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Dark matter research: merits, limitations, and trajectory

Bellini F

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Abstract
Dark matter may be one of the greatest scientific challenges of the modern age; it is something about which startlingly little is known, yet it may ultimately change how we view our universe. Dark matter research has spanned centuries, prompted a collaboration between physicists worldwide and presented a union of two fields of research previously thought to be polar opposites: astro and particle physics. This paper's objective is to review the limitations and merits of dark matter research; including whether or not dark matter is worth researching at all; and propose trajectories. There are three major limitations to studying dark matter. The first is that staggeringly little is known about it in the first place; this lack of knowledge impedes researchers from gathering more data; or indeed; in determining what data to collect. The second is that dark matter requires either a rethink about the uniformity and (dis)similarity of the fundamental forces of nature across orders-of-magnitude mass-velocity, and/or space-time differences; a realization that there may be forces or mass that are undiscoverable using existing knowledge and instrumentation, or that dark matter may operate and/or interact with 'conventional' matter in ways that are as yet unimaginable - such as in more dimensions - or all of the above. Studying dark matter is hence exceedingly difficult, either because the necessary equipment is far too expensive, or has not even been invented yet. The third is that dark matter research is divided between astro and particle physics; there is a clear divide between the two fields, and almost all dark matter studies and theories can be clearly catalogued as originating from one or the other. As a result, many theories simply fail to explain results from studies proposed on the opposing side and many studies fail to use previously established dark matter knowledge in their efforts. As is usually the case – and there is no reason why dark matter should be any different – connections between seemingly disparate concepts; or insightful shifts, result in paradigm changing scientific breakthroughs. Perusal of dark matter research is imperative to discover the true nature of our universe and, as such, is worth researching despite the challenges encountered.

Keywords
Dark matter, WIMP, MACHO, MOND, Black hole, Galaxy, Quantum gravity, Dark energy, Grand unified theory, Thermodynamics

Francesco Bellini, Jumeirah College, 19th Street, Al Safa, Al Safa 1, Dubai, United Arab Emirates. beatrice.lioce@libero.it

Introduction

The study of physics is getting harder and more complicated, and new discoveries occur few and far between. The end of physics has been proclaimed innumerable times by overzealous researchers and philosophers who believed they had simply run out of questions to ask. However, they were proven incorrect as many times, because physics as an idea may be considered to form the basis of natural science. This paper aims to explore the main problem that hinders physics by focusing on its effects on dark matter. This field of research has had extremely slow progress since its inception almost 100 years ago, and it shares this attribute, as well as the reasons for it, with many other fields of research, such as the similarly named dark energy.

The reason dark matter is a good example of this problem is because of the very idea behind this field; dark matter is not an actual theory; rather, it is a placeholder for a theory. It is known that something is adding mass to certain massive astronomical objects and that whatever it is, it is not visible; however, the number of possible explanations for this phenomenon is infinite, we can find more data to narrow those explanations, but it will still be infinite, just less so. It is as though the correct theory was a point on a plane, and the point could be anywhere on that plane; therefore, there are infinite possibilities as to its position. If we find one property of it, such as its distance from the origin, we can narrow it down to a point along a specific circle. However, the number of possible positions is still infinite since there are still infinite points along a circle. If we find out the point passes through a line, we can finally narrow it down to a non-zero amount. However, it could still have two possible positions. Dark matter is similar, there seem to be infinite number of theories that can explain it, and the more we learn about it, the less infinite that number becomes, but there are a lot more variables in play than just the two in a flat plain, which is why a large amount of information is still required before speculation and conjecture can be overcome.

Dark matter exemplifies some of the main challenges encountered in physics research, it is a subject which we know very little about, and most of the work on dark matter is simply theoretical. However, the usefulness of theories is limited when there are infinitely many possible explanations for this phenomenon. They can tell us where to look, but what we need to advance this field is actual experimentation, which is in very short supply. Since dark matter research is so hard and draining on resources, the obvious question arises: is it even worth researching? This paper will discuss the main challenges and the utilitarian value of dark matter research and how to overcome these challenges.

Literature Review

The literature review will outline the progress made in researching dark matter. It will include the three studies conducted on dark matter as well as many of the most important dark matter theories. Three of these theories will be described in detail, which are particularly interesting and varied. Problems similar to dark matter will be discussed and statistical analysis will be used to determine how long this research has taken compared to others.

