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INVESTIGATION OF THE DISTRIBUTION OF DARK MATTER IN THE GALACTIC STRUCTURE

Abstract. We investigate the formation of disk-bulge-halo systems by including the basic components in the theory of the formation of galaxy. The purpose of this article is to investigate the distribution of dark matter in the Galactic structure and examine the impact of subhalo on the halo and the disk components to be included in one simple scenario of the formation of the galaxy. We investigate several important characteristics of galaxies, such as coordinates, position, velocity and masses, to form a stable component of the galaxy. We search for the parameters and physical processes that determine the subhalo-halo ratio, and thus largely explain the origin of the collision or other obstacles through the galactic halo. The spread over the radial velocities of the halo, combined with the spread of obstacles in the distances from the center of the galaxy, may explain the observed spread over the properties of the disk and the bulge. The paper uses data from Auriga_proper_unit - a data file of the main galaxies in Aurig-6 before free run. The units of data length used in Gadget2, such as coordinates and density, are converted from Mpc to kpc and also include star_age.

Key words: dark matter (DM), radial velocity, Galactocentric coordinate system.

I. Introduction

One of the most compelling puzzles in present day astronomy is the question how galaxies formed. In particular, we need to understand the wide variety of sizes, masses and morphologies of galaxies observed, as well as their coordinates, position, velocity and masses. The main morphological parameter that sets the classification of galaxies in the (revised) Hubble diagram is the disk-to-bulge ratio. Disk dominated systems such as spirals are believed to have formed by cooling of the baryonic matter inside a virialized dark halo. As the gas cools, its specific angular velocity is conserved, and the amount of angular velocity of the dark halo thus determines the size of the disk [1].

We envision an inside-out formation scenario for the bulge. It is assumed that the bulge forms out of the low-angular velocity material in the halo, which cools and tries to settle into a small, compact disk. Such disks are however unstable, and we assume here that this instability, coupled with the continuous supply of new layers of baryonic matter that cool and collapse, forms the bulge. This inside-out bulge formation is self-regulated in that the bulge grows until it is massive enough to allow the remaining gas to form a stable disk component. We do not describe the bulge formation in any detail but merely use empirical relations of the characteristic structural parameters of bulges and ellipticals to describe the end result of the formation process as a realistic galaxy. We use this simple formation scenario to investigate the predicted disk-to-bulge ratios and disk scale-lengths as a function of the halo angular velocity, and as a function of formation redshift and cosmology.

II Observational results

In this paper we use data from Auriga_proper_unit - a data file of the main galaxies in Aurig-6 before free run. The units of data length used in Gadget2, such as coordinates and density, are converted from Mpc to kpc and also include star_age. Snapshot_000 is the initial condition of collision simulation, snapshot_029 is a snapshot when the distance between the satellite is about 10 kpc, snapshot 032 is a snapshot when the distance to the satellite is about 5 kpc, and snapshot when the distance to the satellite is about 1 kpc.

In each snapshot file, there are 6 types of particles: gas (type 0), dark matter (type 1), disk (type 2), bulge (type 3), star (type 4; also include wind particles) and black hole (type 5). Gas particles only exist in the host galaxy. Dark matter particles exist in both the host and the satellite: those from the host with particle ID <= 2701512 and the satellite with particle ID > 2701512. Disk and bulge particles only exist in the satellite – they together form its stellar component. Star particles and black hole particle only exist in the host. In total, there are 667454 gas particles, 2371259 dark matter particles (2034059 in the host and 337200 in the satellite), 100000 disk particles, 25999 bulge particles, 1575406 star particles and 1 black hole.

The snapshot files only contain the coordinates, the velocities, the particle IDs, the potentials and the masses (solar mass), and for gas particles, the densities and several other parameters. The units of these data are the same as Illustris, with Hubble parameter h=0.6777. If you want to read the stellar age, metallicity or other fields of particles from the host galaxy provided by Auriga, please refer to the file 'Auriga_proper_units.hdf5'. Note that in this file, I have changed the unit of length of all the data fields that also exist in the snapshot files to kpc/h, while other data fields are unchanged, because this file is used as an initial condition file for my simulation. So when you use it, be careful of the units. For your convenience, here is a free software that can read and display data stored in hdf5 files: https://www.hdfgroup.org/downloads/hdfview/.

