Dark Matter and Dark Energy

By Paul Lewis

Dr. John Stewart

Honors University Physics II – Lab H2

Dark Matter and Dark Energy

Over the centuries, mankind has watched the stars above, curious as to their secrets, their workings. Humanity's curious musings, although not all of such musings were about the stars themselves, have led to various important discoveries – from Newton's fundamental theories in physics and calculus, to the discovery of the atom and the particles comprising it, to the determination of the speed of light. As the years have gone by, more and more findings have been used by mankind to explain the workings of the universe, however the truth eludes astronomers and physicists still. Galaxies have been observed, nebulae photographed, and even ancient radiation detected, but something is affecting our understanding of the universe. Galaxies do not act in the manner expected of them, and the light they give off does not correspond to the mass predicted to be present in them (Bartusiak 196, 211). Even after Einstein's groundbreaking theory, it seems that gravity in deep space cannot be explained. But, as always, mankind searches for an explanation. Currently, that explanation comes in the form of dark matter – invisible matter that does not emit light but does affect light due to its gravitational effect – and dark energy – an even more mysterious property of space, believed to largely affect the space in between matter, especially affecting the expansion of the universe (NASA 2010).

Dark Matter

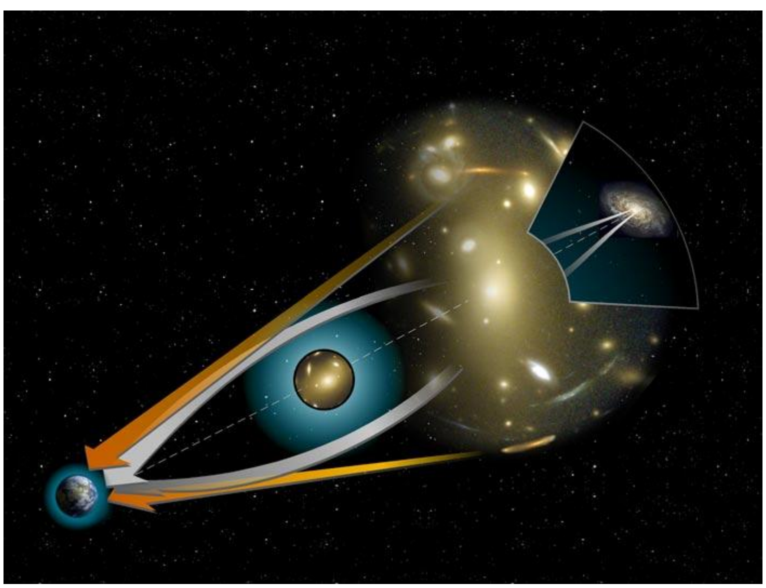
At first, as with many other groundbreaking theories in physics, dark matter was looked at as a radical idea by many. In the 1930s, Fritz Zwicky, a Swiss astrophysicist researching at Caltech, began to observe the first traces of evidence leading to the discovery of dark matter. While examining the velocity information for galaxies in the Coma cluster, Zwicky found that the galaxies were moving at a much faster rate than anticipated when compared to the light emitted by the galaxies in the cluster (Bartusiak 196-197). Essentially, the galaxies were moving as in a manner that would mirror the movement of much more massive galaxies. From the data, the galaxies should have been moving fast enough to escape the gravitational forces holding them together in the cluster, but this was not the case. In order to explain this phenomenon, Zwicky began to wonder if galaxies were somehow just more energetic in clusters. Such a hypothesis seemed outrageous even to Zwicky, a man known for radical ideas and eccentric behavior, and so he dismissed it. The only possible way for the galaxies to stay together in the cluster moving at such speeds would be the presence of more mass than expected, some so called "missing mass." This missing mass would have to be emitting much less light than anticipated or no light at all (Bartusiak 196-197). In this case, the galaxies would be able to move around the cluster at the observed pace without breaking the gravitational fields of one another and leaving the cluster.

At about the same time as this discovery by Zwicky, a discovery that was mostly brushed aside by physicists at the time, a Dutch astronomer by the name of Jan Oort noticed a closely related phenomenon to Zwicky's. While measuring the speed and direction of many stars in the Milky Way, Oort found that the stars in our galaxy tend to bob up and down as they move alongside the galaxy's rotation. This bobbing motion is described to be somewhat like a "merry-go-round horse," as the stars move down towards the main part of the galactic disk, attracted towards the massive collection of stars, until they overshoot the disk to only later eventually slow down and be pulled back up past the disk, somewhat like a pendulum (Bartusiak 197). This led Oort to propose that the disk of the Milky Way had considerably more matter than expected due to the gravitational force required to move the stars in such a manner at the speeds as observed

(Blitz 103). Once again, this is a case of "missing mass," similar to the one presented by Zwicky with respect to the Coma cluster. The evidence was beginning to pile up, but still astrophysicists and astronomers did not pay attention to the phenomena, attributing them to faulty instruments or simply ignoring them altogether (Bartusiak 201).

