Dark matter halo shapes in the Auriga Milkiway-like galaxy simulations

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September 18, 2017

1 Introduction

A complete physical picture of Dark Matter (DM) is still missing. This is one of the biggest puzzles to fully understand the composition of our Universe. So far, its presence can only be measured through its gravitational effect on the surrounding visible matter. One of best the astronomical systems that can be used to probe DM in astronomical scales is our own galaxy: the Milky Way (MW). Probing the DM density field around our galaxy (it's so-called DM halo) can shed light on the nature of DM [referencias] and our galaxy's formation history [referencias].

One of the most basic features that can be measured in the MW DM halo is its shape. Different observational methods have been developed to constrain it. They range from the use of Jean's equations [1] to the satellite systems such as the Sagittarius stream and the Large Magellanic Cloud [2, 3, 4]. However, different assumptions are made in these studies, producing widely different results. Thus, constraining the density field of the DM halo of the Milky Way remains an open research topic in present-day astronomy.

Today, computational astrophysics can support all these observationally projects by helping to prove (or disprove) the range of validity of different assumptios. [referencias]. Simulations can also serve to find priors on the expected MW DM halo shape. However, using simulations comes at a cost. First, different degrees of realism in the implemented physical models should yield different results. Second, artifacts can appear due to the always limited numerical resolution. For these reasons, the study of simulations of astronomical or cosmological systems, as well as the research for reducing the aforementioned biases of computation, is an important field of study in modern astrophysics.

Recently, the growth of computational power and the improvement of numerical models have made possible the performance and further study of very realistic simulations. These realistic simulations trace the non-linear interactions of DM and baryonic components. They can reproduce important features of our observable universe in a wide range of scales. On one hand, they reproduce the cosmic star formation rate density and galaxy luminosity function in cosmological simulations. On the other hand, they reproduce specific features of MW-type galaxies such as their stellar masses, rotation curves, star formation rates and metallicities. These simulations have freedom in measurements and control over the state of the systems and its observables. This constitutes the biggest advantages over observational astronomy.

In this context, the analysis of realistic simulations of MW-like galaxies is of great importance to observational astronomy. These simulations have only been possible until very recently [5] and can support the proces of probing the DM halo shape in observations regarding our galaxy. However, realistically reproducing the features of our MW galaxy is not an easy task. It requires producing the correct initial conditions and not only having a sophisticated full-physics model to reproduce observables and a powerful computer, but to very carefully tune the free parameters of these models. These free parameters are associated to the many dissipation and feedback processes of baryonic matter. A bad tunning of these parameters may produce observables which are not comparable to the observational data.

These are the reasons why, before the arrival of realistic MW-like simulations such as Aquarius [5], there was a generation of DM-only simulations. These simulations used the final state of the evolution of DM to reproduce, via semi-analytical models, the statistical features of the observable universe. This type of simulations have substantial information to work with, but may be biased in aspects regarding the historical relation between DM and baryonic matter. This is an important aspect to have into account when studying our galaxy's DM density field [6]. The task of incorporating baryonic matter in these simulations is very difficult. Even with the most correct prescriptions of that date, Aquarius is a recent set of just six MW-like galaxies. This can make any study performed on it of low statistical significance.

More recently, it has been developed the latest and most accurate hydrodynamical code AREPO [7]. This code comes with associated improvements of the physical numerial models regarding baryons. The code AREPO reconciles the advantages and solves the flaws of the two paradigms of cosmology-oriented numerical hydrodynamics models, namely Smoothed Particle Hydrodynamics (SPH) and Eulerian hydrodynamics with Adaptive Mesh Refinement (AMR). Furthermore, its associated physics models can simulate magnetic fields, which is a novel feature in computational astrophysics. With these state-of-the-art tools it has been possible the simulation of thirty MW-like galaxies in the project Auriga [8]. Therefore, it becomes clear that the study of the DM density field on the simulations of this project may produce a more complete insight due to the statistical significance of the sample.

In this order of ideas, the principal objective of this monograph is to use the results of the pioneering Auriga project [8] to study the halo density field of these thirty galaxies. Specifically, we will focus on the shape of the DM halo in function of its radius and its history. We will follow to the guidelines stablished in a previous study over the Aquarius simulations by Vera-Ciro et al. [9]. Studies of the DM density field like this have not been carried out yet on this nouvelle project Auriga. This represents one of the strongest motivations of this monograph. Hopefully, with this study we can elucidate some aspects about the history and relation of baryonic matter and DM in MW-like galaxies. These aspects can then be extrapolated to the observational field of study, contributing in this way with our grain of sand in the transcendental enigma that DM represents to modern physics.

2 General objectives

Study the distribution of DM in MW-like galaxies.

3 Specific objectives

- Study of the distribution of DM in full-physics state-of-the art simulations.
- Study how the presence of gas affects the distribution of DM in full-physics simulations.

4 Methodology

The student will perform the mentioned research individually with the periodic (weekly) support of his advisors. This will be achieved through in-person meetings in the Astrophysics group or electronic message interchange. In these meetings the student will obtain feedback about his work development and it will be decided if more time is necessary to discuss the partial results of this thesis.

The student has visited the Heidelberg's Institute of Theoretical Studies (HITS) where he worked for one month as an invited scientist. This internship was sponsored by the Latinamerican Chinese European Galaxy Formation Network (LACEGAL) [**?**]. Specifically, the student worked with the Theoretical Astrophysics (TAP) group which was under the leadership of Volker Springel. It was there where the main ideas of this project were born. Some other visits to HITS are planned during the course of this monograph with the objective of obtaining in-person feedback from the co-advisor. These visits will also be fully funded by the LACEGAL project.

The proposed methodology has a strong computational component related to the analysis of high resolution galaxy simulations. The student has access, from his previously mentioned visit, to the computational cluster at HITS where the information of these simulations reside. He will at most need access to the Uniandes computational cluster. Furthermore, the revision of specialized bibliography is indispensable.

5 Cronogram

Tareas \ Semanas	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1	X	X	X	X	X	X										
2				X	X	X	X	X	X							
3							X	X	X	X	X					
4										X	X	X	X	X	X	X
5												X	X	X	X	X
9							X	X	X	X	X	X	X	X	X	X
Tareas \ Semanas	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31	32
5	X	X	X	X												
6	X	X	X	X	X	X										
7				X	X	X	X	X								
8									X	X	X	X	X	X		
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

- Task 1: Bibliography revision and familiarization with the output data of MW-like simulations.
- Task 2: Development of numerical methods for characterizing the shape of the principal DM halo in low resolution simulations at specific redshifts.
- Task 3: Revision of results and comparison with previous work on this topic.
- Task 4: Optimization and parallelization of the previous code to be performed in high resolution simulations.
- Task 5: Revision of results and comparison with state-of-the art observations.
- Task 6: Application of numerical methods to characterize the historical shape of the DM halos.
- Task 7: Confirmation of the results of this work by comparison with previously performed similar studies.

- Task 8: Summary and development of conclusions of this work, including summarizing graphics.
- Task 9: Writting of final document

6 People who know about this topic

- Alejandro Garcia (Universidad de los Andes)
- Benjamin Oostra (Universidad de los Andes)
- Beatriz Sabogal (Universidad de los Andes)

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