Dark Matter and Dark Energy

University Physics II

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The question of dark matter and dark energy is a question of the mass of the universe, or rather, the missing mass of the universe. In astrophysics electromagnetic radiation is the main source of information for far away objects. Many methods exist for determining the absolute magnitude (or luminosity) of an object given its apparent magnitude, its position relative to a standard candle, etc. Once its absolute magnitude is known the distance the object is away from you, its relative velocity, and other useful information can be calculated. Using standard gravitational laws and what is known as the Virial Theorem the mass of large celestial bodies can even be calculated, but there is a problem with these calculations. It has been discovered that using these equations that the mass to luminosity ratio of much of the universe is much higher than that of the current standard- the Sun. If the Sun is indeed an average star then its mass to luminosity ratio should be comparable to that of other stars. This means that there is a large amount of mass which is unaccounted for. This discrepancy between observed and theorized is the genesis of dark matter and dark energy.

Dark Matter

History and Evidence

It all begins with a Swiss astrophysicist named Fritz Zwicky. In 1933

Zwicky was working at the California Institute of Technology studying the motion of galaxies in galactic clusters. Specifically, he studied the velocities of several galaxies in the Coma cluster and used the Virial theorem to estimate its mass. What he came up with was something unexpected; the galaxies were moving far too fast for the cluster to remain stable. In order to remain stable the estimated mass of the cluster would have to have been orders of magnitude greater than would be expected from its luminosity. Obviously something was missing in this picture. Zwicky proposed that there was a substantial amount of matter that did not give off light or “dark matter” which made up for the missing mass. A few years later in 1937 Sinclair Smith was studying the Virgo cluster and ran into the same problem-the cluster had to have a larger mass than expected from its luminosity in order to remain stable. Even after both of these discoveries the presence of dark matter was not widely accepted. It would take more evidence for others to start to truly question whether all the mass of the universe was accounted for.

It was later in the 1970's when Vera Rubin started examining spiral galaxies that people started to accept the possibility of dark matter. She discovered the rotational velocities of spiral galaxies were much faster than they should be according to estimates based on visible stellar mass and neutral hydrogen and helium that can be detected using the infrared spectrum. Rubin worked on galactic rotation curves-graphs of orbital velocity versus the distance a star is from the center of a galaxy. What she found was a seeming paradox, the velocities of stars farther out tended to remain constant with respect to distance instead of dropping off as gravitational theory suggests it should. Rubin proposed there must be a large halo of dark matter around the core of the galaxy to account for the high velocities of stars at the edges of the galaxies.