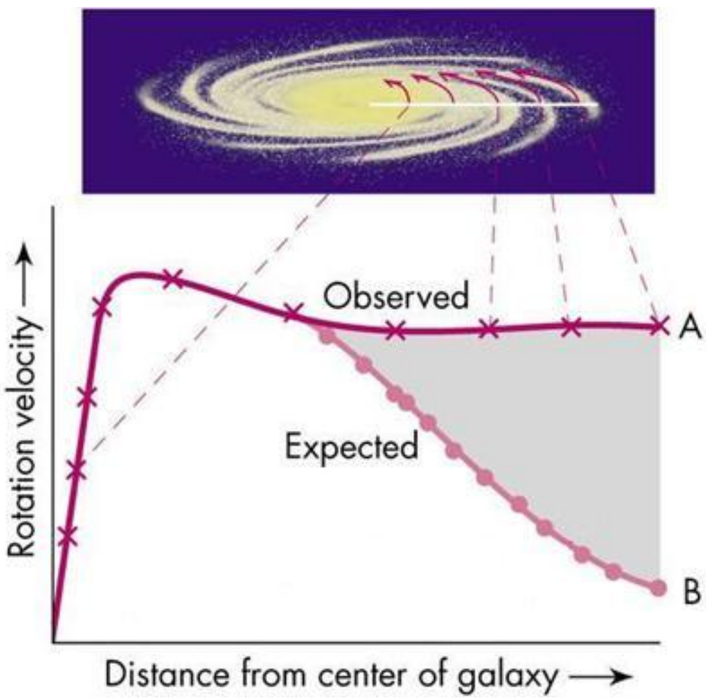
Astronomer Sinclair Smith provided even more support for Zwicky's proposed dark matter theory. Because so many of Zwicky's colleagues had criticized the lack of data in Zwicky's original analysis of the Coma cluster, as there were only seven galaxies included in the data he analyzed, Zwicky needed more evidence to substantiate his theory. This evidence came from Sinclair Smith after he investigated data available on the Virgo cluster. After his investigation, he found that there was a similar phenomenon present for the galaxies in this cluster. He concluded that, "It is possible . . . that the difference represents a great mass of internebular material within the cluster," with respect to the phenomenon found in the Virgo cluster, which was identical to the phenomenon in the Coma cluster (Bartusiak 198-199). Since then, a variety of clusters have been found to follow the same principle of "missing mass."

As more information was found regarding dark matter, it led Zwicky to a novel idea two decades later of how to determine the presence of the unknown matter, something he had called, *dunkle Materie*, or dark matter, a name that has stuck over the years for the mysterious matter (Bartusiak 197). This idea included using a gravitational lens to better determine the amount of matter within a galaxy. By applying Einstein's theory of general relativity, Zwicky determined that as light from further objects pass around galaxies, their light would split about the galaxy, making the celestial bodies further away seem to be in a different position than they actually were. Using this, Zwicky determined one could use the light bent by a gravitational lens, which could be entire galaxies or the sun itself, to determine the mass of the gravitational lens itself, or simply the presence of dark matter affecting the lens. Although Zwicky did not live long enough to see proof of an actual gravitational lens, in 1979 the first instance of a gravitational lens was discovered by astronomer Dennis Walsh while comparing a photographic plate to find a visible image with its radio source counterpart. At first glance, the photographic plate seemed to indicate two starlike objects were present, however after close inspection, he determined that the two images were light bent around an elliptical galaxy halfway between the Earth and the object. Walsh determined that the object was a quasar, and found that the two celestial objects on the plate had identical spectrum, leading the astronomer to decide that the two images were indeed of the same object, a quasar about 8 billion light years away, something he confirmed using the object's radio position as well (Bartusiak 199-201). This phenomena is illustrated in the figure below, where the galaxy on the right appears to be located near the top and also near the bottom of the cluster of galaxies, however it is only one galaxy. The light emitted by the galaxy is bent by the massive object, and the new direction it reaches the Earth in results in a skewed view of the galaxy's actual location.



