European Astronomical Society (EAS) Conference:

"HERA24 -The Nature and the Dynamics of Structures Observed in Galactic Disks"
15 – 20 September 2024, Academy of Athens, GREECE

Book of abstracts:

1. **Anelise Audibert, Instituto de Astrofísica de Canarias**

- **Feedback from low-power radio jets on the gas reservoirs of quasars**
Low-to-moderate luminosity kiloparsec scale radio jets are starting to be recognized as potential drivers of multi-phase outflows and as relevant mechanisms for active galactic nuclei (AGN) feedback. In radio-quiet quasars, compact radio jets are associated with morphological and kinematic distinct features in the ionized and molecular gas, such as increased turbulence and outflowing bubbles. These jet-gas interactions on galactic scales suggest that jets can be the dominant feedback mechanism in highly accreting radio-quiet quasars, where radiative feedback would be expected to prevail. To investigate the impact of low-to-moderate power jets on the cold gas reservoirs of AGN, we present high-resolution ALMA CO(2-1) and CO(3-2) observations of a sample of 5 radio-quiet quasars at z~0.1. Spatially resolved molecular line ratio maps were used to constrain changes in gas excitation and outflows characterized using kinematic modeling. We compare the outflow, host galaxy, and jet properties, finding mass outflow rates lower than those expected from their AGN luminosities, while the outflow kinetic power can be driven by the combined jet power and bolometric luminosity of their hosts, depending on their coupling. Despite AGN feedback not depleting the gas reservoirs and quenching global star formation, our observations reveal that the radio jets/winds disturb the cold gas morphology and kinematics within the central kiloparsecs of galaxies. Our findings provide further evidence that the coupling between the jet and the interstellar medium is relevant to AGN feedback, even in the case of radio-quiet galaxies, which are more representative of the radio emission across the AGN population

2. **Marcel Bernet, University of Barcelona – ICCUB**

- **The Milky Way kinematic substructure as a dynamics discovery tool: the cases of the bar and the tidal spiral arms.**
In this talk I will discuss the imprints in the Milky Way substructure of two dynamical phenomena; the galactic bar and tidal spiral arms.
First, we study the ridges and moving groups in Gaia DR3. With the improved dataset and methodology, we are able to compute the gradient of the azimuthal velocity as a function of radius and azimuth for each part of each moving group. We then compute the same gradients sweeping a dense grid of galaxy models using Backwards Integration. We find that the radial gradient cannot be reproduced by our simple models of the Galaxy. This result corroborates the need for more complex dynamics (e.g. a different bar potential, spiral arms, a slowing bar, a complex circular velocity curve, external perturbations, etc.). We will also discuss the future possibilities of these new observables, which contain information of the large scale substructure of the Milky Way.
In the second part of the talk, I will discuss our latest work: the use of data-driven dynamical analysis techniques in the characterization of the tidal spiral arms evolution. We start by characterising the kinematic signature of a tidal spiral arm in a test particle simulation. Then, using the Sparse Identification of Nonlinear Dynamical Systems (SINDy, Brunton et al 2016) technique we can recover the partial differential equation governing the system. This allows us to evolve the first order moments of the system in a semi-analytic way, and characterise the properties of the system, as well as the potential imprints it could show in the Gaia data.

3. **Kamran Bogue, The University of Manchester (JBCA)**

- **The Impact of Magnetic Fields on the Star-Forming ISM in Simulated Galaxies**
The precise role of magnetic fields in the large-scale dynamics of the Interstellar Medium (ISM) has been historically difficult to constrain. In our work, we run two seperate Arepo simulations of an isolated galaxy; one with and one without magnetic fields. This allows us to directly interrogate the impact of the magnetic field, and investigate how it shapes the alignment of dense structures in the ISM and their subsequent star formation. We compare the global properties of these isolated galaxy disc models, finding differences in

morphology and vertical extent. We also study the impact of the magnetic fields on the star formation history of the galaxy, as measured by sink particles, and find a notable shift in the Kennicutt-Schmidt relation. Finally, we utilise our embedded chemical network to examine the correlation between the magnetic field and the HI and H2 gas using the Histogram of Relative Orientations (HRO) technique. This provides insight into the importance of magnetic fields in shaping the formation of clouds.

4. **Chiara Buttitta, Astronomical Observatory of Capodimonte**

- **The case study of NGC4277: a slow bar in a dark-matter dominated lenticular barred galaxy**

Barred galaxies represent the two-thirds of disc galaxies in the Local Universe. The bar angular frequency Ω_bar (or pattern speed) is one of the most important parameters which characterise a bar. It controls the positions of the resonances, affects the stellar dynamics, and constrains the dark matter (DM) content. The bar pattern speed is usually parameterised by the rotation rate R (R=R_cor/a_bar) which distinguishes bars into slow (R ≥ 1.4) and fast (1 ≤ R < 1.4). Fast bars form spontaneously in isolated and unstable stellar discs, while theoretical studies predict slow bars as a consequence of the slowdown of a fast bar after the interaction with a centrally concentrated DM halo through dynamical friction. Observational studies show questionable results: bars in the Local Universe are compatible with the fast regime and the few slow bars detected so far have too large uncertainties to be considered genuinely slow. NGC4277 is the first case of a bright lenticular galaxy hosting a slow bar and the measure of its Ω_bar is amongst the most accurate measure of bar pattern speeds. NGC4277 also has well-studied properties in terms of photometry, stellar kinematics, and mass modelling. The DM content was constrained by modelling the photometric and kinematic properties with a Jeans axisymmetric model which suggests that NGC4277 is DM-dominated within the bar radius, with the 53 per cent of the dynamical mass in DM.

