

## **Mergers which Formed Milky Way Halo**

Vinay Chakawri & Marleen Besseling

The Milky Way's stellar halo likely formed through at least one major merger event, as shown by the Gaia-Sausage and Gaia-Enceladus studies, which identified two distinct halo populations with different metallicities and orbital properties. The Gaia-Sausage results show that many halo stars move on highly radial orbits and include a relatively metal-rich population, supporting the idea of a massive progenitor galaxy merger rather than simple monolithic collapse. The Gaia-Enceladus analysis further suggests the merger had a mass ratio of about 0.24 and a relatively low star formation rate, inferred from its low  $[\alpha/\text{Fe}]$  abundance ratios.

## **Mergers which Formed Milky Way Halo**

Noah Kaijser & Maria Eugenia Redondo Gonzalez

Gaia has revolutionized the study of Milky Way mergers and stellar streams by providing precise 6D phase-space information (positions and velocities), enabling the discovery and mapping of many more stellar streams and revealing signatures of past merger events such as the Sagittarius dwarf galaxy interaction. The presentation highlights that structures such as the phase-space spiral in the  $V_z$  plane are evidence that the Galactic disk is not in equilibrium and was likely perturbed by a recent interaction with the Sagittarius dwarf galaxy. Stellar streams are powerful probes of both the Milky Way gravitational potential and dark matter substructure, since stream gaps, widths, and kinematics can reveal the effects of the Galactic bar, spiral arms, and even low-mass dark matter subhalos predicted by cosmological models.

## **Mergers which Formed Milky Way Halo**

Ines Bercuk & George-Luca Iconaru

Gaia data has revolutionized our understanding of the Milky Way halo by showing that the inner halo ( $<20$  kpc) is composed of both accreted stars from mergers and stars formed in situ within the Milky Way itself, identified through stellar kinematics and chemical abundances. Deason et al (2019) used Gaia proper motions and red giant branch stars to estimate a stellar halo mass of  $\sim 1.4 \times 10^9 M_\odot$ , supporting the idea that a major merger event — Gaia-Enceladus/Sausage — dominates the inner halo structure. Belokurov & Kravtsov (2022) showed that in-situ Milky Way stars can be separated chemically using abundance ratios such as  $[\text{Al}/\text{Fe}]$ , revealing evidence for rapid early disk spin-up followed by a violent merger (“Splash”) phase that dynamically heated the early Milky Way.

## **Lindblad Resonances, Spiral Density Waves**

Yara Beekhuizen & Myrdhin van der Zwet

Spiral structure in galaxies can arise through several mechanisms — including bars, tidal interactions, density waves, and transient instabilities — and spiral arms differ in properties such as pitch angle, number of arms, and lifetime. The quasi-stationary density wave theory proposes that long-lived spiral patterns rotate with a fixed pattern speed and are maintained through swing amplification between Lindblad resonances and corotation, transporting angular momentum through the disk. However, modern simulations discussed by Sellwood suggest that many spiral arms are instead short-lived, recurrent transient structures produced by repeated gravitational instabilities and shear, with spiral patterns continually breaking apart and reforming rather than persisting as rigid long-lived waves.

## **Elliptical Galaxy Scaling Relations**

Ids Nieuwstraten & Philip Stoot

Early-type galaxies are more meaningfully classified by their stellar kinematics than by visual morphology alone, using the observational spin parameter  $\lambda_R$  to separate galaxies into fast rotators and slow rotators. Fast rotators (~85% of ETGs) are generally oblate, regularly rotating systems that retain angular momentum and likely form through dissipative processes or minor mergers, while slow rotators (~15%) are more massive, triaxial systems with complex kinematics such as decoupled cores, likely produced by major mergers that disrupt ordered rotation. The ATLAS 3D survey refined the division between these classes to  $\lambda_R \approx 0.31\epsilon$ , demonstrating that the traditional Hubble classification of elliptical and lenticular galaxies is incomplete because galaxies with similar visual appearance can have very different dynamical structures and evolutionary histories.

## **Gas, Dust in Spiral Galaxies**

Ines Froes Heitor & Margarida Pólvara Fonseca

The PHANGS surveys use high-resolution, multiwavelength observations (ALMA, JWST, HST, VLT) to study how molecular gas, dust, and galactic structure regulate star formation in nearby spiral galaxies on cloud scales of ~50–150 pc. Molecular gas properties strongly depend on galactic environment: gas surface density and turbulence increase toward galaxy centers, barred galaxies show enhanced gas inflow and turbulence, and spiral arms contain denser, more gravitationally bound molecular clouds than inter-arm regions. JWST and ALMA observations further show that filamentary ISM structures are best explained by fragmentation on the 3D turbulent Jeans scale rather than classical 2D Toomre instability scales, implying that gravity dominates over galactic rotation in shaping molecular cloud structure on these small scales.

