more dynamic and complex, while the more diffuse regions at larger radii are more static and simpler. I will finally discuss these results in the context of the Local Group (in particular the Milky Way) and offer some thoughts for future UV space-based and deep HI surveys of the CGM of galaxies.

Jianhui Lian (University of Utah)

Revealing the Milky Way's Star Formation History: A Recent Gas-rich Merger?

Our picture of how galaxies evolve and enrich the Universe relies directly on our understanding of when, where, and how our own Galaxy's stars evolved and died, but until recently, our measurements of the Milky Way's enrichment history were largely limited to the solar neighborhood. Now, massive stellar surveys are yielding spectroscopic datasets of unprecedented quantity and quality for stars through out the Galactic disk. These measurements reveal complex, position-dependent patterns of age and abundance that comprise the most rigorous observational constraints to date for models of Galactic star formation—indeed, demanding novel modeling frameworks to reproduce them.

I will give a talk to introduce our recent work on revealing the Milky Way's star formation and chemical enrichment history, from the Galactic bulge to the outskirts of the disk, by applying a novel star formation model to age and chemical information of 10^5 stars from the APOGEE survey. We conduct the first systematic fitting of a multi-phase accretion and star formation numerical framework to the multi-dimensional constraints of ages and abundances. The most striking and exciting finding is that a recent vigorous gas accretion event, associated with a starburst occurred around 5 Gyr ago, is required to explain these new data, especially the existence of a young, metal-poor and alpha-enhanced population in the disk. We speculate that a gas-rich dwarf galaxy recently captured by the Milky Way supplied this gas accretion, possibly the Sagittarius precursor. Our result suggests that minor mergers in the very nearby Universe, although much less frequent than those in the high-redshift Universe, are still playing an important role in shaping galaxies like the Milky Way.

Nicolas Martin (Strasbourg Astronomical Observatory)

Unveiling the Proto-Milky Way with Extremely Metal-poor Stars

I will present the latest results from the Pristine survey, a combined photometric and spectroscopic survey that aims at mapping the very metal-poor —and therefore old— Milky Way. In particular, with the combination of Pristine and the Gaia DR2 data, we are able to show that a significant fraction of stars with [Fe/H]<-2.5 show disk-like kinematics, hinting at the presence of a very old stellar disk in the Milky Way. Such a stellar component is at odds with expectations from state of the art simulations of disk galaxies like the Milky Way and could hint that those are missing crucial ingredients to explain the Milky Way formation.

Alberto Manuel Martínez García (Instituto de Astrofísica de Canarias {IAC})

Disentangling the 3D Internal Kinematics of the Sculptor dSph Galaxy

The Gaia second data release (DR2) has set a new benchmark by providing unparalleled astrometry for stars of the Milky Way (MW) and its satellites. Among its numerous applications, DR2 has opened a new window for understanding the internal dynamics of dwarf spheroidal galaxies (dSph) which remain mostly unknown. In this work we present the preliminary results of a detailed study of the internal dynamics of the Sculptor dSph. Our results are based on 934 member stars for which precise Gaia proper motion and line-of-sight velocities from other catalogs are available. This has allowed us to construct full 3D velocity vector space and study, for the first time, signs of internal rotation in Sculptor dSph using all the components of velocity. Special attention has been paid to membership selection making use of advanced Machine Learning techniques. This proved to be a highly efficient method to discard MW stars, which could significantly impact the results. We plan to extend our method to other satellites of the MW's system. Our results will shed light on the internal dynamics of other dSphs and on the physical processes involved on their evolution.

Clara Martínez-Vázquez (Cerro Tololo Inter-American Observatory (CTIO))

Tracing the Early Chemical Evolution of Local Group Dwarf Galaxies Using RR Lyrae Stars

RR Lyrae stars (RRLs) are powerful tracers of the early evolution of their host stellar system, since they provide direct insight into the age and the chemical evolution of the old (>10 Gyr) population they belong to. Their pulsation properties can be used to obtain individual metallicities, and derive the metallicity distribution of a purely old population. From the most complete, extensive, and updated catalog of RRLs in the Sculptor dSph (which contains 536 RRLs), we have traced in detail the early chemical evolution of this galaxy. We have found that a large metallicity spread is present in the population of RRLs, consistent with a rapid chemical enrichment that occurred at the early stages of Sculptor's life. When comparing the metallicity distribution of the RRLs (purely old population) with the RGB stars (age-degenerated population) we found that i) the star formation in the center of Sculptor lasted substantially longer than in the outer parts, thus constraining the timescales for the outside-in evolution of this galaxy, and ii) the RRL population has an intrinsic metallicity spread and presents a clear spatial metallicity gradient, which therefore was in place at a very early epoch. We have also extended our approach to six M31 dwarf satellites observed with the Hubble Space Telescope (HST). From 111 HST orbits, we have detected around 900 RRLs in these six galaxies, deriving metallicities for individual RRLs and providing their metallicity distribution function. Finally, we broadened our approach to a dozen LG galaxies more, located in different environments, to show the potential of this approach for more distant objects for when the JWST and the next generation of ELTs is operative. Interestingly, we find robust evidence of an early chemical enrichment in the old population of some of them.

Pol Massana (University of Surrey)

SMASHing the Star Formation History of the Small Magellanic Cloud

The Small Magellanic Cloud (SMC) constitutes an excellent laboratory to study galaxy formation and evolution in exquisite detail. It is believed to have had a very recent close encounter with the Large Magellanic Cloud (LMC) around 150 Myr ago, that left significant imprints on its star formation history (SFH). The study of the implications of galaxy interactions in the star formation rate of galaxies is a topic that, despite generating significant interest inside the community, has not been properly characterised yet. The complex nature of the SMC, which is in turn being affected by the Milky Way halo, presents many characteristics that allow a proper study of all the effects as they are happening. I present here the first detailed determination of the SFH corresponding to the full main body of the SMC using very deep data (g~26) from the Survey of the MAgellanic Stellar History (SMASH). The colour magnitude diagrams (CMD), that reach down to 2-2.5 magnitudes below the oldest Main Sequence Turn-Off, are compared to state-of-the-art modelling of CMDs allowing for a comprehensive study of the SFH with unprecedented detail (resolution up to ~300 pc). I discuss the spatial variations of the stellar ages and metallicities of different components of the SMC including azimuthal and radial trends. Finally, I compare the SFHs of both the LMC and SMC with their orbital history to place strong constraints on their evolution and past interactions.

Kevin McKinnon (University of California, Santa Cruz)

Chemical Properties of the Milky Way's Stellar Halo

As the Milky Way assembles hierarchically, assuming a Lambda-CDM cosmology, the progenitor systems mix in ways that are difficult to disentangle with kinematics alone, even when considering long-lived structures like the stellar halo. Chemical abundances, however, preserve information about a given star's origin and allow the tracking of merger histories. In this work, we compare medium-resolution spectra from the HALO7D (Halo Assembly in Lambda-CDM: Observations in 7 Dimensions) survey to a synthetic grid of model spectra to determine stellar properties (T_eff, log g, [Fe/H], [alpha/Fe]). The HALO7D dataset consists of Keck II/DEIMOS spectroscopy and Hubble Space Telescope-measured proper motions of MW halo main-sequence turnoff stars in the CANDELS fields. As a complement to Gaia, HALO7D pushes ~4 magnitudes fainter, which allows us to probe halo MS stars that are up to ~10 times further away (D ~ 100 kpc). This work is the third in the HALO7D series; the first two papers presented radial velocities and 6D positional/kinematical measurements, respectively, while we focus on the 7th dimension of chemical abundance. The stellar parameters are fit simultaneously in a Bayesian hierarchical model that considers both photometric and spectroscopic information; this framework allows us to combine the multiple observations of each star in a way that reduces the impact of systematic errors from the reduction pipeline. Our chemical abundance measurement method is applied to two well-studied, mono-metallicity globular clusters (M2 and M92) to assess the method's accuracy, and then we explore the MW's chemical properties in four CANDELS fields. These measurements can help us trace the relative importance of different halo formation mechanisms, constrain stellar halo progenitor masses, and highlight additional halo substructure that has been phase-mixed out, especially from early accretion events.

Dante Minniti (Universidad Andrés Bello)

New Globular Clusters in the Galactic Bulge

The VISTA Variables in the Via Lactea Extended Survey (VVVX) is a public near-IR surveys of the Southern Milky Way (http://vvvsurvey.org). I will present our latest discoveries and recent results on the globular clusters of the Milky Way bulge.

Exploration of our deep near-IR images have enabled the discovery of dozens of new candidate globular clusters in the bulge, that had hitherto remained hidden due to the severe crowding and differential reddening in the inner regions of the Galaxy.

The near-IR PSF photometry and the multi-epoch observations of variable stars have allowed the accurate measurement of the physical parameters (sizes, reddenings, distances, ages, luminosities, etc.) for several known globular clusters that were poorly studied thus far.

These studies contribute to a deeper understanding of the formation and evolution of the Milky Way globular cluster system.

Antonela Monachesi (Universidad de La Serena)

Insights from Stellar Halos and Bulges of MW-like Galaxies: Assembly History of M31 and the MW into Context

During the last decade, significant progress has been made to resolve the halos of nearby galaxies. These halos show a large diversity in their properties for Milky Way-like galaxies that are alike in terms of total luminosity and stellar mass. In this talk I will mostly focus on the results from the GHOSTS survey, an HST imaging survey of nearby galaxies beyond the Local Group. One of the most important results from this survey is the discovery of a stellar halo mass-metallicity relation, which allows to constrain the mass and metallicity of the most massive accreted satellite. I will also present the results from the stellar halos and bulges of the Auriga simulations, a suite of forty cosmological magneto-hydrodynamical zoom-in simulations of Milky Way-mass galaxies performed with the moving-mesh code AREPO. The Auriga simulations represent one of the largest and highest resolution sample of simulated Milky Way-mass galaxies with which it is possible to investigate in detail the properties and origin of individual stellar halos and bulges of Milky Way-like galaxies. I will compare the results from the Auriga simulations with those obtained from observations of nearby galaxies. I will then discuss observational signatures that allow us to decode the accretion and merger history of observed galaxies.

Catalina Mora-Urrejola (Universidad de La Serena)

Vertical Oscillation Patterns in Milky Way-type Galaxies Using Hα Data

In the past five years, a significant number of observational studies have provided strong evidence of an oscillating vertical asymmetry in our own galactic disk. The well-known characteristics observed in the Milky Way, such as the Monoceros Ring, TriAnd clouds and the recently discovered A13 overdensity, can naturally be explained by this asymmetry. Successful models to describe the origin of this type of disturbance are mainly based on the interaction between a host disk and its satellites, and studies based on cosmological simulations of late-type galaxies have shown that such patterns are expected to be common. . However, the evidence of vertical oscillatory patterns in external galaxies is extremely limited, and complete 2D maps have not been reported, showing consistent and global characteristics similar to those observed in the Milky Way. During this talk, I will present a sample of nearby late-type galaxies where it is expected to find these oscillatory patterns and, the candidate galaxies in which they are observed

Ethan Nadler (KIPAC/Stanford)

The Galaxy-Halo Connection Including the Impact of the LMC

The population of Milky Way (MW) satellites contains the faintest known galaxies, and thus provides essential insight into galaxy formation and dark matter microphysics. In this talk, we present a model of the galaxy--halo connection combined with newly derived observational selection functions based on satellite searches in DES and Pan-STARRS to fit the position-dependent MW satellite luminosity function. We report decisive evidence for the statistical impact of the LMC system on the MW satellite population due to an estimated 6.5 +/- 1.5 currently observed LMC-associated satellites, consistent with the number of LMC satellites inferred from Gaia proper motion measurements. In addition, we show based on satellite abundances that the LMC fell into the MW within the last 2 Gyr. These findings confirm the predictions of cold dark matter models for the existence of satellites within satellite halos. Moreover, we find that the faintest observed satellites inhabit halos with peak virial masses below ~2 x10^8 Msun at 95% confidence, and we place the first robust constraints on the fraction of halos that host galaxies in this regime. We predict that the faintest potentially detectable satellites occupy halos with peak virial masses above 10^6 Msun, highlighting the potential for powerful galaxy formation and dark matter constraints from future dwarf galaxy searches.