5. **Bianca-Iulia Ciocan, Centre de Recherche Astrophysique de Lyon, France**

- **The MUSE Hubble Ultra Deep Field survey: Dark matter halo properties of intermediate-*z* star- forming galaxies**"

The concordance Λ Cold Dark Matter model is very successful in reproducing the large-scale structure, but on galactic scales, it fails for some galaxies where rotation curves indicate flat dark matter profiles. Baryonic processes, such as stellar feedback, have been proposed to alleviate the tension between the predicted cuspy dark matter profiles and the observed constant density cores of intermediate and low-mass galaxies.

This study focuses on analysing the dark matter halo properties of an extensive sample of 136 intermediate-redshift ($0.3<z<1.5$) star-forming galaxies spanning a broad range of stellar masses ($7<\log(M_\star/M_\odot)<11$). For this, we employ integral field unit observations from the MUSE Hubble Ultra Deep Field Survey, as well as photometry from HST and JWST.

We analyse the morpho-kinematics of our sample with a 3D forward modelling approach, which allowed us to measure individual rotation curves in the outskirts of galaxies, at radii up to 2−3Re. We performed disk-halo decompositions with a 3D parametric model, which includes a stellar, dark matter and gas component, as well as corrections for pressure support. Our 3D methodology was validated using mock data cubes generated from idealised disk simulations. The dark matter halo was parametrised using six different dark matter density profiles, including the Navarro-Frenk-White, and the generalized profile of Di Cintio et al. We employ a Bayesian model comparison to select the model that fits the data best.

We find strong evidence that the DC14 halo model is preferred by the data, compared to the other halo models, and conclude that dark matter density profiles with varying inner slopes, γ, fit the sample best. The rotation curves of our sample show diverse shapes, similar to what is observed for local galaxies. The disk stellar masses, $M_\star$, obtained from the disk-halo decomposition agree with the values inferred from the spectral energy distributions. For 66% of the galaxies from our sample, we infer $\gamma < 0.5$, and these systems are consistent with having cored dark matter density profiles. We do not find any correlation between γ and the specific star formation rates of the sample. The stellar mass-halo mass relation inferred from our 3D modelling is in good agreement with the predicted relation. We find that the halo scale radius and dark matter surface densities evolve with stellar mass, while the core densities remain constant with stellar mass, similar to what was found for local disk galaxies. We observe a mild evolution of the halo scale radius and density with redshift, which suggests that the dark matter cores of $z\sim0.85$ systems are slightly smaller and denser than those of their local counterparts. We find that 89% of the sample has dark matter fractions larger than 50%

6. **Lara Cullinane, Potsdam (AIP)**

- **Stellar Structures in the Magellanic Clouds**
  As the most massive satellites of the Milky Way, and the closest pair of interacting dwarf galaxies, the Large and Small Magellanic Clouds (LMC/SMC) are an excellent laboratory for the study of stellar populations and galaxy interactions. While the LMC retains a disk-like structure, it displays many indications of past perturbations, including a tilted, off-centre bar; a single spiral arm; and a warped, flared disk. Recent panoramic maps of the Magellanic system have also revealed a wealth of low-surface-brightness stellar substructures surrounding both Clouds; clear evidence of tidal interactions between them, as well as with the Milky Way. However, the interaction history of the Magellanic system beyond the most recent LMC/SMC close passage remains poorly constrained. In this talk, I will present recent and forthcoming efforts to constrain the history of the Clouds. We use a combination of Gaia astrometry and spectroscopically-derived radial velocities to determine 3D kinematics, as well as elemental abundances, for thousands of stars across the extended disks and tidal features of the Clouds. We find that most substructures show significant perturbations from equilibrium disk kinematics, plausibly requiring multiple interactions to fully explain the observed dynamical properties. I will also discuss the forthcoming 4MOST 1001 Magellanic Fields (1001MC) survey, which will significantly expand upon these efforts.

7. **Mark Cunningham, University College London**

- **Influence of Early Galaxy Properties on Disk Dynamics**
  This talk investigates the properties of high and intermediate redshift galaxies, focusing on the detection of Lyman alpha and CIII] emissions to understand the epoch of reionization. While my current research has primarily centered on identifying these emissions, I aim to explore potential connections between early galaxy characteristics and the dynamics of galactic disks. By examining how line emissions might reflect structural and dynamical features, this discussion will serve as a thought piece to explore whether and how these early galaxy properties could influence the understanding of disk dynamics and vice versa. The goal is to bridge the gap between the epoch of reionization and the broader topic of disk dynamics, fostering new insights and directions for future research.

8. **Ahlam Farhan, Boğaziçi University in Istanbul**

- **Deciphering Water Megamaser Galaxies: Optimizing AGN Aspects for Better Detection Techniques**
  Water megamasers are pivotal in astrophysics and cosmology, providing the most accurate method for calculating black hole masses outside the Milky Way and offering the only direct means to measure distances to galaxies without relying on the distance ladder. Despite their significance, the limited detection rate of these masers presents a challenge, driving researchers to seek improved characterization techniques. Our study reveals the previously observed absence of a correlation between the central supermassive black hole (SMBH) mass and maser luminosity, contradicting the expected tight correlations. This underscores the necessity for more detailed classifications and systematic studies to uncover the underlying physical conditions. Additionally, we identified a significant inverse correlation between maser luminosity and the Fe Kα emission line at 6.4 keV, indicating that AGN feedback mechanisms may play a crucial role in regulating maser activity. Dense gas tracers, such as HCN and HCO+, have proven promising indicators for detecting masers. We found strong correlations between maser emission and dense gas fractions, especially in galaxies with normal infrared luminosity. These findings highlight the critical role of dense gas in the megamaser environment, offering valuable insights for refining detection strategies. By refining our understanding of maser-AGN relationships, we aim to enhance the techniques for discovering water megamasers, ultimately advancing our knowledge of galaxy evolution and the interplay between AGN and their surrounding medium.

