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The Dark Mystery of the Universe

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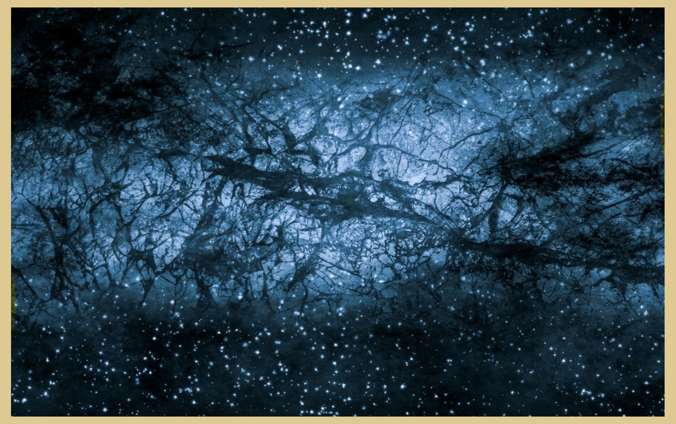

Introduction

- Dark matter remains to be one of the greatest mysteries of the universe
- Dark matter is thought to account for ~85% of the matter of the universe, yet has gone undetected due to its weak interaction with normal matter and no interaction with light
- Many contributions have been made to better understand the fundamental properties dark matter, yet no one has been able to detect it

Evidence for Existence

- Since dark matter does not interact with light, the proof of the existence of dark matter comes from indirect observations

Rotational Curves of Spiral Galaxies

- The relation between the velocity of stars in orbit around a galaxy and the distance between the stars and the center is given by the Keplerian curve
- According to this, the velocity of stars should fall at further distances from the center, but that's not what is found from observations (Sofue & Rubin, 2019)

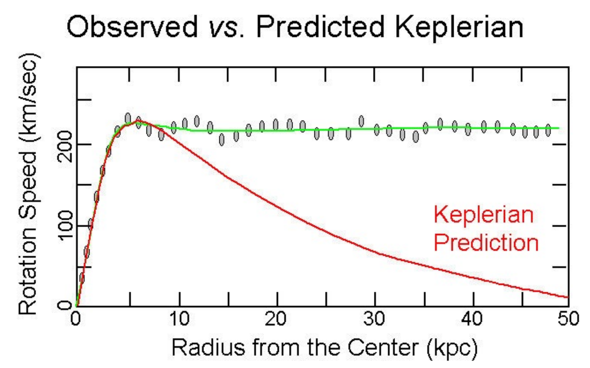

Fig 1: Predicted vs Observed Graphs of Rotational Spiral Galaxies

- The amount of luminous matter present is not enough for the stars near the edge to be moving at these high speeds (Bahcall, 2015)
- There must be other mass present, pointing to the possible existence of dark matter (Bahcall, 2015)

Gravitational Lensing

- Gravitational lensing describes the phenomenon in which large amounts of matter creates a gravitational field that distorts and magnifies light coming from distant galaxies (Massey et al., 2010)
- Gravitational lensing provides information in the foreground based on its effects on the background galaxies (Massey et al., 2010)
- The amount of distortion of light provides strong evidence for the existence of vast amounts of dark matter within and in between galaxies (Bahcall, 2015)

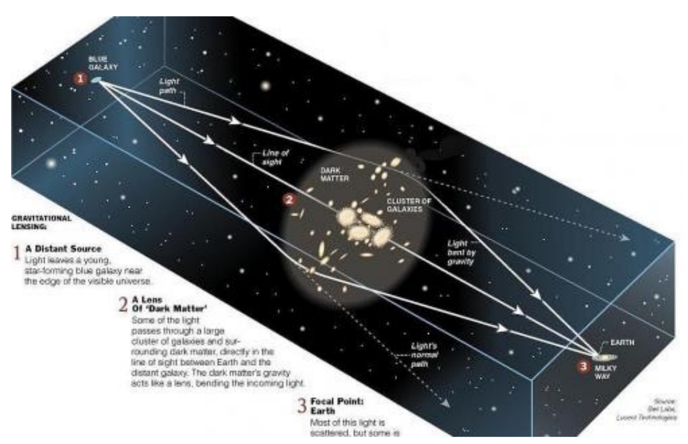

Fig 2: Gravitational Lensing Diagram

Cosmic Microwave Background Radiation

- The cosmic microwave background radiation shows what the universe looked like before galaxies and clusters were formed (Jones & Lasenby, 1998)
- Ordinary matter interacts strongly with radiation while dark matter does not
- Ordinary and dark matter perturbations leave different imprints on the CMB, again pointing to the existence of dark matter (Bahcall, 2015)

