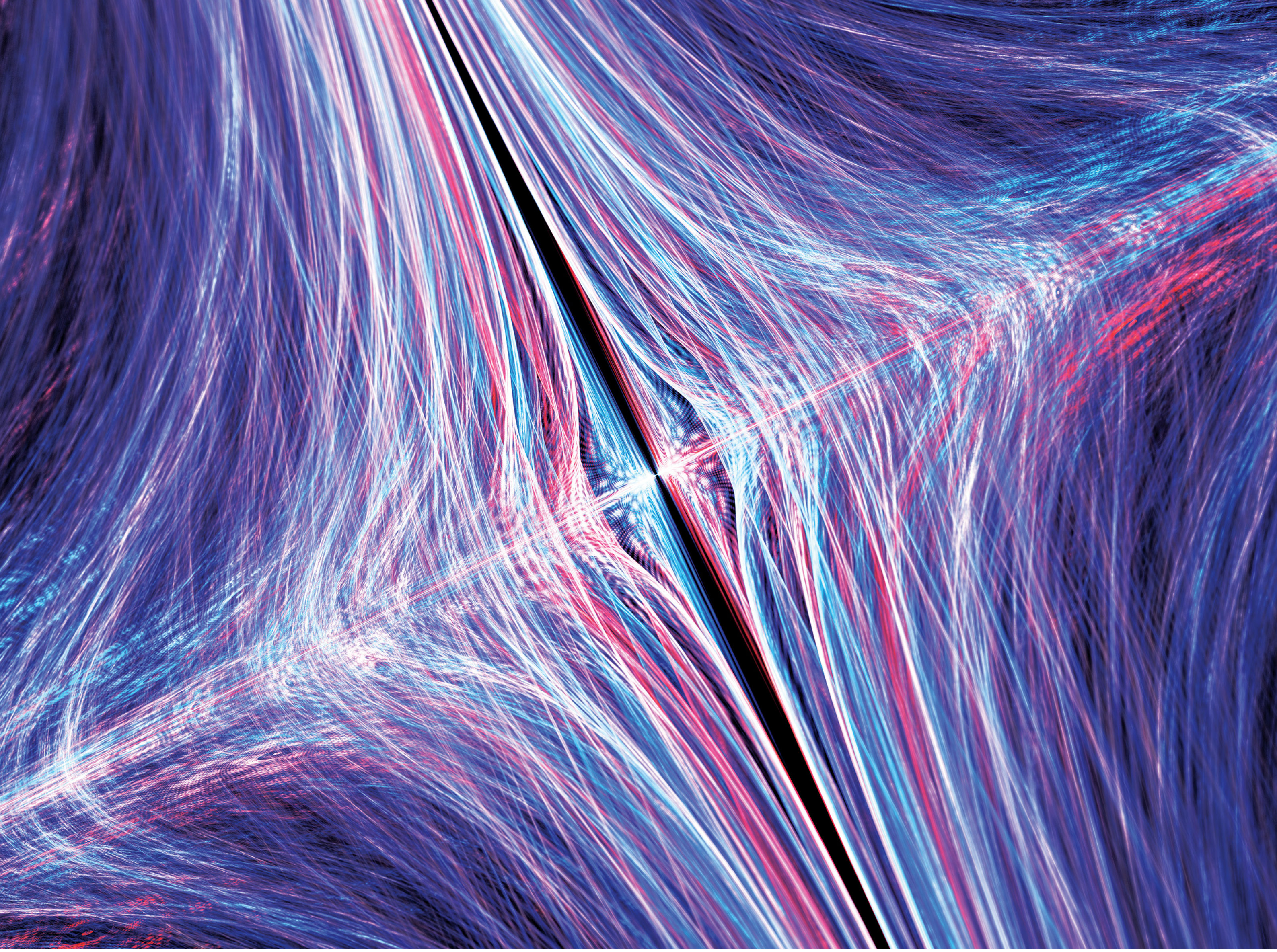


Originating in the 1950s, the many-worlds theory posits that parallel worlds constantly branch off from each other, moment by moment.

SHUTTERSTOCK

QUANTUM PHYSICS

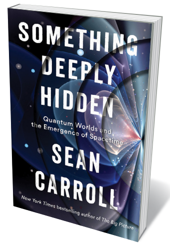
The allure of many worlds

Robert P. Crease enjoys Sean Carroll's foray into a 60-year-old theory.

At the beginning of *Something Deeply Hidden*, Sean Carroll cites the tale of the fox and the grapes from Aesop's Fables. A hungry fox tries to reach a bunch of grapes dangling from a vine. Finding them beyond his grasp, but refusing to admit failure, the fox declares the grapes to be inedible and turns away. That, Carroll declares, encapsulates how physicists treat the wacky implications of quantum mechanics.

Carroll wants that to stop. The fox can reach the grapes, he argues, with the many-worlds theory. Originated by US physicist Hugh Everett in the late 1950s, this envisions our Universe as just one of numerous parallel worlds that branch off from each other, nanosecond by nanosecond, without intersecting or communicating. (The many-worlds theory differs from the concept of the multiverse, which pictures many self-contained universes in different regions of space-time.)

Six decades on, the theory is one of the most bizarre yet fully logical ideas in human history, growing directly out of the fundamental principles of quantum mechanics without introducing extraneous elements. It has become a staple of popular culture, although the plots of the many films and television series inspired by it invariably flout the theory by relying on contact between the parallel worlds, as in the 2011 movie *Another Earth*.



