Theology and Science, 2015
Vol. 13, No. 4, 378–393, http://dx.doi.org/10.1080/14746700.2015.1082872

The Quantum Amplification Problem Appears to be Unsolvable

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Abstract *For quantum mechanics to form the crux of a robust model of divine action, random quantum fluctuations must be amplified into the macroscopic realm. What has not been recognized in the divine action literature to date is the degree to which differential dynamics, continuum mechanics, and condensed matter physics prevent such fluctuations from infecting meso- and macroscopic systems. Once all of the relevant physics is considered, models of divine action based on quantum randomness are shown to be far more limited than is generally assumed. Unless some sort of new physical mechanism is discovered, the amplification problem cannot be solved.*

Key words: Divine action; Noninterventionism; Quantum mechanics; Protectorates; Amplification

A. Nonintervention and quantum mechanics

Working at the border of science and theology, one finds that physics giveth, and physics taketh away. Newton appealed to God in order to explain the dynamic stability of the planets; Lagrange later showed that the solar system is sufficiently stable that we don't need to worry about it.[1] Theists hailed the Big Bang as proof of creation a finite time ago; cosmologists now seem determined to eliminate the singularity from their spacetime models.

Then there is the question of how God governs creation. In particular, are there ways in which God might act without violating the laws of nature? Many today in science-and-religion circles believe that quantum mechanics has answered this question. The intrinsic randomness of the quantum world, we're told, provides the means through which God can act without breaking natural law. And so physics giveth. As we shall see, physics has once again turned fickle. The central argument of this paper is that whatever God might do at the quantum level, nature by and large prevents those actions from affecting the macroscopic realm.

Some readers know that I have just thrown down the gauntlet. For those who aren't sure what the fight is about, let's go back to the idea of noninterventionism: God does not violate the laws of nature. One extreme version of this was Enlightenment-era deism, in which God creates and sustains the universe, but that is it. No miracles, no special revelation.[2]

Today, many noninterventionists take a more hands-on approach. On their view, God actively governs, but does so, again, without violating any laws of nature. The most popular version of this is what I will call *quantum determination*. It starts with the idea that quantum mechanics is indeterministic, at least under its most familiar interpretation. Some events at the quantum level are metaphysically random, as opposed to the mere epistemic randomness found in classical mechanics. So, consider the radioactive decay of a specific uranium 232 atom. Such events are random in the sense that they are not physically determined by any prior cause.[3] As far as nature is concerned, there is only a probability that a decay event will occur at any given time. This particular uranium atom has a 50% chance of decaying any time in the next 69 years, and a range of such chances for times sooner and later than that. Under quantum determination, God could will this atom to decay in exactly five minutes without violating any laws, since there is some physical probability that it will, in fact, do so. God merely chooses the timing of this objectively random event. And since nature is, at root, quantum mechanical, God can influence the physical world without breaking the laws of nature. Well-known proponents of quantum determination include Robert Russell, Nancey Murphy, and Thomas Tracey.

A persistent problem with this idea is that, apart from a handful of exceptions mentioned below, what goes on at the quantum level stays at the quantum level, at least when we are talking about those random collapse events through which God is supposed to act. In the literature, this is known as the *amplification problem*. There might be plenty of opportunities for God to act at the quantum level, but unless those events can be amplified into the macroscopic realm, then there isn't much that God can do with them. As Tracy puts it,

> [I]ndeterministic chance at the quantum level would need to make a difference in the way events unfold in the world. Chance will be irrelevant to history if its effects, when taken together in probabilistic patterns, disappear altogether into wider deterministic regularities. It is commonly said that this is the case with quantum indeterminacies, since the statistical patterns of these events give rise to the deterministic structures of macroscopic processes.[4]

So while there are many indeterministic quantum events, they rarely have anything to do with the realm of our experience. For God to effectively govern nature by way of quantum mechanics, these events must be amplified.

Before getting to the problems, we should note that there are some good examples of amplification. One involves the electro-chemical nature of the mammalian eye:

> In some species the eye can detect individual photons falling on the retina. The photon is absorbed by a molecule of rhodopsin, eventually resulting in a nervous impulse coming out of the opposite end of the cell with an energy at least a million times that contained in the original photon.[5]

A better-known example deals with genetic mutation and evolution:

> A second example has been presented by Ian Percival, who states that "DNA responds to quantum events, as when mutations are produced by single photons,

> with consequences that may be macroscopic—leukemia for example." In this case the amplifier is the developmental process by which the information in DNA is read out in the course of the organism's developmental history. […] Indeed, mutations caused by cosmic rays may well have played a significant role in evolutionary history.[6]

Cosmic rays and terrestrial radiation are cited here as a possible mechanism for theistic evolution. Quantum events can cause genetic mutations, which in turn affect the evolution of a species.[7]

I take these to be possible cases amplification, but they also exhaust the store of good examples. While eyesight and point mutations in DNA-based organisms are significant, this falls far short of a robust theory of special divine action. In other words, quantum determination does work as a mechanism for theistic evolution. If that's all one wants from quantum mechanical randomness, then I have no objection. There is, however, a large gap between a mechanism-for-theistic-evolution on one hand and a robust-model-of-divine-action on the other. I take quantum determination to be the more ambitious of the two. Most advocates of quantum determination are hoping that the program can be broadened, although most also agree that the amplification problem remains largely unsolved.