(ScienceBlogs 2011)

The last phenomenon to investigate involves the rotational velocity of the outer arms of the Andromeda galaxy. A discovery largely attributed to Vera Rubin, she determined from observations that the rotational velocities of stars and gas at the outer edge of spiral galaxies were the same as those closer to the center of the galaxy. This was contrary to the prediction that the stars on the outer edges of the spiral galaxy would move at a slower speed compared to those near the center of the galaxy (Bartusiak 209-212). Something was wrong with astrophysical predictions once again.



(Philica 2006)

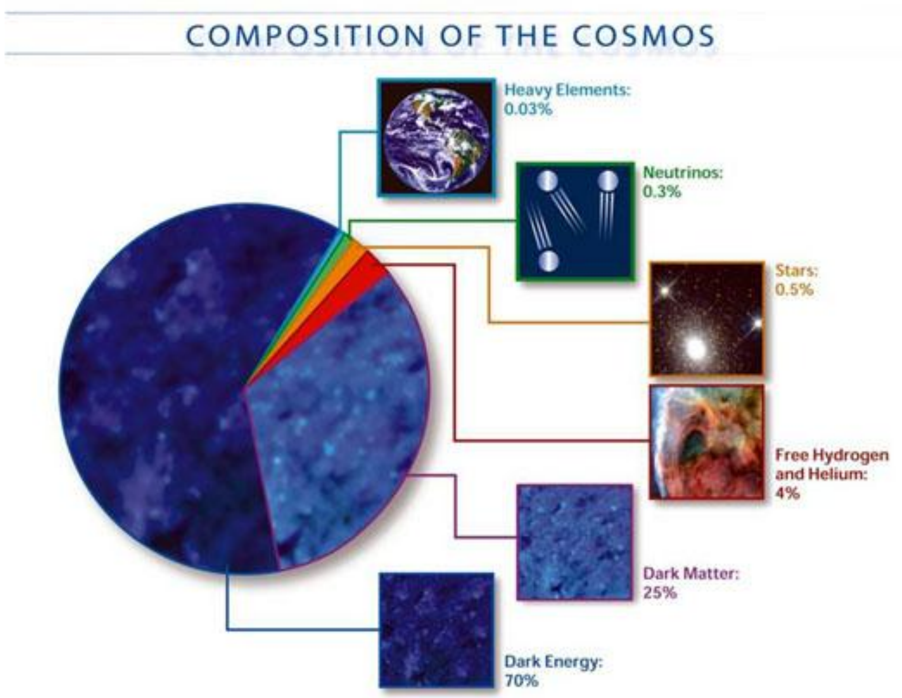
The only real explanation for such a phenomenon would be gravity, and therefore another instance of "missing mass." With so many phenomena indicating the absence, or rather the presence, of matter in the universe, obviously something was either missing from the current theories or something was missing in galactic observations. With so much sound evidence pointing towards the issue of "missing mass," it seemed that Zwicky's belief in the presence of dark matter in the universe might just be the only explanation available. However, the only problem was that Zwicky had not determined what this matter was exactly, what types of particles make up that matter, or if it is anything like the matter that mankind deals with every day here on Earth. Over the years though, this has been a prominent issue in modern physics and astronomical research (Croswell 160-162).

In the past few decades, mankind's knowledge concerning dark matter has increased a considerable amount, although at the same time no direct proof has been collected on the elusive matter. There is no one concrete theory as to what dark matter is, but it seems like there are two broad possibilities for the composition of dark matter around the Milky Way – dim astronomical objects, and exotic subatomic particles. One of the possibilities includes the presence of Massive Compact Halo Objects, or MACHOs. MACHOs include well known celestial objects such as black holes, neutron stars, and brown dwarfs. Such objects would emit very little, if any light, and also very little radiation, making them very hard to detect. At the same time, these MACHOs consist of baryonic matter, similar to the matter mankind has in abundance on Earth, but are close to being completely invisible to modern observational techniques. Considering that these MACHOs are made mostly of the same matter as the matter mankind has first-hand experience with, it seems that this explanation may be the easiest to grasp (Croswell 160-163). MACHOs are, simply put, just massive objects hidden out in space affecting the gravitational fields of galaxies and other celestial objects.

