Fundamentalists:

Social Construction of Physics at a Research Institution

Milo Beckman

December 17, 2018

Abstract

Academic physicists and philosophers of physics subscribe to a collection of individual and institutional beliefs about a collection of truth-claims which I will call the physics canon. This paper explores the entry of new truth-claims into the physics canon, and the ways in which the processes of presentation and contestation are mediated by sociological factors irrelevant to the objects of study in physics. The focus is on ontology, the set of objects considered "real" or "fundamental" within a model of particle physics. In particular, the case study of quantum mechanics is used, because it is a case where there is no consensus among high-ranking physicists as to the "correct" ontology.

Methodologically, this paper includes data primarily from direct observation of presentation and contestation of interpretations of quantum mechanics taking place between high-status physicists and philosophers of physics at a research institution which I will call University X. Many of the theoretical moves are informal and to some extent incomplete, and it is hoped that additional observation and development may lead to a stronger argument.

I. THE PHYSICS CANON

In an official report issued by the Stanford Linear Accelerator Center, a curious turn of phrase, not atypical of the form, is used:

> There are several experiments, which are either already or will be soon producing B physics: BaBar, Belle, CDF, LHC-b, and BTeV. [1]

What is physics that it can be produced with the aid of a machine? This much is uncontroversial: there is some process which takes place across a number of sites—particle accelerators, research institutions, conference halls—that results in a body of work generally referred to by participants and outsiders alike as "physics." The precise nature of this body of work is the subject of many strongly held individual and societal beliefs, particularly in relation to notions of truth, order, origin, and significance. As such, the term "physics" is often taken to describe an object or idea not fully accessible (or not *yet* fully accessible) to humans, an idealized and fundamental "physics" of which the present body of work represents merely an approximation. This paper directs its attention to the actual, present body of work, rather than the hypothetical object which it may aim to reproduce. The term *physics*,[1] as used in this paper, refers to the collective body of work that is produced by self-described physicists, holding relevant degrees from accredited institutions of higher education and research, in their capacity as physicists.

Producers		*Consumers*
theoretical physicists		engineers
experimentalists	$\longrightarrow$ physics $\longrightarrow$	high school students
philosophers of physics		physics majors
science communicators		military
		aspirational reading

Physics consists of a vast collection of textbooks, journal articles, lectures, lecture notes, lecture videos, general-interest "aspirational reading" books, documentaries, science journalism, edutainment videos, blog posts, Wikipedia articles, question-and-answer threads on online forums, homework assignments, and exams. In all cases,

[1] Throughout this paper, terms in quotation marks indicate an observed usage, while italicized terms (typically accompanied by a definition) indicate a usage specific to this paper.

these materials of physics are created and delivered with an orientation of teaching or explanation. That is to say, all parties to these materials agree to the premise that the producer of such materials has a greater authority than the consumer to determine or ascertain what is or is not considered physics. This linear scale of authority, which we will call *physics authority*, is a primary focus of §4; for now it suffices to say that there is general consensus among physicists of the highest rank as to what is "good physics."

Consequently, the materials of physics which are accepted as good by high-ranking physicists can be thought of as windows into a single underlying *physics canon*. An individual textbook, for instance, will typically focus on a single subfield of physics, will target an intended audience of a specific sort ("introductory undergraduate," e.g.), and will employ a literary style particular to its author or authors. But in order to be used by professors for instruction, the textbook must be considered by high-ranking physicists to accurately present some portion of the physics canon. Similarly, while the popular online question-and-answer forum Physics Stack Exchange displays answers contributed by users of any educational background, the "best answer" selected by users, indicated by a green check-mark and positioned directly below the question, is typically contributed by one of a small handful of "power users" with advanced degrees in physics, indicated by "reputation points."

At heart, then, the physics canon consists of a set of claims considered true. This is the central thread uniting all the various materials referred to as physics: they agree on the facts. (Notable exceptions to this claim are discussed later in this section.) There are other notable commonalities across materials of physics, such as a conventional set of terminological definitions and mathematical notations; a number of "canonical examples" which are almost always used to introduce a given topic; and a shared physics lore consisting of a largely consistent cast of physicists, experiments, and conferences considered significant to the development of theory. These additional commonalities, however, all exist in service of the underlying accepted truths. Throughout this paper we will focus on the physics canon as this set of truth-claims, discussing the canonical definitions, notations, examples, and historical narratives only when they are seen to influence the development of these canonical truth-claims.