Studies conducted on dark matter

The first major dark matter study was conducted by Fritz Zwicky (1933), a Swiss astrophysicist, who estimated the average density of the Coma cluster in 1933 by calculating the density necessary to keep the system stable given the velocity dispersion (the statistical dispersion of velocities about the mean velocity). He then estimated the mass of the Cluster by observing its luminosity; this is done by measuring the amount of X-ray radiation emitted from the superhot gas in galaxy clusters. He found a significant discrepancy in the two estimates for the mass, leading him to believe that the amount of luminous matter in the coma cluster is a minuscule fraction of what was actually present. He attributed this to a new type of previously undiscovered matter, which he named dark matter (1). While this study was both the first of its kind and the first recorded study to indicate the existence of dark matter, the results do seem to be reliable as they were later confirmed by another similar study led on the Virgo cluster by Sinclair Smith (1936) (2). The fact that the same discrepancy was found between these two completely separate clusters was astounding and showed that Zwicky’s results could not be an anomaly. Furthermore, the fact that these two clusters had the same ratio between the velocity dispersion estimate and the luminosity estimate for their masses may have definitely contributed to the discrediting of the theory of dynamic equilibrium proposed by Ambartsumian (3), since it was evident these two discrepancies were caused by the same phenomenon.

Zwicky’s study was also confirmed by a completely separate study on rotation curves carried out decades later by Vera Rubin and Kent Ford (1970). Rotation curves are diagrams showing the orbital velocities in gas orbiting a galaxy as a function of its distance from the galaxy's centre. They can be used to estimate the mass of a galaxy. The velocity of orbiting gasses is expected to decline farther away from the centre. These are known as Keplerian galaxies (4). However, most galaxies were discovered to have a flat rotation curve, indicating that the orbital velocities of the gas within them were constant. This indicated that these galaxies had more gravity than previously estimated from their observed light. This gravity was attributed to the mass of the unobserved dark matter. Rubin and Ford analysed the rotation of the Andromeda nebula, and they observed that the velocity largely remained constant with radius. This experiment was conducted up until a very large radius and the pattern held throughout. A considerable number of similar studies have been conducted on many galaxies, and they usually attributed their surprising findings of a flat rotational curve to a large undetected mass at large radii. They concluded that the ratio of mass and luminosity did not necessarily remain constant with the galactic radius and, therefore, there must be a matter which was not visible (5). Not only did this study have a very sound mathematical basis, but it was also supported by decades of previous research into dark matter by the likes of Zwicky (1933) (1,2). Furthermore, it was carried out by a Senior Fellow of the Department of Terrestrial Magnetism at Carnegie Institution of Washington, which brought a lot of credibility to the theory, especially to American astronomers, whereas before, the theory of dark matter was seen as very unlikely by the international community. This is widely regarded as the point at which the dark matter theory began to gain traction amongst the international astrophysics community.

The third study was carried out almost a decade later by physicist James Peebles and astronomers Jeremiah Ostriker and Amos Yahil at Princeton University, who set out to find the real mass of a select series of galaxies by summarising the work of their predecessors, Zwicky (1933), and Rubin and Ford (1970). The estimate at the time for the ratio of gravitational energy to kinetic energy was 0.01; however, this estimate did not account for the mass of dark matter as it was only calculated shortly after the theory of dark matter started to gain popularity in the international astrophysics community. If one were to include the estimate for the mass of dark matter given by the study conducted by Rubin and Ford (1970), the ratio would reach 1. This would agree with the closed universe theory, according to which the universe's density is large enough to counteract its expansion force, leading to a stable, spherical universe. The study also collated the previous studies conducted on the masses of galaxies and clusters, as well as rotation curves, including those conducted by Zwicky and Rubin and Ford. They concluded that the mass of a galaxy increases proportionally with its radius between 20 and 500 kiloparsecs: $M(r) \propto r$ {20kpc>r>500kpc}. This supported the aforementioned study on flat rotation curves in demonstrating that the density of a galaxy remains constant for most of its radius, which directly contrasts with its luminosity. Therefore, as the radius of a galaxy approaches 500kcp, the ratio of luminosity to mass will decrease greatly. According to these results, it can be estimated that the ratio of gravitational energy to the kinetic energy of a galaxy is 0.2; this study argues that this figure is close enough to 1 to support the possibility of a closed universe. However, considering that this conclusion requires one to increase the results by a factor of 5, it would be wise to consider that the authors may be over-reaching so as to arrive at a more appealing conclusion. The large ratio of mass to light emission was, at the time, attributed not to dark matter but to a "giant halo of faint stars". A large number of stars with high mass but low luminosity could very well lead to this result. However, what is more likely the case is provided by the descendant of this very theory, the MACHO theory (6).