## **Disk Galaxy Scaling Relations**

Garrett Coey & Nikolaos Ladopoulos

Galaxies follow scaling relations between stellar mass and specific angular momentum ( $j_*$ ), with disk-dominated galaxies having systematically higher angular momentum than elliptical galaxies at the same stellar mass, though both follow a similar power-law relation  $j_* \propto M_*^\alpha$  with  $\alpha \approx 0.6-0.7$ . The Fall & Romanowsky model explains galaxy morphology as a combination of independent disk and bulge components, where disks retain much more angular momentum than bulges, producing an offset of roughly a factor of 5–8 between pure disks and pure ellipticals. Rather than forming discrete classes, galaxies appear to lie on a continuous curved surface in  $(j_*, M_*, \beta_*)$  space, suggesting that morphology can be understood quantitatively through angular momentum and bulge fraction instead of only through traditional Hubble classifications.

## **Mapping Dark Matter via the Jeans Equations**

Lotte Langerak & Leonor Ferro

The Milky Way's dark matter halo can be mapped using stellar kinematics and Jeans equations, which relate observed stellar motions to the underlying gravitational potential and allow acceleration maps of the Galaxy to be reconstructed from survey data such as SDSS and Gaia. The observed accelerations cannot be explained by visible (baryonic) matter alone, providing strong evidence for a dark matter halo whose shape is likely oblate rather than spherical. Independent methods using halo tracers such as K giants and blue horizontal branch stars (Bird et al. 2022) give consistent measurements of the Milky Way's enclosed mass and circular velocity profile, showing that local acceleration-field methods and halo-tracer methods provide complementary constraints on the Galaxy's dark matter distribution.

## **Elliptical Galaxy Scaling Relations**

Dylan Gavran & Jacqueline Beran

The ATLAS 3D project showed that early-type galaxies are better classified by their kinematics than by morphology alone, separating them into fast rotators and slow rotators using the angular momentum parameter  $\lambda_R$ , with fast rotators behaving more like disk galaxies and slow rotators dominating dense cluster environments. Dynamical JAM (Jeans Anisotropic Multi-Gaussian Expansion) models successfully reproduce observed galaxy kinematics and demonstrate that the "tilt" of the Fundamental Plane arises from systematic variations in galaxy mass-to-light ratio rather than simple virial scaling alone. When galaxy mass is used instead of luminosity, galaxies follow a tighter "Mass Plane" much closer to the virial prediction  $R_e \propto \sigma_2 \Sigma_e^{-1}$ , implying that stellar populations and dark matter fractions are key drivers of the observed scaling relations of elliptical galaxies.

## **Milky Way Mass Using Gaia**

Zuzanna Ryduchowska & Erin Corcoran

Gaia and APOGEE data allow precise measurements of the Milky Way's circular velocity curve, which traces how mass is distributed throughout the Galaxy and provides strong evidence for an extended dark matter halo. Both Eilers et al. (2019) and Nitschai et al. (2021) find that the Milky Way rotation curve declines gently with radius rather than remaining perfectly flat, implying that dark matter dominates the Galaxy beyond  $R \gtrsim 14$  kpc while still being centrally concentrated. Dynamical Jeans modeling using millions of Gaia stars further suggests that the Milky Way's dark matter density profile is steeper than a standard NFW profile, indicating that the Galaxy's mass distribution may be more centrally concentrated than previously thought.

## **Cores and Cusps in Elliptical Galaxies**

Arianna Zirotti & Ottavia Zanello

Elliptical galaxies can be divided into two physically distinct classes: “core” galaxies, which show missing central light relative to a Sérsic profile, and “coreless” galaxies, which show extra central light and steeper central brightness profiles. The presentation shows that these two classes follow different Faber–Jackson relations, with core galaxies obeying a much steeper relation ( $L \propto \sigma^{8.3}$ ) than coreless galaxies, implying that massive ellipticals evolve mainly through dissipationless (“dry”) mergers that increase mass without greatly increasing velocity dispersion. The cores themselves are thought to form when merging galaxies bring together supermassive black holes whose binary interaction ejects stars from the center (“core scouring”), producing the observed light deficit and linking core formation directly to SMBH growth and galaxy merger history.

## **Milky Way Satellite Review**

Frederique van Holk & Bente Zandbergen

The “missing satellite problem” arises because cold dark matter simulations predict many more Milky Way satellite galaxies than are actually observed, especially for both very low-mass and very massive dark matter subhaloes. Ultra-faint dwarf galaxies (UFDs) may explain part of the discrepancy at low masses: they are extremely faint, dark-matter dominated, metal poor, and contain mostly ancient stars, making them important relics of the early universe and sensitive probes of dark matter on small scales. At the high-mass end, the “too big to fail” problem shows that simulations predict dense subhaloes massive enough that they should host bright dwarf galaxies, yet no observed Milky Way satellites match their properties, suggesting either missing baryonic physics in the models or a need to revise aspects of the dark matter framework itself.