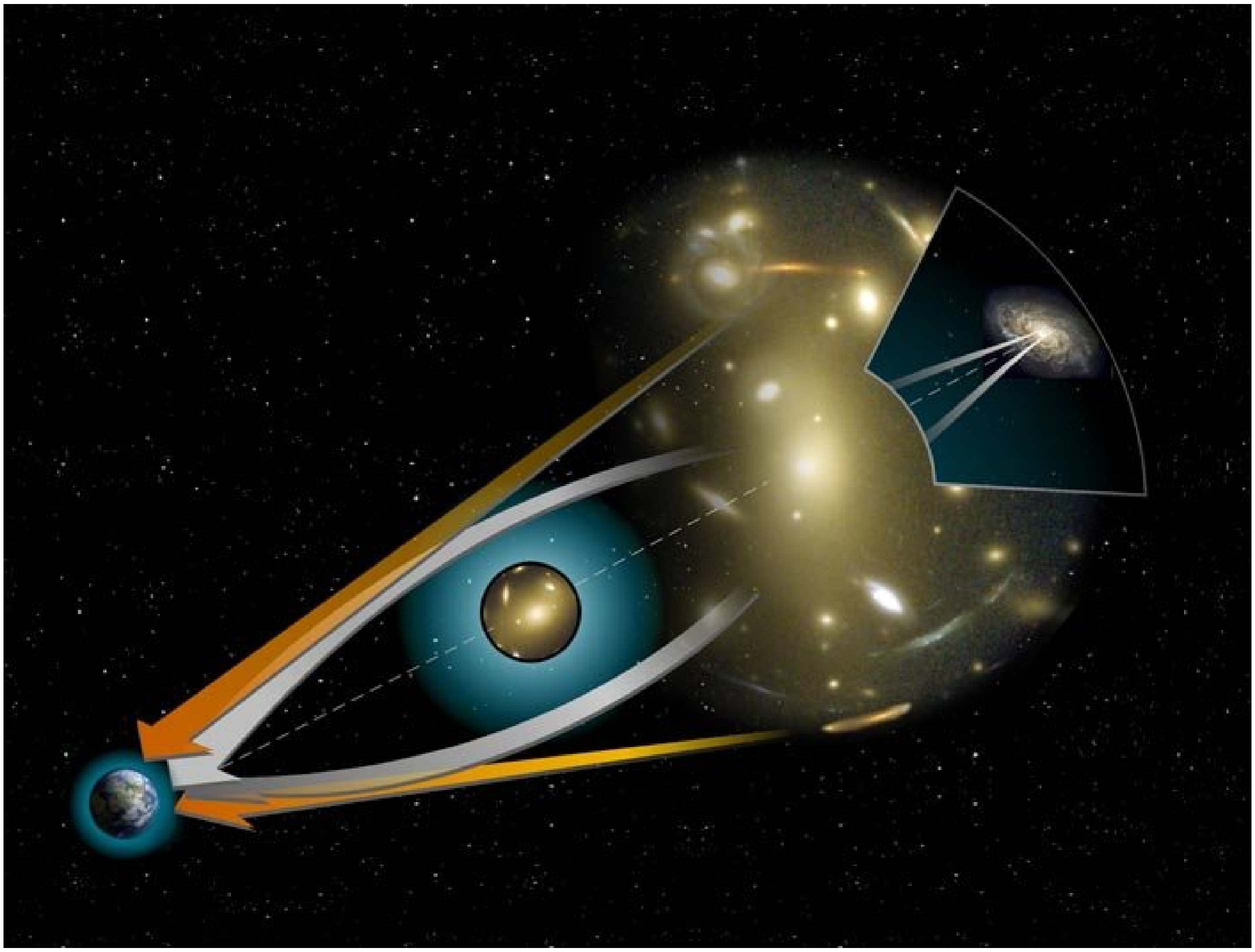
Rotational Curve of a spiral galaxy with (A) predicted and (B) observed curves [1]

Currently, the best evidence for dark matter has come from studying a two colliding clusters of galaxies known as 1E0657-558 or “The Bullet

Cluster." In 2006 Douglas Clowe, with others, studied x-ray emitted from the plasma that makes up most of the system and gravitational lensing of the system. What they discovered, and what makes the Bullet Cluster such good evidence for dark matter, is the apparent separation of gravitational lensing from detectable baryonic matter in the system. This not only suggests that there is dark matter in the system but also defies current attempts to eliminate the need for dark matter by proposing a different theory of gravity, such as Modified Newtonian Dynamics (MOND).

Candidates/Detection Methods

There are several candidates for dark matter. They fall into several categories which are not all mutually exclusive: baryonic matter, non-baryonic matter, hot dark matter, and cold dark matter. Baryonic matter is, of course, the regular kind that people interact with each day such as protons, neutrons, etc. The first baryonic candidate is a part of cold dark matter called MACHOs or Massive Compact Halo Objects. This itself is a category of dark matter which often contains within it brown dwarfs, black holes, and neutron stars; however, the exact composition of a MACHO doesn't change the gravity exerted by the object and therefore gravity itself can be used to detect it. The current method of detection of a MACHO, called gravitational micro-lensing works by attempting to see distortions in light as a light source passes behind a large mass such that gravity causes the image to brighten, magnify, or otherwise change. The next baryonic candidate is simply non-luminous gas clouds. Gas clouds are largely made up of hydrogen which conveniently gives off radio waves of 21 cm wavelength when cold and x-rays when hot. However, there is a problem with gas; measurements of x-rays and radio waves seem to indicate that gas fails to make up the amount of matter needed to indicate it is dark matter.



