MVSem WS2021/22 (A. Just, R. Spurzem)

Dynamics of galaxies, star clusters and planetary systems

Abstracts topics J* (Supervisor Just)

Milky Way: J1, J6 (disc); J2, J5 (bar); J4 (halo); J* (open clusters)

Supermassive Black Holes: J8, J9

J1

The GALAH survey and Gaia DR2: Linking ridges, arches, and vertical waves in the kinematics of the Milky Way

Show affiliations

Khanna, Shourya; Sharma, Sanjib; Tepper-Garcia, Thor; Bland-Hawthorn, Joss; Hayden, Michael; Asplund, Martin; Buder, Sven; Chen, Boquan; De Silva, Gayandhi M.; Freeman, Ken C.; Kos, Janez; Lewis, Geraint F.; Lin, Jane; Martell, Sarah L.; Simpson, Jeffrey D.; Nordlander, Thomas; Stello, Dennis; Ting, Yuan-Sen; Zucker, Daniel B.; Zwitter, Tomaž

Gaia DR2 has revealed new small-scale and large-scale patterns in the phase-space distribution of stars in the Milky Way. In cylindrical Galactic coordinates (R,φ ,z), ridge-like structures can be seen in the (R,V_φ) plane and asymmetric arch-like structures in the (V_R,V_φ) plane. We show that the ridges are also clearly present when the third dimension of the (R,V_φ) plane is represented by < z >, < V_z >, < V_R >, <[Fe/H]>, and < [α /Fe]>. The maps suggest that stars along the ridges lie preferentially close to the Galactic mid-plane (|z|< 0.2 kpc), and have metallicity and α elemental abundance similar to that of the Sun. We show that phase mixing of disrupting spiral arms can generate both the ridges and the arches. It also generates discrete groupings in orbital energy - the ridges and arches are simply surfaces of constant energy. We identify eight distinct ridges in the Gaia DR2 data: six of them have constant energy while two have constant angular momentum. Given that the signature is strongest for stars close to the plane, the presence of ridges in < z > and < V_z > suggests a coupling between planar and vertical directions. We demonstrate, using N-body simulations that such coupling can be generated both in isolated discs and in discs perturbed by an orbiting satellite like the Sagittarius dwarf galaxy.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 489, Issue 4, p.4962-4979

J2

The pattern speed of the Milky Way bar from transverse velocities

Show affiliations

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We use the continuity equation to derive a method for measuring the pattern speed of the Milky Way's bar/bulge from proper motion data. The method has minimal assumptions but requires complete coverage of the non-axisymmetric component in two of the three Galactic coordinates. We apply our method to the proper motion data from a combination of Gaia DR2 and VISTA Variables in the Via Lactea (VVV) to measure the pattern speed of the bar as Ω _p=(41± 3) km s^{-1 kpc^{-1}} (where the error is statistical). This puts the corotation radius at (5.7± 0.4) kpc, under the assumptions of the standard peculiar motion of the Sun and the absence of non-axisymmetric streaming in the Solar neighbourhood. The obtained result uses only data on the near side of the bar which produces consistent measurements of the distance and velocity of the centre of the Galaxy. Addition of the data on the far side of the bar pulls the pattern speed down to Ω _p=(31± 1) km s^{-1 kpc^{-1}} but requires a lower transverse velocity for the Galactic centre than observed. This suggests systematics of 5-10 km s^{-1kpc^{-1}} dominate the uncertainty. We demonstrate using a dynamically formed bar/bulge simulation that even with the limited field of view of the VVV survey our method robustly recovers the pattern speed.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 488, Issue 4, p.4552-4564

J3

The HESTIA project: simulations of the Local Group

Show affiliations | Show all authors

Libeskind, Noam I. ; Carlesi, Edoardo ; Grand, Robert J. J. ; Khalatyan, Arman ; Knebe, Alexander ; Pakmor, Ruediger ; Pilipenko, Sergey ; Pawlowski, Marcel S. ; Sparre, Martin ; Tempel, Elmo ; Wang, Peng ; Courtois, Hélène M. ; Gottlöber, Stefan ; Hoffman, Yehuda ; Minchev, Ivan ; Pfrommer, Christoph ; Sorce, Jenny G. ; Springel, Volker ; Steinmetz, Matthias ; Tully, R. Brent ; ...

We present the HESTIA simulation suite: High-resolutions Environmental Simulations of The Immediate Area, a set of cosmological simulations of the Local Group. Initial conditions constrained by the observed peculiar velocity of nearby galaxies are employed to accurately simulate the local cosmography. Halo pairs that resemble the Local Group are found in low resolutions constrained, dark matter only simulations, and selected for higher resolution magneto hydrodynamic simulation using the AREPO code. Baryonic physics follows the AURIGA model of galaxy formation. The simulations contain a high-resolution region of 3-5 Mpc in radius from the Local Group mid-point embedded in the correct cosmographic landscape. Within this region, a simulated Local Group consisting of a Milky Way and Andromeda like galaxy forms, whose description is in excellent agreement with observations. The simulated Local Group galaxies resemble the Milky Way and Andromeda in terms of their halo mass, mass ratio, stellar disc mass, morphology separation, relative velocity, rotation curves, bulge-disc morphology, satellite galaxy stellar mass function, satellite radial distribution, and in some cases, the presence of a Magellanic cloud like object. Because these simulations properly model the Local Group in their cosmographic context, they provide a testing ground for questions where environment is thought to play an important role.

