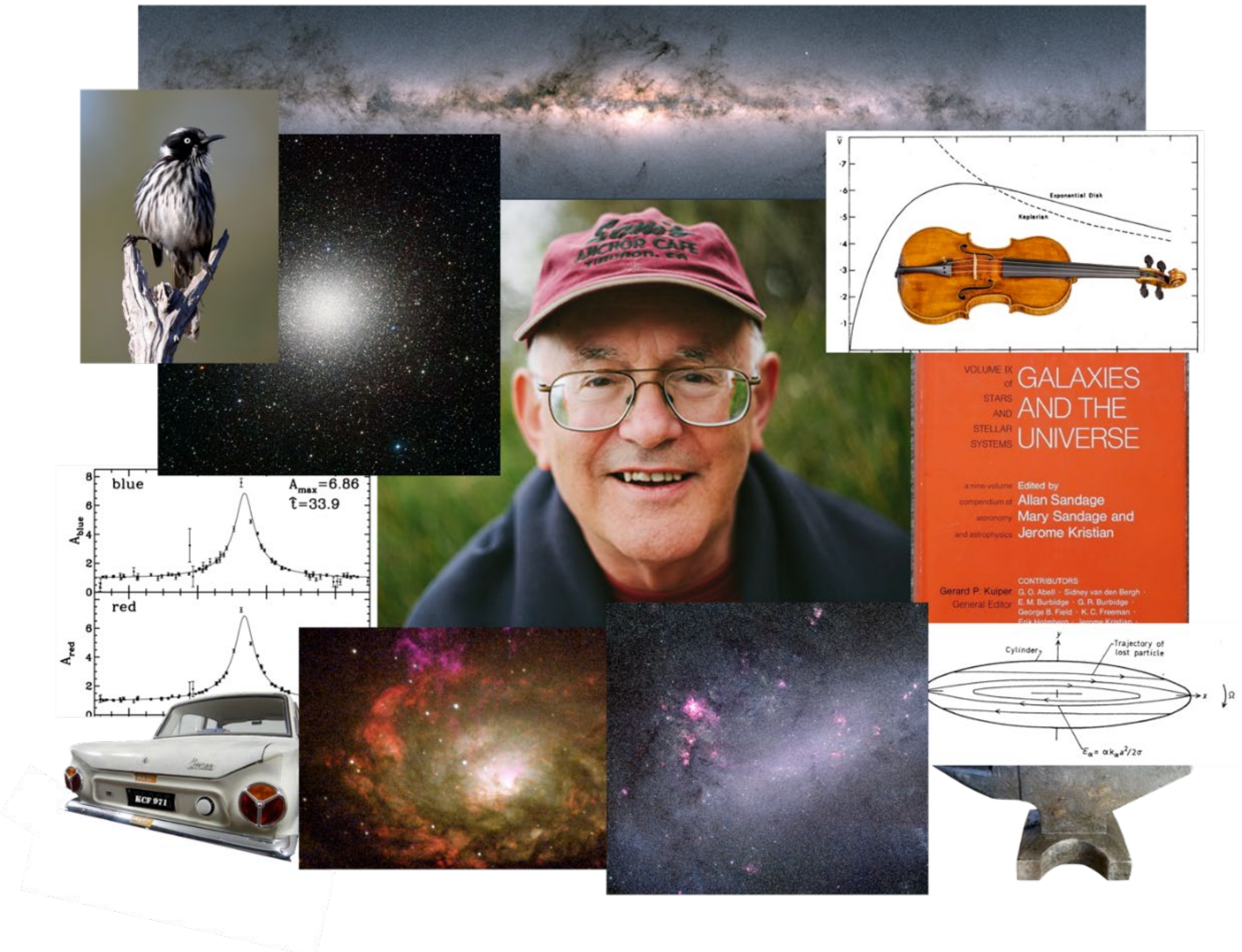
WHAT IS THE MILKY WAY TELLING US ABOUT GALAXY FORMATION AND EVOLUTION?



KEN FREEMAN 80th BIRTHDAY CONFERENCE

SEPTEMBER 20 – 23, 2022

The University of Western Australia

Perth, Western Australia

Australian National University

International Centre for Radio Astronomy Research

The University of Sydney

The University of Western Australia

Contents

Acknowledgement of Country

Kaya! Wandjoo!
Hello! Welcome!

We acknowledge that Aboriginal and Torres Strait Islander People are Australia's first astronomers.

We acknowledge their long-standing systems of knowledge on which we continue to build, and we acknowledge the Traditional Custodians of the unceded lands on which we are meeting today.

We are on Wajuk Noongar boodja, Wajuk Noongar country, and we pay our respects to their Elders past and present, and extend that respect to all First Peoples joining us here today.

We acknowledge the Wajarri Yamatji as the traditional owners of the Murchison Radio-astronomy Observatory site.

Welcome!

Our good friend, mentor and colleague, Ken Freeman turned 80 in 2020. It was our plan to celebrate that event in September 2020 with an international conference and we started planning late in 2019. Unfortunately, COVID arrived and caused major changes to our lives, across personal, family and professional activities, that may last for some time to come. In January 2022 the Scientific Organizing Committee (SOC) of the KCF@80 meeting, that has now been together for almost three years, decided to "take the plunge" and run the meeting in September 2022. Our intension was to have a small, select, face-to-face meeting involving Ken's colleagues, students past and present, and international researchers working on topics close to Ken's heart. The health status and associated travel risks for some potential attendees, the significant increase in international travel costs and the fact that Perth is about as far away as you can get from North America, has meant we did not get the attendance numbers we would have liked. The SOC recognizes the significant commitment of many attendees to be here in Perth so we can jointly celebrate the life and works of Ken. We hope you all have an enjoyable and exciting week discussing the connection of our ever-increasing knowledge of the Milky Way to galaxy formation and evolution in general, while sharing some good times with Ken.

