Summary: The relationship between the morphology and kinematics of galaxies and its dependence on dark matter halo structure in EAGLE

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1 Introduction

Morphology and kinematics are two main characteristics of galaxies, they have been used to classify them and inferring some aspects from the evolution process. They are broadly correlated with other properties of galaxies like mass, colour and star formation rate. These means that morphology and kinematics contains information about the formation processes of galaxies.

Ever since we were able to get a wider integral field spectrographs we have been able to obtain larger samples of galaxies. It has been possible to see that "there is not a simple mapping between galaxy morphology and internal kinematics". A good example for that are the early type galaxies, where the kinematics is not mostly rotational. This seems to indicate that kinematics is a better way to classify galaxies, instead of relying only on morphology.

Recently many simulations of galaxy formation have effectively reproduce some observed key characteristics of galaxy population. They used initial cosmological conditions in which dark matter and baryonic components are evolved and give as a result the morphological and kinematical properties. Such simulations in large cosmic volumes allow to examine relationships between morphological and kinematical properties in well sampled population of galaxies.

2 Numerical Methods

2.1 Simulations and subgrid physics

Evolution and Assembly of GaLaxies and their Environments (EAGLE) enclose hydrodynamical simulations of the formation, assembly and evolution of galaxy using ΛCDM cosmology, and its evolution of galaxies population is very realistic. At standard resolution the simulation "marginally resolve the Jeans scales at the density threshold for stars formation in the warm and diffuse photoionised ISM" (interstellar medium).

The analysis of this paper focus on the simulation of largest volume Ref-L100N1504

2.2 Identifying and characterizing galaxies

Galaxies are interpreted as stellar components of structures with self-bound gravity. The subhalo that contains the particle with the lowest gravitational potential is defined as *central*. The other surrounding subhalos are called *satellite subhalos* and may contain satellite galaxies.

These analysis is focused on the central galaxies in order to avoid environmental influences on morphology and kinematics.

2.3 Characterising galaxy morphology with shape parameters

The disc galaxies in EAGLE simulation differ from the real ones in their more vertical-extended shape. To overcome that it is performed a "detail structure decomposition to characterise galaxies' morphologies." This is made by modelling the spatial distributions of the stars with an ellipsoid with

$$\epsilon = 1 - \frac{c}{a} \quad ; \quad T = \frac{a^2 - b^2}{a^2 - c^2} \tag{1}$$

ϵ being the flattening and T the triaxiality parameters. a, b and c are the moduli of the mayor, intermediate and minor axes. These axis lengths are defined by the eigenvalues of a matrix of the 3-dimensional mass distribution, the tensor of the quadrupole moments of the mass distribution.

$$M_{ij} = \frac{\Sigma_p m_p r_{pi} r_{pj}}{\Sigma_p m_p} \tag{2}$$

But using an iterative form of the reduced inertia tensor which mitigates the external contributions of particles far away from the center.

$$M'_{ij} = \frac{\Sigma_p \frac{m_p}{\tilde{r}_p^2} r_{pi} r_{pj}}{\Sigma_p \frac{m_p}{\tilde{r}_p^2}} \tag{3}$$

The iteration begins estimating the initial axis lengths where the stellar particles enclosed by the ellipsoid of equal volume are

$$\tilde{r}_p^2 = r_{pa}^2 + \frac{r_{pb}^2}{(b/a)^2} + \frac{r_{pc}^2}{(c/a)^2} \leq \left(\frac{a^2}{bc}\right)^{2/3} (30pkpc)^2 \tag{4}$$

r_{pa}^2, r_{pb}^2 and r_{pc}^2 are the distances projected on that direction defined by the eigenvectors in the previous iteration. The iterations goes on until the fractional change of both fractions (c/a and b/a) converges to $< 1\%$

2.4 Characterising galaxy kinematics

The frame of reference is always, in all computations, centered on the galaxy's potential minimum, and the mean velocity of stars particles within 30pkpc of this center define the velocities.
Fraction of counter-rotation stars: It is assumed that the bulge component doesn't have net angular momentum and its mass is estimated as twice the mass counter-rotating with respect to the galaxy.
Rotational kinetic energy: It is based on the parameter κ_{co} that specifies the fraction of the total kinetic energy K that is invested in co-rotation K_{co}^{rot}. It was found that dividing the population of stars particles about a threshold in κ_{co} makes possible to divide the "blue cloud" (disk star-forming galaxies) and the "red sequence" (spheroidal passive galaxies) in galaxy colour-stellar mass diagram.

