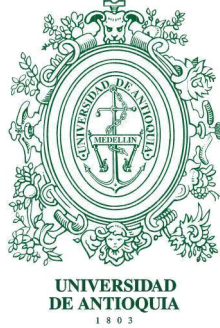


UNIVERSIDAD DE ANTIOQUIA
FACULTAD DE CIENCIAS EXACTAS Y NATURALES
INSTITUTO DE FÍSICA

THE PLACE OF THE MILKY WAY AND ANDROMEDA IN THE COSMIC WEB

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The next web page contains updated information about this thesis and related topics:

<https://github.com/sbustamante/Thesis>

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First Edition, September 2013

To all my family and friends.

Abstract

Observaciones de la CMBR y algunos surveys muestran que en $z=8$ aproximadamente, los modos del campo de densidad de materia comienzan a entrar en régimen no lineal. Una de las características más interesantes de este régimen es el clustering debido al colapso gravitacional de las regiones sobredensas y la formación de estructuras jerárquicas a gran escala, en especial la estructura de red que se manifiesta tanto en simulaciones como en surveys (e.g. The Sloan Digital Sky Survey) y que presenta una alta anisotropía a escalas de Mpc pero tiende a ser isotrópica a escalas de Gpc. Ahora, esta alta anisotropía a escalas de Mpc permite definir un entorno para galaxias y clusters, donde según el esquema usado, se puede cuantificar de diferentes maneras; un esquema común constituye cuatro tipos de entornos: voids, filaments, sheets y knots, basados en la geometría local de la distribución de materia (e.g Hoffman Y. Metuki O. et. al., 2012, MNRAS, 425, 2069, Forero-Romero, J. E. Hoffman Y. et. al., 2009, MNRAS, 396, 1815, Hahn O. Porciani C. et. al., 2007, MNRAS, 409, 355).

Recientes estudios han mostrado que la influencia del entorno en el cual están embebidos los halos de materia oscura tiene importantes implicaciones en las propiedades de formación de las galaxias. Siguiendo esta línea, se estudia la influencia del entorno en sistemas tipo grupo local (LG), definidos en este caso como sistemas de dos halos tipo Vía Láctea – Andrómeda (Andrómeda es la galaxia más cercana y junto con la Vía Láctea forman un sistema aproximadamente aislado.) que satisfacen propiedades de aislamiento, de distancia relativa, entre otras (ver Forero-Romero, J. E. Hoffman Y. et. al., 2009, MNRAS, 396, 1815).

Los sistemas tipo LG son extraídos de catálogos de simulaciones cosmológicas de materia oscura; una de las simulaciones tiene condiciones iniciales completamente aleatorias y es suficientemente grande (250 Mpc/h) para ser usada en la construcción de distribuciones estadísticas necesarias, y tres simulaciones restringidas (Gottloeber et. al., 2010, arXiv:1005.2687) en las cuales las condiciones iniciales son escogidas específicamente para reproducir el universo local a $z=0$, que aunque con un volumen menor (64 Mpc/h), poseen sistemas tipo LG muy bien definidos. A partir de la muestra de LG de las simulaciones restringidas se propone un método para determinar una muestra análoga en simulaciones no restringidas partiendo de la forma local de la distribución de materia, después de esto se buscan correlaciones respecto al entorno en el que están embebidos los LG y posibles sesgos producidos en las historias de acreción.

Este estudio sugiere que el entorno más favorable para la formación de sistemas tipo LG son regiones dos dimensionales o sheets, para las cuales la distribución local de materia colapsa en una dirección y se expande en otras dos, mientras que no hay un sesgo aparente en las historias de acreción debido al método de construcción de la muestra LG en la simulación no restringida.

Acknowledgements

Estos son los agradecimientos.

Sinceramente,

Sebastian Bustamante

September 2013

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*“Equipped with his five senses, man
explores the universe around him
and calls the adventure Science”*

Edwin Hubble

CHAPTER

1

Preliminaries

“What is our place in the cosmos?” This is one of the simpler and transcendental question that human beings have wondered from ancient times; furthermore, this, being powered by our innate curiosity, has led to a relatively understandable and structured picture of our Universe. Despite of that, this knowledge is very new regarding to our whole history, so the astronomy can only be considered as a scientific rigorous discipline since the seventeenth century.

1.1 Prehistory

Almost in every scientific discipline, a significant theoretical development is accompanied by a technical and instrumental improvement. That is why at the beginning of the seventeenth century, Johannes Kepler could establish his three well-known empirical laws of the planetary movements based upon the very precise data of astronomical bodies compiled by Tycho Brahe. This event was very remarkable in the history of the astronomy since it was the first of many strikes against the well established anthropocentric notion of the cosmos. Although Kepler’s laws constituted the most crucial test to the Nicolaus Copernicus’s heliocentric model, it was only until 1685, when Isaac Newton formulated the law of universal gravitation

1. PRELIMINARIES

(from which can be derived all the Kepler's laws), when the astronomers could count with enough powerful theoretical tools to start a depth and serious discussion about the real nature of our universe on scales bigger than the solar system, and thus inaugurating the *sciences of gravity* [2].

After the establishment of the law of universal gravitation, the next significant theoretical achievement in this area came in the centuries eighteenth and nineteenth with the development of classical mechanics, i.e. Hamiltonian and Lagrangian formalism, and powerful numerical tools. All those achievements propelled the study of key topics as the many body problem, chaotic phenomenons, etc. Allowing a depth understanding of the dynamic of complex gravitational system, as planetary system, star clusters, etc.