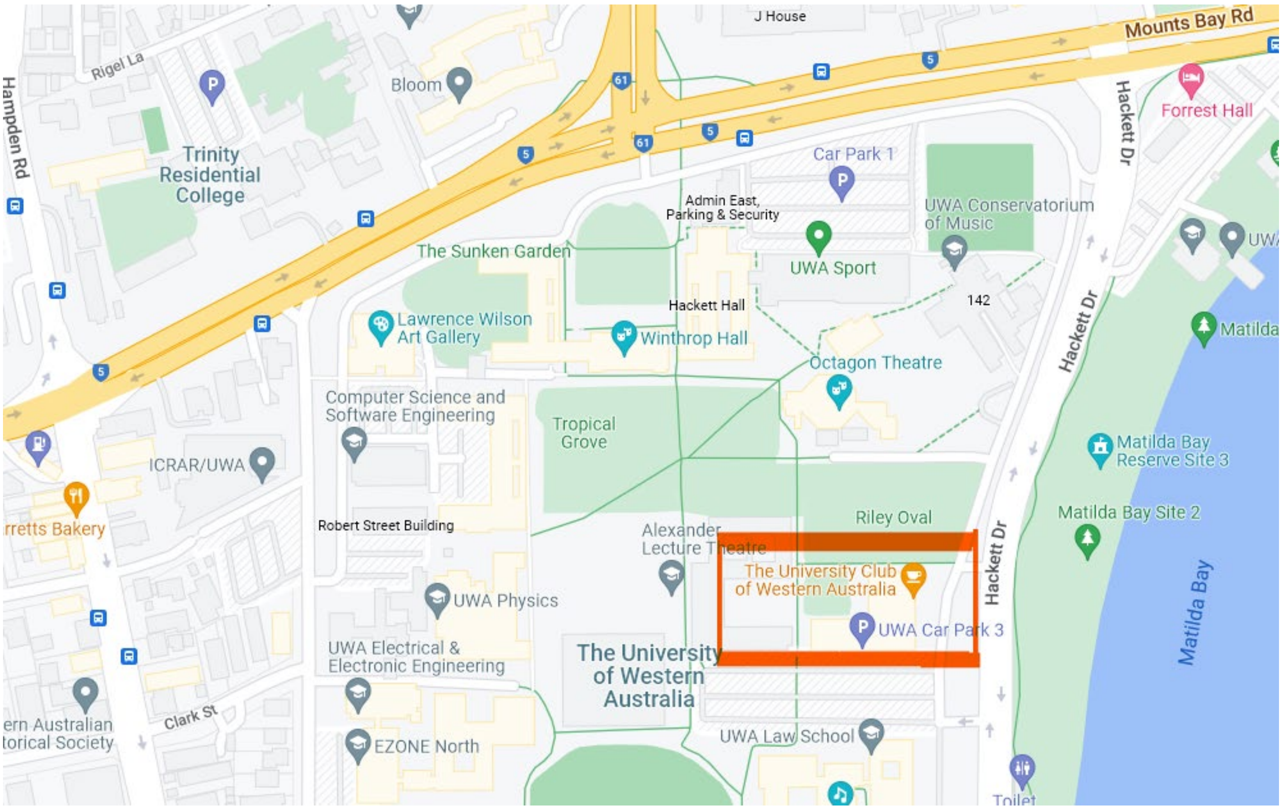
The KCF@80 SOC
20 September 2022

Conference Information

Venue

The Conference will take place from **Tuesday, 20 September – Thursday, 22 September** and will be held at the University Club of WA, which is situated on the main campus of The University of Western Australia.

University Club of WA
Entrance 1, Hackett Drive,
Crawley 6009
Ph: (08) 6488 8770 | W: https://universityclub.uwa.edu.au/contact-us/



Registration

The registration and support desk will be located in the foyer outside the conference venue. Please collect your registration package during the day on Tuesday 20th September.

Speakers

To ensure the smooth running of sessions all speakers will be required to upload their talks to the conference computer prior to their allotted session. The session chairs will assist with this process.

Proceedings

All presentations (as well as photos etc) will be made available through the conference website.

Wi-Fi

Wi-Fi is available for the duration of the Conference in the UWA Club.

Tuesday, 20th September	Wednesday, 21st September	Thursday, 22nd September
U: 200922 P: 9kcJXD	U: 210922 P: TEut1q	U: 220922 P: BUd7xS

Social Activities and Events

Conference Welcome Reception – Wine Tasting

Date : Monday 19 September 2022
Time : 5pm-7pm
Venue : Lamont's Bishops House, Cnr Spring Street and Mounts Bay Road, Perth
: Ph: (08) 9226 1884 | W: https://lamonts.com.au/bishops-house/

Information : Participants are asked to make their own way to Lamont's to enjoy a wine tasting event.

JWST Public Lecture by Garth Illingworth

Date : Wednesday 21 September 2022
Time : 7pm-8pm, guests to be seated by 6.45pm
Venue : University Club Auditorium, Entrance 1, Hackett Drive, Crawley
: Ph: (08) 6488 8770 | W: https://universityclub.uwa.edu.au/contact-us/

Information : Free event, registration required for seating purposes.

Conference Dinner

Date : Thursday 22 September 2022
Time : 7pm start
Venue : Matilda Bay Restaurant, 3 Hackett Drive, Crawley
: Ph: 9424 5000 | W: https://www.matildabayrestaurant.com.au/contact-us

Information : Participants are asked to make their own way to Matilda Bay Restaurant on the Crawley Foreshore for the final event of the conference program.

Committees

Scientific Organizing Committee


Peter Quinn (Chair)


Joss Bland-Hawthorn


Gary Da Costa


Elena Donghia


Amina Helmi


Lars Hernquist


Rosie Wyse


Gail Zasowski

Local Organizing Committee


Yolandie McDade


Clare Peter


Kate Quinn

Conference Programme – Day 1

Monday, 19 September 2022

17:00 – 19:00	Welcome Wine Event Lamont's Bishops House - https://lamonts.com.au/bishops-house/

Tuesday, 20 September 2022 – The Milky Way and M31

08:00	**Registration / Check In**		
09:00	Prof. Anna Nowak	Acknowledgement of Country and UWA opening address	

	Session 1 CHAIR: Gary Da Costa		
09:30	Joss Bland-Hawthorn	The corrugated disc in the Milky Way	Talk 1
09:55	Ana Bonaca	Orbital resonances in the Milky Way's disk and halo revealed by the H3 spectroscopic survey RRLs in GAIA DR3	Talk 2
10:20		****Morning Tea****	
	Session 2 CHAIR: Danail Obreschkow		
10:50	Ken Freeman	RRLs in GAIA DR3	Talk 3
11:15	Thomas Bensby	The definition of the Galactic thick disk	Talk 4
11:40	Sven Buder	Chronochemodynamics of Milky Way Stellar Populations with the GALAH Survey	Talk 5
12:05	Rosemary Wyse	Implications of the Old, Metal-Rich Milky Way	Talk 6
12:30		****Lunch****	
	Session 3 CHAIR: Joss Bland-Hawthorn		
13:30	Jo Ciuca	The Great Galactic Dip: investigating the effect of mergers on the observed age-metallicity relation in the Milky Way disc	Talk 7
13:55	Matthias Steinmetz	RAVEing with Ken - and unravelling the formation history of the Milky Way	Talk 8
14:20	John Norris	The First Stellar Populations and the Astration of Lithium	Talk 9
14:45	Carl Grillmair	Extending Globular Cluster Tidal Streams	Talk 10
15:10		****Afternoon Tea****	
	Session 4 CHAIR: Rosie Wyse		
15:40	Annette Ferguson	Galactic Accretion Histories beyond the Milky Way	Talk 11
16:05	Magda Arnaboldi	The survey of planetary nebulae in Andromeda (M 31) V. Chemical enrichment of the thin and thicker discs of Andromeda: Oxygen to argon abundance ratios for planetary nebulae and H II regions	Talk 12
16:30	Borja Anguiano	The Subaru Prime Focus Spectrograph Survey in the Milky Way and Local Group galaxies	Talk 13
16:55	END DAY 1		

Conference Programme – Day 2

Wednesday, 21 September 2022 – Physical processes in galaxies and simulations I

Session 5 CHAIR: Martin Bureau			
09:00	Anna Frebel	Characterization of the metal-poor ATARI disk of the Milky Way	Talk 14
09:25	Brad Gibson	The Distribution of Stellar Ages in Galactic Halos	Talk 15
09:50	Elisabete da Cunha	Galaxy physical parameters from spectral modelling: recent successes and future challenges	Talk 16
10:15		****Morning Tea****	
Session 6 CHAIR: Magda Arnaboldi			
10:45	Michael Hayden	The Chemical Evolution of the Milky Way	Talk 17
11:10	Ivan Minchev	Understanding galactic metallicity gradients	Talk 18
11:35	Matthew Wilkinson	Are simulated disk galaxies robust to collisional relaxation?	Talk 19
12:00	Gerhardt Meurer	Scaling Relations for HI-Selected Star Forming Galaxies	Talk 20
12:25		****Lunch****	
Session 7 CHAIR: Claudia Lagos			
13:30	Annalisa Pillepich	Insights from the MW/M31-like galaxies of the TNG50 simulation	Talk 21
13:55	Diego Sotillo-Ramos	The merger and assembly histories of Milky Way- and M31-like galaxies with TNG50: thin disks can survive recent major mergers	Talk 22
14:20	Katy Proctor	The Intrahalo light as a probe of galaxy assembly	Talk 23
14:45	Yuan-Sen Ting	Galaxy Merger Reconstruction with Equivariant Graph Normalizing Flows	Talk 24
15:10		****Afternoon Tea****	
Session 8 CHAIR: Katy Proctor			
15:40	Jean Brodie	The Origin of Ultra Diffuse Galaxies: Challenging the galaxy formation paradigm	Talk 25
16:05	Martin Bureau	Probing the Invisible: Weighing Supermassive Black Holes with ALMA	Talk 26
16:30	Jayanne English	Now for something completely different - magnetic fields	Talk 27
16:55	Ray Carlberg	Globular Clusters and Dark Matter (sub) Halos	Talk 28
17:20	END DAY 2		