Julio Navarro (University of Victoria)

The Fornax Globular Cluster Timing Problem

We revisit the globular cluster (GC) "timing problem" in the Fornax dwarf spheroidal (dSph). Due to dynamical friction, GCs sink to the center of dark matter halos with a cuspy inner density profile but "stall" at roughly 1/3 of the core radius (rcore) in halos with constant-density cores. The timescales to sink or stall depend strongly on the mass of the GC and on the initial orbital radius, but are essentially the same for either cuspy (NFW) or cored halos normalized to have the same total mass within rcore. Arguing against a cusp on the basis that GCs have not sunk to the center is thus no different from arguing against a core, unless all clusters are today at $\sim$ (1/3)rcore. This would imply a core radius exceeding $\sim$ 3 kpc, much larger than seems plausible in any core-formation scenario. A simpler explanation is that Fornax GCs have only been modestly affected by dynamical friction, as expected if clusters started orbiting at initial radii of order $\sim$ 1-2 kpc, just outside Fornax's present-day half-light radius but well within the tidal radius imprinted by Galactic tides. This is not entirely unexpected. Fornax GCs are significantly older and more metal-poor than most Fornax stars, and such populations in dSphs tend to be more spatially extended than their younger and more metal-rich counterparts. Our simulations further suggest that GCs do not truly "stall" at $\sim$ 0.3rcore, but rather continue decaying toward the center, albeit at reduced rates. Dismissing the presence of a cusp in Fornax based on the spatial distribution of its GC population is unwarranted.

David Nidever (Montana State University)

The Evolution of the Magellanic Clouds and their Impact on the Milky Way

The Large and Small Magellanic Clouds (MCs) are the largest satellite galaxies of our Milky Way. This interacting pair of galaxies – with their own system of satellite galaxies - is an excellent nearby laboratory for studying the evolution of dwarf galaxies using resolved stellar populations. I will review the recent progress that has been made in our understanding of the formation and evolution of the Clouds as well as their impact on the Milky Way.

Andrew Pace (Carnegie Mellon University)

Chemodynamic Stellar Populations in Dwarf Spheroidal Galaxies

The distribution of dark matter within galaxies is a key observable to understanding the nature of dark matter and evolution of galaxies. The Milky Way satellite dwarf galaxies are nearby highly dark-matter-dominated systems and excellent laboratories for testing different dark matter models. I will present an analysis examining multiple stellar populations in Milky Way dwarf spheroidal galaxies with new MMT/Hectochelle and Magellan/M2FS spectroscopic data. I have identified distinct chemodynamic stellar populations at high significance with distinct kinematic, metallicity, and spatial distributions in the Draco, Sextans, and Ursa Minor dwarf galaxies. I will discuss the inferred dark matter density profiles and touch on the formation of these galaxies from the chemodynamic stellar populations.

Ekta Patel (University of California, Berkeley)

Satellites of Satellites in the Local Group

Massive satellite galaxies like the Large Magellanic Cloud (LMC) and M33 are ~10% of the mass of their host galaxy halos with infall masses of order 10^11 M_sun. LCDM simulations predict that LMC/M33-mass halos host a population of low mass, ultra-faint satellites (M_* < 10^5 M_sun). Furthermore, both the LMC and M33 are highly likely to be on first infall into the halos of the MW and M31, respectively, suggesting that many of these ultra-faint dwarf (UFDs) satellites are bound to the LMC and M33 today. In the last decade, tens of new UFDs have been discovered in close proximity to the Magellanic Clouds (MCs), but only one candidate satellite of M33 has been discovered to date. In this talk, I will juxtapose these two satellite systems and discuss ongoing efforts to characterize satellites of the MCs and then describe prospects for finding additional M33 satellites.

Using recent proper motions from Gaia DR2, the orbital histories of candidate Magellanic satellites are calculated in the combined gravitational potential of the MW, LMC, and SMC. Through a careful analysis of their orbital properties, we identify three categories of interaction with the MCs: 1) MW satellites that recently (< 1 Gyr) passed nearby the LMC at high speeds (v > v_esc, LMC), 2) short-term satellites that make one passage around the MCs, and 3) and long-term Magellanic satellites completing multiple orbits. Recent results predict that M33 may host up to a dozen of its own faint satellites, and these predictions change as a function of M33's past orbital history. I will discuss these findings and highlight how ground- and space-based observatories can be used to search for the hidden ultra-faint companions in M33's halo. Together, these two systems provide a direct test to LCDM predictions at the low mass end.

Marcel S. Pawlowski (Leibniz-Institute for Astrophysics Potsdam {AIP})

Planes of Satellites in the Local Group: Observational Evidence in Light of Gaia DR2 and Testing Proposed Solutions with Cosmological Simulations

The Milky Way, Andromeda, and Centaurus A host flattened distributions of satellite galaxies which exhibit coherent velocity trends indicative of rotation. The origin of these satellite structures remains an unsolved puzzle. Comparably extreme arrangements are very rare in ΛCDM simulations, giving rise to the Planes of Satellite Galaxies Problem of cosmology. I will briefly review the current status of the observational evidence for such phase-space correlations in the Local Group, emphasizing novel insights from Gaia DR2. This will be followed by a summary of the most-recent results of our investigations of proposed solutions to the problem – using the state-of-the-art hydrodynamical cosmological simulations of the IllustrisTNG project and high-resolution cosmological zoom simulations such as ELVIS and PhatELVIS. Specifically, I will discuss whether halo size, mass, concentration, formation time, or the presence of a central galaxy in a dark matter host halo – as a proxy for the leading baryonic effect on the distribution of satellites – result in more pronounced satellite planes. Another possibility are environmental effects. While in general pairs of host galaxies do not show more pronounced planes of satellites than isolated hosts, the specific environment of the Local Group and the accretion of dwarf galaxies from its nearby cosmic web might offer unique conditions and insights into solving this long-standing puzzle.

Pawel Pietrukowicz (Astronomical Observatory, University of Warsaw, Poland)

Structure and Formation of the Milky Way Disk and Bulge according to OGLE RR Lyrae Stars

RR Lyrae-type variable stars are tracers of stellar populations older than 10 Gyr. These stars witnessed the formation of the Galactic disk and bulge. Nearly 80,000 genuine RR Lyrae stars have been discovered thanks to regular and precise photometric observations of crowded Milky Way regions by the OGLE variability survey. We have used the sample of over 56,000 fundamental-mode (type RRab) pulsators to investigate the structure and properties of the old Galactic bulge and thick disk. We show that the spatial distribution of the old bulge has the shape of a triaxial ellipsoid that becomes more oblate with increasing distance from the Galactic center. Photometric properties of RR Lyrae stars in the inner bulge (within about 1 kpc from the center) and the outer bulge (1-3 kpc) are very similar.

The whole old bulge is formed of two major populations that differ slightly in metallicity (by only 0.02 dex), as seen in the Bailey diagram. Interestingly, the less metal-poor population is completely absent in the disk fields. It seems that the more metal-poor population is the inner extension of the Galactic halo, while the less metal-poor population was formed when the bulge emerged from the disk. Spectroscopic data should verify this hypothesis.

Amanda Quirk (University of California, Santa Cruz)

Kinematics of Resolved Stellar Populations in the Disk of M33

The Triangulum Galaxy (M33) is the only dwarf spiral in the Local Group. At a distance of 809 kpc (McConnachie et al. 2005), we can resolve individual stars, which allows for detailed observations. However, this galaxy has been surprisingly understudied. M33 has a warped and extended HI disk that goes beyond the stellar disk to 22 kpc (Putman et al. 2009). Its high star formation rate makes it more similar to high redshift galaxies than most other galaxies in the Local Group, making M33 important in studying galaxy evolution. In particular, M33 is useful to study the effects of stellar feedback because of its high star formation and low mass disk (measured by McConnachie et al. 2005 to have a stellar mass of approximately 10^9). In this talk, I will discuss the first study of the kinematics of resolved stellar populations across the disk of M33. Using Hubble Space Telescope (HST) 6-filter photometry from the Panchromatic Hubble Andromeda Triangulum (PHAT) survey, I targeted ~3,000 massive main sequence stars, helium burning stars, intermediate mass asymptotic giant branch stars, and low mass red giant branch stars. With spectroscopy from the DEep Imaging Multi-Object Spectrograph (DEIMOS) on the Keck II 10-meter telescope, I explore how velocity dispersion and asymmetric drift change as a function of stellar age. For the asymmetric drift measurements, I compare the movements of the stars to that of the HI (Gratier et al. 2010), Halpha (Kam et al. 2015), and CO (Druard et al. 2014). In this talk, I will discuss my ongoing findings of M33's disk kinematics as a function of stellar age. I will also make comparisons to similar studies in M31 (Dorman et al. 2015, Quirk et al. 2019) and in the Milky Way (Holmberg et al. 2009, Ting & Rix 2019).

Alejandra Recio-Blanco {Observatoire de la Côte d'Azur (Nice, France)}

The Falling Sky and the Revolving Discs: Building Up the Primordial Milky Way

A fundamental element of galaxy formation is the accretion of mass through mergers of satellites or gas. Recent dynamical analysis based on Gaia data have revealed major accretion events in the Milky Way's history. Nevertheless, our understanding of the primordial Milky Way is hindered because the bona fide identification of the most metal-poor and correspondently oldest accreted stars remains challenging. Here we present a new chemo-dynamical diagnostic using neutron-capture elements which detects three distinct components of the Galactic halo. All of them are present among the most primitive stars of the Galaxy, with iron contents several thousand times smaller than that of the Sun. Two massive flat components are distinguishable, one on prograde and one on retrograde orbits. The prograde population, showing imprints of a rapid chemical enrichment, could be associated to the early in situ galaxy. The retrograde population is chemically distinct at intermediate metallicities, having its origin in a system of a few 10^8 M_Sun. A third component can be identified around the polar axis. It embodies a mixture of accretion debris from satellites of different masses, pointing to a likely preferential merger direction, that could be crucial to constrain cosmological simulations of the Local Group. Our results demonstrate that both nature and nurture are relevant to the Milky Way's formation, since its primordial epochs. In addition, the large heavy element abundance scatter in the halo, challenging Milky Way chemical evolution models, should be revised in the light of our conclusions, being a crucial decoding key of our Galaxy building up.

Marina Rejkuba (European Southern Observatory)

Centaurus A and Its Dwarf Galaxy Satellite System

The Centaurus group at a distance of ~4 Mpc is one of the nearest galaxy groups in which we can study in detail stellar population properties, kinematics and spatial distribution of galaxies over a very wide range of luminosities. With two big galaxies, Cen A and M83, and a large dwarf galaxy population it represents an important comparison for Local Group studies. This talk will feature the latest results from studies of the resolved stellar halo of Cen A and its dwarf galaxy satellite system. The newly confirmed dwarf galaxies around Cen A are compared with the dwarf galaxy population in the Local Group in terms of sizes, luminosities and stellar population properties. Their luminosity function is found to be consistent with the cosmological Lambda CDM simulations, when baryonic feedback is included in the models, although we note a somewhat less populated bright end as well as an overabundance of faint dwarfs in the group. The spatial distribution of Cen A satellites is flattened along the line-of-sight and the evidence for corotating plane of satellites discovered by Mueller and collaborators in 2018 is further strengthened by the latest observations.

Martin Rey (Lund University)

How Diverse Are Ultra-faint Dwarf Galaxies?

I present results from high-resolution, "genetically modified” cosmological simulations of ultra-faint dwarf galaxies. I show how the variety of assemblies for ultra-faints results in a large diversity in their properties, including the creation of extreme, highly diffuse systems in the field (Rey et al. 2019).

Ultra-faint dwarfs galaxies are the least luminous objects in the Universe – their stellar masses are greatly sensitive to the interaction between mass growth and feedback. This sensitivity makes ultra-faints an ideal laboratory for testing galaxy formation models, while also generating significant scatter in their structural properties. Quantifying the expected scatter will be essential to interpret findings in the next generation of deep, wide sky surveys.

To begin this quantification, I present an application of ""genetic modifications"" (Roth et al. 2016, Rey et al. 2018) with cosmological high-resolution (3 pc) zoom simulations (Agertz et al. 2019). Genetic modifications allows us to generate different versions of the same cosmological dwarf galaxy, each version systematically varying its assembly history. Our scan through histories cleanly demonstrates (i) the existence of extended scatter in the stellar-to-halo-mass relationship at this mass scale and (ii) the potential for extremely low surface brightness dwarfs, achieved through an early truncation of in-situ star formation and a later growth by dry mergers. Modern imaging experiments (HSC, GAIA) have started to discover such ultra-faint and diffuse galaxies in the Local Group, highlighting future prospects to uncover a population with e.g. LSST.

Ian Roederer (University of Michigan)

Chemically Tagging Accreted Ultra-Faint Dwarf Galaxies Using r-process-enhanced Stars

The small but growing number of known r-process enhanced stars provides a chemical tag to identify and characterize a population of dwarf galaxies that were disrupted long ago by the Milky Way. The kinematics and phase-space clustering of these field stars reveal that a substantial fraction of them may be the disrupted remnants of a few dwarf galaxies. This approach may provide a way to assess the nature and properties of some of the lowest-mass galaxies that formed stars before being accreted by the Milky Way. We summarize the evidence supporting this assertion and discuss future prospects for chemically tagging ultra-faint dwarf galaxies that contributed to the assembly of the Milky Way stellar halo.