9. **Camila de Sá Freitas, ESO**

- **Deriving bar formation epoch in nearby galaxies: First insights on secular evolution**
  The epoch in which galactic discs settle and secular evolution takes place is a major benchmark for testing galaxy formation and evolution models. Yet, this epoch is still largely unknown. Once discs settle and become self-gravitating enough, stellar bars are prone to form and lead the evolution of the host galaxy. Therefore, determining the ages of bars can shed light on the epoch of disc settling and the onset of secular evolution. Nevertheless, until now, timing when bars in nearby galaxies have formed has been proven challenging.

  Together with the TIMER team, we developed the first broadly applicable methodology to derive the bar formation epoch of nearby galaxies. Once the bar forms, its gravitational torques bring gas inwards, building nuclear structures in short timescales, such as the nuclear disc (a.k.a. pseudo-bulge). Therefore, one can use the formation of the nuclear disc to time the bar formation. To that, we use integral field spectroscopic (IFS) data from the TIMER survey (MUSE/VLT) and disentangle the light of the central region of galaxies to derive independent star formation histories. This allows us to derive the formation epoch of the nuclear disc and, thus, the bar. We estimated the bar formation epoch for the TIMER sample, creating a sample with known bar ages for the first time, with around 20 galaxies.

  Our first results find bar formation epochs varying between 1 and 12 Gyrs, illustrating how disc-settling and bar formation are ongoing processes that first took place in an early Universe. We infer the bar fraction over cosmological time within our sample, finding remarkable agreement with the observed bar fractions for different redshifts. Additionally, we find trends indicating that the normalized bar and nuclear disc sizes grow with time, whereas younger bars tend to be relatively smaller and host smaller nuclear discs. Lastly, we find no evidence of downsizing in bar formation, in which more massive discs should have settled first and hosted the oldest bars.

10. **Juan Manuel Espejo Salcedo, MPE**

- **Angular momentum measuremts of high redshift disks**
  I will present an integrated measurement of the stellar specific angular momentum j* of 41 star-forming galaxies at $1.5<z<2.5$. The measurement is based on radial profiles inferred from near-IR HST photometry and a joint multi-resolution kinematic modelling using integral field spectroscopy (IFS) data in both seeing-limited and adaptive optics-assisted modes from KMOS, SINFONI, and OSIRIS. Using the 26 disks identified in this sample (a disk fraction of 63%), we parametrise the j* vs M* relation (Fall relation) and find a power-law slope $\beta=0.26$, which deviates significantly from the commonly adopted redshift zero relation $\beta=2/3\sim0.67$. We find that the steep slopes found in previous studies could be driven at least partially by a combination of two key systematic effects; first, using irregular (non-disk) systems in the parametrisation of the Fall relation (often due to limitations in spatial resolution) and second, relying on measurements of j* from a commonly used Fall+12 approximation which relies on global unresolved quantities.. Finally, we make a qualitative discussion on the possible origin of the shallow slope in the Fall relation for these systems by studying the angular momentum retention factors f_j. We find large f_j values in low-mass haloes that decrease with increasing mass. This suggests a potentially significant role of efficient angular momentum transport in these gas-rich systems, aided by the removal of low-j* gas via feedback-driven outflows in low-mass galaxies. This trend could contribute to the observed shallower slope in the Fall relation.

11. **Paula Gherghinescu, University of Surrey**

- **Action-based dynamical models for M31-like galaxies**
  The position, velocity, and chemical composition of each star provide clues to the evolutionary history of galaxies. While the Gaia mission has offered invaluable information about the Milky Way, it is crucial we also look into stellar fossils in external galaxies. The Andromeda Galaxy (M31) is ideal for this task thanks to its proximity (making it possible for individual stars to be resolved) and its inclination angle, providing a gateway

to external galaxies study. Furthermore, our position outside of this galaxy is ideal for an unbiased view of its dark matter halo.
I am presenting a Bayesian action-based tool that is built to exploit stars harvested in M31. This pipeline aims to recover parameters of the distribution function and gravitational potential of the galaxy. This will be used to understand the galaxy's accretion history and accumulation of dark matter. As a first test, the pipeline has been applied to the Auriga simulations of M31-like galaxies, specifically looking at the stellar halos, in order to test the dynamical equilibrium assumption of galaxies, and the generality with which double-power law distribution functions can be used to fit stellar halo components of galaxies. Secondly, we investigated the effects of missing data in external galaxies and the biases and degeneracies that arise in the recovery of the DM mass distribution and kinematics of the tracers.

12. **Óscar Jiménez-Arranz, University of Lund**

- **The Magellanic Clouds with high resolution glasses**
The exquisite astrometric dataset that Gaia DR3 offers to the scientific community makes the Magellanic Clouds (XMC) a unique test laboratory to investigate and refine methodologies and models. Classification strategies based on Neural Networks allow to select LMC and SMC samples with less than 10% contamination from the Milky Way (Jiménez-Arranz+23a,b). Also, the LMC is the first galaxy for which we can map a 3D velocity field of the complete galaxy (Jiménez-Arranz+23a) and endeavour dynamical studies in detail, such as the determination of the LMC bar pattern speed using different methods (Jiménez-Arranz+24a). For the first time, we can analyse the internal kinematics of an external galaxy and compare them with what theoretical models predict. The results highlight the evidence of the need of high resolution simulations to provide a dynamical interpretation of the information shown by the data. In this talk, we also introduce KRATOS (Jimenez-Arranz+24b), a suite of 28 pure N-body simulations of isolated and interacting LMC-like galaxies, to study the formation of substructures in their disc after the interaction with an SMC-mass galaxy. The KRATOS simulation is well-suited for an initial interpretation of the LMC's kinematic maps provided by Gaia. We also discuss the potential impact of the upcoming astrometric mission GaiaNIR on our understanding of these galaxies.