18:45-20:00 **Garth Illingworth Public Lecture on JWST @ UWA Club Auditorium – REGISTER @ https://www.eventbrite.com.au/e/jwst-comes-to-life-garth-illingworth-university-of-california-santa-cruz-tickets-403842653247**

Conference Programme – Day 3

Thursday, 22 September 2022 – Physical processes in galaxies and simulations II

	Session 9 CHAIR: Lister Staveley-Smith		
09:00	Ortwin Gerhard	The Galactic Bar	Talk 29
09:25	Robert Benjamin	The ISM of the Milky Way Interior to the Bar	Talk 30
09:50	Amelia Fraser-McKelvie	All bar none: characterising the effect of bars on their host galaxies	Talk 31
10:15		****Morning Tea****	
	Session 10 CHAIR: Jayanne English		
10:45	Mike Fall	Formation of galaxies: clues from their angular momenta	Talk 32
11:10	Jennifer Hardwick	Understanding angular momentum scaling relations in the local universe	Talk 33
11:35	Lilian Garratt-Smithson	An investigation into the dark matter - galaxy angular momentum correlation	Talk 34
12:00	Matthew Colless	Spin-filament alignment flips are related to bulge assembly	Talk 35
12:25		****Lunch****	
	Session 11 CHAIR: Lars Hernquist		
13:30	Garth Illingworth	JWST's First Insights into Galaxy Formation and Growth	Talk 36
13:55	Aaron Ludlow	The challenge of simulating Milky Way-mass galaxies in cosmological volumes	Talk 37
14:20	Claudia Lagos	The formation of galaxy disks: what have we learnt from cosmological hydrodynamical simulations?	Talk 38
14:45	Neal Katz	Galaxy Formation Simulations: Problems and Answers	Talk 39
15:10		****Afternoon Tea****	
	Session 12 CHAIR: Anna Frebel		
15:40	Danail Obreschkow	A Fresh Perspective on the Assembly of Mass	Talk 40
16:05	Kenji Bekki	A model for globular cluster formation with multiple stellar populations in the Galaxy	Talk 41
16:30	Lister Staveley-Smith	Dark Matter in Galactic Remnants and Dwarf Galaxies	Talk 42
16:55	END OF CONFERENCE		

19:00 **Conference Dinner – Matilda Bay Restaurant https://www.matildabayrestaurant.com.au/**

Abstract of Talks – Day 1

The Corrugated Disc In The Milky Way — Talk 1

There has been evidence for wave-like patterns across the Milky Way disc for more than 50 years, mostly observed in cool gas and star forming regions along spiral arms. In 2018, the ESA Gaia satellite revealed similar corrugations for the first time in the stellar disc. But are these patterns even related? What excites them and what can we learn? We will attempt to provide answers based on new observations and simulations

Joss Bland-Hawthorn (work with T. Tepper-Garcia and K Freeman)
University of Sydney
jonathan.bland-hawthorn@sydney.edu.au

Orbital resonances in the Milky Way's disk and halo revealed by the H3 spectroscopic survey RRLs in GAIA DR3 — Talk 2

The dynamical history of the Milky Way is encoded in the orbital phase-space of its constituent stars, which has recently revealed the dissolved progenitors of our Galaxy in the halo and its orbital resonances in the local disk. In this talk I will present data from H3, the Hectochelle in the Halo at High-resolution spectroscopic survey, which complements Gaia data at high Galactic latitudes and large distances. Using a sample of ~16,000 H3 giant stars, we find evidence of discrete orbital resonances among the old stellar populations of the Milky Way. The resonances span a range of angular momenta, and are present at similar energy levels both in the high-latitude disk and in the radial halo components. I will discuss what the global nature of these resonances, as well as their persistence over ~10Gyr implies for their origin and the structure of our Galaxy.

Ana Bonaca
Carnegie Observatories
abonaca@carnegiescience.edu

Disk RR Lyrae Stars — Talk 3

RR Lyrae variable stars are believed to be very old (> 10 Gyr). Most of them are metal-poor halo stars ([Fe/H] < -1) which probably came into the Galaxy via the accretion of small dwarf galaxies, but a minority are metal-rich (-1 < [Fe/H] < 0), with kinematics like stars of the Galactic disk. Do these disk RR Lyr stars belong to the ancient thick disk or to the younger thin disk? If they are thin disk stars, they may be older than the thin disk itself.

To determine whether they are thin or thick disk stars, accurate kinematics are needed. We have assembled a sample of 424 RR Lyr stars with well determined metallicities, distances and kinematics from ground-based telescopes and from the recent Gaia DR3 date release.

The kinematics and the [alpha/Fe] ratios for the metal-rich disk RR Lyr stars appear similar to those for the non-variable thin disk stars. If the progenitors of the disk RR Lyr stars were born in the thin disk, then the age of the thin disk would exceed 10 Gyr. Or did they migrate from the inner Galaxy, where there is a large population of RR Lyr stars covering a similar range of [Fe/H]? It is possible that radial migration could generate a population of kinematically cold old stars in the solar neighbourhood.

Ken Freeman (with Heather Morrison (Case Western), Yichen Lin (RSAA))
Australian National University
kcf@mso.anu.edu.au

Abstract of Talks – Day 1

Talk 4 **The definition of the Galactic thick disk**

It is well-established that the Milky Way harbours two disk components, the thin and the thick disks, and that they also are likely to be distinct in terms of kinematics, chemistry, and age. Besides being the thicker of the two, the thick disk also has a shorter scale-length, meaning that it is the dominating disk population in the inner regions of the Milky Way and then it drops off quickly with galactocentric radius. This is likely the reason to why the outer disk region of the Milky Way appears to be void of stars with the chemical characteristics that we in the solar neighbourhood and the inner disk regions associate with the thick disk. This could be a contradict 7hnuy8=\-[pcotory finding, as when looking at other galaxies the radial extension of thick disks are essentially always comparable to, or longer than, the extension of the thin disks. This is the opposite to what we observe in the Milky Way. The question is whether this is due to how the thick disk is defined? In the Milky Way studies beyond the solar neighbourhood, the definition of the thick disk has been based on chemistry, usually the level of a-enhancement, while in external galaxies the definition is based on morphology. In order to gauge other galaxies against the Milky Way, we need a working definition of the thick disk: through chemistry, age, kinematics, morphology, or a combination of them all. I will here present the results of a new study into the nature of the Galactic thick disk, based on the latest astrometric and elemental abundance data available from Gaia and large spectroscopic surveys.