It is no secret that the truth-claims which comprise the physics canon are not stable over time. Nearly all physics taught prior to 1905 is today considered false (or, at best, "not quite true") by high-ranking physicists; the adjectives "classical" and "Newtonian," which describe these formerly dominant models, are considered insults when applied to theories from the post-1930s era of "modern physics." In fact, contemporary physicists broadly agree that the presently dominant model of particle physics, called the "Standard Model," is not correct. While it makes remarkably accurate predictions of most small-scale physical phenomena (for instance, the magnetic field produced by an electron, which has been experimentally verified to 10 decimal places) it is unable to explain a number of observed phenomena (for instance, the tendency of neutrinos to oscillate between three distinct "flavor states"). Higher-level courses in particle physics acknowledge these flaws and speak of "physics beyond the Standard Model," and yet, presently dominant textbooks generally teach the Standard Model in language that implies it is true.

Given this situation, it is crucial to note at this time that the actual validity of truth-claims in the physics canon, by any metric or assessment program of validity, will *not* be considered in this paper. I follow the theoretical orientation of Philip Abrams [2], who recommends that sociologists of the state study not the state-object itself but the relations of persons and institutions to the state-idea. Similarly, the objects of study in this paper are not physical objects and phenomena themselves, but the patterns of individual and institutional belief about physical objects and phenomena collectively called the physics canon. I will not at any point attempt to analyze the truth-claims which comprise the physics canon on their proper merits.

Methodologically, the data used in this paper derives from direct observation and experience of high-ranking physicists at a research institution which I will call University X. As a graduate student in a physics-oriented program at University X, I have been given access to a number of exclusionary spaces in which elements of the physics canon are presented and contested. In particular, evidence is incorporated from a small seminar on "advanced topics" in the philosophical foundations of physics, taught by A, who has authored a textbook on the same topic; an undergraduate physics course taught by B, a highly prominent professor who also writes and lectures for general audiences; a higher-level physics course intended for third-year Ph.D. candidates in physics, taught by C, an experimental physicist affiliated with the Large Hadron Collider; private conversations and correspondence with D, a visiting professor who also writes for popular audiences; private conversations with E, a fellow graduate student who received an undergraduate degree in physics from University X; and other observations and interactions inside the physics building and in particular the area reserved for graduate students in physics. While the particular claims considered true by each self-described physicist differed somewhat, the general attitude toward physics truth-claims was nearly identical across the board, and is taken to be representative of self-described physicists at prominent research institutions in the West.

Truth-claims in physics can broadly be divided into the two categories of *ontologies* and *laws*. A physical ontology consists of a set of objects or object-types considered "real" or "fundamental," as well as a list of "fundamental" or "basic" properties that each object may have. Each property must be expressible mathematically—for instance, (under a certain physical ontology) the property of spin must have a half-integer value such as $-\frac{1}{2}$, and the property of position must take the form of a 3-vector such as $\langle 0, 12, -3 \rangle$. A physical law is a mathematical constraint on the properties of a fundamental object or a set of fundamental objects, effectively constraining the possible "legal" behavior of a system of objects. All objects not included in the fundamental ontology are analyzed as composite objects whose properties and behaviors must be (in theory) derivable from the "lower-level" properties and laws. Such composite objects excluded from the fundamental ontology are referred to as "non-fundamental," "virtual," "emergent phenomena," or disparagingly as "illusions," "approximations," or "commentary." It is common to speak of the objects of an ontology as the only things which exist, as in the claim, "Particles aren't real; all that exists is the wavefunction, and its fluctuations sometimes look like particles."

There is no single canonical physical ontology; rather, there are several ontologies arranged in an implicit hierarchy. The objects described as real and the laws described as absolute depend on the audience being taught. The audience with the lowest physics authority, high school students, is granted access only to the ontology with the least esteem among high-ranking physicists: classical/Newtonian physics. As consumers of physics move further up the hierarchy, becoming undergraduate or graduate students studying physics, they are taught progressively more "advanced" or "fundamental" physics. In practice, each new tier of ontology deals with objects physically smaller than those of the previous tier; the fundamental laws of the previous tier are now reframed as common patterns of behavior of composite objects whose atomic parts, the student is now told, are truly fundamental. This reveal is typically made with the language of debunking or mythbusting: "When you were an undergraduate, they told you that [—]. Well, they lied. In reality, ..."