13. **Evgenia Koutsoumpou, University of Athens**

- **The impact of cosmic rays on gas clouds**
Cosmic Rays (CRs) in active galactic nuclei (AGN) are a potential source of feedback able to regulate star formation. These non-thermal particles, accelerated by shocks, penetrate deep into the molecular gas, driving the heating and chemistry of the interstellar medium (ISM), and launching massive outflows. We examine the impact of CR feedback on ionized gas in a sample of nearby AGN and starburst galaxies. Using CLOUDY photoionization simulations, we inspect the ionization produced by low-energy CRs on the emission-lines in the optical range. Our model grids span a broad range in density (1 to 10^4 cm-3), ionization parameter (-3.5 < logU < -1.5) and CR ionization rate (10^-15 to 10^-12 s-1), and are compared with VLT/MUSE observations of prototypical galaxies (Centaurus A, NGC 1068, and NGC 253). Our study unveils that high CR ionization rates, as those expected in AGN and strong starbursts, can induce a secondary ionization layer beyond the photoionization-dominated regions, enhancing the emission of low-excitation transitions (i.e. [NII]λ6584). AGN models with Crs reproduce the Seyfert locus in BPT diagrams without super-solar metallicities, contrasting pure photoionization models, whereas star-forming models can explain non-AGN sources in the LINER region. Overall, our findings illuminate how AGN and supernova-produced CRs shape ISM, influencing galaxy star formation.

14. **Zoe Le Conte, Durham University**

- **A JWST investigation into the bar fraction at high redshifts z ≥ 1**
The presence of a stellar bar in a disc galaxy indicates that the galaxy hosts, in its main part, a dynamically settled disc and that bar-driven processes are taking place in shaping its evolution. Studying the cosmic evolution of the bar fraction in disc galaxies is therefore essential to understand galaxy evolution in general. Using the Hubble Space Telescope (HST), previous studies have found that the bar fraction significantly

declines from the local Universe to redshifts near one. Using the James Webb Space Telescope (JWST) Cosmic Evolution Early Release Science Survey (CEERS) and the initial public observations for the Public Release Imaging for Extragalactic Research (PRIMER), we extend the studies of the bar fraction in disc galaxies to redshifts $1 \le z \le 3$, i.e., for the first time beyond redshift two. Our sample is present in the Cosmic Assembly Near-IR Deep Extragalactic Legacy Survey (CANDELS) on the Extended Groth Strip (EGS) and Ultra Deep Survey (UDS) HST observations. The sample was visually classified to find the fraction of bars in disc galaxies in two redshift bins, and our results showed the JWST bar fraction to be twice the bar fraction found using bluer HST filters. Specifically, we find that the bar fraction is about 18% at redshifts between one and two, and about 14% at redshifts between two and three. In an upcoming study, we are doubling the sample and extending it to redshift four. We will also evaluate the evolution of the bar length to understand if bars grow with cosmic time. Our results already show that bar-driven evolution commences at early cosmic times and that dynamically settled discs are already present at a lookback time of ∼11 Gyrs.

15. **Paula D.López, IALP - CONICET / Durham University**

- **From bars to boxy/peanut bulges: formation mechanism and evolution in cosmological simulations**
  Understanding the formation and evolution of galactic structures, particularly bars and boxy/peanut-shaped (b/p) bulges, is crucial for comprehending galaxy dynamics. However, it remains unclear why certain galaxies develop a bar structure while others with similar mass and morphology do not. To address this, we use cosmological simulations to explore the formation of a sample of barred galaxies compared to a similar sample that did not form a bar. Our analysis found significant differences in the initial gas and dark matter content, but not in the halo spin values, which were initially similar across both samples. Additionally, we investigate the formation, evolution, and buckling events of b/p bulges in barred galaxies using the Auriga simulations.

16. **Alexander Marchuk, Central (Pulkovo) Astronomical Observatory**

- **Decomposing the spiral arms: what are they?**
  Galaxies with spiral arms are ubiquitous in the local Universe, as well as in the distant past, as revealed by JWST and other telescopes. Despite all the accumulated data, there is little convincing observational evidence that we understand spiral structure correctly, yet it is clear that their influence on disk evolution is significant. Together with my students and colleagues, I am trying to clarify this question in observations of real galaxies, using two different approaches. In the first, we are trying to determine how the spiral arms of real galaxies are organized, primarily photometrically. For this purpose, we have developed a new 2D photometric model where each spiral arm is modeled independently. In our model, the light distribution both along and across the arm can be varied significantly, as well as its overall shape. So far, three fundamentally different samples have been decomposed using it: the M51 galaxy in 17 bands (from the far UV to far IR), 29 close galaxies in 3.6 micron images from the S4G survey, and 159 galaxies from the HST COSMOS and JWST CEERS and JADES surveys with z up to 3. I will present the results of analyzing the parameters of the spiral arms in these samples, including pitch angles, widths, spiral-to-total luminosity ratios, and others, as well as how they change with redshift and the differences between models with and without spiral arms. The second approach is to analyze the resonant corotation radii, which are essential to determine the angular speed of the spiral structure, and therefore understand its nature. Various methods for its estimation have been developed, but they all demonstrate certain limitations and a lack of agreement with each other. To address this question, we have collected a dataset of corotation radius measurements for 547 galaxies, 300 of which have at least two values. I will present the analysis of this dataset, where we observe large inconsistencies in the radius estimates regardless of spiral type, Hubble classification, or presence of a bar. However, we found consistent and thus potentially reliable corotation radii in a relatively small number of galaxies. The availability of such a sample helped us to demonstrate: (a) the validity of the newly proposed method for determining the corotation radius from spiral widths, for which only photometric data is needed; (b) that there are cases with two or even more spiral patterns in the disc, for which the so-called resonance coupling is crucial. Among other things, I obtained predictions about the mutual position of the spiral patterns in such systems for a flat rotation curve and found a new example of double coupling; (c) for a pair of galaxies, we independently confirmed the predicted position of the corotation radii by other methods, thus providing strong evidence for the presence of a density wave in them.