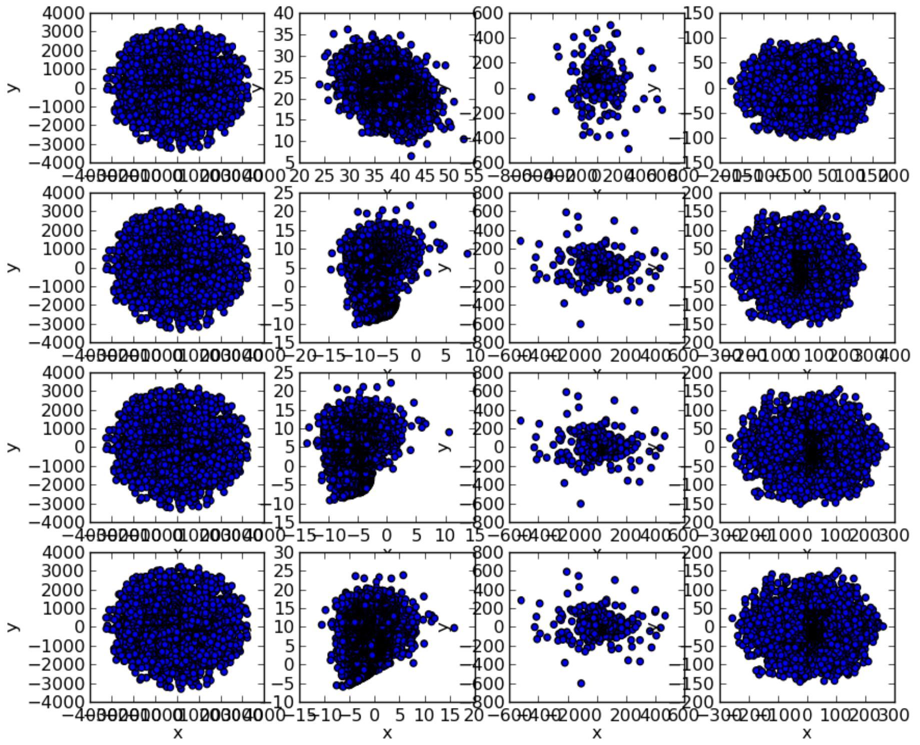

Figure 1 - Distribution of stars in the horizontal coordinate plane. The panels are for stars in our sample located at initial conditions of collision simulation, satellite data from the disk about 1kpc, 5kpc and 10 kpc. a) The first column represents two-dimensional histogram in bins of $D_x = 0.1kpc$ and $D_y = 0.1kpc$ for halo, with the darkness being proportional to the number of counts.; b) The second column represents plane coloured as a two-dimensional histogram of disk; c) same as for bulge; d) but for subhalo

Figure 1 shows the distribution of particles with respect to the center of the Galaxy for the he units of data length used in Gadget2. Snapshot_000 is the initial condition of collision simulation, snapshot_029 is a snapshot when the distance between the satellite is about 10 kpc, snapshot 032 is a snapshot when the distance to the satellite is about 5 kpc, and snapshot when the distance to the satellite is about 1 kpc. In which orbital evolution and masses are consistent with previous models. This model can reproduce the observed location and the LA reasonably well and shows bifurcated structures, which appears to be consistent with observations.

III Distances and Geometry

Remind that galactic coordinates system this is the system with origin placed on the Sun and extended through the center of Galaxy. Its plane coincides with the plane of Galaxy dick [2]. In disk. In doing this, its latitude b is measured from galaxies plane to an object and takes magnitudes from −90° up to +90°. Galactic longitude l is measured at the Galaxy plane from the baseline connected the Sun and galactic center up to the baseline connected the Sun and object. Counting directs to the same way that the right ascension in the second equatorial coordinates. Therefore the galactic longitude puts i limits from 0 ° up to 360°. The position of object in galactic coordinates describes by matrix expression

$$x = r\cos\alpha\cos\delta$$
$$y = r\sin\alpha\cos\delta$$
$$z = r\sin\delta$$

The longitude-velocity distribution (Figs. 1b and 2b) is approximately sinusoidal and that of the latitude-velocity distribution (Figs. 1c and 2c) follows a cosine law. In consequence, the radial velocity momentum distribution of the LMCs can be represented by the following formula:

$$L_x = y \cdot v_z + z \cdot v_y$$
$$L_y = x \cdot v_z + z \cdot v_x$$
$$L_z = x \cdot v_y + y \cdot v_x$$

We assume that we start with a 3D position in the ICRS reference frame: a Right Ascension, Declination, and heliocentric distance (α, β, r). We can convert this to a Cartesian position using the standard transformation from Cartesian to spherical coordinates:

$$r = \sqrt{x^2 + y^2 + z^2}$$

where $v_r \approx 200 - 230 km/\sec$. This distribution law admits a simple interpretation (or “inversion”), namely: it reflects a roughly uniform flow of HVCs that comes approximately from galactic coordinates $l_0 = 90^0$ and $b_0 = 0^0$ and that encloses the whole Galaxy. If $v_{\square}$ and v_r are the velocities of the Sun and of the LMC flow with respect to the Galactic center respectively, the radial velocities of the LMCs with respect to the LSR are given by

$$v_r = \frac{x \cdot v_x + y \cdot v_y + z \cdot v_z}{r}$$

This model is therefore one of the successful models in the present study. The physical properties can be well reproduced by the present models, as long as we adopt the velocity type. However, models with the velocity type cannot reproduce well the observed locations. The physical properties in models with different velocity types are briefly discussed in Figure 2.