Thomas Bensby
Lund Observatory
tbensby@astro.lu.se

Talk 5 **The next steps of Galactic Archaeology with HERMES (GALAH)**

In Summer 2020 the third data release of the Galactic Archaeology with HERMES (GALAH) survey is/was published. This release includes spectra, stellar parameters, element abundances and value-added-catalogs for dynamics and stellar ages for more than 650,000 stars. With this amazing set of chemodynamic information on stars of the extended solar neighbourhood, we will be able to explore the evolution of our Galaxy and understand the formation by tracing different populations via age and chemodynamic tracers. As the main spectroscopic analyst of the survey, I show how we manage the analysis of all this data. I showcase how we can use it to understand the populations and substructures in chemodynamic space, including the understanding of the disk populations, the halo-disk transition and the chemical signature and ages of accreted stars. Understanding how distinct or correlated these substructures are, will ultimately help us to unravel the most likely formation scenario of our Galaxy.

Sven Buder
Australian National University
sven.buder@anu.edu.au

Talk 6 **Implications of the Old, Metal-Rich Milky Way**

The inner regions of the Milky Way contain old, metal-rich stars, consistent with having formed in an early starburst. Simulations of Milky Way-like galaxies fail to reach sufficiently high metallicities at early epochs, plausibly reflecting the low-mass structures in which the ancient stars form. I will quantify this comparison between observations and predictions from two different simulation suites, using public databases, then interpret the results in the context of the recent JWST detections of high-redshift galaxies.

Rosemary Wyse
John Hopkins University
wyse@jhu.edu

The Great Galactic Dip: investigating the effect of mergers on the observed age-metallicity relation in the Milky Way disc — Talk 7

We employ our Bayesian Machine Learning framework BINGO (Bayesian INference for Galactic archaeOlogy) to obtain precise relative stellar age estimates with uncertainties for 68,865 red giant and red clump stars observed by the high-resolution (R ~ 22,000) spectroscopic survey APOGEE DR17. By combining the age and metallicity information, we dissect the Galactic disc stars into four radial components, namely, the inner disc (R < 6 kpc), the local disc (6 < R < 8 kpc), the outer disc (8 < R < 10 kpc) and the most outer disc (R > 12 kpc). We then examine the age-metallicity relationship and identify a broad dip in metallicity starting approximately 9 Gyr ago across the disc's local, outer and most outer regions, consistent with a gas dilution event early on in the history of the Milky Way. We further explore the AMR in two of the Auriga suite of zoom-in cosmological simulations, Au18 and Au23, to identify a similar dip, albeit less broad, affecting the outer regions. In both these simulations, this dip starts happening soon after a gas-rich merger (Au 18) or galactic fountain event (Au 23), further supporting the scenario that the metallicity dip emerges as stars form from metal-poor gas. We also discuss the implications of bar formation in the simulations soon after the gas-rich event.

Jo Ciuca
Australian National University
ioana.ciuca@anu.edu.au

RAVEing with Ken - and unravelling the formation history of the Milky Way — Talk 8

Galactic Archaeology has experienced a dramatic evolution in the past two decades. While the Hipparcos catalogue gave a first look into the rich dynamical structure of the solar neighbourhood, radial velocity and spectroscopic information was dearly missing. Here is where the RAdial Velocity Experiment (RAVE) came in, as the first systematic spectroscopic Galactic Archaeology Survey in 2003, followed by higher resolution deeper studies such as APOGEE and GALAH. I will present some highlights of these exploration phase on the disk structure and the quest for low metallicity stars, with particular focus on the contribution by Ken. Considering present work, and to fully exploit the information provided by large astrometric and spectroscopic data sets, however, a proper theory framework is required. The HESTIA simulation suite is designed to fill in that gap and to create Local Group type of environments (with Milky Way and Andromeda analogues) in a full cosmological setting under particular consideration of the local cosmological environment (local voids, walls and clusters). I will demonstrate how in this cosmological framework the the merger debris are chemically distinct from the survived dwarf galaxies. Accreted stellar haloes, including individual debris, reveal abundance gradients in the ELz, where the most metal-rich stars have formed in the inner parts of the disrupted systems before the merger and mainly contribute to the central regions of the hosts. Therefore, abundance measurements in the inner MW as provided by RAVE, APOGEE, and GALAH - and soon Gaia, WEAVE and 4MOST - will allow to better constrain the parameters of building blocks of the MW stellar halo. Combining a set of abundances allows to capture chemical patterns corresponding to different debris, which are the most prominent as a function of stellar age.

Matthias Steinmetz
Leibniz Institut for Astrophysics Potsdam (AIP)
msteinmetz@aip.de

Abstract of Talks – Day 1

Talk 9 — The First Stellar Populations and the Astration of Lithium

The lithium abundances of the oldest and most-metal poor stars of the Galaxy have the potential to tell us about its first stellar populations and the early Universe, during the first few billion years. Following a critique of the Spite Plateau in the (Lithium vs. Teff) - and (Lithium vs. [Fe/H]) - planes, I shall discuss the astration of lithium in three early evolutionary phases of the Galaxy: (1) First star formation in C-rich environments, with depleted Li, (2) silicates-dominated star formation and destruction of primordial Li during pre-main-sequence evolution, and (3) materials from these two phases co-existing and coalescing to form C-rich stars with Li abundances below the Spite Plateau. I shall also discuss the suggestion by Aguado et al. that the upper envelope of the observed plateau favours a lower primordial lithium abundance than generally accepted.

John Norris
Australian National University
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Talk 10 — Extending Globular Cluster Tidal Streams

Tidal streams have become an important new source of information on the shape and extent of the Galactic potential and the distribution of dark matter. The usefulness of tidal streams as probes of the potential depends strongly on the length to which they can be traced and on the orbital phases they describe. Streams generated by extant globular clusters are particularly valuable as we then have progenitors with well-measured positions and velocities and well-characterized stellar populations. In this contribution I describe an ongoing campaign to use Gaia photometry and proper motions to extend the known tidal tails of globular clusters over much larger fractions of their orbits.

Carl Grillmair
California Institute of Technology
carl@ipac.caltech.edu

Talk 11 — Galactic Accretion Histories beyond the Milky Way

Thanks to Gaia and other state-of-the-art surveys, we have now developed a very detailed understanding of the main merger and accretion events experienced by the Milky Way. In order to place our galaxy's particular history in context, knowledge of the accretion histories of other large spirals is required. One way to achieve this is through the study of the stellar halos of galaxies in the 1-5 Mpc distance range, where individual giant stars can still be resolved over wide fields from the ground. I will review the progress made towards this goal over the last decade and present some results from ongoing work. I will also discuss the fabulous prospects for advancing these ""extragalactic archaeology"" studies with forthcoming facilities such as Euclid and LSST.

Annette Ferguson
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Abstract of Talks – Day 1

The survey of planetary nebulae in Andromeda (M 31) V. Chemical enrichment of the thin and thicker discs of Andromeda: Oxygen to argon abundance ratios for planetary nebulae and H II regions Talk 12

