A Guess at the Riddle: Essays on the Physical Underpinnings of Quantum Mechanics, by David Z. Albert. Cambridge, MA: Harvard University Press, 2023. Pp. x+144.

Before the 1990s, the quantum measurement problem was just not that visible in philosophy of quantum mechanics (QM). Still less was the idea that we might consider changing quantum mechanics in response to it, or even that the core question in philosophy of QM would be whether and how to make those changes.

David Albert's incisive and indefatigable critiques of the orthodoxy played a critical role in changing this. To a first approximation, the next twenty years of philosophy of QM was a three-way debate between Bohmian, dynamical-collapse, and Everettian ('many-worlds') approaches to QM, with Albert's earlier book *Quantum Mechanics and Experience* (Albert, 1994) setting an agenda which largely persists to this day. The core of that agenda has been to find an approach to QM that is realist in the traditional philosophical sense, that allows us to understand QM as providing a mind-independent, third-party-describable, objective account of what the world is like, or else to discard QM itself and replace it with something that provides that account

But ever since that agenda was set, Albert himself has been at least as concerned to understand the metaphysical pictures that go with it. To Albert, a solution to the measurement problem is a means to an end: once we have our realist account of QM, we can finally return to the question of what the world is like according to physics – or rather, what the world is *fundamentally* like, since Albert is consistently and unapologetically focused on fundamental physics, and at most passingly concerned with partial, higher-order physics theories.

For nearly thirty years, Albert has defended a specific answer to that question: *wave function realism*, the view that quantum mechanics is fundamentally about the undulations of a field-like entity, the `wave-function' (mathematically: the particle-mechanics quantum state in the position representation), in an unfathomably-high-dimensional space, with the three-dimensional world of the manifest image understood as at best emergent, at worst illusory. *A Guess at the Riddle* is many things, but first and foremost it is Albert's latest and sharpest defense and exploration of wavefunction realism. More specifically, it is primarily (if sometimes tacitly) a defense of the position against a rival: the *primitive ontology* approach (see, e.g., (Allori *et al* 2008, Esfeld *et al* 2017, Maudlin 2013), according to which physics is – indeed, necessarily must be – about objects in space and time. According to primitive ontologists, conglomerates of these objects make up the entities of the manifest image, while alien and high-dimensional entities like the wavefunction play at most an indirect role, dynamically influencing the primitive ontology but not directly observable.

This is a lot of introduction before I get to the book itself, but that's unavoidable: as Albert himself acknowledges in the introduction, *A Guess at the Riddle* doesn't really pretend to be self-contained. It needs to be understood as a set of moves in a long-standing debate (a debate, it must be said, largely carried out within a fifty-mile radius of New York City). But that debate has been influential in the metaphysics of physics as little else has, and *A Guess at the Riddle* is a deep and carefully considered set of arguments from which even those not directly invested in the debate can learn much.

The book itself consists of three long essays, each largely self-contained (like Albert's previous book, *After Physics* (Albert, 2016), this is more a collection of long papers than a single coherent narrative). The first and longest essay, the eponymous "A guess at the riddle", is a novel first-principles case for wave-function realism. Albert's original argument for wave-function realism was motivated by the mathematical form of (non-relativistic) quantum mechanics: that theory is traditionally presented as a theory of a complex function on a 3N-dimensional configuration space (with N being the number of particles being modelled), and Albert initially argued for wave-function realism as a form of *literalism*: as he previously put it,

> [wave-function realism is] the simplest and, most straightforward, and most flat-footed way of thinking—in this new realistic spirit—about quantum mechanical wave functions, which is to think of them as concrete physical objects (Albert, 2013, p.53)

That argument didn't convince many doubters, and I think they were right to be unconvinced: apart from anything else, there are myriad mathematically equivalent ways to formulate non-relativistic quantum mechanics, and the 'literal' metaphysics one would read from them would differ sharply from one to another In this chapter, Albert tries something quite different: instead of starting with the formalism of quantum mechanics and then interpreting it, he works up to that formalism through a series of simpler toy theories that lead us – as he interprets them – to see how physics contains two fundamentally distinct conceptions of space. The first is the space of ordinary physical things – the space we observe, the space in which tables and chairs reside. The second is the space of elementary physical determinables – the space which provides a complete, separable, description of the world at the fundamental level. (In wavefunction realism, of course, the second space is the configuration space on which the wavefunction is defined.)