With that in mind, I am going to argue for a surprisingly strong thesis: In light of current physics, the amplification problem cannot be solved. Not only are amplification mechanisms hard to find, but the physics between scales puts obstacles in the way. In other words, nature is strongly predisposed to block the amplification of indeterministic quantum events. Note that the "strong thesis" needs to be understood in light of the previous paragraph. It holds only insofar as the amplification problem remains unsolved, as most noninterventionists believe. Others might be content with the examples mentioned above and so do not recognize a further problem. Very well. My argument is addressed to those who believe that the amplification problem is still seeking a solution. The conclusion will be that if current physics is correct, then it cannot be solved.

To see why, let's start with a familiar idea from the debate on reductionism: the notion of levels. *Reductionists* claim that high-level laws and phenomena can be reduced to lower-level ones, at least in principle. So psychology will one day be reduced to neurophysiology, neurophysiology to molecular biology, molecular biology to organic chemistry, all the way down to quantum field theory. *Emergentists* are betting that this reduction will fail. What both sides agree on is that natural causes tend to run along their own level. The level of causes and laws that biochemists study, for example, is distinct from that of botany. The same goes for paleontology and population genetics. There are distinct levels in nature, and the natural sciences more or less break down accordingly. (While there are reasons to be skeptical of this strong view of levels,[8] it's the easiest way to state the argument, so I'll make use of it here.)

What is not recognized in the divine action literature is this: There are many levels at which phenomena are blind to perturbations at smaller scales. In these instances, changes of state at the more fundamental level have an undetectable effect at higher levels. Nature has, in other words, placed roadblocks between some levels of reality such that small changes, including quantum changes, cannot influence the goings-on at the next level up. These "roadblocks" are what Nobel physicist Robert Laughlin refers to as "protectorates."[9] A protectorate is a domain of physics whose behavior is independent of the microdetails found at smaller scales.[10]

Let's try to approach it *via negativa*, as the medievals would have put it. The effect of an emergent protectorate[11] is exactly the opposite of what we see in chaos theory. In chaotic systems, there is *sensitive dependence on initial conditions*, a.k.a. "the butterfly effect." To give the standard example, if the atmosphere evolves chaotically, then a butterfly flapping its wings in Japan today might be enough to change the weather in Miami sometime next year from what would have been a sunny day into a hurricane. Any slight perturbation in a chaotic system will produce a dramatic change in the future state of that system.

In the examples to follow, we find a kind of "anti-chaos": extreme *insensitivity* to small changes. The state of a system within a protectorate is largely independent of the state of its micro-scale constituents. As Laughlin and Pines put it, these "emergent physical phenomena regulated by higher organizing principles have a property, namely their insensitively to microscopics."[12] In other words, protectorates block the influence of lower levels, rather than amplifying them. Examples like gene mutation (above) are cases in which there is no protectorate and so amplification is possible. These appear to be exceptions rather than the rule.

Given the preeminence of physics even among philosophers and theologians, that will be the focus of this paper. We should note, however, that philosopher of biology William Wimsatt has been talking about these ideas for 30 years. As he says, upper-level biological phenomena and laws are often insulated from "*lower-level changes* .... [generating] *a kind of explanatory and dynamic (causal) autonomy of the upper-level phenomena and processes*" [italics in the original].[13] That is the key idea to watch for: protectorates are insulated from changes at lower levels.

B. Differentiable dynamics

Turning to physics, let's start with some recent history. Since the rise of chaos theory in the 1980s, a mathematical entity known as a *strange attractor* has received considerable attention. Strange attractors are creatures of *phase space*, which is itself AQ1
a geometrical way of representing the state and evolution of a system. Each point in a phase space represents a possible state of the system. As the system evolves over time, the state point changes, carving a trajectory through the phase space. Trajectories (or *orbits*) in the phase space represent a system's possible evolution from different initial conditions.

If the system allows for dissipation (usually friction), then *attractors* can develop in its phase space. As the name implies, an attractor is a set of points toward which neighboring trajectories flow. Once a trajectory encounters an attractor, it remains there unless the system is perturbed. The presence of a *strange* attractor entails that the system is chaotic and displays sensitive dependent on initial conditions, which, once again, means that minute changes in a system of state at one time can completely change the way a system will evolve in the future.

Advocates of quantum determination often appeal to chaos as a way of amplifying quantum events. It's the butterfly effect, again, but this time at the quantum level. Jason Colwell's account is a good example. God, he says, can choose

> the position of an electron at one time while preserving its probability density function through His pattern of choices over all time. The electron's position at that moment could influence the motion of one, then several air molecules. This would soon affect the flow of a tiny region of air. Amplified through chaos, this could cause a significant meteorological event after more time had elapsed. God, being omniscient, sees all the intricate workings of chaotic systems. He knows where tiny changes would have huge effects later on. This enables Him to act providentially in many situations to produce a desired result.[14]

This wedding of chaos to quantum determination for the purpose of amplification is what Polkinghorne refers to as "the hybrid scheme."[15] (We should note that neither Russell nor Polkinghorne appeal to chaos for help in solving the amplification problem.[16] Tracy also recognizes the difficulty of connecting the dots from quantum mechanics to classical chaos.)