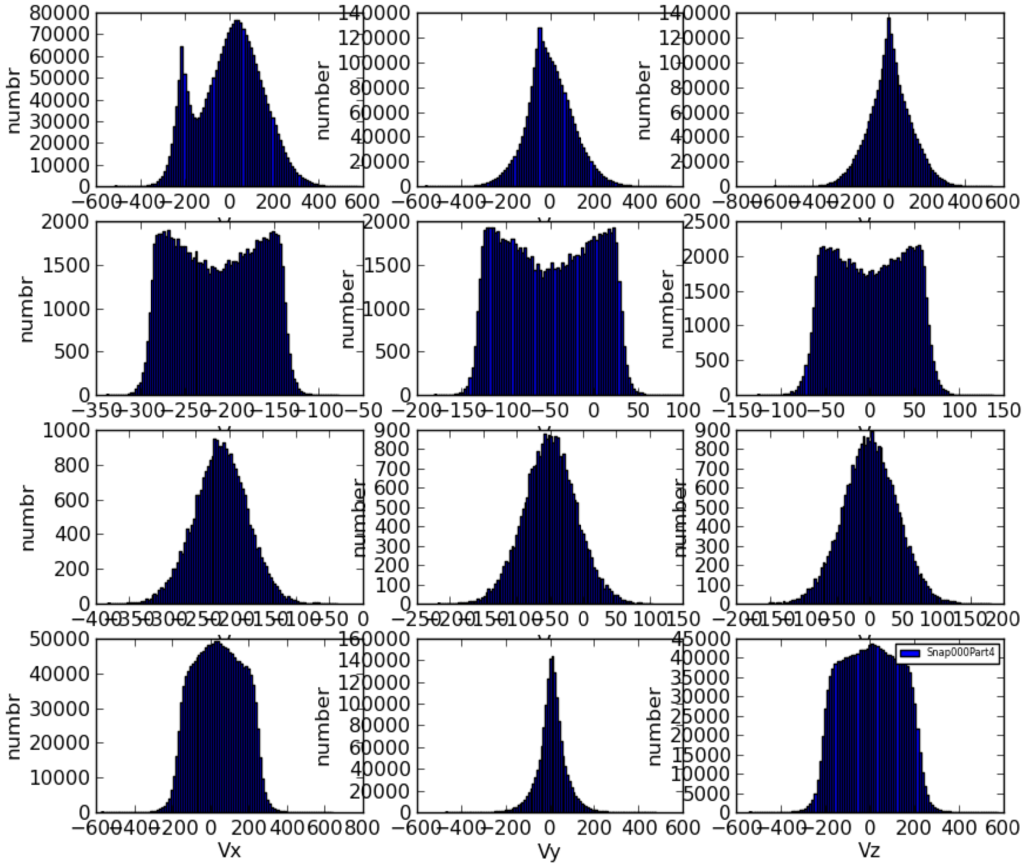

Figure 2 - Distribution of velocity in the horizontal coordinate plane. The panels are for stars in our sample located at the satellite data from the disk about 1kpc, from left to right is velocity in v_x, v_y, v_z coordinate direction, from top to bottom stellar halo, disk, bulge and dark halo

IV Observational results

We explore the parameter space in terms of the coordinates, position, velocity and masses, and the bar pattern speed. Besides, we run control simulations without satellite for both 2-d and 3-d configurations. All simulations were run for 8-12 kpc from the sun, an order of magnitude longer than the satellite merger timescale. The models are listed in Table 1, showing also the amount of mass that reaches the inner 8 kpc (a generous definition of the central region).

Figure 6 shows the distribution of the star velocity in the horizontal coordinate plane for the its units of data length used in Gadget2. Snapshot_000 is the initial condition of collision simulation, snapshot_029 is a snapshot when the distance between the satellite is about 10 kpc, snapshot 032 is a snapshot when the distance to the satellite is about 5 kpc, and snapshot when the distance to the satellite is about 1 kpc. In which orbital evolution and masses are consistent with previous models. This model can reproduce the observed location and the LA reasonably well and shows bifurcated structures, which appears to be consistent with observations.

From the parameter astrometric solution and line-of-sight velocities of these particles, we derived distances (as $1/\varpi$), positions and velocities in the cylindrical Galactic reference frame, that is ($R, \varphi, Z, V_R, V_\varphi, V_Z$). For convenience, we took φ positive in the direction of Galactic rotation and with origin at the line Sun-Galactic Centre. For these transformations, we adopted a vertical distance of the Sun above the plane of 8 kpc, a distance of the Sun to the Galactic centre of 8.34 kpc and a circular velocity at the Sun radius of $V_c\left(R_\odot\right) = 240\ km \cdot s^{-1}$. We assumed a peculiar velocity of the Sun with respect of the Local Standard of Rest of $\left(U_\odot, V_\odot, W_\odot\right) = \left(11.1, 12.24, 7.25\right)\ km \cdot s^{-1}$. Our choice of values give

$\left(V_c\left(R_\odot\right)+V_\odot\right)/R_\odot = 30.2 km\cdot s^{-1}kpc^{-1}$, which is compatible with the reflex motion of galaxy. To derive the uncertainties in these coordinates, we propagate the full covariance matrix. The median errors in the V_R, V_φ, V_Z velocities are 1.4, 1.5, and $1.0 km\cdot s^{-1}$, respectively, and 80% of dark matter particles have errors smaller than 3.3, 3.7, $2.2 km\cdot s^{-1}$ in these velocities. The positions in the Cartesian coordinates X-Y and X-Z of the sample are shown in Extended Data Fig.1.

