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# Spiral arms across stellar populations in hydrodynamical simulations

**Ardèvol, J.**[1,2,3]**, Antoja, T.**[1,2,3]**, Semczuk, M.**[1,2,3] **and Debattista, V. P.**[4]

[1] Institut de Ciències del Cosmos (ICCUB), Universitat de Barcelona (UB), Martí i Franquès 1, E-08028 Barcelona, Spain
[2] Departament de Física Quàntica i Astrofísica (FQA), Universitat de Barcelona (UB), Martí i Franquès 1, E-08028 Barcelona, Spain
[3] Institut d'Estudis Espacials de Catalunya (IEEC), c. Gran Capità, 2-4, 08034 Barcelona, Spain
[4] Jeremiah Horrocks Institute, University of Central Lancashire, Preston, PR1 2HE, UK

## Abstract

The majority of galaxies in the Local Universe are spiral galaxies. However, the formation and evolution of spiral arms is not well understood. Different theories explaining how spiral arms work give different predictions on their rotation and relative orientation between stellar populations. High-resolution hydrodynamical simulations with star formation are essential in providing predictions that can be compared with observations.

To better understand how spiral arms work, we analyse high-resolution simulations of an isolated disc galaxy. We quantify the presence of spiral arms adopting the method of the local dimension, which was previously used in cosmological studies of filaments in the large scale structure of galaxies.

Using the local dimension, we study how the morphology of spiral arms differs between young and old stellar populations. In agreement with previous works, we find that the spiral structure is most prominent in young stars and it weakens with growing age of stars. Despite this age dependence, both young and old populations show very similar patterns in the inner disc.

## 1 Introduction

One of the most impressive non-axisymmetric features of galaxies are spiral arms. It is still not fully understood how they form and work. The key element in pushing forward our understanding of spirals are comparisons observations and computer simulations. Since spiral arms can change their appearance when seen in different stellar populations, it is also crucial to analyse spiral structure while taking into account this aspect.

The most natural way to study spiral arms in simulations across stellar populations is to include hydrodynamics of gas and star formation. Since such simulations have become viable only recently, only a few authors focused on using them to study spiral arms. For example, [3] studied stellar migration along spiral arms. [5] and [6] analysed azimuthal shifts in simulations where spiral arms were induced by tidal interactions. Most recently, [4] examined metallicity variations associated to spiral arms of an isolated galaxy.

Studying spiral arms in a simulation requires that they can be easily detected. This is a challenging task, given their dynamic and non-axisymmetric morphology. In this work, we present a new method that allows to trace spiral arms from the local geometry of the stellar distribution. We apply it to the isolated galaxy M1_c_b from [2] (which is comparable to the Milky Way in terms of mass). Our aim is to understand how different populations participate in arms and interact with them.

## 2 Method

Our inspiration to develop a new method of detecting spiral arms through the local dimension ($D$) comes from its use in cosmology [7, 8, 1]. In the case of a spiral galaxy, the underlying disc density distribution corresponds to a two-dimensional structure ($D \sim 2$). Spiral arms, however, can be considered as filament-like features with lower dimension ($D \sim 1$). Given that, spiral arms can be detected by selecting regions where the local dimension is lower than a given threshold close to 2. Lowering this threshold yields sharper, but less complete spiral arms. The value of the threshold can also be used as a limit between the arm and the interarm region, and it can be applied homogeneously to any stellar population.

We determine the local dimension at a given point by counting particles within concentric cylinders of increasing radius ($r$). These cylinders have bases parallel to the galactic plane and infinite height. The number of particles ($N$) within each of them can be approximated by $N(< r) \propto r^D$, where $D$ is obtained by fitting the power-law from $r_{min}$ to $r_{max}$.

During the counting step, we weight particles so that more importance is given to low-density environments. Each particle's weight is the inverse of the surface density at its galactocentric radius. We take $r_{min} = 0.2$ kpc and $r_{max} = 2$ kpc to focus the analysis on the structures from this scale, instead of highlighting spurious small-scale features.

## 3 Results

Fig. 1 shows surface density distributions (left) and corresponding maps of local dimension (middle) of the modelled galaxy at the time of 8.5 Gyr since the start of the simulation. The top row shows young stellar particles (of ages less than 0.5 Gyr) while the bottom row presents older stars of age range between 2.5 and 3.5 Gyr. Both young and old stars have three-armed spiral structure at that time –which is more apparent through the local dimension, especially for the old stars. The spiral structure extends up to $\sim 10$ kpc for both populations. While some segments of arms in old stars may seem blended or split at $X < 0$ kpc, the overall shape of spiral morphology between the populations is in a good agreement, especially in the ring between 4 and 10 kpc (which is consistent with results of [4]). We find that this agreement across populations holds at other times in the simulation.