Very well, so what's the problem?

First, there isn't enough chaos in the world to help solve the amplification problem. Mathematically speaking, chaos lives in the realm of nonlinear differential equations. While there are far more nonlinear models than linear ones, nonlinearity is a necessary but not sufficient condition for chaotic dynamics.[17] Having a nonlinear model does not guarantee that the system will evolve chaotically. In fact, most nonlinear systems do not exhibit chaos.[18]

Moreover, chaos is a lot like noise: there can be a little, or there can be a lot.[19] To say that a system is chaotic does not entail that the overall behavior of the system is completely unpredictable. Healthy heartbeats are chaotic, but only a bit. Heartbeats are for the most part quite regular. In most real-world examples, the chaotic part of a system's dynamics is hard to find because its influence is negligible on most scales. Often the effect of chaos is so small that it requires very precise equipment and lots of data to detect. So, yes; there is chaos in nature—but not that much of it, relatively speaking.

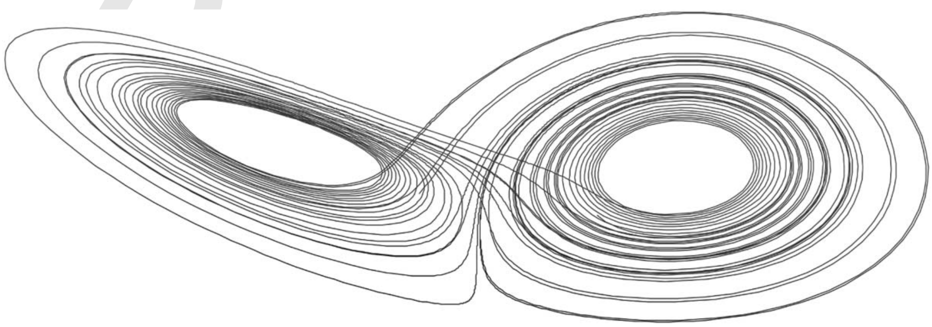

Figure 1 The Lorenz mask.

This is enough to show that chaos will not solve the amplification problem, but matters are actually worse than this suggests. Let's go back to the part of the story we tend to rush through in order to get to chaos. Strange attractors are only one member of a family of attracting sets in dissipative systems.[20] In the neighborhood of a point attractor, for example, no matter where the system starts, it always ends up in the same final state, like those coin funnels you see at the mall. Wherever the coin starts rolling, they all end up at the bottom of the funnel. There are also limit cycles, which represent something like the pendulum of a clock. No matter where, precisely, you lift the pendulum to get the clock ticking, the clock's mechanism ensures that the pendulum will oscillate in a perfectly regular way. There are also attractors in the shape of a torus and many more at higher dimensions. The technical literature contains a menagerie of attracting and repelling sets, most of which have nothing to do with chaos. There are also nondissipative systems, which do not have attractors of any kind.

In the vast family of systems described by ordinary differential equations and represented by phase spaces, strange attractors are relatively rare. They are the white Bengal tiger of mechanics—they're out there, but there are far more numerous types of feline in the world. But with nonchaotic attractors, there is no sensitive dependence on initial conditions. In fact, no matter where one starts within the basin of attraction, the system will inevitably fall into the attractor itself. Any small change to a system state in the basin of a nonchaotic attractor will produce little if any change in the final state of the system. This is the case for most dissipative systems.

Chaos theory did not solve the amplification problem. As we have seen, even if chaos were ubiquitous in nature, its effects are often so small that they are difficult to detect. For chaos to serve as an amplifying mechanics for quantum events, it must dominate the dynamics of a system, rather than being a matter of noise along fringes. When we consider the whole of dynamics, however, the problem gets worse. From the point of view of quantum determination, nonlinear dynamics not only failed to be an ally, it turns out to be an enemy at the gate. Nonchaotic models are more prevalent than their chaotic cousins and are insensitive to small scale change. For the majority of dissipative dynamical systems, then, any

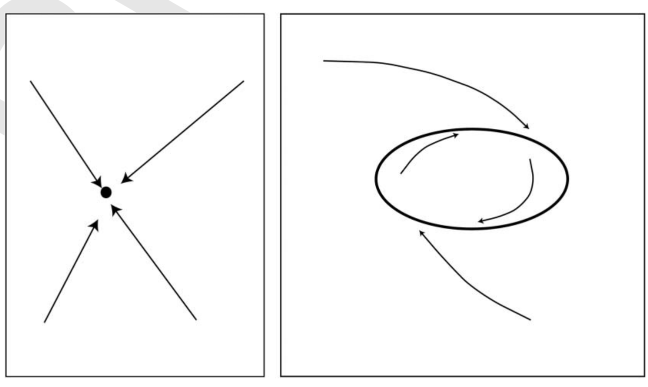

Figure 2 Nonchaotic attractors.

change of state that God might make at the quantum level will have no measurable effect on the final state of the system.