The Andromeda (M31) galaxy presents evidence of a recent substantial mass accretion, differently from the Milky Way that had a rather quiescent evolution. We want to use the oxygen and argon abundance of the low extinction and high extinction planetary nebulae (PNe), as well as those of the H II regions to constrain the chemical enrichment and star formation efficiency in the thin and thicker disc in M31. The argon element is produced more by Type Ia supernovae (SNe) relative to the oxygen element, thus the chemical enrichment and star formation efficiency information which is encoded in the [alpha/Fe] vs. [Fe/H] distribution of the stars is also imprinted in the oxygen-to-argon abundance ratio, log(O/Ar), vs. argon abundance (12 + log(Ar/H)) for the nebulae emissions of the different stellar evolution phases. Thus we wish to use the log(O/Ar) vs. (12 + log(Ar/H)) distribution of stars with different ages to constraint the star-formation histories of parent stellar populations in the thin and thicker M31 disc. We find that the mean log(O/Ar) values of PNe as a function of their argon abundances traces the inter-stellar matter (ISM) conditions at the time of birth of the M31 disc PN progenitors. Within a galactocentric radius RGC = 14kpc, the chemical evolution model that reproduces the PN mean log(O/Ar) values as function of argon abundances for the high- and low-extinction PNe requires metal poorer gas to be brought into the M31 disc during a wet satellite merger. This wet merger triggered a burst of star-formation in the thin M31 disc. In the outer M31 disc at RGC >18 kpc, the log(O/Ar) vs argon abundance distribution of the younger high extinction PNe indicates that they were formed in a burst, mostly from the metal poorer gas. The H II regions show a range of oxygen vs argon ratios which is indicative of local variations, consistent with a present day rainfall of metal poorer gas onto the M31 disc, with different degree of mixing with the previously enriched ISM. For the first time we propose and implement the use of the log(O/Ar) vs argon abundance distribution as alternative to the [alpha/Fe] vs. [Fe/H] diagram that have been widely used to constrain the star formation efficiency in the Milky Way. Our diagrams for PNe with different ages in M31 revealed that a secondary infall event affected the chemical evolution of the M31 disc. Furthermore the kinematically distinct thin and thicker discs in M31, and different radial ranges in these components, are linked to distinct log(O/Ar) gradients and distributions as function of argon abundance, indicating different chemical enrichment histories. In M31, the thin disc has a shorter star formation timescale than the thicker disc, with both thin and thicker disc reaching similar high argon abundances (12 + log(Ar/H))~6.7.

Magda Arnaboldi
European Southern Observatory
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The Subaru Prime Focus Spectrograph Survey in the Milky Way and Local Group galaxies Talk 13

The Subaru PFS Survey is an ambitious 360 night survey to be undertaken over 5 years which fully exploits the unique capabilities of PFS to address outstanding questions relating to the history and fate of the Universe as well as the physical processes and role of dark matter in governing the assembly of galaxies including our Milky Way. I will review the main goals and the status of the project

Borja Anguiano
University of Notre Dame
astrobaj@gmail.com

Abstract of Talks – Day 2

Talk 14 **Characterization of the metal-poor ATARI disk of the Milky Way**

We have developed a chemo-dynamical approach to assign 36,010 metal-poor SkyMapper stars to various Galactic stellar populations. Using two independent techniques (velocity and action space behavior), Gaia EDR3 astrometry, and photometric metallicities, we selected stars associated with the so-called "metal-weak thick disk" by minimizing contamination by the canonical thick disk or other Galactic structures. This sample comprises 7,127 stars, spans a metallicity range of -3.5

Anna Frebel
Massachusetts Institute of Technology
afrebel@mit.edu

Talk 15 **The Distribution of Stellar Ages in Galactic Halos**

The Milky Way's stellar halo presents clear age gradient indicative of an inside-out scenario, with the outer halo appearing ~2 Gyrs younger than the inner halo. The magnitude of this gradient may provide a powerful and independent diagnostic of the relative contribution of accreted vs in-situ stellar formation within Galactic halos. Making use of a suite of simulated Milky Way-like analogs, we examine the impact of accreted vs in-situ populations, prograde vs retrograde, and alternate spatial, kinematical, and halo star phase space selection criteria, in shaping the distribution of stellar ages within Galactic halos. [w/Tim Beers, Leah Cox (PhD), Gareth Few].

Brad Gibson
University of Hull
brad.gibson@hull.ac.uk

Talk 16 **Galaxy physical parameters from spectral modelling: recent successes and future challenges**

It is not an overstatement to say that our empirical understanding of galaxy formation and evolution relies on our ability to derive the intrinsic physical parameters of observed galaxies, such as their stellar masses, star formation histories, dust content, etc. In the last 20 years, there has been an explosion of multi-wavelength datasets containing large samples of galaxies, from ultraviolet-to-radio photometry to integral field unit spectroscopy, from the local Universe to increasingly higher redshifts. These observational advances have motivated the development of increasingly sophisticated tools that aim to extract galaxy properties from their observed emission, in which models for the multi-wavelength emission are combined with computational statistical methods to optimally constrain parameters in a complex parameter space. In this talk, I will attempt to summarize the main features of these tools, with an emphasis on their recent successes, and I will discuss some future challenges posed by new and upcoming observations of galaxies

Elisabete da Cunha
International Centre for Radio Astronomy Research, University of Western Australia
elisabete.dacunha@uwa.edu.au

Abstract of Talks – Day 2

The Chemical Evolution of the Milky Way — Talk 17

I will describe our detailed chemical evolution models, which are the first to reproduce the global chemoydnamic structures of the Galaxy. These models incorporate many physical processes that govern the evolution of the disk, including gas physics as accretion, cooling, and heating, along with stellar evolution and state of the art yields, and as well as secular evolution to account for radial mixing of stars and gas within the disk. I will highlight our upcoming work to use the Milky Way as a benchmark for galaxy evolution, such as producing IFU data cubes of the Milky Way with a range of properties (inclination, extinction model, spatial and spectral resolution, etc.) to enable direct comparisons of our Galaxy to external systems. I will also discuss the upcoming large ESO-MUSE program GECKOS, which will observe 35 systems edge on to large effective radius and to high S/N, enabling direct comparisons of these systems with the Milky Way

Michael Hayden
University of Sydney
michael.hayden@sydney.edu.au

Understanding galactic metallicity gradients — Talk 18

Metallicity gradients seen today in the interstellar medium (ISM) and stellar component of disk galaxies are the result of the entire chemo-dynamical evolution since the beginning of disk formation. In a pioneering paper, Matteucci & Francois (1989) have established that the observed negative Milky Way disk metallicity gradient results from an inside-out disk formation. That the Milky Way has formed inside-out is now evident from the more centrally concentrated older stellar populations, also seen in external galaxies. Knowledge of the ISM metallicity gradient evolution with cosmic time is very important, as it can be related to the SFR and gas properties throughout the galaxy lifetime. I will discuss the abundance gradient evolution of groups of stars with similar age (or mono-age populations) in galaxy formation simulations. It will be shown that gradient inversion with distance from the disk midplane seen in both Milky Way data and simulations results from the mixture of stars with different ages, disk flaring, and inside-out disk formation. Finally, I will present a novel technique for constraining the evolution of the Galactic ISM metallicity with radius and time directly from the observations, while at the same time recovering the birth radii of any stellar sample with good metallicity and age measurements

Ivan Minchev
Leibniz Institut for Astrophysics Potsdam (AIP)
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Are simulated disk galaxies robust to collisional relaxation? — Talk 19

It was recently identified that the lack of nearly circular stellar orbits in simulated disk galaxies is at odds with the expectation from observations. We propose that the choice to model dark matter and stars as point-like particles causes this discrepancy by unintentionally subjecting galaxies to collisional relaxation. Among other effects, this introduces spurious perturbations to stellar orbits, eventually leading to an overall change in the structure of the disk. To explore the repercussions on galaxies formed self-consistently, we ran a sub-volume of the cosmological hydrodynamical simulation, EAGLE, with increased dark matter resolution. In agreement with our models, we find the stellar kinematics of the high-resolution dark matter galaxies diverge from the fiducial EAGLE galaxies at approximately Milky Way masses, i.e., galaxy kinematics below Milky Way mass are unresolved in typical modern large volume cosmological simulations. We show that improving only the dark matter resolution produces galaxy populations with more global rotational support and more circular orbits, resolving the tension with observations to some extent. Understanding the limitations of simulated physics is a necessary step towards a greater understanding of disk galaxies, real and simulated alike