Main theories on dark matter

The "WIMP" (weakly interacting massive particle) theory is probably the most well-known and the first theory which will be discussed. The theory hypothesises that there are several particles that make up dark matter; given that dark matter comprises the vast majority of the universe, some have theorised that there may be an entire standard model larger than our own (7). This theory is currently the most popular and is currently being tested in the research lab of DAMA/LIBRA (8). So far, the results of this experiment are both promising and interesting as not only do they indicate a concentration of Weakly Interacting Massive Particles that could satisfy the 85% dark matter threshold, they revealed more about how dark matter interacts with our universe. The experiment showed that the number of WIMPs passing through the earth every day varies greatly based on the season. While this speculation is highly controversial since its results were inconclusive and found not to be replicable (9), if the results were to be true, astrophysicists speculate that it could be due to the direction of the earth's movement during these seasons. Since the Earth is orbiting the sun, which is orbiting in our galaxy, half the year it is moving with the orbit of the sun, and half the year it is moving against it. In other words, the speed at which the Earth orbits the milky way galaxy varies throughout the year. The most prominent explanation for this seasonal change in WIMP detections is that the earth itself is moving through the WIMPs, and its velocity changes in syncrony with the seasons;

therefore, the earth's movement speed is proportional to the rate at which WIMPs pass through the earth (7). This theory is probably the most popular and the most likely as it hypothesises that WIMPS do not interact with the electromagnetic force and thus do not emit, absorb, or reflect light. Because of this, WIMP theory is spared from the uncertainties and complexities of other theories that rely on interactions with light. Furthermore, this theory provides a clear explanation for the observed clustering of dark matter; since they only interact with other particles through the weak force, they are able to form dense objects. It is also worth noting that this is the main problem with WIMP theory, i.e. there is currently no evidence that dark matter is weakly interacting.

The "MACHO" (massive astronomical compact halo object) theory varies greatly from the others as it does not propose a new type of matter; it instead suggests that dark matter is just that, dark matter, regular matter in high concentrations which does not emit light, making it impossible to observe. This theory proposes that dark matter consists of extremely dense, non-black hole objects which emanate very little or no light at all. These objects include neutron stars, white dwarfs and brown dwarfs. While we know that these objects do exist, what makes this theory controversial is the amount of dark matter there is. And while it is not impossible for 85% of the universe to be made up of just the aforementioned objects, it is unlikely (10), especially considering that all of those objects are the last or next to last stage in the life cycle of a star, a life cycle which takes billions of years. Given the relatively young age of our universe, it seems very unlikely for there to be so many dead stars. However, as mentioned above, even though this theory seems unlikely, it is very challenging to disprove it, given the limited knowledge of dark matter. Most of the evidence for this theory comes from a process called gravitational microlensing. While these MACHOs do not emit light, they should still have a gravitational field; therefore, they should be detectable through gravitational microlensing. When a MACHO passes in front of a star, its light appears brighter because the MACHO's gravitational field bends the light (11). It is worth noting that multiple studies have been conducted in an attempt to detect these objects, and they have came far short of the theoretical predictions (10). While it is estimated that dark matter makes up around 85% (5) of the observable universe, even the most generous studies only estimate that MACHOs make up 20% (10) of the observable universe. This could indicate that these objects contribute to the great discrepancy between visible and dark matter; however, it is extremely unlikely that they are the sole cause. Still, due to our lack of evidence, it is unwise to rule out the possibility.

Amongst dark matter theorists, many seem to gravitate towards a new standard model; one such theory is the "Hidden Sector" or "Hidden Valley theory". This theory stipulates that dark matter is comprised of particles less massive than protons, though the exact mass could be as low as a milli-electron-volt. This particle would be completely independent of the standard model (12). Since dark matter does not emit or reflect light, these particles cannot interact through the electromagnetic force or, therefore, photons. Furthermore, this theory states that these particles cannot interact through the strong or weak forces either (12). The only interaction these particles would have with regular matter would be gravitational force, as dark matter has been proven to interact with the standard model through gravity (5). While this theory was initially conceived by Kathryn Zurek (2015), a theoretical physicist, there is another subsection of this theory created by Sean Carroll (2017) which differs in one significant way; while the original theory states that dark matter particles can only interact through gravity, this alternate version proposes that dark matter particles may interact amongst themselves through their own interactions, such as dark magnetism; these forces would also use different bosons, such as the proposed dark photon as exchange particles (13). While this is one of the less likely models for dark matter as of now, it has yet to be ruled out; therefore, it is still possible. Zurek also came up with an experiment to prove her theory: this dark matter particle should hypothetically cause disturbances in the regular matter; she planned a way to detect these disturbances through the use of the quasiparticle phonon (a quasiparticle is a collective of phenomena that act as one particle); vibrations in this phonon would suggest the presence of dark matter. Another advantage of this theory is the fact that it is able to solve both the Muon g-2 anomaly and the beryllium-8 decay anomaly (12).