17. **Alex Merrow, Liverpool University**

- **Did GES form the Milky Way's Bar?**
  The Milky Way's last significant merger, the Gaia Enceladus/Sausage (GES), is thought to have taken place between 8 and 11 Gyr ago. Recent studies in the literature suggest that the bar of the Milky Way is rather old, indicating that it formed at a similar epoch to the GES merger. We investigated the possible link between these events using one of the Auriga cosmological simulations that has salient features in common with the Milky Way, including a last significant merger with kinematic signatures resembling that of the GES, and a bar which forms less than 1 Gyr later. Additionally, to highlight the effects of the merger, we reran the simulation from z = 4 with the progenitors of the GES-like galaxy removed well before the merger time, observing a delay in bar formation. Across all Auriga galaxies with GES-like merger events, those with stellar mass ratios below 10% form bars within 1 Gyr of the merger, while bar formation is delayed in the more massive merger scenarios. We also investigated some of the general effects of galaxy interactions on the pattern speed of bars.

18. **Ana Mitrašinović, Astronomical Observatory Belgrade**

- **Double bars in the aftermath of a galaxy flyby**
  Galaxy flybys are interactions during which two galaxies inter-penetrate but detach later. These interactions are frequent and can significantly affect the evolution of individual galaxies, inducing the two-armed spiral structure and bars. Equal-mass flybys are extremely rare and almost exclusively distant, while typical flybys have mass ratios of 0.1 or lower, with a secondary galaxy penetrating deep into the primary. We have demonstrated that this can result in comparable interaction strengths between the two flyby classes and lead to the same effects. One specific and interesting case is the formation of double misaligned bars in moderately strong flyby. The bar and two-armed spiral structure form early on, during, or immediately after the interaction. The early-formed bar evolves slowly in length and strength, allowing inner parts of the spiral structure to wrap around it, forming a short-lived ring. These features quickly evolve to discernable double bars that co-evolve and co-exist for a long time (i.e., more than 2 Gyr). When two bars are aligned, the feature is detected as a single bar for short periods until they finally align to form a single, strong, long bar. The formation pathway of double bars through tidal forces has been recently reported and independently demonstrated. However, more research is needed to shed light on the formation pathways and the evolution of double bars in a nuanced and robust manner.

19. **Samir Nepal, Leibniz Inst.Potsdam (AIP)**

- **Milky Way's old thin disc and a young bar: new insights on MW disc history with Gaia, machine learning and precise stellar ages**
  Machine Learning applications such as the hybrid-CNN (Guiglion et al. 2024) allows to homogeneously combine Gaia RVS spectra, photometry (G, BP, RP), parallaxes and the XP coefficients to obtain precise stellar parameters down to S/N=15. Thanks to the ML technique and Gaia we explore the very early evolution of the Milky Way disc using a set of over 200,000 Main Sequence Turn-Off (MSTO) + Subgiant (SGB) stars with precise ages including 8500 stars with [Fe/H]<-1.0. Using StarHorse, a bayesian isochrone fitting algorithm, we achieve precise distances and stellar ages with median uncertainties of ~2% and ~12% respectively. Firstly, in Nepal et al. 2024a, we investigated a homogeneous and extensive sample of super-metal-rich (SMR) stars. We report a metallicity dependence of the distribution of the guiding radius (Rg) shown by peaks at 6.9 and 7.9 kpc, first appearing at [Fe/H] ∼ +0.1 dex, becoming very pronounced at higher [Fe/H]. There is an abrupt

scarcity of metal-rich stars beyond ~9.2 kpc suggesting a limit to the migration from the inner galaxy, beyond this location, by the Galactic bar's outer Lindblad resonance (OLR). We show that SMR stars can be used to establish tighter constraints on the epoch of bar formation and its impact on the Milky Way's star formation history. We find hints of recent bar activity at ~4-3 Gyr ago. Secondly, in Nepal et al. 2024b we explore the very early evolution of the Milky Way disc. We find old stars in disc orbits with a wide range of metallicities from metal-poor to super-solar [Fe/H]. We estimate the vertical velocity dispersion for the high-[α/Fe] thick disc as 35 km/s, the low-[α/Fe] disc at same age range is lower by 10 to 15 km/s. Similar to the high-z disc galaxies observed by ALMA and JWST, our results suggests that MW thin disc formation started already in the first billion year after the Big Bang.

