The Shortcomings of Extra-Empirical Justifications for String Theory

Joshua Nowry

A Thesis submitted to the Faculty of Graduate Studies

in Partial Fulfillment of the Requirements for the

Degree of Master of Arts

Graduate Program in Philosophy

York University

Toronto, Ontario

August 2024

Abstract

The main goal of the thesis is to level counterarguments against Richard Dawid's extra-empirical arguments for the scientificity of string theory. I will use the luminiferous aether as a parallel case study to show that if we were to accept Dawid's extra-empirical arguments, an equally compelling case could have been made for the scientificity of Henri Poincaré's aether theory—which has since been refuted. I also suggest that the lack of empirical corroboration of supersymmetry at the Large Hadron Collider undermines the trustworthiness of his meta-inductive argument in particular and that Dawid may be guilty in this argument of committing the base rate fallacy as identified in the Bayesian probability theory on which he relies. Furthermore, I argue that since there is a substantive difference between how Dawid's extra-empirical arguments are used in the canonical scientific method and how he proposes to use them in support of string theory's scientificity, the former cannot justify the latter. Lastly, I object to taking string theory's final theory claims seriously since certainty of string theory's scientific validity is their truth condition, and empirically or extra-empirically, this is unobtainable.

To my spouse, Marica Villeneuve,

who has gracefully endured more philosophical conversations,

than any non-philosopher should ever have to.

Acknowledgements

From my tumultuous secondary school days through to graduate school, I would like to thank the following: my 11th-grade physics teacher, Mr. James, who inspired me to pursue a bachelor's degree in physics and nurtured my interest in string theory; Jocelyn Hawkins and Andrew Chouinor without whom the likelihood of my graduating high school would have been significantly reduced, as they fostered creativity and independent thought when I felt they were anathema to the education system—thereby rekindling my passion for learning; Professor Randy Lewis who during my physics degree indulged me in frequent and—often times lengthy—philosophical discussions, many of which paved the way for much of the content of this project; and Dr. Jill Cumby who convinced me that I would be well-suited for graduate school, and therefore, quite literally without whom this thesis would not have been written. From graduate school on, I would like to express my gratitude to my supervisor, Professor Jagdish Hattiangadi, for his saintly patience and indispensable advice, to Professor Matthew Leisinger for his steadfast encouragement and for his refusing to let me throw in the towel, even if I were to have been willing to, and to Nisha Khan for ensuring that everything on the administrative side of things went as smoothly as possible. Last but certainly not least, I would like to thank my spouse's parents, Anne-Marie and Pierre Villeneuve, for their support and for being so accommodating (e.g., permitting me to remain ensconced in their office on holidays, only emerging for meals while I completed sections of this project) and my parents Mark Nowry (who taught me at an early age perhaps the most valuable lesson of all: to never stop questioning) and Suzanne Bessette (who will tell anyone who will listen that I was born a philosopher) for their sage guidance, endless pep talks, and unwavering support.

Table of Contents

List of Figures

List of Acronyms

The following table defines the acronyms used in the main body of this thesis and provides the page on which each acronym is introduced.

Acronym	Meaning	Page
ATLAS	A Toroidal LHC Apparatus	72
CMS	Compact Muon Solenoid	72
IBE	Inference to the Best Explanation	40
KKLT	Kachru, Kallosh, Linde, and Trivedi	18
LAM	Luminiferous Aether Models	66
LHC	Large Hadron Collider	72
MIA	Meta-Inductive Argument	38
NAA	No Alternatives Argument	38
TCS	Theorem of Corresponding States	53
UEA	Argument of Unexpected Explanatory Coherence	34
UEC	Unexpected Explanatory Coherence	39

Introduction

The current zeitgeist of contemporary fundamental physics is embodied by polemics. Both internally (within the discipline itself), as well as externally (from the vantage point of the philosophy of physics). The dispute centers around the scientific status of string theory—a prospective theory of everything—which mathematically unifies the standard model of particle physics (consisting of the various quantum field theories) and Einstein's theory of general relativity. The following words of physicist Sheldon Glashow encapsulate the reservations that some physicists have regarding the theory's scientificity: "[f]or the first time since the Dark Ages, we can see how our noble search may end, with faith replacing science once again.[1] Superstring sentiments eerily recall "arguments from design" for the existence of a supreme being" (1). Another common criticism of string theory is that its mathematical elegance and the conceptual rapprochement that it facilitates—in isolation—do not constitute nomological necessity, which is eloquently expressed by Nobel laureate physicist Philip W. Anderson:

> [String theory] is an interesting mathematical specialty and has produced and will produce mathematics useful in other contexts, but it seems no more vital as mathematics than other areas of very abstract or specialized math, and doesn't on that basis justify the incredible amount of effort expended on it. My belief is based on the fact that string theory is the first science in hundreds of years to be pursued in pre-Baconian fashion, without any adequate

[1] My utilization of this quote should not be construed as a substantive claim about the rational incompatibility of science and theology—as this is a topic exterior to my project. For my purposes, the takeaway should simply be that theology's epistemological arsenal (e.g., fideism: that certain knowledge can only be attained by faith) has been sundered from that of science's, enabling it to have its own individual intellectual identity. Therefore, insofar as science appropriates the epistemological canons of theology, it would blur the line between these disciplines, and compel science to abdicate its hard-earned independence—thereby dissolving itself.

> experimental guidance. It proposes that Nature is the way we would like it to be rather than the way we see it to be, and it is improbable that Nature thinks the same way we do. (Anderson)

This discord has become so fervent and prolific that it has spilled over into the public sphere. String theory's grandiose final theory claim—advocated for by many of its adherents (i.e., that its theoretical schema will never be supplanting by that of a subsequent theory)—coupled with its inability to deliver empirical corroboration for approximately 40 years after its inception, has cast it into the veritable limelight (Dawid 3, 64). Due to technological bottlenecks for future experimentation and some of string theory's theoretical postulates appearing to be unconfirmable in principle, an emphasis has been, rightly, placed on ascertaining what indeed qualifies as a scientific theory within the fields of physics and philosophy. Barring a breakthrough innovation providing an alternative experimental means of validation—which does not appear to be on the horizon—these bottlenecks are the practical impediments (e.g., infeasible size demands, magnetic field strength limitations, etc.) of constructing particle colliders capable of plumbing the energies of the Planck scale where the theory's entities are predicted to exist (i.e., around 10^{16} TeV), when the maximum energy at which our current particle accelerators can penetrate reality is 13 TeV (more will be said about these theoretical entities in the first section of the succeeding chapter) (Yau and Nadis 270).

Concerning untestable postulates, the mathematical formalism of string theory permits solutions which describe sundry universes each with fundamental physical constants that differ from those of our own. If we assume—as particular card-carrying scientific realists who are exponents of string theory might—a straightforward hypostatization of these umpteen-for-the-price-of-one, freebie universes where they are simply "bundled together" into a multiverse model (i.e., these universes have been, and will continue to be, causally disconnected from each other), then these universes will not even be indirectly detectable (Read and Le Biahn 7757-7758).[2] Of course, an antirealist proponent of string theory may merely consider these adjunct universes to be a mathematical surfeit and, therefore, would wager against their measurability, but irrespective of one's interpretational partiality the conclusion remains the same: string-theoretic parallel universes appear to be empirico-phobic.

Under ordinary circumstances, physicists typically are more than capable of resolving a debate about whether a particular theory is scientific or not—as exemplified by the relatively cordial history of the present-day paradigm of science; specifically, one predominately characterized by consensus concerning theory choice. However, when questions regarding the sufficiency of the tried-and-true scientific methodology arise, the services of philosophers are often enlisted because devising arguments to potentially revise the scientific method are outside the purview of physics. (For instance, physicist Richard Dawid felt that it was incumbent upon him to complete a second Ph.D. in philosophy to adequately confront the methodological conundrum posed by string theory.)

In his book *String Theory and the Scientific Method*, Dawid aptly describes the general

---

[2] Read and Le Bihan—in their article "The Landscape and the Multiverse: What's the Problem?"—explicate two string-theoretic multiverse models and suggest that they seem, at least prima facie, to not be blatantly hostile to empirical adjudication—namely: eternal inflation and the brane multiverse. Though I cannot address these counterexamples exhaustively here given the enormity of these topics, as doing so would significantly derail the overarching trajectory of this project. Nevertheless, I will make a few remarks. Since their overall objective is to showcase multiverse models that are latently empirically viable which need only be amenable to a string-theoretic framework, they have not established a robust theoretical connection (much less a necessary one) between string theory and eternal inflation (where the latter is a cosmological theory). As a result, even if eternal inflation were to be empirically validated, it is not at all clear that this would be a harbinger of string theory's scientific legitimacy, since string theory is not the only theory of quantum gravity simpatico with eternal inflation (i.e., the theories would be underdetermined by the experimental data). Nor have they—in the case of the brane multiverse—shown how this model could be empirically distinguishable from a no-frills, non-multiverse big-bang model. Therefore, my assertion that string theory's multiverse postulate appears to be unconfirmable, in principle, should remain uncontroversial—at least for the time being.

character of the disagreement between string theorists and their detractors in terms of accusations of psychosocial predilection. In his own words, "[t]he debate between string physicists and critics of string theory on the legitimate assessment of the theory's success and viability thus is characterized to a significant extent by allusions to psychological or sociological aspects" (Dawid 25). I concur with Dawid that allegations of groupthink, tribalism, traditionalism, etc., dominate the dissensus, since appeals to empirical evidence are out of the question, and because both factions contend that their opponents are asserting a view which is in contradiction with the established scientific method—or rather their respective perspectives of it. A brief survey of the battlefield will illustrate this, while modestly clarifying the casus belli of the string war.

Lee Smolin in his book *The Trouble with Physics* ascribes the longevity of a theory bereft of experimental confirmation to the academic culture inherent to theoretical physics. He states that in a field where theories could conceivably remain untested for a practitioner's lifetime, there is a vested interest in indoctrinating subsequent generations of physicists: "[t]he sociology of science is not a mysterious force; it refers to the influence that older, established scientists have over the careers of younger scientists" (Smolin 267). It is evident here that Smolin must resort to a psychosocial analysis of the innerworkings of academic mentorship to explain the persistent sacrosanct status of string theory, since for him, it violates the central tenets of the scientific method. In *Not Even Wrong*, Peter Woit provides further arguments for the purported acculturation in theoretical physics by adducing the following catch-22: physicists who are skeptical of the viability of string theory, but who are not well-versed in string theory, are criticized on ultracrepidarian grounds (lack of expertise), however, if an individual devotes the amount of time necessary to obtain the specialized expertise and their doubts endure, it is quite unlikely that they would renounce their life's work. Woit phrases it in this way, "[b]y the time they achieve some real expertise they typically have invested a huge part of their career in studying superstrings, an investment which is psychologically and professionally very difficult to give up" (206). The leitmotif of Sabine Hossenfelder's *Lost in Math* is the ubiquity of beauty (e.g., simplicity, naturalness, elegance, etc.) as a theoretical virtue in contemporary fundamental physics—in spite of it being idiosyncratic, arbitrary, and wanting specificity. She expresses apprehension regarding the observed reliance on these ill-defined qualities in the research program of string theory and suggests that an obsession with aesthetics is obfuscating the truth about string theory (viz., that it is unscientific): "[n]either could I find a mathematical basis for simplicity, naturalness, or elegance, each of which in the end brought back subjective, human values. In using these criteria, I fear, we overstep the limits of science" (Hossenfelder 102).

On the opposing side, Leonard Susskind lauds string theory for providing insights into adjacent theoretical problems: "[t]he debate about black holes and information was a long one that was only settled by string theory" (179). Additionally, he extols its virtues on the basis of its mathematical prowess, "[i]ndeed reconciling quantum mechanics with gravity has been the other really great accomplishment of string theory," as well as its being related to an underlying explanatory framework that many high-energy particle physics discoveries were predicated upon—notably, confinement, linear Regge Trajectories and hadronization (Susskind 175). (I will not be pursuing these non-methodological claims any further per se, but the explanatory-framework relation they partake in and the line of reasoning that it implies will be central to this work—more will be said about this shortly.) While other proponents of string theory participate in, the now familiar, armchair psychologizing of their rivals attributing their distaste of string theory to either ignorance, or a pathological attachment to normalcy. They epitomize the viewpoint, alluded to by Dawid, of physicists in the midst of an incremental, unconscious transition into an extra-empirically expanded scientific method in response to the theoretical demands of high-energy physics; antagonists of string theory would interpret this as the fabled boiling frog syndrome—except with string theorists in a pot of increasingly extra-empirical methodologies.[3] However, in the eyes of the advocates of string theory, an adherence to the canonical scientific method was never disrupted.

Dawid proposes a strategy for avoiding the previously outlined impasse between string theorists and their adversaries. He advises broadening the scope of the analysis and recasting the fray through a kind of Kuhnian lens. As a philosopher of science, Dawid is not situated within the conceptual edifice he is inspecting, therefore he has the luxury of being able to pose the question: what epistemic processes should the scientific method consist of? Consequently, he introduces his notion of a "paradigmatic rift" to characterize the schism occurring in fundamental physics since, for him, the magnitude of dissent signifies a departure from the activities of normal science. However, Dawid differentiates his notion of a "paradigmatic rift" from the Kuhnian notion of a "paradigm shift" in two salient ways—although they have the commonality of both contrasting periods of normal science. Firstly, Dawid's paradigmatic rift is extrinsic to the scientific enterprise and is concerned with what evidential avenues we should permit for assessing a theory's scientificity within a given scientific paradigm (almost in a meta-paradigmatic fashion is how Dawid couches it), whereas a Kuhnian paradigm shift is intrinsic to the scientific enterprise and pertains to the content of scientific theories, and in particular, how scientific precepts are altered in order to account for natural phenomena which conflict with the

[3] A brief note on terminology: I have chosen to call what Dawid refers to as "non-empirical" theory assessment, evidence, arguments etc., "extra-empirical" theory assessment, evidence arguments etc., as I feel that this parlance results in a few modest misnomers based on how Dawid expounds these elements. Namely, though they certainly lie beyond the bounds of empiricism—as it is traditionally conceived—they are not completely uncoupled from it.

prevailing scientific paradigm (27). Secondly, unlike a paradigm shift which is typified by a scientific revolution drastically upending a period of normal science, the hallmark of a paradigmatic rift is the subtle segue from normal science to a novel evaluative scheme (or meta-paradigm) via an almost indiscernible methodological drift. Dawid asserts that the psychosocially suffused preconceived notions miring the discourse can be circumvented by superimposing his concept of a paradigmatic rift over string theory's scientificity scrimmage. I agree that implementing this analytical technique is a prerequisite for ascertaining, impartially, the appropriate criteria for theory selection in this case. However, it is at this juncture where my position diverges from Dawid's.

In response to being confronted by the taciturnity of the tribunal of sense experience and the ensuing deadlock over the scientificity of string theory, Dawid identifies the etiology of the crisis as the lack of (explicit) inclusion of extra-empirical criteria in the canonical scientific method. He pleads that the canonical scientific method should be amended accordingly, then scientific confidence can be renewed in string theory and fundamental physics can carry on unaffected. However, if we adopt this solution then we run the risk of normalizing making an appeal to extra-empirical arguments to substantiate a theory whenever empiricism cannot—even if the theory's empirical recalcitrance is in fact a reflection of its abject failure.

Before continuing, I would like to clarify the denotation of "scientificity." Perhaps the best place to start is by explicitly articulating what I do not intend to convey by its usage (and what I take Dawid's use of the word likewise to exclude). Namely, it is not meant to refer to theories that are merely constructed within the scientific enterprise. Of course, there is an obvious sense in which these are scientific theories; however, I want to distinguish these theories from scientific theories that have gained credibility via methods of scientific inquiry, are enjoying a period of empirical success (irrespective of how short-lived it may be), have passed some kind of severe test, etc. To further elucidate this distinction, theories of the former type can be considered candidate scientific theories since, prior to their being substantiated to any degree by the methodologies of science, it seems premature from a certain perspective to label them scientific theories (for instance, they might fail the initial round of empirical testing indicating that they do not accurately describe reality); whereas theories of the latter type that have, for example, accumulated empirical corroboration have been supplied with a proportionate degree of scientificity—in the sense of scientific credibility. Naturally, a theory's scientific status in this latter sense can be revoked if experimental data conflict with it (i.e., a theory can lose its scientific credibility if the methods of science no longer support it), so scientificity is not a static trait of theories but rather a designation for established (accepted) scientific theories during the period of time within which they are effective at depicting and predicting natural phenomena. Accordingly, since Dawid aims to legitimize extra-empirical arguments as a method of furnishing a candidate scientific theory with scientific credibility, they should be construed as attempting to furnish a theory with scientificity in this sense; thus, it is in this sense that I will be using it for this project.

Returning now to Dawid's view, the features of string theory previously mentioned while canvassing Leonard Susskind's standpoint—that he touted as support for the theory's scientificity—foreshadowed the type of extra-empirical arguments for a theory's acceptance in physics upon which Dawid's viewpoint depends. For the sake of this work, Susskind and Dawid's positions will be taken as paradigmatic of both string theorists and philosophers of physics sympathetic to string theory being recognized as a scientific theory. The extra-empirical arguments to be utilized as a means of theory assessment that Dawid advances are the "no alternatives argument," "the argument of unexpected explanatory coherence," and "the meta-inductive argument" (31-35). The no alternatives argument states that around 40 years after its genesis, string theory, appears to have a monopoly on theories unifying all four fundamental forces of nature, and therefore, it is unlikely that it is the incorrect theory. The argument of unexpected explanatory coherence asserts that a theory which delivers an unanticipated coalescence of purportedly unrelated theoretical structures and offers a basis for explaining hitherto inexplicable results, is on the right track. Lastly, the meta-inductive argument holds that since theories posited in the high-energy regime of physics with no plausible alternatives, and which provide unforeseen theoretical coherence have been vindicated by experiment, then it is likely that string will be empirically confirmed because it also possesses these features.

I will be propounding an alternative to weakening the canonical scientific method to accommodate extra-empirical theory assessment. The canonical scientific method that I have in mind is one that is committed to the primacy of empiricism (e.g., the hypothetico-deductive model, the Bayesian inductive model, etc.). Though perhaps Ladyman et al.'s characterization of the scientific method as "our set of institutional error filters" is more robust, as they recognize that there is no one size fits all scientific method—even within any one scientific discipline—and in its place there are a collection of fastidiously vetted checks and balances centered around empiricism, that are continuously purified (28). I will argue that the canonical scientific method is not faltering, but instead that the empirical dormancy germane to string theory is symptomatic of the culmination of a series of incremental deviations of physics from mind-independent reality. In other words, depending on one's ontological view of mathematics string theory either bears more on our noetic infrastructure (e.g., if one subscribes to mathematical nominalism), or the existing, objective, abstract entities of mathematics (e.g., if one is a mathematical Platonist), than on physical reality. Dawid takes the rather precarious approach of claiming that these arguments of theory assessment on extra-empirical grounds have been stowaways on the vessel of the high-energy research program of physics all along and that, therefore, their utilization is not anathema to the scientific method. I will attempt to expose the logical slight of hand that this line of reasoning rests upon and I strive to demonstrate the defeasibility (in the epistemological sense) of these arguments of extra-empirical theory confirmation in general. If I am successful in providing reasonable doubt that this cutting edge physical theory corresponds to the true nature of reality—which then offers an alternate explanation for string theory's empirical doldrums—then avenues in physics and philosophy investigating the cause of the disparity of physics from mind-independent reality must be exhausted as possible solutions to the ongoing crisis—especially if Dawid's approach of massaging the scientific method in an extra-empirical manner is revealed to be untenable. This would mark a significant departure from the current research program and would inspire an interdisciplinary collaboration that, as I will argue, may very well be the linchpin to resolving this predicament.

This work will be separated into four chapters. The first three chapters will present arguments that are designed to be undercutting defeaters for Dawid's arguments of extra-empirical theory assessment in physics, and the final chapter will sketch an argument intended to be a rebutting defeater to bolster my alternative position of the derailment of physics from mind-independent reality. The first chapter will consist of an introduction to the theoretical entities of string theory, followed by a few global criticisms of Dawid's approach to justifying the theory's scientificity.

In the second chapter, I will scrutinize Dawid's argument of unexpected explanatory coherence and raise two types of historical counterinstances against it. The first type will be an antiquated theory (i.e., the luminiferous aether) situated within a research program that exhibited unexpected explanatory coherence such that Dawid's extra-empirical arguments could have been applied by the physicists of the era to justify its scientificity, even though by virtue of a paradigm shift (i.e., Einstein's special theory of relativity) it was demonstrated to be empirically inadequate and superseded. The second type will be in the form of theories that catalyzed paradigm shifts even though their predecessor theories displayed unexpected explanatory coherence within the now passé research program to which they were endemic—thereby revealing that a paradigm shift can disrupt a pattern of unexpected explanatory coherence indicating a theory's fruitfulness.