To conclude, while the studies presented differ from each other in some aspects, they all conclude that dark matter makes up around 85% of the observable universe, showing a clear pattern that the entire field of research is based on: there is more out there than we can see. The theories vary a lot more, some propose solutions based on astrophysics, such as previously undiscovered massive objects, and others propose solutions based on particle physics, such as previously undiscovered fundamental particles. While they may seem at opposite extremes, all major dark matter theories agree on a version of the previously stated trend: there is something out there that we cannot see.

Other theories of dark matter

Table 1 lists the several theories that have been proposed to describe and explain dark matter, along with their advantages and disadvantages. As the table shows, the theories range from extrapolation of observable existing phenomena such as the tendency of matter to maximize entropy, proposed new particles (or counterparts to existing particles) or new dimensions or new forces. Similar to certain mass-velocity regimes being better described by Newtonian equations and quantum equations better describing others; some theories such as the Modified Newtonian Dynamics propose that that instead of dark matter, the observed gravitational effects in galaxies are due to modifications in the laws of gravity at low accelerations. This theory is appealing because there are precedents. Akin to the modification of the rest mass to the mass at the speed of light, or some equations working in some mass-velocity regimes but not in others; the modification in the laws of gravity may be possible in high mass (such as dark matter) regimes. The lack of specific information on dark matter is partly responsible for this variety of theories.

Table 1. Other theories on dark matter

Theory name	Description	Advantages	Disadvantages
Axion	The axion dark matter theory suggests a low-mass, electrically neutral particle.	It is compatible with other theories.	It has not been experimentally proven and has several versions (14).
Sterile neutrinos	The sterile neutrino theory proposes that dark matter is composed of sterile neutrinos, which are similar to regular neutrinos but do not interact with matter as much.	It is able to explain the observed structure of the universe and the distribution of dark matter.	It has not been definitively proven, and there is not yet enough evidence to support it. Additionally, there are some discrepancies between the predictions of the theory and observations (15).
Extra dimensions	The extra dimensions theory suggests that dark matter is composed of particles that exist in extra dimensions beyond the three spatial dimensions we experience.	It is able to explain why dark matter does not interact with regular matter.	It requires the existence of extra dimensions, which have not been observed; it is unclear how these extra dimensions would even be detected (16).
Supersymmetry	Supersymmetry suggests that every known particle has a corresponding "superpartner" particle with a different spin.	It offers the potential to unify all fundamental forces of nature, including gravity, and shed light on the mystery of dark matter.	Some physicists argue that the theory is too complex and requires too many arbitrary parameters to be fully viable (17).
Little Higgs theory	The Little Higgs theory suggests that there is a new type of particle, known as the "heavy photon," which interacts with ordinary matter through a weak force.	This theory offers the potential to explain the origin of dark matter and provide a more complete understanding of the fundamental forces of nature.	Some physicists argue that the theory is too complex and requires additional experimental evidence to be fully viable (18).
Self-interacting dark matter	Self-interacting dark matter is a theory that suggests dark matter particles can interact with each other through a new force. This force would allow dark matter to clump together and form structures, which could help explain the observed distribution of dark matter in the universe.	It could potentially solve some inconsistencies between observations and simulations of dark matter.	It faces challenges in explaining the observed properties of some dark matter structures and requires further experimental evidence to confirm its validity (19).
Strangelet	The strangelet hypothesis proposes that dark matter may consist of strange matter, a type of matter made up of strange quarks.	It could potentially explain the observed abundance of dark matter in the universe, as strange matter would be stable and could exist in large quantities.	It struggles to explain the lack of detection of strange matter in laboratory experiments and requires further evidence to confirm its validity (20).
Primordial black hole	Primordial black hole theory stipulates that black holes were formed in the early universe due to fluctuations in the density of matter.	It could potentially explain the observed gravitational lensing effects and the origin of supermassive black holes in the centres of galaxies.	The theory faces challenges in explaining the lack of detection of primordial black holes in our galaxy and requires further evidence to confirm its validity (21).
Macroscopic dark matter	Macroscopic dark matter theory proposes that dark matter is made up of large, massive objects such as black holes or planets.	It could potentially explain the observed gravitational lensing effects and the lack of detection of dark matter particles.	The theory faces challenges in explaining the distribution of dark matter and requires further evidence to confirm its validity (22).
Tensor–vector–scalar gravity	Tensor–vector–scalar gravity is a theory of dark matter that hypothesises the existence of a new type of force interacting differently with different types of matter.	The theory has the advantage of potentially explaining the observed rotation curves of galaxies and the large-scale structure of the universe without requiring the existence of dark matter particles.	It is currently not well-supported by observational evidence and struggles to explain the observed gravitational lensing effects. Further research is needed to determine the validity of this theory (23).
Entropic gravity	Entropic gravity is a theory of dark matter that suggests gravity arises from the tendency of matter to maximise entropy. This theory posits that gravity is not a fundamental force but rather an emergent phenomenon that arises from the statistical behaviour of matter. To put it simply, matter is simply more likely to clump together than to stay apart.	One advantage of this theory is that it does not require the existence of dark matter particles, potentially simplifying our understanding of the universe.	It faces challenges in explaining the observed rotation curves of galaxies and the large-scale structure of the universe (24).
Modified Newtonian Dynamics (MOND)	The Modified Newtonian Dynamics (MOND) theory proposes that instead of dark matter, the observed gravitational effects in galaxies are due to modifications in the laws of gravity at low accelerations.	The theory has the advantage of not requiring the existence of unknown particles or extra dimensions.	It has been criticised for failing to explain certain observations, such as the Bullet Cluster collision, and for lacking a solid theoretical foundation (25).

