The Return of Realism in the Logos Approach to Quantum Mechanics (Reply to Arroyo and Arenhart)

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Abstract

In a recent paper [3] Arroyo and Arenhart presented a detailed critical analysis regarding some essential aspects of representational realism and the logos approach to Quantum Mechanics (QM) addressed in terms of i) "a diagnosis of what is wrong with currently available solutions"; ii) "a proposal of a new methodology for addressing the problem"; and finally, iii) "a positive proposal to answer the question, which is arrived at by following the methodology suggested." In this work we provide a detailed reply to some deep misunderstandings that arise in this presentation and which, in turn, allow Arroyo and Arenhart to conclude that "contrarily to what de Ronde has suggested, his proposal is not a way to avoid commitment to uncritical images of reality, but rather, one further position in the already huge cart of options of quantum mechanics." After providing a more accurate account of our diagnosis, we continue to address our methodology which —like that of Einstein, Heisenberg, Pauli and Schrödinger— goes back to the Greek-Modern account of physics. We then present our proposal grounded on the invariant-objective search for theoretical unity and discuss why intensive *powers of action* cannot be considered in dispositional or teleological terms with respect to actuality. Finally, we list some of the main results already accomplished by the logos approach and discuss the essential role of 'intuition' and 'understanding' within the realist setting.

Key-words: Realism, anti-realism, logos approach, representation, quantum theory.

I imagined a labyrinth of labyrinths, a maze of mazes,
a twisting, turning,ever-widening labyrinth that contained
both past and future and somehow implied the stars.

Jorge Luis Borges

Introduction

Recently, Raoni Arroyo and Jonas Arenhart provided a detailed critical analysis of *Representational Realism* and the *Logos Approach to Quantum Mechanics*. In their paper [3], they articulated their analysis through a characterization of the program divided in three main steps: first, "a diagnosis of what is wrong with currently available solutions"; second, "a proposal of a new methodology for addressing the problem"; and third, "a positive proposal to answer the question, which is arrived at by following the methodology suggested." After discussing in detail the many papers where this approach has been presented they conclude that the logos approach —supplemented by representational realism— is, in fact, just one between the many interpretations that can be found within the orthodox literature:

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> "The fact that de Ronde is willing to somehow subvert the current approaches and avoid most of the difficulties faced by other traditional approaches is a merit of his approach; however, as we argued, he ends up in the same boat as everyone else. The result is that contrarily to what de Ronde has suggested, his proposal is not a way to avoid commitment to uncritical images of reality, but rather, one further position in the already huge cart of options of quantum mechanics." [3, p. 907]

In this work we attempt to show why our scheme —contrary to the attempt by Arroyo and Arenhart— is capable to avoid being captured and dragged inside the walls of the interpretational maze created by orthodoxy. More specifically, according to our viewpoint, this wrong conclusion is built on a series of deep misunderstandings regarding some essential points of divergence between what we consider to be the orthodox (anti-realist) approach to "standard" QM (in both physics and philosophy of physics) and our own (realist) proposal. Of course, this lack in understanding might be very well consequence of my own incapability to explain the ideas I attempt to support. Thus, in this work I will do my best not only to address the many critical arguments raised by Arroyo and Arenhart against representational realism and the logos approach but also to be more explicit about the differences between the orthodox scheme, grounded on the re-foundation of physics that Bohr and positivists accomplished during the 20th century, and our own proposal, which goes back through the works of Einstein, Heisenberg, Pauli and Schrödinger to the Greek and Modern scientific program of science. In short, what we have proposed in our work is not a new methodology but to recover the original realist roots of physics that were established by the ancient Greeks and developed in modernity by Galileo, Newton and many others through the notions of (mathematical) invariance and (conceptual) objectivity. As we shall see, what is truly at stake in this debate is the explicit definition, meaning and reference of physical theories.

The paper is organized as follows. In section 1 we discuss the main points of our general diagnosis grounded on the consequences of the radical re-foundation of (quantum) physics in the 20th century as established through the Bohrian-positivist alliance. In section 2 we address the need to re-turn to the realist Greek-Modern methodology of science and the search for theoretical (formal-conceptual) unity. While section 3 addresses our Spinozist account of scientific representation and knowledge, section 4 discusses the intuition and understanding provided by the physical concept of *power of action*. In section 6 we recapitulate the main results of the logos categorical approach to QM reached by following the realist theoretical pre-conditions of operational-invariance and conceptual-objectivity and provide some specific replies to Arroyo and Arenhart.

1 Diagnosis: The 20th Century Triumph of Anti-Realist Realism

As Arroyo and Arenhart depict, our line of research has been grounded on a critical diagnosis regarding the present situation in both quantum physics and philosophy of QM. However, their presentation of our diagnosis is not only inaccurate but omits some kernel elements. One of such elements present in our diagnosis is the radical and complete re-foundation of physics that —according to us— took place during the last century through the work of Niels Bohr in tune with the positivist *Zeitgeist*. As a result, a new anti-realist scheme would effectively subvert the very meaning of both physics and realism. Following *Michael Corleone's strategy*: "Keep your friends close, and your enemies closer", Bohr's anti-realist realism —as we have called it elsewhere [23, 24]— would not attempt to eradicate its enemy, but —instead— would set the conditions to effectively engulf it. By creating an inconsistent though effective methodology Bohr would be able to develop a highly complex matrix capable to capture, subvert and control realist rebels. After the war, transformed in orthodoxy, anti-realist realism would justify and legitimize the replacement of the systematic unity, consistency and coherency required by physical *theories* by a multiplicity of inconsistent and vague *models* supplemented by another multiplicity of —also inconsistent and vague— fictional narratives. In turn, the dogmatic approach supported by anti-realist realism would very soon lead to persecution of any critical student or researcher who would attempt to do more than just "shut up and calculate!" It is in this context, that the role played by philosophy of QM would become essential, not to produce a critical re-consideration of this completely new anti-realist (realist) understanding of physics but, on the contrary, to naturalize it as the only possible approach to science reinforcing the attack against realists by framing them as "fanatic believers" in *interpretations* floating free from empirical science itself. Let us thus address these four main points, which constitute our diagnosis, in some further detail.

1.1 The War Between Realism and Anti-Realism

The war between realists and anti-realists is the history of western scientific thought. A story which begins during the 6th century B.C. in the Greek city of Miletos, on the coast of Asia Minor, where the Ionians had established rich and prosperous colonies. Three men —Thales, Anaximander, and Anaximenes— appeared in quick succession claiming the existence of what they named *physis* —translated later on as 'reality'. For the first time in the history of western thought physicists replaced mythical stories and narratives by rational explanation. As remarked by Jean-Pierre Vernant:

> "Myths were accounts, not solutions to problems. They told of the sequence of actions by which the king or the god imposed order, as these actions were mimed out in ritual. The problem found its solution without ever having been posed. However, in Greece, where the new political forms had triumphed with the development of the city, only a few traces of the ancient rituals remained, and even their meaning had been lost. The memory of the king as creator of order and maker of time had disappeared. The connection is no longer apparent between the mythical exploit of the sovereign, symbolized by his victory over the monster, and the organization of cosmic phenomena. When the natural order and atmospheric phenomena (rains, winds, storms and thunderbolts) become independent from the functions of the king, they cease to be intelligible in the language of myth in which they had been described hitherto. They are henceforth seen as questions open for discussion. These questions (the genesis of the cosmic order and the explanation for *meteora*), in their new form as problems, constitute the subject matter for the earliest philosophical thought. Thus the philosopher takes over from the old king-magician, the master of time. He constructs a theory to explain the very phenomena that in times past the king had brought about." [58, p. 402]

The impact of this shift from myth to *theory* would reinforce the transformation of the structure of the Greek society and as a consequence, priests and kings would be forced to share their power with the first physicists and philosophers. Unlike in the previous mythical society, in this new democratic system known as science, all citizens would be entitled to openly debate and gain theoretical understanding about reality.[1] There are three fundamental presuppositions that would come to guide this new form of theoretical thought and *praxis*. First, the presupposition that *physis* is not chaotic, that it possesses an order, what the Greeks called —after Heraclitus— a *logos*. Second, that *physis* is one, nonseparable. Like Heraclitus would express: "Listening not to me but to the *logos* it is wise to agree that all things are one" [f. 50 DK]. And third, that even though "*physis* loves to hide" [f. 123 DK] the logos of physis could be actually *known* through the development of *theories*, namely, through the creation of unified, consistent and coherent schemes of thought that could explain phenomena and, at the same time connect themselves —in an immanent manner— with *physis*. Already the first philosophers showed a clear recognition of the difficult problems involved within this scheme. To relate the *logos* of men understood as discourse to the *logos* of *physis* was obviously a difficult task, but through hard work and sensibility the latter could be revealed in the former.[2] *Theories* relate on the one hand to *physis* (the One), and on the other to the multiplicity of phenomena (the Many). And it is this kernel aspect which marks the characteristic feature of scientific understanding itself. As a young Wolfgang Pauli would explain to his friend Werner Heisenberg during a conversation in 1921:

> "[...] knowledge cannot be gained by understanding an isolated phenomenon or a single group of phenomena, even if one discovers some order in them. It comes from the recognition that a wealth of experiential facts are interconnected and can therefore be reduced to a common principle. [...] 'Understanding' probably means nothing more than having whatever ideas and concepts are needed to recognize that a great many different phenomena are part of coherent whole. Our mind becomes less puzzled once we have recognized that a special, apparently confused situation is merely a special case of something wider, that as a result it can be formulated much more simply. The reduction of a colorful variety of phenomena to a general and simple principle, or, as the Greeks would have put it, the reduction of the many to the one, is precisely what we mean by 'understanding'. The ability to predict is often the consequence of understanding, of having the right concepts, but is not identical with 'understanding'." [40, p. 63]

However, as we all know, very soon a strong opposition to these realist ideas also appeared in Greece. In Athens, which had already become during the 5th. century B.C., the rich and prosperous capital of the Greek Empire, sophists —as they would be called— would produce the first (anti-realist) assault against the realist program. Assuming a skeptic standpoint, they would convincingly argue that the reference to 'a reality of things' is meaningless, and even if such 'reality' would actually exist, we would not be able to grasp it. We humans can only gain knowledge of our exterior surroundings through our (limited) perception, our knowledge is always *relative* and limited by our own personal experience of the 'things' that surround us. As Protagoras would argue: "Man is the measure of all things, of the things that are, that they are, of the things that are not, that they are not"

[1] Something that has been lost in contemporary empirical science where the democratic access to science has been replaced by the ruling of "experts".