The physics canon thus consists of multiple mutually contradictory components, not all of which can be considered true at the same time. The focus of this paper is on the highest-level (which is to say, physically smallest) ontologies in the physics canon—the truth-claims which high-ranking physicists themselves believe. Additionally, the focus is on physical ontology, the models of what is real and what is true, rather than the mathematical formalism resulting from an ontology or the experimental predictions resulting from a mathematical formalism. Lastly, in a final narrowing of focus, we will examine only the process of *entry into the canon*—how a newly proposed fundamental onotology is presented and contested—without exploring the institutional processes which maintain and propagate an ontology once it has entered the physics canon.

In §2 I will introduce the case study of quantum mechanics, a mathematical formalism considered by many high-ranking physicists to be fundamental (or nearly so), and describe the difficulties that the physics community has had in associating a single coherent ontology to quantum mechanics. In §3 I will describe the process by which a physicist or philosopher of physics proposes a new ontology for entry into the canon, using the case study of interpretations of quantum mechanics. This process of presenting and contesting ontology is influenced by a number of social, cultural, and aesthetic conditions which are taken as exogenous for the purposes of §3. The bulk of the theoretical content lies in §4, which turns to these seven social, cultural, and aesthetic conditions, exploring each condition as it exists in practice at University X and, by extension, at many research institutions in the West. While I forego an explicit thesis statement, the evidence presented in §3 and §4 should suggest that the set of ontological claims considered true by high-ranking physicists at a given time are influenced by sociological factors unrelated to the objects which they study.

II.
CASE STUDY: INTERPRETATIONS OF QUANTUM MECHANICS

Of all the subfields of physics, quantum mechanics makes an ideal candidate for studying the proposal and contestation of physical ontology for two reasons. First, quantum mechanics is considered a "fundamental" field. Its mathematical formalism describes and predicts the behavior of objects such as electrons and photons which have never been observed to decay into smaller[2] components and have never been subdivided in high-energy laboratory experiments. As such, many fundamental physicists believe

[2]The world "smaller" is imprecise; strictly speaking, these objects are not formally assigned a size.

that quantum mechanics (or at least many of its key features) is "true" in a way that other subfields, such as Newtonian mechanics or Maxwellian electrodynamics, are not. Thus disputation of ontology in quantum mechanics is internally viewed not merely as a matter of how best to teach or intuitively characterize phenomena, but instead a debate over what the veritable out-in-the-world nature of reality is.

Second, quantum mechanics is notorious for its resistance to ontology. The mathematical formalism of quantum mechanics involves a function ψ, which takes as input a $(3n + 1)$-dimensional vector and produces as output an imaginary number. The outcomes of experiments involving certain particles are then predicted by computing an integral of $|\psi|^2$, a strictly mathematical process which assigns a numerical value to each possible experimental outcome. For reasons that are not known, this numerical value corresponds exactly to probability: if the number 0.7863 is assigned to an outcome, and the identical experiment is repeated millions of times, that outcome will be observed precisely 78.63% of the time. The empirical validity of this bizarre mathematical method has been repeatedly corroborated by new and different experiments, and the predictions of quantum mechanics have been used to derive many of the laws of chemistry, but physicists have not reached a consensus as to the correct story to tell about why such a pattern of phenomena should be observed, nor even what the "wavefunction" ψ, its fundamental object, is.

In choosing quantum mechanics as my case study, I am subscribing to the notion that complex processes can often be better understood by focusing on circumstances in which they have failed. An analogy can be made to research in neuroscience which attempts to understand the typical functioning of the brain by investigating the causes and mechanisms of neurological disorders; or to sociological treatments of the state such as Theda Skocpol's *States and Social Revolutions* which focus on revolutionary conditions in which the typical functioning of the state ceases. The foundations of quantum mechanics is a case where the typical processes of building consensus around physical ontology have broken down.

Typically, a new experimental result or pattern of experimental results can be simply incorporated into existing theoretical models with a novel theoretical "mechanism." An example is illustrative. The Standard Model of particle physics as originally proposed in the mid-20th century predicted a certain type of symmetry in nature known as CP symmetry, which was later found to not be experimentally accurate. In the subsequent years a series of mechanisms were proposed that slightly modified the Standard Model, introducing new adjustible paramters, that could explain the observed asymmetry. A proposal of Makoto Kobayashi and Toshihide Maskawa introduced three new parameters and an object called the CKM matrix, which could be used to theoretically predict the observed asymmetry. Subsequently, two large and expensive experimental apparati were constructed to test other predictions of this "CKM mechanism"; after over 10 years of data collection, the experiments produced results consistent with this mechanism's predictions (under certain parametrizations) and were thus closed, reporting that "All main goals have been reached... results are consistent each other *[sic]* and consistent with the SM [Standard Model] predictions" [3]. As indicated by this language, the CKM matrix is today considered an integral part of the Standard Model, taught in introductory textbooks as though it had been theorized simultaneously with the rest of the model.