The third chapter will unveil the weakness of Dawid's meta-inductive argument by exposing that the Bayesian probabilistic underpinning for induction—that he puts forward—yields a paltry posterior probability associated with our trust in string theory's scientificity. Furthermore, the meta-inductive argument will be shown to be a double-edged sword for Dawid, as it can be invoked to supply at least the same probability in favor of string theory being unscientific by adducing an antithetical inductive trend. Issues will also be raised with respect to string theory's final theory claim, as well as the purported retroactive utilization of Dawid's extra-empirical arguments in empirical confirmation in the regime of high-energy particle physics.

Lastly, the final chapter will address Dawid's no alternatives argument by making a case for the alluded to alternate view of string theory's empirical latency. Specifically, that the symptomatology of string theory's antiempirical ailment seems befitting of the following diagnosis: since our metaphysical presuppositions are not infallible, they somewhere, somehow have gone awry, and as a result, empirical contact is shrinking, and experimental data are confounding our expectations. The goal of this chapter will be to buttress the plausibility of this perspective by fleshing out that the available evidence supports it at least as much as it does its nemesis: the position that string theory is scientific and extra-empirical theory evaluation can make this manifest.

1

String Theory and the Cost of Extra-Empirical Justifications

I will now, as promised, provide a cursory rundown of the dominant string-theoretic entities, and elucidate wherein the descriptions of alternate universes emerge. This chapter will touch on the scientific breakthroughs that culminated in the variety of string theory that is widely known today, and then will raise general objections to the implementation of extra-empirical modes of substantiating its scientificity. String theory is such a propitious candidate for a theory of everything because the topological space upon which its mathematical formalism depends, i.e., the Calabi-Yau manifold, imparts to it the requisite extra-dimensions to generate the elementary particles of physics along with the conjectured quantum of gravity: the graviton.

1.1 The History of String Theory in Broad Strokes

The cardinal posit of string theory is—rather expectedly—an ontological commitment to "strings;" one-dimensional objects that underlie the elementary particles of nature giving rise to them through peculiar vibrational patterns. These elementary particles are of two main varieties: bosons (e.g., photons) and fermions—where class membership is assigned due to a particle's intrinsic angular momentum or "spin." Specifically, bosons have integer spin (e.g., 0, 1, 2, etc.) and fermions have odd half-integer spin (e.g., $\frac{1}{2}$, $\frac{3}{2}$, $\frac{5}{2}$, etc.); fermions can also be further subdivided into quarks and leptons—where an electron is an example of the latter. According to the standard model and its mathematico-physical framework of gauge field theory, every sensorial aggregate of macroscopic phenomenal experience (e.g., chairs, tables, etc.) is composed of—or mediated by—a combination of these particles. Though the standard model has been a triumph for unificatory programs—since it is a cohesive mathematization of three of the four fundamental forces of nature: electromagnetism, and the strong and weak nuclear forces—string theory's nascence was bedeviled by impediments. Following in the footsteps of physicists Theodor Kaluza and Oskar Klein, who early in the 20th century developed a mathematical framework unifying general relativity with classical electromagnetism by generalizing Einstein's field equations and spacetime to a five-dimensional topology, extra-dimensional extensions became string theorists' unificatory modus operandi (Yau and Nadis 126). Furthermore, they appropriated the theoretical attribute of compactification from Kaluza-Klein theory, which treats extra dimensions as being finite and curled like the surface of a cylinder such that traveling along it would eventually entail your returning to your origin. Following Kaluza and Klein, string theorists also propounded that the compactification radii would be infinitesimal. For string theory, they are predicted to be in the neighborhood of the Planck length (i.e., $l_p \approx 1x10^{-35}\ m$)—along with the strings which inhabit them—because at this scale the gravitational coupling constant is proportional to unity and in this regime gravity is expected to be quantum in nature (Dawid 11).

The previously mentioned birth pangs occurred in the form of unphysical anomalies (e.g., negative probabilities, untameable infinities, etc.) vitiating string theory's scientific viability at its outset. However, in 1984, Michael Green and John Schwarz redeemed the theory by demonstrating that the gauge field theory of the standard model could be recovered from strings within a ten-dimensional spacetime (i.e., the three dimensions of space and one of time that we are intimately acquainted with, and then six additional spatial dimensions), and most crucially that the aforementioned anomalies cancelled within this spacetime background (Yau and Nadis 125, 212-214; Dawid 10). In particular, the anomaly produced by the gravitation field was equal in magnitude, but opposite in sign, to the anomaly engendered by the gauge field—this theoretical advancement has been christened “the first string revolution.” With a theoretical template drafted, string theorists foraged the recherché topological terrain of multidimensional manifolds for the ideal shape with which to flesh out their theory. (Where a manifold is a space that is locally homeomorphic to Euclidean space—viz., there is a neighborhood for every point which can be mapped in a one-to-one manner with Euclidean space.) Their geometric expeditions furnished them with their holy grail in the form of the Calabi-Yau manifold, since topologically it is a six-dimensional, non-simply connected space (i.e., it has one or more holes), it is a compact manifold, and it is capable of orchestrating the oscillatory modes of strings in such a way that the properties of the point-like particles (e.g., bosons and fermions) of the standard model can be realized. Many distinctive geometries can populate Calabi-Yau manifolds, and they can be categorized topologically by a genus number representing the number of “holes” that they possess. Geometries like a two-dimensional sphere, torus (donut), and double torus (pretzel) are classified as genus 0, 1, and 2 respectively (Yau and Nadis 7, 65). The Calabi-Yau manifold facilitates this transformative feat by enforcing that closed strings (a rubber band can be used as a conceptual reference point) are threaded through a certain number of its holes—causing them to encircle the manifold—which prescribe their oscillatory modes yielding specific species of point-like particles, and the manifold’s dimensionality—in concert with the four-dimensional spacetime of general relativity—supplies strings with the necessary degrees of freedom, and abundance of hole-threading combinations, to transform them into the panoply of particles that physicists have catalogued to date (Yau and Nadis 140).

Additionally—rather serendipitously—one of the oscillatory modes of the strings yields the graviton (a massless spin-2 boson) which would mediate gravitational interactions at the quantum level; gravity it seems is built into string theory’s mathematical framework (Dawid 13).

The foregoing has been articulated in certain contexts by drawing an analogy to acoustic vibrations to intuitively convey string theory's principal notion, and although it is an oversimplification, it does retain the theory's general thrust. Particularly, the oscillatory modes (i.e., normal modes) of standing waves (e.g., occurring in stringed instruments like guitars, violins, etc.) produce longitudinal soundwaves in the local media (e.g., air) of characteristic frequencies and energies. In a similar way, the oscillatory modes of string theory produce waves within their corresponding quantum fields of characteristic energies and quantum numbers—where thanks to wave-particle duality these waves (i.e., excited states of quantum fields) can be depicted just as readily as point-like particles.

Moreover, the Calabi-Yau manifold is a nontrivial vacuum solution to Einstein's field equations, which therefore guarantees its compatibility with general relativity (Yau and Nadis 100, 123). A vacuum solution is a special solution to Einstein's field equations in which the manifold is Ricci flat (i.e., the stress-energy tensor is zero indicating no matter or cosmological constant) and the trivial solution happens when the spacetime metric itself is flat—that is to say, that the space the metric measures is the higher dimensional analog of a one-dimensional flat line segment with a Gaussian radius of curvature of zero. (Where a metric can be crudely defined as a function which allows one to trace out the geometry of a space by calculating the distance between any two points within it, and Ricci curvature roughly denotes how a volume element on average is deformed when traversing a geodesic (i.e., the shortest distance between two points on a curved surface) when compared to Euclidian space.) To fully understand the idea of radius of curvature it may be beneficial for one to evoke in their mind's eye a curve connecting two points (an arc length) which is approximately semicircular, then to imagine filling in the remainder of the circle so that its radius R can be attained, the reciprocal of this superimposed R is the radius of curvature: $R_c = \frac{1}{R}$. This can be seen intuitively by continuously enlarging R, because as $R \to \infty$, $R_c \to 0$ (i.e., the curvature would approach zero) and the envisaged circle—with a nearly infinite radius—would correspond to a curve on the cusp of ceasing to be such, as it would instead resemble a line. From these definitions we can conclude that if a metric is flat, then it is necessarily the case that the Ricci curvature is zero. However, the converse is not true, since it is conceptually possible for a manifold to have Gaussian curvature (thereby having a non-flat metric) and yet—due to its geometry—have a volume element which on average is not deformed while traversing geodesics on it (Yau and Nadis 99).

Shing-Tung Yau proved mathematically, in 1978, that a multiplicity of Calabi-Yau manifolds exist which exhibit Ricci flatness, but whose geometries—and as a result metrics—would not be flat. (These are not the only cases of curved manifolds with zero Ricci curvature, as Schwarzschild metrics too meet these criteria and are vacuum solutions to Einstein's field equations mathematically portraying the region of spacetime near massive celestial bodies and blackholes.) It was critical for string theorists to ground their theory upon a geometry which had the property of Ricci flatness, since during the theory's formation the scientific consensus was that the spacetime geometry of the universe was flat (i.e., spacetime had no inherent curvature) and a four-dimensional spacetime of this kind could only be derived from the theory if this condition was met (Yau and Nadis 127).[1] However, it has since been experimentally

[1] It is important to distinguish spacetime curvature from spatial curvature where the latter pertains to the spatial geometry of the universe—i.e., whether the geometry of the universe has zero curvature (the universe is flat), positively curved (a 3-sphere), or negatively curved (hyperbolic)—whereas the former concerns the scalar curvature of the Lorentzian metric describing spacetime. The discovery of a positive cosmological constant means that the Lorentzian manifold of Einstein's field equations possess positive scalar curvature (i.e., de Sitter space). The spatial curvature of the universe can be determined by the foliation of the four-dimensional spacetime manifold into a purely spatial three-dimensional hypersurface (i.e., slicing the Lorentzian manifold yields a manifold reduced by one dimension). In the case of de Sitter space, this foliation can be conducted in such a way that it yields a flat or positive spatial curvature, which is consistent with the recent findings from the Planck telescope that the spatial geometry of the observable universe is likely flat. (However, since there is an error margin attached to these results, it is also possible that the observable universe is positively curved with a very large radius of curvature).

substantiated (through cosmological data) that our universe has a positive cosmological constant, and as a result, theorists had to devise a means of reproducing a four-dimensional spacetime (effective theory) with inherent curvature from the compact, Ricci-flat six-dimensional space embedded within the ten-dimensional mathematical framework of string theory. In order to explain how this can be accomplished we have to take a slight detour to recount the events that ushered in the "the second string revolution."

Originally, there was an assortment of five string theories where each was formulated with subtly different theoretical attributes (e.g., symmetry groups, disposition of the string: open loop or closed loop, etc.), which was in and of itself a conspicuous defect since string theory boasted its exclusivity as a theory of everything—occasioning a disconcerting intertheoretical antimony (Yau and Nadis 147). However, Edward Witten in 1995—a physicist elevated to the station of sage in certain circles—managed to express these ostensibly distinct iterations of string theory as interconnected fragmentary manifestations of a more global theory: M-theory. He achieved this by adding yet another spatial dimension (increasing the total to eleven: ten spatial dimensions and one temporal dimension) and by capitalizing on mathematical dualities. For instance, if one string theory postulated open strings, it could be demonstrated that their behaviour was mathematically equivalent to closed strings in the theoretical framework of one of its companion theories. This consolidative discovery was—in a manor of speaking—the meet-cute between string theorists and D-branes—the final theoretical entity exhausting the dramatis personae of my condensed, highlight-reel version of this historical drama (Yau and Nadis 148). (Where the latter are submanifolds within the higher dimensional Calabi-Yau space that open strings are fastened to, and which can come in a range of dimensions within M-theory—e.g., a one-brane is simply a string, a two-brane is a membranous surface, etc.)

With these theoretical-entity ingredients in tow we can now discuss one of the most contentious facets of string theory "the landscape," and address how string theory's geometrical underpinning (i.e., the Calabi-Yau manifold) can be squared with the contemporary cosmological finding that the rate of our universe's expansion is accelerating. A seminal 2003 string theory paper titled "De Sitter Vacua in String Theory," detailed a mathematical procedure eponymously labeled "the KKLT mechanism"—standing for Shamit Kachru, Renata Kallosh, Andrei Linde, and Sandip Trivedi (the physicists responsible for its creation)—which is capable of stabilizing string vacua (Yau and Nadis 233). Kachru et al.'s inducement for devising this mechanism was to redress a seemingly intractable problem, specifically "the moduli problem." However, an avenue for eliciting the four-dimensional spacetime of empirical decree was inadvertently—albeit fortuitously—attained as an outgrowth from this objective. The "moduli problem" is in essence one of Calabi-Yau manifolds initially having overly permissive parameters, consequently, a circumscription technique was required. The moduli of string theory can be understood as scalar fields (of which a temperature field is an example) that encode values for every point in space describing the size, shape, twisting, etc., of the Calabi-Yau manifold (Yau and Nadis 227-228). If these parameters are not constrained, then the Calabi-Yau manifolds become nonphysical on account of their instability. For example, if the size modulus (scalar field) is massless—and is thereby free to transition to any value—then string theory's extra-dimensions would expand and no longer be compactified, and of course our phenomenal knowledge by acquaintance informs us that we do not encounter six-dimensional spaces during our quotidian affairs (Yau and Nadis 231).

This stumbling block can be sidestepped by exploiting fields which are unique to string theory—occupying the innermost recesses of this colossal, labyrinthine theoretical undertaking, but omitted from calculations for expedient's sake (Yau and Nadis 228-229). The properties of these fields resemble those of the electromagnetic field in that they have the capacity to induce fluxes—though in the case of the latter the topological space that they reside within has a higher dimensionality. To gain some insight concerning the function of these flux fields, we can recall the effect of exposing iron (ferromagnetic) filings to an external magnetic field (e.g., a bar magnet) (Yau and Nadis 229). Namely, that the magnetic flux (i.e., the number of magnetic field lines that perpendicularly pass through a given surface area) causes the filings to coat and cling to the bar magnet until the net force becomes unbalanced. In a conceptually analogous way, the flux fields of string theory affix the moduli parameters. Furthermore, these fields like the electromagnetic field (i.e., photons) are quantized such that only integer values of flux are allowed, and in this way the size moduli can only assume discrete values—thus constraining the set of geometric possibilities. The KKLT paper formally catalogued these fields and their stabilizing utility, and also introduced an equilibrating technique employing D-branes—in which these multidimensional membranous submanifolds envelope the compact six-dimensional Calabi-Yau manifolds precluding them from unfurling (Yau and Nadis 231). (To aid in the conceptualization of this rather abstruse mechanism, one can conceive of rolled-up cutlery in a restaurant where the function of the adhesive napkin band that is orthogonally wrapped around the napkin—which is rolled lengthwise around the utensils—is to prevent the napkin from unfurling.)

However, each stable compactification configuration—that the aforesaid mechanisms produce—corresponds to a distinct metastable (or stable) vacuum energy (being solutions to Einstein's vacuum equations)—which translates to a different zero-point energy for the quantum fields, and accordingly different elementary particles (Yau and Nadis 228-235; Dawid 16). The lower limit of possible vacuum states and associated vacuum energies (ground states) is 10^{500}, which is commensurate with the number of possible universes—all with their own unique mélange of particles, forces, and physical constants—that is described by a unique Calabi-Yau geometry. This compendium of possible universes is the so-called string theory “landscape,” whose conservatively estimated membership class is 420 orders of magnitude greater than the estimated number of atoms in the observable universe ($10^{500} \gg 10^{80}$). Where one of these compactification configurations instantiates a universe with a positive cosmological constant in line with the current cosmological data. Although, the nature, relations, and orientations of the exotic theoretical entities (e.g., antibranes) required to produce this universe are quite contrived, and their hypostatization is even more questionable than the hypostatization of a nonexotic string theory in toto (Yau and Nadis 233).

The magnitude of the landscape of possible string backgrounds (universes) occurs from a mathematical estimation of the upper bound of topologically distinct Calabi-Yau manifolds (i.e., the maximum number of holes that a Calabi-Yau manifold can have is 500), coupled with the supposition that the discrete integer values that the field fluxes can assume span from 0 to 9, which yields 10^{500} uniquely stabilized compactification configurations (Yau and Nadis 233). Though if these presumptions prove to be illusory, then the landscape of possible universes may very well exceed this figure. The confidence that string theorists place in the scientificity of their theory is derived from their conviction that one of the universes in the landscape is in fact our own—which from a probabilistic perspective appears sensible. However, it is worth noting that string theory is not devoid of technical issues, intratheoretical kinks that would need to be ironed out for it to be considered a coherent physical theory by its own lights—in addition to the methodological problems that are posed by attempting to establish its scientificity (which is the topic that will constitute the bulk of this project).

Firstly, it is not at all obvious that our universe is among the universes that dwell in the string landscape. Solutions to string theory (i.e., metrics for the Calabi-Yau manifold) are few and far between because finding them requires numerical methods and considerable computing power, and save for the previously mentioned KKLT antibrane approach (which is rife with extraneous exotic theoretical entities), no solutions have been obtained which are simultaneously compatible with the standard model and a positive cosmological constant (i.e., de Sitter space) (Yau and Nadis 233). On the contrary, anti-de Sitter space solutions seem more amenable to string theory's mathematico-physical framework, leading some physicists (e.g., Obied et al. in their paper "De Sitter Space and the Swampland") to conjecture that de Sitter space universes are relegated to the swampland (i.e., they are not solutions to string theory and are not contained in the landscape). Read and Le Bihan summarize the situation thusly: "[g]iven the dearth of models of string theory compatible with the standard model (we have yet to find a single one), if anything there may be better grounds to claim that string theory is already falsified, rather than being unfalsifiable" (7755).

Secondly, there is significant tension between string theory's mathematical framework and that of general relativity, since the latter is background independent whereas the former—at least so far—has resisted a background free formulation (Ladyman et al. 169). A physical theory is background dependent just in case a given spacetime structure must be selected in an extra-theoretical fashion, as opposed to arising naturally from a theory's dynamic equations (e.g., Einstein's field equations)—or being derivable from a theory's first principles. One of the merits of background independence is that it attenuates the potential for bias modifying a theory—

during a period of time when preliminary experimental findings seem contrary to a theory—by proscribing the reverse-engineered, backwards-looking, post-hoc penciling-in, so to speak, of whichever spacetime structure will salvage our cherished mathematico-physical models in the face of sets of empirical data which conflict with them. Moreover, since string theory has been lionized as the foremost contender for a theory of everything, its not specifying a background structure—combined with its supersymmetric version incorporating an inordinate inventory of 105 loosely constrained or free parameters (depending on the number of ground states)—defeats its purpose and cheapens its explanatory allure (particularly in view of its final theory claim), because no rationale for selecting a background could be offered beyond a heuristic, ad hoc rationalization—which amounts to little more than token curiosity-appeasement. For instance, in a hypothetical scenario where string theory became an accepted final scientific theory, the explanandum: "why should our four-dimensional effective theories of general relativity and quantum field theory be grounded in a six-dimensional compactified background spacetime?" would live out its days as a forlorn singleton ever longing for its epistemic mate: a genuine explanans. Qualms regarding string theory lacking this attribute have prompted string theorists to concede that background independence does indeed appear to be a desideratum for the theory (Ladyman et al. 169).

1.2 Coarse-Grained Concerns

Prior to delving into the finer points of Dawid's extra-empirical arguments, I want to discuss my general concerns regarding Dawid's approach. To wit, the worries that I will be lodging in this section will be directed at extra-empirical arguments in general as opposed to the particular trio of extra-empirical arguments which Dawid proposes (to which the subsequent chapters will be devoted). Though at first glance it may appear that these criticisms are misplaced, since the support for Dawid's extra-empirical arguments are based on inductive trends (i.e., the tracking of the features that successful theories exhibit) within a given research program, all extra-empirical arguments which can be substantiated in this way must be endorsed along with Dawid's specific set (53). Of course, such arguments will not all possess the same degree of cogency, but those arguments that represent the cream of the crop, so to speak, must be as epistemically robust and share the same logical foundation as Dawid's arguments; consequently, their fates are intertwined, to the extent that to champion one is to champion them all. Also, before I begin, I want to pre-emptively fend off a rather ruinous objection to the forthcoming arguments. The arguments of this section all have an enthymeme (hidden premise)—specifically they presume that Dawid's final theory claim for string theory is false. However, I do not maintain that the claim is patently false at face value, accordingly, the third section of the third chapter will be devoted to demonstrating its falsity—or at the very least subverting its veracity. Otherwise, if no theories could ever be more fundamental than string theory, then many of my worries would be mitigated—if they were to not evaporate altogether.