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Abstract of Talks – Day 2

Talk 20 Scaling Relations for HI-Selected Star Forming Galaxies

In 1970, Ken Freeman demonstrated that optically-selected spiral and lenticular galaxies have a disk plus bulge structure, with the exponential disk component having a nearly constant characteristic surface brightness. We have performed surveys of star formation in HI-selected galaxies which we imaged in the Optical and Ultraviolet. These surveys re-confirm Ken's basic findings. In addition they show several other remarkable scaling relations. Most notably, we find that that the Equivalent Width of H-alpha emission has a narrow and peaked distribution over a wide range of galaxy luminosities. This hints at the important role that the existing stellar populations in the disk have at maintaining the current rate of formation of the most massive stars in HI rich galaxies. The scaling relations that we find hold over a limited range of size and/or luminosity: this marks the realm over which the disk is the dominant feature in galaxies. Subtly different correlations found in ultraviolet light are a symptomatic of the non-universal nature of the stellar Initial Mass Function

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Talk 21 Insights from the MW/M31-like galaxies of the TNG50 simulation

The TNG50 cosmological magnetohydrodynamical simulation returns about 200 galaxies that can be consider analogs of the Galaxy and Andromeda because of their stellar mass, stellar disky morphology and overall environment. I will give an overview of what we are learning from this large sample of simulated galaxies including e.g. the diversity of their structural properties, from the bulge, disk and stellar halo to their dark matter halo and assembly history; the link between SMBH feedback and the formation of eROSITA-like bubbles in the circum-galactic medium; the connection between radial migration, spiral arms and disk structure; the dependence of satellite abundance on host properties and the diversity of MW/M31-like satellite properties; the location and origin of the most metal poor stars; and the variations of stellar properties across different azimuthal angles within the disk

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Talk 22 The merger and assembly histories of Milky Way- and M31-like galaxies with TNG50: thin disks can survive recent major mergers

We analyze the merger and assembly histories of Milky Way (MW) and Andromeda (M31)-like galaxies to quantify how and how often disk galaxies of this mass range can survive a recent major merger. For this, we use the cosmological magneto-hydrodynamical simulation TNG50, where we identify 198 analog galaxies. Firstly, major mergers are common: 85 per cent (168) of MW/M31-like galaxies in TNG50 have undergone at least one major merger across their lifetime. In fact, 31 galaxies in our sample (16 per cent) have undergone a major merger recently, i.e. in the last 5 Gyr. The gas available during the merger is sufficient to either induce starbursts at pericentric passages or to sustain prolonged star formation after coalescence: in roughly half of the cases, the pre-existing stellar disk is destroyed because of the merger but reforms thanks to star formation. Moreover, higher merger mass ratios are more likely to destroy the stellar disks. In comparison to those with more ancient massive mergers, MW/M31-like galaxies with a major merger in the last 5 Gyr have, on average, somewhat thicker stellar disks, more massive and somewhat shallower stellar haloes, larger stellar ex-situ mass fractions, but similarly massive kinematically-defined bulges. All this is qualitatively consistent with the different observed properties of the Galaxy and Andromeda and with the current constraints on their most recent major mergers, 8-11 Gyr ago and ~2 Gyr ago, respectively. According to contemporary cosmological galaxy simulations, a recent quiet merger history is not a prerequisite for obtaining a relatively-thin stellar disk at z=0

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Abstract of Talks – Day 2

The Intrahalo light as a probe of galaxy assembly — Talk 23

The stellar halos of Milky Way-like galaxies are built-up from the disrupted remnants of previously accreted dwarf galaxies and therefore offer a glimpse into a galaxy's assembly history. Recent observational studies of the Milky Way's stellar halo, for example, have provided insights into its progenitors and merger history. Despite these recent observational advances, the low surface brightness nature of stellar halos hampers efforts to obtain a statistically representative sample from extra-galactic systems, making it difficult to place the Milky Way and its formation in a broader cosmological context. We address this issue using a sample of disk galaxies drawn from the EAGLE simulation. We employ a novel galaxy decomposition technique based on stellar kinematics and binding energy that is able to isolate the various components of each galaxy, including their disks, bulges, and stellar halos. In this talk, I will discuss the formation of stellar halos and how they relate to galaxy assembly history, with emphasis on Milky Way-like galaxies. Comparing our results to observations obtained for nearby systems offers some intriguing clues into the mechanisms responsible for the broad variation in the properties of their stellar halos

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Galaxy Merger Reconstruction with Equivariant Graph Normalizing Flows — Talk 24

A key yet unresolved question in modern-day astronomy is how galaxies formed and evolved under the paradigm of the _CDM model. The quest to understand the connection between the near-field cosmology and the high-redshift cosmic past has led to many semi-analytical models to infer the galaxy properties from their merger history. However, most of these classical approaches rely on studying the global statistical connection between dark matter haloes and galaxies, often reducing the study to focusing on the connection of individual haloes and galaxies or summarizing their formation environment with crude summary statistics based on human heuristics. The advancement in graph neural networks has opened up many new possibilities for studying the evolutionary history of galaxies. That is because a graph is a natural descriptor of the systems at hand – any progenitor system at a high redshift can be regarded as a graph, with individual progenitors as nodes on the graph. In this presentation, I will discuss the power of Equivariant Graph Normalizing Flows Model to connect high-redshift progenitor graphs with the local observables. We demonstrate that, by treating the progenitors as a graph, our model robustly recovers their distributions, including their masses, merging redshifts and pairwise distances at redshift $z = 2$ conditioned on their $z = 0$ properties. In addition, the generative nature of the model enables other downstream tasks, including inferring probabilistically the property at $z=0$ given the configuration at $z=2$, detecting anomalies and identifying subtle correlations of progenitor features

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The Origin of Ultra Diffuse Galaxies: Challenging the galaxy formation paradigm — Talk 25

I will discuss observational results on the origin of Ultra Diffuse Galaxies (UDGs) and their globular cluster systems along with current thinking on their formation pathways. UDGs have the sizes of giant galaxies (>1.5 Kpc) but the luminosities of dwarfs. I will review the evidence that the universe has created three types of UDG. One type has properties consistent with regular dwarf galaxies that have been puffed-up and made "ultra diffuse" by reasonably well-understood processes. A second type has characteristics (in particular rich globular cluster systems, often associated with massive dark matter halos) that are not reproduced by simulations. These UDGs appear to have formed some stars and many star clusters at an early epoch but, by some as yet unknown mechanism, they ceased subsequent star formation. This type of UDG has been dubbed "Failed Giant". The third type, dark matter (DM) deficient, lies at the other extreme of the ratio of dark to normal matter for galaxies hosting populous star cluster systems. Very recent work may be able to explain the "DM free" UDGs

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Abstract of Talks – Day 2

Talk 26 **Probing the Invisible: Weighing Supermassive Black Holes with ALMA**

Supermassive black holes are now known to lurk at the centre of most galaxies, and to play a key role in their evolution. Here, I will present key results from the mm-Wave Interferometric Survey of Dark Object Masses (WISDOM), a high resolution survey of molecular gas in galaxy nuclei. I will first show that carbon monoxide (CO) can be used to easily and accurately measure the mass of these supermassive black holes. I will then discuss substantial ongoing efforts to do this, and present many new spectacular measurements from the Atacama Large Millimeter/sub-millimeter Array (ALMA), the latest of which rival the best black hole measurements to date. This effort opens the way to literally hundreds of measurements across galaxies of all morphological types, both active and non-active, with a unique method. It thus promises to revolutionise our understanding of the co-evolution of galaxies and black holes.