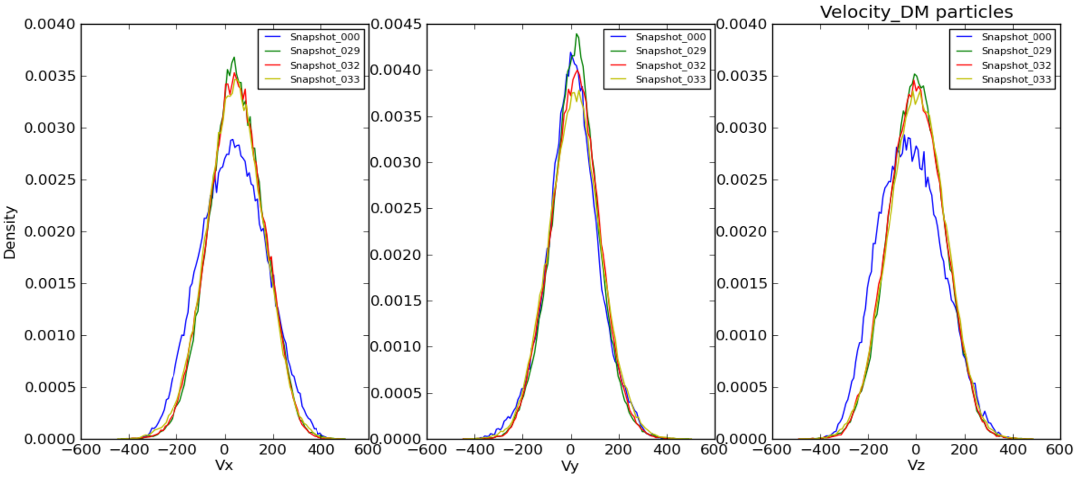

Figure 12 - Distribution of radial velocities (v_x, v_y, v_z) of the dark matter particles within 5 kpc of the sun in various snapshots with the center of the main galaxy as the coordinate system. The position of the sun is x=8kpc

Given an initial distribution of stars $Z(t=0)$ and $V_Z(t=0)$, the vertical amplitudes of the orbits can be derived through the conservation of energy and using the fact that at the vertical turn-around point of the orbit $(V_Z=0)$, the (vertical) kinetic energy is null. Assuming that stars follow a simple harmonic oscillation (but with different frequencies), the movement of the stars with time is described by Eq. (3) where the initial phase of the stars $\varphi 0 \equiv \varphi(t=0)$ is obtained from the initial distribution of Z and V_Z and the corresponding amplitudes.

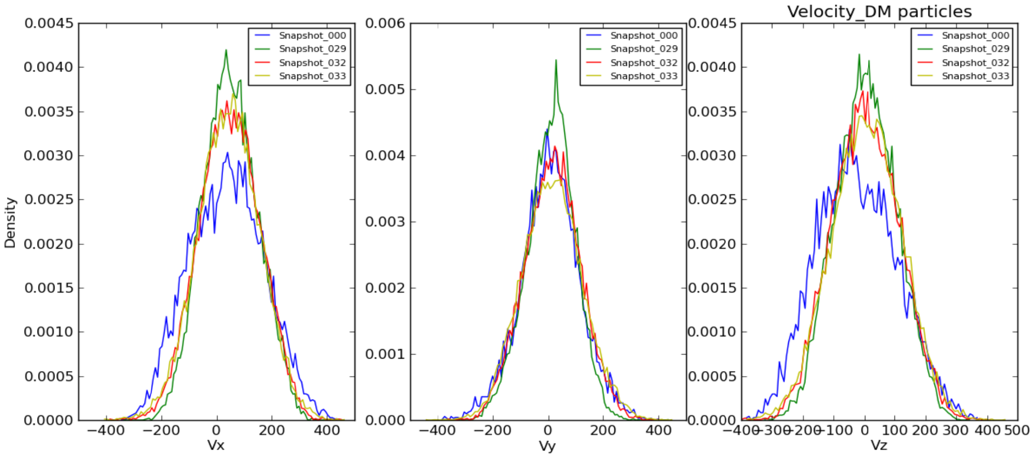

Figure 13 - Distribution of radial velocities (v_x, v_y, v_z) of the dark matter particles within 2 kpc of the sun in various snapshots with the center of the main galaxy as the coordinate system