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Pub Date: October 2020

J4

Evidence of a population of dark subhaloes from Gaia and Pan-STARRS observations of the GD-1 stream

Show affiliations

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New data from the Gaia satellite, when combined with accurate photometry from the Pan-STARRS survey, allow us to accurately estimate the properties of the GD-1 stream. Here, we analyse the stellar density variations in the GD-1 stream and show that they cannot be due to known baryonic structures such as giant molecular clouds, globular clusters, or the Milky Way's bar or spiral arms. A joint analysis of the GD-1 and Pal 5 streams instead requires a population of dark substructures with masses $\approx 10^7$- $10^9\ \mathrm{M}_\odot$. We infer a total abundance of dark subhaloes normalized to standard cold dark matter $n_{\mathrm{sub}}/n_{\mathrm{sub,CDM}} = 0.4^{+0.3}_{-0.2}$ (68 per cent), which corresponds to a mass fraction contained in the subhaloes $f_{\mathrm{sub}} = 0.14^{+0.11}_{-0.07}\ \mathrm{per\ cent}$, compatible with the predictions of hydrodynamical simulation of cold dark matter with baryons.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 2, pp.2364-2380

J5

Mapping the tilt of the Milky Way bulge velocity ellipsoids with ARGOS and Gaia DR2

Show affiliations

Simion, Iulia T.; Shen, Juntai; Koposov, Sergey E.; Ness, Melissa; Freeman, Kenneth; Bland-Hawthorn, Joss; Lewis, Geraint F.

Until the recent advent of Gaia Data Release 2 (DR2) and deep multi-object spectroscopy, it has been difficult to obtain 6D phase space information for large numbers of stars beyond 4 kpc, in particular towards the Galactic Centre, where dust and crowding are significant. We combine line-of-sight velocities from the Abundances and Radial velocity Galactic Origins Survey (ARGOS) with proper motions from Gaia DR2 to obtain a sample of ~7000 red clump stars with 3D velocities. We perform a large-scale stellar kinematics study of the Milky Way bulge to characterize the bulge velocity ellipsoids in 20 fields. The tilt of the major-axis of the velocity ellipsoid in the radial-longitudinal velocity plane, or vertex deviation, is characteristic of non-axisymmetric systems and a significant tilt is a robust indicator of non-axisymmetry or bar presence. We compare the observations to the predicted kinematics of an N-body boxy-bulge model formed from dynamical instabilities. In the model, the l_v values are strongly correlated with the angle (α) between the bulge major-axis and the Sun-Galactic centre line of sight. We use a maximum likelihood method to obtain an independent measurement of α, from bulge stellar kinematics alone, performing a robust error analysis. The most likely value of α given our model is α = (29 ± 3)°, with an additional systematic uncertainty due to comparison with one specific model. In Baade's window, the metal-rich stars display a larger vertex deviation (l_v = -40°) than the metal-poor stars (l_v = 10°) but we do not detect significant l_v-metallicity trends in the other fields.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 2, pp.1740-1752

J6

Co-formation of the thin and thick discs revealed by APOGEE-DR16 and Gaia-DR2

Show affiliations

Beraldo e Silva, Leandro; Debattista, Victor P.; Nidever, David; Amarante, João A. S.; Garver, Bethany

Since thin disc stars are younger than thick disc stars on average, the thin disc is predicted by some models to start forming after the thick disc had formed, around 10 Gyr ago. Accordingly, no significant old thin disc population should exist. Using 6D coordinates from Gaia-DR2 and age estimates from Sanders & Das, we select ~24 000 old stars ($\tau > 10\,\mathrm{Gyr}$, with uncertainties $\lesssim 15$ per cent) within $2\,\mathrm{kpc}$ from the Sun (full sample). A cross-match with APOGEE-DR16 (~1000 stars) reveals comparable fractions of old chemically defined thin/thick disc stars. We show that the full sample pericentre radius (r_{per}) distribution has three peaks, one associated with the stellar halo and the other two having contributions from the thin/thick discs. Using a high-resolution N-body + SPH simulation, we demonstrate that one peak, at $r_{\mathrm{per}} \approx 7.1\,\mathrm{kpc}$, is produced by stars from both discs that were born in the inner Galaxy and migrated to the Solar Neighbourhood. In the Solar Neighbourhood, ~1/2 (~1/3) of the old thin (thick) disc stars are classified as migrators. Our results suggest that thin/thick discs are affected differently by radial migration inasmuch as they have different eccentricity distributions, regardless of vertical scale heights. We interpret the existence of a significant old thin disc population as evidence for an early co-formation of thin/thick discs, arguing that clump instabilities in the early disc offer a compelling explanation for the observed trends.