Predictions from LMC Analogs in the APOSTLE Cosmological Simulations

Isabel Santos-Santos (University of Victoria)

We search for analogs to the Large Magellanic Cloud (LMC) in the APOSTLE simulations (a suite of 12 zoom-in cosmological hydro-simulations of a Local Group-like environment) to study how the accretion of the LMC may have affected the Milky Way's stellar and gaseous halo and satellite population. Satellites with similar dynamical characteristics as observed in the LMC today are not uncommon in APOSTLE, and we analyze them as they undergo their first pericentric passage. In particular, we explore the satellite number and mass functions before and after infall, to address how many MW satellites may be associated with the LMC. Moreover, we compute their orbital angular momentum vectors and compare to recently measured proper motion data from Gaia. We also search for any bimodality in the position/velocity distribution of stars in the halo after the accretion, and for streams or shocked gas as a sign of the interaction. These predictions from cosmological simulations can be used to constrain both the past and future histories of the LMC+MW pair.

Alessandro Savino (Zentrum für Astronomie der Universität Heidelberg, Astronomisches Rechen-Institut)

The Oldest Stellar Population in the Galaxy

The central kiloparsecs of the Milky Way are known to host an old, spheroidal stellar population, whose spatial and kinematical properties set it apart from the boxy/peanut structure that constitutes most of the central stellar mass. The nature of this spheroidal population, whether a small classical bulge or the innermost extension of the stellar halo, remains unclear. Furthermore, hierarchical dark-matter paradigms suggest that the central spheroid should host some of the oldest stars in the Galaxy, making it of great value for galaxy formation studies. In this talk I will address the topic of the inner stellar spheroid age, using spectroscopic and photometric metallicities for a sample of 935 RR Lyrae stars that are constituents of this component. I will present a stellar population synthesis framework and derive an age-metallicity relation for RR Lyrae populations. When applied to the RR Lyrae stars in the bulge spheroid, this model infers an extremely ancient age, suggesting that these stars were among the first to form in what is now the Milky Way galaxy. I will explore the connection between the central spheroid and the large-scale stellar halo, pointing out differences and similarities. I will conclude with some challenges to overcome to deepen our insight in the early formation history of the heart of our galaxy.

Nora Shipp (University of Chicago)

Dynamical Modeling of Stellar Streams in the Southern Sky

The dynamical modeling of stellar streams - the tidal remnants of dwarf galaxies and globular clusters - is a powerful method for studying the distribution of matter in the local Universe on large and small scales. This in turn informs our understanding of galaxy formation and the nature of dark matter. I will discuss the stellar streams in the southern hemisphere recently discovered in the Dark Energy Survey, and observed by the Southern Stellar Stream Spectroscopic Survey (S5). Full 6D+1 observations by DES, S5, and Gaia make this a uniquely powerful set of streams for studying the local matter distribution and the formation history of our Galaxy, including multi-stream modeling of the local gravitational potential and novel studies of population statistics of stellar streams. In particular, I will present constraints on the mass of the Large Magellanic Cloud by the S5 streams, and comparisons between orbital properties of stellar streams and intact globular clusters and dwarf galaxies around the Milky Way.

Michael H Siegel (Pennsylvania State University)

Swift/UVOT Surveys of the Local Group

The Swift/UVOT Survey of Hot Stars has produced UV imaging and photometry for globular clusters, open clusters, M31, M33 and the Magellanic Clouds. UV photometry, especially when combined with multi-wavelength data from other missions, provides excellent constraints on the properties of young stellar populations, with concomitant insight into star formation histories, rare phase of stellar evolution and the UV extinction properties of dust. This not only provides insight into the Local Group itself, but provides a template for studying distant unresolved stellar population whose emissions peak in the rest-frame UV.

Adam Smercina (University of Michigan)

The Satellite Populations and Stellar Halos of MW-mass Galaxies

The outskirts of galaxies like the Milky Way (MW) are important testing grounds for our understanding of galaxy formation and evolution. Models and observations agree that their vast accreted halos, while incredibly faint and difficult to observe, tantalizingly encode the properties of past merger events. Further, discrepancies between the predicted properties and distribution of their satellite galaxy populations constitute some of the most important open challenges to galaxy formation models. Yet, to-date, our observational insight in both of these regimes has been limited to the Local Group. To address this deficit, we have surveyed the halos and satellite populations of several nearby galaxies with the Subaru Hyper Suprime-Cam. Thus far, we have gained a number of fundamental insights. The sparse satellite population of the `lonely giant' M94 challenges all current model predictions, and suggests that low-mass galaxy formation could be more stochastic than previously thought. Additionally, we have recently used the stellar halo of M81 to show that it has experienced a surprisingly quiet prior accretion history. Yet, its current interaction with M82 will eventually result in one of the most massive stellar halos in the nearby universe, supporting diversity in MW-mass galaxies' largest mergers as the primary driver of observed stellar halo diversity. Armed with this first-ever sample of galaxies for which both stellar halos and complete satellite populations have been measured, powerful and unexpected relationships emerge between satellite populations and merger history. These relationships present even more acute challenges to current models, and suggest a fundamental gap in our understanding of the formation of MW-mass systems — a crucial hurdle towards understanding the origins of our own Local Group.

Stefano Souza (Universidade de São Paulo - IAG-USP)

Self-Consistent Analysis of Globular Clusters: Simple and Multiple Stellar Populations

Globular clusters (GCs) are fundamental pieces to understand the formation and evolution of the Milky Way. From the color-magnitude diagrams, it is possible to get physical parameters such as age, distance, reddening, among others. The wealth of information available in high quality photometric, spectroscopic and/or astrometric data, allows performing a comprehensive and self-consistent analysis combining different data and techniques. We developed a code based on a Bayesian approach, named SIRIUS, to extract as much as possible information of a GC. Additionally, SIRIUS can characterize both simple (SSP) and multiple stellar populations (MPs). For the context of SSP, SIRIUS was applied to the Bulge GC HP~1 with deep near-infrared photometry obtained with the GSAOI + GeMS camera at the Gemini-South telescope combined with archival F606W-filter HST ACS/WFC images. Results from SIRIUS indicate an age of 12.8 ± 0.9 Gyr, confirming that HP~1 is one of the oldest clusters in the Milky Way. In the analysis of MPs, we study seven GCs located in the Galactic bulge, and two GCs located in the Galactic Halo, making use of the public photometry from \emph{The HST UV Legacy Survey of Galactic Globular Clusters} to derivate a possible age difference among their MPs. For the case of the halo GC NGC~6752, that hosts three stellar populations, we found an age difference between 1G and 2G of ~ 200 Myr, and ~ 500 Myr between 1G and 3G stars. For a sample of seven Bulge GCs, which host two stellar populations, we derived a mean age difference of 50 ± 500 Myr. With these results, SIRIUS also could help to constrain a possible formation scenario of MPs in GCs.

Salvatore Taibi (Instituto de Astrofisica de Canarias)

Stellar Chemo-kinematics of Isolated Dwarf Galaxies

The internal kinematic and chemical properties of Local Group (LG) dwarf galaxies can be studied in great detail from their resolved stars. This makes these systems a perfect laboratory to understand galaxy evolution and test LCDM predictions on the smallest galactic scales.

However, the majority of dwarf galaxies in the LG are found to be satellites of the Milky Way or M31, and thus to minimize the role of the environment and gain insights into the intrinsic properties of these objects, we focused on a sample of 3 LG isolated dwarfs: the two early-type Cetus and Tucana, and the late-type dwarf Aquarius. We have obtained line-of-sight velocities and metallicities ([Fe/H]) for sizable numbers (>~50) individual red giant branch stars per galaxy from VLT/FORS2 MXU spectroscopic observations in the region of the near-IR CaII triplet. The spatially extended coverage of our data allowed to obtain information on the wide-area kinematical and chemical properties of these objects.

Results of the kinematic analysis of Cetus and Tucana showed they are pressure supported systems with no significant signs of internal rotation, which is similar to their MW-satellite counterparts. For Tucana, which was claimed to be an exception to the too-big-to-fail problem, we found a lower velocity dispersion than that previously published in the literature, which brought it in line with values of similarly luminous companions. On the other hand, the study of Aquarius revealed an unexpected counter-rotation between the gaseous and stellar components, first such case observed for a LG dwarf and probably linked to a recent accretion event.

All 3 galaxies show signs of radial metallicity gradients, independent of their morphology or internal kinematic status. If confirmed, metallicity gradients may be an intrinsic feature of dwarf galaxies, whose strength depends on the stellar mass, star-formation and dynamical histories of these systems.

Tomas Tamfal (University of Zurich)

Wakes and Global Halo Modes Triggered by Massive Satellites and their Observability with Gaia

The orbital decay of a satellite galaxy within a larger host plays a key role in hierarchical structure formation. Since many decades there have been various attempts to determine the underlying physics and timescales of the drag mechanism, ranging from the local dynamical friction approach of Chandrasekhar (1943), to descriptions based on global modes induced in the background system (e.g. Tremaine & Weinberg 1984). An ultimate solution to this problem has been difficult owing, among other things, to the limited resolution of numerical simulations employed to test theoretical models. Here we present ultra-high resolution N-Body simulations of massive satellites orbiting a Milky Way-like galaxy (with a quarter billion particles), that appear to capture both the local dynamical friction "wake" and the global modes induced in the primary halo. We present novel analysis of the satellite-host interaction mechanism, and we discuss the prospect to observe the global halo modes using the recent Gaia data that reconstruct accurately the density distribution of the stellar halo of the Milky Way. Furthermore, as a by-product of this work, I will also elaborate on the topic of disk heating, including, the formation of the thick disk of the Milky Way, in a regime in which the full dynamical response of the system is ultimately captured, and the disk remains perfectly axisymmetric in isolation.

Roeland van der Marel (Space Telescope Science Institute)

Local Group Dynamics: Improved Understanding from Future Facilities

Our knowledge of the dynamics of galaxies in the Local Group has long been limited by the fact that only line-of-sight velocities were available. This introduces significant degeneracies in dynamical models, which can only be resolved by measuring also the velocity components perpendicular to the line of sight. However, beyond the Milky Way, the corresponding proper motions (PMs) were generally too small to measure. The ASTRO2010 NAS Decadal Survey listed astrometry as an "Area of Unusual Discovery Potential", and this has proven correct. Hubble has been able to make many accurate measurements over the past decade, and a further revolution has come with the release of the all-sky Gaia DR2 in April 2018. Yet, many questions remain unanswered. I will discuss how further progress will be enabled by future facilities in space (e.g., future Gaia Data Releases, JWST, WFIRST) and on the ground (e.g., LSST, 30m-class telescopes). This complement of observational capabilities will open up new subject areas for investigation through crucial advances in depth, spatial resolution, field-of-view, time baselines and time resolution.

Kathy Vivas (Cerro Tololo Inter-American Observatory)

The Giant Satellite Galaxy Crater II

Crater II is a fascinating galaxy. It is the fifth largest galaxy among the satellites of the Milky Way but significantly less luminous than other galaxies of its size. This galaxy lies in the frontier between classical satellites and ultra-faint dwarf galaxies. The extreme low surface brightness of Crater II makes it difficult to study because of the large contamination by both foreground stars and background faint galaxies. We explore the stellar population of Crater II through both its variable star population and a deep color-magnitude population. The large field of view of the Dark Energy Camera (DECam) at the 4m Blanco Telescope at Cerro Tololo Inter-American Observatory (CTIO), Chile, was the ideal instrument to observe this large galaxy. We identified 130 periodic variable stars, including RR Lyrae stars, anomalous Cepheids, SX Phoenicis stars, and eclipsing variables. The large number of RR Lyrae stars allowed us to obtain an accurate distance modulus, to explore the shape of the galaxy, and to asses the metallicity spread of the old population of Crater II. On the other hand, the deep CMD shows only old stars with a clearly bifurcated subgiant branch that feeds a narrow red giant branch. We plan to search for extra-tidal debris around this galaxy in the near future. Both the very low velocity dispersion of Crater II and its fiducial orbit, which brings it as close as 33 kpc from the Galactic center at perihelion every ~2 Gyr, predict that this ultra-diffuse galaxy must be disrupting by the tidal forces of the Milky Way.

Dan Weisz (University of California, Berkeley) CANCELLED

The Star Formation Histories of M31 Satellites

Satellites of the Milky Way (MW) have long anchored our knowledge of low-mass galaxy formation. However, multiple lines of evidence now indicate MW satellites may not be typical. Here, I will present the star formation histories of 25 M31 satellites measured from HST-based color-magnitude diagrams that extend below the horizontal branch. These SFHs suggest that the M31 satellites may have systematically different formation histories than their MW counterparts. Specifically, the M31 satellites do not follow the size-luminosity-age trends that are evident in the MW halo. I will describe how the different accretion histories of M31 and the MW may have influenced the formation and quenching timescales of their satellites. Finally, I will preview results from the Cycle 27 HST Treasury program that is acquiring main-sequence turnoff depth imaging of all M31 satellites in order to measure precise SFHs to cosmic dawn across the entire M31 halo.