C. Continuum mechanics

Let's now switch gears to a different area of physics. We tend to think of classical mechanics as ultimately being about the behavior of atoms, but atomism was still in doubt in the early nineteenth century. Some, like Ernst Mach, thought the whole idea was just a useful fiction. Others, like Ostwald and the energetics movement, were suggesting that molecular phenomena could be reduced to energy itself.[21] AQ2 Still others, like Lorentz, argued that electromagnetism composed the most fundamental level, rather than atoms.[22] Even in the early twentieth century, Bertrand Russell could (reportedly) ask whether nature is deep down a pail of sand or a bucket of molasses. The pro-molasses folks were betting that, in one way or another, the most fundamental "stuff" in nature is not discrete and atomic, but rather smooshed out and continuous.

Now, how can it be that whole areas of classical physics were developed under conflicting and sometimes false views about the nature of matter? As Poincaré observed,

> In most questions the analyst assumes, at the beginning of his calculations, either that matter is continuous, or the reverse, that it is formed of atoms. In either case, his results would have been the same. On the atomic supposition he has a little more difficulty in obtaining them—that is all.[23]

How can that be?

Let's consider classical fluid mechanics, governed by the Navier–Stokes equations. These are nonlinear, partial differential equations, which means they are beyond our ability to solve in most instances. (In fact, it still isn't known whether unique solutions for the equations *exist*, except for some special cases.) What Poincaré was alluding to is that there are completely different ways to understand the nature of fluids. One of these treats matter as a bunch of point particles—not atoms, but mathematical points.[24] There is another, much more straightforward way of understanding matter as a true continuum, like a field. On this approach, there are no particles. As I mentioned, many nineteenth-century physicists were betting that the continuum approach was the more realistic one.[25] Very few believed that matter consisted of point particles, Father Boscovich being a famous exception.

But, again, it didn't seem to matter, since either approach yields the same equations for the behavior of macroscopic fluids. Clifford Truesdell, the dean of twentieth-century rational mechanics, put it this way:

> Continuum physics stands in no contradiction with structural [i.e., molecular] theories, since the equations expressing its general principles may be identified with equations of exactly the same form in sufficiently general statistical mechanics. […] Long experience with molecular theories shows that quantities such as stress

> and heat flux are quite insensitive to molecular structure: Very different, apparently almost contradictory hypothesis of structure and definitions of gross variables based upon them, lead to the same equations for continua.[26]

Thus the true nature of a fluid at microscopic scales is irrelevant.[27] To this day, as far as engineers and applied physicists are concerned, a fluid could ultimately be made up of molecules, continua, Boscovichian point particles, or Leibnizian monads; it doesn't matter.

So how does this fit in with my thesis? The common theme running through all these examples is that physics contains levels where small scale changes are blocked from having macroscopic effects. If one thinks that God governs the world by way of quantum mechanics, that's an unwelcome bit of news.

What I am arguing here is that in continuum mechanics, there is an effacement of the small.[28] Fluid and continuum systems would behave the same way even if matter were a true continuum all the way down. Let's say that God miraculously did that: changed a fluid system composed of atoms into a true continuum. This would mean that an entirely different kind of state space would be needed to describe the system at micro scales. (For example, a phase space would have to be replaced by, say, a Hilbert space, or something more exotic.) Yet because of the effacement of the small, if this miraculous change were to happen, we would detect no difference in the behavior of the macro fluid. Textbooks on fluid mechanics could remain unchanged, except for the odd footnote. *How* do we know that, again? Because, as Poincaré and Truesdell and a lot of other folks working in continuum mechanics explicitly say, the same macro equations can be derived from either a particle or a true continuum base.

To understand why, let's consider how continuum mechanics relates micro to macro scales. In solids, *constitutive relations* specify how a body will respond to deformation (changes from the equilibrium state) and how stress is distributed at a given time. Say that a tiny volume element within a body experiences a contact force on one side. This force stretches the element from equilibrium. This stretching (strain) produces a force (stress) that tries to bring the element back into equilibrium. This force is then experienced as a contact force by the next element, which induces a strain, and so on down the line. Technically, constitutive equations in continuum mechanics relate the stress tensor $\boldsymbol{\sigma}$ to the strain $\boldsymbol{\varepsilon}$. In undergraduate texts, these are reduced to simple vectors or scalar quantities.

Note that the "volume elements" mentioned here lie far above the level of atoms, and yet they encode all of the causally relevant information about small-scale interactions. As far as stress/strain relations are concerned, the micro level might actually be atomic or a true continuum. But those micro details are irrelevant. Volume elements are blind to the smaller-scale interactions between atoms. All sorts of things can be happening at lower physical levels that have no bearing on that of applied physics. In short, the observable behavior of a continuum system is largely independent of the details found within its micro base.[29]

This effacement of the small has a corollary that reductionists have generally ignored: the relative autonomy of systems at observable levels. This is a common theme in the emergence literature. The macro often behaves in ways that are

