The Expected Shape of the Milky Way's Dark Matter Halo

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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 on 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 [1, 2] and our galaxy's formation history [3, 4, 5].

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 applied to stellar kinematics [6] to modelling the dynamics of satellite systems such as the Sagittarius stream and the Large Magellanic Cloud [7, 8, 9]. 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 assumptions [10, 11, 5]. 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 can 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 to perform realistic simulations. These simulations can trace

the non-linear interactions of DM and baryonic (i.e. usual gas and stars) components. For instance, the recent development of an state-of-the-art simulation AREPO [12] have made possible simulations that were considered impossible a decade ago. This code has been used to perform the *Auriga Project* [13], which simulates 30 galaxies that reproduce the main Milky Way features such as their stellar masses, rotation curves, star formation rates and metallicities.

For this thesis we will use the results from Auriga project [13] to study the halo density field of the 30 simulated galaxies. Specifically, we will measure the shape of the DM halo as a function of its radius and its time evolution. We will follow the methods presented in a study of the simulation project that preceeded the Auriga Project over 5 year ago [5] that simulated 5 times less galaxies, without any hydrodynamics and at a lower numerical resolution. This is the first time that studies of the DM density field are performed with this level of realism. The simulations in the *Auriga Project* were performed with different hydrodynamical characteristics which will also allow us to measure the impact of such differences on the DM halo shape.

The results from our study will help to constrain the expected DM density distribution around our galaxy, providing a benchmark for all researchers interested in a better understanding of our Galaxy and its dark matter distribution.

2 General objectives

Study the DM distribution around MW-like galaxies.

3 Specific objectives

- Measure the shape of the DM halo in simulations from the *Auriga Project*.
- Measure the different results in the DM halo shape for different degrees of realism in the baryon physics.

4 Methodology

This project has a strong computational component related to the analysis of high resolution galaxy simulations from the *Auriga Project*. This will be done using the computational resources available both at the Heidelberg's Institute of Theoretical Studies (HITS) and Uniandes.

The student visited HITS in the Summer 2017 where he worked for one month as an invited scientist to the Theoretical Astrophysics (TAP) led by Volker Springel. Since July 2017 the student has access to the computational cluster at HITS where the information of these simulations is stored. The student will pay a second visit to HITS in December 2017 to work on this thesis. Those internships are sponsored by the

Latinamerican Chinese European Galaxy Formation Network (LACEGAL) [14] funded by the European Union, whose one of its co-PI is Jaime Forero at Uniandes.

Besides these internshipts in Germany, there will be weekly meetings with his advisors, either in person or virtually.

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)

References

[1] C. Nipoti, P. Londrillo, H. Zhao, and L. Ciotti. Vertical dynamics of disc galaxies in modified Newtonian dynamics. *MNRAS*, 379:597–604, August 2007.

[2] J. I. Read and Ben Moore. Tidal streams in a mond potential: constraints from sagittarius. *MNRAS*, 361(3):971–976, 2005.

[3] J. I. Read, G. Lake, O. Agertz, and Victor P. Debattista. Thin, thick and dark discs in cdm. *MNRAS*, 389(3):1041–1057, 2008.

[4] J.I. Read, L. Mayer, A.M. Brooks, F. Governato, and G. Lake. A dark matter disc in three cosmological simulations of Milky Way mass galaxies. *MNRAS*, 397:44–51, July 2009.

[5] C.A. Vera-Ciro, L.V. Sales, A. Helmi, C.S. Frenk, J.F. Navarro, V. Springel, M. Vogelsberger, and S.D.M. White. The shape of dark matter haloes in the Aquarius simulations: evolution and memory. *MNRAS*, 416:1377–1391, September 2011.

[6] S.R. Loebman, v Z. Ivezic, T.R. Quinn, F. Governato, A.M. Brooks, C.R. Christensen, and M. Juric. Constraints on the Shape of the Milky Way Dark Matter Halo from Jeans Equations Applied to Sloan Digital Sky Survey Data. *APJL*, 758:L23, October 2012.

[7] C. Vera-Ciro and A. Helmi. Constraints on the Shape of the Milky Way Dark Matter Halo from the Sagittarius Stream. *APJL*, 773:L4, August 2013.

[8] N. Deg and L. Widrow. The Sagittarius stream and halo triaxiality. *MNRAS*, 428:912–922, January 2013.

[9] D. R. Law and S. R. Majewski. The Sagittarius Dwarf Galaxy: A Model for Evolution in a Triaxial Milky Way Halo. *APJ*, 714:229–254, May 2010.

[10] A. D. Ludlow, A. Benıtez-Llambay, M. Schaller, T. Theuns, C. S. Frenk, R. Bower, J. Schaye, R. A. Crain, J. F. Navarro, A. Fattahi, and K. A. Oman. Mass-Discrepancy Acceleration Relation: A Natural Outcome of Galaxy Formation in Cold Dark Matter Halos. *Physical Review Letters*, 118(16):161103, April 2017.

[11] J. M. Bardeen, J. R. Bond, N. Kaiser, and A. S. Szalay. The statistics of peaks of Gaussian random fields. *APJ*, 304:15–61, May 1986.

[12] V. Springel. E pur si muove: Galilean-invariant cosmological hydrodynamical simulations on a moving mesh. *MNRAS*, 401:791–851, January 2010.

[13] R. J. J. Grand, F. A. Gomez, F. Marinacci, R. Pakmor, V. Springel, D. J. R. Campbell, C. S. Frenk, A. Jenkins, and S. D. M. White. The Auriga Project: the properties and formation mechanisms of disc galaxies across cosmic time. *MNRAS*, 467:179–207, May 2017.

[14] Lacegal latinamerican chinese european galaxy formation network., 2017.

Firma del Director

Firma del Estudiante