Andrew Wetzel (University of California, Davis)

Simulating the Formation of the Local Group

I will present new results from the FIRE-2 cosmological zoom-in simulations regarding predictions for the formation history of the Local Group in a cosmological context, including comparisons to observations. First, I will discuss the formation history of the MW and M31 galaxies, addressing the following questions: (a) When did the single main progenitor of the MW or M31 likely form? (b) How many progenitor galaxies contributed to their formation? (c) Does their formation depend on the MW and M31 being in a Local Group pair? Second, I will discuss the formation histories of satellite dwarf galaxies in these simulations, quantifying how the current satellite population is a highly incomplete census of the progenitor population that formed the Local Group. I also examine the star-formation histories of these simulated satellites and compare against HST measurements of the Local Group, to understand the role of the Local Group environment in regulating galaxy formation via star-formation quenching.

Adam Wheeler (Columbia University)

Abundances in the Milky Way across Five Nucleosynthetic Channels from 4 Million LAMOST Stars

Large stellar surveys are revealing the chemodynamical structure of the Galaxy across a vast spatial extent. However, the many millions of low-resolution spectra observed to date are yet to be fully exploited. We employ The Cannon, a data-driven approach to estimating abundances, to obtain detailed abundances from low-resolution (R = 1800) LAMOST spectra, using the GALAH survey as our reference. We deliver five (for dwarfs) or six (for giants) estimated abundances representing five different nucleosynthetic channels, for 3.9 million stars, to a precision of 0.05 - 0.23 dex. Using wide binary pairs, we demonstrate that our measurements provide additional chemodynamical discriminating power, beyond metallicity alone. We show the coverage of our catalogue with radial, azimuthal and dynamical abundance maps, and examine the neutron capture abundances across the disk and halo, which indicate different origins for the in-situ and accreted halo populations. LAMOST has near-complete Gaia coverage, which provides an unprecedented perspective on chemistry across the Milky Way.

Coral Wheeler (California Institute of Technology)

Sweating the Small Stuff: Or How I Learned to START Worrying and Love the Smallest Galaxies

The currently favored cosmological paradigm, Lambda Cold Dark Matter Theory (LCDM), has been widely successful in predicting the counts, clustering, colors, morphologies, and evolution of galaxies on large scales, as well as a variety of cosmological observables. Despite these successes, several challenges have arisen to this model in recent years, most of them occurring at the smallest scales — those of low mass dwarf galaxies (Mstar < 10^7 Msun). To investigate these challenges, I will introduce a suite of extremely high-resolution cosmological hydrodynamic (GIZMO/FIRE2) simulations of dwarf galaxies run to z = 0 that allow me to probe smaller physical scales than previously possible in cosmological simulations, and to make detailed predictions for the counts, star formation histories, and chemical composition of the lowest mass galaxies ever observed. My simulations confirm many results at lower resolution, suggesting they are numerically robust (for a given physical model), but I also discover several intriguing discrepancies with observations. I will also discuss the implications of my work for the emerging low surface-brightness sky.

Jennifer Wojno (Johns Hopkins University)

Elemental Abundances in M31: [Fe/H] and [α/Fe] in M31 Dwarf Galaxies Using Coadded Spectra

We present chemical abundances of red giant branch (RGB) stars in the dwarf spheroidal (dSph) satellite system of Andromeda (M31), using spectral synthesis of medium resolution (R∼6000) spectra obtained with the Keck II telescope and DEIMOS spectrograph via the Spectroscopic and Photometric Landscape of Andromeda's Stellar Halo (SPLASH) survey. We coadd stars according to their similarity in photometric metallicity or effective temperature to obtain a signal-to-noise ratio (S/N) high enough to measure average [Fe/H] and [α/Fe] abundances. We validate our method using high S/N spectra of RGB stars in Milky Way globular clusters as well as deep observations for a subset of the M31 dSphs in our sample. For this set of validation coadds, we compare the weighted average abundance of the individual stars with the abundance determined from the coadd. We present individual and coadded measurements of [Fe/H] and [α/Fe] for stars in ten M31 dSphs, including the first [α/Fe] measurements for And IX, XIV, XV, and XVIII. These fainter, less massive dSphs show declining [α/Fe] relative to [Fe/H], implying an extended star formation history. In addition, these dSphs also follow the same mass-metallicity relation found in other Local Group satellites. The conclusions we infer from coadded spectra agree with those from previous measurements in brighter M31 dSphs with individual abundance measurements, as well as conclusions from photometric studies. These abundances greatly increase the number of spectroscopic measurements of the chemical composition of M31's less massive dwarf satellites, which are crucial to understanding their star formation history and interaction with the M31 system.

Yanbin Yang (Paris Observatory)

Toward A Complete Understanding of the Magellanic Stream and the Clouds

The origin of Magellanic Stream has been an unresolved mystery since its discovery 40 years ago. The recent discovery of a huge amounts of ionized gas, more than 10^9 solar masses, associated with the Stream and the extraordinary elongated 3D structure of SMC make them even more enigmatic. After having carefully analyzed the deepest HI survey, we found that the overall Stream is actually structured into two ram-pressure tails. The ram pressure is induced by the diffused multiphase gas in the MW halo. Kelvin-Helmholtz instabilities in the mixing phase of the stripped gas are sufficiently efficient to explain the huge amounts of ionized gas associated with the Stream. The collision between the two Clouds at 200-300 Myr ago has completely reshaped the system, including, e.g., by fully reshaping the SMC young stellar structure into a 30-kpc tube along the line of sight. Illustrating with fully-resolved hydrodynamical simulations, I will present a comprehensive study on this system, giving an overall and physical view based on the "ram-pressure plus collision” scenario.

Yong Zheng (University of California, Berkeley)

Conducting Time-Resolved Metal Census in Local Group Dwarf Galaxies

The mass and distribution of metals in galaxies closely trace galaxies' evolution histories. As galaxies evolve, metals are produced and distributed into interstellar medium (ISM), stars, circumgalactic medium (CGM), and beyond. Dwarf galaxies in the Local Group provide a unique opportunity to conduct time-resolved metal census because of their well-studied star-formation histories and accessible CGM metal contents with UV absorption lines. I will present HST/COS observations of two nearby isolated dwarf galaxies, WLM and IC1613, the CGM of which are probed by multiple quasar sightlines at different impact parameters. By estimating metal masses contained in their CGM, ISM, and stars, and comparing the values with the total amount of metals even been synthesized, I will discuss how the distribution of metals in dwarf galaxies are shaped by feedback processes due to their past star formation activities.

Paul Zivick (University of Virginia)

Deciphering the Kinematic Structure of the Small Magellanic Cloud in the Age of HST and Gaia

We present an overview of our evolving understanding of the Small Magellanic Cloud (SMC) kinematics through the age of HST and the introduction of Gaia and placing it in the larger picture of the Local Group dynamics. We first present initial proper motion (PM) measurements of the Clouds from the Hubble Space Telescope (HST) revealed they are on their first infall into the Milky Way. Follow up HST observations of the SMC improved the known systemic PM. Modeling the past interactions of the Clouds using the new SMC PM, we find the Clouds have undergone a direct collision (mean impact parameter of ~7 kpc) roughly 150 Myr ago. The second data release from the Gaia Space Telescope further expanded this picture, providing individual stellar kinematics for hundreds of thousands of stars within the Clouds. We present an analysis of these kinematics in the Magellanic Bridge which reveal more supporting evidence for the scenario of a recent and violent interaction between the Clouds. Finally, we present a new analysis of the SMC Gaia red giant (RG) stellar kinematics, cross matching with existing public RV catalogs to build a collection of 3D kinematics for the SMC. We find a need to model the RG population as distinct from the younger populations with a different systemic PM and center of mass in addition to a clear signal of tidal expansion in the SMC that will play a critical role in future modeling of the SMC kinematics.

Poster Abstracts

STScI

First Name	Last Name		Poster Title/SLACK Link
Hollis	Akins		Quenching Timescales of Dwarf Satellites Around Milky Way-mass Hosts / #poster-akins
Miranda	Apfel		Using Bullock & Johnston Simulated Stellar Halos to Assess the Diagnosic Power of the HAO7D Survey / #poster-apfel
Luciana	Bianchi		Young Stellar Populations in Local Group Galaxies: the UVIT View / #poster-bianchi
Annalisa	Calamida		A Merger Scenario for the Formation of Omega Cen / #poster-calamida
Katie	Chamberlain		The Frequency of Dwarf Galaxy Pairs over Cosmic Time / #poster-chamberlain
Michele	De Leo		Revealing the Tidal Scars of the Small Magellanic Cloud / #poster-deleo
Andres	del Pino Molina		And Yet It Rotates: The Internal Dynamics of the Sagittarius Dwarf Spheroidal Galaxy / #poster-delpino
Carrie	Filion		Towards the Low Mass Stellar Initial Mass Function of the Ultra Faint Galaxy Boötes I / #poster-filion
Sal Wanying	Fu		The Metallicity Distribution Functions of the Faintest Galaxies / #poster-fu
Marco	Grossi		VCC135 and VCC324: Positive Metallicity Gradients in Virgo Cluster Star-forming Dwarfs / #poster-grossi
Francois	Hammer		Can M31 Be Assembled through a Recent Major Merger? / #poster-hammer
Sten	Hasselquist		Exploring the Stellar Age Distribution of the Inner Milky Way Using APOGEE / #poster-hasselquist
Jaclyn	Jensen		Kinematic Detections of the Low-Density Stellar Stream NGC 5466 / #poster-jensen
Harshil	Kamdar		Clustered Star Formation in the Milky Way Disk / #poster-kamdar
Dhanesh	Krishnarao		Physical Conditions of Outflowing and Inflowing Gas: The Fermi Bubbles and Tilted Disk / #poster-krishnarao
James	Lane		Inferring Properties of the Sausage and Sequoia with APOGEE and Gaia / #poster-lane

Hannah	Lewis		First Keplerian Orbital Parameters for an Extragalactic Symbiotic System – Draco C1 / #poster-lewis-h
Megan	Lewis		Populations in the Bulge Asymmetries and Dynamical Evolution (BAaDE) Survey / #poster-lewis-m
Khyati	Malhan		Probing Dark Matter with Accreted Globular Cluster Streams / #poster-malhan
Kristen	McQuinn		Scylla: Probing the Star Formation History and Assembly of the Large and Small Magellanic Clouds in the Local Group / #poster-mcquinn
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Bridget	Ratcliffe		Tracing the Assembly of the Milky Way's Disk through Abundance Clustering / #poster-ratcliffe
Henrique	Reggiani		The Most Metal-Poor Stars in the LMC Are R-process Enhanced / #poster-reggiani
Hannah	Richstein		Using Deep HST Photometry to Characterize Ultra-faint Dwarfs and "Satellites of Satellites" / #poster-richstein
Alex	Riley		Snakes on a Plane (of Satellites): Do Milky Way Substructures Align with the Vast Polar Structure? / #poster-riley
Jenna	Samuel		The Spatial and Dynamical Distribution of Satellite Galaxies around MW/M31-mass Hosts in the FIRE Simulations / #poster-samuel
Nicholas	Smith		Widening Our View of Andromeda Satellite Galaxies: WIYN pODI Photometry of Cassiopeia III and Perseus I / #poster-smith WITHDRAWN
Nathaniel	Starkman		A Symmetric Pal 5 Stream and Dark Matter Halo Constraints / #poster-starkman

Charles	Sven		Physics of Dark Energy #poster-sven
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Erik	Tollerud		Local Galaxies and Reionization: What we learn by Combining HI, Optical, and Simulations / #poster-tollerud
Sachithra	Weerasooriya		Testing Semi-Analytical Modeling Using the Milky Way Dwarf Satellites / #poster-weerasooriya
Maria Katy	Wimberly		Ultrafaint Dwarf Galaxies: Smallest Scales Quenching & Predictions / #poster-wimberly
Rosemary	Wyse		Local Group Science with the Subaru Prime Focus Spectrograph #poster-wyse
Tomer	Yavetz		Separatrix Divergence of Stellar Streams in Galactic Potentials #poster-yavetz
Gail	Zasowski		Complex Stellar Populations Beyond the Milky Way / #poster-zasowski
Peter	Zeidler		A Young Star Cluster in Motion – The Complex Velocity Structure of Westerlund 2 / #poster-zeidler

Quenching Timescales of Dwarf Satellites Around Milky Way-mass Hosts

Hollis Akins (Grinnell College)

We present measurements of the quenched fractions and quenching timescales of dwarf satellite galaxies, derived from the Justice League suite of 4 ultra-high-resolution cosmological simulations of Milky Way-mass halos. We show that these simulations accurately reproduce the satellite luminosity functions of observed nearby galaxies, as well as variations in quenched fractions across stellar mass. We trace the histories of satellite galaxies back to z ~ 15, and find that most intermediate-mass satellites quench within 2 Gyr of infall into the host halo. A characteristic stellar mass scale of 10^8 solar masses is apparent, above which infalling satellites are largely resistant to rapid environmental quenching.

