Remembering the Future: How to Predict a Scientific Revolution

For historical perspective on this historic occasion, let us turn to the twin revolutions of science and theology — of facts and values — simmering in early modern Europe.

On June 4, 1539 in Wittenberg, Germany at his dinner table with colleagues and students, Martin Luther called Galileo that fellow who wants to prove the earth moves and turns all astronomy upside down. Luther had already turned religion upside down. In 1517 he catalyzed the

Protestant Reformation by proclaiming 95 points of public debate against indulgences or cash donations in exchange for salvation during a papal campaign to fund needed repairs to St Peter's Basilica.

Pope Leo X excommunicated Luther, a professor of biblical interpretation. On the authority of scripture, Luther later agreed with Galileo's inquisitors that the sun revolves around the earth. Their official proof text, Joshua 10:12-14, narrates Israel's victory over the Amorites; Joshua commands a rotating sun to stand still at Gibeon, and the moon at Aijalon. Because of his dissenting proof of the laws of motion, Galileo spent the rest of his life from 1633 onward a heretic under house arrest at his villa near Florence.

This first crucible of political and biblical theology turned the ground of certainty spinning upside down in all directions.

Science and theology would never be the same: a foretaste of the way testable proof — and strong emotions — can cause revolutions.

Fast forward September 18, 2019, to my seminar table talk on the physical foundations of theory, Department of Physics, Princeton University. A small group took on quantum gravity. Gerard ‘t Hooft, one of our esteemed speakers today, spoke of quantum mechanics as a tool to solve problems. Turning quantum mechanics upside down, he said, is a solution.

String theorist Edward Witten responded. The fact that quantum mechanics can be used to solve non-quantum mechanical problems suggests that quantum mechanics is more powerful than classical mechanics.

Christopher Tully: With all the great achievements of quantum mechanics we are not certain that our discussion of origins is on solid theoretical ground. What if you have an infinite number in initial conditions? Does that mean your initial state and properties in only one state make a superposition? Initial conditions are special. Why hasn't gravitational instability taken over? Why hasn’t everything collapsed into a black hole?

James Peebles: We are in one giant wavefunction from the start. And we don’t know what’s beneath quantum mechanics. We do not have the state under quantum mechanics. What is the deeper underlying theory?

How deep do you go? How do you know when to stop?

Intense discussion: Are observables in the early universe fixed initial conditions? Are all sets of initial conditions consistent with what we observe today? Suppose you do an EPR experiment to test the hypothesis. You measure two CMB photons at the same time. Do they have some level of entanglement consistent with initial conditions?

Wavefunction initial conditions are hidden, and it’s unclear that the numbers are well defined.

Questions: Are the laws of nature definable? If you deny definability do you deny the existence of pure, precise laws of nature? Are we using the right concepts? What's up with free will, initial conditions, and nonlocality? Do ontological states exist with zero uncertainty at an entangled initial state wired for infinite expansion?

As to one giant wavefunction from the start, we understand the wavefunction to be the quantum state of everything that exists. It is foundational to quantum mechanics, and it needs to be better understood for any real progress to be made in observational cosmology.

Sir Roger Penrose, one of our online seminar participants, published with Stephen Hawking a mathematical description of the gravitational collapse that produces black holes. He now believes that the Copenhagen interpretation of quantum mechanics is subjective and thus uncertain because of observer dependence on the collapse or state reduction of the wavefunction. The wavefunction quantum state up to proportionality, he says, should be given the objective ontological status of a physical object.

Here we encounter the challenge of quantum gravity, with the help of the right tools, to turn quantum mechanics upside down. More on this in a few minutes.

What if the wavefunction is not simply a mathematical formulation of all possible or probable observable states determined by observation and measurement? Perhaps gravity — or dark matter! — induces the state reduction of the wavefunction.

Catalina Curceanu, also an online seminar participant, runs a laboratory in Gran Sasso. She is constructing a wavefunction model relating to physical reality and, importantly, to nonlocality.

Her experiments will advance our knowledge of entanglement and quantum gravity.

Experimental work of this nature can give us a better understanding of the wavefunction at the initial state. It can inform models of quantum gravity. It will help modify the standard model to give us more precise laws of nature toward a coherent ontology of quantum mechanics and its underlying nature — not just new mathematics where the axioms of arithmetic are unprovable.