With that out of the way, we return to my overarching concerns. Dawid, in his book *String Theory and the Scientific Method*, explicitly qualifies that he is not endeavoring to use his extra-empirical evaluative framework to exculpate string theory of its anti-scientific imputations: "[t]he present book does not constitute an attempt to demonstrate at a philosophical level the viability of string theory or the related final theory claims"—as he contends that a theory's scientificity can only be decisively determined by scientists (Dawid 4). However, his tacit aim seems to be to outfit physicists—who are sympathetic to string theory's scientific acceptability—with a tenable methodology to uphold their view, and if physicists approve of it, then his arguments of extra-empirical theory assessment would become an addendum to the canonical scientific method (i.e., an empirically forward scientific method)—and therein lies the rub. If we were to modify the canonical scientific method to incorporate extra-empirical theory assessment, this would set a perilous precedent because it countenances the erosion of physics' commitment to empirical corroboration—its time-tested standard for conferring upon theories their scientific status—by granting this designation to untested theories on the basis of persuasive extra-empirical argumentation. Thus, if we assume that extra-empirical arguments that mirror Dawid's—or which at least resemble them functionally—could be composed to render virtually any promising theory's scientificity defensible, then for as long as a theory remains untested it could evade being relegated to physics' detritus pile. (Where this seems like a relatively safe assumption since history vouches for theoretical physicists being an exceptionally ingenious bunch and because Dawid's conceptual architecture would serve as a template of which they could avail themselves—in order to hit the ground running so to speak.)

Moreover, string theory's landscape conjures up Karl Popper's aphorism "[e] very 'good' scientific theory is a prohibition: it forbids certain things to happen. The more a theory forbids, the better it is" (36). Which via a minor variation on its theme can be rephrased in the following way: a scientific theory's explanatory power is inversely proportional to the number of extraneous, phenomenally distinct, counterfactual explanations that must accompany the sought-after explanation. A similar criticism can be levelled against the line of reasoning that Dawid employs to defend string theory—from a meta-methodological standpoint. Since the conclusion C of Dawid's extra-empirical arguments reflecting a cogent argument for a theory T's scientificity (case 1) is indistinguishable from an alternative scenario (case 2) in which their concluding T's scientific credibility is instead a corollary of our present epistemic limitations—because say there will be consensus in the physics community regarding an experiment that significantly erodes our confidence in T's scientificity in the near future—then Dawid's sequitur C stating the scientificity of T, is therefore not loyal to case 1. Additionally, since Dawid's altered scientific method could plausibly result in a profusion of experimentally disconnected physical theories being accepted as scientific, then if Dawid's extra-empirical theory assessment is adopted—although it might lend scientific credence to string theory—it comes at the cost of likely extending it to a host of theoretical aberrations having no bearing on reality whatsoever. However, the wide net cast by Dawid's extra-empirical arguments is disanalogous to string theory's landscape in at least one crucial respect: the price to be paid for an overly indulgent methodology is a much higher one.

For string theory, the possible universes—at worst—merely constitute causally inert ontological clutter and reduced explanatory power. Whereas on the methodological side of things, spurious scientific theories masquerading as the real McCoy would gum up the works until such a time as these interlopers could be unmasked. Even if one could procure an omniscient perspective and be privy to the prescient knowledge that string theory is deserving of the scientific status that Dawid's extra-empirical arguments attempt to provide it, would it be worth the fallout of lowering the empirical gold standard of conformation and allowing unscientific theories to flourish until such a time that an experimental resurgence grants their empirical testability—if indeed this ever occurs? In other words, if string theory is in fact accurate (despite empiricism giving it the cold shoulder), perhaps a justificatory avenue other than extra-empirical arguments is much preferable. (Experimental validation is assuredly the most efficient means of scientific corroboration, if we cease to rely on it without a commensurable replacement, scientific progress will have no tangible timeframe to speak of. Of course, empirical feedback can be a long-drawn-out process, but history attests to its dependability.) To aggravate matters, naturally the unenviable outcome of extra-empirical arguments erroneously determining a theory's scientificity also applies to string theory. Therefore, Dawid runs the risks of legitimizing a weakened scientific method that could potentially wreak havoc in the field when all the while its conclusion (i.e., that string theory is scientific)—based on his extra-empirical arguments—would be susceptible to an epistemic Judas kiss; to incur all that turmoil and possibly end up empty handed strikes me as a fairly deplorable cost-benefit ratio.

Karl Popper—in *Conjectures and Refutations*—has persuasively argued that in order for a theory to be considered scientific and supersede its predecessor it is imperative that the theory be independently testable and more so that it passes "some new, and severe, tests" (242). Namely, Popper claimed that the grounds upon which we should decide whether a theory is a "serious candidate for examination by empirical tests" is if the theory can make predictions that are independently testable (242). Though even if new theories are refuted during the first round of empirical testing, it often still provides us with deep insight into novel theoretical issues with which we must contend (i.e., by uncovering unaccounted for experimental facts)—thereby facilitating further theory construction. Nevertheless, Popper maintained that new theories must also be substantiated empirically (i.e., they must pass their independent tests) so that we may be able to differentiate upon their inductively likely refutations which portion of their theoretical content is to be discarded and which is to be preserved as a part of our background knowledge (243-244). As I have shown string theory does satisfy the condition of making independent predictions, e.g., the existence of the graviton, compactified extra dimensions, etc., but due to string theory's large parameter space of energies corresponding to these posits, a first-round experimental refutation serving an exploratory purpose and guiding future theory construction is out of the question. Alternatively, on the passing-a-severe-test score, string theory falls short due to their being experimental bottlenecks concerning those features of the theory which are, in principle, detectable and the noncausal aspects of the theory being, in principle, undetectable (as discussed above). Therefore, according to Popper, since string theory is divorced from empirical testing in the aforesaid fashion, heralding string theory as a scientific theory would impede scientific progress, compromise scientific rationality, and possibly contribute to the stagnation of the research program within which it is situated (244).

Insofar as we wholeheartedly embrace extra-empirical theory assessment, we discount the possibility that the gears of empiricism have grinded to a halt because our theories no longer accurately depict reality. If a given theory is an empirical dead end in the shadowy catacombs of the scientific enterprise, then extra-empirical theory assessment encourages us to leave it shrouded in darkness while operating under the erroneous assumption that it is unobstructed, thereby divesting us of any impetus to seek greater illumination, when this very illumination may allow us to identify that an empirically negotiable passageway had lain just outside the bounds of our prior visibility. Phrased differently, in the event that our allegiance to certain untrustworthy axioms (or ampliative rationales, aesthetic qualities, or theoretical virtues) is responsible for string theory being empirically vain (i.e., because a minor discrepancy in the accuracy of our presuppositions about the natural world has culminated in a substantial chasm between our theoretical representations and mind-independent reality), then for as long as the research program is mistakenly usurped by this theory constructed upon this shaky theoretical foundation, it unknowingly sanctions its own stagnation; squandering precious resources while simply spinning its wheels by arbitrarily choosing to embargo the prosperous path of ontic-commitment overhaul. Given the ambiguous, dualistic interpretation of string theory's lack of empirical corroboration, should we not—in the interest of intellectual honesty and self-protection—entertain the notion that it is a function of string theory's empirically mutinous temperament just as ardently as string theory's experimental allergy being mere happenstance—which therefore has no impact on its validity?

Furthermore, if we were to weaken the scientific method to include extra-empirical justifications for a theory's scientificity in the way that Dawid recommends, this stagnation might very well become more widespread for a different reason than the one I have argued for above and which I take Popper to be sympathetic to (viz., prematurely designating a theory as scientific despite experimental corroboration of its independent predictions being unavailable). Specifically, the following perverse incentive (i.e., an incentive that runs contrary to the intended motivation behind appealing to extra-empirical justifications) would accompany an endorsement of Dawid's methodology which he appears to have overlooked:[2] assuming that the scientific status endowed by extra-empirical arguments and empirical corroboration would have to be equivalent (this assumption will be defended momentarily), physicists would be incentivized to formulate theories for which empirical corroboration is unavailable but whose scientificity is justified via extra-empirical arguments with the same zeal as conceiving of orthodox theories which are amenable to empirical corroboration. The way in which Dawid intends his extra-empirical arguments to be implemented can be characterized as a downstream-motivated application (i.e., a theory that was constructed to be empirically tested but which nevertheless finds itself disconnected from experimentation then appeals to extra-empirical arguments), which

---

[2] I have borrowed the notion of a "perverse incentive" from the economic literature. The German economist Horst Siebert coined the term "cobra effect" in his book *Der Kobra-Effekt* to refer to a situation in which deliberately incentivizing a particular action inadvertently motivates an action with which it is in conflict. The prototypical cobra-effect scenario—which inspired its name—anecdotally occurred in India during British rule when the government offered a bounty for killing cobras, which backfired when individuals began farming cobras for profit.

can be contrasted with the perversely incentivized upstream-motivated application (i.e., extra-empirical arguments are taken into consideration during the theory construction process such that empirical testability is never a priority). Since I have already attempted to demonstrate the drawbacks of the downstream-motivated application by way of epistemic risk, I will now examine upstream-motivated applications.

To illustrate why condoning this equivalence is problematic, we can imagine a hypothetical scenario in which a cabal of duplicitous, diabolically clever physicists manufacture non-falsifiable theories under the guise of a measured employment of Dawid's extra-empirical methodology (i.e., a downstream application), when in actuality this is a machination due to a vested interest in developing an untestable theory, as it is a sure-fire way of cementing their intellectual immortality. Hence, they would tyrannize the field for as long as their theories could skirt experimental scrutiny, and since under this altered scientific method, their theories qualify as scientific, they would be beyond reproach. In other words, an unintended consequence of accepting Dawid's methodology in combination with the assumption that the scientificity it confers upon theories is equivalent to the scientificity conferred upon theories by the canonical scientific method, is that it makes non-testability something of a theoretical virtue—placing it on the same footing as the usual suspects (e.g., simplicity, unification, coherence, etc.). Though it is possible that these deviously designed theories could be corroborated if they were to gain empirical contact, this would be more coincidental than expected since it seems rather unlikely that a theory that was expressly designed to be non-falsifiable—but which extra-empirical arguments could be deployed to substantiate—would turn out to correspond to reality. Accordingly, it seems that the majority of the theories fabricated by this rogue band of physicists would be theoretical dead-ends; thus, we would need a means of discriminating between these theories and the theories earnestly constructed by utilizing extra-empirical arguments in the way that Dawid intends (i.e., downstream applications).

However, the only way of differentiating between their theories and the theories of the honorable physicists (which were unfeignedly formed in the crucible of experimental forsakenness) would be by means of a fishing expedition to lure out a confession that is unequivocally indicative of mens rea. Nothing less can suffice, since one of our self-interested, mendacious physicists could simply claim that a warranted application of the theoretical virtue of non-testability guided their theory construction, and complexity, or eccentricity of approach, would not be telltale signs of deception—as these theoretical features run the gamut in parallel with the personalities and preferences of the theories' creators. Therefore, in this scenario, theory selection involving untestable theories must be based on the intentionality of theoreticians' mental states—absurdly reducing a theory's scientificity conditions to the nature of its originators' private mental content. Though this is a comedic, histrionic, and quite unlikely example, it nonetheless seems like Dawid's methodology would be powerless to prevent it, along with the more plausible scenario in which well-intentioned physicists formulate and promote non-testable theories—which are destined to be refuted empirically but are currently non-falsifiable or are in fact non-falsifiable in principle and therefore unscientific—solely because compelling extra-empirical arguments for their scientificity happen to be easily found and this scientificity is epistemically on par with the scientificity granted to empirically congenial theories (another upstream-motivated application)—where an argument based on the latter scenario retains much (if not all) of the same force as the original argument. In contrast, both cases would be strictly verboten by its methodological forerunner: an empirically centric scientific method; therefore, should we really settle for a scientific methodology devoid of a failsafe for utterly nonsensical situations—rarity notwithstanding—and serious repercussions when we already have a methodology of a higher caliber at our disposal?

In the interest of completeness, I anticipate that an objection may be raised against the above argument. Namely, that one may be incredulous concerning compelling extra-empirical arguments being found for a scientific theory for which our evil-genius physicists have taken great care in designing to be non-testable or of which conventional virtuous physicists become proponents—despite the theory being empirically refutable or unscientific. However, upon examining Dawid's specific triumvirate of extra-empirical arguments (which will be the topic of the first section of the second chapter), the guarantee of future testability does not seem to be a sine qua non of their cogency; thus, it would be surprising if their generalization would spontaneously yield such a condition. Moreover, the evil-genius case does not demand that theories designed to be non-falsifiable must always be justifiable via extra-empirical arguments, but rather—more modestly—that it is logically possible for theories of this sort to be substantiated in this way. Nevertheless, given the catastrophic aftereffects of accepting (even for a limited time) a theory that does not correspond to reality (i.e., by way of contributing to the stagnation of a research program), even if extra-empirical arguments can only be made for a small set of deceptive theories, the damage sustained would be considerable. On the other hand, for the well-intentioned physicists, it stands to reason that theories genuinely constructed to be promising—i.e., to solve theoretical problems, provide unification, etc.—would lend themselves to extra-empirical arguments and hence would be built with these arguments in mind in an upstream-motivated manner, even if ultimately the ease with which these arguments were marshaled has no bearing on the theory's scientificity.

To close the chapter, I will now defend the aforementioned necessary equivalence between the scientific status acquired by extra-empirical arguments and that by experimental verification, demonstrating it via the following argument. If we assume that the scientificity that extra-empirical arguments grant is—and could only ever be—inferior to that of empiricism, then Dawid would be left with the following repugnant trilemma: 1) the epistemic import of experimental evidence greatly exceeds that of extra-empirical arguments such that the latter could under no circumstances promote a theory to the ranks of anything even remotely resembling scientific acceptance; 2) some degree of extra-empirical justification (presumably a large amount) is tantamount to considerably less empirical corroboration; and 3) extra-empirical arguments are capable of furnishing theories with some semblance of scientificity—scientificity not of a different degree, but of a different kind. Where the trouble with 1) is self-explanatory; 2) is problematic because it is not clear that a suitable metric exists (or even could exist for that matter) to quantitatively translate one epistemic modality into another (and even if one were to, the threshold for parity could be so high that there is no guarantee that sufficient extra-empirical arguments could be made to reach it); and finally, 3) is undesirable since it is unclear what kind of epistemic credentials (if any) this quasi-scientificity would have or whether there could be any compelling reasons for placing any stock in it—especially when a substandard scientificity seems like a will-o'-the-wisp which tends to collapse—under the most delicate of inspections—into an epistemic certification which is wholly unscientific. Ergo, via proof by contradiction, the only way for Dawid to circumvent this cursed trilemma and for his position to hold water is if his extra-empirical arguments are, at the very least, equivalent to the weakest form of canonical scientificity (viz., consensus from the physics community that a theory has passed the first round of empirical testing)—and if further amassed combinations are capable of approximating stronger forms of empirical substantiation. (The thread of this argument will be picked up in the second section of the third chapter in response to Dawid's claim that his extra-empirical arguments have already infiltrated the high-energy research program of contemporary physics and have been implicitly endorsed through the practices of physicists.)

2

Dawid's Argument of Unexpected Explanatory Coherence

The aim of this chapter is to demonstrate the defeasibility (in the epistemological sense) of, and pitfalls inherent to, amending the scientific method to include Richard Dawid's argument of unexpected explanatory coherence (UEA) as a means of extra-empirical theory assessment—the underlying incentive of which is to rescue string theory from its empirical ineffectuality. The UEA asserts that physical theories which are capable of unifying seemingly disparate areas of the current research program, or which provide insight into unresolved theoretical problems—that they were not designed to address—are scientifically bona fide. Historical counterinstances of physical theories which did not possess these characteristics, but that were nevertheless subsequently empirically confirmed, will be deployed against Dawid's UEA to undermine its credibility. I will begin by examining Dawid's specific extra-empirical arguments in more detail.

2.1 Dawid's Triumvirate of Extra-Empirical Arguments

Dawid's extra-empirical guidelines for theory assessment, as detailed in his book *String Theory and the Scientific Method*, are dependent upon the notion of limitations to the underdetermination of scientific theories. He disentangles three distinct variations of underdetermination on the basis of their scope and the principles that they employ. Specifically, he contrasts underdetermination by the available evidence based on logical possibilities (type "1b underdetermination") with underdetermination by all possible evidence predicated upon the ampliative assumptions that are necessary for the scientific practice (type "2a underdetermination"), and lastly, with underdetermination by the available evidence founded on the ampliative tenets adopted by scientists (type "2b underdetermination") (Dawid 45).

Dawid cites Hume's problem of induction and the Duhem-Quine thesis as examples from the philosophical literature of type "1b underdetermination." Regarding the former example, Dawid intimates that the underdetermination emanates from the fact that Hume's account of causation (i.e., as the mental habituation of repeatedly observing constant conjunction) does not logically entail the uniformity of nature. Therefore, it is not a guarantee that a theory constructed in light of the available empirical data will predict that physical phenomenon subsequently, since it is underdetermined logically by possible worlds in which the constant conjunctions of the putative causal relations that the theory describes are severed. With respect to the Duhem-Quine thesis, for Dawid, it pertains to the available evidence and logical possibilities, because the underdetermination arises due to the myriad auxiliary hypotheses and theoretical postulates that comprise any given theory, such that when the theory is tested it faces the battle royale for empirical hypostatization in its totality. Consequently, any theoretical constituent—with sufficient logical motivation—can be given a privileged position and be preserved by modifying its retinue. For instance, Dawid outlines Duhem's perspective on underdetermination—during the bygone advent of atomism—by noting that Duhem felt that malleability was a desideratum for a theory's ontological posits prior to empirical confirmation, since too narrow a conception of them could prompt their renunciation given experimental results with even a scintilla of antagonism towards them—even if they are veridical under a more general formulation (107). However, though this ontological amorphism may be warranted, Duhem affirms that it can be a wolf in sheep's clothing, because if scientists adopt atomism as a preconceived notion, then any empirical evidence can always be logically interpreted as supporting it—thereby thwarting its rejection.

Dawid delineates type “2a underdetermination” by articulating the underdetermination Quine espouses in “On the Reasons for Indeterminacy of Translation.” Quine submits that physical theories can be underdetermined by all possible data (viz., that there will always be an empirically equivalent—but incongruous—alternate theory, even if every possible observable event could be accounted for) (209). His rationale for supposing this is the perceived vagueness of theoretical terms, or to use his vernacular, the “slack” which occurs due to how “flexible” the “observational criteria of theoretical terms” are; especially in the most cutting edge and conjectural nooks and crannies of physics (210). Thus, Quine’s conclusion is that ampliative reasoning and assessments predicated upon theoretical virtues (e.g., simplicity, fruitfulness, consistency etc.) notwithstanding, physical theories will always be underdetermined by all possible observations.[1] However, Dawid focuses on “type 2b underdetermination,” since he notes that physicists are predominantly concerned with this flavor of underdetermination, “[t] he claim of … underdetermination in a certain field at a given time asserts that it would be possible to build several or many distinct theories which qualify as scientific and fit the empirical data available in that field at the given time” (46).

Dawid labels this underdetermination “scientific underdetermination” and explicates it as the type of underdetermination that scientists face when they devise theories which incorporate the available empirical evidence. Typically, these theories supply different predictions and therefore experimental results can function as a means of adjudication. However, he states that

[1] Quine’s raison d'être for formulating his argument for a global species of underdetermination (i.e., the argument from above) was to reinforce his thesis of “indeterminacy of translation” via an approach distinct from the “inscrutability of terms.” Whether the argument is successful is controversial and philosophers have questioned the plausibility of two incompatible theories exhibiting the same degree of simplicity, fruitfulness, explanatory power, etc. given the available data, much less all possible data. For example, Lars Bergström explores the merits (or lack thereof) of Quine’s argument in his paper “Quine, Underdetermination, and Skepticism.” I will not be tendering my own appraisal of Quine’s argument from above in this work, because to do so would take me too far afield.

circumstances at times in history (e.g., technological bottlenecks, lack of experimental ingenuity) have temporarily prohibited rival theories from being distinguished by virtue of their predictions. Moreover, Dawid mentions that the supersession of scientific theories as epitomized by Kuhnian paradigm shifts offer empirical corroboration for the underdetermination of scientific theories. Nevertheless, in both scenarios prior to empirical confirmation, Dawid notes, that there is not an unruly plethora of competing theories, and therefore he concludes that though the underdetermination of scientific theories is apparent, it is circumscribed in a significant way.

