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

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1 Introduction

Nowadays, the esence of Dark Matter (DM) remains unknown and is one of the biggest puzzles needed to understand the fundamentals that constitute our universe. As it is assumed by the nature of its discovery that it does not posses electromagnetic interactions, observing DM directly is practically impossible. However, due to its strong gravitational effect on the surrounding vissible matter, (acceleration curves, weak lensing), its presence can be sensed and furthermore, its density field can be constrained.

In this context, it is of much interest to probe the density field of the DM that clusters (DM halo) around the Milkyway as it can shed light in this fundamental enigma and it may have implications in many areas of physics. Specifically, the complete density field of the DM halo of our host galaxy is strong evidence to deduce many features of its formation history and evolution.

Many methods have been developed to constrain the shape of the Milkyway's DM halo, ranging from the use of Jean's equations [**?**] to the satellite systems such as the Sagittarius stream and the Large Magellanic Cloud [**?**, **?**, **?**]. However, due to the difficulty in the observation of some specific sensitive details of our galaxy and its surrounding systems, many assumptions have to be done over these models, producing considerably different results between each other. Then, it is safe to say that the constraints on the density field of the DM halo of the Milkyway is still an open research topic in astronomy.

Recently, with the growth of computational power and the improvement of numerical models, the performance and further study of realistic simulations which trace the non-linear interactions of DM and baryonic components has been possible [**?**, **?**, **?**]. These simulations can reproduce important features of our observable universe in a wide range of scales, from the cosmic star formation rate density and galaxy luminosity function in cosmological simulations as Illustris [?] to more specific features of Milkyway-type galaxies in AURIGA and AQUARIUS [?, ?] such as their stellar masses, rotation curves, star formation rates and metallicities. These simulations are an important field of study that complements observations and theory due to its freedom and control over the state of the systems and its observables.

In this context, the analysis of realistic Milkyway-like galaxies, which has only been possible until very recently [?], is of great importance to complement and perhaps give clues about details to have into account when probing the DM density field in observations regarding our galaxy. However, realistically reproducing the features of our Miklyway 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, but to very carefully tune the free parameters of these models such as the ones associated to the many dissipation and feedback processes of baryonic matter.

This is why, before the arrival of realistic Milkyway-like simulations such as Aquarius, there was a generation of DM-only simulations which used the final state of the evolution of DM to reproduce, via semi-analytical models, the statistical features of the observable universe. These type of simulations have substantial information to analyze in this field of study, but may be biased in aspects regarding the historical relation between DM and baryonic matter, such as the question of our galaxy's DM density field /citerelation DM baryons is important. The task of incorporating baryonic matter in these simmulations is in fact so difficult that, even with the most correct prescriptions of that date, Aquarius is a set of just six Milkyway-like galaxies, which can make any study performed on it of low statistical significance.

More recently, with the deveolpment of the latest and most accurate hydrodynamical code AREPO [?] and the improvements of the physical numerial models regarding baryons, it has been possible the simulation of thirty Milkyway-like galaxies in the project AURIGA [?]. This code AREPO conciles the advantages and solves the flaws of the two paradigms of cosmology-oriented numerical hydrodynacs models namely Smoothed Particle Hydrodynamics (SPH) and Eulerian hydrodynamics with Adaptative Mesh Refinement (AMR). Furthermore, it can simulate magnetic fields, which is a novel feature in this type of simulations. Therefore, it becomes clear that the study of the DM density field on these simulations may produce a more complete insight when performed on these simulations due to the statistical significance of the sample which is also strong evidence of the big improvements of the baryonic physics models.

The principal objective of this monography is then to use the results of the AURIGA project to study the halo density field of these thirty galaxies obtaining statistically significant results which can then be compared to the state-of-the-art observations. Specifically, we will study the shape of the DM halo in function of its radius and its history according to the guidelines stablished in a previous and similar study over the Aquarius simulations by Vera-Ciro et al [?], in order obtain a better understanding about the relation between DM and visible matter in Milkyway-like galaxies and how can it be extrapolated to the observational field of study.

2 Objetivos Generales

Obtain the shape of the principal DM haloes in the AURIGA simulations in terms of the radius and the history of the galaxy.

3 Objetivos Específicos

- Compare the results of the halo shapes between the DM-only simulations with that of the full-physics simulations
- Study and understand the effect that the presence of visible matter exerts in the shape of the DM haloes in Milkyway-like galaxy simulations.
- Study and understand the relation of the final shape of the DM halo with respect to its historical shape.
- Compare our future results with the state-of-the-art observations that constrain the shape of the Milkyway's DM halo.

4 Metodología

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

The proposed methodology has a strong computational component related to the analysis of high resolution galaxy simulations. The student has access to the computational cluster at Heidelberg's Institute of Theoretical Studies (HITS) where the information of these simulations reside, and will need at most acces to the Uniandes computational cluster. Furthermore, the revision of specialized bibliography is indispensable.

5 Cronograma

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	X	X	X							
3								X	X	X	X	X	X	X	X	X
4												X	X	X	X	X
5										X	X	X	X	X	X	X
9					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
4	X	X	X	X	X	X										
6			X	X	X	X	X	X								
7						X	X	X	X	X	X					
8									X	X	X	X	X			
9	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X

- Tarea 1: Desarrollo de redes neuronales simples
- Tarea 2: Investigación del diseño y funcionamiento de redes neuronales
- Tarea 3: Investigación de modelos teóricos sobre redes neuronales
- Tarea 4: Desarrollo de intuiciones o modelos verificables sobre el funcionamiento del aprendizaje de las redes
- Tarea 5: Preparación de la presentación de avance
- Tarea 6: Verificación de las conclusiones de los modelos anteriores sobre las redes neuronales artificiales específicas
- Tarea 7: Ampliación a redes neuronales más complejas
- Tarea 8: Desarrollo de resultados y conclusiones del trabajo
- Tarea 9: Escritura del documento final

6 Personas Conocedoras del Tema

- Juan Manuel Pedraza (Universidad de los Andes)
- Alonso Botero (Universidad de los Andes)
- Juan Gabriel Ramírez (Universidad de los Andes)

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Firma del Director

Firma del Estudiante