By contrast, the mathematical formalism of quantum mechanics was conspicuously impossible to retrofit into the existing models of "classical" physics. Every existing model up until this time had assigned a definite position to each particle; the new formalism instead assigned only probabilities. Thus the old ontology was abandoned, not because new experimental results refuted it (this is common) but because the theoretical mechanism proposed to explain the new experimental results could not be slotted into the existing ontology. Nearly a century later, with the mathematical formalism well-developed and widely taught, there is still no consensus as to the "correct" ontology.

A proposed interpretation of quantum mechanics must do three things. First, like any ontology, it must propose a set of fundamental objects and their mathematical properties as well as a set of laws which constrain their behavior. Second, it must include a mathematical demonstration that this fundamental ontology leads to the exact same empirical predictions as the “textbook QM” that is currently taught in universities and used experimentally. Third, it must propose answers to numerous canonical “puzzles” in the philosophy of physics literature, such as the double-slit experiment, the delayed-choice quantum eraser, and the EPR paradox.

There are many possible ontologies that satisfy these constraints. This uncontroversial claim—that multiple theoretical models can be used to explain any set of experimental data—is not itself sufficient to lead to crisis; for instance, there are certainly alternatives to the CKM mechanism that could have explained the observed results equally well. The curious situation for quantum mechanics arose because the first theoretical mechanism which successfully satisfied the three constraints was catastrophically unappealing to physicists and philosophers of physics. This proposal, the Copenhagen interpretation, held that particles themselves existed only as waves of probability until they were observed by humans; that is, this interpretation *included the human observer as part of the fundamental ontology.*

In the decades since, while the Copenhagen interpretation is still used as a heuristic “rule of thumb” for making experimental predictions, physicists and philosophers of physics have attempted to erase this fundamental subjectivity (in physics parlance, “observer-dependence”) by proposing new interpretations of quantum mechanics. The following sections describe this process of proposal in further detail.

III.
PRESENTATION AND CONTESTATION OF PHYSICAL ONTOLOGY

In this section I will outline the process by which an interpretation of quantum mechanics is proposed for entry into the physics canon and subsequently debated by physicists and philosophers of physics. The process is by no means uniform, but evidence is drawn from numerous proposed ontologies including two interpretations which are typically taught in introductory courses on philosophy of quantum mechanics (Bohm's interpretation, and GRW) as well as two recent interpretations that have not received wide acceptance (Newtonian QM, and a variant on an existing theory proposed by D, the visiting professor introduced in §1). Throughout this discussion, several social, cultural, and aesthetic conditions which play a role in the success or failure of an ontology are mentioned but treated as exogenous, to be looked at in further detail in §4.

I have divided the process into two distinct stages, presentation and contestation, though both stages involve elements of the other and there is not in reality a sharp division between the two. I have had more access to the former stage, presentation, and so the discussion of the latter stage is relatively underdeveloped at present.

In the stage of presentation, a physicist or philosopher of physics who we will call the *proponent* ideates and organizes his[3] proposal, completes all requisite calculations, and discusses the proposal with peers, culminating in the eventual publication of the proposal in a peer-reviewed journal. These steps taking place prior to first publication are surely very significant, and a paragraph will be spent discussing the process of ideation in particular. Unfortunately, this analysis must be largely speculative, as it is difficult to access these private processes without interviewing a proponent of an interpretation of quantum mechanics. The majority of the analysis of the presentation stage will focus on the publication itself, which is quite easily accessible, and in particular the features of this first published article which contribute to the proposal's early

[3] In every case that I am aware of, "his" is the correct pronoun.

prospects.

Despite lack of direct access, at least the following can be said about the process of ideation. As the person performing the mental act of ideation is invariably a physicist or philosopher of physics, the external events which spark the ideation process are most likely to be the type of events which occur in the lived experience of a professional academic physicist or philosopher of physics. If one accepts that persons of different background and with different day-to-day lived experiences are likely to come to significantly different personal ideologies as to the nature of reality, the limitation of ontology ideation to individuals who have dedicated much of their adult life to learning and teaching the existing physics canon must be seen as an inherent filter on possible theories. This is the filter of *involved population*.

The unseen processes which follow ideation are likely significant, and I expect that most proposed ontologies do not make it to the point of publication. However, this portion of the presentation stage must be omitted due to lack of relevant evidence.