[2] In this respect, it is important to recognize that physicists never claimed that *theories* "mirrored" reality. In fact, the idea that realism implies a one-to-one correspondence relation between theory and reality-in-itself is an idea constructed by anti-realists in order to subvert the realist program.

[DK 80B1]. From this skeptic standpoint, sophists criticized the physical idea of theoretical knowledge: realists —namely, physicists and philosophers— are too naïve, they do not recognize their own finitude and thus have ended up believing they can access the infinite, the totality of existence. The first battle of the war between realists and anti-realists had already begun. It is then important to stress that in Modernity anti-realists would develop a co-relational scheme grounded on an essential anthropocentric-ontological presupposition according to which 'the physical world is composed of individual entities, subjects (i.e, human beings) and 'objects' (e.g., tables, chairs and dogs)'. Today, this ontological principle is firmly in place within philosophical debates —either implicitly or explicitly. According to the Oxford Dictionary in Philosophy [6]: "Ontology is the study or concern about what kinds of things exist —what entities or 'things' there are in the universe."

Consequently, we might argue that the most important distinction between realism and anti-realism is the radical difference in the understanding of what *is*. While realists understood that one should begin with the presupposition of the notion of reality and only then attempt to specify in theoretical terms particular *moments of unity* as metaphysical creations, in the case of anti-realists one always begins with the subjective perception of observable entities such as 'tables', 'chairs' and 'dogs' conceived as empirical *givens*. In this latter case theories are developed in order to account for such already presupposed (pre-theoretical) individuals: "Any fundamental physical theory is supposed to account for the world around us (the manifest image), which appears to be constituted by three-dimensional macroscopic objects with definite properties." [47, p. 60]. Thus, while in the first case *moments of unity* are theoretically created and the possibility of scientific observation is something *derived* from the theory, in the latter case there is an ontological presupposition according to which 'there are entities which compose reality' supplemented by an empiricist standpoint according to which some of these (pre-theoretical) entities can be unproblematically accessed (e.g., 'tables', 'chairs' and 'dogs'). It should be quite obvious that realism and anti-realism do not share the same presuppositions and principles of analysis which, in turn, shape their praxis and goals of research.

To sum up, in the case of realism *physis* is one, non-separable, and it can be known through the weaving of concepts and mathematical formalisms which need to be consistently and coherently articulated into a coherent theoretical whole. It is only theories which produce *moments of unity* capable to account for a multiplicity of experience and —at the same time— express reality.

I. **Theories create their *moments of unity* in an immanent manner, through a net of interrelated concepts which together with a consistent mathematical formalism weave a formal-conceptual representation that makes possible to access in a specific manner both experience and reality.**

II. **Scientific observation is always *derived* from theoretical pre-conditions which make understandable a field of phenomena.**

III. **Knowledge is achievable by the true connection, expressed through an immanent experience, between theories and *physis*.**

On the contrary, anti-realism always begins with a change of perspective and the necessary reference to dualities. In the co-relational anti-realist scheme it is the "interior" subject which relates to the "exterior" world/reality composed of entities (such as 'tables', 'chairs' and 'dogs') through observation. Unlike in the case of realism, these entities do not require a metaphysical or categorical definition, they are grounded in "common sense" and intersubjective agreement. It is important to remark that the (anti-realist) ontological claim according to which "reality is composed of individual entities" is not part of realism but one of the main anti-realist standpoints. The idea is that it is through observation that we gain knowledge about the objects of the exterior world allowing the development of models which are justified, not in terms of a reference to reality, but —instead— in purely pragmatic or instrumentalist terms.

I. **The world is composed of individual entities which the subject is capable to access as *givens* of experience.**

II. **Empirical science begins with the observation of the entities that surround us. And it is this unproblematic access to "exterior reality" which allows to develop scientific theories. In turn, scientific theories also allow us to access an "unobservable reality" which stands beyond our "common sense" experience.**

III. **Scientific theories are not necessarily capable of any *true* description of anything. At most they can be seen in pragmatic terms, as "tools" that we humans have created in order to expand our capabilities to live in a dangerous world that is *given* to us in perception yet we cannot truly understand.**

Now, what took place in the 20th century is the replacement of the basic pillars of physics —grounded on the realist Ancient Greek program of science— through the establishment of a new anti-realist program that was able to capture and control any realist rebel who would dare to criticize the new orthodoxy. It is to this essential period to which we now turn our attention.

1.2 The Bohrian Anti-Realist (Realist) Re-Foundation of Physics

One cannot understand the present without a proper account of the past. And certainly, in order to understand the triumph of anti-realism within physics, it is essential to understand the historical process which lead to this paradoxical outcome. As we already pointed out, even though we might find its initial point already within the ancient Greeks —when sophistry was initiated—, the coming into power of anti-realism finds its origin in modernity, a controversial period which can be regarded not only as the peak of the Greek program of science but, at the same time, as the origin of its end. It can be certainly seen as the peak of the realist program because it is in the 17th century that we find the creation of the first physical theory as a direct result of the Greek creation of physics and philosophy (to which we will return more explicitly in section 2). Classical mechanics was a realist achievement, made possible through the more than two millennia conceptual debate between realists. This same methodology would continue to give its fruits in the 18th century, with Kant's notion of objectivity, and in the 19th century with the creation of electromagnetism and classical statistical mechanics. In this respect, it is important to stress that both classical mechanics and electromagnetism were developed not only through the construction of operational-invariant mathematical formalisms but also through particular systems of concepts capable to account for different fields of experience in terms of specific *moments of unity*, namely, 'particles' and 'electromagnetic waves' evolving within Newtonian space and time. Of course, already here we find the true power of physical theories which is not restricted to the prediction of an evolving state of affairs but, more importantly, to the possibility to think about new experiences in consistent, coherent and unified terms. And it is this theoretical (formal-conceptual) construction that would open the doors to advance a qualitative understanding of completely new forms of experience, capable, in turn, to produce new technological developments that couldn't have been imagined within the representational constraints of earlier theories —something clearly exposed with QM.[3] However, modernity can be also understood as the ending point of realism and the beginning of a new ruling, for it is in modernity that we find the most radical shift in the fundament of though from the Greek notion of *physis* to the modern reference to *subjectivity*. It is this shift, embraced by both rationalists and empiricists, that would allow anti-realists to "cut" reality into pieces, imposing a completely new dualistic (binary) way of thinking. *Divide et impera*, this is the motto which characterizes the strategy that would allow anti-realism to subvert the kernel concept of her enemy. Interior and exterior realities, objective and subjective, material and cognitive, actual and potential, human and natural, phenomenic and noumenic, etc. All these dualistic distinctions would help to disperse the power of *physis*, relativizing knowledge in terms of a circular co-relation —with no true foundation— between subject and object. Within the Kantian matrix, the replacement of the true scientific knowledge of *physis* by the objective knowledge of subjects would impose to scientists an impossible Promethean task they would be forced to repeat, guided by a moral imperative, knowing themselves the impossibility of success. The Ancient Greek knowledge of *Physis* would then come to be replaced by the modern acknowledgment of the impossibility to know the *Thing-in-Itself* —a notion analogous to an all powerful mighty God that even though would rule the fate of humans would remain to them always unreachable.

The following centuries would become footnotes to Kant, inconclusive debates about the possibility (or not) of scientific knowledge and its non-referential meaning. But it is in the 20th century, that anti-realism would feel powerful enough to erase the realist remainings of physical theories still present within the Kantian architectonic. In the new matrix designed by the Danish physicist Niels Bohr, objectivity, as the search for categorical conceptual unity would be finally abandoned as a necessary precondition of physical theoretical representation and soon replaced by a pre-theoretical ontological principle (section 1.1) that would impose the most radical re-foundation of the discipline in the history of science. This re-foundation, was of course, in tune with the postmodern anti-foundational, anti-metaphysical *Zeitgeist* of the 20th century and the logical positivist program of science which had been already developed by Ernst Mach during the second half of the 19th century. Instead of creating *moments of unity* in formal-conceptual terms, capable to unify invariantly and objectively a specific field of experience, theories would come to be understood within the new dualistic positivist matrix, in terms of unproblematic *givens* of observable experience and abstract mathematical models with predictive capacities. It is in this context that Bohr would go even further within this dualistic construction, incorporating the impossibility of representation as a form of knowledge that would allow us to finally unveil reality-itself. The new impoverished, impotent understanding of

[3]Notice that instrumentalism, taken seriously, is incapable of producing any advancement, for there is no guide whatsoever apart from empirical success. Thus, instrumentalism, and anti-realism in general, even though introduces some sort of reference it immediately denies it, creating a self-contradicting anti-system with no method.