Problems similar to dark matter

Quantum gravity is a theoretical framework that attempts to reconcile the principles of quantum mechanics and general relativity, which are two fundamental theories of physics that govern the behaviour of particles and the structure of spacetime; its research aims to provide a better understanding of the nature of gravity and the universe as a whole. The benefits of this research include the potential to unlock new technologies and insights into the origins and evolution of the cosmos. Research on quantum gravity started in 1900 (26).

Dark energy is a mysterious force that scientists believe is responsible for the accelerating expansion of the universe. Its research aims to uncover the nature of this force and its impact on the structure and evolution of the cosmos. The benefits of this research include the potential to gain a better understanding of the fundamental nature of the universe and how it came to be. Research on dark energy started in 1998 (27).

The Grand unified theory is a theoretical framework that aims to unify the three fundamental forces of nature - the strong nuclear force, the weak nuclear force, and electromagnetism into a single, coherent model. Its research aims to provide a more comprehensive understanding of the underlying principles that govern the behaviour of matter and energy in the universe. The benefits of this research include the potential to unlock new technologies and insights into the nature of the universe. Research on grand unified theory started in 1974 (28).

The black hole information paradox is a theoretical problem that arises from the fact that information appears to be lost when matter falls into a black hole, which contradicts the principles of quantum mechanics; its research aims to resolve this paradox and provide a better understanding of the fundamental nature of black holes. The benefits of this research include the potential to gain a better understanding of the behaviour of matter and energy in extreme environments and the potential to unlock new technologies. Research on the black hole information paradox started in 1976 (29).

Overall, these problems have, on average, been researched for the last 62 years, with a standard deviation of 40; both values are rounded to the nearest year to reflect the resolution of the original data. In order to calculate the mean average, The value 2024 was used as the current year as opposed to 2023 due to rounding.

Electromagnetism is a fundamental aspect of physics that has numerous practical applications in our everyday lives, from the functioning of electronic devices to the generation of electricity. However, understanding the complexities of electromagnetic fields and their behaviour can be a daunting task. This is where Maxwell's equations come into play. These four equations describe the behaviour of electric and magnetic fields and their interactions, providing a framework for understanding and predicting electromagnetic phenomena. This laid the foundation for modern communication technologies (30).

Special relativity is a fundamental theory in physics that explains how space and time are intertwined. One of the main benefits of special relativity is that it has led to a better understanding of the nature of light and its behaviour; It has also paved the way for the development of advanced technologies such as nuclear power plants and GPS systems. Furthermore, special relativity has provided insights into the relationship between energy and mass, leading to a greater understanding of the structure of matter and the universe as a whole (31).

Thermodynamics is another fundamental theory in physics that studies the relationship between heat, energy, and work; It provides a framework for understanding how energy is transferred and transformed in various natural and artificial systems. One of the key insights of thermodynamics is the concept of entropy, which measures the degree of disorder or randomness in a system, which has led to the development of technologies such as heat engines and refrigeration systems, which have transformed modern society by enabling us to harness energy in ways that were once unimaginable. In addition, thermodynamics has provided a deeper understanding of the behaviour of matter and radiation, revealing the fascinating world of phase transitions and critical phenomena (32).