The majority of the work of presentation is visible in the first journal publication. There are two conditions which influence the proposal's prospects before a single potential ally even reads the first word of the proposal, namely, the identity of the author, and the name of the journal in which the proposal is published. Within the relatively small world of academic physics, and the extremely tight-knit world of philosophy of physics, most authors are recognizable names with existing reputations. The perceived *physics authority* of the proponent will decide whether the proposal is taken seriously or largely ignored. Similarly, there is a clear ranking of *journal prestige*; proposals published in low-prestige journals are likely to be dismissed as unserious regardless of content. Sometimes, a proponent who has already made a name for himself as a physics communicator and author of general-interest physics content may in a sense go "straight to the public" with a new or speculative idea, including it in a book positioned in the marketplace as objective non-fiction. This is akin to publishing in the lowest-prestige journal of all, and such theoretical innovations are universally considered unserious and even distasteful.

If a proposed ontology of quantum mechanics is attached to an established and respected name and published in a well-received journal, it has a legitimate chance of entering the discourse—but it still must meet several stringent requirements to be taken seriously. These requirements of a first journal publication are nowhere made explicit but can be deduced from a reading of several such proposals and consideration of their subsequent reception. I have identified three such requirements which all proposed interpretations satisfy, though apparently to greater or lesser effect.

First, the proposed theory must be contextualized into the broader historical narrative of fundamental physics, with attention drawn toward existing *precedent* for theories of this nature. Careful mathematical analogies are made, with notations used in the precedent case borrowed or slightly modified for use in the new proposal. If no such precedent exists, the theory may be contextualized within a neighboring field such as mathematics or fluid dynamics. Precedents taken from the broader field of Western philosophy, outside of philosophy of science, are *not* observed and would likely be considered unserious; so too would precedents drawn from other fields of academic study or (almost unthinkably) from religious, traditional, or other non-scientific belief systems.

Second, the ontology must satisfy a number of implicit desiderata, which I will controversially describe as *aesthetic desiderata*, as to what a fundamental picture of reality should look like. Once again, such aesthetic desiderata are never made explicit, but are heavily implied by the relatively narrow range of proposed ontologies as well as the open disdain with which members of the physics community discuss certain ontological notions.

Third, the paper itself must meet what can be described (again controversially) as *literary requirements*. That is, the paper must read like a serious work of physics—and all serious works of physics adopt a particular literary form, with certain common tropes and linguistic patterns. The specifics of all three of these requirements of the first journal publication are elaborated in §4.

If a journal article fails to meet the requirements outlined above—for instance, if the proposal is contextualized relative to a precedent from a less-respected field, or if the proposed ontology is considered in some broad sense "ugly"—then this interpretation of quantum mechanics will die in the presentation stage. The article will be read and considered by high-ranking members of the physics community, but the process will end there. The proponent will receive no offers of collaboration, will not be invited to espouse the position at conferences, and will likely not attempt a follow-up publication.

If this journal article checks all the necessary boxes, however, the presentation stage is complete and the contestation stage begins. As mentioned previously, the contestation stage is notably less accessible than the journal proposal itself, and my analysis of this stage is largely drawn from a single semester-long weekly seminar course led by A where recent proposals were contested, including a single two-hour seminar in which D visited to defend his recent proposal against attacks from A, as well as a number of papers written in response to recently proposed interpretations. I will attend a full week-long conference on recent proposals in the philosophy of physics in the summer of 2019, where I hope to further expand my understanding of this stage of the process.

The contestation phase of entry into the canon appears to follow the contours of the process of ally recruitment described by Susan Greenhalgh: it is ultimately a contest of "rhetorical strategies used by the scientists to extend their influence" [4]. Contestation occurs across three arenas: in warring journal publications, alternately attempting to debunk and reinforce the new theory; at conferences, either in private or on debate stages before public audiences; and in private conversations and seminars. In all cases, proponents and opponents of the theory both attempt to position themselves as the figure with higher physics authority, more published citations on his side, and greater ability to express his points elegantly and scientistically. Once again, the social conditions influencing this contestation process are outlined §4.

The highest possible marker of success for an interpretation of quantum mechanics is inclusion into the small number of ontologies taught in introductory courses on philosophy of physics. At present, only four such theories (Copenhagen interpretation, GRW, Bohm's interpretation, and the Everett or "many-worlds" interpretation) are generally included as part of the standard physics canon. These four interpretations are subsequently written into textbooks and assigned green check-marks on Physics Stack Exchange; they are explained to lay audiences in YouTube videos, general-interest "aspirational reading" books, and science journalism.