realism, conceived as the subjective believe in fictional (metaphysical) narratives designed by naive agents in order to account for *the thing-in-itself* or God's eye view, would be then supplemented by the true foundational knowledge provided by QM. Adding a paradoxical twist to the impossibility of knowledge of reality, Bohr would argue that with QM, we humans, had finally reached the irrepresentable ontological nature of reality-istelf. It is this new form of fictional-realism which he would effectively apply in order to supplement his (inconsistent) algorithmic model of the atom with a story about "microscopic planetary systems" that could not be consistently represented —because of its radical departure from our "common sense" intuitions. His success in a field already constrained by the positivist postmodern *Zeitgeist* would teach him not only the importance of narratives —linked to "common sense"— in order to market his inconsistent ideas but also of misdirection. In this respect, the constant addition of layers of narratives, more strange and alien as the story would evolve, would allow him to create the necessary confusion about what even needed to be actually explained. Essential to the production of "commonsensical" narratives and metaphors would be the imposition of dogmas that would ground and justify their application. Following the anti-realist ontological presupposition according to which "the world is composed of individual entities", Bohr would impose the idea that QM had to describe a microscopic realm (populated by quantum particles) in *correspondence* with our classical macroscopic world. As always, turning a failure into a solution, the complete lack of a theoretical explanation that would bridge the gap between the quantum and the classical realms would be taken as an expression of the limits of representability of nature itself. As a counterbalance, his doctrine of classical concepts would impose a complementary (incompatible) account of essentially irrepresentable yet microscopic quantum entities. It is in this way, that we end up with a new double co-relational reference with no foundation —different to that of Kant. While on the one hand we might take as a standpoint from empirical positivism, the epistemic ground of observability making possible the (pre-Kantian) account of 'tables', 'chairs' and 'dogs'; on the other, we might also take as an ontological ground of such macrosocpic entities, microscopic particles which cannot be actually observed nor represented and would require —closing the circle— the representation provided by the macroscopic realm. This inconsistent circularity is typical of the contemporary postmodern research where physicists claim, at first, to be unveiling the most profound mysteries about reality, but when a few questions are asked they immediately shift to an instrumentalist position and shout: "It works! So, shut up and calculate!" The dualistic circular reference of the Bohrian anti-realist realist scheme that has been embraced in contemporary physical and philosophical research can be summarized in three dogmatic principles which interrelate in a rhetorical self-contradicting progression that goes back and forth between the "realist" reference to 'things' in the world, the skeptic distance with respect to the possibility of understanding the quantum realm and the claim that QM provides a fundamental knowledge about the irrepresentability of nature-itself.

I. **Mythical Atomist Narrative:** *QM describes a microscopic realm constituted by elementary quantum particles such as electrons, photons and the like particles.*

II. **The Irrepresentability of Quantum Reality:** *Quantum particles and their "jumping" evolution cannot be theoretically represented. This is not due to an epistemological or technical constraint but an exposition of an ontological finding regarding the irrepresentability of (quantum) reality-in-itself.*

III. **Instrumentalism:** *QM cannot be understood in representational terms as describing an underlying reality. Thus, QM must be understood as a "tool", as an algorithmic "recipe" which predicts measurement outcomes or observations —which must be always described in "commonsensical" classical terms.*

The anti-realist realist scheme imposed by the Danish physicist can be pictured as a Möbius strip machine which through the constant introduction and immediate replacement of dualistic poles is capable of producing the feeling of tension and motion within a circular dialectic with no synthesis. However, also essential to the establishment of this scheme was the destruction of the realist *praxis* as a search for unity —namely, the attempt to account for *the same* within *change*— guided by general theoretical preconditions (section 2). In QM, Bohr himself would command the anti-realist attack to the cornerstones of realism through a series of crucial operations (see [8, 9, 20, 23, 24]):

- The replacement of a (realist) search for a metaphysical, consistent, coherent and unified system of concepts by a dualistic (anti-realist) reference, on the one hand, to a classical language describing our *given* intuitive macroscopic reality, and on the other, to an "atomist-planetary" narrative about an essentially *irrepresentable* microscopic quantum reality.

- The introduction of *correspondence* acting as a principle that would secure "bridging the gap" between our "commonsensical" macroscopic intuitive account of the world (in terms of tables, chairs and dogs) and the microscopic "irrepresentable" quantum realm (populated by quantum particles).

- The introduction of *complementarity* naturalizing the *inconsistent* representation of *the same* quantum entity in terms of the dualistic self-contradicting contextual reference to classical concepts such as 'waves' and 'particles'.

- The presupposition of the existence of "quantum particles" acting not only as the foundation of our "commonsensical" macroscopic (classical) reality but also as expressing the irrepresentable nature of microscopic (quantum) reality-itself.

- The presupposition of the existence of "quantum jumps" as an effective misdirection that would allow to shift the attention from the main problem of consistently defining "electrons" to the problem of finding their unseen "trajectories".

- Bohr's replacement of (Kantian) *objectivity* (understood as the condition of possibility of categorically defined moments of unity) by the *intersubjective communication* of binary information about 'clicks' in detectors or 'spots' in photographic plates —always supplemented by "commonsensical" narratives.

Of course, the work of Paul Dirac would be also key in bridging the gap between the Bohrian matrix of physics and the logical-positivist philosophical understanding of science. In this case, the English engineer and mathematician would accomplish in formal terms what Bohr had already produced in a purely conceptual manner. In his book, *The Principles of Quantum Mechanics* [35], Dirac would convincingly and effectively embrace Bohr's inconsistent presuppositions in order to justify his vectorial formalism while at the same time combine it with the positivist understanding of science (see [32]):

- Dirac's inconsistent re-definition of the physical notion of (quantum) *state* in terms of (non-invariant) operational certainty and the (non-operational) abstract invariance of vectors.

- Dirac's replacement of 'reference frames' as referring to *the same* state of affairs by 'bases' referring to *different* experimental situations (or contexts) and states.

- Dirac's *ad hoc* introduction of a non-linear (irrepresentable) "collapse" process (i.e., a new "Bohrian jump") in order to bridge the gap between quantum superpositions and binary outcomes generating an essential inconsistency regarding the evolution of states.[4]

The main result of this scheme is the complete replacement of the *global* objective-invariant theoretical representation of states of affairs by algorithmic predictive models *contextually* (i.e., non-invariantly) related to measurement situations and outcomes.[5] In short, we might characterize this new scheme of physics as one that replaces the theoretical rationality imposed by the requirement of consistency, coherency and unity by the modelistic tolerance towards inconsistency, vagueness and fragmentation (more in section 2).

1.3 The Instrumentalist Inquisition

Two years after the publication of Dirac's book in 1930, the Bohrian triumph of the "Standard" version of QM would be reinforced by the prestigious mathematician John von Neumann who would attempt in his book [59], *Mathematical Foundations of Quantum Mechanics*, to provide a "more rigorous" mathematical formulation of Dirac's work. But it is three years later, in the famous EPR battle between Einstein and Bohr that the triumph of the new orthodoxy would be finally sealed. In 1935 Einstein would attempt —with two of his collaborators— to address the many inconsistencies of SQM by relating the theory explicitly to specific theoretical pre-conditions that would allow a meaningful reference to physical reality. The EPR paper [36], as it would become to be famously known, would be immediately responded by Bohr himself in another paper [7] where the Danish conjurer would apply all his rhetorical powers to defeat his enemy once and for all. The community of physics which had already chosen sides, would use this final encounter to declare Bohr as the only true champion of physics. As described by Jim Baggott [4]: "The popular reading of subsequent history suggests that Bohr emerged the victor in the debate, browbeating the presumed-senile Einstein into submission, and the Copenhagen interpretation became a dogmatic orthodoxy." And then, just a few years later, the war started and debates about physical reality would become replaced by military goals. In this context, the success of the *Manhattan Project* in 1945, exposed to everyone in

[4]The introduction of this new (non-linear) evolution would turn the mathematical formalism of QM essentially inconsistent. Quantum superpositions would evolve according to the Schödinger equation (a linearevolution), but when measured they would suddenly "collapse" (a non-linear evolution) to a single outcome.

[5]It is interesting to notice that this is exactly what Kuhn would later on call "exemplars" in the postscript to the second edition of *The Structure of Scientific Revolutions* [41].

Hiroshima and Nagasaki, would end up justifying the instrumentalist approach to science. After all, regardless of the complete lack of understanding, QM had proven to be a useful (military) tool. Back in the U.S., after the second world war, Bohr's anti-realist realism would become embraced by a new physics community that would guide the discipline worldwide in the decades to come. It is in this context that the anti-realist re-foundation of physics in tune with both German positivism and the English empiricist-pragmatic heritage would flourish in the U.S. giving birth to "instrumentalism", the natural extension of both pragmatism and empirical positivism presented by the U.S. philosopher John Dewey. While pragmatism sustained that the value of an idea is determined by its usefulness, instrumentalism, rejecting the need of any metaphysical fundament, was ready to take a step further and claim that the kernel (realist) question regarding the reference of theories was simply meaningless. As described by Olival Freire Jr.:

> "In the US, which after the Second World War became the central stage of research in physics in the West, the discussions about the interpretation of quantum mechanics had never been very popular. A common academic policy was to gather theoreticians and experimentalists in order to favour experiments and concrete applications, rather than abstract speculations (Schweber 1986). This practical attitude was further increased by the impressive development of physics between the 1930s and the 1950s, driven on the one hand by the need to apply the new quantum theory to a wide range of atomic and subatomic phenomena, and on the other hand by the pursuit of military goals. As pointed out by Kaiser (2002, pp. 154-156), 'the pedagogical requirements entailed by the sudden exponential growth in graduate student numbers during the cold war reinforced a particular instrumentalist approach to physics'." [37, pp. 77-78]

But instrumentalism was just a new name for an old idea. As remarked by Karl Popper [48] at the end of the 1950s:

> "Today the view of physical science founded by Osiander, Cardinal Bellarmino, and Bishop Berkeley, has won the battle without another shot being fired. Without any further debate over the philosophical issue, without producing any new argument, the *instrumentalist* view (as I shall call it) has become an accepted dogma. It may well now be called the 'official view' of physical theory since it is accepted by most of our leading theorists of physics (although neither by Einstein nor by Schrödinger). And it has become part of the current teaching of physics." [48, pp. 99-100]

According to Popper, the new understanding of science as an "empirical" and "pragmatic" program would become wildly accepted for two main reasons. Firstly, due to the influence of Bohr's complementarity approach in QM —which he himself famously criticized [57]—, and secondly, due to the effectiveness of the *Manhattan Project*, exposed to the world with a "big bang" in August 6, 1945 [48, pp. 101]. Even though we agree that these two points were essential for the anti-realist triumph, Popper's diagnosis leaves out a kernel element, namely, the systematic, violent oppression and persecution against critical thinkers. Something that would become customary within the academic world after the war... and up to our days. The strict limitations of an essentially inconsistent program difficult to be defended in the Agora of rational democratic debate would force their followers to apply plain brutality against critical voices. It is only through the constitution of a violent oppressive regime, which has continuously blocked the possibility of rational open debate and the search for understanding through the systematic persecution in classrooms and research institutes, that SQM and the complementarity approach to physics was actually established. Fortunately, there are many documented records through the decades which expose how this violence was continuously exerted on rebel students and researchers who would dare raise their voice and ask questions. Let us mention just a few of them in order to grasp the depth of this still unrecognized problem. For example, David Mermin would recall his student days in the late 1950s:

> "[The] vivid memories of the responses my conceptual inquiries elicited from my professors —whom I viewed as agents of Copenhagen— when I was first learning quantum mechanics as a graduate student at Harvard, a mere 30 years after the birth of the subject. 'You'll never get a PhD if you allow yourself to be distracted by such frivolities,' they kept advising me, 'so get back to serious business and produce some results.' 'Shut up,' in other words, 'and calculate'." [45]

The recently awarded Nobel prize winner, John Clauser, would also recall his experience as a student in physics during the 1960s in a similar fashion:

> "[G]iven Bohr's strong leadership, the net legacy of their arguments is that the overwhelming majority of the physics community accepted Bohr's 'Copenhagen' interpretation as gospel, and totally rejected Einstein's viewpoint. Any physicist who openly criticized or even seriously questioned these foundations (or predictions) was immediately branded as a 'quack'. Quacks naturally found it difficult to find decent jobs within the profession.

> [...] Religious zeal among physicists prompted an associated powerful proselytism of students. As part of the 'common wisdom' taught in typical undergraduate and graduate physics curricula, students were told simply that Bohr was right and Einstein was wrong. [...] Any student who questioned the theory's foundations, or, God forbid, considered studying the associated problems as a legitimate pursuit in physics was sternly advised that he would ruin his career by doing so. I was given this advice as a student on many occasions by many famous physicists on my faculty at Columbia and Dick Holt's faculty at Harvard gave him similar advice." [14, pp. p.70-73]

Of course, Clauser's work was not left without punishment. As described by Adam Becker:

> "Despite his groundbreaking experiment, John Clauser's career had also stalled out —and unlike Zeh, he didn't have a permanent position. When his postdoctoral position at Berkeley ended, Clauser struggled to find another job. 'I was sort of young, naive, and oblivious to all of this,' Clauser recalled. 'I thought it was interesting physics. I had yet to recognize just how much of a stigma there was, and I just chose to ignore it. I was just having fun.' Clauser's PhD advisor, Pat Thaddeus, wrote a 'recommendation' letter for Clauser's new job search, in which he warned prospective employers that Clauser's Bell experiments were 'junk science.' Thankfully, Clauser was alerted to the problem in the letter and didn't use it for his job applications. Instead, Shimony, d'Espagnat, and others wrote glowing letters in support of Clauser. But Thaddeus wasn't the only one who thought Clauser's work wasn't truly scientific. 'When I saw d'Espagnat last week he had a letter from the Dep't Chairman at San Jose, inquiring whether what you have been doing is real physics,' Shimony wrote to Clauser. 'Needless to say, he'll write a strong letter answering the question in your favor.' But their efforts led nowhere: Clauser couldn't get a permanent academic job." [5, pp. 254–255]

Lee Smolin, another U.S. physicist would share a similar recollection of his student days one decade later:

> "When I learned physics in the 1970s, it was almost as if we were being taught to look down on people who thought about foundational problems. When we asked about the foundational issues in quantum theory, we were told that no one fully understood them but that concern with them was no longer part of science. The job was to take quantum mechanics as given and apply it to new problems. The spirit was pragmatic; 'Shut up and calculate' was the mantra. People who couldn't let go of their misgivings over the meaning of quantum theory were regarded as losers who couldn't do the work." [51, p. 312]

During the 1980s the witch-hunting had not stopped. David Albert recently referred to the abuse he suffered as a PhD student in physics consequence of reading a text by the philosopher David Hume and expressing his interest in foundational issues about QM.

> "This was in the Physics department at Rockefeller. There were within fairly short order proceedings instituted to expel me from the PhD program. This was back in the late, very late 1970s, early 1980s. So this was in dark old days, but worrying about issues like that was profoundly unpopular. I got to stay in the program on the condition that I would work on a thesis topic assigned to me by the department, instead of one that I chose, and the one that was assigned was clearly one that was thought to be good for my character." [1]

These expositions must not be considered as a series of amusing stories or funny anecdotes, as they are many times banalized in the contemporary literature, but as true records exposing a deep and serious problem within the contemporary academic world. We are talking here of a program which has systematically exerted oppressive violence on students and researchers who ask critical scientific questions. Of course, violence is not enough, essential to the establishment of this irrational *status quo* in physics has been the tolerant, submissive role played by philosophy of QM itself, to which we now turn our attention.

1.4 Philosophical Tolerance and the "Map of Madness"

Today, the postulates of SQM are instructed to physics students as unquestionable rules which defy rational debate. Students are taught to respect the combination of instrumentalism and mythical narratives, to tolerate vagueness, inconsistency and fragmentation securing in this way the techno-instrumentalist ruling of science. In this context, theories have become replaced by a multiplicity of —not necessarily consistent— algorithmic models capable to account for specific situations in pragmatic terms. Guided by the anti-realist focus on measurement results, detached from the search of theoretical (formal-conceptual) consistency, coherency and unity, physics has become a purely instrumentalist enterprise only capable to predict outcomes through algorithmic models supplemented by a completely ungrounded yet highly effective fictional marketing. As clearly described by the U.S. philosopher of physics, and former physicist, Tim Maudlin:

"What is presented in the average physics textbook, what students learn and researchers use, turns out not to be a precise physical theory at all. It is rather a very effective and accurate recipe for making certain sorts of predictions. What physics students learn is how to use the recipe. For all practical purposes, when designing microchips and predicting the outcomes of experiments, this ability suffices. But if a physics student happens to be unsatisfied with just learning these mathematical techniques for making predictions and asks instead what the theory claims about the physical world, she or he is likely to be met with a canonical response: Shut up and calculate!" [44, pp. 2-3]

Sean Carroll, a popular U.S. physicist and youtuber, has recently uncovered what happens to students who choose not to "shut up":

"Many people are bothered when they are students and they first hear [about SQM]. And when they ask questions they are told to shut up. And if they keep asking they are asked to leave the field of physics..." [12]

Indeed, as described in the previous section, students and researchers seeking answers have been systematically persecuted within the field of physics. However, during the 1980s, things were seemingly starting to change. The marginal work by John Bell during the 1960s together with the experimental efforts by John Clauser one decade later, would set the conditions —at least, apparently— for a new realist debate. Outside the limits of empirical science, Philosophy of QM would become a new facility open to everyone willing to discuss once again, in the open, the true meaning of the theory of quanta —something which had been forbidden since the establishment of the Bohrian orthodoxy. Not only physicists, but also philosophers, logicians and mathematicians would congregate with enthusiasm in the growing number of meetings that would take place during the 1980s specially in Europe.[6] However, open as it might have seemed at first sight this new facility would become immediately controlled by the anti-realists creed. Realists would be forced to "tolerate" the main results imposed by SQM and produce only a superficial critique to orthodoxy. Very soon, the role that philosophy of QM ended up playing was not that of producing a deep critical analysis of SQM or the new instrumentalist approach of physics, but on the contrary, that of reinforcing the anti-realist —pragmatic, empirical and relativist— understanding of science. Anti-realists had strictly constrained the debates and problems that could be actually discussed within the new field, precluding any deep criticism against orthodoxy. An excellent example of this procedure would be the focus on the infamous measurement problem created by Dirac through his addition of the "collapse" of the quantum wave function, something done in order to secure the empirical-positivist requirement according to which QM should not refer to *intensities* —as Heisenberg had originally considered in order to develop QM— but to single *binary* 'clicks' observed in detectors. Quite ironically, this problem created by anti-realists themselves, would be soon called "the reality problem".[7] According to anti-realists its solution would require the help of realists who would add "interpretations" —namely, narratives of doubtful application— claiming to unveil the quantum reality-in-itself. In this way, philosophical debates would end up, instead of attacking the anti-realist foundation of QM, helping to subvert the understanding of realism, engulfing it within the limits of anti-realism itself.