Parallel to the previous theoretical advances, on the observational branch was beginning to arise the idea of *island universe*, from which would evolve the concept of galaxy. All of this was powered by the development of the telescope, furthermore allowing to understand that galaxies are just a large collection of stars like our sun. It was also very remarkable the pioneer work of William Herschel, who tried to build a complete map of our galaxy determining distances from the assumption of stars with the same intrinsic luminosity and with the inverse square law for the intensity decay (see figure 1.1). Although his results were very imprecise due to the incorrect assumption on which were based, the importance of his work lies on the recognition of some structure (disk-like) for our galaxy.

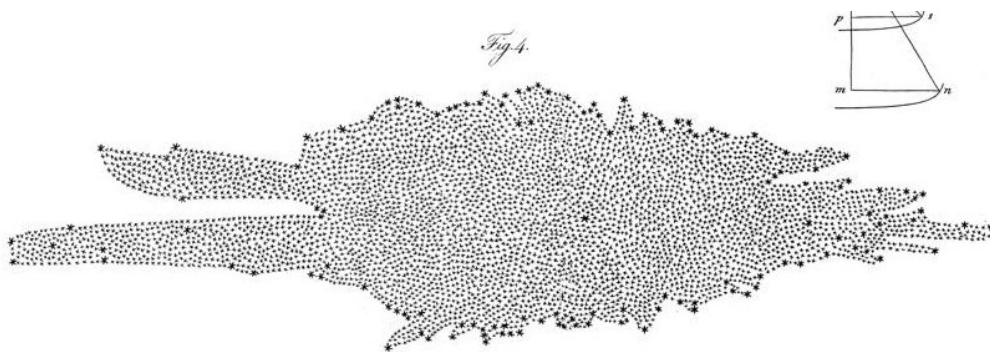


Figure 1.1: William Herschel's model of our galaxy based upon star counts and the equal luminosity assumption.[1]

Another important observational question, that was emerging among scientists in that time, was about the existence of *island universes* like ours. It was already well-known the existence of extended objects that do not fit to the definition of stars or planets, like nebulae, planetary disks and galaxies. Even, William Herschel and his son, John Herschel, contributed with the realization of a large (for the epoch) catalogue of extended bodies known as *Catalogue of Nebulae and Clusters of Stars* and a subsequent improved and expanded version finished by John Dreyer in 1888, *New General Catalogue of Nebulae and Clusters of Stars*, which together with *Index Catalogues* of 1895 and 1908 constitute a large collection of bodies widely used in current astronomy, referred with the abbreviations *NGC* and *IC* respectively [2]. Despite of those observational advances, the real nature of these objects was a complete mystery, especially if they lie within our own galaxy or are completely independent systems.

This question remained until twentieth century and together with the real size of the universe were the two big issues treated in the well-known *Great Debate*, also called the *Shapley-Curtis Debate*, an important event in the history of astronomy where the astronomers Harlow Shapley and Herber Curtis gave respectively different arguments in favour of and against the belonging of these objects to our galaxy and the Milky Way as our whole universe. Despite of this, their arguments were not very conclusive and the solution to these issues had to wait until 1924 when Edwin Hubble measured the distance to Andromeda Galaxy (M31 or NGC 224) and demonstrated unquestionably the real extragalactic nature of this object, and in the following years for other ones. This achievement together to the observational verification of expanding universe (also due to Hubble) were the beginning of modern observational cosmology.

It also happened in the twentieth century a key event for the modern sciences of gravity, Albert Einstein formulated his theory of General Relativity, changing completely the previous conception of space and time and laying the foundation of current cosmology picture.

1. PRELIMINARIES

1.2 The Current Cosmology Picture

The conceptions of space and time were misunderstanding before 1900 century and their connection with the gravitational interaction was completely neglected, both key issues for the adequate understanding of our universe, it is for these reason that the formulation of the General Relativity opened the door to a complete set of theoretical tools

1.3 Cosmological Observations

1.4 Numerical Simulations

*The cosmos is all that is or ever was
or ever will be. Our feeblest con-
templations of the Cosmos stir us,
there is a tingling in the spine, a
catch in the voice, a faint sensation,
as if a distant memory, or falling
from a height. We know we are ap-
proaching the greatest of mysteries.*

Carl Sagan

CHAPTER

2

Theoretical Framework

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2.1.1 General Relativity and Friedmann Equations

2.1.2 The Perfect Fluid Equations

2.1.3 Simple Solutions of the Universe

2.1.4 Cosmological Parameters

2.2 Nonlinear Evolution and Structure Formation

2.3 Quantification of Cosmological Environment

2.3.1 The T-web Method

2.3.2 The V-web Method

2.4 The Local Group

*Historical methodology, as I see it,
is a product of common sense ap-
plied to circumstances.*

Samuel E. Morison

CHAPTER

3

N-Body Simulations and Environment Characterization

A brief introduction to N-body simulations bla bla bla bla bla bla bla bla bla
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CHAPTER

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Results

A brief introduction to Results section

4. RESULTS

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4.1.1 Environment Distributions

4.1.2 Halos Distributions

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4.2.1 Statistical Properties of Pairs

4.2.2 Angular Momentum and Energy

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4.3 Correlations Between the Environment and Pairs Properties

4.4 Orientation of Pairs Angular Momentum

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Nomenclature

IC Index Catalogues

LG Local Group

NGC New General Catalogue of Nebulae and Clusters of Stars

Declaration

I herewith declare that I have produced this work without the prohibited assistance of third parties and without making use of aids other than those specified; notions taken over directly or indirectly from other sources have been identified as such. This work has not previously been presented in identical or similar form to any examination board.

The dissertation work was conducted from 20XX to 2013 under the supervision of Name Surname and Name Surname at the University of Deusto.

Bilbao,

This dissertation was finished writing in Medellín, Colombia on Sunday 15th
September, 2013

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