20. **Periklis Okalidis, from MPA**

- **Radial transport of gas and stars in disc galaxies in the Auriga simulations**
Within the narrow plane of the disc of late type galaxies both gaseous and stellar matter are subject to motions in the radial direction. Gas that has been accreted from the outskirts of the disc is slowly dissipating energy and losing angular momentum giving rise to radial flows towards the center, a process which among other things can cause a mixing of material with different chemical properties. In the meantime, stars that have been born at a given location with specific orbital characteristics are subject to torques that can alter their orbital parameters and cause their mean orbital radius to 'migrate' to inner or outer regions. This process, called 'stellar migration', can potentially affect the range of properties, such as ages and metallicities, of the stellar populations that we observe at a given region of the disc. In this talk I will be presenting a study of these two processes as they happen in Auriga, a state-of-the-art cosmological zoom-in simulation suite of Milky Way analogues. We are utilising a set of ~15 individual disc galaxies of Milky Way mass which reside in relatively isolated haloes, an ideal environment to focus on the secular evolution of the system. Firstly, I will be talking about the radial gas flows, which we study by considering the bulk flow of material, finding an average inflow velocity of the order of -2.5 km/s in our sample. In addition, we look at the amount of scatter that gas at given radii experiences at varying timesteps identifying a potential correlation of this scatter to the amount of mass accreted perpendicularly to the plane of the disc. In the second part of the talk I will discuss the presence of stellar migration in the same Auriga galaxies. In particular our findings indicate a strong stellar migration signal only in those galaxies that harbour a central bar, an effect that leaves a noticeable imprint on the stellar metallicity profiles by flattening the outer gradients. Moreover I will show how the stellar migration strength varies as a function of the age of the stellar populations and the different radii within the disc. Finally I will give a brief view of how we can model these two processes with simple parametrised forms -extracted by the aforementioned studies- that can be easily input into semi-analytic models and show a preliminary application to the L-Galaxies semi-analytic model.

21. **Stavros Pastras, MPE**

- **Gas transport and galactic structure at z~1-3 in simulations**
The understanding of gas flows in disk galaxies is crucial to elucidate the processes through which galaxies evolve from the turbulent, gas-rich systems at high redshift to the low dispersion, quiescent ones we see today. Thus, studying the flow of gas in these gas-rich disks through the use of high resolution, cosmological simulations and comparing the results with the latest observations is very important in constraining their evolution. To that end, we present our study of a z~3 zoom-in resimulated galaxy of the TNG100 simulation of the IllustrisTNG project using AREPO and the TNG physics model. We identify correlations between the loci of the spiral arms with regions of gas inflows, while outflows of gas are observed in the interarm regions. While these flows cause an azimuthal dependence of the gas flow rate, we quantify the resulting net radial inflow rate which we find is of the order of the global SFR of the galaxy. We examine the dependence of our results on properties of the host galaxy, such as the gas fraction, by running a set of idealised simulations of typical cosmic noon disk galaxies and comparing their evolution. We also produce mock observations of our zoom-in simulated galaxy and analyse them quantifying the properties of these radial flows that could be extracted by the latest and deepest resolved observations of similar galaxies. Finally, we compare our results with actual resolved observations of high redshift galaxies finding significant agreement between the signatures of inflows in our simulated systems and the evidence for rapid, large scale inflows in the observed early disk galaxies ~10 billion years ago, at the peak epoch of cosmic star formation activity.

22. **Jurgen Popp, The Open University, Walton Hall**

- **Investigating Star-forming Clumps in Galaxies from SDSS, CLAUDS and HSC-SSP using Deep-Learning based Object Detection**
  Giant star-forming clumps (GSFCs) are areas of intensive star-formation that are commonly observed in high-redshift ($z \gtrsim 1$) galaxies but their formation and role in galaxy evolution still remain unclear. Observations of low-redshift clumpy galaxy analogues are rare but the availability of wide-field galaxy survey data makes the detection of large clumpy galaxy samples much feasible. In previous work (Popp et al., 2024), we have shown how Deep Learning-based object detection models can be successfully applied to identify GSFCs in low-redshift ($z \lesssim 0.3$) galaxies. The Faster Region-based Convolutional Neural Network (FRCNN) object detection framework relies on a CNN component as a 'backbone' feature extractor which benefits strongly from an already pretrained domain-specific classification CNN, i.e. 'Zoobot' (Walmsley et al., 2023). We have extended our tests of DL-based object detection on imaging data from the Hyper Suprime-Cam Subaru Strategic Survey (HSC-SSP) and CFHT Large Area U-band Deep Survey (CLAUDS), also changing the model architecture to make use of the full (U)GRIZY dataset. We show that using every available filterband as input and allowing for multi-class detections improves the detection performance of our FRCNN-models. Once the positions of these star-forming regions have been located in a sample of ~700,000 HSC-SSP galaxies we derive the physical properties using SED-fitting based on the recovered UGRIZY-fluxes.

23. **Louis Quilley, Centre de Recherche Astrophysique de Lyon (CRAL)**

- **Tailoring galaxies along the Hubble sequence: how bulge growth shapes the evolution of galaxies**
  We perform bulge and disk luminosity profile-fitting with SourceXtractor++ on the 4458 nearby galaxies of the EFIGI catalog with visual morphological classification. The absolute NUV − r color versus mass diagram shows the known bimodality and the intermediate Green Valley, that are continuously spanned by the consecutive morphological types of the Hubble sequence – indicating that it can be considered as an inverse sequence of galaxy physical evolution (Quilley & de Lapparent 2022). Across the Green Valley, galaxies undergo a systematic disk reddening of 0.2 mag in (g-r), a marked bulge growth by a factor of 2 to 3 - excluding a sudden quenching scenario (Q & dL 2022), and also exhibit a higher frequency of both inner and outer rings (Quilley et al. 2024b, in prep.). We highlight color gradients within the bulges and disks of spiral galaxies, and discuss their implications in terms of nuclear star formation, and scenarii of inside-out quenching, respectively (Quilley et al. 2024c, in prep.). Moreover, we measure the size-luminosity and Kormendy (size-surface brightness) relations for bulges and disks separately, and notice a continuous transition, characterized by a joint increase in effective radius, Sérsic index and bulge-to-total ratio, from pseudo-bulges to classical bulges, all along the Hubble sequence (Q & dL 2023). Overall, by examining bulges, disks, bars, rings and spirals arms, we paint a picture of galaxy evolution suggesting that internal dynamics, likely triggered by mergers or flybys, may be the key to galaxy aging. Finally, we present how Euclid data can be leveraged to witness over cosmic times the morphological transformations suggested by our studies of EFIGI.