It is in this context that an avowed anti-realist like van Fraassen [53] would provide an impotent definition of scientific realism in terms of interpretations. According to the Dutch logician [54]: "[s]cience aims to give us, in its theories, a literally true story of what the world is like; and acceptance of a scientific theory involves the belief that it is true." An interpretation provides a description of "what the world could be like if the theory were true." This scheme is of course explicitly clear in the context of SQM where physicist understood the theory as a "recipe" to predict measurement outcomes which are consequence of microscopic quantum realm that no one really understands. The debate about the meaning of quantum particles and reality would become then restricted to a purely philosophical debate that would avoid any critical consideration of the anti-realist praxis implemented to QM by instrumentalist physicists. In this way, philosophy of QM would help not to fight but to reinforce the Bohrian-Positivist orthodoxy. Given that interpretations of QM were conceived as narratives with no clear connection to the empirical theories they were supposed to explain, very soon their unregulated, limitless production would generate their exponential growth (see for a detailed discussion [2] and references therein). After a few decades of unconstrained production of narratives David Mermin [46, p. 8] famously declared: "[Q]uantum theory is the most useful and powerful theory physicists have ever devised. Yet today, nearly 90 years after its formulation, disagreement about the meaning of the theory is stronger than ever. New interpretations appear every day. None

[6] A good example are the series of encounters that took place in Loma-Koli and Johensu in Finland, during the years 1977, 1985, 1987, 1990, 1992 and 1994 organized by the physicist Kalervo Laurikainen and jointly edited as Symposia Proceedings by Claus Montonen, Pekka Lathi and Pieter Mittelstaedt.

[7] As Tim Maudlin [43] explains today: "The most pressing problem today is the same as ever it was: to clearly articulate the exact physical content of all proposed 'interpretations' of the quantum formalism is commonly called the measurement problem, although, as Philip Pearle has rightly noted, it is rather a 'reality problem'."

ever disappear." Philosophers of QM had no way for deciding which interpretation was meaningful and which was not, something that was called "the underdetermination problem" (we will return to this problem in section 5). Of course, physicists themselves could not care less. As Maximilian Schlosshauer explains, the interpretational results of philosophy of QM have remained completely unnoticed by the contemporary physics community.

> "It is no secret that a shut-up-and-calculate mentality pervades classrooms everywhere. How many physics students will ever hear their professor mention that there's such a queer thing as different interpretations of the very theory they're learning about? I have no representative data to answer this question, but I suspect the percentage of such students would hardly exceed the single-digit range." [50, p. 59]

The reason for the complete lack of interest is quite simple. Contemporary physicist take for granted the anti-realist account of science. As described by van Fraassen [53, pp. 202-203]: "an empiricist account of science is to depict it as involving a search for truth only about the empirical world, about what is actual and observable", more specifically, "science aims to give us theories which are empirically adequate: an acceptance of a theory involves as belief only that it is empirically adequate." And, of course, in this context, the "realist interpretational debate" cannot be regarded as part of the scientific enterprise. This is why Roberto Torretti [52, p. 367] is correct when pointing out that interpretations of QM should be considered as "meta-physical ventures [...] for they view the meaning and scope of QM from standpoints outside empirical science."

To conclude, the main result of this philosophical adventure has been to reinforce the orthodox *status quo* avoiding critical revolts. Today, while philosophers persist in publishing more and more ungrounded stories about QM, physicists continue to learn SQM in the same mythical-instrumentalist fashion that Bohr designed —with the help of Dirac and von Neumann— almost a century ago. There is no doubt that philosophers of quantum physics have been completely unable to produce any relevant effective criticism capable of forcing any change in the instrumentalist uncritical fashion in which quantum physics continues to be exploited. As a consequence, the role played by philosophy of QM has not only helped to reinforce the anti-realist understanding of empirical science, but has also allowed physicist to continue to uncritically apply their instrumentalist praxis to a theory they do not understand.

2 The Return of the Greek-Modern Scientific Methodology

The methodology that we have followed within the logos approach to QM is directly derived from our account of physics as a discipline which has always attempted to provide a solution —in different ways— to the Ancient Greek problem of movement: to define in theoretical terms what is *the same* through *change*, what is the *unity* that can be found within the *multiplicity* of experience, what is *identity* within *difference*. Plato and Aristotle would provide the first metaphysical solution to this problem through the construction of categorical systems grounded on specific principles. As we pointed out earlier, this understanding of metaphysics as a systematic conceptual account and production of experience acting as a pre-condition for discussing about any meaningful scientific observation is of course in contraposition to the contemporary negative account of metaphysics conceived as a mere narrative detached from experience.[8] In this context, the work of Galileo regarding *mathematical invariance* within physics must be considered as a development and extension of the line of research initiated by the Ancient Greeks, a solution to the problem of movement not only in terms of a difference in the evolution of the state of affairs but also in the consideration of different perspectives of analysis. It is then in classical mechanics that we reach the peak of the Greek program of science through the creation of infinitesimal calculus —developed by Newton and Leibniz— in order to account for a new conceptual representation of reality in terms of Newtonian space-time and metaphysical atomism —a picture extensively discussed and developed by Descartes and Newton, between many others. Continuing this development, in 1781, almost exactly one century after the publication of Newton's *Principia Mathematica* in1687, another physicist called Immanuel Kant would publish his *Critique of Pure Reason* where he would translate the mathematical notion of invariance to a conceptual level in terms of his kernel notion of *objectivity*, namely, the possibility to construct in categorical terms a moment of unity capable to be intersubjectively considered from different empirical perspectives as being *the same*.

It should be thus clear then that, contrary to the presentation provided by Arroyo and Arenhart, the methodology of physics we have proposed to follow within the logos approach is nothing but the way in which physical theories were developed since classical mechanics until the Bohrian-positivist re-foundation of physics —that we partially described in section 1.2. In short, following the characterization proposed by Einstein, Heisenberg and Pauli, any physical theory requires not only a mathematical formalism capable of a quantitative predictive account of

[8] As stated by van Fraassen [56, p. 36] explicitly: "The story of empiricism is a story of recurrent rebellion against a certain systematizing and theorizing tendency in philosophy: a recurrent rebellion against the metaphysicians."

experience but also a set of physical concepts capable of a qualitative account of phenomena. Both of these systems need to be consistently and coherently connected. The obvious example is the construction of infinitesimal calculus in order to account, in mathematical terms, for the physical concepts of space and time that had been discussed and developed —since the Greeks— for two millennia. As we pointed out above, while in mathematical terms the construction of moments of unity requires a *transformation* which allows to describe in invariant terms a state of affairs independently of reference frames, in conceptual terms what is required is the construction of an objective (in the Kantian sense) system of concepts that is able to bring into unity the multiplicity of experience independently of different empirical perspectives. In turn, both mathematical and conceptual systems must be also brought, consistently and coherently, into unity. In a nutshell, the construction of a physical theory implies the creation of consistent, coherent and unified systems of representational thinking that lead to specific *moments of unity* such as the notion of 'particle' in classical mechanics or the notion of 'electromagnetic wave' in the theory of Maxwell.

As it should be clear by now, this realist praxis stands at safe distance from the contemporary anti-realist realist methodology (described in section 1) where the *moment of unity* is taken for granted as an unproblematic (pre-theoretical) *given* which requires no explicit definition whatsoever. In this case, the lack of a systematic account of *what there is* is not something restricted to observable entities (such as tables, chairs and dogs) but is also extended to non-observable ones (such as atoms, electrons and quarks). It is because unity is understood as an unproblematic *given* that the Bohrian-positivist understanding of physical theories grants the tolerant acceptance of inconsistency and vagueness which leads immediately to an extreme fragmentation within the modelistic-interpretational account of empirical science. Since the anti-realist presupposes a (pre-theoretical) reference which requires no explicit definition and cannot be truly unveiled, the best we can get —according to the skeptic viewpoint— is a multiplicity of —not necessarily consistent— models which can be vaguely defined and, in turn, supplemented with fictional narratives —called in the philosophical jargon 'interpretations'. The complete lack of any theoretical constrain opens then the door to the anarchic fragmentation of both models and interpretations. As Fayerabend —following Bohr explicitly (see for a detailed analysis [57])— would famously claim: "Anything goes!" This is in fact, a simple reformulation of Bohr's complementarity approach exposed also by Ian Hacking when characterizing the modelistic work of instrumentalist contemporary physicists:

> "Various properties are confidently ascribed to electrons, but most of the confident properties are expressed in numerous different theories or models about which an experimenter can be rather agnostic. Even people in a team, who work on different parts of the same large experiment, may hold different mutually incompatible accounts of electrons. That is because different parts of the experiment will make different uses of electrons. Models good for calculations on one aspect of electrons will be poor for others. [...] There are lot of theories, models, approximations, pictures, formalisms, methods and so forth involving electrons, but there is no reason to suppose that the intersection of these is a theory at all." [38, pp. 263-264]

To sum up, while realist physicists search for theoretical (formal-conceptual) representational systems following the principles of operational-invariance and objectivity, in the anti-realist case we find an ontological (non-metaphysical) standpoint in the modern presupposition that the "physical world is composed of entities." Thus, while the realist methodology implies a search for theoretical unity, in the anti-realist case unity is *given* right from the start in terms of presupposed —observable or unobservable— entities. While in the first case representation is a construction guided by consistency and coherency, in the latter case inconsistency and vagueness are tolerated as expressions of the impossibility of any *true* representation of reality-in-itself. The essential point we would like to stress here is that these completely different presuppositions imply not only completely different goals but also radically different ways of achieving them. The radical divergence between realist and anti-realist presuppositions impose, consequently, a radical divergence with respect to their basic methodology and praxis. It becomes now evident why the presentation provided by Arroyo and Arenhart —which grounds itself in the anti-realist realist scheme— subverts our realist approach right from the start, by changing the basic presuppositions and concepts at stake.

3 A Spinozist Account of Scientific Representation and Knowledge

Today, the problems discussed in the orthodox philosophical literature about SQM are the direct consequence of the self-contradictory presuppositions imposed by anti-realist realism. In short, we can list them in three groups. Notice that all these problems were constructed through the imposition of a necessary link to the classical realm and its conceptual representation.

