How the Enigma of Dark Matter Challenges the Modern Scientific Enterprise

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1 Introduction

The unknown is a fundamental feature of experience. One of the myriad ways humans have grappled with it is through curiosity. We can characterize this epistemic stance towards the world by wonder, interest, and a strange desire to understand. One of our most fruitful expressions of this curiosity has been the scientific enterprise. Its remarkable success is undeniable, as we have been able to manipulate and intervene in many of nature's processes. We know that this enterprise has been disturbed, if a problem remains in the abstract for too long. This has been the case with the enigma of Dark Matter. Roughly 85% of the matter density of the universe is of unknown origin, and has remained so for decades. Dark Matter has eluded our most advanced theories, and detection attempts. As such, the time is ripe for a reassessment of science, and an exploration into the philosophical foundations of our scientific processes.

In this paper, I will assess how Dark Matter challenges our modern scientific enterprise. I will begin by establishing a solid philosophical foundation from which to construct my best estimation of a framework of science. This framework will utilize important concepts first articulated by Thomas Kuhn and Bas van Fraassen, whose views I will briefly outline. Turning to physics, I will survey the best evidence we have for the existence of Dark Matter. From within my framework, I will then address how our early emphasis on particles, such as axions and neutralinos, have perpetuated Dark Matter's mystique. In conclusion, I will emphasize what our most theoretically and empirically virtuous experimental methodology is.

2 The Philosophical Ground

2.1 On Physical Theories

As our scientific theories have evolved, so have the ways we symbolically articulated them. Consider the movement from theories based in language, to ones based in mathematics, as pictured in Figure 1. What is lost in this transition, and what is preserved? It appears that natural language syntax is removed, and these symbolizations isolate the *relations* that hold between *entities.* I want to claim that these two features, relations and relata, are essential units of a scientific theory. Finding a philosophical ground will result from analysis of these core elements.

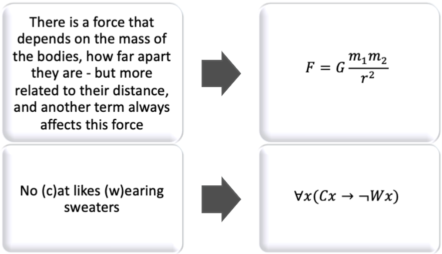

Figure 1

2.2 Realism and Instrumentalism

Do scientific theories aim to give us a literally true story of what the world is like, or do they simply function to provide a comprehensive, accessible and adequate description of the phenomena around us? A scientific realist would hold that a true physical theory is representative of an independently existing, objective world. Alternatively, an anti-realist reading of a theory asserts that the "function of a physical theory is to offer an intelligible, systematic conceptual pattern for observed data, thereby uniting phenomena that are otherwise surprising, anomalous or wholly unnoticed" [23]. As such, theories are judged on their usefulness in deriving actual observable quantities. Moreover, for many anti-realists, the entities posited, such as electrons, Higgs bosons, and quantum fields, are merely theoretical instruments that do not correspond to anything actual. Each of these philosophies has a standard counter-argument. Scientific realism is often challenged with the *pessimistic meta-induction.* It argues that our faith in our current scientific models is unfounded. Given that almost all of our previous theories were found to be false, what's to say our current theories won't suffer similar fates? The counter to anti-realist positions is the *no-miracles* argument. This argument states that it would be miraculous if our theories were so successful in their predictive power, yet did not provide a true empirical account of the way the world is. I want to focus on what I consider the most defensible form of realism, known as structural realism. One of the central questions posed by its group of adherents is whether relations, or relata have ontological priority. I want to explore the idea that both relations and relata appear to be fundamentally contingent on our embodied form.

2.3 The Contingency of Particulars

The perceived distinction between macroscopic objects is seemingly self-evident. The boundary between a coffee cup, and a pencil, no matter how close they get, is clear. It's implausible that you'd ever mistake them as coinciding, or being the same object. Yet, suppose we were sensitive to infrared radiation – their boundaries would begin to blur. Imagine if we could visually resolve the bacterium present on each of these objects, again the difference between them would begin to fade. This line of reasoning can be applied to all the entities we perceive. The boundaries between objects, the way in which we intuitively parse the world, is deeply rooted in our psychology. It is highly contingent on the specific regions of the electromagnetic, auditory, olfactory, and particulate spectrums we have evolved to be sensitive to. However, the situation becomes even stranger when we consider consequences of Einstein's Theory of Special Relativity [8]. Objects become not only contingent on our embodiment, but on our inertial frame of reference within spacetime. In certain cases, objects can differ in length, and events can differ in perceived simultaneity for separate inertial observers. An even more peculiar circumstance arises if we consider the Unruh Effect [12]. It is theorized that an accelerating observer will observe blackbody radiation where an inertial observer would see none. As such, we appear to be in a position where the particular entities we see are restricted by our sensory faculties, and whether we see them *at all* is contingent on our inertial frame of reference.

2.4 The Contingency of Relations

The entities we perceive have been shown to be highly relational to our embodiment. In this section, I want to demonstrate the following three points. Firstly, that formal mathematical systems are limited in their scope. Secondly, that formal systems are limited by virtue of being axiomatic. Finally, that the axioms that present themselves as self-evident are highly contingent on our embodiment.