Discussion

Dark matter research has limitations and merits. There are three significant factors which explain why the rate of new discoveries is far lower in dark matter research than in other fields, such as the study of fundamental particles or of quantum mechanics. This discussion will analyse each of these problems, their causes, and their effect on dark matter research. This section will also compare dark matter to other problems in physics using the statistical analysis from the literature review. The slow rate of progress on dark matter research leads to the question of whether these problems can be realistically solved and take stock of the yield of this research and its importance to physics as a whole in order to determine whether it is worth carrying on.

The first problem with researching dark matter

The first apparent problem with studying dark matter is that we know very little about it. This seemingly unbeatable paradox stems from the fact that in order to observe something, we must first know where and how to look, yet that cannot be achieved without first observing it. It is as though we were trying to find the diet of an animal without first knowing where it can be found or at what time it comes out to feed. In order to study dark matter, we must first know what areas of the universe it can be found in. Is it more prevalent in Galaxies or in intergalactic space? We must also know how we can observe it, and we already know that it is “dark”, meaning that it does not interact with the electromagnetic force. However, we know it must interact with gravity. We do not know whether it can interact with the strong and weak forces, nor if it moves roughly with the galaxies and clusters of our universe or completely independently of conventional matter. One result which may answer this could be the DAMA/LIBRA annual modulation. However, this is itself highly contested. Without this basic knowledge of dark matter, it is very hard to learn more about it, as studies such as DAMA/LIBRA rely on this information to experiment on dark matter.

The second problem with researching dark matter

The second major problem with studying dark matter is that it is exceptionally hard to find since its effects on conventional matter are relatively weak; in order to notice them, we must look at space on a much larger scale and see the bigger picture. In order to observe it, we need either equipment capable of observing far away galaxies or clusters in order to determine their velocity and mass or equipment capable of detecting every single dark matter particle passing it over the course of months at a time. Ideally, we would need the ability to travel ourselves to these galaxies or capture a dark matter particle and study its properties. The problem is that all of this equipment is incredibly expensive and labor-intensive to set up at best, and at worst, it is completely impossible with the technology of our time. This is a significant problem as there is no real way to circumvent it; other fields, such as black hole research, have resolved this issue through computer simulations; however, this is impossible in the study of dark matter due to the first problem, *viz.* we do not know enough about dark matter and its effect on our universe to accurately simulate it. Another possible solution would be machine learning to study dark matter, which would not require much information about it. This is why machine learning is used to study relatively unknown phenomena such as solar flares; however, this is also impossible as we do not have enough data about dark matter for artificial intelligence to study in order for it to develop a sufficiently accurate model. Because of our limited knowledge of dark matter, the only significant way it can be studied is either through gravitational microlensing or through scintillator detection, both of which are extremely time-consuming, expensive, and have an extremely high cost to benefit ratio or a return on investment.

The third problem with researching dark matter

The third problem is that the study of dark matter itself is divided. Since dark matter is both an astrophysics and a particle physics problem, almost all of the research and theories regarding it are distinctly situated in either one of these fields. This causes many problems as theories on one side of the coin cannot explain the results of experiments conducted on the other. WIMP theory cannot explain the many massive objects found by gravitational microlensing, and MACHO theory cannot explain the detection of previously undiscovered particles by crystal scintillators at DAMA/LIBRA. This not only leads to a significant amount of unnecessary arguing but also means that many theories are simply incomplete.

Any attempt at studying dark matter first requires information about it which often is simply unavailable and must be obtained from more theoretical studies and speculation, and such was the case with DAMA/LIBRA. It will then need expensive equipment specially designed for that purpose and which has little use outside of that study. Finally, it will require people, time, and money at the least, analysing the influx of data and maintaining the equipment for as long as needed, year-round if necessary.

These problems have greatly affected the field as a whole. Since there is so little concrete information on dark matter and obtaining more information is so difficult, most of the research work is theoretical instead of practical; there are many theories as to what dark matter may be, and they all vary greatly, contradicting each other on how many particles make up this new standard model, the forces dark matter interacts with, the number of dimensions dark matter exists in and even whether or not dark matter is a new type of matter at all, or just another phenomenon that can just as well be explained by modifications of Newtonian physics (MOND theory).

