Observational evidence for Dark Matter

Introduction

Dark Matter; most have heard of it, few know about it, and none have directly observed it. Its inception can be dated back to the 1880's, although the first evidence came about in the 1930's when Fritz Zwicky observed the redshift of galaxies in the Coma cluster. Peculiarly, the galaxies were rotating with such velocity that they should not have remained held together – and yet they were. Zwicky, using the virial theorem, inferred the existence of the mysterious 'Dark Matter', which accounted for the large amount of missing mass that provides the sufficient gravitational attraction to hold the cluster together. His work, however, (due to too much uncertainty in his findings, and overestimated claims) was not widely accepted, until Vera Rubin's much more accurate findings in the 1970's. Rubin catalogued several galaxies and found rotational velocities were much faster than expected. Instead of velocity dropping off as radius increased it remained constant and hence, in addition to Zwicky's work, highlighted the existence of an unknown influence acting on the celestial objects. So began the journey into narrowing down what Dark Matter is, and what it is not.

What is known

While scientists still do not know precisely what it is, their research and observations can eliminate options. For instance, it cannot be an electron, or a proton as it does not interact with the electromagnetic force. It cannot be a neutron since they decay too fast, and dark matter is thought to be collisionless and do not interact with themselves; However, if it did, then there would be Dark Matter black holes, planets, stars etc for us to see clearly. Furthermore, from calculations using the Cosmic Microwave Background (CMB), the curvature of the universe, and with the rotation velocities of galaxies, it is known that Dark Matter accounts for 27% of the universe while Baryonic matter and dark energy account for 5% and 68% respectively.

What is not known

The main unknowns are the size of Dark Matter and whether it is a particle of another fundamental force. Thanks to scientists like Zwicky and Rubin, among others, we now know that Dark Matter exists, but in what form no one knows for certain. There is a myriad of theories but as research stands today there are three main concepts for what Dark Matter could be.

What it could be

Firstly, it could be a new particle not on the standard model with unknown traits such as an Axion like particle or extra dimensions. Secondly, it could be part of the current standard model or particle physics such as a Neutrino, a very light particle such as a Weakly Interacting Massive Particle (WIMP). Scientists have been looking for such a particle for over 25 years, searching the Milky Way's Dwarf galaxies for Gamma rays from annihilating Dark Matter particles. Setting up tanks of atoms such as Argon with high sensors below ground to hopefully witness one interacting with an atom. The CERN hadron collider has tried creating them, with no success perhaps because more energy is needed to create such a massive particle.

The third theory is the laws defining gravity are incorrect or incomplete, being replaced by modified Newtonian Dynamics (MOND) where baryonic matter interacts differently with gravity. However, for these, scientists have to replace all existing verified predictions, which is a tall order and unlikely relative to the first two theories. The MOND theory, for example, has been put into doubt with the discovery of the Bullet cluster. Which shows the main mass of the galaxy clusters does not lie with the majority of the Baryonic matter, (the gas clouds in-between), but with the galaxy clusters themselves. Also, a recent discovery of some dwarf galaxies with no Dark Matter, ironically is proof of its existence, since if it is the laws of gravity that are wrong then it would be the case for all galaxies, this lack of "Missing mass" shows us the reverse.

Observational evidence

Through the years, observational evidence of Dark Matter has been accumulating. As mentioned in the introduction, the first evidence was discovered by Fritz Zwicky (with his work on the Coma cluster, the virial theorem and *velocity dispersions*) and was later supported by the Vera Rubin's *rotation curves of galaxies*. Additionally, Dark Matter can be seen via *weak and strong gravitational lensing*. Originally hypothesised by Einstein in 1912, lensing involves a distribution of matter, in our case Dark Matter, bending light from a distance bright object as it passes through or around its pull. With this concept, Dark Matter can actually be mapped as to its location and quantity. *CMB* is another observational evidence of Dark Matter. Although Dark Matter does not interact with radiation directly, it does affect the CMB by its effect on ordinary matter, particularly its density and velocity, and its gravitational potential. Studying the fluctuations in the CMB show how Dark Matter is essential for the creation of galaxies and it is responsible for the cosmic webs structure.

Other observational evidence of Dark Matter include: hot gas in the clusters, structure formation, bullet cluster, type Ia supernova distance measurements, sky surveys and baryonic acoustic oscillations, with out a doubt it exists, it is just a matter unveiling her cloak of mystery.

Future work

Millions of pounds are being funded into Dark Matter all around the world, from hope of finding it via gravitational waves to interactions with electrons, to computer simulations with copious amounts of data showing its true and full nature. Telescopes are being built for this purpose, more underground tanks for the continued search of WIMPS, and so much more. Discovering what Dark Matter really is will change the universe we live in, much like the discovery of the electron changed mankind and allowed all this research to be collimated from around the world on one device within seconds.

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