The right column of Fig. 1 shows an overlap of surface density maps with contours of constant $D = 2$. This overlap highlights a strong correlation between density and local dimension and showcases the efficiency of $D$ in detecting spiral arms, even in regions of low surface density.

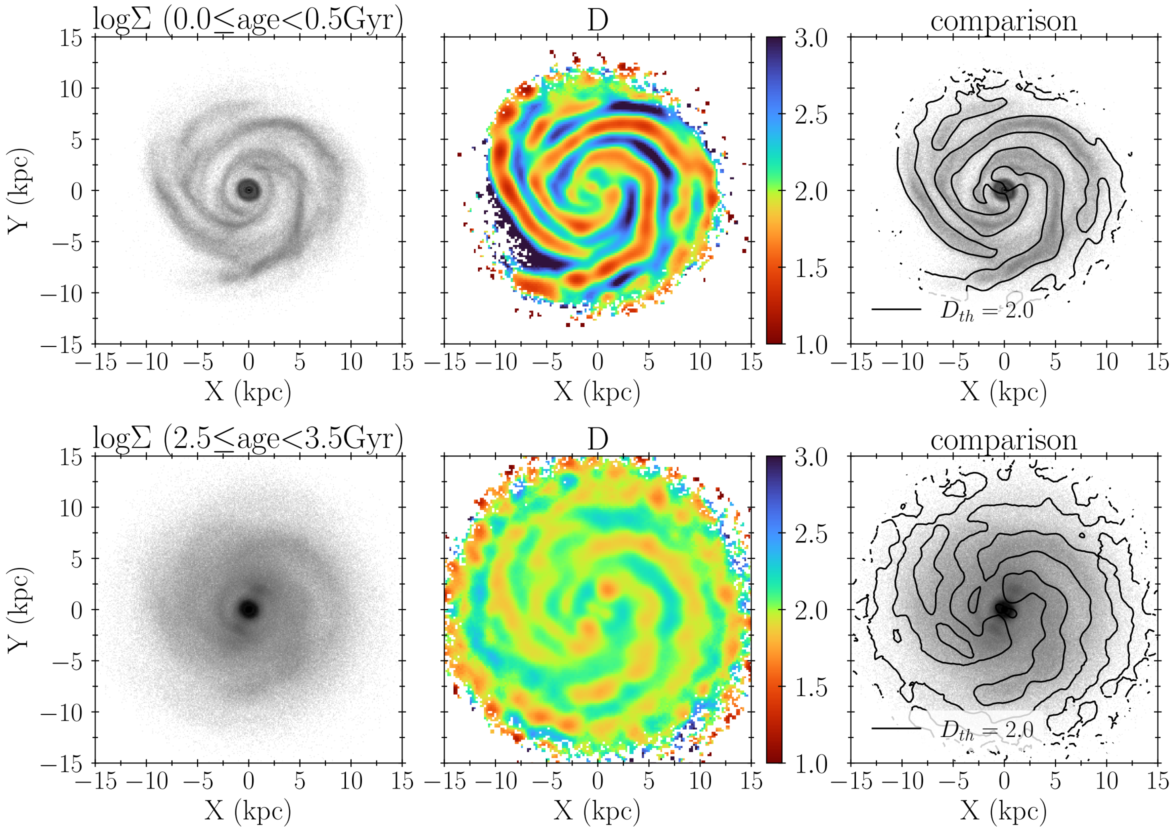


Figure 1: Comparison between local dimension and density of stellar particles younger than 0.5 Gyr (top row) and of those with ages from 2.5 to 3.5 Gyr (bottom row) at 8.5 Gyr. *Left*: density map; *centre*: local dimension map; *right*: left panel with $D = 2$ contours overplotted.

## 4 Conclusion

In this paper we presented a promising new method of spiral arms detection using the local dimension. Currently, this method can be used in particle-based simulations in a homogenous way thanks to its geometrical definition. In the future, it could also be adapted to observational data from the Milky Way or external galaxies with spatially resolved stellar populations. This would enable the analysis of the observations and simulations within the same framework.

We applied this new method to the N-body+Smooth Particle Hydrodynamics simulation from [2] and showed that stellar particles of all ages participate in the spiral structure. In agreement with previous works, we find that young stars show clearer spiral arms and the signal weakens with growing stellar age.

More extended analysis will be published in Ardèvol et al. *(in prep.)*.

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