It is worth bearing in mind that physicists operate within an epistemic context that is insulated from the other versions of underdetermination (e.g., the Duhem-Quine thesis, Hume’s problem of induction and Quine’s global underdetermination), which Dawid also recognizes. This is so, because without presupposing the uniformity of nature, physics could not get off the ground. Additionally, contemporary physicists subscribe to a form of pragmatism by default as they are not vexed by metaphysical musings, or the conundrum of what constitutes a philosophically complete definition of a scientific explanation. On the contrary, physicists display an air of instrumentalism when conducting their business. They may be committed to certain explanations or unobservables for the sake of methodological utility, but they almost relish their ontic agnosticism, and so they should; irrespective of the universe’s ontology, their theories are exceptionally effective at predicting physical phenomena. This is not to say that the methodology of physics is anything but rigorous and robust, aside from the canonical scientific method, secondary ampliative reasoning—such as inference to the best explanation (abduction), or involving coherence, consistency, Occam’s razor (the principle of parsimony), etc.—has been inherited from the field’s predecessors in combination with their theoretically prosperous modalities of cogitation. Though of course, the vicissitudes of experience compel physicists to refine, prune, and expand the corpus of ampliative reasoning as they go along. It is on these ever-strengthening methodological underpinnings that scientific theories are erected.

It is at this point that Dawid appeals to extra-empirical justification for string theory utilizing the notion of limitations to scientific underdetermination. Within the orthodox model of the scientific method ampliative criteria are implemented as a distillation process of sorts, yielding only the few authentically scientific candidate theories, and then if the theory is underdetermined by empirical data, this is settled by an experimental trial by fire using the theories' respective predictions. However, since string theory is exceptionally gifted at evading experiment, David wants to construct a way of buttressing the scientific conceivability of string theory with a tangentially empirical argument. He argues that if a cogent case can be made for limitations to scientific underdetermination, that is sufficiently detached from empiricism, then this would substantiate the continued pursuit of string theory while the empirical arbiter slumbers. Dawid's arguments of extra-empirical theory assessment are presented in a mutually reinforcing tripartite structure. Given this, my approach will be to examine each one with the other two out of focus but not out of frame, since separating them is not an option. If I can reveal the deficiencies of each argument as they are being emphasized—with their respective entourage in the background—then mutually supportive or not, the cogency of the arguments in totality should be dubious.

Dawid's arguments of extra-empirical theory assessment on the grounds of limitations to scientific underdetermination are the following: the no alternatives argument (NAA), the argument of unexpected explanatory coherence (UEA), and the meta-inductive argument (MIA) (using Dawid's acronyms) (50). For Dawid NAA suggests that when the pool of possible scientific theories that can account for a given body of empirical data is drastically constrained, then this imposes limits to scientific underdetermination, and increases the likelihood that a proposed theory will be successful. In the case of string theory, Dawid affirms that because it is the sole contender for a theory of everything, its empirical triumph is highly probable. However, he is careful to qualify that this argument in isolation is unconvincing, since a lack of alternative theories may merely reflect the absence of a hypercreative, watershed-bestowing maverick, as Dawid states, “[l]imitations to human intellectual capacities provide no good argument for the viability of the theory scientists came up with” (51).

Turning now to UEA, Dawid asserts that scientific theories' ability to predict physical phenomena that they were not initially devised to describe contributes to limiting scientific underdetermination as these theories are typically substantiated in the empirical domain (52). However, in the case of string theory, the unexpected explanation of additional physical phenomena is exchanged for unexpected theoretical consolidation. Dawid claims that the unexpected explanatory coherence (UEC) observed in theoretical structures due to string theory would be extraordinary without the limitations of scientific underdetermination conferred by NAA since it is highly unlikely that—out of numerous unique theories—an arbitrary theory would provide considerable unification or solve unrelated theoretical problems (53). However, he demonstrates that if one accepts NAA vis-à-vis string theory (viz., the belief that the absence of rival theories signifies that string theory is most likely valid), then the witnessed UEC no longer appears spectacular.

Lastly, Dawid propounds that MIA (i.e., the notion that aspects of theories that are empirically fruitful in a research program are inductively justified as indicators of future theoretical success) is also related to limitations to scientific underdetermination since one necessary aspect of successful scientific theories is that they have few competitors—or none at all (56). Dawid then posits that in the high-energy research program—which string theory is situated within—NAA and UEA have supplied MIA with theoretical aspects to assess inductively, and MIA, in turn, has corroborated NAA and UEA (i.e., theories that have been empirically verified have exhibited UEC and did not have alternatives). Therefore, Dawid concludes that these extra-empirical arguments are mutually reinforcing, and all undergird limitations to scientific underdetermination. He then proposes an extra-empirical evaluative system that depends upon inference to the best explanation (IBE), and he claims that it analogizes the orthodox scientific evaluative procedure and the role that IBE plays within it (66). Namely, Dawid argues that the theory selection process in physics consists of promising theories (i.e., theories that agree with the current empirical data) running the empirical gauntlet. And if the explanation that a theory offers can withstand this testing of its mettle (i.e., if it can surpass its competitors' ability to depict accurately and predict physical phenomena), then it will be inferred to be the best explanation due to limitations to scientific underdetermination and will be awarded the title of "accepted scientific theory." Dawid extends this architecture to the "meta-level," where he suggests that IBE compels us to accept that the best explanation of the presence of MIA, UEA, and NAA within the high-energy research program is that they deliver limitations to scientific underdetermination. Therefore, he contends that the "ground level" running of the empirical gauntlet by promising theories—which limits scientific underdetermination—can be replaced by this "meta-level" IBE (see figure 1 below). (Where H is a scientific theory, Y is limitations to scientific underdetermination, and observations a), b), and c) are MIA, UEA, and NAA, respectively.)

2.2 The Luminiferous Aether Models

Returning now to Dawid's UEA. My scrutinization of this argument in this section will

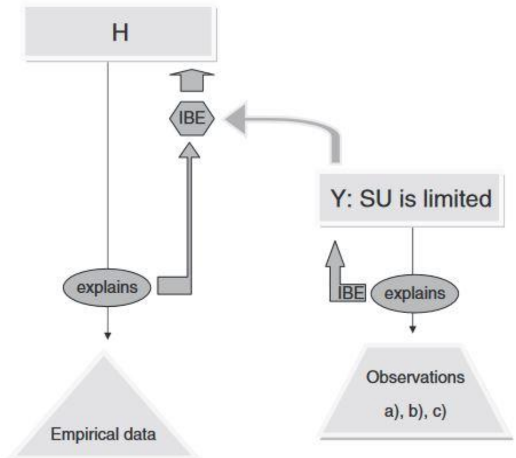

Fig. 1. Dawid's meta-level architecture; Dawid, Richard. *String Theory and The Scientific Method*. Cambridge Univ. Press, 2015, p. 68.

incorporate glimpses of MIA and I will specifically attempt to refute their overlapping portion. Counterarguments focusing exclusively on MIA will be reserved for the third chapter. Three historical counterexamples will be presented to demonstrate that within a research program previously displaying UEC, a theory can emerge that contradicts the widely held theoretical presuppositions characterizing the research program—thereby not representing an instance of UEC within that research program—though it will nevertheless be subsequently confirmed experimentally. The first counterexample to be examined is Einstein's theory of special relativity. This historical analysis will be carried out via comparing the menagerie of models of the luminiferous aether prior to their theoretical vanquishment at the hands of special relativity. Therefore, a hierarchical taxonomy of models ranked according to their theoretical plausibility and lack of contrived ad hoc hypotheses will be sketched.

By the mid 19th century, the prevailing view of light in the physics community was that it was a transverse wave and—following in the ideational footsteps of Christiaan Huygens—it was supposed that it was a mechanical wave entailing a medium (i.e., the luminiferous aether) to enable its propagation (Miller 18). As a result, the notion of the aether became an entrenched feature of Maxwellian electromagnetic theory (Resnick 17). Moreover, Galilean relativity—with its associated transformation—was considered to be at that time an integral, commonsensical, and virtually inviolable aspect of Newtonian mechanics; where the Galilean transform is a mathematico-physical tool which describe the invariance of Newton's laws of motion when switching from one inertial reference frame to another which is traveling at a given velocity relative to it. Galilean relativity takes for granted that spatiotemporal measurements are absolute, and thus they are unaffected by converting from one reference frame to another (Resnick 7). However, in the case of the propagation speed of a light wave and all other electromagnetic phenomena (e.g., Maxwell's equations), Galilean invariance is contravened, and according to it light can only propagate at speed $c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$ in the privileged reference frame of being at rest with respect to the propagating light wave—the reference frame of the aether (Resnick 17). This can be seen by applying the Galilean transformation (of a primed reference frame that is moving with a velocity $\boldsymbol{v}$ along the x-direction with respect to an unprimed reference frame) to the wave equation:

$$x' = x - v_x t, \tag{1.1}$$

$$y' = y, \tag{1.2}$$

$$z' = z, \tag{1.3}$$

$$t' = t, \tag{1.4}$$

$$\nabla^2 \boldsymbol{E} = \frac{1}{c^2} \frac{\partial^2 \boldsymbol{E}}{\partial t^2}, \tag{1.5}$$

substituting (1.1), (1.2), (1.3), and (1.4) into (1.5) and using the chain rule when evaluating the partial derivatives $\frac{\partial^2 \boldsymbol{E}}{\partial x^2}, \frac{\partial^2 \boldsymbol{E}}{\partial y^2}, \frac{\partial^2 \boldsymbol{E}}{\partial z^2}$, and $\frac{\partial^2 \boldsymbol{E}}{\partial t^2}$ yields:

$$\frac{\partial^2 \boldsymbol{E}}{\partial x'^2} + \frac{\partial^2 \boldsymbol{E}}{\partial y'^2} + \frac{\partial^2 \boldsymbol{E}}{\partial z'^2} + \frac{1}{c^2}\left(2v_x \frac{\partial^2 \boldsymbol{E}}{\partial x' \partial t'} - v_x^2 \frac{\partial^2 \boldsymbol{E}}{\partial x'^2}\right) - \frac{1}{c^2}\frac{\partial^2 \boldsymbol{E}}{\partial t'^2}. \tag{1.6}$$

Therefore since:

$$\nabla'^2 \boldsymbol{E} + \frac{1}{c^2}\left(2v_x \frac{\partial^2 \boldsymbol{E}}{\partial x' \partial t'} - v_x^2 \frac{\partial^2 \boldsymbol{E}}{\partial x'^2}\right) - \frac{1}{c^2}\frac{\partial^2 \boldsymbol{E}}{\partial t'^2} \neq \nabla^2 \boldsymbol{E} - \frac{1}{c^2}\frac{\partial^2 \boldsymbol{E}}{\partial t^2}, \tag{1.7}$$

the wave propagation speed is not reference-frame invariant under Galilean relativity.

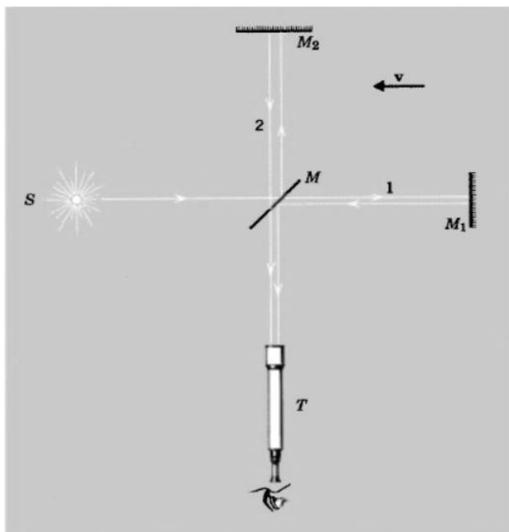

Fig. 2. Schematic of Michelson-Morley experiment; Resnick, Robert. *Introduction to Special Relativity*. John Wiley & Sons, Inc. 1968, p. 20.

Experimentalists of the era were eager to confirm the existence of the luminiferous aether (the absolute frame) and constructed novel experimental apparatuses for the express purpose of doing so. In the primary model of my luminiferous-aether taxonomy, it was supposed that the aether was stationary with respect to the angular and orbital velocity of the earth, such that when the earth moves through it an "aether wind" would be generated comparable to the wind produced by a vehicle travelling at highway speeds (i.e., around 100 km/h or 60 mph)—even on an eerily calm day the air would be moving at 100 km/h with respect to the vehicle (Resnick 18). One such experimentalist was Albert A. Michelson who invented a type of interferometer with the intention of detecting the previously characterized aether wind. His eponymous device was designed to measure the anticipated discrepancy in velocity between two beams of light, one which is travelling parallel to the motion of the earth, and the other which is travelling orthogonal to it. It was hypothesized that the beam traveling parallel to the motion of the earth would have a greater travel time, since its speed traveling against the aether wind would be $c - v$ and its speed traveling with the aether wind would be $c + v$ (Resnick 21). The traversal time for the parallel path length of beam 1 would be the following:

$$t_1 = \frac{2l}{c}\left(\frac{1}{1 - \frac{v^2}{c^2}}\right), \tag{1.8}$$

and for the orthogonal path length of beam 2 the time would be (see figure 2 above):

$$t_2 = \frac{2l}{c}\left(\frac{1}{\sqrt{1 - \frac{v^2}{c^2}}}\right). \tag{1.9}$$

Equation (1.9) can be derived by applying the Pythagorean theorem to the orthogonal path length from the reference frame of the aether and rearranging the following expression for t_2:

$$ct_2 = 2\sqrt{\left[l_2^2 + \left(\frac{vt_2}{2}\right)^2\right]}. \tag{1.10}$$

Michelson failed to arrive at (1.10) when he conducted his experiment in 1881, as he did not take into consideration the horizontal component of motion for the orthogonal arm in the aether's reference frame (Miller 23). Hendrik Lorentz identified Michelson's mathematical blunder and ascertained its fons et origo. However, correcting Michelson's arithmetic oversight rendered the requisite experimental accuracy—for observing the predicted quantitative effects of the aether and hence decisively determining its existence—in excess of the empirical exactitude of the 1881 edition of the experiment. The degree of accuracy demanded by the rectified mathematical description, instigated by Lorentz's incisive criticism, impelled Michelson to extend the sensitivity of his interferometer, and in 1887 the experiment was replicated with the aid of his colleague Edward M. Morley. It was at this point that Michelson and Morley's famed null result occurred. The general thrust of the experiment was to examine the fringe patterns of the two beams when they are recombined and either constructive or destructive interference results based on the phase difference of the beams—due to the expected difference in path length (Resnick 21). Specifically, rotating the experimental apparatus by 90º would cause the mirrored arms to exchange positions with respect to the aether inducing a shift in the observed fringe pattern (Miller 22). This method was preferred because in the unlikely—but possible—eventuality that the apparatus was oriented in such a way that it was at rest with respect to the aether, the interference would be entirely constructive, since the arms were crafted to be of approximately equal length and no fringe shift would be detected—which would be phenomenological indistinguishable from the scenario where the aether wind is in fact incorporeal. However, due to the fact that Michelson and Morley made myriad measurements both throughout the sidereal day and year inspecting the fringe pattern for deviations, the aether wind—if it did indeed exist—would have been witnessed; especially given that the 1887 apparatus was sufficiently sensitive to register a shift of 1/100 of a fringe (Resnick 24).

The model that is assigned the tertiary slot in my luminiferous-aether taxonomy is that of George Stokes'—which he propounded in 1845. He hypothesized that the earth would not pass through the aether without exerting an effect on it. Namely, he maintained that the aether—being a universal substance—would accumulate at the planet's surface along its direction of motion counteracting the aether wind, and in this way the aether would be completely dragged by our planet—which would account for the null result of the Michelson-Morley experiment (Miller 18). However, in 1886 Lorentz demonstrated mathematically the untenability of Stokes' complete aether drag theory (Miller 23). Furthermore, the phenomenon of stellar aberration (first discovered in 1727 by James Bradley) and Fizeau's 1851 experiment of the velocity of light in moving water, both refute Stokes' aether model—which elucidates why it occupies the third position within my hierarchical taxonomy (Resnick 28). The former is the empirically established effect of being unable to view a celestial body by placing an observational instrument (e.g., a refracting telescope) parallel to the incident light waves. Instead, as the earth revolves around the sun the necessary placement angle for the instrument to view a body directly overhead traces out an arc, with a maximal value of 20.5 arcseconds, that is dependent on the earth's velocity $\boldsymbol{v}$—in a similar manner to how the rain's angle towards a vehicle, on a windless day, would be dependent on its velocity (Resnick 28). This phenomenon conflicts with Stokes' aether model, because if the aether is completely dragged by the earth, then the light from a celestial body would move with the telescope and stellar aberration would not occur.

Moreover, since it was known in the 19th century that light propagated at a slower rate in denser media (i.e., index of refraction), stellar aberration was expected to be potentiated if a telescope were equipped with a glass portion, because glass has an index of refraction of $N = 1.52$, unlike air which has an index of refraction of $N = 1.0003 \approx 1.00$ (Resnick 33). As a result, since stellar aberration can be expressed as:

$$\tan\alpha = \frac{v}{c}, \tag{1.11}$$

where $v \approx 30.0\ km/s$ and $c \approx 3.00x10^5\ km/s$ and where α as previously stated would be 20.5 arcseconds, it was predicted that the angle of stellar aberration for different media would be:

$$\tan\alpha = \frac{Nv}{c}, \tag{1.12}$$

which for crown glass yields a value of 31.3 arcseconds:

$$\alpha_w = \tan^{-1}\frac{(1.52)(30.0\ km/s)}{3.00x10^5\ km/s}.$$

However, nature was not convivial to this theoretical prognostication, and this value was never observed. In an attempt to provide rapprochement between a wave model of light and the astronomical data that François Arago collected in 1810 with a telescope equipped with a glass portion adjacent to the objective lens—which revealed that the glass medium had no affect on stellar aberration—Augustin-Jean Fresnel in 1818 introduced a coefficient:

$$k = 1 - \frac{1}{N^2} \tag{1.13}$$

(where N is the index of refraction of the body) (Miller 17). In particular he proposed that moving objects only partially dragged the aether in accordance with (1.13); to wit material objects travelling at a velocity $\boldsymbol{v}$ with respect to the absolute reference frame of the aether will drag a varying degree of the aether depending on their index of refraction (N). (Fresnel's model occupies the secondary position in my luminiferous-aether taxonomy.) The stellar aberration formula modified to include Fresnel's dragging coefficient was capable of resolving the unanticipated result, and thus Fresnel's partial drag (predominantly stationary) model of the aether was consistent with the empirical findings. Snell's law, when utilized in tandem with Galilean relativity from the aether's perspective, returns an angle of refraction and light-path orientation through the optical device which blatantly contradicts the trajectorial data gleaned from stellar aberration experiments. Ergo, Fresnel fabricated his ad hoc mathematical artifice (1.13) to safeguard Galilean relativity and Snell's law.