The idea that certain formal systems are fundamentally incompatible is not a radical notion. Scientists have long been searching for a framework to unify general relativity (GR) with quantum mechanics. One of our most successful models of the universe so far has been the Standard Model of Elementary Particles. This theory is founded on a set of quantum field theories (QFT), which are fundamentally based on Lie Group symmetries. In searching for a strategy of unification, it was proven, via the Coleman-Mandula Theorem [13], that GR and QFT cannot be unified within the framework of Lie Algebras. Thus, this theorem places a limit on the compatibility of two formal systems.

If we move one level deeper, we find that the basis of our theorems are logical axioms. These statements are by definition unprovable, as they are the first principles from which deductive systems are based. When asked for a proof of an axiom, we can only look to direct experience. An example being the Law of Non-Contradiction, the straightforward claim that a proposition and its negation can never obtain at the same time. In 1931, Kurt Gödel published his famous Incompleteness Theorems [15]. These sent shockwaves through the mathematical community. The first theorem states that within a system, there can be true but unprovable statements. His second theorem states that an axiomatic system can never prove its own consistency, and, if it can, it is inconsistent. Mathematicians working on unsolved problems, such as the Poincare Conjecture, or Fermat's Last Theorem, now began to wonder if a proof existed at all. Thus, not only are our formal systems sometimes incompatible, but all systems are fundamentally restricted by the axioms they are based on.

Axioms are often thought to arise from inductive generalization. They are features of our experience that occur with such regularity and applicability, that we generalize them as being unquestionably true. However, it has been shown that certain tautologies in classical logic, such as the distributive law, cannot withstand the instantiation of quantum variables [3]. The distributive law, as written in the language of first-order logic, appears as follows: $P \wedge (Q \vee R) \equiv (P \wedge Q) \vee (P \wedge R)$. Consider the following variables:

- P = x-momentum is in the interval [0,1/6]
- Q = x-axis particle position is in the interval [-1,1]
- R = x-axis particle position is in the interval [1,3]

We notice that the left side of the equation places the particle within the interval [-1,3], whereas the right side places it strictly in the interval specified by either Q or R. As such, the right-side places tighter restrictions on the position than allowable by Heisenberg's Uncertainty principle. If we imagine an abstract type of embodiment on this scale, this phenomena would be highly relevant and regular. This is similar to how embodiment on the scale of an ant would make surface tension a much more relevant phenomena than it is on the human scale. As such, the inadequacy of the distributive law would be highly salient to us, and we would likely not inductively generalize it as being axiomatic. Not only are our theories restricted by virtue of being axiomatic, but self-evident axioms themselves are contingent on our embodied form.

2.5 On Groundlessness

There appears to be a fundamental groundlessness to our theories. Both the relations we create, and the relata we observe, are deeply dependent on our embodiment. The entities that we perceive are contingent on our sensory domain and frame of reference. Similarly, the relations we use are based on axioms, that are themselves grounded in our embodied experience.[1] Thus, there appears to be a fundamental contingency in the structure of our physical theories. Staving off this contingency is done by staying firmly rooted in the realm of empirical phenomena. Ignoring this contingency can lead us into the realm of pure speculation, and no actionable science comes from there.

3 Frameworks of Science

3.1 Introduction

The philosophical groundlessness explored in the first section will form the base of the dynamical framework of science I will construct. I will argue that the notion of contingency forces us to place an emphasis on what we collectively view as empirical phenomena. Before this exposition, I want to begin by introducing two philosophers of science, Bas van Fraassen and Thomas Kuhn. Van Fraassen helped outline a stance that science consists of constructed, and ever-evolving conceptual schemas [22]. Thomas Kuhn introduced the important notion of a shared unit of science [11]. After expounding these viewpoints, I will elaborate and synthesize them into a novel framing of the scientific enterprise.

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[1] Many of our best scientific theories are based on unintuitive systems, for example non-Euclidean geometries. However, a different embodiment would have given us different starting axioms. Whether our current formal systems would have been re-derived had we begun from a fundamentally different starting point, is to my knowledge, an unexplored claim.

3.2 On Constructive Empiricism

Bas van Fraassen introduced constructive empiricism in his 1980 book *The Scientific Image* [22]. It is a version of scientific anti-realism stating that: “science aims to give us theories which are empirically adequate, and that acceptance of a theory involves as belief only that it is empirically adequate.” He states that our limited human embodiment dictates what features of nature are relevant and directly observable. As such, our epistemic attitude towards science should stem from its adequacy in explaining empirical phenomena, that exist in specific relation to our contingent human form. A persuasive reason for adopting this view is the fact that it is far less metaphysically taxing. We simply hold that our scientific theories adequately describe observable phenomena, rather than holding them to the extraordinary standard of actually and truly describing the fundamental ontology of reality. Our selection of one theory over another is not based on any deep metaphysical truth, but hinges only upon its success in empirical explanatory power. Thus, it is no miracle that we have such empirically adequate theories, since they exist in an environment that actively selects for such theories.