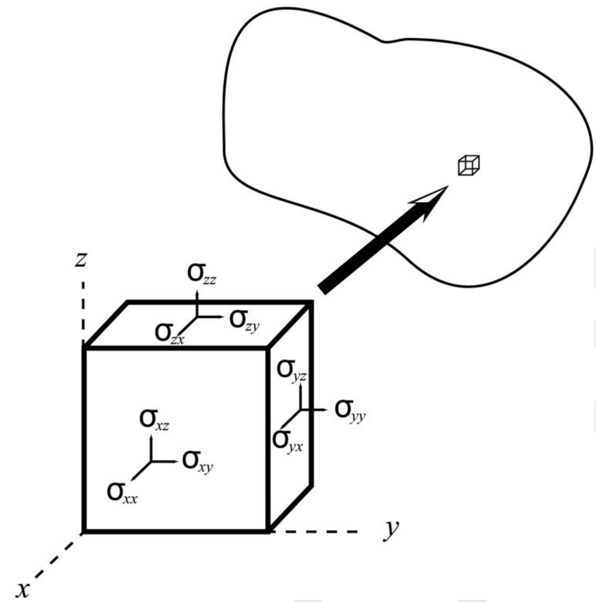

Figure 3 Stress on a volume element.

largely independent of the micro, and so mid-scale systems cannot simply be reduced to their small scale constituents. For our purposes, the thing to notice is that *this same autonomy insulates many macroscopic systems from changes at far smaller scales*. And this, again, is exactly the opposite of what one would hope in trying to solve the amplification problem. Advocates of quantum determination are looking for ways in which micro changes can influence the macro. In continuum mechanics, that typically cannot happen.

Now, some readers might be thinking, "typically" doesn't mean "always," so there must be exceptions. And there are. But keep in mind that the amplification problem cannot be solved by way of exceptions. Every time one has to resort to special cases to keep quantum determination alive, the less plausible it becomes as a model of divine action.

One might instead say, "Well, we don't believe in *classical* continuum mechanics anymore. We now know that the world is atomic and quantum mechanical, so we can safely ignore these examples." And that would be a good argument, if only it were true. Let's now finally turn to the area of research for which Laughlin and Pines coined the term *quantum protectorate.*

D. Condensed matter physics

Condensed matter physics is hard to characterize, since it includes everything from phase transitions to superconductivity. What these phenomena have in common are lots of interacting degrees of freedom, and it's all those degrees of freedom that make these systems hard to study. There are too many moving parts for one to know which properties are causally relevant. (Typically, physicists can only deal with around 10 particles before moving to statistics.[30])

Fortunately, some ways have been discovered to tame this complexity. One surprise on the experimental side is that extremely diverse systems sometimes give rise to the same observable properties. Many fluids with completely different chemical compositions, for example, can exhibit identical behaviors. More surprising is that phase transitions in liquids are mathematically identical to changes in magnets. The transition from liquid to vapor mirrors changes found in electromagnetic materials, which would seem to be an unrelated set of phenomena.[31] (Specifically, they share the same *critical exponents*, which describe a shift in phase.) Now, even without all of the technical details, it should be obvious that liquids and magnets are physically quite different. How is it that the two, which *prima facie* have no relation whatsoever, obey the same sorts of mathematics? Physicists want to know.

This is where a branch of applied mathematics known as *renormalization group* (RG) theory comes in. It's a bit esoteric, so we will only consider the broadest of descriptions here. We have already seen that strange attractors are creatures of phase space rather than physical space. Renormalization group theory uses a still more exotic space of Hamiltonians, where a Hamiltonian is a function that captures interactions between the degrees of freedom within a system as well as the influence of any external fields. In many areas of physics, finding a Hamiltonian is the key to describing a system's behavior. This is why condensed matter physics is so difficult. The Hamiltonians involved are extremely complicated since all those degrees of freedom have to be accounted for. The trick of renormalization is to move from a Hamiltonian of the actual system of interest to one that behaves the same way, but with fewer degrees of freedom.[32] In principle, it's the same idea as when engineering textbooks reduce a three-dimensional bridge to two dimensions. 2D is manageable for engineering students; 3D is not. Renormalization group analysis likewise boils the physics down to the properties that causally dominate the behavior of a system, stripping away the noise.

What we find is that systems in condensed matter physics also exhibit the effacement of the small. Renormalization shows that what's going on at the lowest levels of condensed matter systems is not causally relevant. What really matters for the behavior of these systems are mid-scale properties like dimension and symmetry, as philosopher of physics Margaret Morrison explains:

> [T]he framework provided by [RG theory] … has shown that while emergent phenomena, especially the "universal" phenomena in condensed matter physics are certainly composed of micro constituents [like atoms], they are nevertheless largely insensitive to changes in their microphysical base.[33]

Or as Robert Batterman puts it, RG analysis reveals

> a class of macrostates of various systems at the scale of everyday objects (fluids) that are essentially decoupled or independent of their microdetails. The renormalization group explanation provides principled physical reasons (reasons grounded in the physics and mathematics of systems in the thermodynamic limit) for ignoring details about the microstructure of the constituents of the fluids.[34]

It's that decoupling and stability under perturbation mentioned here that Laughlin and Pines had in mind when they coined the term *quantum protectorate*. A quantum protectorate is a stable state of matter whose behavior is independent of the goings-on at the quantum level. Such protectorates are found throughout condensed matter physics.

E. What it all means

We have looked at examples that cover vast stretches of applied physics including differential dynamics, continuum mechanics, and condensed matter physics. What they have in common are phenomena at the macro scale that are insensitive to changes at lower levels, thus the phrase "the effacement of the small." Laughlin and Pines refer to such systems as "protectorates" to describe their relative autonomy from lower levels. They are "protected" from the small-scale to-ing and fro-ing of the quantum level.