In 1870, George Airy conducted a variation of Arago's experiment with a water-filled telescope to ascertain if the refraction light would undergo within it would affect the stellar aberration angle. However, he too only ever observed a null result, further validating Fresnel's coefficient. Fresnel's mathematical adjunct can be derived by considering a geometrically simplified version of Airy's (or Arago's) experiment in which from the viewpoint of an individual at rest with respect to the earth—by virtue of stellar aberration (i.e., the motion of the earth)—the incident angle of light impinging on the surface of an optical device is 0º (i.e., is orthogonal to the objective lens of the telescope) due to the star's apparent position. Then—due to Snell's law—the angle of refraction will also be 0º and the light will continue on its vertical trajectory through the telescope. In this scenario, an asymmetry manifests itself from the perspective of an individual at rest with respect to the aether, since the star's actual position is behind the telescope, and if this observer makes use of Snell's law, she will calculate a deviation in the light's path. (Though the refraction angle "r" would be shallower than the incident angle "i," since the light is passing into a denser media, the observed angle of $r = 0°$ will not be recovered by this observer.) This can be depicted mathematically as follows:

$$\sin i \approx \tan i \text{ for small angles,} \tag{1.14}$$

$$\tan\alpha = \frac{v}{c} = \tan i, \tag{1.15}$$

$$\tan i = \mathrm{N}\tan r, \tag{1.16}$$

$$\tan\alpha = \mathrm{N}\tan r, \tag{1.17}$$

$$\mathrm{N}\tan r = N\frac{\overline{PQ}}{\overline{OQ}} \tag{1.18}$$

$$= N\frac{\overline{PR} - \overline{QR}}{\overline{OQ}} \tag{1.19}$$

$$= N\frac{v - kv}{\frac{c}{N}} \tag{1.20}$$

$$= N^2\frac{v}{c}(1 - k), \tag{1.21}$$

$$k = 1 - \frac{1}{N^2}, \tag{1.22}$$

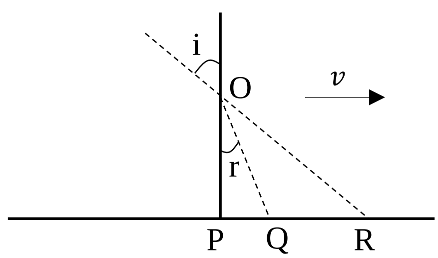

Fig. 3. Stellar aberration in a telescope with an optical interface.

where (1.15) comes from the fact that stellar aberration is equal to the incident angle of Snell's law, (1.16) is a restatement of Snell's law from (1.14); the line segment $\overline{PQ}$ is the horizontal distance the light would be refracted in the aether's frame, $\overline{PR}$ is the horizontal distance the light would need to be refracted in the aether's frame to agree with the light's trajectory from the earth's frame ($v\Delta t$), $\overline{QR}$ is the distance the water-filled telescope must partially drag light with a fraction k of its velocity ($kv\Delta \mathrm{t}$), and $\overline{OQ}$ is the trajectory of the refracted light from the aether's frame ($\frac{c}{N}\Delta t$); (1.22) is the value of k after rearranging (1.21) given that it must be equal to $\frac{v}{c}$. (This derivation was completed in lockstep with Janssen and Stachel's from their article "The Optics and Electrodynamics of Moving Bodies.")

In figure 3, the dashed line segment $\overline{OR}$ represents a ray of light emanating from a star in its actual position—as seen from a perspective at rest with respect to the aether—which impinges on the telescope's objective lens at an angle i from the vertical. The telescope is positioned vertically parallel to the line segment $\overline{OP}$. From the reference frame of the earth, the stars apparent position is directly overhead, and its rays would follow $\overline{OP}$. If there were no medium change as the telescope translates from point P to R with velocity v in the x-direction, the light would hit point R at the bottom of the telescope (as seen from the aether), which would be complementary to the observation made from an earthbound frame of reference. However, in the case of Airy's water-filled telescope due to the index of refraction changing, the light ray would follow the line segment $\overline{OQ}$ from the perspective of the aether, which contradicts Snell's law from the reference frame of the earth, and the experimental data. Therefore, Fresnel assumed that light was partially dragged by the telescope, such that after the time Δt had elapsed for the light to travel through the telescope and for the telescope to translate from point P to R, the light would arrive at point R in accord with experiment:

$$\overline{PR} = v\Delta t$$

$$= \overline{PQ} + \overline{QR}$$

$$= \overline{PQ} + kv\Delta t \qquad (1.23)$$

where (1.23) has been substituted into (1.18) and (1.19) to yield (1.20). Now substituting $N_w = 1.33$ into (1.21) and solving for α we obtain 20.5 arcseconds.

Turning now to Fizeau's 1851 experiment. The experiment was conducted by sending a beam of light through a beam splitter and multiple reflecting mirrors, where one beam (beam A) traveled within two tubes of water moving at a speed v_w in the same direction as the light beam and where the other beam (beam B) traveled against v_w. The light beams were then recombined, and the interference fringes produced by the experiment were analyzed to determine if the path lengths of beam A and B differed. Hippolyte Fizeau found that his data were consistent with Fresnel's dragging coefficient (1.13). Fizeau's aspiration for his 1851 experiment was to determine the value of k (Fresnel's dragging coefficient)—and in doing so—to settle the theoretical debate concerning which aether model more accurately represents reality. Specifically, since the speed of light within the lab with respect to the aether's frame can be represented by:

$$c' = \frac{c}{N} + kv, \tag{1.24}$$

then if the aether is completely dragged with the earth k should be measured as 1, and if the aether is not dragged at all the experiment should find k to be 0 (Miller 16-17). However, the outcome of Fizeau's experiment was that the observed fringe shift, that occurred when the static water in the tubes began to flow, agreed with Fresnel's partial drag model of the aether within only a 14% error margin:

$$\%_{error} = \left|\frac{\delta_{experimental} - \delta_{theoretical}}{\delta_{theoretical}}\right| \cdot 100 \tag{1.25}$$

$$= \left|\frac{0.23 - 0.2022}{0.2022}\right| \cdot 100 = 14\%$$

(Miller 16).

The outcomes of the Fizeau experiment and Michelson's interferometer experiment of 1881, whose measured effects were to first order in $\frac{v}{c}$, in concert with stellar aberration were sufficient to dismiss both Stokes' tertiary model and the primary model of a stationary aether. Be that as it may, Fresnel's model only outlasted its competitors until Michelson and Morley's 1887 experiment—as previously mentioned—illuminated the aether's effects (or lack thereof) to second order $\left(\frac{v}{c}\right)^2$—the null result of the Michelson experiment to first order was consistent with Fresnel's partial drag aether model, but this model could not account for the absence of second order effects. This brings us to the quaternary (and final) model of my luminiferous-aether taxonomy.

In 1892, Lorentz too become beguiled by the siren song of ad hoc hypotheses and posited length contraction:

$$l = l'\sqrt{1 - \frac{v^2}{c^2}}, \tag{1.26}$$

as a means of salvaging the notion of a stationary aether in view of the second order null interferometer result (Miller 28). Namely, he envisioned that the arm of the Michelson-Morley interferometer parallel to the motion of the earth would be horizontally compressed due to the aether interfering with the intermolecular forces within a material body. This hypothesis was unfalsifiable at the time of its advancement due to technological limitations, so Lorentz reframed the verificatory burden by supposing that the mode of interaction between the aether and intermolecular forces was tantamount to the interplay of the aether on charged material particles (which he had developed in his 1892 treatise *La Théorie Électromagnétique*)—the impetus for this conceptual choreographing was to mitigate the vulgarity of the standalone theoretical assumption (Miller 29). The precursor for Lorentz's length contraction was the following transformation equation (which was utilized to recover Poisson's equation during Lorentz's procedure for converting an electrodynamic problem into an electrostatic one):

$$x' = \gamma x \tag{1.27}$$

Additionally, Lorentz concocted the mathematical mechanism of "local time:"

$$t' = t - \frac{v}{c^2}\gamma^2 x, \tag{1.28}$$

where t is a reference frame in motion with respect to the aether, t' is a contrived reference frame (according to Lorentz) constructed to obviate the intractability of the differential equations produced by expressing the reference frame moving with respect to the aether, in terms of the reference frame at rest with respect to it by a Galilean transformation; where:

$$\gamma = \frac{1}{\sqrt{1 - \frac{v^2}{c^2}}} \tag{1.29}$$

(Miller 32). Given that the Taylor expansion of γ is:

$$\gamma = 1 + \frac{v^2}{2c^2} + \frac{3v^4}{8c^4} + \cdots \tag{1.30}$$

truncating the series before terms of second order in $\frac{v}{c}$ yields:

$$\gamma = 1 \tag{1.31}$$

and accordingly (1.27) and (1.28) become:

$$x' = x \tag{1.32}$$

$$t' = t - \frac{v}{c^2}x. \tag{1.33}$$

Equations (1.32) and (1.33) allowed Lorentz to have a theory in which the mathematical descriptions of electromagnetic phenomena are coordinate covariant and that accounted for the optical experiments (e.g., Fizeau's experiment, stellar aberration etc.) respectively, both to first order in $\frac{v}{c}$ (Miller 33). The latter of which categorically encapsulates Lorentz's inchoate "theorem of corresponding states" (which will hereafter be referred to as TCS). Full generality eluded Lorentz upon his initial articulation of the TCS, as it was delimited by the omission of terms of second order and above in $\frac{v}{c}$, and by being specific to the source free Maxwell equations (Janssen 167).

This prototypical TCS is a mathematical technique that allows one to convert between a Galilean reference frame that is at rest with respect to the aether (S_0) and one that is moving with respect to it (S), while preserving the solutions to Maxwell's equations, via an intermediary, imaginary reference frame S' that is constituted by fictive, ancillary quantities like the electric and magnetic fields $\boldsymbol{E}$' and $\boldsymbol{B}$'—local time (1.33) being such a quantity (Janssen 169). As a result of Lorentz's reference frame stepping-stone, Galilean invariance for optical phenomena could be safeguarded to first order in $\frac{v}{c}$, and theoretical harmony with experiment could be restored. Moreover, (1.33) enabled Lorentz to embed Fresnel's dragging coefficient (1.13) within a broader theoretical framework, because Fresnel's dragging coefficient could be derived from the TCS—thereby anchoring it and countervailing its free-floating, spontaneously appearing, prior state (Miller 34; Janssen 175).

The TCS was also tacitly instantiated by the transformation of electrodynamic problems to electrostatic problems, where (1.32) fulfilled the role of an ancillary quantity in—what was according to Lorentz—the stopgap reference frame of S' (Janssen 188). In *La Théorie Électromagnétique* he postulated that charge-possessing infinitesimals—which are subject to Newton's laws of motion—comprise all material bodies (McCormmach 463). These charged particles were thought to give rise to the electromagnetic waves whose propagation depends on the aether. Consequently, Lorentz's "fundamental equations" or the Maxwell-Lorentz field equations—based on his theory of electromagnetism—limned the condition of the aether at any spatial coordinate predicated upon the charge configuration occupying said location (Miller 24). Alternatively, in the case where no charges are present, Lorentz's equations like Maxwell's equations are source independent and in the aether's frame the speed of light is invariable (Miller 25). Availing himself of his transformation equations and namesake force:

$$\boldsymbol{F} = \rho\left(\boldsymbol{E} + \frac{\boldsymbol{w}}{c} \times \boldsymbol{B}\right) \tag{1.34}$$

(where ρ is a particle's charge density and $\boldsymbol{w}$ is the particles velocity relative to the aether), he determined that the forces exerted by the aether on the charged material particles in the lab frame (moving with respect to the aether)—due to their generating both electric and magnetic fields within it—could be mathematically reconceived as a static frame in which the configuration of particles is similar to what they would be in the static frame of the aether, except for their proximity in one dimension (i.e., they are contracted along the direction of their motion) (Janssen 193-195; Miller 31).

Lorentz codified this two-pronged approach in his seminal 1895 work *Versuch Einer Theorie der Electrischen und Optischen Erscheinungen in Bewegten Körpern* (*Attempt at a Theory of the Electrical and Optical Phenomena in Moving Bodies*), where the optical-electromagnetic bifurcation of the TCS heralded his aether-redeeming explanans for the gamut of experimental results collected to first order. It was only as a coda in the *Versuch*, titled "Experiments which Cannot be Explained without Further Ado," that Lorentz extended his electromagnetically oriented mathematical machinery (1.27) to second order in $\frac{v}{c}$, retaining the second term of (1.30)—the Taylor expansion of γ (Miller 28-30). He evinced that when a configuration of charged particles in an electrodynamic problem undergoes his mathematical metamorphosis and becomes an electrostatic problem (to second order in $\frac{v}{c}$) the dimension of the charge configuration along the x-axis in frame S moving with respect to the aether (assuming that the earth is moving in the x-direction) is contracted by $(1 - \frac{v^2}{2c^2})$ (Miller 29). Specifically, rearranging (1.27) and keeping terms up to second order in $\frac{v}{c}$ in the Taylor expansion of $\frac{1}{\gamma}$ yields:

$$x = \left(1 - \frac{v^2}{2c^2}\right)x'. \tag{1.35}$$

Lorentz then argued that if intermolecular forces were affected by the aether in the same way, then the arm parallel to the motion of the earth on the Michelson interferometer would similarly be contracted, thereby explaining Michelson and Morley's 1887 null result (Janssen 193-194). This can be seen by considering the traversal-time difference between the parallel and orthogonal paths of the interferometer utilizing (1.8) and (1.9):

$$\delta t = t_1 - t_2 = \frac{lv^2}{c^3}. \tag{1.36}$$

Now if we substitute $l(1 - \frac{v^2}{2c^2})$ for l in the parallel path t_1 (1.8), Taylor expand γ^2 in (1.8) and γ in (1.9) to second order in $\frac{v}{c}$, simplify the expressions (dropping terms of higher order than $\left(\frac{v}{c}\right)^2$), and recalculate δt, we arrive at the following:

$$t_1 = \frac{2l}{c}\left(1 - \frac{v^2}{2c^2}\right)\left(1 + \frac{v^2}{c^2}\right) \tag{1.37}$$

$$= \frac{2l}{c} + \frac{lv^2}{c^3} - \cancel{\frac{lv^4}{c^5}}$$

$$t_2 = \frac{2l}{c}\left(1 + \frac{v^2}{2c^2}\right) \tag{1.38}$$

$$\delta t = \left(\frac{2l}{c} + \frac{lv^2}{c^3}\right) - \left(\frac{2l}{c} + \frac{lv^2}{c^3}\right) = 0 \tag{1.39}$$

(Miller 29). Although, in contradistinction to length contraction, Lorentz did not construe local time (1.33) to be anything more than an abstract, a posteriori, mathematical Rube Goldberg machine, devoid of physical significance, but reliably able to vouchsafe the appropriate experimental results (Miller 26; Janssen 170). Due to the piecewise nature of his theory in the *Versuch*, Lorentz went on to refine and generalize his conception of corresponding states in 1904, in order to bridge the gap between first-order and second-order phenomena (Janssen 199).

Henri Poincaré responded to Lorentz's *Versuch* in 1895. In particular, he execrated Lorentz's conceptual contorting to justify Michelson and Morley's 1887 null result by proposing length contraction, and in turn saving the phenomenon of absolute motion (Miller 38). For Poincaré the dearth of experimental confirmation of the earth's motion impacting optical phenomena was sufficient to discount it. His argument was an inductively tinged reductio ad absurdum. The essence of which is the following: if experimental precision increases to the point where the affect of the earth's motion on optical phenomena to orders higher then $\left(\frac{v}{c}\right)^2$ are detectable and yet this effect continues to elude observation (which seems eminently likely), then it is preposterous to continually spare the notion of absolute motion from the empirical guillotine by hypothetical amendment, and since Lorentz is culpable of this to second order, his approach is proportionally nonsensical. Moreover, Poincaré exposed the fact that Lorentz's theory infringed upon Newton's third law, which he found to be sacrilegious, because in 1895 to him, Newton's laws self-substantiated their necessity as conventions (Miller 39). (Where for Poincaré a scientific convention has a restricted denotation—in contrast to its usage in common parlance—viz., it refers to the presuppositions (definitions) that act as the scaffolding by which successful scientific theories can be erected, but which in themselves cannot be corroborated experimentally.) Finally—in a fashion diametrically opposed to Lorentz—Poincaré interpreted local time (1.28) to be a tangible property of the physical world due to its ability to explain a diverse array of experimental data to first order in $\frac{v}{c}$ (Miller 38). Despite the criticisms that

Poincaré levelled against Lorentz, he reckoned that his theory was the best option out of a contestable compendium of choices—which is a thinly veiled lambasting in its own right.

Nevertheless, inspired by the explanatory power that Lorentz's TCS offered, Poincaré was determined to make the necessary revisions to his mathematical framework to reconcile it with Newton's third law of motion. Poincaré's underlying motivation for this theoretical recasting was twofold. Firstly, dispensing with Newton's third law carries with it the repugnant repercussion of having the law of conservation of energy caught in the crossfire and winding up a casualty (Miller 40). Secondly, due to his philosophical inclinations—which are positioned within a longstanding tradition that included Gottfried Leibniz and Ernst Mach—he was not amenable to the notion of absolute space, and by virtue of the intimate connection he perceived them to have, jettisoning Newton's third law would mean sacrificing the principle of relativity on the alter of Lorentz's predilection for the stationary, absolute frame of the aether (Miller 42). This purported conceptual propinquity can be ascribed to Poincaré uncovering—in 1899—that based on Heinrich Hertz's 1890 theory of electrodynamics, the satisfiability of both the conservation of energy and the principle of relativity—by matter alone—implies that Newton's third law is also satisfied by matter alone (Darrigol 15). Although, Hertz's theory falling under the tertiary position within my luminiferous-aether taxonomy—alongside Stokes' aether model (i.e., a complete drag model)—relegated it to the collection of theories that are empirically inadequate, because they are in conspicuous conflict with experimental findings. Moreover, abandoning the principle of relativity was inconceivable to Poincaré, as he was under the impression that it was the Apollonian countermeasure to the erratic, chaotic, Dionysian interplay between theory and the body of optical and electromagnetic experiments that had theretofore been amassed.

In 1900, Poincaré advanced his revised version of Lorentz's TCS (omitting Length contraction and second order phenomena) that extended the conventions of classical mechanics to electromagnetic theory (e.g., Newton's third law, conservation of energy, etc.) on pragmatic grounds, because within the former subdiscipline an illustrious track record was a testament to their utility (Miller 38). It was within the context of this theoretical framework that he ventured his purely mathematical "fictitious fluid," in which electromagnetic energy (i.e., perturbations of the aether) possessed momentum, to resurrect Newton's third law and the conservation of momentum (Miller 41). Additionally, Poincaré considered a Hertzian oscillator moving with respect to the aether that is unidirectionally emitting electromagnetic radiation and the recoil that it would experience; a phenomenon about which all electromagnetic theories of the time were in agreement (Poincaré, "La Théorie" 9). (This recoil can be understood, analogously, by visualizing an ice skater throwing a ball from rest and sliding in the opposite direction.) Poincaré demonstrated that this recoil, in tandem with his fictitious fluid, and the conservation of energy, required the inclusion of an "apparent complementary force" provided by the aether, for a frame moving relative to the Hertzian oscillator, in order for Lorentz's theory to satisfy the principle of relativity to first order in $\frac{v}{c}$ and account for the experimental data (Granek 22; Darrigol 26).

Poincaré foresaw the potential hypocrisy of resorting to hypothesis-augmenting fancy footwork when constructing a theory and therefore—to circumvent falling prey to the same criticism that he had directed at Lorentz—he distinguished between summoning a mathematico-physical deus ex machina to shield a single theory from an experimentally precipitated demise (viz., Lorentz's length contraction), and the introduction of a mathematical device that salvages a theory serving as the explanans for sundry explananda, and which preserves reliable conventions. However, Poincaré was displeased with his mathematical suturing, as this formulation of the principle of reaction (Newton's third law) did not strictly pertain to matter. Instead, it imparted material properties to the aether, and it relied on the aether's intercession to be fulfilled, rendering it non-simultaneous (Darrigol 25, Granek 27).

Furthermore, Poincaré discerned that, unlike Hertz's theory, Lorentz's theory did not demand that the principles of relativity and Newton's third law be mutually satisfied (when applied to matter alone) due to the theory's differing provisions. Specifically, he revealed that imposing Newton's third law—via his fictitious fluid—on Lorentz's mathematical formalism violates the principle of relativity when applied to matter alone, which caused him to uncover the (previously alluded to) apparent complementary force (Darrigol 26-27). Hence, Poincaré upheld his supposition of the mutual dependence of the principles of relativity and reaction by noticing that, for Lorentz's theory, both of these principles could be mutually satisfied, if they were extended beyond matter alone to accommodate the absolute frame of the aether and its mediative function (Poincaré, "La Théorie" 277).

In response to Poincaré's criticisms, Lorentz put forward a more general electromagnetic theory in 1904 with his paper "Electromagnetic Phenomena in a System Moving with Any Velocity Less than that of Light," undergirded by a mathematical description of a deformable electron. This theory broadened the boundaries of his TCS to encompass second-order (and higher-order) optical effects, posited that all forces behave like electromagnetic forces (i.e., length contraction), and attempted to account for the mass of the electron (Miller 66). Poincaré was no longer antipathic to Lorentz's notion of length contraction, because embedded within this more sophisticated theoretical scheme, he felt that it had obtained a newfound rigour and credibility. In fact, he endeavored to appropriate Lorentz's enhanced theory, though he desired to make a few minor adjustments to it, because he was convinced of the overt veracity of the principle of relativity; contrary to Lorentz who clung to the idea—with an almost dogmatic fervor—that the aether's effects were not fundamentally inaccessible to experimentation, despite his acceptance of the invariance of the electro-optical phenomena in question to all orders in $\frac{v}{c}$ (Darrigol 33).