Gravitational Lensing caused by a massive object. The orange lines are the apparent direction of light whereas the white lines are the actual path of light. [2]

In addition, there are non-baryonic candidates which includes those possibilities that are made up of exotic material. Non-baryonic dark matter has within it subdivisions of hot dark matter and cold dark matter. Hot dark matter is dark matter that travels at speeds close to the speed of light. The best candidate for hot dark matter would be neutrinos. Neutrinos are very small, nearly mass-less particles that only interact through gravity and the weak interaction. Because they don't interact with normal matter through the electromagnetic and strong forces neutrinos can easily pass right through normal matter and are thus very hard to detect directly. Once again though there is a problem, neutrinos existing just after the big bang would have traveled with such high velocities that they would tend to smooth out changes in density to the extent that galaxies and other structure as it currently exists in the universe should not be able to form. This means that neutrinos alone could not be the answer to the dark matter riddle.

Non-baryonic cold dark matter is seen as one of the most promising candidates to date for the missing mass of the universe. One of the more popular types of non-baryonic cold dark matter is a WIMP or weakly interacting massive particle. Due to their large mass WIMPs would be relatively slow moving and therefore clump together easier. This, of course, side steps one of the main problems of a purely hot dark matter explanation by allowing structures such as ones in existence today to form. There are several methods for detecting WIMPs. One method used by the Cryogenic Dark Matter Search is supercooling germanium and silicon crystals and wrapping them in tungsten and aluminum to detect the recoil of atomic nuclei as WIMPs hit them. Another similar method employs scintillators such as Argon. As WIMPs hit atomic nuclei in the scintillator light is produced which can then be detected and if background noise is filtered would indicate that a WIMP did indeed hit an atom.

