What is dark matter and how can we detect it?

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Introduction: Astounding evidence for invisible 'dark' matter has been found from many different experimental studies. Although all studies indicate that there is a dominant presence of non-luminous matter in the universe (about 22% of the total with 5 times more dark matter than normal matter), its identity and its 'direct' detection has not yet been achieved. Dark matter in the form of massive, weakly interacting particles (WIMPs) could be detected through their collisions with target materials. This requires detectors to be extremely sensitive and therefore, very difficult to build. This research discusses some of the techniques and challenges to detecting dark matter.

Evidence for Dark Matter: The apparent disagreement between luminous mass observations and expected mass calculations was first discovered in the early 1930s. Since then, evidence for such dark matter has been found through many different types of studies:

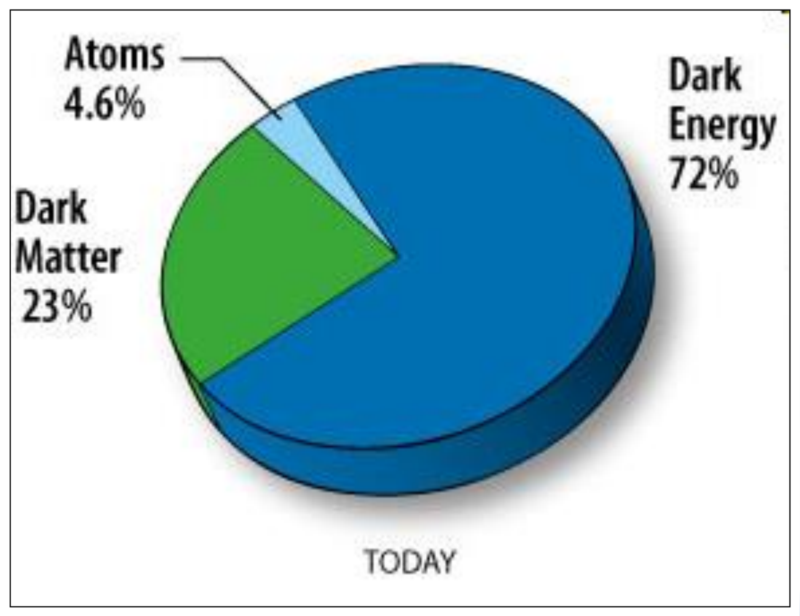

Figure 1: The current "composition" of the Universe.[1]

- Analyzing the motion of gas/stars in galaxies.[2]
- Analyzing the motion of gas/galaxies in galaxy clusters.[2]
- Measuring the distortion of spacetime from general relativity through gravitational lensing.[2]
- Fitting the fluctuations in the Cosmic Microwave Background (CMB) radiation to determine the "composition" of the Universe.[1]

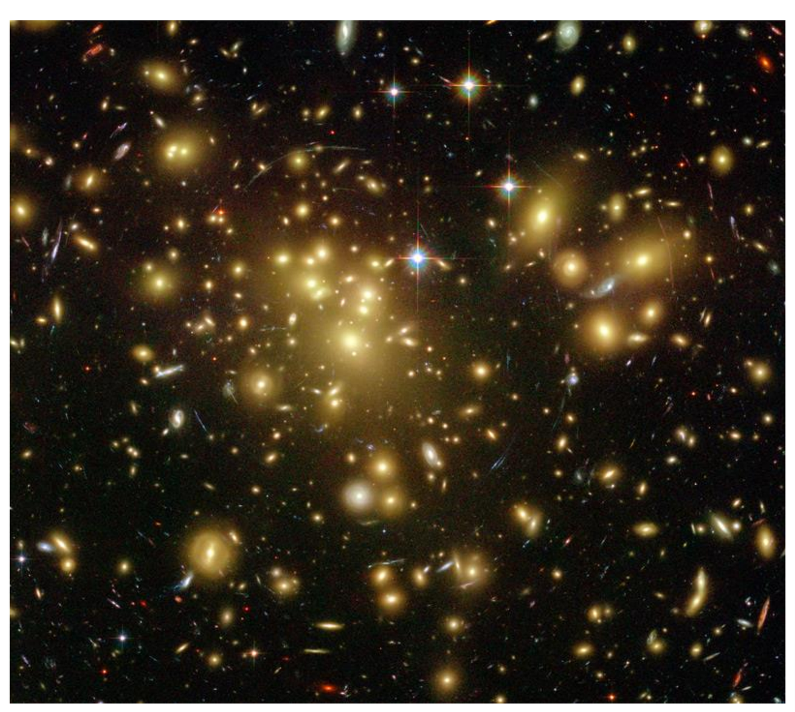

Figure 2: Gravitational lensing.[2]