Let me try to give some of the flavor of Albert's subtle and involved argument. He starts with the Hamiltonian of a system with two degrees of freedom, with coordinates x_1 and x_2, most naturally interpreted as a pair of particles moving in one dimension and interacting via a short-range potential. We could instead interpret it as a single particle moving in two dimensions, but Albert (reasonably enough) claims that this is not the natural interpretation, not least because it would violate the homogeneity and isotropy of space. (It matters here that we are taking the system to be a toy model of an entire Universe; I have some qualms about this way of proceeding, but put those aside.)

Albert then adds two more degrees of freedom, with coordinates x_3 and x_4, to the model, along with a potential that couples x_3 and x_4. And now (as he tells the story) things become interestingly different: it still makes sense to interpret the four coordinates as describing four one-dimensional particles, but the complete qualitative description of events in one-dimensional space underdetermines the full physical state, because it lacks the resources to say which particle interacts with which. If we know two particles are approaching each other while the other two are far away, we cannot know from this alone if the particles are going to bounce off each other or pass harmlessly through one another, because we cannot know from this alone whether the two approaching particles are 1 and 2 (or 3 and 4), which interact, or 1 and 3 (or 2 and 4), which do not. So (according to Albert), we need to take seriously the full two-dimensional space, not as a surrogate for ordinary material space but as the deeper description of reality. Now the space or ordinary physical things, and the space of elementary physical determinables, have come apart, and the former can be seen as a sort of shadow on the wall cast by the latter.

Albert's third step is to introduce a new (but weak) interaction term that couples the (x_1,x_2) and the (x_3,x_4) points in the two-dimensional space. Now we have two pairs of particles, each pair moving in one-dimensional space in a straightforward manner, but with a subtle interaction that means we cannot simply be discussing something like alternative possibilities. As he puts it,

> It would be a little closer to the mark to say ... that the introduction of a second point-like item into the two-dimensional space is like the introduction of some additional one-dimensional world - some parallel or possible or alternate one-dimensional world - that the single original pair of particles somehow also (but differently) inhabits. But ... the fact that the two point-like items in the two-dimensional space can now interact with one another shows that thinking of them as parallel or possible or alternate one-dimensional worlds can't be quite right either. The analogy that it will be helpful to have in mind, going forward, is (instead) this: Introducing another point-like item into the two-dimensional space is like adding another term, like adding another branch, to the quantum-mechanical wave-function of the single, original, two-particle system in the one-dimensional space. (*A Guess at the Riddle*, p.29).

Now the connection to quantum mechanics becomes manifest: the two pairs of particles are akin to a pair of particles in a superposition; the preferred connections between particles, to entanglement; the subtle coupling between pairs, to interference. And Albert's further developments of the position take it closer and closer to full quantum mechanics, and specifically to wave-function realism.

The full details are too rich to fully present here; suffice it to say that I found them at least suggestive and in places compelling, and they are well worth your time. But philosophy makes strange bed-follows. The arguments in this chapter, though novel, have something in common with arguments advanced by David Deutsch (notably in (Deutsch 1997); cf my explication and expansion of Deutsch's ideas in (Wallace, 2012, ch.10)) in defense of the many-worlds interpretation. Deutsch argues that the very phenomena of quantum theory require us to interpret the theory as a multiplicity of parallel goings-on – and Albert agrees! The only difference is that, because Albert thinks probability is unintelligible in a many-worlds theory, he is committed to some dynamical mechanism which causes the multiplicity to wither away before it becomes macroscopic, or else to some additional ontology which accompanies the multiplicity and (somehow…) serves to ground our unique experiences. Read through the prejudices of an advocate of the many-worlds theory, *A guess at the riddle* is an interesting reminder that – unlike the primitive ontologists, whose objections to many-worlds are deep and manifold – Albert is quite sympathetic to this overall way of understanding quantum mechanics, ultimately demurring from it for fairly specific reasons. (Deutsch makes no mention of the deep metaphysics that Albert ultimately takes to underpin this emergent talk of multiplicity and parallelism, but that talk is itself neutral between various solutions to the measurement problem.)