Using Bullock & Johnston Simulated Stellar Halos to Assess the Diagnostic Power of the HALO7D Survey

Miranda Apfel (University of California- Santa Cruz)

The HALO7D survey consists of Keck II/DEIMOS spectroscopy and Hubble Space Telescope-measured proper motions of ~200 Milky Way (MW) halo main sequence turnoff stars in 4 of the CANDELS fields. The survey provides valuable data in the exploration of the accretion history of the MW, such as the characteristic epoch of accretion, and properties such as mass and orbits of progenitor objects. We use the Bullock and Johnston (2005, 2008) simulated stellar halos to explore how different accretion histories and survey parameters affect the observable properties of the stellar halo, allowing us to examine the effects that number of stars, number of lines of sight, and our specific position in the galaxy have on the measurements. By recreating the HALO7D survey at different locations around the galactic center in multiple simulated halos, we probabilistically characterize a halo's observables and determine the most likely survey data result. This method allows us to look at all 7 dimensions (3 spatial coordinates, 3 kinematical components, and chemical abundances), as well as quantities derived from them such as the anisotropy parameter and angular momentum, and make statistical predictions of their distributions based on accretion history. Our experiments with the halo models will also allow us to quantify the degree to which our proposed extension to the original HALO7D survey, using archival HST, GAIA data, and new Keck II/DEIMOS spectra, will improve constraints on the accretion history of the MW halo.

Young Stellar Populations in Local Group Galaxies: the UVIT View

Luciana Bianchi (Johns Hopkins University)

Far-UV data are indispensable to identify the hottest, most massive stars, the most relevant players in the chemical and dynamical evolution of galaxies. Far-UV measurements, with complementary optical data, allow us to correctly establish the hottest stars' Effective Temperature and Luminosity by breaking the [temperature,extinction] degeneracy and providing better sensitivity to the hotter temperatures, resulting in a precise characterization of the youngest massive stars, and dust, that cannot be achieved with optical colors alone. HST imaging of star-forming sites in Local Group galaxies resolved the compact cores of the youngest stellar associations into their stellar constituents. GALEX wide-field FUV,NUV imaging yielded a comprehensive, unprecedented view of the youngest populations (and dust) across entire galaxies from our closest neighbors, the Magellanic Clouds, to beyond the Local Group, and changed some of the previous views on star formation. Now filling the critical gap between HST's sub-pc (projected on the sky for Local Group galaxies) resolution over field-of-views of a few 100pc, and GALEX's 10-20pc resolution across 1.2degrees fields, UVIT on Astrosat is delivering a more conclusive, quantitative view of star-forming galaxies, sampling large portions of them (28arcmin diameter field-of-view) with spatial resolution comparable to contemporary ground-based surveys. Its richer set of FUV (and initially NUV) filters enables a better characterization of extinction by dust and therefore also of stellar parameters. We present results from ongoing programs for the very low metallicity Magellanic Clouds (SMC and MB fields, paving the way for an upcoming extensive survey), the low-metallicity spiral M33, the nearby dwarf NGC6822, an ongoing survey covering the whole extent of M31, and a glimpse beyond the Local Group with UVIT imaging of NGC300.

A Merger Scenario for the Formation of Omega Cen

Annalisa Calamida (Space Telescope Science Institute)

I present in this poster results from multi-band photometry covering ~ 5x5 degrees across Omega Centauri collected with the DECam on the Blanco telescope combined to HST for the central regions. The unprecedented photometric accuracy and field coverage allows me to confirm the different spatial distribution of blue and red main-sequence stars, and of red-giant branch (RGB) stars with different metallicities. The blue main-sequence stars show a more extended spatial distribution compared to red main-sequence stars, and their frequency increases at a distance of ~ 30' from Omega Cen center. Similarly, the more metal-rich RGB stars show a more extended spatial distribution compared to the more metal-poor ones in the outskirt of the cluster. Moreover, the center of the distributions of metal-rich and metal-poor RGB stars are shifted in different directions with respect to the geometrical center of Omega Cen. For the first time, a stellar density profile for Omega Cen was built based on star counts of RGB, sub-giant branch and main-sequence stars. By fitting dynamical models to the density profiles, the best fit is obtained with the SPES models, which include a surrounding halo of potential escaper stars, constituting ~ 2% of Omega Cen mass. This circumstantial evidence suggests a merging scenario for the formation of the peculiar stellar system Omega Cen.

The Frequency of Dwarf Galaxy Pairs over Cosmic Time

Katie Chamberlain (University of Arizona)

Galaxy mergers are the foundation of hierarchical structure formation and therefore a key driver of galaxy evolution. Merger rates for massive galaxies are well studied both theoretically and observationally. However, similar studies for low mass dwarf galaxies do not yet exist even though they are the most abundant class of galaxies across all redshifts and will dominate observations with next generation instruments (e.g. JWST, WFIRST). Different merger identification techniques are required for dwarf galaxy pairs due to their morphological differences from massive galaxies. Calibrated observability timescales are necessary to transform pair fractions of low mass galaxies into merger rates, yet these calibrations currently only exist for massive galaxies. Cosmologically motived orbital parameters for dwarf galaxy interactions are needed to calibrate the observability timescale in this low mass regime. Only two local dwarf galaxy pairs have detailed orbital models (the Magellanic Clouds and NGC 4490/4485), and both are consistent with high eccentricities and long orbital timescales. Nevertheless, it is unclear whether dwarf galaxy pairs generically display these orbital characteristics. I will present findings that utilize the Illustris simulation suite to constrain the frequency of dwarf galaxy pairs out to z~2 and show that analogs of the Magellanic Clouds were much more abundant at earlier times. I will also discuss the typical relative separations and velocities of these pairs, placing the Magellanic Clouds in a cosmological context via their dynamics for the first time. This work will enable calibrations of dwarf galaxy observability timescales, which are crucial for interpreting merger rates in the era of JWST.

Revealing the Tidal Scars of the Small Magellanic Cloud

Michele De Leo (University of Surrey)

The Large and the Small Magellanic Clouds (LMC/SMC) constitute two of the most fascinating objects of our Local Group of galaxies. Due to their proximity to us and to their turbulent interaction history -evidenced by the various different features that characterise the Magellanic system (like the Magellanic Stream and Leading Arm)- they provide natural laboratories to understand how galaxies form and evolve as well as how tidal interactions shape these processes. Historically, the SMC has been less investigated than the LMC due to its greater distance from us and its apparently more disrupted state. Basic properties of the SMC such as its centre of mass, its line-of-sight depth and its dynamical state all remain highly debated. With the aim of understanding the structure, dark matter content and dynamical state of the SMC, I present in this talk new spectroscopic data for ~2000 SMC red giant branch stars observed using the AAOmega spectrograph at the AAT. These observations are complemented by further spectroscopic data from Dobbie et al. (2014) and proper motions from the Gaia DR2 catalogue. I will show here that the SMC centre of mass is clearly offset from the velocity centre of its associated HI gas, demonstrating that the latter is likely to be far from dynamic equilibrium. I will also present the first unequivocal confirmation that the SMC is currently undergoing tidal disruption by the LMC. I find evidence of tidally stripped stars, projected along the line-of-sight, well within 2 kpc of the photometric centre of the SMC. In order to gain further insights into how advanced is the state of tidal disruption in the SMC, I compare these findings to numerical models of the SMC/LMC system disrupting around the Milky Way. This work has been submitted as a paper to the MNRAS journal.

And Yet It Rotates: The Internal Dynamics of the Sagittarius Dwarf Spheroidal Galaxy

Andres Del Pino Molina (Space Telescope Science Institute)

The Gaia mission has revolutionized our view of the Milky Way (MW) and its satellite galaxies. Thanks to its unparalleled astrometric capabilities we can study the tangential motion of the stars (PMs), opening a window to new dynamical analysis of such galaxies. In this poster, we present a detailed study of the Sagittarius dwarf spheroidal galaxy (Sag) making use of more than 1.4×10^5 member stars, ~3500 RR-Lyrae, and ~1500 spectroscopically observed stars with derived line-of-sight velocities. We have combined all the data through advanced Machine Learning techniques obtaining the full phase-space of Sag, i.e., the 3D positions and 3D velocities. Sag is a triaxial system with a bar-like structure and arms that depart from it just 1.5 kpc from its center. The main body of the galaxy is inclined with respect to the plane of thee sky ($\sim$40 deg) and it rotates in the line-of-sight with an observed gradient of $\sim$20kms in the inner 2 kpc. The inner parts of the galaxy (< 1.8 kpc) are collapsing into the core, whereas areas at larger radii seem to be on expansion towards the Sag stream as the galaxy gets disrupted by MWs tidal forces. Results found here point to Sag being in a inclined prograde orbit around the MW. We have tested this theory with N-body simulations, being able to reproduce the main properties of Sag.

Towards the Low Mass Stellar Initial Mass Function of the Ultra Faint Galaxy Boötes I

Carrie Filion (Johns Hopkins University)

We present new results on the low-mass end of the stellar initial mass function (IMF) for Boötes I ultra faint dwarf spheroidal galaxy. These results were obtained utilizing new ultra-deep Hubble Space Telescope Advanced Camera for Surveys observations in the F606W and F814W bands, with photometry reaching down to I = 27.5 and extending to a lower mass regime than previous investigations of Boötes I. The stellar population of Boötes I is universally old and very metal-poor (age ~ 12 Gyr, mean [Fe/H] ~ -2.5) and it likely underwent only a short epoch of star formation, completed early in cosmic history. Boötes I is the most luminous ultra faint dwarf galaxy (Mv ~ -6) and relatively nearby (distance ~60kpc), and thus is an ideal target for the study of the faint end of the stellar luminosity function. At the depth of photometry reached by this work, the present day mass function is very close to the initial mass function, and thus the IMF can be modeled from direct star counts after accounting for the presence of unresolved binary stars. To characterize the uncertainties on the derived IMF, we are developing machine learning techniques.

The Metallicity Distribution Functions of the Faintest Galaxies

Sal Wanying Fu (University of California-Berkeley)

The metallicities and abundance patterns of stars in ultra-faint dwarf galaxies (UFDs) are rich in information about the baryonic processes that shaped the formation of the lowest-mass galaxies in the Universe. However, the paucity of bright stars in UFDs means that remarkably little is known about even their basic chemical properties, such as their metallicity distribution functions (MDFs). Here, I will describe a new program aimed to measure the MDFs of ~20 UFDs using the narrowband Calcium H & K filter on the Hubble Space Telescope (HST). The unique blue-optical sensitivity of HST can provide photometric metallicities for dozens to hundreds of faint stars in UFDs, providing for well-populated MDFs, and in turn, windows into the processes that shaped their formation. I will present preliminary CMDs and MDFs from our ongoing observations.

VCC135 and VCC324: Positive Metallicity Gradients in Virgo Cluster Star-forming Dwarfs

Marco Grossi (Observatório Do Valongo, Ufrj)

The study of the radial distribution of heavy elements in galaxies allows us to understand their mass assembly history, the gas accretion process, and the inside-out transportation of metals across the disk. Here we present integral field spectroscopy observations of two star-forming dwarf galaxies in the Virgo cluster (VCC 135 and VCC 324). We derive metallicity maps and we measure positive gas metallicity gradients, contrarily to what is usually found in other dwarfs or in spiral galaxies. Such a trend has been observed in only few, very isolated galaxies, or in systems at higher redshifts ($z > 1$) and it is thought to be associated with accretion of metal-poor gas from the intergalactic medium. However, the location of the dwarfs in the outskirts of the Virgo cluster would hamper this scenario because of the effects of ram-pressure stripping and/or starvation. The presence of weak underlying substructures in both galaxies and the analysis of morphological diagnostics and of ionised gas kinematics suggest that the inflow of metal-poor gas to the central regions of the dwarfs may be related to a recent merging event with a gas-rich companion. We argue that VCC 324 is the remnant of a major merger, while a minor-merger scenario seems more favored for VCC 135.

Can M31 Be Assembled through a Recent Major Merger?

Francois, Hammer (Paris Observatory)

We show that a single and recent 4:1 merger can explain the very unusual age–velocity dispersion relation in the M31 disk, together with the Giant Stream and most properties of M31 (the long-lived 10 kpc ring, the shells and clumps surrounding the disk, the halo density profile). This has been done by performing and analysing more than 300 high-resolution, hydrodynamical simulations in the LCDM context. It leads us to propose that the bulge, disk, and halo morphologies and their metal abundance distributions could be due to a single merger with a galaxy that has now fully coalesced with the Andromeda galaxy. We discuss how one may distinguish a major from a minor merger origin for, e.g., the Giant Stream. Constraints on a major merger are so numerous and heavy that the model could predict how such a violent event may have impacted the M31 halo and perhaps, part of the Local Group content.