Dark Energy

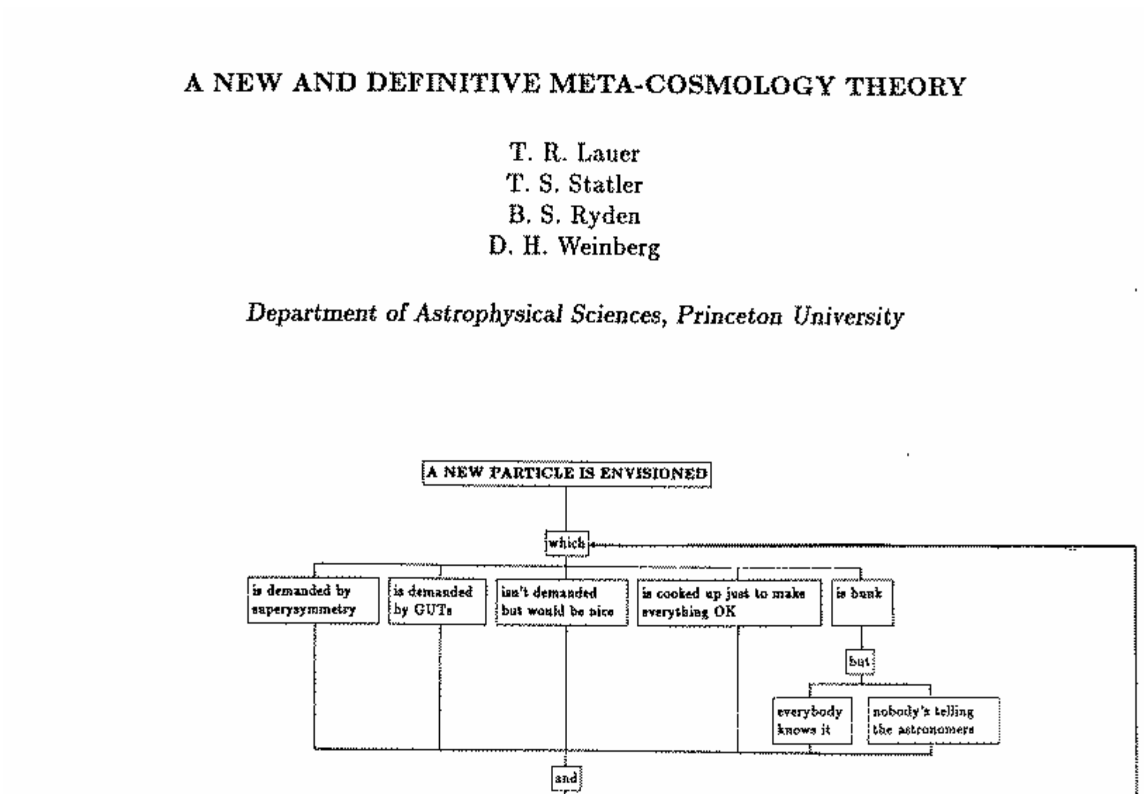
History/Evidence

Even less is known about dark energy than dark matter. Its history begins relatively recently in 1998 when the expansion of the universe was being measured using the Hubble space telescope. Adam Riess led a study of type 1a supernovae to examine the rate of expansion of the universe. Type 1a supernovae are known for their relatively constant brightness because they are caused when white dwarfs in a binary system gather enough mass to pass the Chandrasekhar limit- the amount of mass beyond which a white dwarf will fail to remain stable. After a white dwarf passes this limit the star collapses and explodes causing a supernova. The consistent brightness of this type of supernova makes it easier to determine their distance which in turn gives the age of the explosion. Examining the redshift of the light given off by the supernova also helps determine how much the universe has expanded since the explosion occurred. What Riess found was that contrary to previous theories the rate of expansion of the universe is actually increasing instead of decreasing.

Candidates/Detection Methods

So what would dark energy be? Not much is currently known about dark energy so the candidates are mostly speculation. Some physicists think that dark energy may be the cosmological constant Einstein proposed as a modification of his theory of relativity. It may be that the universe has a negative pressure that is implicit within its structure. Another proposed candidate is the so-called quintessence. Quintessence would cause the rate of acceleration to change, which agrees with current observations. However, this is similar to the Infinite Turtle theory in that it only moves the mystery of dark energy one step farther because the exact nature of quintessence is unknown. Much like the ancient Greeks who proposed quintessence as a fifth unknown element, not much can be said currently about it beyond some of its apparent properties.

Much of what we know about dark matter and dark energy is underscored by the large amount that we do not know. Science is and has always been a constantly developing field that is refined over time as new discoveries and theories arise. Various candidates for dark matter and dark energy may be ruled out as individual solutions but taken together they may represent the missing piece of the puzzle astrophysicists have been looking for. The only thing we know for sure is that with time new discoveries and theories will come that will hopefully shed more light on the mysterious dark energy and dark matter.



