Detection of galaxies superclusters in simulated cosmological structures

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1 Abstract

Recently Tully et al. (2014) [1] used local cosmic flow information to define our local supercluster, Laniakea. In this work we present a study on large cosmological N-body simulations aimed at establishing the significance of Laniakea in a cosmological context. We explore different algorithms to define superclusters from the dark matter velocity field in the simulation. We summarize the properties of the supercluster population by their abundance at a given total mass and its shape distributions. We find that superclusters similar in size and structure to Laniakea are relatively uncommon on a broader cosmological context. We finalize by discussing the possible sources of systematics (both in our methods and in observations) leading to this discrepancy.

2 Introduction

In the Universe scene at large scales the galaxies group themselves in structures similar to a filament web which go through large voids regions and cross in regions called superclusters. Even though these structures can be easily detected at simple view, there are different possibilities to delimited them from physical criteria [2].

A proposal to define a supercluster is to use the flow of galaxies in this region of space. Within a supercluster, galaxies tend to flow to the most dense region as a consequence of the gravitational attraction process. In this way, spacial regions where the galaxy flow is convergent represent galaxies superclusters.

Recently a team build a galaxies velocities flow map of the local group in a scale of hundreds of light years [3]. In this map converging points were found and this team identified Laniakea, the galaxies supercluster which includes our galaxy, the milky way [1].

We propose to develop a method to detect a statistical significant number of galaxies supercluster in cosmological simulations. With this we aim to quantified if Laniakea can be considered as an atypical structure in the Universe.

3 Background

4 Methods

As we support the open-source community, we used the N-Body simulation open software Gadget-2 [4] to generate the simulations and source code in C and Python to treat the data obtained from the simulations. The development of the code will be in Github `https://github.com/sercharpak/Monografia/`.

4.1 Simulations

We used the N-Body simulation software Gadget-2 [4] widely used in the scientific community to generate a box of size 500 Mpc/h with 512^3 dark matter particles (DM). The initial conditions were generated with Springel's N-Genic software. The simulations ran on the HPC cluster at UNIANDES with 48 processors and took approximately 10 hours to run.

By DM particle we mean a particle which only interacts through gravity interaction. In the simulation each particle represents a galaxy. We then use different algorithms to identify the superclusters within the simulation.

4.2 Algorithms

So far we have used a naive way to approach to the problem.

1. We calculate the magnitude of the velocity (the speed) of each particle.
2. We look for regions where the center has the highest speed and from it the speed decreases while the particle is further away from the center.
3. We define the limits of this region the regions where the speed begins to increase with the distance from the center.

We used a region growing algorithm, a simple image segmentation algorithm used to identify different regions in a image [5].
$f(x, y, z)$ denotes the input data. $S(x, y, z)$ denotes a seed array, with value 1 where the particle can be define as a seed and 0 where not. It is the same size of $f(x, y, z)$. Q denotes a predicate which is to be apply to the input data and determines if the region which starts at the seeds grows or not. Here Q denotes: "if the speed of the close particle is lower than the marked one but greater than a threshold, mark that particle and continue."

1. We choose seeds to begin the growth. In this case we choose the particles with high velocities. Here
$$|v| > v_{max} - \frac{\sigma_v}{4}$$
2. We open a window of particles to look for 2 close particles from the seed s which do not for part of $S(x, y, z)$. Here:
$$window = 20000$$

3. Once we found the 2 close particles c we apply the predicate Q. Here:

$$Q := |v_s| > |v_c| > |th_{low}|$$

With $th_{low} = v_{min} = \frac{\sigma_v}{2}$

4. If the particle c satisfies Q, it is marked, $S(c) = 1$

5. Apply the algorithm to c, and so on (Recursion).

The first version of the algorithm was written in python using the module pyGadgetReader [6] to read the data and transform it to NumPy arrays in Python. In Appendix A we attach the source code used.

5 Results

The simulation ran correctly on 48 processors in approximately 10 hours. We first visualized the simulation and its distribution of velocities.

We first visualize the speed histogram.

Our hypothesis is based on the distribution of the speed. The lower speed particles will mainly be in the region borders and the higher speed particles will be in the region's center.

We produce cuts in the z-direction to visualize in 2-D the speed distribution.

Finally we apply our region growing algorithm and we obtain the following results.

We have three main observations:

1. The details of the region seem accurate with what we would expect. It is more dense in the center and less dense in the borders.

2. The region obtained has a dimension of only a few tens kpc/h (Laniakea's dimension is one order of magnitude higher).

3. There is only one region identified. There should be more. Clearly there is a problem with the algorithm.

The script in Appendix A was executed in a student's laptop because of inconveniences with the HPC cluster. We think the main problem in the laptop is the limited memory (8GB). We expect to run it in the HPC to get more accurate results.

6 Future Work

- Understand more in detail how the work done by Hoffman et al[7] in the V-web algorithm, was used to determine Laniakea.
- Write our own Gadget-2 snapshop reader in C or Python which implements the region growing algorithm.
- Optimize our Algorithm. The current results are not sufficient.
- Run a bigger simulation (boxsize: $5 \times 10^6 Mpc/h$ and 1024^3 DM particles.
- Run the algorithm on this simulation.
- Compare the properties of the results with the Laniakea supercluster.
- Discuss the sources of systematics in both methods and observations.

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A Region Growing Algorithm