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Introduction to Astroparticles: The Unknown Dark Matter

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Abstract

This project's main goal was to address the need to introduce the student to basic concepts important for a future project in astrophysics. After revising theoretical aspects of special and general relativity, cosmology and dark matter (evidences, candidates and detection), an experimental focus was given to rotation curves of spiral galaxies. It was used the standard "exponential disk + dark matter halo" model [1] and the program Wolfram Mathematica 10.0 to obtain fits for the rotation curves of the spiral galaxy NGC 3198.

Key words: Astrophysics, Dark Matter, Rotation Curves.

Introduction

Since **Dark Matter**'s existence was postulated by Zwicky in 1937 [2], after the first studies on galactic rotation curves, a variety of evidence has accumulated in support of it, including gravitational lensing of distant galaxies by foreground structure.

The name comes from the fact that it does not interact with electromagnetic radiation like ordinary matter (it does not emit or absorb light). However, it is possible to detect its presence indirectly by its gravitational effects, and may be detected in a near future by annihilation products or nuclear recoils.

According to PLANCK Collaboration's results [3] from 2013 on the Cosmic Microwave Background, the **Ordinary (Baryonic) Matter**, which forms everything we know exist, contributes with only 4.9% of the observable universe, leaving 26.8% of it for the mysterious **Dark Matter (DM)**. The 68.3% left are attributed to a **Dark Energy** that could explain the accelerated expansion of the universe.

The possible connection of this dark matter, whose nature is still unknown, with theories beyond the Standard Model makes it one of the most important open problems in modern cosmology and particle physics.

Results and Discussion

The mass distribution in a spiral galaxy can be studied by a rotation curve, i.e. rotation velocities of the mass components as a function of their distance from the galactic center (r). However, the experimental curves cannot be explained only by the amount of visible matter (gas+stars), based on Newtonian dynamics (Equation 1). An example is shown in Image 1 (purple dots are observed data). Far from the galaxy's visible extent (at radius R_{25}: isophote of constant brightness 25 mag arcsec^{-2}), velocities are still rising or remain constant. To account for the missing mass, a spherical halo of DM with mass (M(r)) given by Equation 2 is added.

$$v=\sqrt{GM(r)/r} \quad (1) \qquad \rho(r)=\rho_0\left(1+(r/R_c)^2\right)^{-1} \quad (2)$$

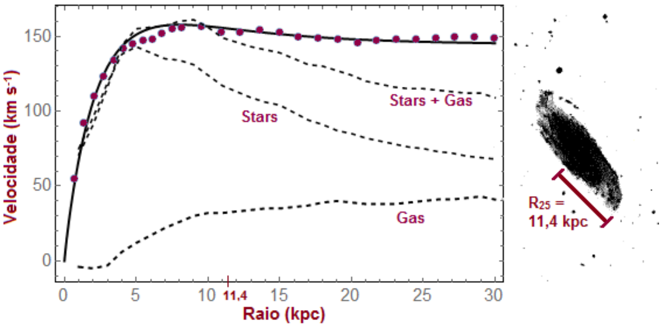

Image 1. Galaxy NGC 3198. Left: Experimental rotation curve (dots) [4], fit with DM (full line) and separate luminous contributions (dashed lines) [5]. Right: Optical image with visible extent indicated.

There are three types of DM candidates [6]:

(1) Hot Dark Matter: particles that were relativistic at the time of galaxy formation, for example neutrinos.

(2) Cold Dark Matter: the ones that were non-relativistic like axions, WIMPs (Weakly Interacting Massive Particles) and MACHO's (Massive Compact Halo Objects) like brown and white dwarfs, neutron stars and even black holes.

(3) Warm Dark Matter: the ones that were semi-relativistic like gravitinos and sterile neutrinos.

Conclusions

The project proved to be very important for a first approach to the astrophysical world. The Dark Matter issue was better understood, and the reproduction of the rotation curves was very useful due to the closer contact with computational tools.

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