The second essay, "Physical Laws and Physical Things", is a spirited criticism of a rival way to understand the wave-function (common among advocates of Primitive Ontology): as a physical law rather than a physical thing. On this conception of the wave-function, it simply codifies the dynamics of the physical particles that actually make up reality. The idea, as Albert reconstructs it, is that the fundamental laws of Universe (again on the fiction that non-relativistic quantum mechanics is exactly true) would be something like

> At each time t there exists a complex function ψ(t) such that it satisfies such-and-such equation, and such that the velocities of all material particles at time t are determined by ψ (t) in such-and-such fashion.

Albert's criticism of this approach is somewhat indirect. He begins with a superficially similar case: spacetime relationism in Newtonian physics. As he tells the story, the natural reading of Newtonian physics includes a notion of inertial frame, determined by absolute space-time. Relationists (Mach is a classic example, Julian Barbour a more recent one) have sought to eliminate this notion and replace it with a dynamics stated directly in terms of inter-particle distances. Attempts like this have had some success, but have features that

Albert thinks are undesirable: notably, in place of local interaction with absolute space, they have a wildly nonlocal interaction with distant matter.

Albert expresses some admiration for these relationalist approaches, but he thinks that they are working too hard. There is a simple alternative, which (Albert says) gets all the advantages of relationism without its disadvantages, and in particular without non-locality: simply let the laws of physics say that

> The physically possible sequences of interparticle distances are just the ones that have at least one faithful embedding into [absolute] space-time such that, on that embedding, they satisfy [the absolutist's version of the laws of physics]. (p.63)

Or put another way, the laws state that *there exists an embedding of the relative motions of particles such that the motion of the particles is inertial with respect to that embedding*. (At which points the parallel to the wave-function-as-law approach is hopefully obvious.)

As an aside: I think Albert is too quick to claim that this embedding version of relationism avoids non-locality. Suppose that I am trapped inside a large and windowless cylindrical chamber, and that initially I am stationary with respect to the walls of that chamber. Am I flung towards those walls? It depends, of course, on whether it is rotating; but what does 'rotating' mean? To the Newtonian absolutist, it means 'rotating with respect to absolute space': a local notion, even if one that is hard to measure directly save via its dynamical effects. To Mach or Barbour, it means (roughly) 'rotating with respect to the reference frame picked out by the overall distribution of matter', and so might depend in principle on very distant matter – this is exactly the non-locality that disturbs Albert. But to Albert it means, 'rotating with respect to that coordinate system picked out by the requirement that the embedding of all the matter in the Universe in absolute space via that coordinate system satisfies Newton's laws.' This account is no less non-local than the relationalist's: the need to ensure that distant matter embeds correctly can and in general will determine the permissible embeddings right here and now. Indeed, at least at the formal level Barbour's version of relationism is equivalent to Albert's, only with the additional requirement that the embedding is such that the total angular momentum and energy of the Universe vanish.

But this detail is not critical to Albert's overall argument, which is that moves like this might be innocuous, but are importantly disanalogous to the moves that treat the wave-function nomically. As in the first chapter, Albert works up to his overall conclusion via a number of examples: he asks, for instance, how we would consider a theory which apparently contains N+M pointlike particles but where in fact only N particles really exist. The other apparent particles in the theory represent a law, which he summarizes as

> The physically possible motions of the N existing particles are just the ones that have at least one faithful embedding into a *larger* collection of N+M particles, floating around in [absolute] space-time, in accord with [given laws of classical particle motion].

Albert argues – or, perhaps, simply makes a compelling intuitive case – that in some profound sense theories like this are cheating. They eliminate ontology too cheaply: the formalism of the theory screams at us that it describes N+M particles, and our claim that only N of the particles are 'real' becomes at best unmotivated, at worst unintelligible. And he makes his way, step-by-step, through cases like these until he arrives back at the wavefunction. To deny its existence, he argues persuasively, is far more akin to denying the M particles than to denying absolute space.

(To make Albert's position vivid here, we can modify the example: suppose that the N particles comprise *New York City*. Then we can cheaply deny that anything exists except New York, simply by treating those apparent 'particles' that are not in New York as mere mathematical superstructure whose entire role is to determine how New York behaves. Even the most ardent Manhattanite shouldn't think it's quite that easy to deny that anything else exists!)