3.3 On Paradigms

The notion of a shared unit of science was first fully explored by Thomas Kuhn, in his infamous work *The Structure of Scientific Revolutions* [11]. He called the shared unit of the scientific community a paradigm. We need this so that we don’t continually argue over first principles - it serves as a basis to our scientific practices. In learning a paradigm, “the scientist acquires theory, methods, and standards usually together in an inextricable mixture.” Kuhn is slippery when it comes to defining the word, and it is used in many different contexts throughout the book. However, one can ascertain several key features. Paradigms are a conceptual structure that contains the methodologies, criteria for meaningful problems, viable solution parameters, and first principles for a given scientific sub-domain. He explicitly states that a paradigm must leave open unsolved problems that the community can work on, and that its explicatory power must be “sufficiently unprecedented to attract an enduring group of adherents away from competing modes of scientific activity” [11]. Kuhn acknowledges that since the paradigm contains the criteria for legitimate problems, certain problems are necessarily left out. Paradigms are never totally adequate, and he views science as, “not progress to the truth – but progress away from less adequate conceptions of and interactions with the world” [11].

3.4 The Modern Scientific Enterprise

What is it that transforms speculative philosophy into precision science? Physicist Max Tegmark would argue that it is “precision data” [21]. This isn’t a controversial claim – however it subtly shifts the goal posts, as we must now articulate a notion of what *precision* and *data* mean. The precision data from the 1600’s supporting the phlogiston theory of heat transfer is wholly inadequate by today’s standards. Yet, the scientists of the time did exactly what van Fraassen prescribes, they “constructed models based on the empirical data available.” What those scientists considered valid empirical data was contingent on the paradigm they adhered to. We thus need a framework that accounts for the fluid and evolutionary nature of the scientific enterprise. A system that is flexible enough to change, incorporate new data, yet rigid enough to be useful. I want to present a schema of science that contains shared, created and found elements – which I name collaboration, representation and experimentation respectively.

- Collaboration: Shared significance landscape
- Representation: Creation of intelligibility frameworks
- Experimentation: Finding information through operations

Figure 2. shows the interpenetration of these social, mental and physical aspects of science. I think that the above sentences help to define the core of what the modern scientific enterprise is. It is hard to determine which of these interrelated systems came first, and as will be made clear, this is a necessarily self-referential system. The three primary components of it are the Significance Landscape, Intelligibility Framework and Operations – and I will explain the necessity of each of these in detail.

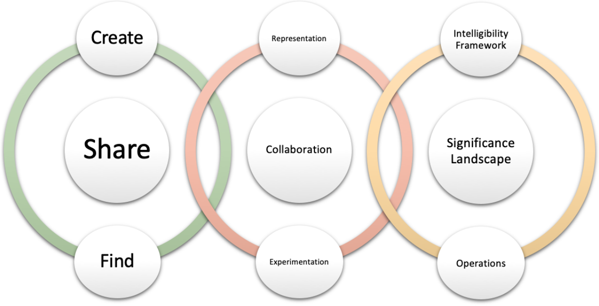


Figure 2

3.4.1 Significance Landscape

I'm calling the shared unit of science the significance landscape. It contains three subsections: Relational Salience Criteria, Consistent Epistemic Horizons and Symbolic Standards. These components must be shared by the scientific community for coherent research to be conducted. I consider this an elaboration on Thomas Kuhn's notion of a paradigm – but with increased specificity in regions I deem important. The primary goal of this landscape is to provide criteria for what makes something significant.

3.4.2 Epistemic Horizons and Symbolic Standards

A *consistent epistemic horizon* is the agreement of the scientific community on the limitations and scope of knowledge. No sub domain of science can claim independence from the whole. Biology cannot proclaim to have answers to problems that physics has not yet solved. Every sub field of science must be in relative agreement over how much of the world is understood. This section provides one of our first demarcations between science and pseudoscience. Pseudoscientific research programmes are often independent from the rest of the scientific cannon. For instance, astrology claims that emotional cycles are causally related to the orbital position of planets. Yet, not even our most advanced neuroscience has fully schematized the human emotional landscape, nor have astronomers constructed any theory as to the mechanics of this connection. Borrowing a turn of phrase from Ludwig Wittgenstein, these projects bear no "familial resemblance" [24] to each other .

Symbolic Standards refers to the fact that all practicing scientists must be using the same well-defined linguistic, and mathematical symbols. The usage of language, and subfield specific jargon is often an important clue as to the nature of a scientific research project. For better or for worse, straying too far from conventional symbolic standards can lead to academic isolation.