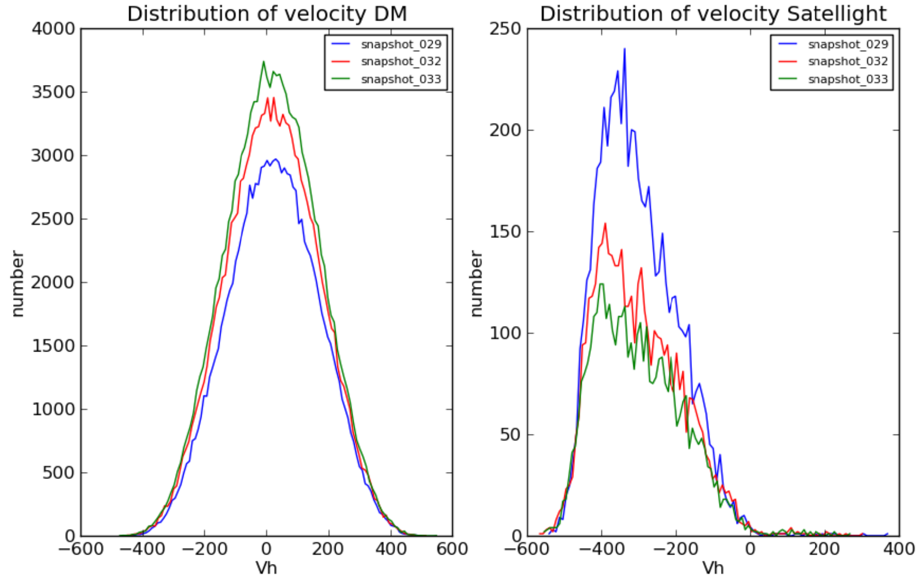

Figure 14 - Distribution of heliocentric velocities (v_h) obtained for the solar reflex motion using the circular motion of the LSR at the Sun and Sun's peculiar velocity of the satellite and dark matter and satellite particles within 2 kpc of the sun in various snapshots with the center of the main galaxy as the coordinate system

For part of our study, we selected from our sample the 2371259 dark matter particles located in the solar Galactic cylindrical ring, that is with Galactocentric radius $8.24 < R < 8.44\ kpc$ (dotted lines in Extended Data Fig.2). For this selection, the median errors in the V_R, V_φ, V_Z velocities are 0.5, 0.8, and $0.6\ km \cdot s^{-1}$, respectively, and 80% of dark matter particles have errors smaller than in these velocities 1.1, 2.0, 1.3 $km \cdot s^{-1}$. We note that the velocity uncertainties are significantly smaller than the sizes of the substructures detected and that, together with the number of dark matter particles in our samples, this is what made possible their detection. Although there are some correlations between the astrometric Gaia observables, these are not responsible for the correlations and substructure seen in our phase space plots. This is because the particles in our sample are distributed through all sky directions, and the phase space coordinates come from combinations of astrometric measurements and radial velocities, in different contributions depending on the direction on the sky. Besides, the astrometric correlations for our sample are small (smaller than 0.2 in their absolute value for more than 50% of dark matter particles) and this, combined with the small errors, makes their contribution nonsignificant.

Alternatively, we used the mode of the posterior distribution and a prior of an exponentially decreasing density of dark matter particles with a scale length of 8 kpc from the center of the Milky Way. We found the differences between this distance determination and the inverse of the parallax are between -2% and 0.6% for 90% of the 6,376,803 dark matter particles for the different snapshots. Therefore, the difference in velocity presented here is in the change of v_y and v_z. We can see that in the initial condition of snapshot_000, the dark matter particles move according to the original trajectory, but when the satellite passes through the galaxies, the velocity of the dark matter particles in the snapshot-029, snapshot-032 and snapshot-033 changes subtly. When observing the running trajectory on the side of the v_x, we cannot observe the large parallax error due to the deviation of the line of sight direction, but for velocity v_y, v_z due to the longitudinal observation, when the satellite passes through the galaxies, we can find the radial velocity of dark matter particles has changed. For these dark matter particles, the estimator of the parallax inverse will produce a non-physical distance.

V. Models for the vertical phase mixing of dark matter density

We first reproduced the spiral shape observed in the $Z - V_Z$ plane with the Gaia DR2 data by using a simple toy model. Often the classic harmonic oscillator is employed to describe the vertical movement of dark matter particles in galaxy disks under the epicyclic theory. However, in this approximation, which is valid only for very small amplitude orbits for which the potential changes little vertically, stars have the same vertical oscillatory frequency ν and there is no phase mixing, unless orbits at different guiding radius, thus with different frequencies, are considered [3]. Instead, we used an anharmonic oscillator with the potential. We took the coefficients $\alpha_0, \alpha_1, \alpha_2$ corresponding to the expansion for small Z, derived elsewhere, with values of $a = 6.5kpc,\ b = 0.26kpc,\ M = 10^{11} M_{\odot}$. These coefficients α depend on Galactocentric radius R .

The phase space evolution described above is shown in the top row of Extended Data Fig.3. Initially, the particles followed a Gaussian distribution in $Z(t=0)$ and $V_Z(t=0)$ with mean and dispersion of $-0.1kpc$ and $0.04kpc$, and $-2km \cdot s^{-1}$ and $1km \cdot s^{-1}$, respectively. We located all particles at the same Galactocentric radius $R = 8.5kpc$, and thus, they all move under the same functional form of the vertical potential. The initial conditions are shown in Extended Data Fig. 3a, where we colour-coded the particles according to their period. Following Eq. (3), each star follows a clockwise rotation in the $Z - V_Z$ plane. However, they do it at a different angular speed: stars with smaller period located at the closer distances from the mid-plane $(Z = 0)$ revolve faster than those located at the largest distances from the mid-plane. The whole range of frequencies is what creates, therefore, the spiral shape. Extended Data Fig.3b shows the evolution of the system for three initial phases of the time evolution when the spiral shape begins to form. Extended Data Fig.3c shows the spiral shape after $1000Myr$ of evolution.