I. **The quantum to classical limit:** We need to provide an account of the (presupposed) path from the microscopic quantum realm to the macroscopic classical realm, namely, explain the way in which quantum particles end up transforming themselves into tables, chairs and dogs.

II. **The classical no-problems of QM:** We need to explain what "quantum particles" really are in terms of classical concepts. Something which has produced a purely negative characterization of quantum objects in terms of many sub-problems such as non-locality, non-individuality, non-separability, non-identity, etc.

III. **The measurement problem:** Given that SQM *must* predict (binary) 'clicks' in detectors, we need to explain the "collapse process" imposed in an *ad hoc* fashion by Dirac —namely, how to bridge the gap between quantum superpositions and single measurement outcomes— through the addition of an 'interpretation'.

However, as we argued above, if we shift our presuppositions to realist ones we are faced with a completely new set of problems which, in turn, impose a new methodology. In this respect, two of the most essential problems for any realist who attempts to make sense of contemporary physics are the following:

I. **Representation, truth and reality:** How can we make sense of scientific theoretical representations as providing true knowledge about *physis*? Or, how can we understand *truth* as a relation between theoretical representation and reality which escapes its subjective relativization in terms of *beliefs* or its naive (pre-Kantian) account in terms of *correspondence*?

II. **Different representations but the same reality:** How can we construct a metaphysical scheme where completely *different* theoretical representations (e.g., classical mechanics and quantum mechanics) can provide true knowledge about *the same* reality?

Representational realism is a Spinozist attempt to solve these two interconnected problems —which clearly depart from the anti-realist problems discussed in the orthodox literature. While the first implies a necessary reconsideration of the role of physical representation in terms of a truthful formal-conceptual determination of experience —beyond the purely abstract mathematical account of algorithms or the unrealistic reference to mythical narratives grounded on subjective beliefs—, the second problem requires to make sense of the way in which *different* representations are capable —all of them— to account in a truthful manner for *the same* reality.

As remarked by Arroyo and Arenhart: "A physical theory, according to the representational realist program, is an enterprise to represent nature." This is indeed the case, however, our main attempt is to critically reconsider the role of *representation* itself. As discussed in [15, 16], representational realism attempts to provide an understanding of representation not in terms of a *mirror* which unveils a reality (composed of entities) waiting to be discovered, but in terms of a *net* which is capable of *expressing* the immanent relations of *physis* —which is not "Some-Thing". According to this viewpoint, physical theoretical representations —which, of course, are themselves part of reality— must be understood as weaving together mathematical formalisms with conceptual systems, creating a net capable of producing an immanent operational connection with a specific field of experience derived immanently from the representation itself.[9] It is this powerful immanent relation which allows not only to bridge the gap between *theory* and *physis* in terms of coherentism, but also to go beyond it, explaining and predicting phenomena in quantitative and qualitative terms, generating a new field of thought-experience which allows to surf reality beyond the technical and conceptual limitations of previous experience and representations. This is, according to us, the true power of physics which goes beyond prediction and explanation. The creation of consistent, coherent and unified (invariant-objective) theoretical (formal-conceptual) representations allows to investigate new fields of experience through *thought*, opening the doors not only to new observations but —more importantly— to new ways of observing.

4 A Positive Proposal: Intensive Invariance and Objectivity

It must be clear by now that a specific methodology is not only grounded on particular principles but also imposes a series of problems, goals and ways of achieving them. Now, given the Greek-Modern methodology we described, the obvious question that rises is the following: can we apply it to QM? And also, what would be the result of this unorthodox line of research? It is exactly this which we have attempted to find out within the logos categorical approach to QM. Let us discuss the consequences of this positive proposal in some detail.

In the first place, by following the thread of operational-invariance in order to address the mathematical formalism of QM, it becomes evident that there was, in the historic development of the theory, a shift of reference from intensive values —originally considered by Heisenberg in his matrix mechanics— to the binary results of 'clicks' in detectors —imposed by Bohr, Dirac and von Neumann within the standard vectorial formulation of the theory.

[9] Notice once again that conceptual systems are not "added to the theory", as implied by Arroyo and Arenhart in many passages of their text. Conceptual systems constitute the theory. Without a conceptual system, there is no theory.

This fact becomes obvious once we address Heisenberg's creation of the theory. As he remarked, his approach was guided by the abandonment of the —still modern— metaphysical picture that Bohr wanted to impose in terms of microscopic particles following spatiotemporal trajectories, and its replacement by the strict consideration —following Mach's principle of observability— of the intensive values that were actually measured in the lab. The formalism was thus constructed in order to account for the observed intensities in invariant terms right from the start. And the explicit destruction of this invariance, just a few years later, was a direct consequence of the shift imposed by Dirac from the intensive values discussed by Heisenberg's theory to the binary measurement outcomes that Bohr wanted to address in terms of (irrepresentable) microscopic particles. As a direct consequence of the destruction of invariance Dirac would embrace the contextual (inconsistent) reference to quantum objects that Bohr had already imposed through his notion of *complementarity*, but now explicitly developed in mathematical terms through a re-definition —in fact, a complete subversion— of the notion of (quantum) *state* itself. According to Dirac the notion of quantum state, giving up the consistent translation secured by operational-invariance, would become dependent on the choice of each particular basis. This lack of a global valuation of the same quantum state, as considered from different bases, would be exposed decades after by the famous Kochen-Specker theorem [42]. Now, what was explicitly demonstrated in the first paper of the logos approach, is that if one restores the original reference to *intensive values* it is possible to obtain a *global intensive valuation* for all bases dependent representations of the same *intensive state of affairs*. This formal-conceptual move allows to escape the contextual reading of the theory of quanta that was imposed by Bohr, Dirac and von Neumann allowing, in turn, to rehabilitate a detached invariant representation in tune with Einstein's objectivist-invariant understanding of physics.

The logos approach provides an invariant scheme grounded on the intensive values of projection operators and in this way allows to restore a consistent reference to *the same* (intensive) state of affairs independently of any particular basis. In technical terms, what has been demonstrated is that by considering an *intensive*, rather than *binary*, state of affairs, it is possible to restore a consistent global valuation for all projection operators independently of the basis. In order to see this more clearly, let us recall some results from [30]. While a *Global Binary Valuation* (GBV) is a function from a graph to the set $\{0,1\}$, a *Global Intensive Valuation* (GIV) is a function from a graph to the closed interval $[0,1]$. We term projection operators as *intensive powers*.[10] Let H be a Hilbert space and let $\mathcal{G} = \mathcal{G}(H)$ be the set of observables. We give to $\mathcal{G}$ a graph structure by assigning an edge between observables P and Q if and only if $[P,Q] = 0$. We call this graph, *the graph of powers*. Among all global intensive valuations we are interested in the particular class of Intensive State of Affairs (ISA).

Definition 4.1. *Let H be a Hilbert space. An* Intensive State of Affairs *is a global intensive valuation $\Psi : \mathcal{G}(H) \to [0,1]$ from the graph of powers $\mathcal{G}(H)$ such that $\Psi(I) = 1$ and*

$$\Psi(\sum_{i=1}^{\infty} P_i) = \sum_{i=1}^{\infty} \Psi(P_i)$$

for any piecewise orthogonal projections $\{P_i\}_{i=1}^{\infty}$. The numbers $\Psi(P) \in [0,1]$, are called intensities or potentia and the nodes P are called powers. *Hence, an ISA assigns a potentia to each power.*

Intuitively, we can picture an ISA as a table,

$$\Psi : \mathcal{G}(H) \to [0,1], \quad \Psi : \begin{cases} P_1 & \to & p_1 \\ P_2 & \to & p_2 \\ P_3 & \to & p_3 \\ & \vdots & \end{cases}$$

Theorem 4.2. *Let H be a separable Hilbert space,* $\dim(H) > 2$ *and let $\mathcal{G}$ be the graph of powers with the commuting relation given by QM.*

- *Any positive semi-definite self-adjoint operator of the trace class ρ determines in a bijective way an ISA $\Psi : \mathcal{G} \to [0,1]$.*
- *Any GIV determines univocally a set of powers that are considered as truly existent.*

Proof. Using Born's rule, we can assign to each observable $P \in \mathcal{G}$ the value $\mathrm{Tr}(\rho P) \in [0,1]$. Hence, we get an ISA $\Psi : \mathcal{G} \to [0,1]$. Let us prove that this assignment is bijective. Let $\Psi : \mathcal{G} \to [0,1]$ be an ISA. By Gleason's theorem there exists a unique positive semi-definite self-adjoint operator of the trace class ρ such that Ψ is given by the Born rule with respect to ρ.

[10] For a detailed introduction, analysis and discussion of the notion of 'intensive power' we refer the interested reader to [16], and more specifically, [30, Sect. 8] and [28, Sect. 3].

Consider the function $\tau : [0,1] \to \{0,1\}$, where $\tau(t) = 0$ if and only if $t = 0$. Now, given a GIV $\Psi : \mathcal{G} \to [0,1]$, the map $\tau\Psi : \mathcal{G} \to \{0,1\}$ is a well-defined map.

□

Iit is then possible to derive a non-contextuality theorem which demonstrates that a global (intensive) valuation for all projection operators of the same state is always possible.