3.4.3 Relational Salience Criteria

The core component of the significance landscape is the Relational Salience Criteria. We are forced to confront an important question: what makes empirical datum relevant? Or rather, what makes anything relevant. Relevance is highly context sensitive. The number four is relevant to the question, "What is 2+2"? Yet, totally irrelevant to the question, "Have you seen my friend Jack"? Significance, or relevance, is not self-evident. It depends on something standing out against a background. But in order for this to occur, we must not only define a background and a foreground, but criteria for standing out. A foreground must be salient against a background, and only then do you have something relevant. In particle physics, the criterion for relevance is held to the high standard of a 5σ confidence level. Within a landscape of well-defined background phenomena (coherent scatterings at a given energy scale), a predicted particle is deemed significant if there is a roughly 1 in 3.5 million chance that your observation of it was due to the null hypothesis. The context of your salience criteria is sociological and pragmatic. This confidence degree is so rigorous, because the consequence of an error is billions of dollars spent on particle colliders, as well as decades of wasted research. In short: the stakes are high and so the salience criteria is proportionally high. Salience criteria for new medical treatments is significantly lower, requiring p-values of 0.05. The pharmaceutical industry would much rather accept an inert medication than miss a potential cure. If medicine required 5σ confidence – we would have nothing on the shelves.

To summarize, this criterion is context dependent and heavily reliant on the background hypotheses that one accepts. It is here where another demarcation can be drawn, this time between metaphysics and physics. Salience is not quantified in metaphysics. Without this criterion, there is no feasible means of demonstrability with which one can bring the ideas from the realm of the subtle, into the shared significance landscape. As Einstein once said, "every true theorist is a kind of tamed metaphysicist" [9]. To make a theory with concrete predictions, you must restrict it so that it can be assessed from within the current landscape.

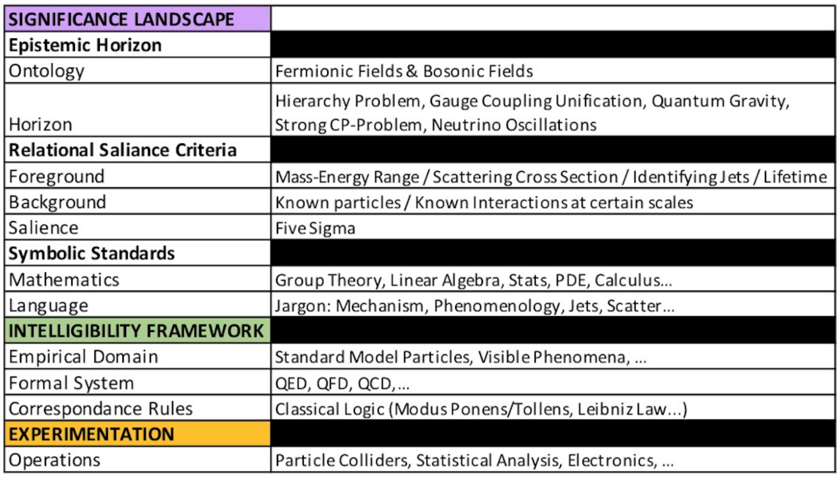
The discovery of energy quanta, and the discovery of general relativity, are commonly considered Kuhnian paradigm shifts. However, within this framing, they can be thought of as alterations to the significance landscape. The precise mechanism of the shift can now be identified. Scientific revolutions dramatically change our *background*, the domain of phenomena we accept as constituting a kind of fundamental ontology. An example from quantum mechanics is the notion of a minimum scale, the Planck length. Nothing can be salient on the order of less than $10^{-35}m$. Similar changes occurred after the introduction of General and Special Relativity. Objects were no longer in a static container of space, moving linearly in time. Foreground and background now blurred, as mass-energy content now dictated the very structure of space and time. The notion of objectivity was substituted for relativity, and our shared notion of significant phenomena changed in meaning once again. As has been made clear, without at least a loosely articulated significance landscape, it is hard to see how the scientific enterprise would allow for such large-scale collaboration.

3.4.4 Intelligibility Frameworks and Operations

The *Intelligibility Framework* is one of the creative aspects of science. This is the conceptual structure we use to not only probe the world, but to determine what constitutes the external world. There was a time when emotions were deeply personal, and accessible only through introspection. Yet, in the age of neuroscience and brain scans, we have been able to correlate certain neural pathways with certain emotional states. As such, emotions are slowly entering the shared empirical realm of science. The *empirical domain* is thus a malleable entity, and one of three interpenetrating aspects of the intelligibility framework. The other two being *formal systems*, and *correspondence rules.* This schema harkens back to van Fraassen's view of conceptual structures that are constructed in relation to the empirical world.

The empirical domain is the field we scientifically operate on. It's the domain of phenomena with which the community has reasonable, consistent and reproducible access to. The further we move from the natural extension of our senses, the more subtle the world becomes. This domain of phenomena has a variety of interesting features. It often increases in an instant, yet is only properly understood decades later. Consider the huge time delay between the discovery of DNA's double helix structure, to creating a carefully articulated model of it that enables consistent intervention - such as CRISPR and other methods of gene editing. Another example is Max Planck observing that energy is quantized [5], long predating our theories of quantum mechanics that have allowed for extraordinary inventions such as phones, computers and the internet. Rapid growth of the empirical domain often leads to anomalies, and sometimes contradictions within our theories. Thus, we need a mechanism that can alter itself and recouple to this new domain – *formal systems.* These are articulations of abstract entities, and the relations that hold between them. These fields also co-create each other – as much of the empirical domain remains in the abstract until it is brought out by a correct theoretical articulation.