Exploring the Stellar Age Distribution of the Inner Milky Way Using APOGEE

Sten Hasselquist (University of Utah)

Using the Cannon trained on a sample of nearby luminous red giant stars with relatively precise (0.2-0.3 dex in log(age)) ages derived from Baysian Isochrone matching, we derive ages for ~60,000 luminous (log(g) < 2.0), metal-rich ([Fe/H] > 0.5) red giant stars observed by the Apache Point Observatory Galactic Evolution Experiment (APOGEE). These ages are unique in that they are among the first ages for APOGEE luminous red giant stars that utilize a training set specifically selected to cover the parameters of the luminous giants, which cover large Galactocentric distances in APOGEE. In this work, we present and analyze the age distribution of stars located in the inner Milky Way (MW) to understand how the bulge/bar formed and evolved. We find that unlike the inner disk (3.5 kpc < R < 6.5 kpc), which has a steep vertical age gradient, the inner MW (R < 3.5 kpc) appears to be comprised primarily of older stars (age ~ 10 Gyr) at all |Z|. This results in a relatively steep radial age gradient in the plane (|Z| < 0.25 kpc) of the MW from 0 to 6.5 kpc. We also find that stars on the bar side of the inner MW are 2-3 Gyr younger, on average, than stars found on the off-bar side of the inner MW, but only at |Z| < 0.25 kpc. This suggests that while the bar is apparently an old structure (Age ~ 10 Gyr old), there has been some star formation in the plane of the inner MW as recent as 2-4 Gyr ago. We find that ~40-60% of stars with [Fe/H] > +0.2 found in the plane of the inner MW are younger than 5 Gyr.

Kinematic Detections of the Low-Density Stellar Stream NGC 5466

Jaclyn Jensen (University of Victoria)

The advent of all-sky surveys in the Gaia era has proven astounding for the field of Galactic Archeology; charting the Milky Way has never been more achievable. In this work, we traced substructure in the stellar halo via two tracer populations featuring the Canada-France Imaging Survey (CFIS). The CFIS u-band is instrumental for a) disentangling stellar populations and thereby b) determining absolute magnitudes and distances. We exploited CFIS' excellent photometric clarity and depth (which extends 3 magnitudes deeper than that of SDSS) to probe Blue Horizontal Branch stars and Red Giants in the stellar halo. In conjunction with Gaia proper motions, we obtained a sample of giants forming stream whose progenitor is a well-studied globular cluster (NGC 5466). This stream has largely been ignored for the past decade since its first detection in 2006, yet its morphology and observed parameters show interesting and unique results. For local cosmology in particular, long, thin, dynamically cold stellar streams are prime for constraining properties of the Milky Way's dark matter halo. We explored this stream traced by these observed giants in detail in this work.

Clustered Star Formation in the Milky Way Disk

Harshil Kamdar (Harvard University)

The clustered nature of star formation should produce a high degree of structure in the combined phase and chemical space in the Galactic disk. In this talk we present a new dynamical model of the Galactic disk that takes into account the clustered nature of star formation. This model predicts that the combined phase and chemical space is rich in substructure, and that this structure is sensitive both to the precise nature of clustered star formation and the large-scale properties of the Galaxy. The model self-consistently evolves 4 billion stars over the last 5 Gyr in a realistic potential that includes an axisymmetric component, a bar, spiral arms, and giant molecular clouds. All stars are born in clusters with an observationally motivated range of initial conditions. We demonstrate that the combination of chemical and phase space information is much more effective at identifying truly co-natal populations than either chemical or phase space alone. Furthermore, we show that co-moving pairs of stars are very likely to be co-natal if their velocity separation is less than 2 km/s and their metallicity separation is less than 0.05 dex. We also present a more holistic view of the disk by characterizing the two-point correlation function in both the data and our simulations. The results presented here bode well for harnessing the synergies between Gaia and many current and upcoming spectroscopic surveys to reveal the assembly history of the Galactic disk.

Dhanesh Krishnarao (University of Wisconsin-Madison)

Physical Conditions of Outflowing and Inflowing Gas: The Fermi Bubbles and Tilted Disk

M31 is no longer the closest example of a Low Ionization (Nuclear) Emission Region—LI(N)ER. Recently, we discovered diffuse ionized gas associated with the bar of the Milky Way ~1 kpc from Galactic Center (The Tilted Disk) that exhibits optical emission line ratios characteristic of LI(N)ERs in other galaxies. The inner Milky Way and inner region of M31 may be more similar than previously understood when considering the ionization conditions. Both galaxies show a lack of star formation around the transition region from the disk at large to the nuclear region, have evidence for a tilted distribution of gas flowing in non-circular orbits, and require a significant source of ionization from a still unconstrained source. Here, we use the Wisconsin H-Alpha Mapper (WHAM) to study ionized gas in optical emission lines from the inner Milky Way associated with the Tilted Disk (bar inflowing gas) and the Fermi Bubbles (nuclear outflowing gas) in two directions with existing UV absorption line detections. Ultimately, if the Fermi Bubbles originated as a Galactic Center outflow, the gas associated with it likely traversed the bar, through the Tilted Disk. Local gas, the Tilted Disk, and the Fermi Bubble show largely different behaviors in the ratio of [NII]/Ha emission, signaling distinct physical conditions among these regions of the disk and halo ISM. The Milky Way now provides the only place in the universe to study LI(N)ERs and large scale outflows using all wavelength bands, including UV absorption, and will allow us to finally constrain individual ionization sources (OB stars, hot evolved stars, shocks). Combining M31 and the Milky Way will provide a face-on extragalactic counterpart to an edge-on highly resolved picture seen from within the Galaxy and unveil how these Local Group galaxies relate to larger samples across cosmic time.

Inferring Properties of the Sausage and Sequoia with APOGEE and Gaia

James Lane (University of Toronto)

Gaia DR2 has shown us that a large portion of the Milky Way stellar halo is composed of the remnants of a few major accretion events. At least two of these events, known as the Sausage and Sequoia, correspond to observed overdensities in phase space that reflect the kinematic properties of the merger event. Despite extensive study, there remains uncertainty in the both the physical properties of these stellar populations, as well as their mass fraction with respect to the remainder of the stellar halo. We use APOGEE DR16, Gaia DR2 to make an accurate determination of the mass of the stellar halo in individual mono-abundance and mono-kinematic bins, with a focus on the Sausage and Sequoia. By leveraging the well-understood selection function for APOGEE-2, we can infer the underlying properties of these accreted stellar populations using a robust statistical framework.

First Keplerian Orbital Parameters for an Extragalactic Symbiotic System – Draco C1

Hannah Lewis (University of Virginia)

Symbiotic stars are interacting binaries consisting of a giant star transferring mass onto a hot, compact companion -- typically, a white dwarf. The Sloan Digital Sky Survey-IV Apache Point Observatory Galactic Evolution Experiment (APOGEE) Data Release 16 (DR16) provides high-resolution (R~22,500), multi-epoch, infrared (1.51 to 1.69 micron) spectra of the red giant-component (the hot, compact component is not detectable at these wavelengths) of three such systems contained in two of the Local Group dwarf galaxies. These systems -- LIN 183 and LIN 358 in the Small Magellanic Cloud, and Draco C1 in the Draco dwarf spheroidal -- have 12 or more precise radial velocity (RV) measurements in DR16, which is a sufficient number for the fitting of orbital parameters. With precise stellar parameters from APOGEE (effective temperature and surface gravity) for the red giant star, and derived orbital parameters, we also report improved mass measurements for the giant component and compact companion in each system. This work, for the first time since the discovery of these symbiotic systems, constrains precisely the geometries of the binaries.

Populations in the Bulge Asymmetries and Dynamical Evolution (BAaDE) Survey

Megan Lewis (University of New Mexico/National Radio Astronomy Observatory)

The Bulge Asymmetries and Dynamical Evolution (BAaDE) survey is the largest ever SiO maser survey of infrared-selected Asymptotic Giant Branch (AGB) stars in the Galactic Plane. One goal of the survey is to measure the line-of-sight velocity of thousands of point-mass probes of the Galactic gravitational potential. As the SiO maser transitions occur at radio wavelengths, they do not suffer from extinction and will be especially useful to trace the structure in the Plane and Bulge. About 19,000 targets have been observed with the VLA with over half of them hosting maser emission, and the ALMA portion containing 9,000 additional targets in the south is underway. We show that all observed SiO transitions closely trace the stellar velocity, ensuring that any BAaDE detection gives reliable velocity data. In addition to measuring stellar velocities, the SiO maser properties in combination with infrared spectral energy distributions and Galactic positions will statistically yield detailed information on the populations and evolution of low- to intermediate-mass evolved stars in the Galaxy. We show that BAaDE data can be used to establish infrared cuts between AGB stars and YSO sources, O-rich and C-rich AGB stars, and Bulge and Disk O-rich AGB stars allowing for large scale studies of the contents of the Plane.

Probing Dark Matter with Accreted Globular Cluster Streams

Khyati Malhan (Stockholm University)

With ESA/Gaia's precise astrometry facilitating efficient identification of stellar stream members, recent studies have revealed rather complex structural morphologies in some of the low-mass streams of the Milky Way. These newly-found complexities lend credence to a scenario where these streams were produced by globular clusters that formed and evolved within their parent dark satellite galaxies and later accreted onto the Milky Way. Under this "accretion" framework, a natural question to ask is - do the present day physical properties of these accreted streams encode information about the initial conditions and the dark matter density structure of their parent subhalos?

The talk will aim at presenting these newly-found observed complexities in some of the well studied stellar streams of the Milky Way, and at discussing the prospects of employing such stream systems in probing the dark matter properties of their parent subhalos.

Scylla: Probing the Star Formation History and Assembly of the Large and Small Magellanic Clouds in the Local Group

Kristen McQuinn (Rutgers University)

The Small and Large Magellanic Clouds (SMC and LMC, respectively) provide a unique opportunity to study interacting dwarf galaxies in exquisite detail. Scylla, a newly awarded 500-orbit Hubble Space Telescope program, will use deep, 5-band imaging with the Wide-Field Camera 3 to probe the history of the Clouds and their intertwined evolutionary history. One of the main science goals of Scylla is to use color-magnitude diagram fitting techniques to extract high temporal resolution star formation histories and chemical enrichment histories of the LMC and SMC, thereby determining the stellar mass assemblies of the galaxies. The deep imaging, reaching below the oldest main sequence turn-off, will provide precise ages at the earliest of epochs, allowing us to discern different evolutionary scenarios of low-mass galaxies. The SFHs of the Magellanic Clouds will be combined with their infall timescales, projected collision history, and orbital modeling to understand the connection between the interactions and star formation and the assembly of the Local Group. In this poster, we will present the overall science framework of the Scylla project, with an emphasis on the history of the Magellanic Clouds. Scylla's other main science goals include mapping the extinction curve, mapping the dust grain properties, and constraining the multidimensional structure of gas in the LMC and SMC.

Stellar Streams from Globular Clusters: Constraints of the Dark Matter Distribution in the Milky Way Halo

Jordi Miralda-Escudé (Institute of Cosmos Sciences, University of Barcelona)

Stellar streams from globular clusters are being discovered in large numbers. Among others, we have recently identified stellar streams produced by M68 and NGC 3201. We study the dynamics of these two streams and that of Palomar 5 and use them together with other data on the Milky Way disk circular velocity and motions of satellite galaxies to constrain the potential of the Milky Way and the dark matter distribution in the halo. The halo dark matter is remarkably close to spherical, which is not expected in the Cold Dark Matter theory and suggests a peculiar conspiracy of an anisotropic velocity dispersion compensating the disk potential for the halo dark matter.

The Formation and Evolution of Dwarf Galaxies in the Local Group Based on Long Period Variable Stars

Madieh Navabi (Institute for Research in Fundamental Sciences)

A large number of nearby dwarf galaxies in the Local Group (LG) establishes a comprehensive galactic environment that is ideal for studying the joint between resolved stellar populations and galaxies formation. In this study, we have conducted an optical monitoring survey by the 2.5-m Isaac Newton Telescope (INT) from 55 LG dwarf galaxies in the northern sky (including 22 satellites of Andromeda galaxy, 20 satellites of Milky Way galaxy, and several isolated galaxies). The aim of this survey was to detect long-period variable (LPV) stars in these dwarfs and reconstruct their star formation history (SFH) based on LPVs' properties. LPV stars in the red giant and supergiant category are significant because they achieve their highest luminosity at the endpoints of their evolution. Hence, their luminosity can be related to their initial mass by combining their photometry to the theoretical evolutionary tracks. Accordingly, by applying an identical method, we are able to reproduce the mass function and SFH of all different types of dwarfs that cause a great field for comparing the mechanisms of the formation and evolution in the nearby galaxies.

Authors:

M.Navabi, E.Saremi, A.Javadi, H.khosroshahi, J.Van Loon, H.abdollahi, Sh.Dehghani, M.Gholami, M.Noori, T. Parto.