Theorem 4.3. (Intensive Non-Contextuality Theorem) *Given any Hilbert space H, then an ISA is possible over H.*

Proof. See [30]. □

Now, the elements that can be consistently considered in invariant formal terms are the *projection operators* which are quantified intensively —a quantification which can be computed through the Born rule. These are, evidently, the formal moments of unity we where looking for. But according to our realist understanding of theories as formal-conceptual-operational schemes, these mathematical elements require a conceptual counterpart. And it is exactly this which we attempted to develop through the notion of *power of action*. Given this formal choice and the restoration of an operational-invariant mathematical formalism, it is then necessary to develop an objective conceptual scheme that matches the basic features of that formalism. In the conceptual level, the thread of Ariadna that guides our way out of the anti-realist maze is of course objectivity (in the Kantian sense), namely, the possibility to define in consistent categorical terms a *moment of unity* capable to make sense of (quantum) phenomena. Just in the same way as the notion of 'particle' in classical mechanics or the notion of 'electromagnetic wave' in the theory of Maxwell were able to unite different —in principle incompatible— phenomena, the notion of *power of action* must be able to consistently and coherently bridge the gap between the invariant formalism of the theory and a —still required— conceptual scheme capable of explaining —in consistent and coherent terms— what the theory is really talking about. This conceptual system is not a mere "interpretation" of the mathematical formalism but a necessary component of the theory itself without which —as repeatedly stressed by Einstein and Heisenberg— it becomes simply impossible to say what has been observed.

The realist line of research does not impose the anthropocentric need to subsume the representation of QM within the gates of the ontologically presupposed micro-macro spatiotemporal scheme. The concept of *power of action* —which is still work in progress— needs to be developed by taking seriously the constraints imposed by the operational-invariant mathematical formalism of the theory.

- QM is a theory that refers to *intensive elements*.
- QM provides an operational-invariant description of an *intensive states of affairs* which cannot be reduced to an underlying binary representation or actual state of affairs.
- Quantum probability provides an intensive quantification of the invariant elements the theory talks about. Unlike in classical statistical mechanics, quantum probability cannot be understood in terms of ignorance about an underlying actual state of affairs.
- The mathematical space of QM (i.e., configuration space) is a discrete multi-dimensional space of *degrees of freedom* (or powers of action) which cannot be consistently related to Euclidean space.
- In QM, the intensive elements interact between each other according to the formalism of the theory in a manner that escapes the classical representation.

As it becomes clear from these constraints, the theory must necessarily depart from the modern ontological account of physical reality restricted to the representation of a material, actual, spatiotemporal world composed of entities. The intensive elements the theory talks about have nothing to do with particles, waves or any other form of spatiotemporal entity. There is an obvious divergence between the anti-realist program, which imposes the need to link QM —understood as describing a microscopic realm— with our classical "manifest image" of the world, and the realist program which does not involve any "correspondence" or "limit" between QM and the classical representation. Classical concepts have no primacy over the new systems of concepts that can be developed in order to understand new physical theories. An essential aspect of the realist Spinozist methodology discussed in the previous sections is that every theory can be regarded —following Heisenberg's understanding— as a *closed theory* which connects to *physis* in an independent and immanent manner —evading the pre-Kantian "mirror" account of truth-correspondence.

Our account of powers goes against the basic cornerstones of anti-realism. On the one hand it detaches itself completely from the ontological principle and the metaphysical account of the actuality (i.e., the idea that physical reality must be understood in terms of 'entities' in the world) and on the other, it also distances itself from the the empiricist account of actuality in terms of (binary) events, measurement outcomes or observations. As noticed before, the reference to microscopic particles is considered in this context as an epistemological obstruction imposed by the modern-illuminist tradition. Arroyo and Arenhart implicitly presuppose the anti-realist setting when analyzing the logos approach, and for this reason they implicitly subvert the concepts we have developed. A clear example is the way in which they analyze *powers of action*. For example, when they claim that powers are *dispositions* which need to actualize: "The result is that a kind of ontology of unactualized potencies will be seen as the more appropriate subject matter of the theory. A newly developed version of hylomorphism is required [...]" This is clearly missing the point. We have been explicit about the fact that powers of action are not defined in terms of an hylomorphic actualization. In fact, escaping the teleological reference to actuality we have proposed to consider a new *intensive effectuation* which addresses the interactions between powers described by the theory of quanta —independently of actualities. Our claim, which distances ourselves not only from the many interpretations but from empirical science itself, is that QM simply does not talk about actualities (see for detailed discussions [16, 17, 18, 19]).

It is through the ontological principle that Arroyo and Arenhart also attempt to subsume the understanding of powers in terms of their dependence to subjects (or agents).

> "[The] discussion concerning the difference between dispositions with and without a bearer is important, and we cannot find any easy option for de Ronde. If dispositions have a bearer, then, it seems, we are back to an object-oriented ontology, which he abominates. If, on the other hand, they do not have a bearer, we miss the analogy with the Messi-Neymar case, which would confer the intelligibility of the view (or, to the same effect, the baseball players analogy)." [3, p. 898]

Once again, the question of bearers is imposed on us through an anti-realist ontological presupposition. The physical world is composed of entities and if powers exist they need to be necessarily understood in relation to these presupposed existents. Of course, this dogmatic idea is clearly unnecessary. The example of Messi and Neymar is completely analogous to the way in which the theory of electromagnetism is able to account for the magnetic attraction between two rocks. Electromagnetism can explain the phenomena even though it does not talk about rocks. Just in the same way that electromagnetism can explain this observable phenomena in terms of electromagnetic waves without the need to see the rocks as bearers of the magnetic force, QM is also capable to explain the interaction between powers without the need to refer to Messi and Neymar. Obviously, this new way of thinking implies the need to go beyond the limits imposed by the anti-realist —or modern-illuminist— tradition to "physical reality" in terms of the ontological principle —something that breaks down not only "common sense" but maybe the most important cornerstone of the anti-realist scheme itself.

5 (Realist) Understanding or (Anti-Realist) Underdetermination?

Understanding within physics and philosophy, since its Greek origin, has been always related to the search for consistent and coherent theoretical unity. While the mathematical formalism of a theory must be consistent and operationally-invariant, its conceptual system must be coherent and operationally-objective (in the Kantian sense). While the mathematical formalism must provide a quantitative account of experience, the conceptual system must be able to account for it in a qualitative fashion. The realist representation must be seen as a theoretical plane created by a net of mathematical and conceptual operational inter-relations which, in turn, are able to relate to *physis* through experience in an immanent manner. The requirements for constructing a net through these highly complex interconnections strongly constrain the possibilities of development of any theory. Obviously, it is not easy to produce a closed theory which agrees with all these conditions. But once the theory is developed and all interconnections are set it will remain unchanged. This is the reason why classical mechanics or electromagnetism have been always presented in the same manner. There are no different mathematical formalisms or interpretations of these theories. Classical mechanics is only understandable in terms of infinitesimal calculus and a conceptual representation in terms of particles evolving and interacting within absolute and continuous space and time. The same happens with electromagnetism which can be only represented in terms of the physical concept of wave and Maxwell's equations. Both of these theories have a consistent and coherent mathematical formalism, a specific system of interrelated concepts as well as a clear operational account of experience. However, as we all know, these realist conditions, which guide as well as constraint the meaningful production of physical theories, were replaced during the Bohrian-positivist re-foundation of the discipline. And it was the theory of quanta itself which was used in order to change the rules of production and meaning of physical theories in general. As we described in previous sections, the Bohrian-Positivist alliance allowed to replace the general conditions of theory production (e.g., invariance, objectivity, operationality, consistency, coherency and unity) by the tolerant acceptance of any vague or inconsistent model capable of providing empirical results.

Indeed, the anti-realist account of theories established during the 20th century in terms of algorithmic models has only one constrain, namely, to predict measurement outcomes, actualities or events. That's it. It does not really matter if the model is not invariant or inconsistent (like in the case of SQM or decoherence), it is not not truly important if the "added" interpretation is conceptually vague, lacks objectivity or is self-contradictory (like many narratives used to "explain" SQM), it is not essential that the formalism is consistently defined in mathematical terms (like in the case of Quantum Field Theory), and even theories which depart from empirical adequacy are acceptable (like it in the case of Superstring Theory). Anything goes! In the anti-realist pragmatic account of scientific knowledge, while every model must be accepted as a possible way to account for actualities, every interpretation, every ontology and every metaphysical scheme must be "tolerated" as a possible way of "unveiling" —an actually unreachable, irrepresentable, always distant— reality-in-itself. It is certain that we cannot know, but —as a way to justify the addition of narratives required by anti-realists themselves— we also cannot know if we actually know. An interpretation could be *true*, as well as an ontology or a metaphysical scheme, the problem is that —according to the anti-realist skeptic— we cannot actually know if this *is* or *is not* the case. Thus, we might better remain "agnostic" about the narratives of theories [55]. In the anti-realist setting, while the "modelistic knowledge" about the world is only pragmatic, the "interpretational", "ontological" or "metaphysical" layers of "knowledge" cannot be understood as providing any certain *true* account of reality. As explained by Popper:

> "The empirical basis of objective science has thus nothing 'absolute' about it. Science does not rest upon solid bedrock. The bold structure of its theories rises, as it were, above a swamp. It is like a building erected on piles. The piles are driven down from above into the swamp, but not down to any natural or 'given' base; and if we stop driving the piles deeper, it is not because we have reached firm ground. We simply stop when we are satisfied that the piles are firm enough to carry the structure, at least for the time being." [49, p. 111]

The claim that a theory talks about reality in a true manner implies —according to the anti-realist— an unjustified act of faith which goes beyond the scope of empirical science. And in fact, it is not even necessary. So, does this mean that, according to anti-realists, theories do not talk about reality? Well, not so fast. It is at this point that the anti-realist makes a paradoxical move: she will not deny the link, but —instead— relativize it. Her skeptic answer will be: "we simply do not know". Do physical theories refer to the world? Is climate change really happening? Did dinosaurs truly exist? Are galaxies really out there? Only God knows... It is not the denial but the relativization of any true reference which allows the anti-realist to consider a representation without any foundation, without any true reference. Of course, for any true realist who understands that knowledge only makes sense in terms of a *true reference* (to reality), this anti-realist relativization is an inconsistent nonstarter. Knowledge —of course— has meaning only if, firstly, there is a clear *reference* to what we know (i.e., reality), and secondly, if we have a set of conditions that grant us the possibility to distinguish between knowing and not-knowing. If we do not know that we know, then —obviously— it is not knowledge.