Finally, *Correspondence Rules* are the logical relations that we accept as constituting a connection between a system and the empirical domain. This entire structure is the Intelligibility Framework, and utilizing its components, in relation to a significance landscape, helps to stave off the fundamental contingency established in the first section. This framework represents a union between our internal and external landscapes. The final component of the scientific enterprise is experimentation, the way in which we establish this union. An experiment is an operational methodology that allows for consistent, and reproducible articulation of Intelligibility Frameworks. The ingenuity of the scientist is showcased here, in that while seeking coherence between inner and outer landscapes, one can also explore the limits of the significance landscape, by altering background assumptions, salience criteria and so on. Figure 3. outlines how one might fill in this framework within the domain of particle physics.



SIGNIFICANCE LANDSCAPE	
Epistemic Horizon	
Ontology	Fermionic Fields & Bosonic Fields
Horizon	Hierarchy Problem, Gauge Coupling Unification, Quantum Gravity, Strong CP-Problem, Neutrino Oscillations
Relational Saliance Criteria	
Foreground	Mass-Energy Range / Scattering Cross Section / Identifying Jets / Lifetime
Background	Known particles / Known Interactions at certain scales
Salience	Five Sigma
Symbolic Standards	
Mathematics	Group Theory, Linear Algebra, Stats, PDE, Calculus...
Language	Jargon: Mechanism, Phenomenology, Jets, Scatter...
INTELLIGIBILITY FRAMEWORK	
Empirical Domain	Standard Model Particles, Visible Phenomena, ...
Formal System	QED, QFD, QCD,...
Correspondance Rules	Classical Logic (Modus Ponens/Tollens, Leibniz Law...)
EXPERIMENTATION	
Operations	Particle Colliders, Statistical Analysis, Electronics, ...

Figure 3: This table highlights elements of particle physics, parsed with respect to the framework described in the preceding sections.

3.5 Conclusion

To summarize the workings of this model, it is from a shared conception of significance, that we can experimentally connect our formal systems to the empirical domain. All of the outlined components are necessary for the correct functioning of science. If your formal system is not coupled to your empirical domain via experimentation – nothing actionable will come out of your Intelligibility Framework. If the Framework isn't based on the Significance Landscape, your results will be unintelligible to the scientific community. If your experiments aren't directly coupling a formal system to the empirical domain – then you risk being lost in the realm of the abstract and speculative. Attempting to pinpoint exactly how changes occur within this framework is difficult, due to its dynamical and self-referential nature. The interconnection of these systems is apparent if we observe how the intelligibility framework influences the background and foreground of the significance landscape in Figure 3. However, one can idealize this framework in Figure 4. Based within the significance landscape, an experimental operation connects the formal system with the empirical domain, while passing through the correspondence rules. While no schema of science can be all encompasing, I think the above framework highlights meaningful categories, and pinpoints some essential features of the scientific enterprise. Now that we have constructed a framework of science, and emphasized a philosophical ground of contingency – we can turn to the overwhelming evidence for the existence Dark Matter.

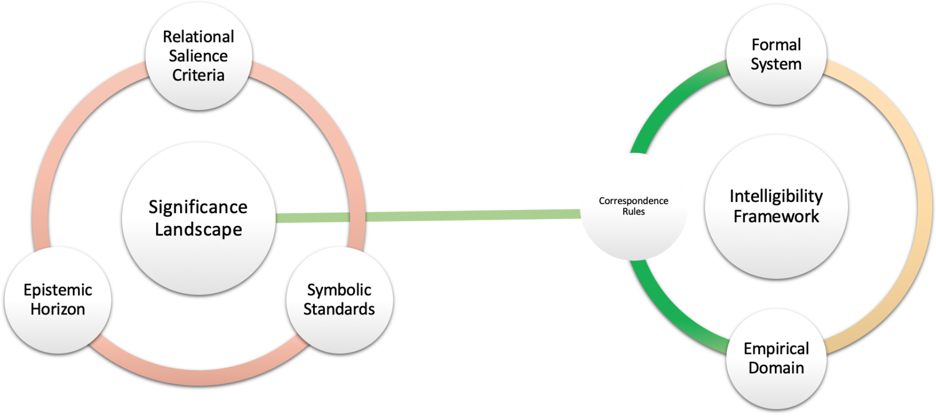


Figure 4: A visual representation of how formal systems are connected with the empirical domain through correspondence rules - which themselves are informed by the significance landscape.

4 Dark Matter

Indirect evidence for the existence of strong gravitational potentials, in regions devoid of visible matter, have been amassing for decades. It has been observed that galaxy clusters behave in ways that necessitate either a modification of our understanding of gravity, or the presence of some kind of exotic non-luminous matter. We have been given strong reason to believe in the existence of a new form of gravitationally interacting matter. It has also been argued that such a substance must also be: non-baryonic, electrically neutral, non-relativistic, and of a specific relic density. In the following sections, I will outline the evidence we have for the existence of a particle meeting these criteria. Next, I will introduce some of the dominant models we are using to search for a Dark Matter particle.