Poincaré's refurbishing of Lorentz's 1904 theory led to his 1905 paper "On the Dynamics of the Electron," wherein he demonstrated that a mathematical framework could be coaxed out of Lorentz's theory that preserved its explanatory power, and concomitantly satisfied his conception of relativity (i.e., as being restricted to matter) (Darrigol 34; Granek 23). This was made possible, in part, due to Poincaré's insistence on the hypostatization of Lorentz's transformation equations (1.27) and (1.28), as well as by his re-expressing Lorentz's electron theory in Hamilton-Lagrange formalism (Miller 80). Poincaré perspicaciously recognized that the intermediary, stationary reference frame of Lorentz's TCS—which Lorentz deemed fanciful—could be re-imagined as: what an observer actually experiences from the reference frame in motion with respect to the aether—which Poincaré dubbed the "apparent states" (Darrigol 27-28). Moreover, due to his incisiveness, Poincaré was able to simplify the aforementioned mathematical procedure—lying at the heart of Lorentz's enhanced theory—by establishing that the complete set of Lorentz transformations form a non-Abelian matrix Lie group (viz., the Lorentz group) (Miller 76; Darrigol 34). Poincaré's epiphanic ebullition arose under the tutelage of a reverence for symmetry, and it was the continuous symmetry (invariance) of Maxwell's equations under the Lorentz transformations—which is captured by the mathematics of Lie theory—that facilitated Poincaré's mathematical abridgment of Lorentz's broadened version of the TCS, since groups in general (i.e., sets of mathematical objects in combination with a binary operation) must possess the property of closure. (Where the property of closure is defined as the condition whereby the binary operation applied to two elements of a set yields another element of the set—the operation being composition via matrix multiplication in the case of the Lorentz group, since Lorentz transformations are linear.) As a result, Poincaré found that the intermediary steps present in Lorentz's broadened TCS were extraneous, as consecutive Lorentz transformations could instead be economically exchanged for a single Lorentz transformation. Furthermore, Poincaré expanded the Lorentz group to include translational symmetry in addition to the rotational symmetry, and boost symmetry (i.e., converting between frames moving with uniform velocity with respect to one another) which the Lorentz group already described; this group is the so-called Poincaré group. This elevated Lorentz's broadened TCS to the level of being on par—in terms of symmetry—with its Newtonian counterpart: Galilean relativity, and associated symmetry group: the Galilean group, and signified Poincaré's realization of a complete reconciliation of the principle of relativity with electromagnetic phenomena.

However, during Poincaré's overhaul of Lorentz's enhanced theory of 1904, he deduced that his claim of the incongruity of the apparent complementary force (present in a reference frame in relative motion with the Hertzian oscillator moving with respect to the aether), and the principle of relativity (applied to matter alone), was erroneous (Darrigol 35). Poincaré acquired this self-overriding acuity by computing that the magnitude by which the deformable electron's mass is transformed in a reference frame in relative motion with respect to the aether, is sufficient to counterpoise the apparent complimentary force that also crops up in this reference frame (Darrigol 41). Consequently, Poincaré rescinded his assertion of the intratheoretical biconditional nature of the principles of relativity and reaction. Furthermore, due to the fact that he had established that his revamped variant of Lorentz's theory satisfied the principle of relativity (applied to matter alone)—while the principle of reaction obstinately opposed conforming to a matter-alone restriction—he decided to repudiate the latter principle (Granek 26). Although, Poincaré's recantation of the principle of reaction appears to have been a reflection of his unwavering commitment to the simultaneous, action-reaction force pairs as described by Newton's third law. In other words, he preferred to lay the principle to rest, than to adopt what he perceived to be a bastardized version of it where it is re-expressed as the conservation of momentum via the inertia of energy, where said momentum is carried electromagnetically, and where the action-reaction pairs—pertaining to matter alone—are subject to a temporal delay in accordance with the cosmic speed limit of c (as advanced by Max Planck and Albert Einstein and as accepted today).

Poincaré's misgivings regarding a violation of the principle of reaction originated from a gedankenexperiment in which two bodies exerting a force on one another—and fixed by a rod without any external force acting on them—continuously accelerate, because a violation of the principle of reaction in conjunction with the principle of relativity, constitute a violation of the theorem of the motion of the centre of mass (which is dependent on the conservation of mass)—and as a result leads to perpetual motion (Darrigol 24-25; Granek 21). Though Poincaré's fictitious fluid rectifies the breaching of the conservation of momentum, its restorative range falls short of the conservation of mass, and—by the property of transitivity—also the theorem of the motion of the centre of mass (Granek 24). However, he did adumbrate Albert Einstein's status quo-shattering revelation of the equivalence of mass and energy (which was also independently proffered by Paul Langevin in 1906) which solved the problem posed by the thought experiment. Additionally, Langevin and Max von Laue (in 1913 and 1911 respectively) illustrated that the mass-energy equivalence could be harvested, organically, from Poincaré's notion of a fictitious fluid endowed with momentum coupled with his aforementioned second-law-of-thermodynamics defying thought-experiment (Darrigol 41; Granek 40).

Poincaré brushed up against the contours of the simplified mathematico-physical architecture (e.g., mass-energy equivalence)—which designated the post-Newtonian changing-of-the-guard—discerning only its nondescript semblance; like Moses being consigned to not enter the promised land, but only behold it. A perdition of his own making, as his allegiance to his notion of conventions and their ineluctability, sealed his fate—exemplifying Paracelsus' dictum "the dose makes the poison." Although, Poincaré did qualify that under special circumstances conventions (principles) can overstay their welcome and exhaust their utility, despite their incontrovertibility (being vital to a theory's structure and always recoverable post-experiment, while being empirically unconfirmable in isolation) (Darrigol 11). For instance, he thought that they ought to be discarded if their rather aloof relationship with reality became exceptionally estranged, due to their preservation entailing exorbitant, or unbridled abstractions (e.g., the aether)—resulting in the fraying of the pragmatic connective tissue between conventions and theory confirmation within the scientific body of knowledge. Nonetheless, Poincaré's scientific weltanschauung collapsed to its convention-affirming default state under the weight of cognitive dissonance. The mental tug-of-war centered on Poincaré's longstanding, and ever-mounting, disillusionment with the aether on the one hand (as he felt that it was little more than a facile conceptual expedient with an evident expiration date, for which experiment had shown no affinity), and it seemingly offering a mechanism to avoid the spooky action at a distance brought on by the non-simultaneity of the action-reaction force pairs on the other—thereby precluding its outright rejection (Darrigol 19, 40; Granek 45). As previously noted even his alleged principle-of-reaction apostacy was actually in some sense due to his devotion to it as a convention. Moreover, he was incapable of taking Einstein's iconoclastic leap of faith in repealing the conservation of mass (in exchange for the conservation of mass-energy) and the absoluteness of space and time, because of their status as conventions; for Poincaré ample evidence against their utility was required for their abolishment—which he felt was absent (Darrigol 40, 44). (As a result, his conception of relativity was weaker than Einstein's, since he did not demote the aether from its position of reference frame privilege, instead accounting for the aether's null results by constraining the principle of relativity to ponderable matter alone—hence the elapsed time and length of objects perceived in Poincaré's apparent states were merely verisimilitudinous.) Poincaré twisted himself into the Gordian knot of still desiring to address his thought experiment, while having the notion of the aether foisted upon him—despite it being repugnant to him—because he was unsympathetic to Einstein's solution due to his adamant conventionalism. He was apprehensive about stepping off of his convention-conserving scaffold, not realizing that solid ground had resided immediately beneath his feet, all the while.

In contrast, Einstein's rather contumacious attitude (which at times negatively impacted his academic progress) enabled him to cull, without compunction, whichever conventions he felt were maintained merely by appeals to authority. He had been emboldened by Ernst Mach's excoriation of the mechanical world-picture (the received view of the period) and the purportedly unimpeachable principles which grounded it (Miller 117). This combined with Immanuel Kant's influence of revealing intuition, synthetic a priori knowledge, and ratiocination to be inextricably linked—epistemically—to empirical knowledge, sanctioned Einstein's Gedankenexperiment-forward approach to theoretical physics—of which a preoccupation with the ontology of space and time was a central feature. The intellectual offspring of this synthesis was Einstein's strong version of relativity (i.e., the special theory of relativity), in which the temporal duration between events and the length of objects is not absolute, but dependent on what fraction of the speed of light an observer's reference frame is moving at with respect to another's—as the speed of light in vacuum is constant for all inertial frames.

2.3 An Undercutting Defeater from Counterfactual Universes

Thus concludes my digressive, serpentine canvass of the historical mise-en-scène in which Einstein's theory of special relativity made its debut. (Though it is by no means exhaustive, as the richness of the subject matter prohibits a comprehensive retrospective given the constraints of this project.) Now that this intricate tapestry has been woven, parallels between the historical period antecedent to the completion and acceptance of Einstein's theory of special relativity characterized by luminiferous aether models (henceforth LAMs), and the contemporary scientific milieu of string theory come into focus. One of which is that the inductive trend of UEC was present within the research program of the LAMs. For instance, James Clerk Maxwell's unification of electricity and magnetism—via his set of differential equation—provided unexpected theoretical consolidation by recognizing that light is electromagnetic radiation when he deduced that their speeds were strikingly similar, unshrouding the consanguinity of electromagnetism and optics. Prior to Maxwell's corralling of the various laws of electricity and magnetism, they existed as segregated models to explain particular phenomena. The empirical success of Maxwell's mathematical framework extoled the virtues of theoretical schemes capable of coalescing formerly disconnected physical models. Especially, if they illuminate darkened corners of the field that they were not initially designed to. Moreover, at the time of its acceptance it was without theoretical rivals.

Similarly, the luminiferous aether theory promised to reconcile mechanics with electro-optical phenomena, and during the course of its theoretical development (and its various taxonomical morphologies) its potential explanatory breadth surpassed the boundaries of the theory's designated purview at the time of its formulation. Three prominent examples of this are the following:

i) that the primary motivation for Lorentz's TCS, (1.27) and (1.28)—as we have seen—was merely to account for the data gleaned from Fizeau's experiment, stellar aberration, and Michelson and Morley's experiments. However, Lorentz's aether-endorsing TCS achieved more than a passable Frankensteinian assemblage of disjointed pieces, it offered a means of theoretically substantiating Fresnel's dragging coefficient and accentuating the kindredness of its empirical building blocks.

ii) that Lorentz's TCS contributed to demystifying the experimental data on the electromagnetic mass of the electron—collected by Walter Kaufmann early in the 20th century (1901-1903)—when Lorentz extended his theory from bulk matter (e.g., the molecules of the interferometer arm) to ions (electrons)—explaining experiments lying beyond those that it was initially employed to address (Miller 63).

iii) that Poincaré demonstrated that Lorentz's transformations are nested within a unifying mathematical architecture vis-à-vis the Lorentz group by capitalizing on their symmetry, which did not just square Maxwell's equations with the principle of relativity, but indicated that Maxwell's equations implied (at least Poincaré's weak conception of) relativity, since they were invariant under Lorentz's transformations.

In the case of string theory, Dawid cites three main instances of UEC:

a) the unforeseen theoretical attributes of the gravitational field arising from string theory's mathematical framework and its "low-energy effective theory" being a quantum field theory, despite its purpose only being "to cure the renormalizability problems of quantum field theories that include gravity"—i.e., string theory implies both gravity and its quantum field theoretic nature, as opposed to simply granting them compatibility (Dawid 33). (Where a) has some commonalities with iii), in that they both concern a deep symmetry-exploiting mathematical framework which strongly implies the elements (or an element) that they were designed to merely make harmonious.)

b) that string theory offers a theoretically foundation for supersymmetry (i.e., a purely mathematically motivated extension of the continuous symmetry groups, which is capable of mathematically depicting gravity in a quantum field theoretic fashion via the graviton and its interactions), as string theories which meet the criteria for being prospective models of our universe are locally supersymmetric (Dawid 34). (Here b) has similarities with i), in the sense that both reference mathematical maneuvers alienated from the scientific enterprise which were subsequently—though inadvertently—enveloped by a sophisticated theoretical scheme.)

c) that string theory coincidentally sheds light on an inexplicable property of black holes (viz., that a black hole's entropy is proportional to the area of its event horizon), since the entropy of specific "supersymmetric black holes" correspond to "the number of degrees of freedom of the string theoretical system" (Dawid 34). (Lastly, it is possible to draw parallels between c) and ii), because each exemplify a theoretical framework fortuitously addressing, and contextualizing, a previously enigmatic result.)

It is important to acknowledge a patently disanalogous aspect between examples c) and ii) of UEC within the research programs of string theory and the LAMs respectively. Namely, concerning the latter, this occurrence of UEC is interpolated with empirical contact. However, this is a nonissue, as these local manifestations of empirical infusion would only serve to strengthen UEA globally—where it is still sequestered from empirical testing. Therefore, it appears that Dawid's UEA can be made at least as (if not more) cogent when applied to the research program of the LAMs as it can when applied to the research program that it was designed for, and yet ultimately in the case of the LAMs, hindsight has exposed its utter unreliability.

To underscore the hazard of relying on Dawid's UEA, we can imagine counterfactual universes where models within the research program of the LAMs have, mutatis mutandis, suffered the same fate as string theory in terms of testability. Let t_1 be the period of time when the research program was typified by the holder of the secondary position in my luminiferous-aether taxonomy: Fresnel's model (circa 1851–1880), and let t_{2A} and t_{2B} be the periods of time when Lorentz's TCS (circa 1892–1894) and Poincaré's refined version of Lorentz's enhanced TCS (circa 1905–1910)—both falling under the quaternary position—respectively dominated the research program.

Consider universe U_1 which did not deviate from ours until t_1, during which empiricism waxed quiescent—without requiring the laws of physics to be altered—then the Michelson-Morley experiments would not have transpired, and therefore Lorentz would never have postulated length contraction. (The laws of physics must remain intact so that if the scientists of U_1 were to have suddenly been able to conduct experiments following t_1, their results would have been identical to our own.) One scenario that fulfills these criteria (though it is certainly not suis generis) is if an extraterrestrial civilization were to have evolved on an exoplanet in a habitable zone of a neighbouring solar system, developed interstellar travel and plundered the earth of its ore by aggressive strip mining, and confiscated all scientific apparatuses consisting of metal, glass etc., before the end of t_1. Consequently, experimental activities would have been involuntarily suspended for the foreseeable future, as the production of scientific instruments would have been arrested and barring remarkable technological innovations bypassing the usage of these resources, suspended they would stay. (The exact reason for empiricism's nomology-preserving vow of silence is irrelevant, since U_1 (as unlikely as it may be) is at least logically possible in the most minimal sense of being noncontradictory—i.e., it constitutes a possible world—and this is sufficient for our purposes.) As a result, Fresnel's would have become the principal—and quite frankly peerless—model, and although by setting the empirical foundering at t_1 we now owe Father Time the chronological tax of the examples i)-iii) of UEC, the fact that Fresnel's dragging coefficient went on to be experimentally corroborated by Fizeau in 1851, supplies it with the stronger (previously encountered) empirically-peppered UEA. Ergo, we can imagine that the scientific community of U_1, confronted with a tight-lipped empiricism, would have constructed an UEA endorsing the validity of Fresnel's model. However, Fresnel's model entails that every wavelength of light is dragged along at a different velocity—since the index of refraction is wavelength dependent—insinuating a potential infinitude of aethers, and because Lorentz's theory would not have existed in U_1, he will not have reinterpreted Fresnel's coefficient as a description of the stationary aether interacting with charged particles moving with respect to it—thereby supplanting Fresnel's model (Miller 27, 90). Given our vantagepoint, of course, we have the luxury of knowing that this model is in error, and incidentally at the time scientists were dismayed by the prospect of a multiplicity of aethers. It is worth qualifying that the total number of wavelengths of light is unknown as there is an experimental limit to how precisely measurements can be made of light, though the mathematics of quantum electrodynamics dictates that the electromagnetic spectrum is continuous unless photons are emitted or absorbed (e.g., blackbody radiation, modes of an optical cavity, etc.). Nonetheless, it is safe to assume that it is an astronomically large number allowing the electromagnetic spectrum to be continuous for all practical purposes. Therefore, irrespective of how farfetched Fresnel's model may appear to us in retrospect, it would not have asked much more from us ontologically speaking, since string theory necessitates a landscape of 10^{500} universes.

In the same vein, if empiricism descended into desuetude in U_{2A} during t_{2A} with all the provisos of U_1, as well as two additional ones: that by some statistical fluke Henri Poincaré-like and Albert Einstein-like individuals were never born, then we can imagine that the scientific community of U_{2A} would have had example i) of UEC at their disposal and would have concluded, due to an UEA, that Lorentz's inelegant algorithm (i.e., due to its superfluous steps)—without any concretized justification—was the apogee of theoretical models. (Poincaré-like and Einstein-like individuals, since the theoretical fruit was ripe for the reaping; if they had not made the contributions that they did, it is exceedingly likely that others would have.) The ontic absenteeism of Poincaré-like individuals in U_{2A} would have deprived said universe of his scathing criticism of Lorentz's coup de pouce (helping hand) of positing length contraction (1.26), which would have pre-empted Lorentz's enhanced theory. Moreover, Poincaré's discovery that the continuous symmetry of Lorentz's transformations could be expressed as non-Abelian Lie groups (streamlining Lorentz's enhanced theory)—along with his proposal for their reification—would not have occurred.

In U_{2B} with conditions matching U_{2A}, save for the existential erasure of Poincaré-like individuals, the most powerful UEA would have been assembled utilizing examples i)-iii) of UEC. (We can even swap out the manufactured metallurgic-marauder cause of empirical dormancy—without maiming the argument—for an inability to detect the aether due to Poincaré's relativity being germane to matter alone—which mirrors string theory in that many of its theoretical features will be untestable over the long term or are so in principle.) However, the model that the U_{2B}-specific UEA would have substantiated is Poincaré's weaker conception of relativity, since (for the reasons mentioned earlier) he was not able to outrun the aether's influence, and Einstein's metaphysically motivated axiomatic recasting (further streamlining the ontology and mathematics of a theory of relativity) would not have come to pass. It is an unsettled historical question as to how indispensable Poincaré's contributions were to Einstein's theory of special relativity, and the bold assertion that Einstein's theory could only have materialized iff Poincaré's worldline was unperturbed, is indubitably tendentious. Nevertheless, the more modest claim: that the version of Einstein's theory that we are acquainted with required Poincaré's involvement, seems defensible, because Einstein was cognizant of Poincaré's work and his thought experiments, and in his 1905 paper "On the Electrodynamics of Moving Bodies" he grounded Poincaré's group theoretic mathematical framework with the two postulates of his theory of relativity (Darrigol 43).

Finally, a comparison can be drawn between the experimental-theoretical ebb and flow of the aether models as conveyed by my luminiferous-aether taxonomy, and the reduction in parameter space of the superpartner particles predicted by supersymmetry (which is an intrinsic property of string theories). Though it is distinctly possible that superpartner particles exist well beyond the energies that our particle accelerator experiments are currently able to probe (e.g., LHCb, ATLAS, CMS etc.), it does discount some string theory ground states (universes of the landscape). As a result, worries harkening back to Poincaré's criticism of saving the phenomenon of the aether by devising a mathematical mechanism to account for experiments to second order in $\frac{v}{c}$, seem apt here. Namely, how many universes from the landscape need be revealed as ontologically barren before it is deemed a theoretical wasteland? Furthermore, Duhem's concerns regarding a theory's ontological posits being too malleable seem especially pertinent, since supersymmetric particles with practically any possible range of energy would be in agreement with string theory, allowing its adherents to simply raise the mass limit arbitrarily to save the theory.

The second historical example is Einstein's theory of general relativity which was published in 1915 (though in the interest of brevity I will hardly be scratching the surface of this topic). The catalyst that brought the theory to fruition was Einstein's great epiphany that gravitational and inertial mass are one in the same (i.e., the equivalence principle) (Janssen et al. 83). Prior to this, in the late 19th century, breakthroughs in geometry had occurred which shook the foundations of mathematics, and which ultimately impacted the physics world. In particular, Euclidian geometry was forced to relinquish its mathematical hegemony, as Nikolai Lobachevsky and Bernhard Riemann both discovered non-Euclidian geometries: hyperbolic and elliptical geometry, respectively (86). Einstein exploited the latter geometry in combination with further developments in differential geometry (viz., tensor calculus) to devise the mathematical framework of general relativity. The scientific paradigm preoccupied with describing the motion of heavenly bodies characterized by the longevous pre-Newtonian and Newtonian research programs contained theories which displayed UEC preceding their empirical validation (e.g., Newton's law of universal gravitation explaining Kepler's three laws of planetary motion, the tides, and the orbits of comets—when its original purpose was to reconcile the accelerated motion of objects falling towards the earth with the accelerated motion of the moon around the earth). However, as a result of general relativity revising some of the fundamental postulates of Newtonian mechanics (i.e., Newton's law of universal gravitation) it constitutes a Kuhnian paradigm shift and is incommensurate with its theoretical forerunner, and therefore cannot be considered to exhibit UEC in the context of the paradigm with which it is incommensurate. No previous physical theory had described the universe as a non-Euclidian, four-dimensional, deformable spacetime manifold. Notwithstanding, in 1919 Arthur Eddington detected the gravitational lensing that was produced by the sun during a solar eclipse, confirming a novel prediction made by general relativity, and thereby empirically verifying the theory.