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Talk 27 **Now for something completely different - magnetic fields**

What roles do magnetic fields play in galaxy evolution? Since they affect the efficiency of star formation, in this role they help sculpt a galaxy's morphology and impact gas consumption over time. The state-of-the-art Continuum Halos in Nearby Galaxies—an EVLA Survey (CHANG-ES) of 35 edge-on galaxies also explores additional roles. The findings support the hypothesis that spiral galaxies commonly have an X-shaped magnetic field distribution in the region of their radio continuum halos. The existence of a dominant field structure could explain observations of the magnetic field in the Milky Way and elucidate why current interpretations of Galactic rotation measure data appear contradictory. Additionally we detect global field patterns in all galaxies with sufficient signal-to-noise data. This indicates that magnetic fields must be integral to galaxy formation, including that of our Milky Way. Using CHANG-ES data this talk presents scientific visualisation experiments employing perception-based colour maps and Line Integral Convolution algorithms. These experiments seek to indicate which observing parameters and galaxy properties most impact the observed radio halo and field distributions. They are a proof of concept that will be relevant as we observe magnetic fields in more galaxies and expand our statistics in the Big Data era of the SKA

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Talk 28 **Globular Clusters and Dark Matter (sub) Halos**

Decades of observational data and careful modeling show that stars dominate the gravitational field of the inner 2-3 half-mass radii of clusters. Gaia (and other new instruments) are providing kinematic data in the outskirts of globular clusters which allows new tests for dark matter and comparison with models. At least 10% of the clusters with sufficient data exhibit the kinematic signature of a local dark halo, including M54 and M13. A local dark halo will increase the retention of gas and black hole binaries.

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Abstract of Talks – Day 3

The Galactic Bar — Talk 29

The Milky Way's inner regions are dominated by the Galactic bar whose central three-dimensional part is the boxy/peanut bulge. Made-to-measure (M2M) dynamical models combining distance-resolved star count and kinematic data constrain the pattern speed of the bar and the mass distribution in these regions and, with a new iterative method and recent VIRAC NIR proper motion data, were used to estimate the dark matter density cusp in the inner Galaxy. Three-dimensional metallicity maps based on the A2A and APOGEE surveys show a pinched distribution in the bulge confirming its disk origin, as well as clear vertical and in-plane gradients. Combining with Gaia proper motions and integrating the orbits of these stars in a realistic M2M-model potential shows how the different stellar populations differ in their kinematics and spatial distributions. In particular, the Galactic bar is found to transition into a radially thick, elongated inner ring of stars which have average solar [Fe/H] and a peak in AstroNN ages between 6 and 8 Gyr, and were likely formed soon after the bar

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The ISM of the Milky Way Interior to the Bar — Talk 30

With the benefit of hindsight, evidence for the strongly barred nature of the Milky Way was there well before infrared surveys of the sky revealed its true extent. The lack of star formation interior to 4 kpc was first demonstrated in 1958 by Westerhout. And notably, the 1957 discovery of the “Expanding"" Three Kiloparsec Arm indicated highly non-circular motion of the interstellar medium between us and the center of the Galaxy. We now know that this structure is neither “expanding” nor “three kiloparsecs” in radius nor an “arm”. But what is it? Gerard de Vaucouleurs took it (correctly) as evidence for the barred nature of the Milky Way, although he got the bar angle wildly wrong. In my contribution, I will review the current status of understanding of the gas densities and phases and star formation interior to four kilo-parsecs radius in the plane of the Galaxy but outside the Central Molecular Zone. This includes the “Connecting Arm”, the “Near/Far Three Kiloparsec” arms, the “+135 km/s Arm”, and the “Bania Clouds”. One surprise was the presence of a significant reservoir of diffuse ionized gas in a tilted distribution with optical emission lines characteristic of LI(N)ER galaxies (Krishnarao, Benjamin, & Haffner 2020). I will provide updates on our attempt to understand the energetics and ionization of this gas. I will conclude with what I consider to be the biggest unresolved (but resolvable!) issue of Galactic structure

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All bar none: characterising the effect of bars on their host galaxies — Talk 31

Bars are strongly suspected of driving significant secular evolution in galaxy disks, including that of our own Milky Way. Theoretical models predict that bars funnel gas to both the central and outer disk regions and in doing so, transfer angular momentum from the inner regions of the disk to the outer disk and stellar halo. The rapid influx of gas into the inner regions triggers a central starburst and uses up a galaxy’s gas budget quicker than it would have otherwise. The end result of bar growth is an accelerated evolution of the overall galaxy, inducing quiescence earlier. We can test many aspects of this theory by comparing barred and non-barred galaxies in the local Universe. I will detail our recent observational results from optical integral field spectroscopic surveys on: 1) the location and significance of star formation within barred galaxies, 2) an earlier peak in the star formation histories of barred galaxies compared to unbarred counterparts, and 3) possible signs of bar-driven angular momentum transfer. These observations corroborate recent idealised N-body simulations of bar evolution, but are at odds with the short lifetimes of many bars in cosmological hydrodynamical simulations. Our observations suggest that bars have a significant long-term effect on their host galaxies, a fact that must be taken into account when considering the Milky Way’s evolutionary history

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Abstract of Talks – Day 3

Talk 32 — Formation of galaxies: clues from their angular momenta

This talk presents new results by the author and his collaborators on the angular momentum and formation of galaxies – subjects closely allied with Ken Freeman's scientific interests. The talk includes theory, simulations, and observations of both early- and late-type galaxies. The centerpiece of the talk is the relation between the specific angular momenta and masses of galaxies (j vs M). This fundamental scaling relation is now quite well determined to be a featureless power law, j a Ma, with an exponent a ~ 2/3 independent of galactic morphology and a morphology-dependent normalization. The j vs M relation tells us that late-type galaxies have retained nearly all the angular momentum they acquired by tidal torques (retained fraction fj ~ 1), whereas early types have lost most of it (fj ~ 0.1), independent of mass. The most likely physical explanations for these results are reviewed in the talk. Furthermore, there is a simple but important connection between the j vs M relation and the stellar-to-halo mass relation (SHMR, M vs Mhalo) of galaxies in CDM-type cosmologies: If one of these relations has a prominent feature, then so must the other; if one is a featureless power law, then so must be the other. The observed power-law j vs M relation and the standard inverted-U shaped SHMR then present us with a puzzle. This puzzle and its profound implications for galaxy formation are resolved and highlighted in this talk.

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Talk 33 — Understanding angular momentum scaling relations in the local universe

Angular momentum (AM) is a fundamental property of galaxies as it is linked to their formation, evolution and morphology. If AM is used to infer galaxy stability it can also be linked to atomic gas fraction. Despite AMs importance in understanding galaxies, many open questions remain. To date, studies of AM have small samples and are often biased towards gas-rich disk galaxies. During this talk, I will explain how we have been investigating whether AM scaling relations are robust to large samples with a wide variety of morphologies. We use HI velocity widths to calculate AM measurements rather than resolved kinematics, to obtain a larger sample than other studies. This sample was uniformly selected in stellar mass and HI gas fraction to avoid biasing the sample. The slope of the specific AM – mass relation (Fall relation) is often used to constrain the relationship between dark matter and baryons in a galaxy. However, we find that the sample used can also affect the slope obtained. Additionally, we studied the Obreschkow et al. 2016 model and found that it could not fully describe all the galaxies in our sample. These results will be able to influence how theories about galaxy stability, AM and gas fraction are developed in the future.