IV.
SOCIAL, CULTURAL, AND AESTHETIC CONDITIONS

The foregoing discussion has outlined the processes of presentation and contestation of ontology in a general form, pinpointing seven conditions impacting this sequence of events which are sociologically mediated. This section explores each such condition as it presently exists at University X, with a focus on how accidents of history, community, and broader society seep into the development of physical theory.

The filter of *involved population* limits the ideation of new physical ontology primarily to secular white men educated at top U.S. colleges who are proficient in mathematics and generally consider themselves (and other secular, educated, white men) apolitical. Department of Education data shows 61.7% of all recipients of Master's Degrees in physical sciences and science technologies are white and male [5], with sociological studies such as [6] investigating the impact of these imbalances on the experiences of members of these communities who do not fit the expected type. Observation of the graduate student area of the physics building of University X suggests a focus on a particular filtering process best described as a hazing ritual, intended to weed out graduate students who don't "have it," thus setting the conditions for inclusion into the higher ranks of the physics community.

The process is initiated by the professor, who assigns weekly problem sets that are notoriously and intentionally long and difficult, often requiring 10–15 hours of labor and the assistance of peers. This assignment results in an culturally important and apparently longstanding ritual among undergraduate and graduate students known as "p-setting": nearly all of the students in an advanced physics class meet the day before a problem set is due to solve physics problems, eat takeout, and drink coffee until early morning hours. During these sessions, collaboration on problems is accompanied by competitive posturing and constant ribbing of fellow students, often of a gendered and racialized nature. The process of problem-solving involves proposing many ideas that are potentially wrong; when a female student is shown to be wrong, male students can be observed suggesting, with an orientation of joking, that she is personally unworthy of induction into the higher ranks. (E.g.: "This is why we don't let girls do math.") A Brazilian student and an Iranian student, both white-presenting, are frequently otherized for their country of origin, for instance with a joke attributing one's behavior to his upbringing in a "third-world country with third-world rules." Even when such explicit aggression is absent, the ritual of p-setting requires that students hoping to advance in the field of physics be willing to spend at least one day a week in a white boy's club.

The effects of this hazing process and other filters are evident in the progressively whiter and maler cohorts of undergraduate physics majors, Master's students, Ph.D. candidates, and, ultimately, professors. Of the 48 professors in the physics department at University X, only 8 are female, indicating to female students that there is an upper limit to their potential advancement.

The social feature of *physics authority* is sufficiently multifaceted and culturally significant to merit its own study. Among members of the international academic physics community there is a clear ranking of physicists, countries, laboratory sites, and occupations [7]. This ranking system extends to the professors of a particular university, with knowledgeable students (such as E, who provided much of this information) being easily able to identify which professors have the highest physics authority—quite independent of whether they are good teachers. Ultimately, though the details are somewhat more complicated, we may summarize the perception of physics authority as being influenced primarily by four factors, often highly correlated and generally conflated by members of the community: proximity to physics, perceived intelligence, access to governmental resources, and white male identity. These four factors are unified under a widespread belief in the physics community as a well-functioning meritocracy. All four will be discussed briefly, with special attention paid to the first factor, proximity to physics.

Proximity to physics is a catchall term which is intended to invoke both social and physical notions of proximity. The inner network of experimental and theoretical physicists is quite small, numbering only a few hundred [7] worldwide; social centrality within this network is a strong indicator of physics authority. Philosophers of physics, for instance, are of lower status than physicists, generally speaking. Additionally, a number of experimental sites are granted near-religious status within the physics community, and physical proximity to these sites and their machines is highly admired.[4] But the term *proximity to physics* is also meant to suggest that physics itself may be located within a physical or conceptual space, inducing a sorting on the persons in that space. In a classroom, the physics is on the blackboard; the professor stands between the physics and the students; the highest-ranking students typically sit near the front and ask questions or make corrections; lower-ranking students sit near the back. Students and professors alike are lauded for spending long stretches of time engaging directly with physics, on paper or on a blackboard, and are effectively shunned

[4]Professor C wins the admiration of students in his Ph.D. class by announcing that he will miss a session because "I am needed in Geneva," the site of the Large Hadron Collider.

for wasting time on appearances, hygiene,[5] and other considerations deemed distant from the work of physics. Photographs of physicists placed throughout the physics building at University X invariably frame their subjects adjacent to blackboards or large experimental machinery, apparently demonstrating these men's proximity to physics. The highest possible success for a physicist is to have a theory, equation, or mechanism named after you—to *become* physics.