Publication: Monthly Notices of the Royal Astronomical Society, Volume 502, Issue 1, pp.260-272

J7

The Effect of Star-Disk Interactions on Highly Eccentric Stellar Orbits in Active Galactic Nuclei: A Disk Loss Cone and Implications for Stellar Tidal Disruption Events

Show affiliations

MacLeod, Morgan ; Lin, Douglas N. C.

Galactic center black holes appear to be nearly universally surrounded by dense stellar clusters. When these black holes go through an active accretion phase, the multiple components of the accretion disk, stellar cluster, and black hole system all coexist. We analyze the effect of drag forces on highly eccentric stellar orbits incurred as stars puncture through the disk plane. Disk crossings dissipate orbital energy, drawing eccentric stars into more circular orbits. For high surface density disks, such as those found around black holes accreting near the Eddington mass accretion limit, the magnitude of this energy dissipation can be larger than the mean scatterings that stars receive by two-body relaxation. One implication of this is the presence of a disk "loss cone" for highly eccentric stellar orbits where the dissipation from disk interaction outweighs scatter via two-body relaxation. The disk loss cone is larger than the tidal disruption loss cone for near-Eddington black hole accretion rates. Stellar orbits within the disk loss cone are lost from the overall cluster as stellar orbits are circularized and stars are potentially ablated by their high-velocity impacts with the disk. We find, however, that the presence of the disk loss cone has a minimal effect on the overall rate of stellar tidal disruptions. Stars are still efficiently fed to the black hole from more-distant stellar orbits that receive large-enough per-orbit scatter to jump over the disk loss cone and end up tidally disrupted.

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J8

Formation of the largest galactic cores through binary scouring and gravitational wave recoil

Show affiliations

Nasim, Imran Tariq ; Gualandris, Alessia ; Read, Justin I. ; Antonini, Fabio ; Dehnen, Walter ; Delorme, Maxime

Massive elliptical galaxies are typically observed to have central cores in their projected radial light profiles. Such cores have long been thought to form through 'binary scouring' as supermassive black holes (SMBHs), brought in through mergers, form a hard binary and eject stars from the galactic centre. However, the most massive cores, like the $\sim 3\,\mathrm{kpc}$ core in A2261-BCG, remain challenging to explain in this way. In this paper, we run a suite of dry galaxy merger simulations to explore three different scenarios for central core formation in massive elliptical galaxies: 'binary scouring', 'tidal deposition', and 'gravitational wave (GW) induced recoil'. Using the GRIFFIN code, we self-consistently model the stars, dark matter, and SMBHs in our merging galaxies, following the SMBH dynamics through to the formation of a hard binary. We find that we can only explain the large surface brightness core of A2261-BCG with a combination of a major merger that produces a small $\sim 1\,\mathrm{kpc}$ core through binary scouring, followed by the subsequent GW recoil of its SMBH that acts to grow the core size. Key predictions of this scenario are an offset SMBH surrounded by a compact cluster of bound stars and a non-divergent central density profile. We show that the bright 'knots' observed in the core region of A2261-BCG are best explained as stalled perturbers resulting from minor mergers, though the brightest may also represent ejected SMBHs surrounded by a stellar cloak of bound stars.

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J9

Formation of counter-rotating and highly eccentric massive black hole binaries in galaxy mergers

Show affiliations

Nasim, Imran; Petrovich, Cristobal; Nasim, Adam; Dosopoulou, Fani; Antonini, Fabio

Supermassive black hole (SMBH) binaries represent the main target for missions such as the Laser Interferometer Space Antenna and Pulsar Timing Arrays. The understanding of their dynamical evolution prior to coalescence is therefore crucial to improving detection strategies and for the astrophysical interpretation of the gravitational wave data. In this paper, we use high-resolution N-body simulations to model the merger of two equal-mass galaxies hosting a central SMBH. In our models, all binaries are initially prograde with respect to the galaxy sense of rotation. But, binaries that form with a high eccentricity, $e \gtrsim 0.7$, quickly reverse their sense of rotation and become almost perfectly retrograde at the moment of binary formation. The evolution of these binaries proceeds towards larger eccentricities, as expected for a binary hardening in a counter-rotating stellar distribution. Binaries that form with lower eccentricities remain prograde and at comparatively low eccentricities. We study the origin of the orbital flip by using an analytical model that describes the early stages of binary evolution. This model indicates that the orbital plane flip is due to the torque from the triaxial background mass distribution that naturally arises from the galactic merger process. Our results imply the existence of a population of SMBH binaries with a high eccentricity and could have significant implications for the detection of the gravitational wave signal emitted by these systems.

Publication: Monthly Notices of the Royal Astronomical Society, Advance Access

J10

J11