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Talk 34 — An investigation into the dark matter - galaxy angular momentum correlation

This work uses hydrodynamical simulations to explore the relationship between the angular momentum of a galaxy and its host dark matter halo. We explore the de-coupling of this relationship using simulations spanning a vast dynamic range – from very high resolution hydrodynamical simulations of isolated galaxies, to full cosmological-scale simulations (namely Illustris-TNG and EAGLE) and a novel suite of cosmological zoom simulations. Using these tools, we explore the halo-galaxy spin relationship and the relative impact of factors such as the hierarchical assembly history of a halo, stellar/AGN (active galactic nucleus) feedback and the any initial de-correlation between the dark matter and gas prior to galaxy formation. Ultimately, we examine the relative importance of dark matter in setting the angular momentum of galaxies, and whether different simulations are able to achieve a consensus.

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Abstract of Talks – Day 3

Spin-filament alignment flips are related to bulge assembly — Talk 35

How do galaxies like the Milky Way acquire their angular momentum, and how does this process relate to the external structure of the cosmic web and to the internal structure of the galaxy? The SAMI galaxy survey provides integral field spectroscopy enabling detailed analysis of the internal structure and dynamics of a large sample of galaxies across a wide variety of environments. We have used the SAMI survey, and the encompassing GAMA redshift survey, to analyse the alignments between the orientations of galaxy spins and the filaments of the cosmic web. We find a strong correlation between flips in these spin-filament alignments and the assembly of mass in galaxy bulges, and suggest that these correlated changes result from interactions and mergers as galaxies migrate onto and then along filaments in the cosmic web

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JWST's First Insights into Galaxy Formation and Growth — Talk 36

Hubble has astonished us with its insights into early galaxy formation at 400-500 Myr, hinting at the nature of galaxy growth before reionization. Combining these early direct, but very superficial, Hubble and Spitzer insights with the details from what we learn by doing ""archaeology"" on the Milky Way, and our neighbours, provides us with a powerful set of tools for unearthing how galaxies grew from their dramatic beginnings at 200-300 Myr. JWST's observations will result in a dramatic change in our view of galaxy formation and buildup on both the earliest and the recent timescales. In particular, even the earliest JWST observations after the Early Release Observations (ERO) are shown on July 12, 2022 are likely to clarify our view of galaxy growth prior to the start of reionization at z~10 (per Planck). I will be optimistic and plan to highlight what JWST is already telling us about the growth of the earliest galaxies, just 2 months after the release of the EROs and of the first science images from Webb!

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The challenge of simulating Milky Way-mass galaxies in cosmological volumes — Talk 37

Many of the structural and dynamical properties of galaxies, such as their masses, sizes, and characteristic velocities, are linked by scaling relations. Prescribing these relations is a primary goal of galaxy formation theory, and is best achieved using large-volume cosmological simulations that sample the diverse environments in which galaxies form, but also provide a faithful representation of their internal properties. The latest generation of cosmological simulations are beginning to reach the required volume and resolution to address these issues, but remain vulnerable to numerical artefacts. For example, stellar particles in simulated galaxies are spuriously heated by dark matter particles in the surrounding dark matter halo, which artificially increases their sizes, velocity dispersions, and in the case of disk galaxies, thickens them making them appear more spheroidal than they otherwise would. Using results from both controlled and cosmological simulations of galaxy formation, I will assess the extent to which spurious collisional heating affects simulated galaxies and discuss the implications for interpreting simulated galaxy scaling relations. I will present a simple empirical model able to disentangle spurious results from robust ones. Our results suggest that the latest generation of large-volume simulations, such as Eagle and IllustrisTNG, only marginally resolve the properties of Milky Way mass galaxies, highlighting one difficulty with simulating Milky Way analogs in cosmological volumes

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Abstract of Talks – Day 3

Talk 38 **The formation of galaxy disks: what have we learnt from cosmological hydrodynamical simulations?**

The current generation of cosmological hydrodynamical simulations has contributed tremendously to the understanding of how a LCDM universe can give rise to observed diversity of galaxy morphologies. Galaxy disks are a particular success of these simulations; and in fact broad agreement between simulations has been reached as to their formation paths. However, important disagreements emerge when studying the formation of galaxy disk subcomponents, such as bars, thick and thin disks and bulges. During this talk I will focus on what we have learnt from the EAGLE hydrodynamical simulations regarding the formation paths of galaxy disks, their subcomponents, and their stellar haloes; and the role stellar and active galactic nuclei feedback play on the efficiency of disk formation, highlighting areas of agreement and tension with other popular simulations

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Talk 39 **Galaxy Formation Simulations: Problems and Answers**

Detailed numerical simulations have become a standard approach to understand galaxy formation and evolution, and are commonly used as framework for interpreting observations. They have led to a new ""baryon cycle"" paradigm for galaxy formation where the CGM and IGM are interconnected repositories for baryons, which move from the IGM through the CGM and then onto galaxies through both hot and cold modes of accretion. Some of these baryons form stars and central black holes, but most leave galaxies through supernova and quasar winds and rejoin the CGM, from which they can potentially reaccrete. Unfortunately, simulations are sensitive to wind implementations. Interactions at wind/halo gas interfaces in the CGM occur on scales that are much below the resolution of any current or near future galaxy formation simulation, making a ""brute force"" approach not viable. To mitigate this impasse, we implement a new wind algorithm that explicitly models the ""subgrid physics"" in the wind-halo gas interaction analytically within a simulation, using the simulation to provide the physical characteristics that will inform the interaction. Unavoidably, this introduces a few free parameters but we can restrict them by matching observed galaxy properties. Previous simulations using a more standard wind model approaches reproduced many observed properties of galaxies and metal-line absorption, but our new wind implementation will allow us to tie empirical successes, and failures, more securely to the underlying wind physics, both the ejection (mass-loading factors and ejection speeds) and the interaction between the wind and gaseous halo, hopefully allowing the simulations to model physics instead of numerical errors

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Talk 40 **A Fresh Perspective on the Assembly of Mass**

Linking observable properties of galaxies to the assembly history of their host haloes is one of the great challenges in cosmology. I will address this challenge from the viewpoint of the “tree entropy”, a mathematical measure of the structure of merger trees. The tree entropy puts every halo’s assembly history on a scale between a “minimal tree”, grown entirely by smooth accretion, and a “maximal tree”, grown exclusively via equal-mass binary mergers. I will first discuss the tree entropies found in a LCDM cosmology and elaborate on how the properties of simulated galaxies relate to their tree entropies. In a second step, I will discuss the assembly history of the Milky Way via its tree entropy inferred from GAIA data. I will conclude with an attempt to link the Galaxy’s morphology to its assembly history in a quantitative way

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Abstract of Talks – Day 3

A mode for globular cluster formation with multiple stellar populations in the Galaxy — Talk 41

The Galactic globular clusters (GCs) are observed to have chemical abundance spreads among their individual stars (``multiple stellar populations', MPs). I will present a theoretical model that can explain a number of recent observations of MPs, such as the number fractions of Na-rich stars depending on GC masses, Li abundances, and Type I and II GC dichotomy. I will particularly focus on the the physical origins of the Galactic GCs that Ken Freeman and his collaborators studied very extensively so far (e.g., Omega Centauri). I will also discus the roles of future large telescopes (e.g., TMT and SKA) in revealing the origin of GCs in other galaxies.

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Dark Matter in Galactic Remnants and Dwarf Galaxies — Talk 42

Many dwarf galaxies appear to be dark matter dominated, so are excellent places to study dark matter properties and the interaction between baryons and dark matter. New radio observations of the tidal remnants of dwarf galaxies around the Milky Way have set strong limits on the fundamental nature (mass and self-annihilating cross-section) of dark matter particles. We also introduce the WALLABY survey of HI which will greatly increase the inventory of nearby gas-rich, dark matter dominated galaxies.

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