The first two theories laid out in the literature review vary greatly. While the first proposes a dark matter made up of new particles, possibly an entirely new standard mode, the second argues that dark matter is nothing of the sort, simply a different form of regular matter which is harder to see. WIMP theory explains the lack of visible matter with matter that does not interact with the electromagnetic force and, therefore, cannot emit, reflect, refract or diffuse light. MACHO theory sustains that the discrepancy between the mass and luminosity of a galaxy is caused by massive dense objects, such as brown dwarfs, which do not emit light and have a low albedo, making them almost invisible to see even with the most powerful of telescopes.

These differences could be attributed to the different methods by which these theories are investigated. Dark matter spans several fields of physics, namely astro and particle physics, and most of the methods used to research it can be categorised in either field. This is important as the two fields differ in many ways other than simply what they seek to research: particle physics aims to learn more about the basic particles that make up our universe and how they interact. Astrophysics, however, tends to focus on larger systems rather than particles, the big picture rather than details. Experiments such as rotational curves and gravitational microlensing are distinctively based in astrophysics; theories derived from those experiments will focus on different ways of arranging the particles already available, theories such as MACHOs. The theory derived mainly from astrophysical studies, such as mainly gravitational microlensing, is also one of the few that doesn't suggest a new undiscovered fundamental particle. Whereas studies such as the DAMA/LIBRA experiment are based on particle physics, looking at individual particles themselves on our own planet rather than larger systems in space. Since these experiments focus more on the particle physics side of the problem, they are more likely to conceive a theory along those lines, *ergo* a theory proposing a new particle, or even an entirely new standard model; a theory such as the WIMP theory.

This trend can also be seen in other similar, yet not as popular, theories. Primordial black holes (small black holes formed shortly after the big bang), similarly to MACHOs, are stipulated to have a large mass yet would not reflect or emit light, making them candidates for dark matter; this theory followers the trend mentioned above as they are mainly detected through distinctly astrophysical methods, such as detecting hawking radiation, gamma-ray bursts, and the observation of neutron stars in globular clusters. In contrast, self-interacting dark matter, not unlike WIMP theory, can be confidently placed within the realm of particle physics. It hypothesises an entirely new particle; this theory is also mostly based on the DAMA/LIBRA study; specifically, it was ideated as a solution to the annual modulation problem. This theory, based on a particle physics study, is itself predominantly a particle physics theory and even proposed the existence of a new particle, following the trend.

The type of study tends to affect the characteristics of the theory it conceives. This may be due to the spirit of particle physics and astrophysics. Where one attempts to understand components and the other attempts to understand the system, leading one to stipulate the existence of a new subatomic particle and the other to stipulate the existence of a new superatomic object. The research of dark matter is currently torn between the two fields, and both sides have as yet operated within their insular and parochial viewpoints.

The possibilities as to what dark matter may be are endless, limited in certain aspects but infinite in many more. Furthermore, since the field is split between two polar opposite areas of scientific research, studies and theories associated with it tend to be deeply entrenched in either field, leading to dark matter theories being seemingly incomplete, as though no consideration was posed to the opposing side of this dilemma. Finally, our lack of information on dark matter makes it even more difficult to study it, especially when the leading theories all have different ideas as to where to look for it, ranging from particle-detecting scintillators to telescopes for gravitational microlensing.

Since dark matter has been studied for 101 years to the nearest year, it is far above the average of 62 but just within the upper limit of the standard deviation, which is 102. This shows that dark matter has been worked on more than most other comparable problems and far more than the average. Given these major problems with dark matter research and the slow rate of discoveries in recent times, it can be easy to dismiss dark matter as a lost cause simply, but these problems may not be insurmountable and over time, we may be able to overcome them. Furthermore, dark matter research is imperative to our progress as a civilisation.

How to overcome the first problem

Our first problem might actually be the easiest to overcome; our lack of knowledge on dark matter will alleviate as research continues. If we are able to keep pushing forward and learning more about dark matter bit by bit, we will eventually reach a point where we know enough about dark matter to study it much more efficiently than we are able to now. There are two main things we need to know about dark matter in order to achieve this. The first is which forces dark matter interacts with; knowing this would let us know exactly in which way we can detect it and thus would greatly help research. The second is where in space, it can be found in the highest densities, and this would allow us to observe the effects dark matter has on regular matter on a much larger scale; since it is denser, its effects will be much more noticeable.