The new physics must solve a deeply problematic conflict of interpretations for one universe governed by two sets of contradictory laws. That conflict explains why so many in the theoretical community think our standard concepts of spacetime will have to change. This means revolution — with profound consequences for cosmology.

Why cosmology? The standard cosmological model requires testable initial conditions to predict certain outcomes. At the initial state, however, no tools or instruments yet exist to test or probe the initial conditions of spacetime emerging, say, from an entangled quantum state to the classical universe described by Einstein’s gravity.

This is why any foundational claim to a consistent ontology of quantum and classical mechanics at the initial state is uncertain. Even if we can infer rightly that the Big Bang was a singularity, it is still conjectural. We have no testable evidence for the initial causal mechanisms of structure formation and expansion from the first singularity. Why? Because the initial state is unintelligible without predictive theory of confirmed, observable initial conditions. Without the evidence of observables we have metaphysics —

holograms, strings — not ontology.

The good news is tools — instrumentation — on the order of Galileo’s 1609 retooled Dutch telescope. Now, from the mountaintops of Chile, Princeton University’s CMB telescope team has confirmed observables defining the cosmic microwave background radiation: fossil evidence of the early universe 380,000 years after the initial state. What happened before that state, however, is vigorously contested.

Contested also is the nature of quantum mechanics at the primordial regime, before

CMB evidence, at all scales such as the Planck scale of primordial pure quantum black holes. Here again we encounter the challenge of quantum gravity. How can primordial black holes from the start of causal structures emerge with interior properties causing laws like gravitation to break down? Newly published images of black holes show that the blackhole boundary confirms general relativity. What else can we infer about the interior of this unitary physical object? Did quantum mechanics apply at initial-condition pure-state quantum black holes at the Planck scale?

The wavefunction describes the quantum state of everything that exists — such as black holes — now given objective status by the Event Horizon Telescope (EHT) directed at Harvard by our speaker Shep Doeleman, where he collaborates with co-speaker Peter Galison directing the Black Hole Initiative. I predict the next-generation EHT (ngEHT) will generate data at the blackhole event horizon from which to credibly infer or observe the properties of physical objects and dynamics inside a black hole. The result? A revolution in laws of nature. I predict the ngEHT will give the quantum state objective status. Observable effects of causal laws underlying the wavefunction may show it to be a physical object in a singularity from which to infer the mechanisms of the initial singularity.

We live in a world of paradox. The probability of an entangled initial singularity emerging from a quantum state and expanding or phase transitioning to a classical state suggests to me an initial condition in which an objectively real wavefunction physically acts upon each state at the effect the EPR paradox. Furthermore, if measurements really do disentangle quantum systems like the wavefunction, fundamental physical theory will have to change, as Sir Roger has suggested.

Will wavefunction initial conditions always be hidden between the lines of the Book of Nature? Or will revolutionary instrumentation like the next-generation Event

Horizon Telescope rewrite the Book of hidden conditions? Quantum theory makes

epistemic claims on the origins of the universe AND our consciousness of it. Are our lives determined by initial conditions at the origins of the universe? Are we as creative agents determined fundamentally by the conditions of our birth, our histories and cultures? Is free will consistent with what's beneath quantum mechanics with gravitational elements — and with our experience of existence? Open questions such as these will shape the future of philosophical and theological discourse on origins and causation.

In conclusion, I raise one more open question, of social construction of theoretical and experimental science. Group dynamics across disciplines can be driven by social pressure to conform to wrongthink, to put it plainly. Great ideas and original thinkers have suffered terrible pain for differing or disagreeing with fashionable trends that we see, for example, in early modern Wittenberg at Martin Luther’s dinner table — or from his savage attack on Desiderius Erasmus in a debate on freedom and bondage of the will. In contemporary life the group dynamic can tend towards ignoring original ideas ahead of the curve. Think of John Bell, Hugh Everett, uncountable brilliant graduate students too worried about getting jobs to challenge their professors as wrong as Luther was to proof-text planetary motion from the Book of Joshua.

We stand at the precipice of a revolution in contemporary physics because of courageous collaborations in modern instrumentation. Let us then listen to and value all voices emerging from the remarkable groundwork they have selflessly built to turn the future of physics and philosophy upside down in all directions!