Under an assumption of well-functioning meritocracy, in which members of the physics community work their way progressively closer to the center of physics as their intelligence is revealed through their work, proximity to physics in the aforementioned respects is considered an indicator of (or perhaps even a facsimile of) intelligence. When E and other graduate students speak of their professors, the observed stand-in for what I am calling physics authority is invariably intelligence. Professor C, for instance, is considered a very smart physicist. He generally begins his lectures with a private anecdote about the Large Hadron Collider for early arrivers, generally about the exorbitant cost of the machinery. ("For 15 billion dollars, what do you get? A billion dollars isn't what it used to be. A light source is a billion dollars. New neutron sources are a couple billion each.") There is an understanding that, as with religious establishments, particle accelerators which probe the fundamental nature of reality should be "free from the constraints of cost-benefit analysis" [7].[6] C's status within the physics community is intimately tied to his access to such funding. That the source of this funding is overwhelmingly from national militaries is not mentioned. Rather, there is a presumption that highly-funded projects must be objectively valuable, and that those entrusted to participate in them must be intelligent. As nearly all of the physicists thus entrusted are white men compounds the existing cultural stereotypes associating intelligence with white male identity [8].

[5]One PhD student is frequently mocked by the others during p-setting sessions for his hair, which is washed and styled.

[6]C, in fact, has a cartoon on his office door depicting a bearded white man atop a cloud, presumably God, holding a book titled "Laws of Physics."

Journal prestige is a consistent ranking of journals of physics and philosophy of physics considered presitigious and worthy of serious attention. The most prestigious papers, such as *Reviews of Modern Physics* and *Living Reviews in Relativity*, typically publish articles written for working physicists and are not intended to be accessible to general audiences. Writing for such audiences demands a careful knowledge of the jargons of academic physics, discussed in further detail below. Proposals published in lower-ranking journals or, still worse, in books intended for general audiences, are not considered serious works.

The process of contextualization and citing of *precedent* naturally favors new proposed ontologies which maintain core features of long-standing threads of physics thought. This naturally leads to institutional inertia, as interpretations proposed in the 2010s must be similar in many mathematical and ontological respects to those proposed in the 1940s, which in turn must be similar to theories from related fields from earlier centuries. Institutional inertia surely plays a significant role in the historical development of every academic field, but its particular manifestation in the field of physics is a restriction of all physics thought to being essentially, in a sense, Newtonian. Isaac Newton was certainly revolutionary for the 17th century, but he presupposed the existence of a single, stationary frame of reference ("the origin") relative to which all objects could be assigned an objective position and velocity. The reasons cited for this ontological preference in his own writings were explicitly Christian [9], and yet this core framework remains at the heart of contemporary secular ontology. Present-day philosophers of physics such as A (as well as papers in this field) make frequent reference to "God" in a largely tongue-in-cheek manner that nonetheless appears to maintain the legacy of its earlier usage. For instance, the question "What would God say the momentum of this particle is?" is expected to have a single, objective answer in any interpretation of quantum mechanics.

Similar to physics authority, the *aesthetic desiderata* applied to physical ontology merits its own in-depth study. For our purposes, a list of three specific desiderata will be provided, as well as a brief commentary about the broader aesthetic culture of theoretical physics. The three key desiderata which are applied to every interpretation of quantum mechanics are "simplicity" or "elegance," "coherence with the manifest image," and *mathematical precision*, the latter of which is generally unstated. Ontological simplicity—including as few distinct objects in the fundamental ontology as possible—is in some sense the very goal of physics. As such, this desideratum is rarely justified explicitly; instead, reference is made to Ockham's razor and to a quote by philosopher Willard Van Orman Quine that in the search of ontology one ought to "have a taste for desert landscapes" [10]. Both of these justifications are ultimately aesthetic, as further evidenced by the occasional repositioning of simplicity as "elegance," and this cultural preference has been criticized by feminist philosophers of science as mediated by societal views on gender [11].[7] Similarly, the term "manifest image" is used to describe the world as it appears to humans, prior to the introduction of scientific knowledge, and it is desired in theory that a physical ontology bear fundamental similarities to *the* manifest image. It is presumed in this phrasing that there is a single way that the world appears to humans, unmediated by cultural context. For instance, the establishment view in philosophy of quantum mechanics is mocking of "many-worlds" interpretations as dramatically deviant from the manifest image, despite the relative commonality of ontologies involving multiple planes of existence among non-scientific systems of belief. Finally, the somewhat self-explanatory desideratum of mathematical precision requires that the fundamental ontology be expressible in strict mathematical terms and that all phenomena be fully explicable in such terms. In a utilitarian sense, for the purposes of engineering, this requirement is sensible; as a condition for ultimate, fundamental truth it is clearly an aesthetic preference.