A NEW AND DEFINITIVE META-COSMOLOGY THEORY

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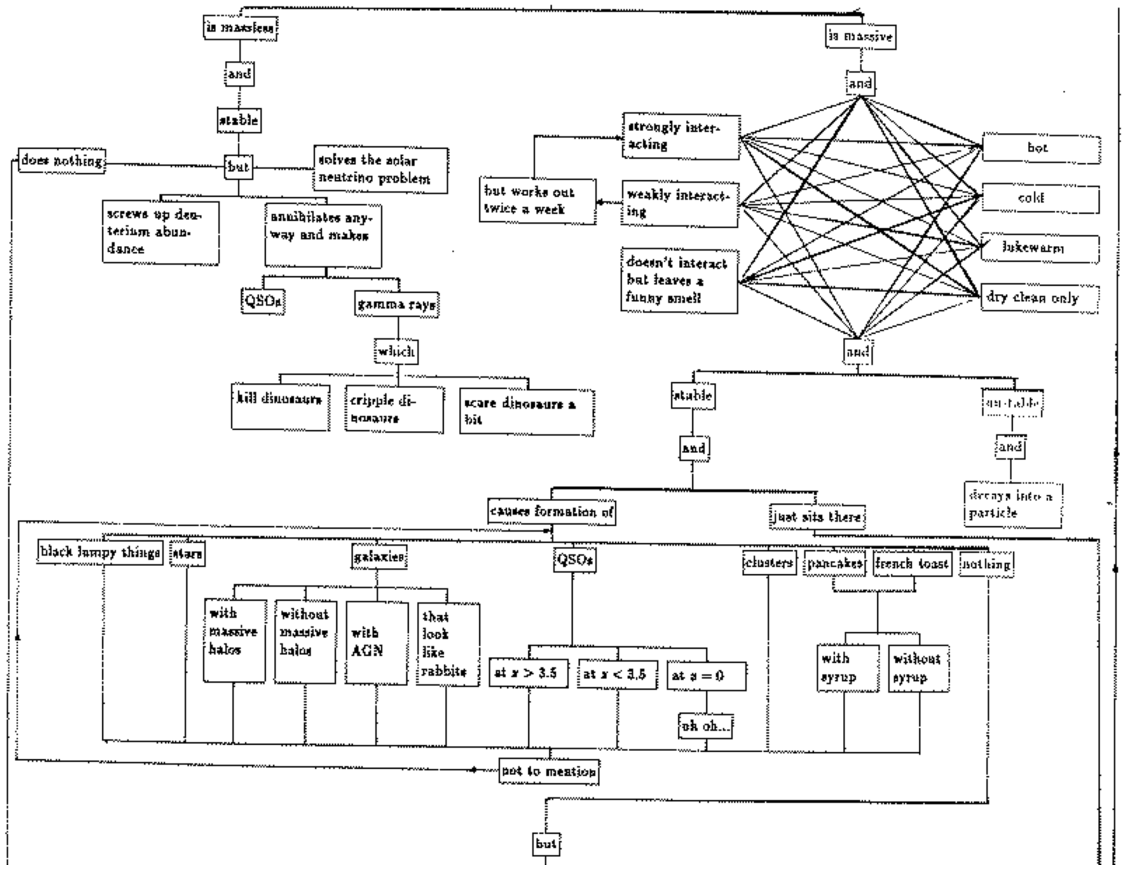
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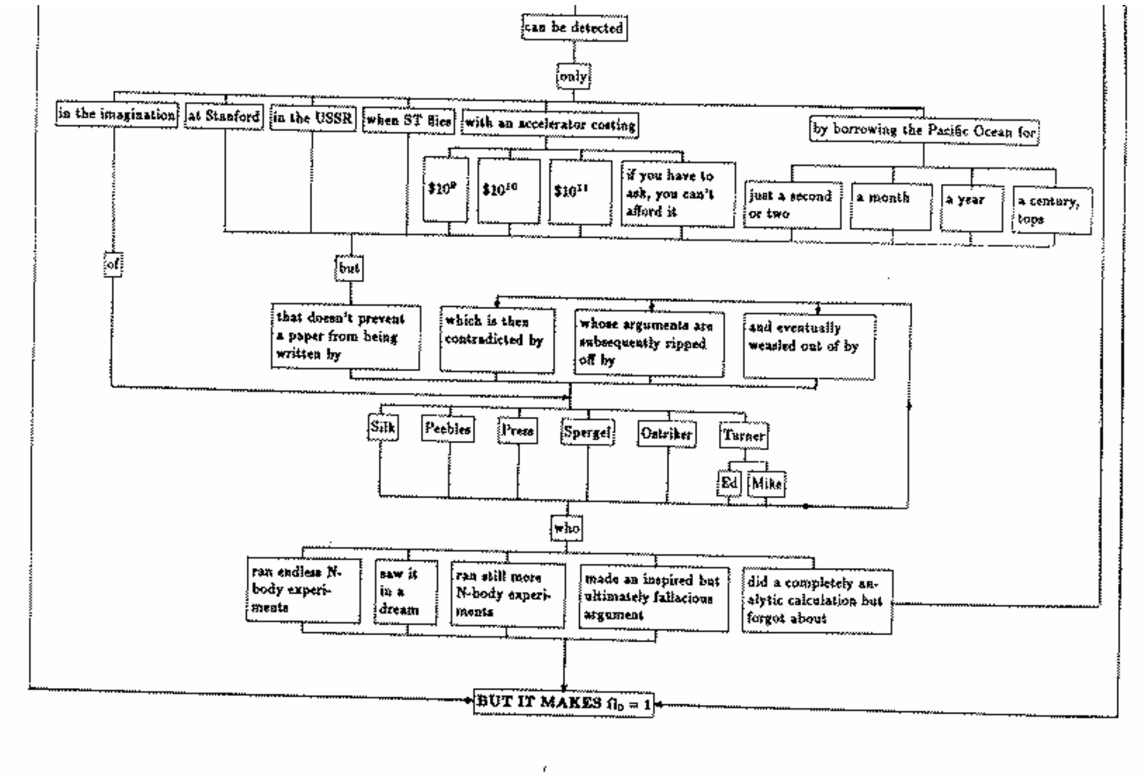

A humorous flowchart for dark matter candidates [3]

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Images

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