On the other hand, there is the chance of new, exotic subatomic particles being present in the galaxy. In contrast with the MACHOs discussed earlier, these particles have been fittingly labeled Weakly Interacting Massive Particles, or WIMPs. WIMPs are considered to be made of nonbaryonic matter. Nonbaryonic matter is just as one would expect – matter that is dissimilar to the conventional matter one would normally expect. Such matter is not expected to be made of the all-too-familiar atom, but rather particles that act in an even weaker manner than individual atoms themselves. This would explain why such matter has not been discovered on Earth, as their interactions are so weak that even mankind's best instruments of detection are eluded by WIMPs (162-163,). Such matter would potentially have to exist in excessively large numbers in order to have the effect observed in the Coma cluster galaxies, or observed on the outer edge of spiral galaxies.

After increasing research on the proposed position of the dark matter surrounding the Milky Way, many types of MACHOs were ruled out – including brown dwarfs, neutron stars, and large black holes. This led scientists to believe that WIMPs played a much larger part, if not the whole part, in the dark matter affecting the Milky Way galaxy compared to the MACHOs. One astronomer, by the name of Charles Alcock, went so far as to say that 80% of the dark matter halo surrounding the galaxy was made of WIMPs. And another astronomer by the name of Bohdan Paczynski, who proposed the method to determine what type of dark matter comprised the dark matter halo surrounding the Milky Way, went so far as to conclude that possibly even the entire halo was comprised of WIMPs (Croswell 169-171). However, how can one believe that there is a massive halo of particles that does not affect the visibility of the matter it surrounds, but still has a tremendous effect on the matter in the Milky Way?

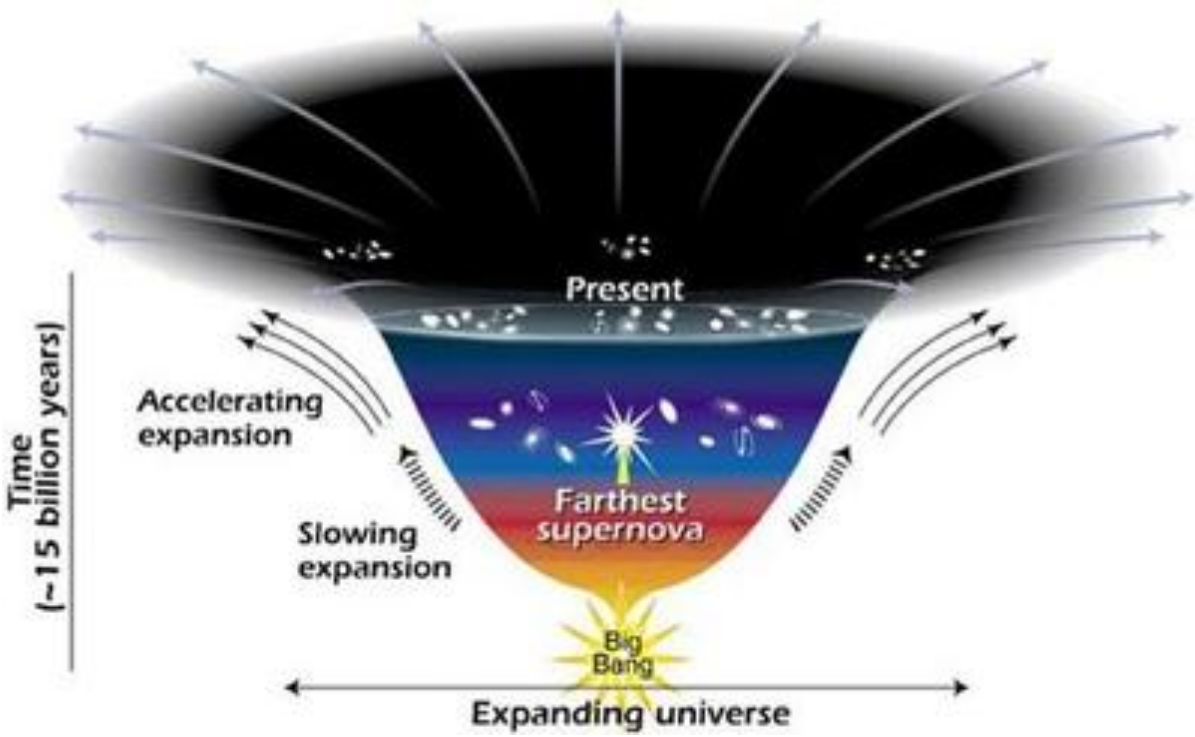
Today, the search for this elusive dark matter still continues. The identity of the WIMPs that mystify astrophysicists so has yet to be determined. And, although particles such as neutrinos have been discovered and labeled as WIMPs, their mass is not expected to make up for the tremendous effect that dark matter has on the universe. Though currently it is estimated that dark matter comprises roughly 25% of the universe, and normal matter about 5%, it turns out that most of the universe seems to be made of another elusive entity known as dark energy (NASA 2010).