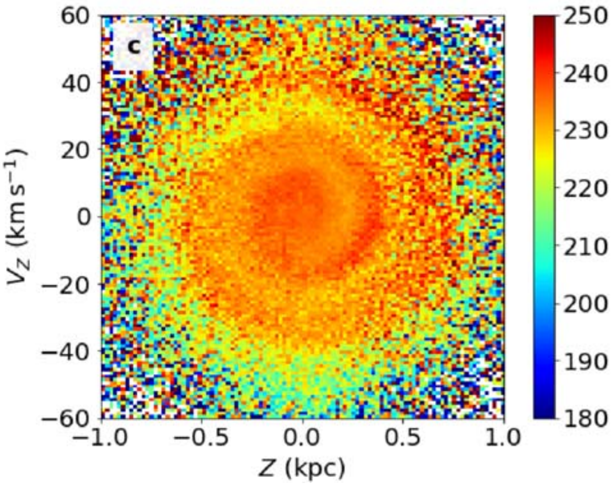

Figure 7 - Distribution of stars in the horizontal coordinate plane within 2 kpc of the sun. The panels are for stars in our sample located at initial conditions of collision simulation, satellite data from the disk about 10kpc and 1 kpc. a) The first column represents two-dimensional histogram in bins of $D_x = 0.1kpc$ and $D_y = 0.1kpc$ for halo, with the darkness being proportional to the number of counts.; b) The second column represents plane coloured as a two-dimensional histogram of disk

In the Gaia data, we do not see a thin spiral but a thick one, with many of the stars in the volume participating in it [4]. A similar effect was reached with our toy model when we included particles at different radius for which the vertical potential changes and the range of amplitudes/frequencies also changes. In Extended Data Fig.3 (bottom row) we let the same system evolve as in the top row but starting with initial radius following a skewed normal distribution, which creates a density decreasing with radius as in galaxy disks, with skewness of 10, location parameter of $8.4kpc$ and scale parameter of $0.2kpc$. The spiral structure is now thickened similarly to the data, with higher density of stars at the leading edge of the spiral.

To estimate the time of the phase mixing event from the spiral seen in the Gaia data (Fig.1) using Eq. (4), we needed to locate two consecutive turns of the spiral and estimate their vertical frequencies from their amplitudes and mean radius. For this, we used Extended Data Fig.5 which has been colour coded as a function of median guiding radius. This was approximated as $R_g \sim \frac{V_\varphi R_\odot}{V_c\left(R_\odot\right)}$, under the hypothesis of a flat rotation curve, where we used the values of $R_\odot = 8.34kpc$ and $V_c\left(R_\odot\right) = 240km \cdot s^{-1}$ assumed in the coordinate transformation of the data. In this panel we see that the density gradient across the spiral shape is created by stars with different guiding radius that arrive at the solar neighbourhood due to their different amplitudes of (horizontal) radial oscillation.

Applying this method to several streams at a variety of Galactocentric distances and orientations with respect to the Galactic disk would allow us to build a comprehensive map of the distribution of DM in the halo – its shape, density profile, and orientation [5]. In the last few years evidence for dSph galaxy tidal tails has been discovered around Milky Way satellites at very large Galactic radii, and other distant streams are known. With SIM Lite, such distant streams can be used to trace the Galactic mass distribution as far out as the virial radius with an unprecedented level of detail and accuracy. This would provide the very first, accurate three-dimensional observational assessment of the shape and extent of a galactic-scale DM halo.

We can begin to understand their spatial distribution and kinematics in stratified formation scenarios as satellite galaxies traverse the main cluster of galaxies in association with the ability to cause tidal flows in the CDR clumps [6]. The global effect has been proposed that re-ionization in this era strongly influences the initial motion trajectory of dark matter particles, directly reaching the tidal flow of a larger mass scale, equivalent to the scale of the Magellanic Cloud [7]. Therefore, the dark matter particle composition and globular clusters of our protogalaxies are distributed in the center of the cluster of galaxies. Since the dark matter particles are too hot to cool efficiently, thousands of similar mass halos are generated during the movement of the original running track. This situation can explain the problem of uneven distribution of dark matter particles caused by satellite galaxies crossing the main galaxies, observing the uneven distribution of density among the thousands of DM substructures visible in Figure 8 at the center of the main galaxies.