In terms of divine action, this autonomy is an unrecognized obstacle for quantum determination. In the presence of an emergent protectorate, the state of the macro system is largely immune to changes of state in its components at the quantum level. Protectorates prevent changes at the quantum scale from bubbling up into the macro. This means that the amplification problem is not merely something that the quantum determination program will solve in the fullness of time. Nature has firewalls in place that keep random events at the quantum level from influencing the realm of our everyday experience. Special cases that circumvent these roadblocks are just that: special cases—uncommon exceptions to the rule. Hence, the amplification problem cannot be solved in a system with a protectorate. Given the prevalence of systems mentioned in this paper, the unhappy consequence is that if God governs the universe by way of quantum randomness alone, then we are left with something very close to deism.

Let's be clear: the micro world is certainly quantum mechanical, and the macro world rests on that foundation. The entire structure of the periodic table depends to some extent on quantum mechanics. What I have presented here is not some sort of AQ3 anti-realist rejection of quantum theory. But quantum mechanics is not synonymous with the random collapse events that quantum determination requires. In fact, many physicists—who surely believe in quantum mechanics—don't believe in the collapse of the wavefunction. The issue here is whether those peculiar and somewhat questionable events can make their way into the realm of our experience. For the most part, the answer is no.

One anonymous referee objects that by acknowledging the exceptions, I have not shown that amplifications cannot occur. Hence, my conclusion is overstated. To see what's wrong with this objection, consider an analogy. Say that your favorite football team has a weak offense. Ultimately, they need to find a way to score more points. It is not a solution to the problem to point out that they do, in fact, score now and then. Similarly, noninterventionists who look to quantum mechanics realize that they need to find still more ways in which quantum mechanical events can be amplified in order for quantum determination to serve as a robust mechanism for divine action. That just is the amplification problem briefly stated. What we have seen is that nature imposes barriers that make it extremely difficult for amplification to occur. (This is one reason why the world appears to obey classical mechanics and why engineers pay virtually no attention to quantum theory.) In order to solve the problem, noninterventionists must find *more* avenues through which amplification might readily occur. It is not enough to show that, despite the barriers posed by protectorates, amplification might happen on occasion.

So, then, have I just destroyed quantum determination as a research program? While it's always nice to be known as the person who ran the conclusive experiment or who decisively refuted a given argument, that seldom happens. There are loopholes, special cases, and exceptions to everything mentioned in this paper. One might think that quantum determination has earned the right to wait until someone comes up with an answer to emergent protectorates. On the other hand, one might conclude that the problems are starting to add up and that the scientific costs are getting a bit steep. In my view, we need to reevaluate the terrain. Just how plausible is quantum determination in light of *everything* we know in physics, not just quantum mechanics?

Do I have an alternative model of divine action? Well, a good place to start would be a suggestion from—surprisingly enough—philosopher of biology Elliot Sober. First, he makes clear what evolutionary biology allows and what it forbids:

> Theists can of course be deists, holding that God starts the universe in motion and then forever after declines to intervene. But there is no contradiction in their embracing a more active God whose interventions into nature fly under the radar of evolutionary biology. Divine intervention isn't part of science, but the theory of evolution does not entail that none occur.[35]

Pressing the point, Sober thinks that theistic evolutionists need not be limited to a noninterventionist view of divine guidance:

> What I want to consider … is the view that God *supplements* what happens in the evolutionary process without violating any laws. An intervention, as I'll understand the term, is a cause; it can trigger an event or sustain a process. Physicians do both when they intervene in the lives of their patients. Physician intervention does not entail any breakage in the laws of nature; neither does God's.[36]

The physician example makes it clear that the interventions Sober has in mind are not limited to quantum mechanics. I believe the theist should say amen and amen. We intervene in the natural order all the time. I am doing so as I type these words into my computer. I am not, however, breaking any laws of nature.

In a similar vein, physicist John Wheeler once asked, "Couldn't God make a go of it without the quantum?" (Robert Bishop, private correspondence). The answer is "yes!" If ontological reductionism is false, then there is more than one level at which God can interact with nature. Quantum mechanics isn't the only game in town. While some well-known noninterventionists, such as Russell[37] and Clayton,[38] have made suggestions in this direction, I believe that their views continue to be burdened by an outdated view of determinism; but I will not press that point here.[39]

F. Final notes on quantum determination

Before concluding, I would like to make a broader observation about the debate on divine action. While this paper has been critical of quantum determination, my aims are somewhat different than those of at least one of its main advocates, Robert Russell. He is not a "hands-off theologian," as Plantinga calls twentieth-century figures like Rudolf Bultmann, Gordon Kaufman, and Maurice Wiles.[40] Russell is instead hands-on where divine action is concerned, but only insofar as it conforms to methodological naturalism. Although his model is not part of science itself, it is nonetheless bounded by what mainstream science says is the case.

Now, some see this as giving away the farm. Instead of accepting this naturalistic bias, many theists argue that science is in no position to dictate the boundaries of divine action. This, I believe, is a legitimate worry. Scientists often bring a number of metaphysical and methodological assumptions to the table regarding reductionism, the causal closure of nature, naturalism, and more, all in the name of science. While these might have great utility when it comes to theory formation/choice, theistic philosophers and theologians need not be bound by those assumptions that conflict with theism itself.