[7] Significantly, the three aesthetic desiderata are apparently conceived of as apolitical by male philosophers of physics, while feminist critiques of them are considered political in nature. When a female student in A's seminar raised the feminist critique of simplicity, A responded, "Even without bringing in political considerations—which I think are legitimate—there are people like von Frassen [a male physicist] who also say, essentially, *come on*."

It is potentially unsurprising that high-ranking members of the physics community agree on an assortment of aesthetic preferences, given that they share a set of physical spaces and a corpus of academic literature. There is a common aesthetic to these spaces and references which can be described as austere, surrealist, and amoral. The physical spaces inside the physics building of University X are spare and gray, with many of the popular classrooms situated underground and lacking windows. The pictures on the walls are nearly all black-and-white, featuring white men in front of blackboards and machinery. One prominent picture features a cyclotron which was formerly housed in the basement of the very same building and which produced the first atom-splitting event in the United States, directly contributing to the development of the nuclear weapons dropped on Hiroshima and Nagasaki. This history is never discussed, and multiple graduate students in physics I spoke to were unaware that this had occurred.

This cold, bare, and latently violent aesthetic permeates other aspects of the culture such as homework problems and canonical examples. The assigned videos for B's undergraduate course depict a number of frequently repeated visual scenarios, involving the characters George and Gracie, two non-descript white children on a bare green field, shooting light-guns at one another, traveling on rockets to nearby stars, and setting off explosions. Homework problems do not mention even in passing the real-world applications of the material, instead discussing, for example, a "relativistic dachshund" hundreds of millions of miles in length, or a coyote chasing a rabbit at three-fifths the speed of light. Physics is to be thought of generally as a mental plaything, taking place on the empty stage of a Cartesian coordinate system, with a cast of characters drawn vaguely from 20th-century Americana. When asked directly in class whether $E = mc^2$ had ever been proven in real life, B cavalierly responded, "Unfortunately, yes" before giving an amoral, physical account of the functioning of a fission bomb.

The sixth and final culturally mediated condition of ontology presentation is the *literary style* of the physics journal article itself. The voice of a physics article is remarkably consistent from author to author, with certain words (such as "manifestly" and "fundamentally") appearing far more often than in regular speech or writing. Certain physics-specific jargons are employed to further signal in-group familiarity, such as substituting the word "unity" in place of "one" and "vanishing" in place of "zero." Physics articles must also demonstrate proficiency in complicated mathematical operations, and typically include a sequence of equivalent equations being rearranged and otherwise manipulated. New notations, if they are introduced, generally use lowercase Greek letters; often such notations from recent papers are used without explicit reference. Physics and math papers are also expected to be written in LaTeX, a typesetting software designed for seamlessly integrating mathematical symbols and equations into written text. LaTeX is a fairly intricate, code-based software that is never taught in school; math and physics students are expected to learn it on their own time or have picked it up "socially" in online forums. Papers which lack these markers of style are seen as unrigorous or somehow flimsy—a published paper on Quantum Bayesianism (a subjective interpretation of quantum mechanics) which contained no mathematical formulae was dismissed by A, who said that the author "needs to show his work."

This sixth sociological condition of the presentation leads directly into the one condition of the contestation phase advanced in §3: scientistic rhetoric. In defending an interpretation of quantum mechanics, a proponent may speak as if reading from a journal article, numbering his thoughts and interjecting spoken headers such as "Claim:" and "Proof:" During the private debate between A and D in the seminar course, both men were politely antagonistic, apparently in competition to speak more quickly, precisely, and with more physics jargon than the other. In this arena as in academic journals, competitors are careful to assert their superior physics authority without directly impugning the intelligence of their opponents. D's original paper refers to other interpretations of quantum mechanics as "too quick," while a response paper criticizing D's proposal refers to his new notion as "fuzzy" and "puzzling" before presenting a series of calculations which the author deems “likely sufficient to doom their attempt” [12].

In the foregoing discussion of social, cultural, and aesthetic factors governing the twin processes of ontology presentation and contestation, it should be clear that the claims of fundamental truth contained in the physics canon accepted by high-ranking physicists are in many respects sociologically mediated. It is hoped that with further research into these processes and the related literature, a sharper thesis can be reached, possibly suggesting the proper role of physical ontology alongside other systems of truth and belief in academia and broader society.

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