4.1 Anomalous Gravitational Fields

Naturally, I will begin by introducing the most important way Dark Matter manifests to us – through gravity. In his 1933 paper entitled *The Redshift of Extragalactic Nebulae*, Fritz Zwicky coined the term Dark Matter [25]. He was measuring the radial velocity dispersion of galaxies in the Coma Cluster. Through his estimations, he determined that the dispersion should be around 80km/s. This was one order of magnitude less than what he was actually observing. The gravitational force from the visible matter alone was not enough to keep this cluster stable. He concludes his paper by stating: "In order to arrive to an explanation of the large velocity dispersion, one would have to permit a much greater density of dark matter" [25]. An invisible form of matter is also what plausibly led to the abnormally high mass-to-light ratio[2] of the Virgo Cluster, being studied by Sinclair Smith in 1936 [20].

The missing matter problem continued to appear in astronomy, most importantly via anomalous galactic rotation curves, as studied by Vera Rubin and Kent Ford [19] in 1970, and Albert Bosma [4] in 1978. They all published rotation curves that did not exhibit the expected velocity drop-off at large distances from the galactic center. Thus, they could all conclude that the gravitational field from the visible disc alone was too weak to provide the necessary acceleration for the outer stars.

As described by Einstein's Theory of General Relativity, spacetime is warped in the presence of a gravitational field. As such, photons travelling through regions of high energy density will have their otherwise straight trajectories deflected, which distorts the images we obtain of celestial objects. This effect is known as gravitational lensing, and occurs most frequently in the form of weak lensing. This is a slight, but consistent systematic alignment of objects that should be otherwise uncorrelated. On the other hand, strong lensing is dramatic, and occurs when a massive body is directly in our line of sight of another object, and can cause that object to appear multiple times in an image. Lensing techniques were used to study the Bullet Cluster in 2004 [6]. Figure 5 shows the high-velocity collision of two clusters of galaxies. By observing the lensing of background objects, it was determined that there was a large spatial offset between the baryonic matter, and the center of mass of the cluster. Most of the mass of the Bullet Cluster was actually concentrated in regions beyond the collision site. Once again, there was the appearance of strong gravitation in regions devoid of visible matter.

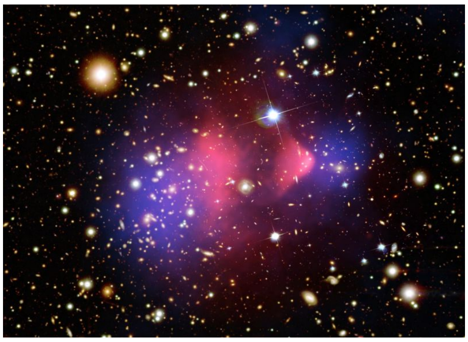


Figure 5: The pink coloring represents the collisional X-rays, whereas the majority of the mass is highlighted in blue.

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[2] Galactic masses are often given in solar mass units, which relates them to the mass of our sun. This allows for easy conversion into a ratio of solar masses to solar luminosity known as mass-to-light ratios (our Sun's is equal to one). This is important, because we generally take our sun to be a standard star, and so its ratio of mass to light should be representative of stars in general.

4.2 Baryonic Abundance Constraints

There is a strong consensus that the extra force of gravitation outlined above is not due to baryonic matter. This was due largely to two independent, but corroborating theories. Big Bang Nucleosynthesis (BBN) was the theoretical remedy to the failure of models of stellar and supernova nucleosynthesis in the 1940s. Astronomers had begun finding an abundance of light nuclides such as deuterium, He^3, He^4 and Li^7 in the cosmos. Given that these elements are not created within stars, but actually used as fuel, a new model to describe their abundance was required. Alpher, Bethe and Gamow created BBN in 1948 [2], and it explained the current light element abundance based on the density of baryons in the early universe. As such, this density is a carefully tuned parameter, and recent BBN calculations and measurements restrict physical baryon density to $\Omega_b h^2 = 2.156 \pm 0.020$ [3].

A second method for constraining baryon density is obtained from analyzing the peaks of the angular power spectrum of the cosmic microwave background (CMB). The most recent PLANCK mission mapped the small temperature anisotropies of the CMB to a high degree of precision. Given that photons and baryons were tightly coupled in the early universe, we can deduce from the specific amplitudes and positions of the intensity peaks what the primordial baryon density was. It has been found to be in incredible agreement with BBN calculations, with a 2016 figure restricting baryons to $\Omega_b h^2 = 2.230 \pm 0.014$ [1]. While we have yet to account for the current state of every baryon, one thing is clear: there are not enough of them remaining to account for all the observed gravitational anomalies.