On the other hand, there is a quasi-apologetic goal to Russell's approach that is not often appreciated. The New Atheists—and the old ones, for that matter—often argue that science disproves religion. In particular, they want to show that divine action is contrary to established science. Russell's version of quantum determination grants everything that anti-theists claim to be scientific truths, including methodological naturalism and the inviolability of natural law. He then goes on to show that nature leaves plenty of room in which God can act without contradicting science. Rather than being foes, science and theism get along just fine, thank you—even in light of theistic claims about God actively governing the universe.

In light of this, even critical theistic scholars should be able to see the quantum determination program in two ways. On one hand, it is a useful tool in undermining the warfare model of science versus religion. There *is* a way for God to act in nature, even if we grant the metaphysical and methodological assumptions of those in the grip of naturalism. As such, quantum determination might open a space for further discussion that would not otherwise happen. On the other hand, there is the in-house theorizing about divine action among theistic philosophers and theologians. Our goal is to discover the right model of divine action (insofar as that is possible), regardless of whether that model is acceptable to those who do not share our metaphysics. In my view, God simply can't do enough by way of quantum mechanics or any of the other mechanisms proposed in the Divine Action Project. In other words, God is far more active in nature than the models in that literature seem to allow. If so, then the in-house discussions on divine action among theists should continue, starting perhaps with a foundational reevaluation of how determinism and causal closure have shaped the debate.[41]

Acknowledgments

Thanks to Robert Russell, Del Ratzsch, and Michael Murray, and two anonymous referees for helpful comments on a previous draft. This work was supported by the *Randomness and Divine Action* project at Calvin College, which was sponsored by the John Templeton Foundation.

Endnotes

1 Or at least, that's what he claimed to have shown. The truth is a bit more complicated. For the complete story, see Florin Diacu and Philip Holmes, *Celestial Encounters : The Origins of Chaos and Stability* (Princeton, NJ: Princeton University Press, 1996).
2 More precisely, as Robert Russell notes (private correspondence), these are miracles in Hume's sense, which are by definition violations of the laws of nature.
3 Although this obviously does not exclude divine causality. If it did, quantum determination could not get off the ground.
4 Thomas Tracy, "Particular Providence and the God of the Gaps," in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert J. Russell, Nancey Murphy, and Arthur R. Peacocke (Berkeley, CA: Center for Theology and the Natural Sciences, 1995), 317.
5 George F.R. Ellis, "Quantum Theory and the Macroscopic World," in *Quantum Mechanics: Scientific Perspectives on Divine Action*, ed. Robert J. Russell, Kirk Wegter-McNelly, and John Polkinghorne (Berkeley, CA: Center for Theology and the Natural Sciences, 2001), 260.
6 Ibid.
7 Russell takes this to be highly significant insofar as it refutes the idea that evolution is in conflict with theism and is intrinsically atheistic. See his *Cosmology: From Alpha to Omega* (Minneapolis: Fortress Press, 2008), chapter 6. Others argue that directed evolution is not compatible with neo-Darwinism, whether there is a violation of natural law or not. Darwinian mutations are random precisely in that "they do not occur according to the needs of their possessors"; see Michael Ruse, "How Not to Solve the Science–Religion Conflict," *The Philosophical Quarterly* 62:248 (2012), 623. If God were to cause mutations to ensure that humans evolve, it would be nonrandom and hence non-Darwinian. As Ruse points out, when Darwin's friend and supporter Asa Gray first proposed a version of theistic evolution, Darwin argued that it was incompatible with his theory. Contrary to this, Russell believes that so long as mutations continue to appear random from a biologist's point of view, God could still arrange them to bring about a particular outcome.
8 Jeffrey Koperski, *The Physics of Theism: God, Physics, and the Philosophy of Science* (Hoboken: Wiley-Blackwell, 2015), 238–242.
9 A (quantum) protectorate is "a stable state of matter whose generic low-energy properties are determined by a higher organizing principle and nothing else"; see Robert B. Laughlin and David Pines, "The Theory of Everything," *Proceedings of the National Academy of Sciences of the United States of America* 97:1 (2000): 29. The idea also applies to cases where the scale is a matter of frequency rather than size.
10 Robert W. Batterman, "Emergence, Singularities, and Symmetry Breaking," *Foundations of Physics* 41:6 (August 6, 2010): 1034.
11 The idea of an emergent protectorate is an extension of Laughlin and Pines' quantum protectorate. The term was coined by philosopher of physics Robert Batterman.
12 Laughlin and Pines, "The Theory of Everything," 29.
13 William C. Wimsatt, *Re-Engineering Philosophy for Limited Beings: Piecewise Approximations to Reality* (Boston, MA: Harvard University Press, 2007), 65.

14 Jason Colwell, "Chaos and Providence," *International Journal for Philosophy of Religion* 48:3 (2000): 135, quoted in Nicholas Saunders, *Divine Action and Modern Science* (Cambridge: Cambridge University Press, 2002), 186.