Lastly, Planck's law and the associated resolving of the ultraviolet catastrophe is taken to be representative of the bulk of experimental discoveries and subsequent theoretical-model building that typified the quantum revolution. Plank's law was formulated circa 1900 on the cusp of the quantum revolution. The equation that was supposed to describe the spectral density of an ideal blackbody at thermal equilibrium based on classical assumptions—as a function of wavelength or frequency (viz., the Rayleigh-Jeans law)—blew up to infinity in the high frequency domain (i.e., ultraviolet light), and therefore, it did not even remotely match experiment. In response, Max Planck suggested the quantization of electromagnetic radiation (i.e., that it comes in discrete values $E = h\nu$) in order to achieve a correspondence between theory and experiment. This accurately described the experimental findings, because in this model energy is not free to be evenly distributed among all the resonant modes of the blackbody, instead the high frequency resonant modes can only exchange large packets of energy, consequently energy is always exchanged with the low frequency modes first, and only if there is sufficient energy in the blackbody will some high frequency resonant modes be activated as well. Hence, model building for physicists at this juncture heavily emphasized heuristics and the a posteriori. Although the mathematical relationships that were ascertained via empirical results were later verified by theoretical physicists working from first principles, at the time of their discovery UEC was nonexistent, because physicists were ill-equipped to cope with the subatomic realm based on their classical presuppositions—and by extension—mathematical frameworks, engendering a paradigm shift. Though there was a history of UEC within the superseded research program, as evinced by the explanatory span of the wave theory of light—whose tenure as a theory abruptly concluded, due to the dawning unmistakability of wave-particle duality.

It is important to note that Dawid does concede that there have been "cases in the history of science where the inference from a concept's success to its viability was invalidated by the fact that just one aspect of the concept was responsible for the success while important parts of the concept were misguided" and references aether theories (35). He ascribes the success of the aether theories to their harbouring the wave equation, since the concept of the aether itself proved to be ontologically bankrupt and was eventually discarded. Moreover, he claims that separating the wheat from the chaff in this way, does not seem viable when it comes to the mathematical structure of string theory, because due to its holistic nature, it must either be confirmed or rejected wholesale. However, I have aspired to show that the concept of the aether (or an effort to protect it) acted as a kind of muse in laying the mathematical groundwork for Einstein's theory of special relativity. Even in relativity's penultimate form (i.e., Poincaré's relativity) it was still wholly compatible with the aether. Moreover, it was Einstein's modifications to the ontic presuppositions of physics which streamlined the theory of relativity (without purging any of the central mathematico-physical components which—at the time of their development—were coupled to the aether), and which ultimately delivered the coup de grâce to the concept of the aether. Antecedent to Einstein's trenchant a priori intuitions—legitimizing the relativity of distances and intervals of time—teasing out the aether from pre-Einsteinian theories of relativity was a fool's errand, and it would have appeared as though the theoretical structure was only capable of being expunged or exalted in its totality—particularly when the vast majority of the theoretical architecture was salvaged by Einstein. Therefore, the research program of the aether theories as a counterexample to UEA cannot be so easily dismissed, because they do not necessarily represent a uniquely dissimilar case. Without a compelling (much less indisputable) argument for the impossibility of a revision in the fundamental principles of physics, triggering a paradigm shift, and lassoing a runaway empiricism, Dawid's UEA is vulnerable to the counterexamples that I have levelled against it; this should at a minimum, provide reasonable doubt regarding its trustworthiness—undercutting its cogency.

On the side of rebutting defeaters, I will be arguing for precisely that in the final chapter (viz., the plausibility of empiricism's dereliction of duty being due to an overdue presuppositional reform). Much like in the case of Einsteinian relativity where an overabundance of mathematico-physical elements were excised from the theory which it replaced—thereby streamlining it—I will propose that string theory has accumulated mathematical machinery comprising a superfluity of ontological posits. As a result of string theory's complexity and the cumulative nature of the empirical content of scientific theories, its potential deviation from mind-independent reality would be far greater than that of pre-Einsteinian relativity.

3

Dawid’s Meta-Inductive Argument, Retroactivity, and Final Theory Claims

The premier goal of this chapter is to examine Dawid’s meta-inductive argument (MIA), demonstrate its defects, and reveal that it cuts both ways (i.e., that the argument can easily be retrofitted to produce a conclusion antithetical to the one Dawid is after). This section comprises two subsections, each containing a counterargument to be mobilized against Dawid’s MIA. The subsidiary intentions of this chapter are: firstly, to confute Dawid’s claim that his extra-empirical arguments have retroactively occupied a position within the theory-choice procedures utilized by physicists who are a part of the high-energy research program—therefore fortifying their credibility—and secondly, to dispel the notion that string theory is entitled to a final theory claim (which will form sections two and three, respectively).

3.1 Dawid’s Meta-Inductive Argument

Just a brief recapitulation to serve as a refresher, Dawid’s MIA is designed to bolster confidence in string theory by picking out certain theoretical attributes which successful scientific theories have evinced. More precisely, theories originating within the high-energy research program, which displayed unexpected explanatory coherence (UEC), and which were without peer (i.e., there were no promising theoretical alternatives), have gone on to be awarded the distinction of “scientifically viable” via empirical corroboration. Therefore, since string theory possesses these characteristics, it is likely scientifically viable as well, and in this way Dawid’s MIA does much of the heavy lifting for his triad of extra-empirical arguments vis-à-vis limitations to underdetermination.

3.1.1 The Supersymmetry Setback

Dawid demonstrates that his extra-empirical arguments can be formalized by way of Bayesian probability (68-72). He asserts that the Bayesian framework captures the essence of theory confirmation within the canonical scientific method, and that without much difficulty, the Bayesian framework can be extended to accommodate his extra-empirical arguments of theory assessment. In particular, he claims that a prior probability $P(I)$ representing the inductive strength of his extra-empirical arguments can be calculated from instances of theories within the high-energy research program that have displayed unexpected explanatory coherence, were without theoretical rivals, and have subsequently been empirically corroborated (call this B_1). If this prior probability is relatively high, then we can be proportionally confident that a theory constructed within this research program exhibiting these properties will subsequently be empirically corroborated as well. On the contrary, if a theory with these features is refuted empirically based on new evidence E_1, then the posterior probability $P(I \mid E_1)$ is updated accordingly, which will then become the prior probability for future predictive analyses. (Though Dawid's Bayesian analysis incorporates limitations to underdetermination, thereby complexifying the formalism, I am confident that my articulation of it is conceptually sufficient for my purposes (69-72).)

For cases in which Bayesian formalism is utilized to depict scientific theories (or hypotheses) within the canonical scientific method (call this B_2), the prior probability $P(T)$ represents the likelihood of—or our confidence in—a certain outcome, say of an experiment probing some physical phenomenon described by a theory, and upon collecting and interpreting the empirical data E_2, the posterior probability $P(T \mid E_2)$ is updated to reflect whether the data bolsters or undermines our confidence in said theory. Now to formalize confidence in the scientificity of a theory based on extra-empirical arguments, Dawid creates a nested Bayes theorem in which the prior probability $P(I)$ from B_1 is substituted for the empirical evidence E_2 in B_2. Consequently, if E_1 is more instances of theories with no alternatives exhibiting unexpected explanatory coherence, then $P(I \mid E_1) > P(I)$ for B_1 which means $P(T \mid P(I)) > P(T)$ for B_2 since $P(I \mid E_1)$ would become the new prior probability $P(I)$ and be substituted for E_2 in B_2. Therefore, according to Dawid, our confidence in the scientificity of T (which has no alternatives and exhibits unexpected explanatory coherence) would increase proportionally despite it not being empirically corroborated. Since it is clear from the above that the scientificity of T (i.e., string theory) is ultimately predicated upon E_1, this prompts the question: what evidence does Dawid amass in support of the aforesaid inductive trend within the research program of high-energy particle physics?

Dawid evinces, rather compellingly, the success of the standard model of particle physics and the discovery of the Higgs Boson as prime examples of theories (i.e., field theories) in which the scientific community had placed a considerable amount of confidence due to extra-empirical arguments in favor of their scientificity—to the degree that the eventual discovery of the latter shocked no one in the field (37). However, it is worth mentioning that in the case of the Higgs Boson, the meta-inductive argument was only used in combination with the no alternatives argument and not the argument from unexpected explanatory coherence; thus, the magnitude of support this supplies Dawid's triad of extra-empirical arguments with is unclear (115). Suppose—perhaps counterintuitively, yet plausibly—that theories in the research program that strictly exhibit no alternatives fare better empirically than theories that exhibit no alternatives and unexpected explanatory coherence. Then, the fact that a theory of the former type is empirically corroborated would not necessarily increase our confidence in the scientificity of a theory of the latter type; the connection between the evidential import of these two types of theories is not at all obvious, but Dawid does not offer us an account of their epistemic relation.

Furthermore, Dawid also claims that if low-energy supersymmetry were to be empirically corroborated, then this would furnish his triumvirate of extra-empirical arguments with additional support. However, as Fischer (2023) and Mummidi et al. (2023) have both stated, the dearth of empirical evidence of superpartner particles from multiple runs of the LHC and numerous other experiments have constrained their energies such that low-energy supersymmetry has been—for all intents and purposes—ruled out. In fact, many of its proponents have moved on to greener pastures, abandoning research on supersymmetry altogether—especially since one of its most appealing features (i.e., that it offered a way of resolving the hierarchy problem) appears to have been made moot by the constraints on its parameter space. Hence, the vicissitudes of experimental investigation have weakened the inductive strength of Dawid's extra-empirical arguments since now it only consists of the evidence supplied by the standard model of particle physics (and possibly the discovery of the Higgs Boson to some degree), thereby reducing the posterior probability, and ergo our confidence in string theory. As Dawid notes, this in and of itself does not significantly diminish string theory's scientific plausibility, as string theory does not require low-energy supersymmetry—just supersymmetry in general. However, the absence of confirmation of superpartner particles does undermine the strength of his extra-empirical arguments—particularly when he only adduces low-energy supersymmetry and the standard model of particle physics as being unambiguously in favor of them (38). Moreover, Dawid does not render explicit his procedure for calculating a prior probability based on this evidence, but it seems like one would be hard-pressed to attain a method that yields a sufficiently high probability from only one unambiguous case—given that low-energy supersymmetry seems to be a bust.

3.1.2 Dawid's MIA and the Base Rate Fallacy

The base rate fallacy (i.e., the statistical fallacy of erroneously concluding the likelihood of a particular outcome by ignoring the background prevalence or rate of an occurrence upon which it is dependent) has cropped up in the philosophy of science literature in discussions of Hilary Putnam's (1975) no miracles argument and Larry Laudan's (1981) pessimistic meta-induction argument—see Howson (2000) and Magnus and Callender (2003) for two noteworthy examples. I will not be evaluating the defensibility of accusations that Putnam's and Laudan's arguments commit the base rate fallacy, as this would be too discursive in light of the scope of this project; suffice to say, a precedent has been established for criticizing certain Bayesian inferences on these grounds. A stock example of the base rate fallacy—which will be used as a point of reference to expose the base rate fallacy that I contend lurks within Dawid's meta-inductive argument—is the administration of a police breathalyser test to ascertain if people are driving under the influence.

Consider a breathalyser test which has a 100% true-positive rate (i.e., if it were administered on 100 individuals whose blood alcohol concentration is greater than the legal limit, then it would detect that all individuals are intoxicated), and therefore, a 0% false-negative rate (since it would not fail to identify any of the inebriated people), as well as a 95% true-negative rate (i.e., if it were administered on 100 individuals whose blood alcohol concentration is below the legal limit, then it would register that 95 are not intoxicated), and therefore, a 5% false-positive rate (since it would incorrectly detect that the 5 remaining individuals are intoxicated when they, in fact, are not). The base rate fallacy occurs when one responds to the question: "what are the chances that an individual is intoxicated if the breathalyzer attests to this being the case?" by stating "that there is 95% chance," since there is only a 5% chance of a false-positive. However, this analysis neglects to consider how many drunk drivers there actually are in the statistical sample (i.e., the base rate). For example, if the drunk driving rate is 1% (i.e., if out of 1000 drivers only 10 are intoxicated), then the Bayesian probability that the driver is in fact drunk upon a positive test result is calculated in the following way:

$$P(D \mid B) = \frac{P(B \mid D)P(D)}{P(B)} \tag{1.40}$$

$$= \frac{P(B \mid D)P(D)}{P(B \mid D)P(D) + P(B \mid S)P(S)} \tag{1.41}$$

$$= \frac{(1.00)(0.01)}{(1.00)(0.01) + (0.05)(0.99)} \tag{1.42}$$

$$= 0.17 = 17\% \tag{1.43}$$

where $P(B \mid D)$, $P(B \mid S)$, $P(D)$, and $P(S)$ represent the breathalyzer's true-positive rate, the breathalyzer's false-positive rate, the probability that a randomly selected individual in the statistical sample is drunk, and the probability that a randomly selected individual in the statistical sample is sober, respectively. Now armed with this straightforward example of the base rate fallacy, we can press on to the analogous case—both conceptually and formally—of Dawid's MIA.

For Dawid's MIA, since it can be construed as a test of scientificity by way of limitations to underdetermination by determining whether a theory exhibits no alternatives and unexpected explanatory coherence, it is analogous to the breathalyzer test indicating that an individual is drunk; hence, a theory with these properties being empirically successful is analogous to an individual actually being drunk. Rather generously we can grant that the true-positive rate for accepted scientific theories possessing these characteristics is 100% (i.e., every empirically successful theory in the high-energy research program has these features), and therefore, a 0% false-negative rate (since there would not be a single successful theory without these features)—generously because, as mentioned above, the gauge field theory describing the Higgs Boson did not exhibit unexpected explanatory coherence; so we are already cognizant of at least one exception (though it seems likely that this it is not an isolated incident). Moreover, we can set the true-negative rate to be 75% (i.e., if there were 100 empirically unsuccessful theories in the high-energy research program, then 75 of them would not possess the properties of interest), and therefore, the false-positive rate would be 25% (since out of these 100 unsuccessful theories 25 would possess those properties); though, it is probably much higher than this since one of the central objectives of theory construction is to make progress on specific theoretical conundrums, thus insofar as a novel mathematico-physical theory achieves this it often—due to mathematics and physics both being highly interconnected spheres of knowledge—provide us with potential insights into other unresolved problems—even if the theory is ultimately a dud. Therefore, if one commits the base rate fallacy, and concludes that there is a 75% chance that a theory that exhibits no alternatives and unexpected explanatory coherence is a successful scientific theory, then an endorsement of the scientificity of string theory based on Dawid's MIA seems adequately cogent. However, if avoiding this snare means that Dawid's MIA loses much of its force, then his rationale for relying on it would become quite puzzling.

The pertinent question then is: what is the base rate of successful theories in the high-energy research program? If we suppose that the probability that a novel theory winds up an empirical success is 10% (i.e., out of a collection of 100 theories 10 will enjoy empirical success), then the Bayesian probability that a theory exhibiting no alternatives and unexpected explanatory coherence goes on to be an empirically successful scientific theory is the following:

$$P(S \mid M) = \frac{P(M \mid S)P(S)}{P(M \mid S)P(S) + P(M \mid U)P(U)} \tag{1.44}$$

$$= \frac{(1.00)(0.10)}{(1.00)(0.10) + (0.25)(0.90)} \tag{1.45}$$

$$= 0.31 = 31\% \tag{1.46}$$

where $P\ (M \mid S)$, $P(M \mid U)$, $P(S)$, and $P(U)$ represent the true-positive rate of using Dawid's MIA as a scientificity test, the false-positive rate of using Dawid's MIA as a scientificity test, the probability that a randomly selected theory is successful, and the probability that a randomly selected theory is unsuccessful, respectively. One might worry that 90% of theories in the high-energy research program being empirical dead ends is far too liberal an estimate; however, since Dawid does not spell out how much time must elapse before a theory without rivals qualifies as having no alternatives, it seems safe to assume that a suitable timeframe is that it must remain unrivaled until the next round of empirical testing (especially since this is the timeframe Dawid emphasizes in conversations concerning his extra-empirical arguments vis-à-vis limitations to underdetermination) (54).

This supposition renders the preceding successful theory estimate judicious because when the high-energy research program was in its nascence, there would have been a period characterized by rapidly alternating theory generation and testing as a new methodological arsenal was developed (largely heuristically) to address the implementation of state-of-the-art experimental technologies (e.g., particle accelerators) probing uncharted domains of the natural world; theory construction during this inchoate phase—in which rounds of empirical tests were more frequent—would have seen theories with no conceivable alternative between rounds, which were quickly demonstrated to be empirically inadequate or which were found post-experiment to have had alternatives (both of which satisfy our timeframe criterion)—given the preponderance of physics papers submitting newfangled theories (farfetched or conservative) in these early days of the research program, this seems like an inevitability. Furthermore, for reasons previously stated, many of these theories likely exhibited unexpected explanatory. Therefore, it looks like Dawid's focusing on cases where theories exhibiting our properties of interest have been successful (which is indicative of a mature research program that has outgrown its propensity for false starts) is due to an excusable recency bias since these discarded theories constructed during this primitive stage of the research program have received no publicity and are camouflaged by their obscurity. Accordingly, it appears that in order to offset this early upsurge in unsuccessful theories exhibiting our properties of interest and increase the probability that they ensure a theory's scientificity, many more cases of empirically successful theories with these properties would be required, and of course, nothing precludes instances of the former occurring within a mature research program; hence, this seems like a tall order. Moreover, if we take string theory's final theory claim seriously—and Dawid recommends that we do (more will be said about this shortly)—then augmenting the current evidence in favour of theories with these properties being empirically successful would be occluded—thereby freezing the probability that these properties ensure string theory's scientificity at approximately 31% (or lower); thus, if string theory does indeed describe reality, then it appears that Dawid's MIA can be of no help in establishing that.

3.2 The Retroactivity of Dawid's Extra-Empirical Arguments

Dawid maintains that extra-empirical arguments are an aspect of the canonical—that is, the empirically centric—scientific method and cites empirical confirmations of the standard model of particle physics as prominent examples of their utilization (63, 112-115). Moreover, he asserts that the MIA is intimately related to empirical corroboration to the point that it can be construed as the following empirical hypothesis in its own right, just at the meta-level (as it is a hypothesis about theories): that theories to which the NAA and UEA apply are empirically viable (36). Dawid admits explicitly that his extra-empirical arguments must pay obeisance to empirical corroboration since our confidence in the former is predicated upon the latter (58). Incorporating extra-empirical arguments as a preliminary attempt to limit underdetermination prior to empirical tests strikes me as a wholly benign practice, and that it has been exploited for this purpose in the above cases seems indisputable. However, there is a substantive difference between harnessing extra-empirical arguments as a guide for selecting those theories that are the best candidates for empirical success when experimental corroboration is close at hand and relying on them as a means of garnering evidence of a theory's scientificity in lieu of empirical confirmation, in that the former has a built-in safety net mitigating epistemic risk which the latter does not.

To illustrate the difference, we can consider three scenarios in which a funambulist (tightrope walker) must traverse a rope suspended over a canyon. In case 1), which is analogous to the canonical scientific method, previously successful tightrope walks would increase our confidence in their ability to safely complete this stunt (which is comparable to a theory that has successfully passed previous empirical tests). However, in this case, a net is placed beneath the tightrope on the off chance that he stumbles (which represents the possibility that a theory we have considerable confidence in is nevertheless refuted)—since in Bayesian terms, a probability of 100% is unobtainable for a theory (i.e., it can never be confirmed once and for all, but can always be refuted).