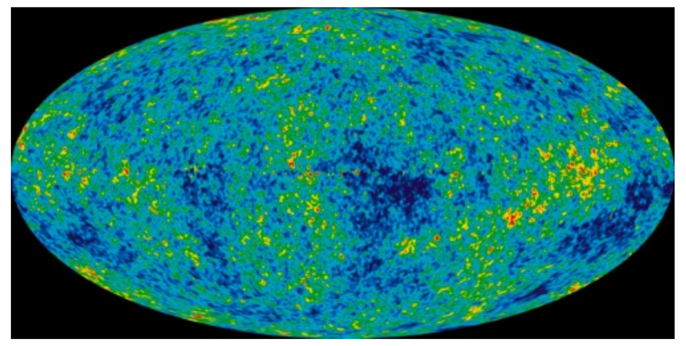

Fig 3: Cosmic Microwave Background Radiation Diagram

Current Experiment Methods

- Although the existence of dark matter is widely accepted by physicists around the world, the form and properties of dark matter have not yet been determined
- There are three ways in which physicist attempt to detect dark matter

Make Dark Matter in Accelerators

- One methods of searching for dark matter is to generate them by smashing protons together at nearly the speed of light (Chodos, 2004)
- Violent head-on collisions convert energy into showers of exotic particles scattering in all directions (Lowette, 2016)
- The hope is that within this debris, a short-lived dark matter particle will blink into existence (Lowette, 2016)
- This is not something new. The same method was used over a decade ago to discover the Higgs boson
- It is being used again by the European Organization for Nuclear Research, or CERN to discover the existence of dark matter

Indirect Detection of Dark Matter

- This method of searching for dark matter focuses on looking for the products of dark matter interactions rather than the particle themselves (Leane, 2020)
- In general, one looks for gamma-rays, cosmic-rays, or neutrinos
- For example, although dark matter may not interact with light, the debris from two colliding dark matter particles may produce things such as gamma-rays, which are detectable (Leane, 2020)
- Some instruments that have been used to detect dark matter indirectly include H.E.S.S., VERITAS, and MAGIC

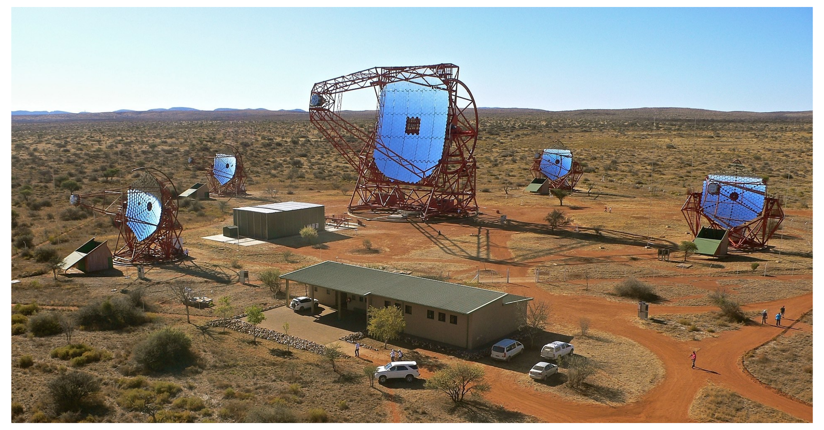

Fig 4: H.E.S.S. Telescope

Direct Detection of Dark Matter

- Direct detection of dark matter attempts to directly measure dark matter collisions on Earth (Billard et al., 2021)
- A big problem is that the surface of the Earth is bombarded by cosmic rays, which create too much noise to be able to use direct detection
- Therefore, detectors designed to directly detect dark matter are placed far underground and inside mountains, where there is barely any noise (Billard et al., 2021)
- One example of an experiment using direct detection is XENON in Italy at the Gran Sasso Laboratory
- It is the brainchild of physicist Elena Aprile at Columbia University
- The experiment uses an instrument called the dual-phase, xenon-based time-projection chamber
- The very first iteration of the XENON series was XENON10 in 2007
- Competing experiments include LUX, ZEPLIN, and PANDAX

Fig 5: Dual-Phase, Xenon-Based Time-Projection Chamber

Results and Conclusion

- There is a great amount of indirect evidence pointing to the existence of dark matter
- No experiment has been successful in uncovering the mystery of dark matter
- Physicists continue to develop better experiments in order to finally detect dark matter
- Understanding the properties of dark matter is important because it is thought to have played a fundamental role in the formation of galaxies and can be the answer to many observations

Results and Conclusion

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