All studies have the same conclusion:
There is a lot more mass than we thought.

One popular model for dark matter is that all galaxies, including our own, are surrounded by a large spherical halo of dark matter made out of particles called WIMPS (weakly interacting massive particles).[2]

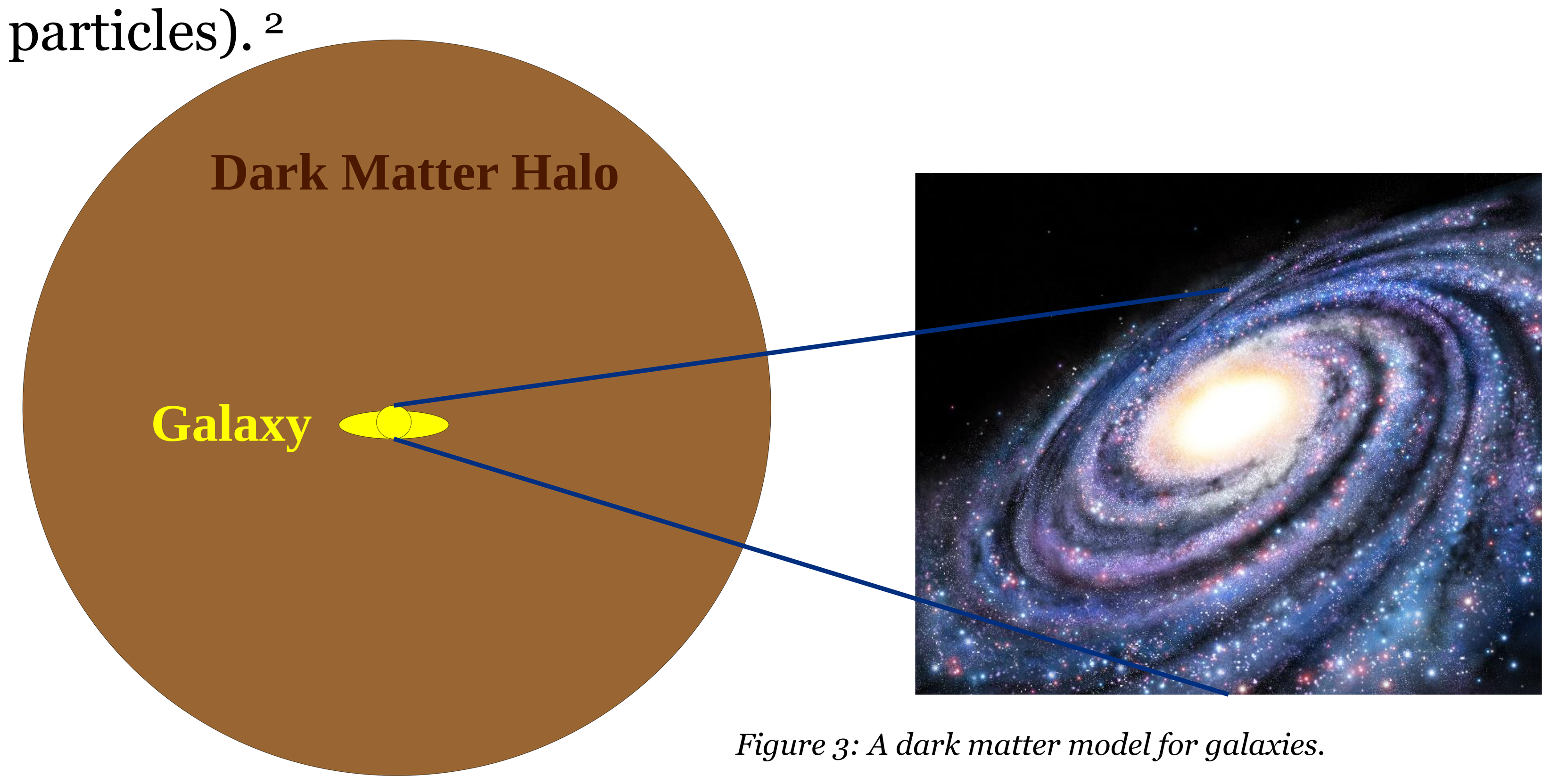

Figure 3: A dark matter model for galaxies.

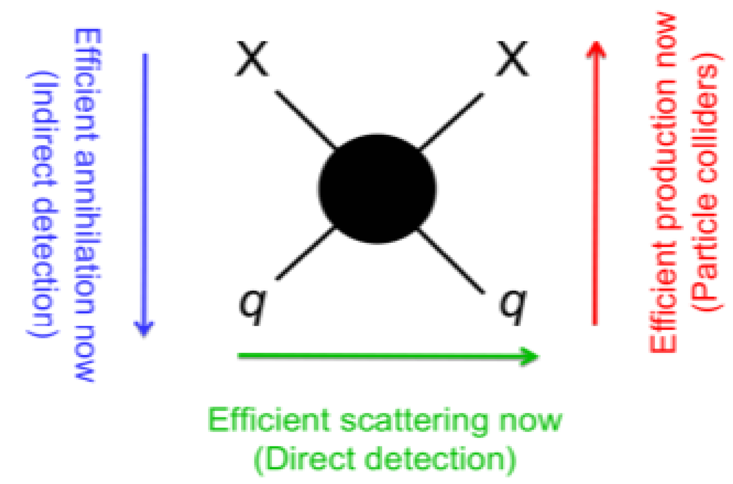

Figure 4: Three methods of detection.[2]

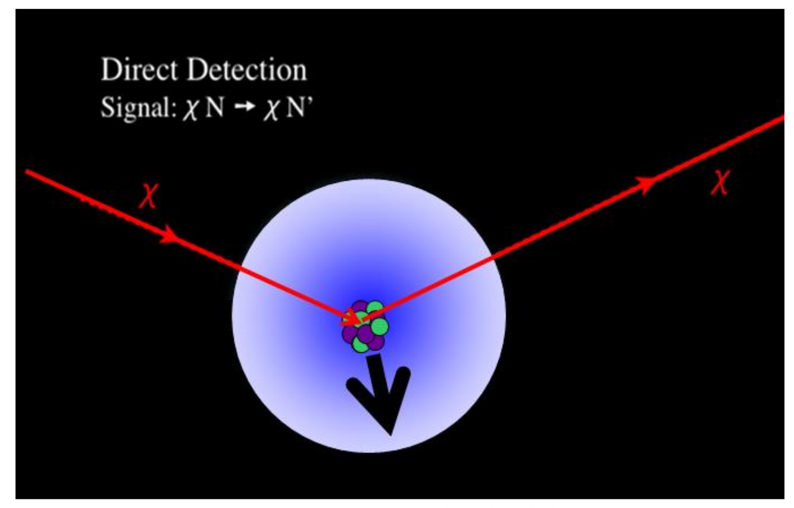

Figure 5: Scattering method of detection.[2]

Detecting Dark Matter: There are three main ways researchers are currently searching for dark matter:

1. Annihilation (ex. balloons): Two WIMPs (X+X) destroying each other and producing normal particles (q+q).
2. Production (ex. LHC): WIMPs (X+X) produced by two normal particles (q+q) colliding.
3. Scattering (ex. DarkSide): One WIMP (X) colliding with a normal particle (q).

Although there is a lot of indirect evidence for dark matter:
Direct detection of dark matter has not been achieved.