Spin parameter: It consist in creating datacubes similar to the ones obtained from integral field spectroscopy. This is made projecting stellar fields in a 2-dimensional grid creating a stellar mass-weighted velocity distribution. It is fitted by a gaussian function where the rotational velocity would be the one at which the gussian peaks. The velocity dispersion is the square root of the variance. With all of the above defined, the spin λ_* is calculated. Then it is all computed from maps in which the galaxies are oriented edge-on with respect to the spin vector.

Orbital circularity The circularity of a particle's orbit ξ is obtained by comparing its angular momentum to the value of one with a circular orbit with the same binding energy. The advantage of this method is that it works classifying the bulge and disk components particles letting a kinematically-defined structural decomposition.

Ratio of rotation and dispersion velocities: They can be estimated from spectroscopic observation of galaxies. It is assumed the rotational velocity V_{rot}equal to the "mass-weighted median" of the tangential velocities $v_{\theta i}$ of the stellar particles. In order to connect this calculations with the observational measurements of the dispersion, that are made on the line-of-sight, we define the "disc-plane" and seek there the velocity dispersion. The ordered co-rotational component are subtracted and this is computed from the tensor viral equation.

2.4.1 A brief comparison of kinematical diagnostics

At the end it is seen that there is a strong positive correlation between each parameter and ν_{rot}/σ_0 (rotation and dispersion velocities). To quantify the strength of the correlations we use the Spearman rank-order coefficient ρ_{Sp}. The five kinematical diagnosis methods are consistent and can be interchanged.

3 The morphology and kinematics of EAGLE galaxies

3.1 The morphology of EAGLE galaxies

Analyzing graphically it is seen that the most populated region of the plane defined by ϵ and T is in the region of flattened, oblate ellipsoids. The media values are determined as $\epsilon = 0.46$ and $T = 0.19$. The two zones of avoidance are at high ϵ

and high T, corresponding to and entire bar-like galaxy, and at low flattening ($\epsilon < 0.1$) corresponding to totally spherical galaxies.

Since the prolate systems show some tidal disturbance and sometimes merger remnants it can be possible that these kind of structures would be induced by external interaction with other galaxies. They also show “blue” structures which means it also induce star formation. These interactions may be able to move some stars particles from the red sequence to the blue cloud.

3.2 Correspondence with the colour-mass relation

In this section it is made the quantitative examination of the relationship between morphology and kinematics and the location of galaxies in the colour-mass plane. The EAGLE galaxies naturally divides between blue clouds and red sequence. It was found that a threshold in ϵ is not enough to obtain a clear separation between these two types of galaxies. The blue cloud is populated mostly with flattened galaxies while the red sequence was dominated only in the low mass end by spheroidal galaxies. Whit the threshold in T it is shown that the high mass end on the red sequence is plotate-dominated while the blue cloud is dominated by flattened systems (Disky galaxies). None of these threshold separate adequately blue cloud from red sequence. To overcome this difficulty it is constructed a morphological parameter $\alpha_m = (\epsilon + 1 - T)/2$ with a threshold in $\alpha_m \simeq 0.5$ showing that it reasonably distinguish these two regions. The last threshold used is in ν_{rot}/σ_0 and it evidences the similarity with the results obtained from the k_{co} threshold.

3.3 The relationship between morphology and kinematics

From graphic analysis between the $\nu_{rot}/\sigma_0 - \epsilon$ plane and the mass of galaxies, it is seen that massive galaxies dominates the high-ϵ region but with diverse values of ν_{rot}/σ_0 because they can be ”rotating disc or prolate spheroids with significant dispersion support”. The graphic results from a reduced sample of 2703 spheroidal ($\epsilon < 0.3$) or oblate ($T < 1/3$) galaxies shows a strong correlation between morphological and kinematics diagnostics. It can be concluded that these two kinds of diagnostics are not interchangeable since the morphology of a galaxy does not depend only on ν_{rot}/σ_0 but at least on one more parameter.

3.3.1 The influence of velocity dispersion anisotropy

Morphology and kinematics collisionless systems are linked with the tensor viral theorem that is used to predict the behaviour between $\nu_{rot}/\sigma_0 - \epsilon$ for different values of velocity dispersion anisotropy δ. Comparing these results with the simulated galaxies it demonstrates that it is a good analytic prediction.
The physical interpretation of this analysis is that the flattening of EAGLE galaxies can be significantly influenced by the velocity dispersion anisotropy.