24. **Fabio Rigamonti, Università degli studi dell'Insubria, (INFN), Italy**

- **Dynamical modeling of bulges and discs: a census across kinematics, mass, and star-formation from the MaNGA survey.**
  In this talk, I will present a new technique (BAyesian modelliNg of Galaxies, BANG) that extends bulge+disc decomposition to galactic dynamics and the results obtained from its application on the MaNGA survey. Our methodology simultaneously fits galaxy photometric and kinematics properties through a self-consistent model where the galaxy's visible and dark components are approximated through potential-density pairs. BANG, publicly available as an online repository, bases its parameter estimation on the most robust Bayesian algorithm available (i.e. nested sampling) still reaching computationally fast performances through a native, GPU-based, parallelization. From the application to MaNGA, we found that below M~10^11 Msun, the

dichotomy in bulges and discs is reflected in the presence of a dynamically hot inner component and a dynamically cold outer disc. Still, our methodology revealed a significant scatter between photometrically determined bulges and galactic kinematics. In the same mass range, exploiting BANG's capability to simultaneously provide luminosity- and mass-weighted estimators of the galaxy kinematics, we demonstrated that the observed decrease in the rotational support of galaxies as they transition below the star-forming main sequence is merely apparent. Indeed, galaxy structural and morphological properties change only slightly during or after the quenching phase as the main process at play is more likely associated with a dimming of the disc luminosity (i.e. disc fading). On the contrary, in a narrow range of higher masses, a significant structural change happening on similar timescales of the quenching process is observed and a different mechanism, most likely associated with galaxy mergers, seems to be dominant

25. Anton Smirnov, Pulkovo Observatory

- **N-body bars in the action space: orbital study**
  Throughout this talk I would like to discuss how the action space of the self-consistent N-body model changes via the bar evolution. Specifically, how the actions of orbits change on a large time-scale at the stage of a mature bar, when they are captured by the bar and then are lifted from the disc plane. I will show that the orbits tend to preserve their adiabatic invariants (superposition of actions exploited by Lynden-Bell in his work on the bar formation) if one takes into account the three-dimensional structure of the orbits. I will also discuss the concept of the so-called Lynden-Bell derivative (partial derivative of procession rate over the vertical projection of the angular momentum) and whether this concept can be applied to describe the behavior of individual orbits that structure the bar.

26. Thomas Tomlinson, Durham University

- **Evidence for bar resonance substructure in a cosmological simulation**
  Over half of disc galaxies in the local Universe, including the Milky Way, contain a galactic bar—a massive structure that influences the orbits of stars from the disc to the stellar and dark matter halo. A manifestation of the bar's influence is the trapping of stars in resonance with the bar. Stars trapped at resonance can appear as overdensities in phase space, as well as in the space of energy and angular momentum. Such features are thought to have been recently identified in the stellar halo of the Milky Way, using data from the Gaia satellite, and have been explored using test particle simulations. Here, for the first time, we report on evidence of this phenomenon in a cosmological simulation from the ultra-high resolution Auriga Superstars suite, made possible by its stellar resolution of 800 $M_\odot$. I will present my analysis of the effects of the trapping of stars in resonances in the stellar halo in different regions of the galaxy, as well as explore how these resonances are observed across different metallicities and in the in-situ and accreted components, in order to inform and interpret recent observational findings.

27. Roman Tkachenko,Southern Federal University, Rostov-on-Don

- **The Influence of the Milky Way bar on the distribution of globular clusters in kinematic space**
  A popular model of the formation of the Milky Way halo is the accretion and subsequent disruption of the dwarf satellite galaxies by the Milky Way. A number of studies have been conducted recently to identify the Milky Way globular clusters as different accretion events, exploring their metallicities and their positions in kinematic spaces. All these studies assume that clusters conserve their energy and momentum for billions of years after accretion by the Milky Way galaxy. This assumption suggests that the potential of the Milky Way remains unchanged during billions of years of galactic evolution. These studies do not take into account, however, the time dependence of the galactic potential, which can significantly change the energy and the angular momentum of the satellites and their remnants during/after accretion. One such obvious influence is the presence of the Milky Way bar, which affects the positions of the clusters in kinematic space. This is especially true for those clusters that have small pericentric radii.
  We use up-to-date data for the parameters of the Milky Way's halo globular clusters and study how the galactic bar affects their dynamics by calculating their orbits. We consider both axisymmetric and non-axisymmetric galactic potentials, taking into account the observational errors of the cluster's positions and

velocities. We examine the influence of the bar on the clusters evolution in the angular momentum-total energy plane, which is commonly used to identify the groups of the globular cluster to be associated with the same accretion event. We focus our study on Gaia-Sausage/Enceladus and Pontus structures, which were thought to be separate accretion events. Our study indicates that, taking into account non-stationarity of the Milky Way potential, it is impossible to distinguish between GSE and Pontus as distinct accretion events. The talk will also include a concise summary of other factors that have a significant influence on the identification of the globular clusters as different accretion events.
This work is supported by the Foundation for the Advancement of Theoretical Physics and Mathematics 'BASIS' for financial support

28. **Aikaterini Niovi Triantafyllaki, Tartu Observatory**

- **Dynamical friction: a case study on its effect on the tails of globular clusters and its application on galactic systems.**