## **Metallicities & Age-Metallicity Degeneracy**

Ana Tejero & Panagiota Ntova

Stellar population synthesis models suffer from the age–metallicity–dust degeneracy because increasing stellar age, metallicity, or dust content can all redden a galaxy’s spectral energy distribution in similar ways, making it difficult to determine galaxy properties uniquely from photometry alone. This degeneracy can be partially broken using spectroscopy: Balmer absorption lines are especially sensitive to stellar age, while metallicity-sensitive indices such as [MgFe] and Lick indices help constrain chemical abundances more robustly. The presentation also shows that gas-phase metallicities derived from strong emission-line calibrations provide an independent constraint on stellar population metallicity, helping narrow the allowed age–metallicity parameter space and improve stellar population fitting.

## **Using Clustering to Infer Masses**

Daniel Fistos & Dimitra Tsioutsia

Passive galaxies are more strongly clustered than star-forming galaxies across a wide redshift range, implying that passive galaxies typically reside in more massive dark matter haloes and supporting the idea that halo environment plays a major role in quenching star formation. The presentations show evidence for a characteristic halo mass threshold of roughly  $5 \times 10^{12} M_{\odot}$ , above which quenching becomes common, although at high redshift ( $z > 2$ ) some star-forming galaxies are still found in similarly massive haloes, suggesting quenching mechanisms are less efficient early in the universe. Clustering measurements also reveal “downsizing”: at earlier cosmic times star formation occurs preferentially in massive haloes, while at later times star formation shifts toward lower-mass haloes, linking galaxy evolution to the growth of dark matter structure over cosmic time.

## **Metallicities of $z>6$ galaxies with JWST**

Sonal Garg & Andreea Suta

Metallicity is a powerful tracer of galaxy assembly history because it reflects the balance between star formation, gas inflows, metal transport, and outflows, and high-redshift JWST observations show that early galaxies were chemically immature, inhomogeneous, and often far from equilibrium. JWST has revolutionized metallicity measurements at  $z>6$  by enabling direct Te -based methods using faint auroral lines such as [OIII] $\lambda$ 4363, revealing that many early galaxies are more metal-poor than local galaxies of the same mass and that local strong-line calibrations often fail at these redshifts. Observations of the lensed source LAPI suggest an extremely metal-poor ( $12 + \log(\text{O}/\text{H}) < 6.3$ ) and possibly near-pristine system, potentially related to Population III star formation, although multiple physical scenarios can reproduce the observed signatures and its true nature remains uncertain.

## **Mass & Environmental Quenching**

Sanne van Beek & Naomi Schutte

Galaxy quenching occurs through two largely separable mechanisms: **mass quenching**, linked to a galaxy's own stellar mass and star formation activity, and **environmental quenching**, linked to dense environments such as galaxy groups and clusters. Environmental quenching is mostly independent of galaxy mass and cosmic time and is associated with processes like ram-pressure stripping and strangulation of satellite galaxies, whereas mass quenching depends on star formation rate and is likely driven by feedback from supernovae and active galactic nuclei (AGN). Simulations of satellite galaxies further show that after infall into a larger halo, satellites continue forming stars for a delay period before quenching rapidly, implying that galaxy environment affects star formation on characteristic timescales rather than instantaneously.

## **Spectroscopy of Early Quiescent Galaxies in the Universe**

Yifan Li & Gökdeniz Baydar

Massive quiescent galaxies already existed at very high redshift ( $z>3$ , and even  $z\sim 7$ ), implying that some galaxies formed enormous stellar masses and quenched star formation within the first 1–2 billion years after the Big Bang, which strongly challenges standard galaxy formation models. JWST spectroscopy is crucial because photometric selection alone can confuse dusty star-forming galaxies with truly quiescent systems; spectroscopic features such as the Balmer/D4000 break and Lyman break provide direct evidence for evolved stellar populations and accurate redshifts. Observations of galaxies such as RUBIES-UDS-QG- $z7$  suggest that star formation in the early universe was more efficient and quenched earlier than expected, possibly requiring stronger feedback, rapid gas depletion, a top-heavy IMF, or revisions to galaxy evolution models.

## **Stellar Population Analyses**

Susana Carneiro & Andrea Gilibaro

Broadband photometry combined with Bayesian modeling tools such as Prospector and BAGPIPES can accurately recover key galaxy properties — including star formation histories, stellar masses, dust content, and quenching timescales — without requiring full spectroscopy for every galaxy. The presentations show that these models successfully reproduce observed spectral features such as H $\alpha$  and H $\beta$  emission, although challenges remain for complex star formation histories, strong AGN hosts, and high-redshift galaxies. The BAGPIPES analysis concludes that massive galaxies quench through multiple mechanisms, with AGN feedback playing a dominant role, and that more massive galaxies tend to form and stop forming stars earlier in cosmic history.