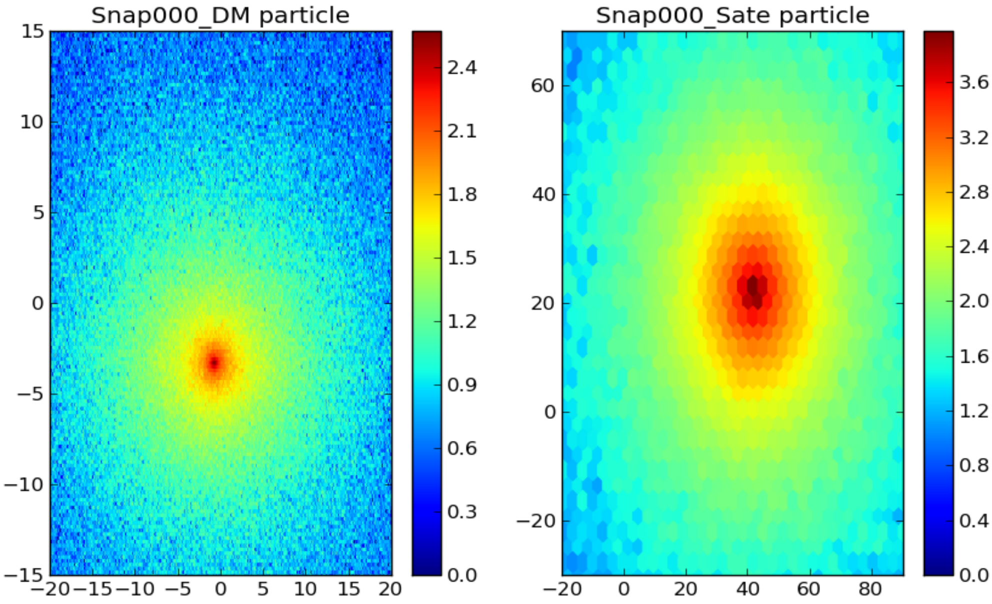

Figure 8 - The density distribution of projections in the Z direction drawn by the particle ID to distinguish the two galaxies (satellite particles and dark matter particles for snapshot_000). The density unit is $(kpc/h)^{-2}$

Most of the rare, luminous protogalaxies rapidly merge together, their stellar contents and DM becoming smoothly distributed and forming the Galactic stellar and dark halo (Figure 4-8). The metal-poor globular clusters and old halo stars formed in these early Milky Way structures become tracers of this early evolutionary phase, centrally concentrated and naturally reproducing the observed steep number density fall off with radius. The most outlying substructures fall in late and survive to the present day as our familiar satellite galaxies. The observed radial velocity dispersion profile and the local radial velocity anisotropy of Milky Way halo stars are successfully reproduced in this model, but only with full three-dimensional orbits can we be assured that the orbital shapes are truly consistent with predictions.

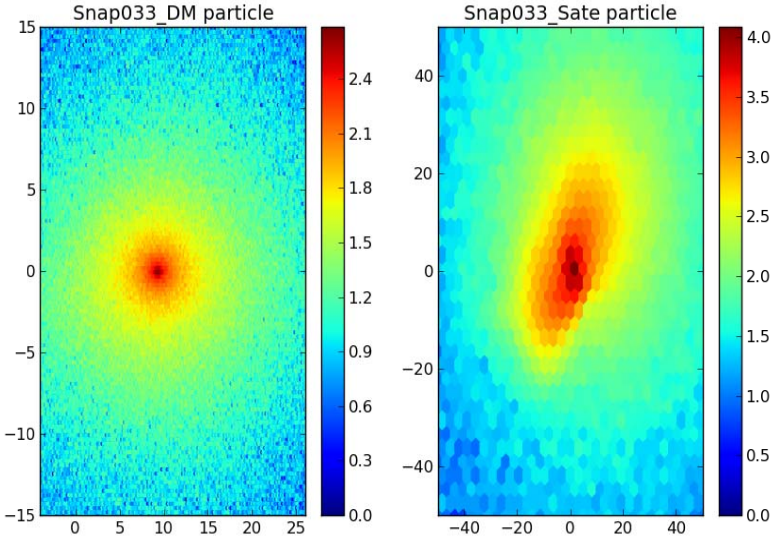

Figure 9 - The density distribution of projections in the Z direction drawn by the particle ID to distinguish the two galaxies (satellite particles and dark matter particles for snapshot_033). The density unit is (kpc/h)$^{-2}$

Determining the nature of the DM that surrounds galaxies and overwhelms the gravitational force from visible matter constitutes a fundamental task of modern astrophysics [8]. CDM particles are characterized by low initial velocity dispersion and high phase space density, resulting from a relatively heavy particle mass. After the satellite galaxies cross the main galaxies, they cause tidal currents in the center of the total cluster due to external shocks, which affect the distribution of dark matter particles, with steep density cusps at the center. In cosmologies with a somewhat lighter DM particle there are reduced phase space densities and higher velocity dispersions. These alternative models, broadly classified as warm DM, produce more constant density cores in galactic halos. In this sense, by precisely measuring the shape of the central DM density profile (characterized by the logarithm of the slope there), one places important constraints on the primordial phase space density of DM, which in turn bears on such microphysical properties of the DM particle as its mass and details of its formation mechanism.