In this ungrounded swampy context, underdetermination is nothing but the natural consequence of the anti-realist anarchy ruled by a dogmatic ontological representation and the algorithmic prediction of measurement outcomes. Given there are no general constraints for empirical theories apart from their predictive capacity, the pragmatic justification of empirical science rapidly leads to different forms of fragmentation. On the one hand, we find a **vertical fragmentation** of "theories" consequence of the layered architectonic grounded on observations —which are known as *givens* and at the same time un-known as *representations*—, supplemented with a layer of models —which describes and does not describe the first—, followed by an interpretational layer —which explains and does not explain the model—, and then with an ontological one —which explains and does not explain the interpretation—, and then with a metaphysical layer —which specifies or not the ontology of the interpretation of the model... On the other hand, we also find in every level of this anti-realist maze, consequence of the uncritical tolerance towards vagueness and inconsistency, an **horizontal fragmentation**. Indeed, due to the complete lack of constraints, it is always possible to create many different models that account for the same set of events (model underdetermination), given there are no restrictions in the conceptual level any narrative can be "added" to the different models (interpretational underdetermination), and —of course— the same applies to the ontological (ontological underdetermination) and the metaphysical layers (metaphysical underdetermination). In this way, anti-realists are able to keep producing models, interpretations, ontologies and even metaphysical schemes even though they remain unable to say what is meaningful and what is not, what is right and what is wrong, what is true and what is false. Every concept —including of course *truth* itself— becomes relativized and *reference* an impossible approximation to an end we can never reach. It is this anti-systemic and anti-methodic praxis which has led the field into an irrational "map of madness" [10], namely, the extreme fragmentation of knowledge, the destruction of all foundations and the disintegration of rational thought and debate. With no guide, with no compass, everything becomes scrambled in a field where there is no up nor down, no clear limit between layers nor definitions of what is actually being discussed.[11] While antirealists patrol in rhetorical circles, tolerance towards the unacceptable becomes extended and failures are taken for solutions. In short, while (realist) understanding is a direct result of the theoretical unity built on the search for a representation of *the same*, (anti-realist) underdetermination (or fragmentation) is the natural consequence of welcoming vagueness and inconsistency within the many layers of an a-systematic representation with no true reference.

The understanding of QM will be reached only if we are capable of providing a consistent, coherent and unified formal-conceptual-operational scheme that explains intuitively quantum phenomena. In this context, "intuitive" cannot be regarded as a synonym of "commonsensical" or "classical" —as implicitly applied by Arroyo and Arenhart— but as implying a new way of thinking about experience in consistent and coherent terms, invariantly and objectively. Again, we agree with Heisenberg [39, p. 172]: "We believe we have gained *anschaulich* [intuitive] understanding of a physical theory, if in all simple cases, we can grasp the experimental consequences qualitatively and see that the theory does not lead to any contradictions." There is thus, an essential divergence in the role of "intuition" in the realist —as we use it— and in the anti-realist —as Arroyo and Arenhart apply it— viewpoints. While the anti-realist takes the classical representation of physics to be describing our intuitive "manifest image" of the world; in the realist case intuition implies a way of thinking about phenomena which is not *given*. In this latter case intuition is always something to be constructed through the careful development of a closed physical theory. When physicists learn the theory of electromagnetism they are capable to develop an "intuitive grasp" of magnetic and electric phenomena in terms of waves which interact within a spatiotemporal medium. This intuitive understanding of electromagnetic phenomena is something that physicists can only reach after following a long course where they learn the theory, namely, how to think in terms of the mathematical formalism and a specific conceptual system. In analogous terms, the notion of *power of action* was —just like the physical concept of electromagnetic wave— developed in order to provide an objective understanding of a specific (quantum) field of experience described in mathematical terms by matrix mechanics. The reference of QM is *physis*, not the classical representation nor any "common sense" manifest image of the world. And for this reason, the conceptual system that is required can be only derived from the conditions imposed by the realist Greek-Modern program of science itself.

6 Results and Replies

Within the logos approach we can list a series of interesting and important results:

- The restoration of invariance and consistency of the mathematical formalism through the re-introduction of intensities as the operational reference of the theory [27].
- The derivation of the non-contextuality intensive theorem [30].
- The critical exposition of the inconsistencies present, in the context of SQM, within the notions of *pure state* [32] and *mixture* [33].
- The critical exposition of the inconsistencies present in the contemporary uncritical account of quantum entanglement [29].
- The derivation of an invariant-objective definition of quantum entanglement [31].
- The derivation of an invariant-objective account of bases and factorizations grounded on the derivation of two theorems, namely, the *Basis Invariance Theorem* and the *Factorization Invariance Theorem* [34].
- The constitution of a coherent bridge between the mathematical formalism and a specifically designed system of operational concepts [25].
- The derivation of an invariant-objective measure for quantum entanglement [26].

All these results show that there is a line of research —different to the mainstream anti-realist production of models and interpretations— which, following the guide of the realist Greek-Modern program of science —namely, the

[11] In fact there is even no consensus within the filed of what is to be considered a 'theory' and what is an 'interpretation' or an 'ontology' or even a 'metaphysical scheme' [2, 13].

search for systematic theoretical unity—, can provide important results when attempting to understand the theory of quanta.

Science does not attempt to reach a subjective consensus between a group of individuals that conform a tribe. And reaching such a consensus does not imply anything about science —QM being a good example of this. Science attempts to produce, through the invariant-objective *reference* to a common *moment of unity*, a rational representation capable to access essential truths about *physis*. *Divide et impera* has been the strategy undertaken by anti-realists in order to fight the realist search for unity. By separating and isolating every element of the realist net, anti-realists have been able to subvert the praxis and reference of science. *Reality* has been dissected through the constant production of binary poles: internal and external, objective and subjective, material and cognitive, human and nature, phenomenic and noumenic, observable and un-observable, etc. And the same has taken place with *theories* in both formal and conceptual terms. While the search for consistent mathematical formalisms has been replaced by a multiplicity of inconsistent models, the need of conceptual systems have been replaced by vague narratives which in themselves possess different layers: an interpretational layer, an ontological layer and even a metaphysical layer —none of which is clearly defined. It is in this context, that Arroyo and Arenhart have attempted to place our scheme back within the walls of the anti-realist maze. A good example of this strategy is the implicit replacement of our realist metaphysical search —i.e., the systematic conceptual production of *moments of unity*— by the dogmatic anti-realist ontological goal:

> "That accounts for the ontology of de Ronde's approach: there is a claim about what populates the world, and, equally important, a claim about how one finds this out: ontology is extracted from the theory. Now, we also have what *we* term 'metaphysics'. This is a distinct enterprise, related to the traditional field of philosophy called metaphysics, dealing with issues of the nature of entities: the nature of particulars, of properties, of space, time, modalities, mind, and so on. In our terms, metaphysics goes beyond ontology, by providing a kind of profile to the posits of the theory." [3, p. 894]

As we discussed above, the presupposition of the existence of 'things' or 'entities' goes clearly against the scientific project understood as a search for an explicit theoretical definition of *moments of unity* that allows to account for experience and observation —not the other way around. While in the first case, the unity is given within experience, in the latter case it is theoretically produced. This marks an essential distinction regarding the primacy of experience, observation and measurement over theoretical representation and vice versa. In the first case, since observation provides a direct access to the 'things' that exist, theories become just a way of characterizing those already presupposed 'entities'. On the contrary, in the latter case, as Einstein would explain to a young Heisenberg: "It is only the theory which decides what can be observed." It is only once we produce a closed theory that we reach the *moments of unity* capable to produce understanding of phenomena. In this respect, representational realism evades the conclusion presented by Arroyo and Arenhart [3, p. 894]: "according to de Ronde's proposal, and using our terminology, quantum theory itself informs us about its *ontology*: immanent powers and their potentia populate the world." Powers of action are not a way of unveiling the entities that populate physical reality (i.e., the ontological principle), they are part of a theoretical net that needs to be constructed in order to understand quantum phenomena and, in this way, trap a true immanent expression of *physis*. However, once again, Arroyo and Arenhart relativize our realist search and subsume it under the anti-realist scheme where, instead, we find a multiplicity of unconstrained narratives used in order to skeptically degrade our realist proposal as just one more —between the many— fictional illusions that can be found in the literature.

> "Perhaps one could claim that the nature of such entities is not granted, but clearly they behave in a way as suggested by de Ronde. They are powers, latencies, dispositions, or something of the kind, right? Notice that even if that is granted (and that is quite a big 'if'), it is very unclear what kind of image is being obtained. Talk of powers and dispositions leaves us very far from a particular image. As French has put it: '[...] if you were to collect 10 defenders of dispositionalism or 'powers' views more generally and put them in a room, you would get 15 different accounts!' (French 2020, p. 191)." [3, p. 898]

What Arroyo and Arenhart do not take into account is that our proposal has followed a series of general constraints which, contrary to the many narratives, allowed us to produce an objective-invariant representation which bridges the gap between the mathematical formalism, the conceptual system and their common operational content. It is their tolerance towards inconsistency and vagueness which allows them to consider our proposal on equal footing to the many fictional narratives that populate philosophical journals. Since "anything goes!", given there is no way to say what is true and what is false, our proposal, according to Arroyo and Arenhart's [3, p. 907] conclusion "is not a way to avoid commitment to uncritical images of reality, but rather, one further position in the already huge cart of options of quantum mechanics." We hope to have shown why this is certainly not the case.

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