15 John Polkinghorne, *Scientists as Theologians: A Comparison of the Writings of Ian Barbour, Arthur Peacocke and John Polkinghorne* (London: SPCK, 1996), 37. For more, see Philip Clayton, *God and Contemporary Science* (Edinburgh: Edinburgh University Press, 1997), 196; Nancey Murphy, "Divine Action in the Natural Order," in *Chaos and Complexity: Scientific Perspectives on Divine Action*, ed. Robert J. Russell, Nancey Murphy, and Arthur R. Peacocke (Berkeley, CA: Center for Theology and the Natural Sciences, 1995), 348–349; and Tracy, "Particular Providence and the God of the Gaps," 317–318.

16 Some of the reasons why are discussed in the following paragraphs. For a fuller discussion on the rocky relation between chaos and quantum mechanics, see Jeffrey Koperski, "God, Chaos, and the Quantum Dice," *Zygon* 35:3 (2000): 545–559.

17 In essence, it's not that different from the measure-theoretic idea that there are far more real numbers than there are whole numbers. The whole numbers have measure zero in the space of real numbers.

18 In chaotic systems governed by ordinary differential equations, there are parameters that can put the system into a chaotic or nonchaotic regime. In the space of parameter values, the chaotic regime is often a small. More precisely, in chaotic systems governed by ordinary differential equations, there are parameters that can put the system into either a chaotic or nonchaotic regime. Experimentalists often have to "tune" these parameters in order for a given system to exhibit chaos. For more on the relation of parameter space to the so-called "routes to chaos," see chapters 2 and 8 of Edward Ott, *Chaos in Dynamical Systems* (Cambridge: Cambridge University Press, 1993).

19 This is the main point of David Ruelle, "Where Can One Hope to Profitably Apply the Ideas of Chaos?," *Physics Today* 47:7 (1994), 24–30.

20 David Ruelle, *Chaotic Evolution and Strange Attractors*, Lezioni Lincee (Cambridge: Cambridge University Press, 1989), 54–57. AQ5

21 P.M. Harman, *Energy, Force and Matter: The Conceptual Development of Nineteenth-Century Physics* (Cambridge: Cambridge University Press, 1982), 146–147.

22 Ibid., 151.

23 Henri Poincaré, *Science and Hypothesis*, trans. W.J. Greenstreet (New York: Dover, 1952), 152.

24 This involves some sleight-of-hand insofar as Newton's second law is applied in different ways to the points themselves and the bundles of points moving in and out of a *control volume*, but that's another story.

25 In some ways, they were right. As Batterman shows, the atomic approach actually yields the *wrong* equations when nonhomogeneities arise at meso scales. See Robert W. Batterman, "The Tyranny of Scales," in *The Oxford Handbook of Philosophy of Physics*, ed. Robert W. Batterman (Oxford: Oxford University Press, 2013).

26 Clifford Truesdell, *An Idiot's Fugitive Essays on Science: Methods, Criticism, Training, Circumstances* (New York: Springer, 1984), 55.

27 There are limits to how different the micro-realm could have been. As Del Ratzsch points out (private correspondence), continuum systems would have different observable properties if the atoms involved were unstable or radioactive. Hence, Poincaré and others are assuming that whatever the particles are, they must be structurally stable.

28 Borrowing a phrase from Mark Wilson, as I am wont to do.

29 Exceptions would include turbulence, the fluid counterpart to sensitive dependence on initial conditions, and other systems that are sensitive to perturbation *at the macro level*. For a pin balancing on its tip, for example, if God were to change the ontology of the pin from a true continuum to particles, it would be very difficult to maintain the perfect symmetry required to keep the pin in balance.

30 Laughlin and Pines, "The Theory of Everything," 28.

31 The phase transition here is between ferromagnetic (below the critical point temperature when dipoles align) and paramagnetic (above the critical point temperature when they are naturally disordered but will line up under the influence of a magnetic field). See Batterman, "Emergence, Singularities, and Symmetry Breaking," 1035.

32 Robert W. Batterman, *The Devil in the Details: Asymptotic Reasoning in Explanation, Reduction, and Emergence* (Oxford: Oxford University Press, 2002), 39–41.

33 Margaret Morrison, "Emergent Physics and Micro-Ontology," *Philosophy of Science* 79:1 (2012): 142.

34 Batterman, "Emergence, Singularities, and Symmetry Breaking," 1037.

35 Elliott Sober, "Why Methodological Naturalism?," in *Biological Evolution: Facts and Theories: A Critical Appraisal 150 Years After* The Origin of Species, ed. G. Auletta, M. Leclerc, and R.A. Martínez (: Gregorian & Biblical Press, 2011), 366–367. **AQ6**

36 Ibid., 362.

37 Robert J. Russell, "The Physics of David Bohm and Its Relevance to Philosophy and Theology," *Zygon* 20:2 (June 1985): 135–158.

38 Philip Clayton, "Emergence from Quantum Physics to Religion: A Critical Appraisal," in *The Re-Emergence of Emergence*, ed. Philip Clayton and Paul Sheldon Davies (Oxford: Oxford University Press, 2006), 303–322.

39 See Koperski, *The Physics of Theism*, 182–190, and Jeffrey Koperski, "What Is Determinism That We Should Be Mindful of It?" (under review). **AQ7**

40 Alvin Plantinga, "What Is 'Intervention'?," *Theology and Science* 6:4 (November 2008): 369–401.

41 For more along these lines, see Ibid. and Koperski, "What Is Determinism That We Should Be Mindful of It?"

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