In case 2), which is analogous to the employment of Dawid's extra-empirical arguments with an empirical safety net (i.e., as a preliminary attempt to limit underdetermination within the canonical scientific method without significantly altering it), an individual is appointed to select between two individuals: a competent funambulist and an untrained funambulist enthusiast, each of which will perform the stunt if selected (where the former represents the outcome in which the extra-empirical arguments successfully predict a theories scientificity via limitations to underdetermination, and the latter, the outcome in which the extra-empirical arguments do not, because the properties of interest which the theories exhibited had no bearing on limitation to underdetermination and this putative relationship was merely coincidental). Suppose further that this talent evaluator's rate of selecting the appropriate individual in situations such as these is 97% (which represents our confidence in extra-empirical arguments based on prior instances of their empirical success) and that the talent evaluator assigns to the chosen individual a 97% chance of completing the stunt (which represents the given theory's (e.g., string theory's) scientificity and—due to the nested Bayesian analysis—is the same as our confidence in the extra-empirical arguments). However, since, in this case, empirical corroboration is available, if our talent evaluator makes the incorrect selection, our funambulist enthusiast will be caught by the net (i.e., our empirical test will reveal that our extra-empirical arguments missed the mark—thereby shielding the research program from stagnation). Moreover, if our talent evaluator chooses the correct individual, but they nevertheless falter (as there is a 3% that they will), then the net will also keep them out of harm's way (which represents the eventuality that the theory is empirically refuted despite the evidence via extra-empirical arguments in its favor).

In case 3), which is analogous to a scientific method wherein extra-empirical arguments are invoked to establish a theory's scientificity when empirical corroboration is unavailable, the empirical safety net is removed. Consequently, since the confidence we have in our talent evaluator selecting the appropriate individual is grounded in empirical evidence, it can never be 100%; accordingly, it is always possible that the funambulist enthusiast is selected in which case they will plummet without a safety net to break their fall (which represents the possibility—since

Dawid's extra-empirical arguments are so too grounded on empiricism—that they had no bearing on limitations to underdetermination and were merely coincidental which absent an empirical safety net leaves the research program vulnerable to stagnation). Furthermore, in this case, there always remains the possibility—since the probability assigned to the funambulist's completion of the stunt must be less than 100%—that they shuffle off this mortal coil (which represents the possibility that the theory is ultimately empirically refuted). Therefore, since case 2) is not liable to the epistemic risk that case 3) is, contrary to what Dawid implies, endorsing case 2) does not give us reason to accept 3)—although instances of case 2) could increase the probability that extra-empirical arguments contribute to limitations to underdetermination, this would not mitigate the epistemic risks incurred by case 3).

Now one might think that in case 3) a theory supported by extra-empirical arguments being susceptible to empirical refutation is forgivable since, after all, even theories that have an abundance of empirical support are not immune to this eventuality. However, in case 3) the situation is potentially far worse, as I have shown with my counterfactual luminiferous aether universes (in the second chapter) in which a paradigm shift is forestalled due to extra-empirical arguments conferring scientificity upon a theory that does not describe reality, since in such scenarios the research program stagnates for as long as contradictory evidence exceeds our grasp. Nonetheless, we now have an independent reason for being reluctant to condone case 3): due to empiricism's epistemic ceiling, even if we could amass sufficient empirical evidence to be confident in an extra-empirical method, the null hypothesis: that the theoretical features that it picks out being connected to limitations to underdetermination is illusory, remains a distinct possibility and the longer the interval between rounds of empirical testing the more worrisome the threat of stagnation becomes (naturally, the apotheosis of angst occurs when extra-empirical arguments are associated with a final theory claim). Another way of cashing out this independent misgiving regarding an extra-empirical method is by considering the decided advantage of the canonical scientific method. In particular, unlike the case of an extra-empirical method in which all evidence in support of it could be rendered irrelevant upon the empirical corroboration of the null hypothesis (since our confidence in the method and our confidence in a theory's scientificity, as per this method, is one and the same), the methodology of empiricism is assumed to be uncontroversial from the outset (i.e., it need not substantiate itself via a more fundamental method); hence, if a theory which has accrued considerable empirical corroboration is nevertheless refuted it is not discarded wholesale, rather, a proportion of its content is preserved through theory change such that this empirical corroboration is not worthless; in the words of Popper, "[d]e mortuis nil nisi bene [of the dead nothing but good is to be said]: once a theory is refuted, its empirical character is secure and shines without blemish" (240). Nothing akin to this cumulative nature can be found in an extra-empirical method—if it leads us astray, this can only be net negative.

If my foregoing arguments have been persuasive, then it appears that Dawid's extra-empirical method cannot be epistemically equivalent to the canonical scientific method. However, on the one hand, it seems that this is his ambition, as he asserts that there is no principled difference between these methods, and our lack of confidence in the former is simply an arbitrary empirical fact about our world (58). Specifically, Dawid argues this by imagining a world in which every successful scientific theory was without an alternative within a research program that has lasted thousands of years. In this scenario, he contends, our trust in a candidate theory also exhibiting no alternatives would be equally as strong as our trust in a theory with comparable empirical corroboration. (However, given my argument above, I see his hypothetical world and raise him the nearby possible world in which, defying all odds, every single one of those theories has alternatives that remain unbeknownst to the physicist of this world, such that the fact that they exhibited this feature had no bearing on limitations to underdetermination and in which the latest theory perhaps pertaining to flight, which possesses this characteristic, does not describe reality causing a tragic plane crash; how could we know prima facie that we are not in this world based on the putative success of the extra-empirical arguments prior to this point?) Whereas on the other hand, as seen above, Dawid underscores his extra-empirical method's subservience to the canonical scientific method. Accordingly, there appears to be tension in his view as the desiderata of his extra-empirical method seem to pull in opposite directions; there is a sense in which he wants to have his cake and eat it to—but empiricism is not flexible enough to accommodate this. Namely, it seems that Dawid requires i) that his extra-empirical method be epistemically equivalent to the canonical scientific method to mitigate the epistemic risk relevant to case 3) (i.e., when extra-empirical arguments are appealed to during long intervals between rounds of empirical testing or in light of final theory claims) and avoid my repugnant trilemma (from the second section of the first chapter), yet he also wants ii) to retain their subordination to empiricism—but he cannot have both. If he abandons i), then since empiricism cannot furnish his methodology with epistemic equivalence, he would have to restrict the application of his method to case 2) to avoid the epistemic risk intrinsic to case 3). In this situation, almost all of my criticism would become immaterial; however, since string theory falls under case 3), I presume Dawid would find this option highly unsatisfying. Ergo, it seems Dawid must give up ii), and since empiricism can be of no avail, another avenue for furnishing his extra-empirical method with epistemic equivalence must be pursued; though Dawid provides us with no hint as to what this alternative avenue might be—if indeed it exists. Furthermore, at least one of string theory's final theory claims seems to necessitate a method that is epistemically superior to the canonical scientific method; thus, if Dawid's extra-empirical method is meant to fulfill this role, then obviously it cannot be empiricism's subordinate.

3.3 Final Theory Claims

Both of string theory's final theory claims are contingent upon Dawid's extra-empirical arguments; therefore, much of my work in demonstrating their untenability is already done. Nonetheless, I will briefly discuss the two final theory claims that Dawid mentions to reveal the ways in which they are connected to his extra-empirical arguments. The first claim pertains to string theory's intratheoretical postulation of a minimal length scale (i.e., that due to T-duality, the probing of distances below a particular lower bound is predicted to correspond to a larger measurable distance—it boomerangs back so to speak—such that this lower bound serves as an ontic boundary beyond which no physical entities exist) and the inability to differentiate between local and global limitations to underdetermination and is argued for in the following way (Dawid 133, 135). Dawid maintains that ordinarily, a distinction can be made between limitations to local underdetermination (i.e., limitations to distinct theories that fit the empirical data for a finite succession of empirical tests) and limitations to global underdetermination (i.e., limitations to distinct theories that fit all possible data) since theories typically contain a threshold length (or energy) which they do not make predictions beyond or above which they remain agnostic. However, according to Dawid, because string theory does not have a length scale cut-off, the local/global underdetermination demarcation is dissolved so that if extra-empirical arguments limit local underdetermination, they commensurately limit global underdetermination (136-139). Though I think Dawid makes a compelling case for limiting global underdetermination, since the same extra-empirical arguments that support the local variety also support the global variety, insofar as they undercut them in the local context they do so in the global context as well.

The second final theory claim is based on the fact that string theory is a “highly predictive” “structurally unique” theory; where a theory is “structurally unique” just in case it does not have any free parameters and thus a variety of models (i.e., one cannot fix parameters based on empirical data) and “highly predictive” just in case “the number of its physically possible ground states is significantly lower than the number of distinct values which could be distinguished by a precision measurement on a continuous free parameter” (Dawid 142, 144). However, though it is the case that the parameter values of every string theory ground state are completely determined by string dynamics, since there may be an infinite number of ground states in the so-called landscape (as discussed in the first chapter), there does not appear to be a meaningful difference between conceptualizing them as free parameters or determined parameters which can take on a continuous set of values. Moreover, if the number of string theoretic ground states is indeed infinite, then string theory would fail to meet the criterion of being highly predictive. Nonetheless, if we grant that string theory is a highly predictive structurally unique theory, then Dawid argues that since they are so uncommon and have a far narrower collection of data sets with which they would be in accordance, it is likely that if evidence for their scientificity could be acquired, that they would not be superseded (145). Although as Dawid acknowledges, since empirical testing is currently infeasible, our only means of procuring evidence for string theory’s scientificity is via his extra-empirical arguments. Thus, once again, insofar as my counterarguments have undermined the cogency of these extra-empirical arguments, they proportionally reduce the plausibility of this final theory claim.

However, there is a deeply problematic aspect of string theory's final theory claims that Dawid is remiss in addressing. Namely, that empiricism can never confirm a theory outright to which Popperian falsificationism, Piercian pragmatism, and fallibilism in general attest; hence, a theory's final theory claim must always remain dubious—as Popper states: "even the greatest physicist can[not] anticipate the secrets of nature" (242). In Bayesian terms, the posterior probability of a theory can never obtain a value of 100%, and even if considerable evidence were to be amassed in favor of string theory, it would not surpass the probability that it will be refuted based on the historico-empirical evidence which has seen every single scientific theory so far superseded. Accordingly, if Dawid wants his extra-empirical method to convince us of string theory's final theory claims, then it seems like it would need to be of a greater epistemic caliber than empiricism.

Conclusion

Assuming that my counterarguments to Dawid's extra-empirical arguments throughout this work have been compelling, I will have raised reasonable doubt against string theory's scientificity. In the wake of this, I would like to propose an alternative explanation for string theory's lack of empirical corroboration. In particular, I want to repurpose my luminiferous aether historical counterexample from the second chapter and the parallels I drew between it and the high-energy research program with regard to string theory and use it to buttress the positive account that the way forward in the latter case is also to challenge our ontic presuppositions. To that end I will begin by making two other comparisons between them.

Firstly, prior to Einstein's streamlining of the overarching mathematico-physical framework associated with the luminiferous aether different models were developed with slightly different specifications of its behaviour, analogously in the case of string theory different types have been posited (e.g., type I, type IIA, M-theory, etc.). (M-theory claims to have unified the other types, but as we saw in the first chapter it does so by adding an additional spatial dimension; therefore, since it predicts that the universe has a different dimensionality than the others, it must be considered a separate type). Secondly, though related to the first, none of the various aether models nor string theory models were/have been experimentally corroborated—and as I argued in the third section of chapter two, the absence of experimental evidence of supersymmetry at the LHC parallels Michelson and Morley's null interferometer results in certain important respects. These two comparisons in combination with the others I have explicated in the second chapter should give us sufficient reason to entertain the possibility that the high-energy research program is on the cusp of a paradigm shift just as the luminiferous aether research program was. Moreover, if this were indeed the case, then string theory would not be without alternatives since an ontic-presupposition reform engendering a paradigm shift would necessarily produce a unique theory. Therefore, insofar as this possibility is plausible and has not been exhausted, Dawid's no alternative argument in favor of string theory is compromised.

Accordingly, I would like to advocate for an interdisciplinary collaboration among historians and philosophers of physics and physicists who would be charged with the task of tracing string theory's historical footprints with the hopes of identifying the ontic presupposition(s) responsible for string theories deviation with mind-independent reality; it seems quite unlikely that one individual would be capable of completing this task in view of the increasing specialization of academic disciplines—polymaths have gone extinct. Although this is a daunting task, to say the least, given the complexity of contemporary physical theories (i.e., the extraneous mathematical baggage that they may have accrued due to erroneous ontological postulates may be considerable), if we are on the verge of a paradigm shift, then this would be our only means of retethering the research program to mind-independent reality. Until this avenue has been thoroughly explored, our insouciance in regard to it just might be halting the scientific enterprise.

The central aim of this project has been to demonstrate the defeasibility (in the epistemological sense) of Dawid's extra-empirical arguments in favour of the scientificity of string theory. I have attempted to undermine the trustworthiness of Dawid's UEA by using the historical case study of the luminiferous aether to reveal that it could have been employed to make as compelling a case for the scientificity of LAMs as it can currently be employed to make for the scientificity of string theory, even though in the latter case it would have endowed a theory without empirical contact with scientificity of which it was undeserving. Regarding

Dawid's MIA, I have argued that a Bayesian analysis shows that Dawid appears to be guilty of committing the base rate fallacy and that the lack of confirmation of supersymmetry at the LHC has rendered the posterior probability associated with the MIA lower than anticipated, both of which reduce the cogency of this argument. To address Dawid's NAA, I have endeavored to recast the historical case study of the LAMs and the parallels that I drew between their research program and the high-energy research program of physics to support the plausibility of the following alternative explanation for the absence of empirical corroboration for string theory: that similar to the LAMs case, a presuppositional reform is in order which will ineluctably produce a theory which is conceptually distinct from string theory.

Moreover, I have tried to show that since string theory's final theory claims are grounded on Dawid's extra-empirical arguments, then insofar as the preceding counterarguments are successful, they commensurately undercut the plausibility of these claims. This then leaves Dawid vulnerable to the criticism that altering the scientific method to include extra-empirical arguments sets a dangerous precedent in the field of physics since they could be utilized to furnish theories with scientificity that do not accurately describe the natural world—thereby pre-empting their warranted dismissal which would cost the field of physics dearly even if string theory were to be empirically successful. Lastly, I have argued that the implementation of Dawid's extra-empirical arguments internal to the canonical scientific method (i.e., an empirically forward scientific method) within the high-energy research program is disanalogous to the way in which he proposes that it be used in relation to string theory (i.e., as part of an extra-empirically modified scientific method); namely, the latter is not merely a difference of degree, but a difference in kind since it is susceptible to significant epistemic risk that the former is not, and hence, evidence of the former does not substantiate the latter. Furthermore, I have claimed that the only way for Dawid's extra-empirically modified scientific method to mitigate this epistemic risk and dodge my repugnant trilemma is if it were to acquire some means of attaining epistemic equivalence to the canonical scientific method (though not via empiricism). However, I have argued that if this were the case, then physicists would be perversely incentivized to construct and pursue potentially non-falsifiable theories congenial to an extra-empirically modified scientific method as ardently as falsifiable theories amenable to experimental tests. Therefore, if I have done justice to this matter, then the counterarguments I have levelled against Dawid's extra-empirical arguments, coupled with the sobering fact that empiricism's faltering vis-à-vis string theory might be due to an overdue presuppositional reform, have demonstrated the shortcomings of extra-empirical justifications for string theory.

Bibliography

Anderson, P. (2005)*: What Do You Believe Is True Even Though You Cannot Prove It?*, *Edge.org*. Available at: https://www.edge.org/response-detail/11811 (Accessed: 07 July 2024).

Bergström, L. (1993). "Quine, Underdetermination, and Skepticism," *Journal of Philosophy*, 90(7), pp. 331–358. doi:10.2307/2940791.

Darrigol, O. (1995). "Henri Poincaré's Criticism of Fin De Siècle Electrodynamics." *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, vol. 26, no. 1, pp. 1–44., https://doi.org/10.1016/1355-2198(95)00003-c.

Dawid, R. (2013). *String Theory and the Scientific Method*. Cambridge: Cambridge University Press. doi:10.1017/CBO9781139342513

Fischer, E. (2023). "The Promise of Supersymmetry', *Synthese*, 203(1). doi:10.1007/s11229-023-04447-1.

Ginsparg, P. and Glashow, S. (1986). "Desperately Seeking Superstrings?", *Physics Today*, 39(5), pp. 7–9. doi:10.1063/1.2814991.

Granek, G. (2000). "Poincaré's Contributions to Relativistic Dynamics." *Studies in History and Philosophy of Science Part B: Studies in History and Philosophy of Modern Physics*, vol. 31, no. 1, pp. 15–48., https://doi.org/10.1016/s1355-2198(99)00027-1.

Hossenfelder, S. (2020). *Lost in Math: How Beauty Leads Physics Astray*. New York, NY: Basic Books.

Howson, C. (2000). *Hume's Problem: Induction and the Justification of Belief*. Oxford: Oxford University Press.

Janssen, M. (1995). *A Comparison between Lorentz's Ether Theory and Special Relativity in the Light of the Experiments of Trouton and Noble*. UMI, 1995.

Janssen, M. and Stachel, J. (2004). “The Optics and Electrodynamics of Moving Bodies,” Max Planck Institute for the History of Science, Preprint 265.

Janssen, M. et al. (2007). *The Genesis of General Relativity*. Dordrecht: Springer Netherlands.

Kachru, S. et al. (2003). “De Sitter Vacua in String Theory,” *Physical Review D*, 68(4). doi:10.1103/physrevd.68.046005.

Ladyman, J. et al. (2014). *Every Thing Must Go: Metaphysics Naturalized*. Oxford: Oxford University Press.

Laudan, L. (1981). “A Confutation of Convergent Realism,” *Philosophy of Science* 48: 19–49.

Lorentz, H.A. (1895). *Versuch einer Theorie der electrischen und optischen Ersche-inungen in bewegten Körpern*, Leiden. E. J. Brill. B.G. Teubner, Leiden.

Lorentz, H.A. (1904). “Electromagnetic Phenomena in a System Moving with Any Velocity Smaller than That of Light,” *Proceedings of the Royal Netherlands Academy of Arts and Sciences*, 6, 809-831.

Magnus, P. D. and Callender, C. (2004). “Realist Ennui and the Base Rate Fallacy,” *Philosophy of Science* 71: 320–38.

McCormmach, R. (1970). “H. A. Lorentz and the Electromagnetic View of Nature.” *Isis*, vol. 61, no. 4, pp. 459–497., https://doi.org/10.1086/350681.

Miller, A. (1998). *Albert Einsteins Special Theory of Relativity: Emergence (1905) and Early Interpretation (1905-1911)*. Springer.

Mummidi, V. S. et al. (2023). “Supersymmetry: A decade After Higgs Discovery,” *Indian Journal of Physics*, 97(11), pp. 3315–3326. doi:10.1007/s12648-023-02812-x.

Obied, G. et al (2018). “De Sitter Space and the Swampland.” arXiv:1806.08362

Poincaré, H. (1900). “La Théorie *de* Lorentz et le Principe *de* Réaction,” *Archives Néerlandaises des Sciences Exactes et Naturelles, 252–278,* p. 278

Poincaré, H. (1905). “On the Dynamics of the Electron,” *Comptes Rendus*, 140, 1504-1508.

Popper, K. (1972). *Conjectures and Refutations: The Growth of Scientific Knowledge*. London: Routledge & Kegan Paul.

Putnam, H. (1975). *Mathematics, Matter and Method*. Cambridge: Cambridge University Press.

Quine, W.V. (1970). “On the Reasons for Indeterminacy of Translation,” *The Journal of Philosophy*, 67(6), p. 178. doi:10.2307/2023887.

Read, J. and Le Bihan, B. (2021). “The Landscape and the Multiverse: What’s the Problem?” *Synthese* 199, 7749–7771. https://doi.org/10.1007/s11229-021-03137-0

Resnick, R. (1968). *Introduction to Special Relativity*. Wiley.

Siebert, H. (2001). *Der Kobra-Effekt: Wie man Irrwege der Wirtschaftspolitik vermeidet*. Stuttgart: Deutsche Verlags-Anstalt.

Smolin, L. (2008). *The Trouble with Physics: The Rise of String Theory, the Fall of a Science and What Comes Next*. London: Penguin.

Susskind, L. (2011). “String theory,” *Foundations of Physics*, 43(1), pp. 174–181. doi:10.1007/s10701-011-9620-x.

Woit, P. (2004). *Not Even Wrong*. New York, NY: Peter Woit.

Yau, S.-T. and Nadis, S. (2010). *The Shape of Inner Space: String Theory and the Geometry of the Universe’s Hidden Dimensions*. New York: Basic Books.