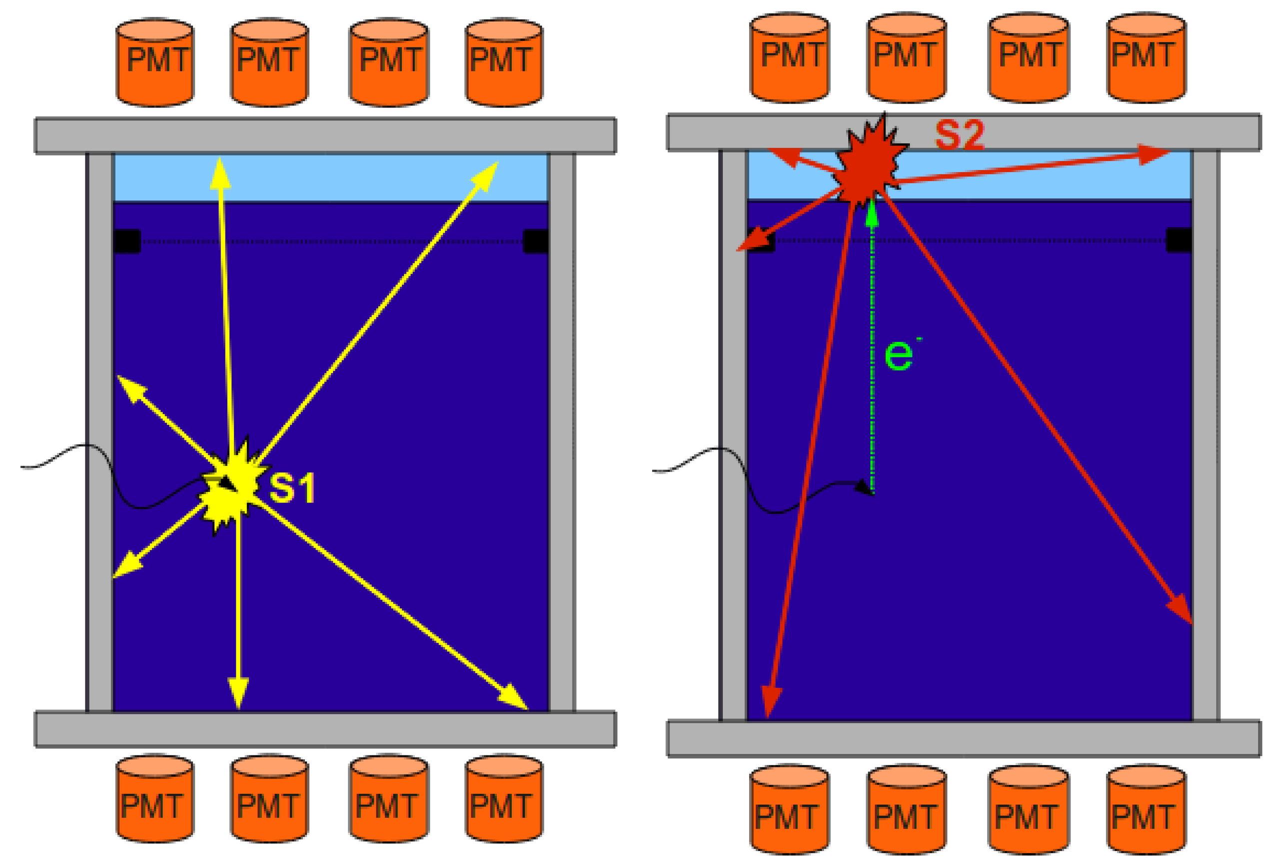

Figure 6: A schematic of how a two-phase TPC works.[2]

Scattering Method: When a particle, such as an electron, neutron, proton, WIMP, etc., enters the detector, the target material can be scattered as shown in Figure 5. The scattering method, also called direct detection, is probably the most popular method currently being used to detect dark matter. One such detector (as shown in Figure 6) consists of two phases (liquid and gas) of the target material (usually a noble gas) in a time projection chamber (TPC).[3] An incident WIMP would come in and hit the nucleus of the target material. The nucleus then recoils and produces both scintillation (light) and ionization (electrons). The scintillation light (S1) is detected by photomultiplier tubes (PMTs) and the ionized electrons move along an electric field to the gas layer where they produce a second scintillation signal (S2). Using a two-phase TPC, it is possible to determine what type of particle caused the signals based on the intensity, duration, and patterns of the S1 and S2 signals. Once you weed out all of the signals from known particles, any signal leftover could be from a newly discovered particle of dark matter.