Globular clusters travel within a galaxy, leaving behind a trail of stars in their orbits. The motions of the stream stars are governed by the potential they are in. The evaporation of these stars results in two tidal arms: the leading and the trailing. While these arms are populated symmetrically in the first approximation, Gaia data and subsequent research reveal asymmetries in the evaporation of open clusters (e.g., Pflamm-Altenburg et al., 2023). Hence, differences between the arms. We hypothesize that these asymmetries and inhomogeneities are caused by the wake of dynamical friction, primarily located on one side of the stream, thus influencing one arm more. We test this scenario by calculating the dynamical friction wake effects on the orbit of a globular cluster. We apply the method introduced by Kipper et al. (2023) to integrate the stars in the vicinity of the globular cluster into the past and then back to the present without the potential of the globular cluster.
We observe a strong dependence on the stream's location: a dark matter halo environment does not induce significant asymmetries, while disc contributions are more pronounced. With every passage through the disc, the wake forms and slightly changes the velocity of the stream stars. (Triantafyllaki 2024, in prep). Using the same method, I aim to extend the analysis away from the inhomogenities (disk, superbubble infulence, DM halos) on the globular cluster tails and streams to map the conditions and environments wherein dynamical friction is observable and the kinematics that occur there. This will unveil the formation of peculiar galactic structures, including lopsided and jellyfish galaxies etc. By employing observational data(Gaia, JWST, J-Pas, bright tracers eg PNe), my objective is to empirically test these hypotheses discern the observational imprints dynamical friction on celestial objects and to constrain the kinematic processes in galaxies.

29. **Charis Tsakonas, U. of Athens**

A major merger model for Andromeda's galaxy (M31) recent accretion event and direct comparison with chemodynamical observations.

Significant observational data is suggesting a gas-rich major merger in the recent past (~2-3 Gyr ago) of our neighboring Andromeda galaxy (M31). The unusually high-velocity dispersion of old stars in the disc, the presence of the pronounced Giant Stellar Stream (GSS), as well as a burst of star formation ~2 Gyr ago, point to such a merger event. Recently, observations from DESI in the halo of the galaxy, revealed coherent (wedge and stream-like) features in the phase space (projected distance vs line of sight velocity) of its major inner halo substructures, along with a large sample of resolved stars having spectroscopic [Fe/H] measurements.
We utilize an N-body hydrodynamical simulation of a major merger (mass ratio of 1:4), which reproduces the main observational features of M31, to study the nature of the substructures in its halo (GSS, NE- and W-Shell) and compare the model-estimated predictions with recent chemodynamical observations.
The model succeeds in reproducing the observed metallicity values of the various substructures of the inner halo of M31. This then allows us to interpret some (still unexplained) observational traits of the galaxy, i.e. the multiple peaks in the metallicity of the giant stream (detected by different surveys) and the features in the phase space of its major stellar substructures (as seen by DESI).
We conclude that the GSS appears to be a superposition of multiple loops along the line of sight, responsible for the apparent coherent regions in the phase space of its stars. These discrete loops are shaped by consecutive pericentric passages of the satellite throughout the major merger.

30. **Namita Uppal, Institute of Astrophysics, Foundation for Research and Technology**

- **Mapping the Milky Way: ISM polarization for tracing Disk Structures and 3D magnetic fields**
  Understanding the formation and evolution of the galaxies has been a topic of interest for centuries. The Milky Way, our own galaxy, offers a unique opportunity to study individual stars in great detail due to our position within it. However, this same position poses significant challenges for observing the entire structure of the Galaxy, as we are embedded in the Galactic disk with various structural features superimposed along our line of sight. Despite these challenges, astronomers have made significant efforts in deciphering the structure of the Milky Way, confirming it as a barred spiral galaxy. However, details such as the number of spiral arms, their positions, and extents are still highly debated. Dust is highly confined to the Galactic disk, making it an ideal candidate for mapping the structure and, specifically, the spiral arms of the Galaxy. Interstellar dust emits thermal radiation primarily in longer wavelengths. However, estimating distances required to study the 3D dust distribution relies on kinematic methods, which exhibit significant uncertainties, especially towards the center and anti-center directions. Alternatively, the properties of dust, such as extinction and polarization, can be used to probe its distribution. While significant efforts have been made to create a 3D extinction map of the galaxy, studies targeting the 3D distribution of dust through interstellar polarization are limited. Leveraging accurate distance estimations from Gaia data, we aim to investigate the dust distribution through starlight polarization caused by interstellar dust. In our study, we targeted Galactic open clusters present towards the anti-center direction to demonstrate the role of interstellar polarization in deciphering the 3D dust distribution and, consequently, the structure of our Galaxy. We selected clusters in the same line of sight but located at different distances in order to determine the number of dust layers and their distances in that sightline. We observed five open clusters spanning 2 to 6 kpc from the 1.04 m Sampurnanand telescope in India using the ARIES imaging polarimeter (AIMPOL). Our automated data reduction pipelines combined with Gaia parallaxes reveal large-scale dust features corresponding to spiral arms and provide evidence of large-scale magnetic field orientations.

31. **Daria Zakharova, University of Padova**

- **Kinematic features of galaxies with bars**
  A significant fraction of the barred galaxies also exhibit vertical growth of their bars which are so-called boxy/peanut-shaped structures (B/PS bulges) at high inclinations. Besides, the galactic bars may be complemented with additional central features such as barlenses. However, the detection of bars and especially more specific bar components is complicated. Using four N-body models with different features, we investigate how the bars and sub-components manifest themselves in kinematic maps. We demonstrate that vertical density distribution could be traced by a vertical velocity component at only face-on position. Furthermore, we show that orbits responsible for vertical growth differ from model to model. We also show that line-of-sight velocity distribution analysis provides an exceptional analysis of the bar presence. We complement our results with a comparison with IFU data results.