How to overcome the second problem

The second problem, our difficulty in finding dark matter, is mostly about patience; we must wait for our species' practical ability to explore and discover to catch up to our ability to theorise and imagine. Many notable previous theories have faced this problem, such as that of the earth being spherical: the ancient Greeks theorised mathematically that the earth should be spherical from the way the sun's rays hit the earth at different angles at different points on the surface. This theory was thought to be true. However, one could argue that it was never definitively proven until Ferdinand Magellan successfully circumnavigated the earth. Similarly, we have formulated many excellent theories on dark matter, and we may even eventually decide on one to cumulatively agree to be true, but we will never know for sure until we are able to venture into space and see it for ourselves.

How to overcome the third problem

The third problem, the divide between astro and particle physics, is the most complicated. Thus its solution is equally complex. Most physicists only specialise in one major. However, dark matter is so complex that it spans across fields, engulfing the border between astro and particle physics. It is astonishing how the same subject can involve two fields that are so at odds with each other, and yet it does, and therein lies the problem. The real solution to this is for physicists to learn more about research being carried out outside of their sub-community and be more involved in developments in the subject that they are researching, even if it means venturing outside their area of expertise. Dark matter is a complex problem, and collaboration between specialists in different fields would likely speed up research significantly. If physicists are able to consult each other on dark matter and keep updated on developments across all fields, it would likely help them figure out aspects of their own theories that they were struggling with.

The importance of researching dark matter

Although dark matter research has been a slow and painstaking process since its inception, it is still worth the trouble because we as a species have always been curious about knowing where our universe came from and how it will end. Dark matter comprises 85% of our universe; thus, we cannot learn more about it until we find out what it truly is. Dark matter may be the key to understanding the big bang and finding out whether our universe will continue to expand forever, fold back in on itself, or reach a point of equilibrium. Dark matter research is also instrumental to understanding the formation of galaxies, as dark matter may be one of the main reasons they exist as they do now.

Furthermore, the successful validation of the dark matter theory could have practical applications, such as improving our understanding of gravity and its effects on space-time; this could lead to advancements in space travel and exploration, as well as the development of more accurate navigation systems, in the far future.

Many of the greatest advancements in our civilization came from solving research problems; Maxwell's equations laid the foundation for modern communication technologies, special relativity has allowed us to harness nuclear power, and thermodynamics has allowed us to harness energy with heat engines or move it around at will with systems such as refrigeration. There is no way of knowing for sure what technological advancements we will gain from understanding dark matter, but there is a very high likelihood that this research will significantly benefit the entire world, just as has happened time and time again.

The beginning and end of our universe is perhaps the biggest issue in physics and a necessary step for our civilisation if we ever wish to expand beyond our solar system. Therefore, dark matter research is an absolute imperative, as without it, we will never be able to accomplish the goal at the centre of physics: understanding the fundamental laws of our universe.

There are also other fields of study in physics that are imperative to learn more about our universe while also suffering from the same problems seen in dark matter research. Namely, the similarly named dark energy has also seen extremely slow progress as we simply do not know how it interacts with matter other than its repulsive gravitational force. The second problem with dark matter can be seen in the matter-antimatter asymmetry topic as well. For some reason, more matter than antimatter was left over after the big bang. This should not be possible, and studying the reasons behind this phenomenon seems almost impossible without being able to see back in time. This means that until we obtain the technology necessary to observe the universe in an entirely new way, we may never know what caused this discrepancy. Quantum gravity is also a topic which perfectly exemplifies the third problem earlier discussed; quantum gravity is the joining point between relativity and quantum mechanics. However, this union is highly chaotic and hard to comprehend as, at first glance, the two should be mutually exclusive.

Conclusion

Challenges in dark matter research are not completely insurmountable, and some of them can be circumvented through ideation, innovation, engineering, and also through patience and determination. Furthermore, dark matter research is simply far too important to physics to give up. Without it, we will likely never know how our universe started or how it will end. Physics has always been the hardest of the natural sciences to research as it deals with the most fundamental components of our universe. However, without the determination of physicists throughout the years, we would never have progressed past the middle ages.

It seems almost uncanny how the natural phenomena of the universe were predicted and/or envisioned before they were actually discovered. Consider the 'aperiodic crystal' proposed by Schrodinger, the 'atomos' proposed by Democritus, the 'eka silicon' proposed by Mendeleev, or the 'neutrino' proposed by Pauli; to name just a few. These are a subset of a plethora of theories which were successful in their predictions. It seems reasonable to assume therefore, that a theory that is successful in predicting the origin of the 'missing mas' may already exist; whether it proposes alterations to exising models, or proposes new ones. We are trying to understand the inner workings of our universe with egregiously inadequate tools. Incremental accumulation of information may eventually lead to a theory that is successful in explaining the 'missing mass' conundrum and which is consistent with existing knowledge about the universe.

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