Based on measured mass-to-light ratios, dwarf spheroidal (dSph) galaxies occupy the least massive known DM halos in the Universe. Dwarf spheroidals are also unique among all classes of galaxies in their ability to probe the particle nature of DM, because phase space cores resulting from the properties of the DM particle are expected to be most prominent in these small halos. In recent years, the measurement of line-of-sight velocities for upwards of a thousand stars in several dSphs has allowed for a precise determination of their masses. However, despite the great progress made in estimating masses of these systems, determining the logarithmic slope of their central density profile, and thus the nature of the DM contained within, remains elusive.

VI. Conclusion

Most of the stars in our Galaxy including our Sun move in a disk-like component and give the Milky Way its characteristic appearance on the night sky. As in all fields in science, motions can be used to reveal the under lying forces, and in the case of disk stars they provide important diagnostics on the structure and history of the Galaxy. But because of the challenges involved in measuring stellar motions, samples have so far remained limited in their number of stars, precision and spatial extent. This has changed dramatically with the second Data Release of the Gaia mission which has just become available. Here we report that the phase space distribution of stars in the disk of the Milky Way is full of substructure with a variety of morphologies never observed before, namely snail shells and ridges when spatial and velocity coordinates are combined. The nature of these new substructures implies that the disk is phase mixing from an out of equilibrium state, and that it is strongly affected by the Galactic bar and/or spiral structure.

The ability of Auriga_proper_unit - by used in Gadget2 to make μ as measurements of the positions of faint stars is unmatched among all planned missions. Tis simulation method will be able to probe accurately the three-dimensional stellar phase space distribution around the outskirts of our own Galaxy, within a nearby sample of dwarf galaxies, and in other Local Group systems – and these are the only galaxies in the Universe for which such data will be available. These measurements provide unique windows on some key astrophysical problems, from galaxy formation and the structure of DM halos, to the nature of DM itself.

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ГАЛАЛТИКАЛЫҚ ҚҰРЫЛЫМЫНДАҒЫ ҚАРАҢҒЫ МАТЕРИЯНЫҢ ТАРАЛУЫН ЗЕРТТЕУ

Аннотация. Галактиканың қалыптасу теориясындағы негізгі компоненттерді қосу арқылы дискілік-гало-гало жүйелерінің қалыптасуын зерттейміз. Бұл мақаланың мақсаты галактик құрылымында қараңғы материяның таралуын зерттеу және негізгі галоға субгалонның әсерін, сонымен қатар галактиканың қалыптасуының қарапайым сценарийіне енетін диск компоненттерін зерттеу болып табылады. Галактиканың тұрақты компоненттерін қалыптастыру үшін координаттар, орналасу, жылдамдықтар және массалар сияқты галактикалардың бірнеше маңызды сипаттамаларын зерттейміз. Субгало-гало қатынасын анықтайтын параметрлер мен физикалық процестерді іздейміз, осылайша галактикалық гало арқылы соқтығысудың немесе басқа кедергілердің пайда болуын айтарлықтай түсіндіреміз. Галактиканың орталығынан қашықтықта кедергілер таралуымен біріктірілген субгалосының радиалды жылдамдықтары бойынша таралуы дискінің қасиеттері мен қабынуының байқалған таралуын түсіндіре алады. Бұл құжатта Auriga_proper_unit - Aurig-6 негізгі галактикалардың деректер файлы еркін айналымнан бұрын қолданады. Gadget2-де координаттар мен тығыздық сияқты қолданылатын деректер ұзындығының бірліктері, мпк-дан кпк-ға дейін өзгертіледі және жұлдыз_жасын қамтиды.

Түйін сөздер: қара материя (DM), радиалды жылдамдық, Галактоцентрический координат жүйесі

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ИССЛЕДОВАНИЕ РАСПРЕДЕЛЕНИЯ ТЕМНОЙ МАТЕРИИ В ГАЛАКТИЧЕСКОЙ СТРУКТУРЕ

Аннотация. Мы исследуем образование систем диск-балж-гало путем включения основных компонентов в теорию образования галактики. Цель этой статьи - исследовать распределение темной материи в структуре Галактики и изучить влияние субгало на гало и компоненты диска, которые должны быть включены в один простой сценарий формирования галактики. Мы исследуем нескольких важных характеристик галактик, таких как координаты, положение, скорость и массы, чтобы сформировать стабильности компоненты галактики. Мы ищем параметры и физические процессы, которые определяют отношение субгало-гало, и, таким образом, в значительной степени объясняют происхождение столкновения или других препятствий через галактическое гало. Разброс по лучевым скоростям гало в сочетании с разбросом препятствий на расстояниях от центра галактики может объяснить наблюдаемый разброс по свойствам диска и выпуклости. В работе используются данные из Auriga_proper_unit - файла данных о главных галактиках в Auriga-6 до свободного запуска. Единицы длины данных, используемые в Gadget2, такие как координаты и плотность, конвертируются из Mpc в kpc и также включают star_age.

Ключевые слова: темная материя (ДМ), лучевая скорость, галактоцентрическая система координат.

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