New Families in Our Solar Neighborhood

Farnik Nikakhtar (University of Pennsylvania)

The standard picture of galaxy formation motivates the decomposition of the Galaxy into stellar populations and chemical abundances. To test this idea, we construct a Gaussian mixture model (GMM) for stars in the Solar neighborhood, assessing data in the space of their measured velocities and iron abundances (i.e. an augmented Toomre diagram). We compare results for the APOGEE-Gaia DR2 crossmatch catalog of the solar neighborhood with those from a suite of synthetic APOGEE-Gaia DR2 crossmatches constructed from high-resolution, cosmological-hydrodynamical simulations of Milky-Way-mass galaxies. We find that in both the real and synthetic data, the best-fit GMM uses five independent components whose properties resemble the populations predicted by galaxy formation theory. The best-fit model matches our physical intuitions about the origin of Solar-neighborhood stars and their spatial, kinematic, and abundance distributions. Quantitatively, we get new insights, as the optimal decomposition features five components: two analogous to the thin disk and the halo, but instead of a single counterpart to the thick disk, there are three intermediate components. We demonstrate how the model trained on the real data, once interpreted using the mock catalog, can subsequently be used to determine interesting subpopulations of stars from other surveys with more complex selection functions.

Properties of Stellar Streams and their Progenitors in Simulations

Nondh Panithanpaisal (University of Pennsylvania)

Stellar streams record accretion history of their host galaxy since they are direct imprints left behind by past and ongoing mergers. We present a set of simulated streams in the FIRE-2 cosmological hydrodynamical simulations with 7 isolated MW-like systems and 3 paired MW-Andromeda-like systems, with a total of 111 candidates. These simulated streams have stellar masses ranging from ~5x10^5 to ~5x10^8 solar masses, similar to those of the Sagittarius and Orphan streams. There are no significant differences in the number of streams and masses of their progenitors between isolated and paired environments. We also study chemical abundances and dynamical properties of simulated streams' progenitors. These progenitors have preferential orbits and lower [Fe/H] compared to present-day simulated satellite galaxies at the same stellar mass. Present-day simulated satellite galaxies are likely to orbit on the plane of the galactic disk, while simulated streams' progenitors tend to have a slight angled orbit. Some progenitors continue to form stars and reach maximum stellar mass after the infall, which in some cases, is significantly different from the stream formation time. The discrepancies between these three timescales can be up to a few Gyr. Moreover, the mass of the stream's progenitor cannot simply be estimated by the velocity dispersion along the stream since the velocity dispersion along the stream fluctuates and is anti-correlated with the location of the pericenter.

Using APOGEE to Determine Radial-Abundance-Age Trends in the Large Magellanic Cloud

Joshua Povick (Montana State University)

Dwarf galaxies are the most abundant type of galaxy in the universe but are especially difficult to study because they are intrinsically faint, and often distant. Unlike the majority of dwarf galaxies, the Magellanic Clouds are close enough to resolve individual stars making them the perfect laboratories to study dwarf galaxies. The dual-hemisphere Apache Point Galactic Evolution Experiment (APOGEE) provides accurate radial velocities and chemical abundances, which makes it an excellent tool to study galactic evolution in our local neighborhood. An important component of APOGEE is APOGEE-2 South, which was able to survey ~5000 red giant branch stars in the Clouds. We have broad azimuthal and radial coverage out to 10 deg in the Large Magellanic Cloud (LMC), and, therefore, the data from the survey forms an ideal dataset to study galaxy evolution. For this work, APOGEE DR16 stellar parameters and abundances, the accurate LMC SMASH red clump distance map from Choi et al. (2018a), and stellar isochrones were used to calculate star-by-star ages. I will present initial results of LMC radial-abundance-age trends and spatial abundance gradients. The density of younger stars was found to be higher in the center of the LMC, however, young stars are found at all radii in our sample. We find a slight negative radial gradient in the mean metallicity and a slight positive radial gradient in mean age out to 9 kpc. As a whole most of the elemental abundance gradients across the LMC are flat; the largest gradient, other than iron at -0.041 dex/kpc, was found to be -0.023 dex/kpc for chromium. One exception is carbon where the oldest stars are highly depleted (by ~0.5 dex) compared to the younger stars.

Swimming on a Stellar Stream: Re-discovering the Sagittarius Tails with Gaia

Pau Ramos (ICCUB)

The sheer amount of data that current and future surveys are providing is making our simple models and assumptions insufficient. In order to answer questions such as “How did our Galaxy came to be?” or “What does the Milky Way (MW) look like?” we have to start taking into account the tangled nature of these systems. Since the MW was born, several dynamical mechanisms have been at work, interacting with each other and reshaping the phase-space in a way that we could easily interpret wrongly if not treated with care.

Particularly, the in-fall of the Sagittarius Dwarf Spheroidal (Sgr) has been responsible for a significant fraction of the substructure that we observe today. The Monoceros ring, thought to be the remnant of an accreted satellite, is now also being linked to the perturbation caused by the interaction with Sgr. Yet, there are still many questions open regarding its orbit and stellar content, which hinders our ability to constrain its effects on the MW.

In this talk I will present the largest sample of Sagittarius stars available to date, obtained entirely from Gaia DR2 proper motions alone. Up until now, we only had access to some line of sight velocities along the stream. Now, thanks to a smart use of the Archive combined with the Wavelet Transform, we have unveiled an almost 360º degrees continuous track of proper motions. To complement this data set, we have also re-discovered the stream within the Gaia table of RR Lyrae. The advantage of using RR Lyrae is that we gain access to the distances and, therefore, to the tangential velocities in km/s and also to the velocity dispersion of the progenitor.

This data will allow us to study in great detail the populations of Sagittarius and obtain the best possible orbit.

Tracing the Assembly of the Milky Way's Disk through Abundance Clustering

Bridget Ratcliffe (Columbia University)

A major goal in the field of galaxy formation is to understand the formation of the Milky Way's disk. The first step toward doing this is to empirically describe its present state. We use the new high-dimensional data set of 19 abundances from 25,135 red clump APOGEE stars to examine the distribution of clusters defined using abundances. We implement a non-parametric agglomerative hierarchical clustering method and explore both linear and nonlinear dimensionality reduction techniques and observe an underlying structure consistent with nucleosynthetic enrichment events. We report that a subset of stars typically associated with the high-alpha sequence more closely resemble the conventionally defined low-alpha sequence in the higher dimensional chemical abundance space. Furthermore, we find that additional groups defined using abundances are spatially separated as a function of age, with the abundance groups representing different distributions in [Fe/H]-age plane. Ordering our clusters by age reveals patterns suggestive of the sequence of chemical enrichment in the disk over time. Our results indicate that a promising avenue to trace the details of the disk's assembly is via a full interpretation of the empirical connections we report.

The Most Metal-Poor Stars in the LMC Are R-process Enhanced

Henrique Reggiani (Johns Hopkins University)

The chemical abundances of the most metal-poor stars in a galaxy can be used to investigate the earliest stages of its formation and chemical evolution. Differences between the abundances of the most metal-poor stars in the Milky Way, M31, and their satellite galaxies have been noted and provide the strongest available constraints on the earliest stages of the Local Group's assembly. However, the masses of the Milky Way and its satellite dwarf galaxies differ by four orders of magnitude, leaving a gap in our knowledge of the early chemical evolution of intermediate-mass galaxies like the Magellanic Clouds. To close the gap, we have extended the Best & Brightest metal-poor star survey to the Magellanic Clouds. We used the mid-infrared metal-poor star selection of Schlaufman & Casey (2014) to target candidate metal-poor stars in the LMC for high-resolution Magellan/MIKE follow-up. The seven stars in our sample have -2.5 < [Fe/H] < -2.0 and are highly r-process enhanced: three are r-II stars with [Eu/Fe] > +1.0 and three are r-I stars with +0.7 < [Eu/Fe] < +1.0. The probability that seven randomly selected very metal-poor stars in the halo of the Milky Way are as r-process enhanced is about five in one billion. For that reason, the early chemical enrichment of the heaviest elements in the LMC and Milky Way were qualitatively different. The substantial r-process enhancement of the most metal-poor stars in the LMC is suggestive of a possible chemical link between the LMC and the ultra-faint dwarf galaxies nearby with r-process enhancement (e.g., Reticulum II and Tucana III).

Using Deep HST Photometry to Characterize Ultra-faint Dwarfs and "Satellites of Satellites"

Hannah Richstein (University of Virginia)

We present new photometric catalogs of ~30 ultra-faint dwarf satellites (UFDs), using data from an HST Treasury program. We examine the Treasury sample as a whole and search for trends in age and metallicity ([Fe/H]) as a function of Galactocentric distance. Additionally, we subdivide the larger sample into two groups based on their likelihood of an association with the Magellanic Clouds and analyze whether there are quantifiable differences between the typical group characteristics. We also provide a more detailed analysis for Horologium 1, an ultra-faint satellite of the Large Magellainc Cloud (LMC) that has been confirmed using simulations of the expected tidal debris from LMC-MW infall scenario. Learning more about these "satellites of satellites" will provide insight on how the mass of the host galaxy in a halo affects the evolution and dark matter content of its sub-halos.

Snakes on a Plane (of Satellites): Do Milky Way Substructures Align with the Vast Polar Structure?

Alex Riley (Texas A&M University)

There is increasing evidence that a substantial fraction of Milky Way satellite galaxies align in a rotationally-supported plane of satellites oriented nearly perpendicular to the Galactic plane. It has been suggested that other Milky Way substructures (namely young halo globular clusters and stellar/gaseous streams) similarly tend to align with this plane, accordingly dubbed the Vast Polar Structure (VPOS). Using an updated census of stellar streams, including new streams discovered using the Dark Energy Survey and Gaia datasets, I will show that stellar stream normals are not clustered in the direction of the VPOS normal. Additionally, using systemic proper motions inferred from Gaia data, I find that globular cluster orbital poles are also not clustered in the VPOS direction, though the population with the highest VPOS membership fraction is the young halo clusters. Comparing orbit integrations of dwarf galaxies and globular clusters with stellar stream tracks does not indicate a common origin for VPOS members, but may be a promising avenue for associating stellar streams with known satellites. These results, in combination with those for the satellite galaxies, suggest that the plane of satellites is either a particularly stable orbital configuration or a population of recently accreted satellites. Neither of these explanations is particularly satisfying in light of other studies, leaving the plane of satellites problem as one of the more consequential open problems in galaxy formation and cosmology.

The Spatial and Dynamical Distribution of Satellite Galaxies around MW/M31-mass Hosts in the FIRE Simulations

Jenna Samuel (University of California, Davis)

The spatial and dynamical distributions of satellite dwarf galaxies in the Local Group (LG) remain important tests of both physical models and numerical resolution in simulations. Using the FIRE-2 cosmological zoom-in baryonic simulations, we examine the radial distributions of satellites with Mstar > 10^5 Msun around 12 Milky Way- (MW) and LG-like host galaxies. We show that these simulations now excitingly agree with a range of LG observations, and our results suggest more undiscovered classical dwarf-mass satellites in the LG. Part of the successes of current simulations comes from key improvements over dark matter-only simulations, which we quantify. We also compare our results with the the SAGA survey of satellites around MW analogs in the local Universe, to provide cosmological context. Finally, we examine the dynamics of LG satellites in the context of the satellite plane problem, quantifying the prevalence of satellite planes in these simulations and how they may form and evolve on cosmological time scales.

Widening Our View of Andromeda Satellite Galaxies: WIYN pODI Photometry of Cassiopeia III and Perseus I

Nicholas Smith (Indiana University) POSTER WITHDRAWN

We present results from WIYN 3.5-m Observatory imaging of two Andromeda satellite dwarf galaxies, Cassiopeia III (And XXXII) and Perseus I (And XXXIII). The two galaxies, along with another satellite called Lacertae I (And XXXI), were discovered in Pan-STARRS1 imaging data in 2013 by Martin et al. (2013a, 2013b). Both Cas III and Per I are fairly luminous (with M_V ~ -12 and -10, respectively), but had escaped detection in previous surveys -- Cas III because of its large size and low central surface brightness, and Per I because of its location in an area with only shallow SDSS imaging. We have obtained deep follow-up, broadband imaging of these two galaxies with the pODI camera on WIYN, which provides a 24' x 24' field-of-view (FOV). Our g,i photometry reaches ~3 mag fainter than the Pan-STARRS1 photometry and our wide FOV allows us to trace the stellar populations well beyond the half-light radii of the galaxies. We use the WIYN pODI data to measure Tip of the Red Giant Branch distances and derive structural and photometric properties for Cas III and Per I. We compare our WIYN results to those presented in the discovery papers and in follow-up spectroscopic and imaging studies of these two galaxies, as well as to the properties of other Andromeda satellites.

A Symmetric Pal 5 Stream and Dark Matter Halo Constraints

Nathaniel Starkman (University of Toronto)

Tidal tails of globular clusters provide a sensitive method for measuring the current and past gravitational potential of their host galaxy. We present the results of a detailed search for members of the Pal 5 tidal tail system in Gaia Data Release 2 (DR2) -- extending the known extent of the Pal 5 tail to $\sim30°$, 7 degrees of which are newly detected along the leading arm. The detected leading and trailing arms are symmetric in length. We use this detection to constrain proposed models in which the Galactic bar truncates Pal 5's leading arm and tighten constraints on the triaxiality of the Galactic dark matter halo.