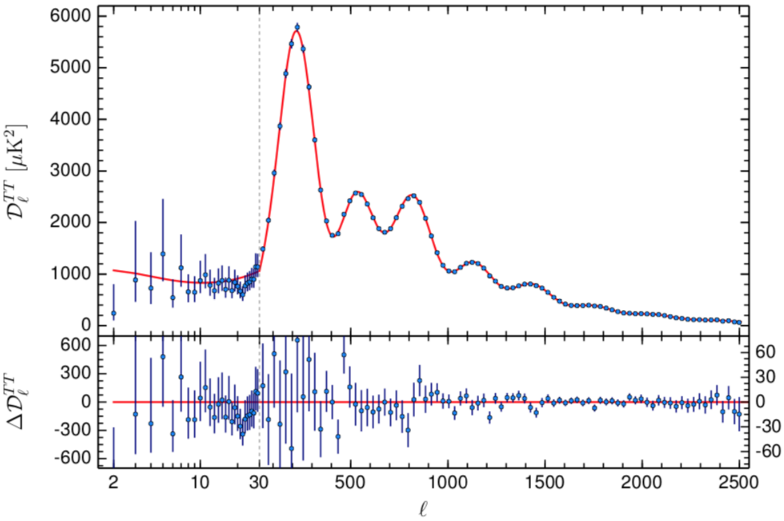

Figure 6: The angular power spectra of the CMB, as calculated from Planck 2015 data. The top portion is the spectra, and the bottom portion plots the residuals [1].

4.3 Neutral, Stable and Cold

The early universe was an asymmetrical landscape of oscillating baryon-photon plasma. These oscillations were driven by gravitational compressions, and pressure induced rarefactions. The initial asymmetry is because of small quantum vacuum fluctuations that occurred moments after the big bang. These were frozen as classical density perturbations after inflation. This provided a slightly inhomogeneous landscape of over-dense regions, that matter began to collect in. However, given that early baryons were coupled with photons until recombination, there wouldn't have been enough time for the complex gravitational structures we currently observe to have formed. Moreover, the forces from the baryons and photons alone cannot account for the amplitudes and location of the peaks in Figure 6. We need an extra force that amplifies the compressions and dampens the rarefactions. As such, we need a particle that interacts gravitationally, but is immune to the photon pressure.

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[3] This unit was chosen by the paper authors - and is scaled by a factor of 100. The Ω_b parameter is the ratio of current baryons over the density required to halt the expansion of the universe (critical density). The h parameter represents the reduced Hubble constant, $H_0/100$.

Further evidence for the electrical neutrality of Dark Matter is apparent in the aforementioned Bullet Cluster. This is because whatever contributed to the high gravitation regions beyond the X-rays must have been able to pass through them unimpeded, and can thus be said to not couple to the electromagnetic field. The non-relativistic nature of this form of matter was derived through simulations run by White, Frenk and Davis in 1983 [7]. It was concluded that the rapid thermal motion of a relativistic particle would have wiped out the initial density perturbations, which were the primordial seeds for the large structures we see today.

4.4 WIMP Miracle

The validity of the Dark Matter's existence is strongly related to the numerous lines of independent reasoning. However, despite the overwhelming evidence, we have no real leads on what this substance could be. In fact, Dark Matter candidates can be said to span an incredible seventy-six orders of magnitude: $9 \times 10^{-72} M_{\odot} \leq M_{DM} \leq 10^{4} M_{\odot}$. This search space has been probed with a variety of theories, including modified gravity, primordial black holes, and massive astrophysical low luminosity objects. Yet, these have all been ruled out as being a primary explanation for Dark Matter, as none can single-handedly account for all the evidence. One of the most promising theoretical routes was that of Weakly Interacting Massive Particles (WIMPs). The WIMP miracle is that many viable Dark Matter candidates were auxiliary predictions of theories created to solve entirely unrelated theoretical problems. I want to briefly introduce two of these particles, and their underlying frameworks: Peccei-Quinn theory's axion, and supersymmetry's neutralino.

4.5 Supersymmetry

Supersymmetry (SUSY) is a theoretical framework that proposes a fundamental symmetry between fermions and bosons [18]. It attempts to unify matter and forces under a single system, by positing that every Standard Model particle has a superpartner, that differs in spin by half a unit. As such, our ontology of fundamental particles and fields is doubled in a SUSY scenario. Investigation into this class of theories began in efforts to solve a host of theoretical problems, such as Gauge Coupling Unification and The Hierarchy Problem. Attention was focused towards Dark Matter when it was seen that some of the proposed supersymmetric particles had many of the sought after dark matter properties. The class of such particles are known as Neutralinos. Through the introduction of a new conserved symmetry, known as R-Parity, the lightest supersymmetric partner particle would be guaranteed to be stable. Furthermore, the early universe production of susy particles is such that the relic density is consistent with Dark Matter predictions.

4.6 Peccei-Quinn Theory

One of the most profound insight in modern physics is CPT symmetry. It has been found that under a simultaneous transformation of parity, charge conjugation and time reversal – the behavior of physical phenomena remains invariant. While systems remain invariant under all three of these transformations, the weak nuclear force has been shown to violate CP symmetry. In 1972, it was proven that Quantum Chromodynamics, the field theory describing the strong interaction, should also violate CP [10]. However, not only has CP violation not been observed, but it would go against many modern observations, such as the neutron's electric dipole moment. In order to rectify this, Helen Quinn and Roberto Peccei introduced the Peccei-Quinn Symmetry, which introduces a new dynamical field, whose quanta is a particle called the axion [17]. It's mass range is substantially smaller than that of Neutralinos, however its relic density and weak interaction with baryons make it a viable DM candidate nonetheless.

