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BOOKSHELF

Book Review: 'Our Mathematical Universe' by Max Tegmark

Is our universe only one of many? If so, how real are the others?

By **PETER WOIT**

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It's a truly remarkable fact that our deepest understanding of the material world is embodied in mathematics, often in concepts that were originated with some very different motivation. A good example is our best description of how gravity works, Einstein's 1915 theory of general relativity, in which the gravitational force comes from the curvature of space and time. The formulation of this theory required Einstein to use mathematics developed 60 years earlier by the great German mathematician Bernhard Riemann, who was studying abstract questions involving geometry. There's now a long history of intertwined and experimentally tested discoveries about physics and mathematics. This unity between mathematics and physics is a source of wonder for those who study the two subjects, as well as an eternal conundrum for philosophers.

OUR MATHEMATICAL UNIVERSE

By Max Tegmark
Knopf, 421 pages, $30

Max Tegmark thus begins his new book with a deep truth when he articulates a "Mathematical Universe Hypothesis," which states simply that "physical reality is a mathematical structure." His central claim ends up being that such a hypothesis implies a surprising new vision of how to do physics, but the slipperiness of that word "is" should make the reader wary. Mr. Tegmark raises here the age-old question of whether math just describes

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physical reality or whether it defines physical reality. This distinction is of relevance to philosophers, but its significance for practicing physicists is unclear.

"Our Mathematical Universe" opens with a memoir of Mr. Tegmark's own career in physics. He's now a cosmologist at MIT whose specialty is interpreting data about the structure and evolution of the universe, much of it gathered from new space and earth-based instruments. His book, however, quickly turns to the topic of the "multiverse"—the idea that our universe is part of some larger unobservable structure. Multiverse theories come in a baffling number of different versions. They have been a hot topic for the past dozen years, with Brian Greene's "The Hidden Reality" (2011) a good example of a recent book covering this material.

Mr. Tegmark categorizes different multiverse proposals in terms of "Levels," a useful method designed to keep track of the various theories. Many of these include some version of the idea that our universe is one of many unconnected universes obeying the same physical laws. This "Level I" type of multiverse is like Jorge Luis Borges's "Library of Babel," which contains all possible books, though most remain inaccessible to his story's narrator due to their remoteness. As far back as 1584, Giordano Bruno proposed a universe of this sort, provoking mind-bending paradoxes involving infinite copies of oneself acting out completely different lives.

A much different type of multiverse arises in what is sometimes called the "many-worlds interpretation" of quantum theory. This is one way of thinking about the relationship between quantum mechanics and conventional human-scale physics. The idea is that while any quantum system is described by a single mathematical object called a quantum wave-function, this can contain within itself a description of an infinity of different possible worlds. These correspond to the different possible states we may observe when we probe a quantum system with a macroscopic experimental apparatus. This multiverse is more like the "Garden of Forking Paths" that Borges describes in his story of that title, with each world branching off when we make an observation. Philosophical debate rages over what to think of such possible worlds: Are the ones we don't end up in "real" or just a convenient calculational fiction? Mr. Tegmark calls the multiverse of such worlds a "Level III" multiverse.

These Level I and III possibilities fit reasonably well within variants of conventional views about our current best understanding of physics. The controversy surrounds what Mr. Tegmark calls "Level II" multiverses. At this level, different parts of a multiverse can have different physics—for instance, different fundamental forces, as well as different fundamental particles with different masses. The problem: There is no experimental evidence for this and, arguably, no way of ever getting any, since our universe likely interacts in no way with any universes whose physics differs from our own. When someone is trying to sell a Level II multiverse theory, pay close attention to what exactly is being marketed; it comes without the warranty of an experimental test.

Since 1984 many physicists have worked on "string theory," which posits a new unification of general relativity and quantum theory, achieved in part by abandoning the idea of fundamental particles. Early on, the new fundamental objects were supposed to be relatively well-defined one-dimensional vibrating string-like objects. Over the years this theory has evolved into something often called "M-theory," which includes a wealth of poorly understood and mathematically complex components.

As far as one can now tell, if M-theory is to make sense, it will have so many possible solutions that one could produce just about any prediction about our observable universe that one might want. Such an unfalsifiable theory normally would be dismissed as unscientific, but proponents hope to salvage the situation by invoking a Level II multiverse containing all solutions to the theory. Our observed laws of physics would just represent a particular solution.

Mr. Tegmark wants to go even further down this rabbit hole. He assumes that what we observe is governed by something like M-theory, with its multiverse of different physical laws. But he wants to find a wider view that explains M-theory in terms of his "math is physics" hypothesis. He argues that his hypothesis implies the conclusion that "all mathematical structures exist." The idea is that every example mathematicians teach in their classes, whether it's a polynomial equation, a circle, a cube, or something much more complicated, represents an equally good universe. The collection of all mathematical structures he calls the "Level IV" multiverse, the highest and most general level.

Interpreting the meaning of "exists" in this way—to include all possible worlds—is a philosophical position known as "modal realism." The innovation here is the claim that this carries a new insight into physics. The problem with such a conception of the ultimate nature of reality is not that it's wrong but that it's empty, far more radically untestable than even the already problematic proposals of M-theory. Mr. Tegmark proposes abandoning the historically proven path of pursuing a single exceptionally deep and very special mathematical structure at the core of both math and physics in favor of the hypothesis that, at the deepest level, "anything goes."

Mr. Tegmark's proposal takes him deep in the realm of speculation, and few of his fellow scientists are likely to want to follow him. There's a danger, though, that his argument will convince some that "anything goes" is all there is to ultimate reality, discouraging their search for a better and more elegant version of our current best theories. To be fair, Mr. Tegmark acknowledges he is going beyond conventional science, even including pithy advice about how to pursue a successful career while indulging in speculative topics that one's colleagues are likely to see as beyond the bounds of what can be taken seriously. It's worth remarking that not taking itself too seriously is one of the book's virtues.

A final chapter argues for the importance of the "scientific lifestyle," meaning scientific rationality as a basis for our decisions about important questions affecting the future of our species. But the great power of the scientific worldview has always come from its insistence that one should accept ideas based on experimental evidence, not on metaphysical reasoning or the truth-claims of authority figures. "Our Mathematical Universe" is a fascinating and well-executed dramatic argument from a talented expositor, but reading it with the skeptical mind-set of a scientist is advised.

—Mr. Woit is the author of "Not Even Wrong: The Failure of String Theory and the Search for Unity in Physical Law."