Physics of Dark Energy

Charles Sven (allnewuniverse.com)

Sensationalized shallow thinking or first impressions leave many to jump to conclusions which lead to poor descriptions.

Shallow thinking accepted the something from nothing, and like the spontaneous generation of life discredited in the mid 1800's, today's spontaneous generation of time, space, and matter out of nothing, requires magic and magic is not acceptable by any serious scientist.

We need to overcome that shallow thinking with Deep Thinking. That is the balance of this presentation:

We have had our observational senses enhanced by the invention of microscopes, telescopes and everything in between that should spur one onto some very Deep Thinking about the deepest questions of the day including how was our Universe created and what is the Physics of Dark Energy?

Today, unsupported by physics, is the current shallow thinking cosmological concept, that our Universe's atoms were created from a 'singleton' popping out of 'nothing,' and consequently not well received.

That indicates that we need to study these atoms for a better explanation.

In that light, here assembled is a number of replicable observations when properly arranged, with Deep Thinking, allows us to understand atoms and how the 'physics' of dark energy was employed in the Creation of our Universe; before, during, and after the Big Bang.

[evidence ...]

All of the above evidence, analyzed with Deep Thinking, finds that the vast, powerful, timeless, and chaotic Dark Energy, bubbled out all the Universe's estimated 10 to the 80th power number of atoms some 27.6 billion years ago, from its existence prior to the Big Bang and continues to exist based on all the light from the atoms redirecting dark energy coming out of stars shinning in all the galaxies in our Universe.

Near Field Cosmology with CoSANG: The Advantage and First Results

Shahram Talei (University of Alabama)

The stellar halo of a galaxy preserves most of the galaxy's information and assembly history, and could play a crucial role to understand the hierarchical structure formation in the local universe. The nonlinear nature of hierarchical structure formation and the wide range of physical processes involved, demand full physics computational models but in practice dynamic range is restricted by extremely high computational cost. A fast and flexible model without ignoring the key physical processes is demanded.

CoSANG (Coupling Semi-Analytic and N-body Galaxies) is a new approach in cosmological simulation, specifically designed for stellar halo studies. In the first phase of CoSANG, we have coupled a fast N-body model, Gadget 3 with a semi-analytic model, Sage. At each timestep, results from the N-body simulation will feed into the semi-analytic code, whose results will feed back into the N-body code. CoSANG self-consistently interacts with the simulation at all time-steps while it is running.

These baryonic effects are especially important for near field cosmology and CoSANG will let us explore structure formation at much higher resolution. We are using the first phase of CoSANG to study the inner structure of the halo and the subhalo distribution.

Using more realistic dynamics in CoSANG can provide more than dark matter-only simulations using particle tagging, which is currently under development. In this phase, CoSANG tags particles according to their dynamical properties. The semi-analytic model provides not only full phase space information but also metallicity, age, and stellar mass of the stellar halo. This new approach could produce more realistic results at higher resolution and could be calibrated by observations and hydrodynamic models.

Bridging the Gap between Theory and Data by Leveraging Large Datasets

Yuan-Sen Ting (Institute for Advanced Study / Australian National University)

Various spectroscopic surveys are providing an immense number of spectra from which we can study the stellar properties and elemental abundances of stars. Modern automated approaches for analyzing spectra either (a) based on data-driven models, which require an extensive grid of empirical spectra with prior knowledge of their stellar labels or are (b) based on theoretical synthetic models that are susceptible to model systematics. I will present a hybrid generative domain adaptation method, Cycle-StarNet, which overcomes the limitations of both data-driven models and ab-initio spectral fitting. I will demonstrate that Cycle-StarNet can generate systematics corrected spectral models through large datasets without relying on any standard stars. Cycle-StarNet can establish data-driven models with an unlabelled training set. Moreover, Cycle-StarNet can identify element-specific missing spectral features in the models. Cycle-StarNet provides a new methodology to auto-calibrate models, in stellar spectroscopy and beyond, capitalizing on large data sets from spectroscopic surveys and the latest technologies in machine learning.

Local Galaxies and Reionization: What We Learn by Combining HI, Optical, and Simulations

Erik Tollerud (Space Telescope Science Institute)

While optical survey-based searches have proven extraordinarily effective at identifying dwarf galaxies in the Local Group, they have limits and systematics. This begs the question: what can be learned by combining these surveys with other wavelengths? To address this, I will describe an approach for comparing HI (21 cm) surveys cross-matched with optical observations to LCDM simulations combined with a basic model for galaxy formation and gas content. When applied to the GALFA-HI survey and the ELVIS simulations, this technique reveals a strong apparent dearth of gas-rich dwarf galaxies. While it is far from certain that this is the cause, reionization provides a plausible explanation for these observations. Under that assumption, these observations provide strong constraints on the mass scales at which reionization must impact Local Group dwarf galaxies. While broadly consistent with theoretical models of inflation, this measurement also suggest a possible tension between those models and the very *existence* of the faintest known gas bearing galaxies (e.g., Leo T).

Testing Semi-Analytical Modeling Using the Milky Way Dwarf Satellites

Sachithra Weerasooriya (TCU)

Dwarf galaxies are the smallest and most common galaxies in the Universe. Extreme sensitivity to external and internal feedback makes them excellent probes of physics of their local environments. The explosion in the number of Milky Way satellites over the last 15 years coupled with high resolution hydrodynamic simulations has provided an excellent laboratory in which probe this physics. However, extrapolating our knowledge of the Milky Way dwarfs to other system rests on the assumption that the Local Group satellites are representative of those in other environments. Although several groups have simulated the Milky Way at high resolution, only minimal simulations exist of the dwarf satellite populations of other Local Volume systems. We present work which constrains the parameters of the semi-analytic model Shark using the wealth of observational and theoretical data of the Milky Way. The results of our study will be used to information semi-analytical modeling of dwarf satellite systems throughout the Local Volume to quantify how typical our Milky Way satellites are and inform ongoing and upcoming wide field surveys, including those proposed for WFIRST.

Ultrafaint Dwarf Galaxies: Smallest Scales Quenching & Predictions

M. Katy Rodriguez Wimberly (University of California-Irvine)

The predominantly ancient stellar populations observed in the lowest-mass galaxies (i.e. ultra-faint dwarfs - UFDs) suggest that their star formation was suppressed by reionization. Most of the well-studied UFDs, however, are within the central half of the Milky Way dark matter halo, such that they are consistent with a population that was accreted at early times - therefore potentially quenched via environmental processes. To study this possibility, we utilize the Exploring the Local Volume in Simulations (ELVIS) suite of N-body simulations to constrain the distribution of infall times for low-mass subhalos likely to host the UFDs. For the ultra-faint satellites of the Milky Way with star formation histories inferred from Hubble Space Telescope imaging, we find that environment is highly unlikely to play a dominant role in quenching their star formation. Even when including pre-processing effects, there is a $\lesssim$ 0.1% probability that environmental processes quenched our UFDs early enough to explain their observed star-formation histories. Instead, we argue for a mass floor in the effectiveness of satellite quenching at roughly $M_{\star}$ ~105 $M_{\odot}$, below which star formation in surviving galaxies is globally suppressed by reionization. Further in the exploration of our ultra-faint satellites, with the second data release of stellar proper motions from Gaia, several groups calculated phase space and orbit information. We use this new dynamic information to compare against the next generation of ELVIS, the Phat ELVIS simulations. This work in progress suggests that while the N-body simulations with an embedded disk potential are statistically more representative of the Milky Way system, the orbits of these lowest-mass satellites are still not well represented. Additionally, when matching dark matter subhalos to observed galaxies based on current distance, the cumulative distribution of pericenters point towards a lighter mass Milky Way.

Local Group Science with the Subaru Prime Focus Spectrograph

Rosemary Wyse (Johns Hopkins University)

The Subaru Prime Focus Spectrograph (PFS) will provide the unique capability of a wide-field (1.3 degree) massively multiplexed (2394 reconfigurable fibers) spectrograph on an 8-m telescope. The PFS team is developing a five-year, 360-night survey to be proposed as a Subaru Strategic Program, to address fundamental questions of cosmic evolution and the dark sector. We will investigate the formation and evolution of structure, from cosmological scales to the Local Group of galaxies. I will describe the motivation for the planned observations of faint stars in the Milky Way, in its satellite galaxies and in M31, and the insight we hope to gain into how galaxies form and evolve.

Separatrix Divergence of Stellar Streams in Galactic Potentials

Tomer Yavetz (Columbia University)

Galaxy simulations indicate that the dark matter halos of galaxies may take on a variety of shapes, including spherical, prolate, oblate, and triaxial configurations. The effects of baryonic physics, dark matter physics, and the environment in which the galaxies form have all been shown to affect the results of these simulations. An observational technique for determining the shape of the galactic potential would therefore be of high value. Recent studies have found that certain regions in triaxial potentials cannot host thin stellar streams, which instead fan out after only a few orbital periods. In this work, we demonstrate that these stream fanning effects stem from a subset of the stream particles belonging to a resonant orbit family. We name this effect Separatrix Divergence, because it affects stellar ensembles that 'straddle' a separatrix. By analyzing the behavior of the fundamental frequencies of resonant and non-resonant orbit families, we obtain estimates for the timescale after which this effect becomes observable and for the mass scale of stellar ensembles that would exhibit observable changes. For a Milky Way-like potential with a triaxial configuration, we demonstrate that this effect can happen within a few Gyr, and lead to the fanning-out of ensembles with a total mass similar to that of typical globular clusters. These results lay the foundation for a method of mapping the resonant regions in a galactic potential using tidal debris from stellar ensembles. In turn, this can be used to characterize the shape of galactic potentials and to place strong constraints on the distribution of dark matter.

Complex Stellar Populations Beyond the Milky Way

Gail Zasowski (University of Utah)

To a large extent, the ingredients of our galaxy formation theories rest on observations of stars and gas within the Milky Way Galaxy — in particular, on the relationships between stellar chemical abundances and dynamics. These relationships reflect different aspects of the formation and evolution of the Milky Way's halo, disk, and bulge. I will present initial results from a new project to measure these chemo-dynamical patterns for the first time in the inner regions of M31, using high-resolution integrated-light spectroscopy. As part of this project, we have also developed a new library of stellar population spectral templates, based on empirical infrared spectra, which will be released to the community for use with future observations. These findings have implications for understanding M31's evolutionary history, the uniqueness of the Milky Way, and the ability to use the Local Group's massive systems to understand galaxy evolution on larger scales.

A Young Star Cluster in Motion – The Complex Velocity Structure of Westerlund 2

P. Zeidler, A. Nota, E. Sabbi, A. F. McLeod

Westerlund 2 (Wd2) is one of the most massive young star clusters in the Milky Way. Its close proximity, young age, and sub-clustered structure provides a unique opportunity to study the cluster's formation and evolution in great detail. By combining *Hubble* Space Telescope and *Gaia* photometry with ground-based VLT/MUSE integral field spectroscopy we are able to analyze the stellar and gas kinematics. The latter reveals that the HII region surrounding the cluster is expanding, which is driven by the stellar winds of the many O and B-stars in the cluster center. We find that not only increases the stellar velocity dispersion with decreasing stellar mass as it is expected in a highly mass-segregated cluster, but the low-mass pre-main-sequence stars are also clustered in five distinct velocity groups. Two pairs of the velocity groups coincide with the two clumps Wd2 is built from, while the stars from the fifth group act as a halo. Given the young age, we conclude that we see the imprint of the initial cloud collapse that formed Wd2. Comparing the dynamical mass with the photometric mass shows that the cluster is super-virial and the system is likely to dissolve in the near future

Invited Speakers

STScI

Name	Affiliation
Dante Minniti	Universidad Andrés Bello, Santiago, Chile
Marla Geha	Yale University
Ana Bonaca	Harvard ITC
David Nidever	Montana State University
Raja GuhaThakurta	UC Observatories
Coral Wheeler	Cal Poly Pomona

Contributing Speakers

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Name	Affiliation
Elaad Applebaum	Rutgers University
Magda Arnaboldi	European Southern Observatory
Randa Asa'd	American University Of Sharjah
Nilanjan Banik	Texas A&M University
Nicholas Boardman	University Of Utah
Jeff Carlin	Aura/Rubin Observatory
Scott Carlsten	Princeton University
Andreia Carrillo	University of Texas, Austin; Cca
Yumi Choi	Space Telescope Science Institute
Charlie Conroy	Harvard University
Giacomo Cordoni	Lab. Lagrange, Observatoire De La Côte D'azur
Lara Cullinane	Australian National University
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Amanda	Quirk	University of California, Santa Cruz
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Daniel	Weisz	University of California, Berkeley
Andrew	Wetzel	University Of California, Davis
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Jennifer	Wojno	Johns Hopkins University
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