DarkSide: DarkSide-10, a 10 kg prototype detector, ran at Gran Sasso National Laboratory (LNGS) in Assergi, Italy from 2012 to 2013. DarkSide-50, a 50 kg dark matter detector, is currently running at LNGS. LNGS is the largest underground laboratory in the world.

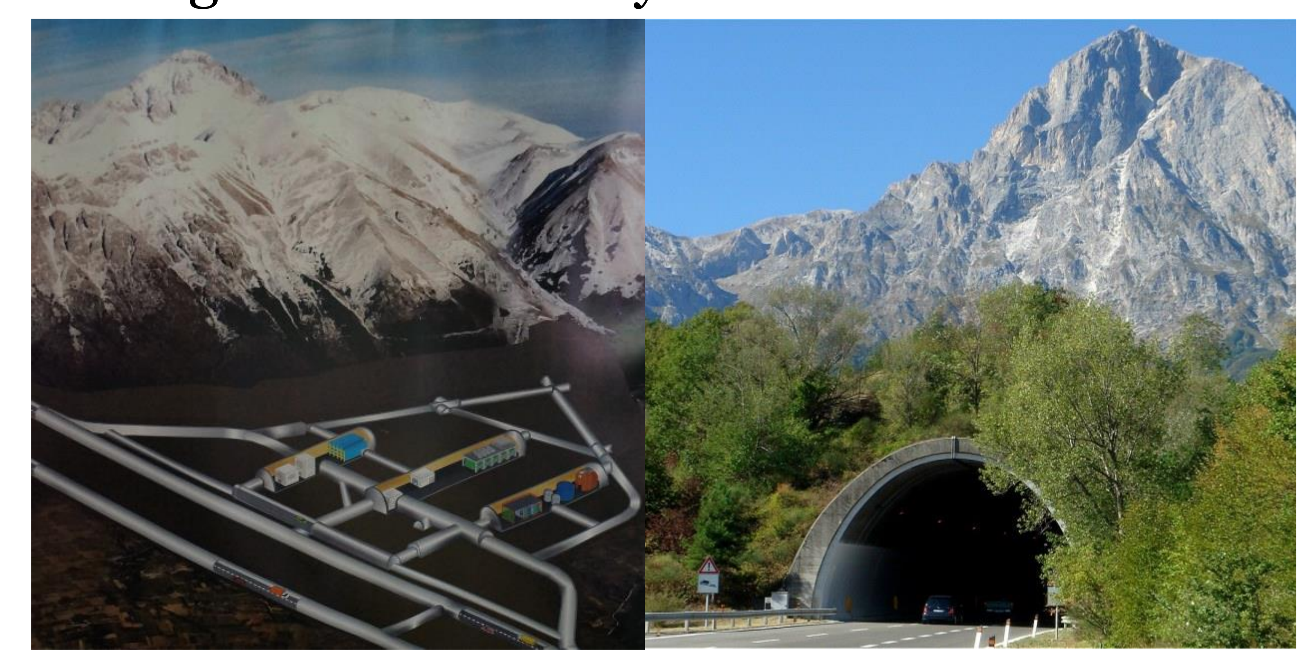

Figure 7: Images of LNGS.[2]

The biggest challenge for detecting dark matter is background radiation.

DarkSide uses argon for the target material inside the two-phase TPC. The electric fields inside DarkSide-10 were tested above 5 kV/cm and were simulated, designed, and tweaked to produce the best particle discrimination.[2]