(LSST 2011)

Dark Energy

Today, it seems that the universe is expanding, a property of the universe that is in part attributed to dark energy. But, where did dark energy come from? It seems that, in a way, Einstein was the first to propose the idea of dark energy, even if indirectly. Einstein was the first to realize that new space could come into existence. With this in mind, he also believed that seemingly "empty" space is actually filled with energy itself. Also, Einstein introduced a cosmological constant to represent the amount of energy per volume of space in his theory of gravity (NASA 2010). In doing so, he was indirectly acknowledging that space had a constantly increasing amount of energy, as when new space came into existence, so did energy. Although this may not have been his intentions, Einstein indirectly pointed towards what is thought of now as dark energy – an entity that facilitates the increasingly faster expansion of the universe (NASA 2010).



(NASA 2010)

Eventually it seems that the acceleration of the universe will prevent any galaxies or materials from gravitationally binding one another, potentially ceasing the creation of galaxy clusters as the galaxies fly apart too fast to be effectively "caught" by the gravitational fields of other galaxies. Essentially, as the universe expands, more and more energy becomes present somewhat along the lines of a constant increase with respect to the amount of space appearing, along the lines of the way Einstein's cosmological constant indirectly works. As more energy is introduced, the universe expands even faster (LSST 2011). It will eventually expand so fast that it could even potentially overcome the constraint of dark matter, that which is believed to hold together many galaxies, galaxy clusters, and other celestial matter.

In a way, this dark energy is representative of the energy present in a vacuum, considering how closely similar to space an actual vacuum is. This is directly related to the cosmological constant that Einstein proposed; a constant that was used to describe the energy density of space itself. Currently, such an assumption is supported by astronomical observations, though they are somewhat limited (LSST 2011). Considering that the universe has been in existence for billions of years, it is understandable that the increasing presence of dark energy would far outweigh the static amount of matter in the universe after so many millennia.

The universe is truly a mysterious place to mankind now, just as always. As of now, the Milky Way, mankind's own home, is held together by invisible matter, comprised of small, undetectable particles known as WIMPs that are not even considered to be made of the same matter as atoms themselves. Also, within the same halo of matter around the Milky Way, MACHOs could be present affecting the movement of celestial bodies within the galaxy. And the only basis for such assumptions are simply bent light from distant celestial bodies, bending said light coming from a source even further away. On one end, such an idea could seem quite absurd, but on the other, what other explanation is there? Some might say that the laws of gravity need some tweaking, such as the proposed idea of Modified Newtonian Dynamics, but at the same time that theory falls apart even faster than the theory of dark matter (Folger 2003). And, as for dark energy, how does space keep expanding into more that is nothing, only to create more energy? Currently, the universe is expanding, and *accelerating* in expansion. Once again an idea that seems absurd to say out loud at first, but at the same time, both of these theories coincide with observations that have been made of various phenomena in the past few decades. For now, the pieces are set to explain the universe's workings, but the evidence is not. And the evidence can sometimes be the hardest part to acquire.

Works Cited

Bartusiak, Marcia. 1993 *Through a Universe Darkly*. New York: HarperCollins.

Blitz, Leo. 1995. “Dark Matter in the Milky Way.” *American Institute of Physics* 336:101-110.

Croswell, Ken. 2001. *The Universe at Midnight*. New York: Free Press.

Folger, Tim. 2003. “Nailing Down Gravity.” *Discover,* October 1. http://discovermagazine.com/2003/oct/cover

LSST. 2011. “LSST—Dark Energy 1.” Accessed April 21. http://www.lsst.org/lsst/public/dark_energy

NASA. 2010. “Dark Energy, Dark Matter.” Last Modified August 19. http://science.nasa.gov/astrophysics/focus-areas/what-is-dark-energy/

Philica. 2006. “Bar-Zohar, D. (2006).” Last Modified December 4. http://philica.com/display_article.php?article_id=65\%27den

ScienceBlogs. 2011. “How Gravitational Lensing Shows Us Dark Matter!” Last Modified April 20. http://scienceblogs.com/startswithabang/ 2011/04/how_gravitational_lensing_show