As Albert acknowledges at the end of the chapter (pp.84-5) it is hard to parlay these intuitions into a systematic – let alone deductively required – theory of which parts of a mathematized theory represent contingent goings-on and which represent nomic structure. But still, the intuitions are compelling. Again, I cannot do full justice to the detailed shape of Albert's argument here, and can only recommend that you engage with its details.

I can't resist observing that here, as in chapter 1, Albert is remarkably close to certain positions adopted by advocates of the Everett interpretation – notably, again, Deutsch's 'Everett in denial' objection to hidden-variable theories, and to Harvey Brown and my development of that objection and our response to the idea that the wave-function might simply be a law (Deutsch 1996, Brown and Wallace 2005).

The third essay ('The still more basic question') might be the deepest in the collection; it is certainly the most inconclusive. Albert himself describes it (p.86) as 'a cry for help'. Here Albert contrasts the primitive ontologists' approach to *macroscopic* ontology with alternatives more suited to wave-function realism, and finds all options lacking.

The common question is: given a microphysical theory (understood, say, as the movements of particles in some low-dimensional space, or as the undulations of a wave-function in a far higher-dimensional space), how are we to recover the familiar three-dimensional world of ‘medium-sized dry goods’? Doing so, of course, is essential if any purportedly ‘physical’ theory is actually to make contact with experiment and observation.

Albert identifies three strategies, which he attributes to the ‘puritans’ (basically the primitive ontologists), the ‘global functionalists’ (perhaps an earlier version of himself), and the ‘libertines’. To the puritans, macroscopic reality is obtained from microphysics by ‘coarse-graining’ or ‘squinting’ – there is a table before us because there is a blob of microphysical stuff before us and it’s table-shaped. (Needless to say, if this is correct then *fundamental* ontology must be present in low-dimensional space-time).

Albert argues – rightly, I think – that this is implausibly restrictive. For one thing, it has clear counter-examples – ordinary macrophysical concepts like *heat* (he could equally have mentioned *color* or *electrical conductivity*) are not visible by squinting in this way. And the counter-examples have a common structure: they are functionally realized in the microphysics. As Albert puts it (p.92, emphasis in original), “we find that molecular motion is the thing that plays the heat *role,* we find that molecular motion is the thing that occupies the heat *node*, in the vast network of causal relations”. The puritans have no space for concepts like this, and so their macro-ontology is unacceptably restrictive.

The natural move – embraced by Albert’s global functionalists – is to lean into functional realization: to the global functionalist, it suffices to recover the macroworld if we can find something macroworld-like that is functionally realized in microphysics. And indeed, ideas like this have been prominent in wave-function realism since its inception: Albert briefly flirted with the idea that the three-dimensional world was *illusory,* but quickly softened this to the idea that it was *emergent* from the underlying high-dimensional reality.

But global functionalism is far too permissive to be acceptable, for a simple reason: given sufficient latitude in our choice of functional reduction, absolutely any microphysical theory can be seen as functionally realizing pretty much anything at all. The point is not entirely original – one thinks of Putnam’s paradox, and of Searle’s observation that anything can be understood as computing every computable function – but it is thrown into sharp relief in Albert’s presentation.

That leaves libertinism. To the libertine, there is more to the world than fundamental physics: there are also logically (and perhaps metaphysically) contingent grounding rules that relate the macro to the micro. Albert dislikes this too: he observes – quite rightly, I think – that our grasp of what microphysical reality *is* depends on its connection to the manifest image. Insofar as it isn’t part of the concept of a particle to (e.g.) be co-located with macroscopic matter, we don’t know what particles are in the first place, and so we have no antecedent understanding of the microphysics that can be supplemented by grounding relations.

So we are left with a profound metaphysical riddle. Albert's last section (p.120) is titled "in lieu of a conclusion": he doesn't know how to resolve the riddle, and neither do I. The nearest I can suggest is that the learning of new physical theories is a bootstrap process: we shouldn't start with the dichotomy of fundamental physics and the manifest image, we should work our way up step by step from the manifest image, expanding our concepts as we do so but not breaking the connections between theories at different levels only to re-establish them *a priori*. But that is barely a gesture at a full answer.

But what *A guess at the riddle* might lack in answers (especially in its final chapter) it more than makes up for with questions, and with imaginative ways to engage with and develop those questions. This is a deep, and deeply important, contribution to the metaphysics of physics, and indeed to metaphysics more generally. It deserves careful and sustained attention.*

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