4.7 Detection Attempts

No matter how weakly-interacting a Dark Matter particle is, there is a non-zero probability that it will scatter off of a known particle. As such, our experimental methods have been centered around either producing Dark Matter through a collision, indirectly detecting it through scintillation or phonon detectors, or by observing radiation produced in Dark Matter annihilation events. These detection attempts have been coupled to the above frameworks, and every year the parameter spaces of both SUSY and PQT are further constrained. If our search attempts are consistent with how we normally conduct science – then this situation is truly an enigma. We've been looking for Dark Matter for decades, using our most robust formal systems, and the most advanced experimental methods – yet we haven't found anything. Despite the initial promise of WIMPs – we have yet to find any evidence for their existence. Dark Matter is very much in the same state it was decades ago. However, in the coming section I want to argue that this is not how we normally do science.

5 The Enigma

5.1 From Massive to Miniscule

Dark Matter is not an enigma. It is yet another case of the empirical domain expanding rapidly, and our formal systems attempting to catch up. Our problem lies in our fascination with *what could be*, rather than *what is*. Despite the theoretical virtues of the forerunners of the particulate Dark Matter movement, Peccei-Quinn Theory and Supersymmetric frameworks, they have no correspondence to the empirical domain. These theories, and their experimental methodologies are not primarily operating on the domain of phenomena the scientific community has reasonable, consistent and reproducible access to. We see this clearly in the fact that the scattering cross-section and masses of particle candidates gets smaller every year, not in comparison with astronomical observations, but simply due to lack of detection. Theories that operate in this regard, risk venturing into the realm of contingency. Using these contingent theories as our primary Dark Matter models is a large reason why this enigma appears as such. We have moved from the realm of the massive (astronomy), to the miniscule (particle physics) too quickly. If Dark Matter is as enigmatic as we think – we should treat it as we once did the visible macroscopic world. We ought to begin studying it in a top down way – learning about its large scale, dynamical properties. This is done by carefully studying what we do know about it, and how it currently manifests in our empirical domain. With respect to Dark Matter, this is strictly the appearance of anomalous gravitational fields. As such, gravitational lensing surveys offer an experimental technique, rooted in a formal system (general relativity), that has consistent access to the empirical domain. This would satisfy our earlier definition of the scientific enterprise – as we now have an experimental method with an actual foothold on our shared experience.

5.2 Distribution and Density

We have yet to reproducibly determine how Dark Matter is distributed in the cosmos. Through careful study of visible matter and lensing events, we can start to create a picture of how Dark Matter forms structures. Yet, this is a delicate and sensitive endeavor, and exotic behavior continues to manifest on all scales. This is especially apparent when attempting to determine the inner density profiles of dwarf galaxies through rotation curve calculations [16]. The cuspy-core problem is a recurring issue in this field. Demonstrating an asymmetry between theory and observation, it describes how Cold Dark Matter simulations of halo formation indicate a sharp density cusp. In constrast, observed galaxies appear to have uniformly dense cores out to several parsecs [14]. Additionally, Dark Matter is surprisingly absent from many galactic regions, and apparently from Earth's immediate neighborhood as well. This supports the view of patchy Dark Matter distribution, and that it appears in criss-crossing filament structures spanning the universe [14]. These highlights point to questions pertaining to how these hierarchical structures form. What is the kinematic behavior of DM, how does it self-interact, and is there perhaps a unique form of baryon interaction present. The more carefully we account for the behavior of our *background* (baryonic matter in this case), the more precisely we can isolate anomalies, to which Dark Matter may be attributed. Thus far, there have been incredible lensing surveys conducted, using a variety of ground and space based telescopes. However, if lensing proves to be the optimal operation for probing Dark Matter - then dedicated in-orbit telescopes will one day be built for this purpose.

6 In Closing

I began this paper by arguing that if we uproot ourselves from our embodiment, we are confronted with contingency from all sides. As such, we must be careful when speculating about phenomena that are not empirically accessible to us. To combat this notion of contingency, I constructed a framework of science emphasizing collaboration, creativity and experimentation. Our scientific enterprise is grounded in a shared space of empirically relevant phenomena. I then introduced our best evidence for the existence of a non-baryonic, gravitationally interacting particle. From within my framework, I investigated the strange fact that despite knowing almost nothing about Dark Matter's macroscopic behavior, we are already probing its fundamental nature.

At this stage, pursuing axions and neutralinos as primary Dark Matter candidates is not consistent with how we normally do science. As such, gravitational lensing was proposed as a methodology that is firmly rooted in an accepted theory, has empirical access to our only form of Dark Matter evidence, and can reveal more about its interactions both with itself, and Standard Model particles.

The search for Dark Matter will almost certainly end as a particle discovery. However, an important lesson in the interim is what this enigma has demonstrated to us. When science is confronted with an enormous unknown, we cling even more tightly to the frameworks we've already created. There is a philosophical incongruency with how we're treating Dark Matter. If it is truly as mysterious as we claim, we ought to embody our original epistemic curiosity, and probe it as we once did the visible world – from the top down. This approach emphasizes how it currently manifests in our empirical domain. We should place utmost importance on this, because with respect to Dark Matter, it's all we actually have.

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