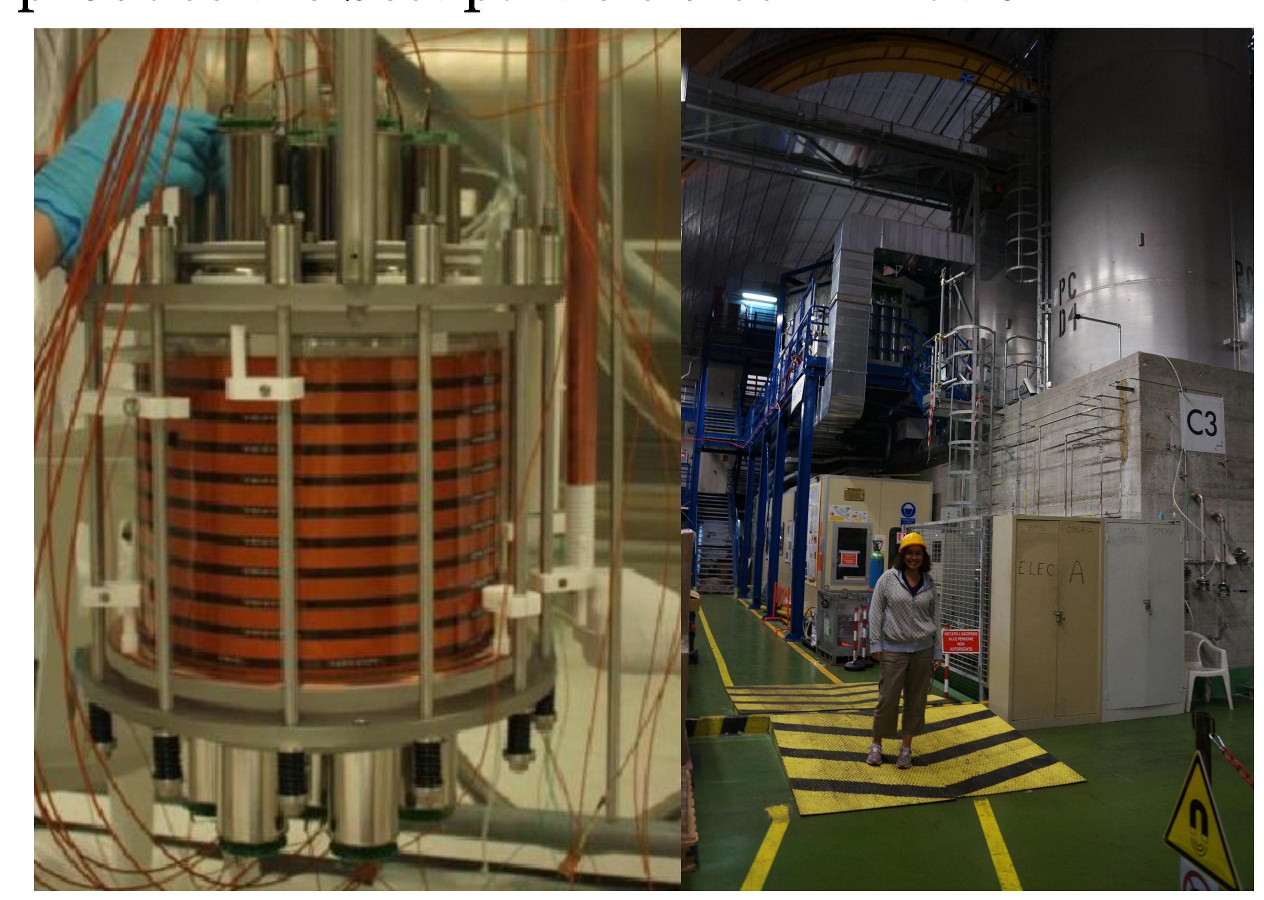

Figure 8: DarkSide-10 on the left and DarkSide-50's location inside LNGS.[2]

Conclusion: There are a lot of experiments that have shown indirect evidence for a large amount of non-luminous, missing mass called dark matter. There are three main ways to gain direct experimental evidence for new particles that make up the dark matter. DarkSide uses two-phase argon TPCs for the detection of scattering caused by WIMPs at LNGS, a lab deep underground. There are many experimenters currently searching for direct evidence of new particles and none have been successful yet.

References:

[1] WMAP, http://map.gsfc.nasa.gov/universe/uni_matter.html

[2] Love, C. PhD Thesis, Temple University, 2013.

[3] DarkSide, http://darkside.lngs.infn.it/