Something Deeply Hidden: Quantum Worlds and the Emergence of Spacetime
SEAN CARROLL
Oneworld (2019)

In *Something Deeply Hidden*, Carroll cogently explains the many-worlds theory and its post-Everett evolution, and why our world nevertheless looks the way it does. Largely because of its purely logical character, Carroll calls Everett's brainchild "the best view of reality we have".

CATCH A WAVE

Quantum mechanics is the basic framework of modern subatomic physics. It has successfully withstood almost a century of tests, including French physicist Alain Aspect's experiments confirming entanglement, or action at a distance between certain types of quantum phenomena. In quantum

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mechanics, the world unfolds through a combination of two basic ingredients. One is a smooth, fully deterministic wave function: a mathematical expression that conveys information about a particle in the form of numerous possibilities for its location and characteristics. The second is something that realizes one of those possibilities and eliminates all the others. Opinions differ about how that happens, but it might be caused by observation of the wave function or by the wave function encountering some part of the classical world.

Many physicists accept this picture at face value in a conceptual kludge known as the Copenhagen interpretation, authored by Niels Bohr and Werner Heisenberg in the 1920s. But the Copenhagen approach is difficult to swallow for several reasons. Among them is the fact that the wave function is unobservable, the predictions are probabilistic and what makes the function collapse is mysterious.

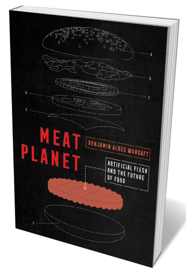
> ***"Carroll argues that the many-worlds theory is the most straightforward approach to understanding quantum mechanics."***

What are we to make of that collapsing wave? The equations work, but what the wave function 'is' is the key source of contention in interpreting quantum mechanics. Carroll outlines several alternatives to the Copenhagen interpretation, along with their advantages and disadvantages.

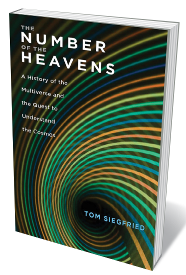
One option, the 'hidden variables' approach championed by Albert Einstein and David Bohm, among others, basically states that the wave function is just a temporary fix and that physicists will eventually replace it. Another tack, named quantum Bayesianism, or QBism, by Christopher Fuchs, regards the wave function as essentially subjective. Thus it is merely a guide to what we should believe about the outcome of measurements, rather than a name for a real feature of the subatomic world. Late in his life, Heisenberg proposed that we have to change our notion of reality itself. Reaching back to a concept developed by Aristotle — 'potency', as in an acorn's potential to become an oak tree, given the right context — he suggested that the wave function represents an "intermediate" level of reality.

Carroll argues that the many-worlds theory is the most straightforward approach to understanding quantum mechanics. It accepts the reality of the wave function. In fact, it says that there is one wave function, and only one, for the entire Universe. Further, it states that when an event happens in our world, the other possibilities contained in the wave function do not go away. Instead, new worlds are created, in which each possibility is a reality. The theory's sheer simplicity and logic within the conceptual ▶

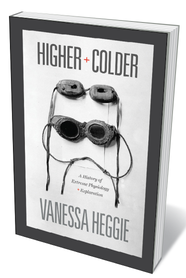
Books in brief



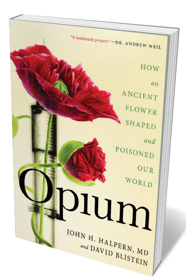
Meat Planet
Benjamin Aldes Wurgaft University of California Press *(2019)*
In 2013, physiologist Mark Post wowed world media with a lab-grown burger, cultured from bovine muscle cells at a cost of nearly US$300,000. Yet that brave new food is still a fledgling biotechnology. Historian Benjamin Wurgaft explores this "small, strange world" in a thoughtful study mixing science reportage with philosophical meditations. He interviews Post, visits hotspots such as 'cellular agriculture' institute New Harvest in New York City, and even muses over the cultivation of human cells for consumption. *In vitro* meat, he shows, opens horizons as much moral as environmental.



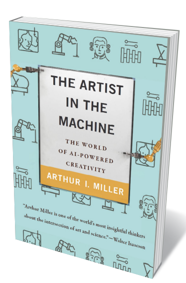
The Number of the Heavens
Tom Siegfried Harvard University Press *(2019)*
The philosopher Aristotle saw the idea of multiple worlds as illogical. In 1277, Étienne Tempier, bishop of Paris, countered by insisting that God could create any number of them. In this sparkling history, science journalist Tom Siegfried follows manifestations of the multiverse, from Renaissance scholar Nicholas of Cusa's worlds "without number" to the "different heavens" theorized by René Descartes, the discovery of galaxies, inflationary cosmology and a pick-and-mix of multiverses, be they 'quilted' or holographic. Whether you find the concept liberating or scientifically absurd, this is a mind-bending journey.



Higher and Colder
Vanessa Heggie University of Chicago Press *(2019)*
The North Pole, South Pole and 'third pole', Mount Everest, were prime twentieth-century expeditionary challenges. To physiologists such as Nello Pace and Kåre Rohdal, they were also labs for probing the physical impacts of extreme cold and altitude. But their scientific record, as medical historian Vanessa Heggie reveals in this insightful study, is overwhelmingly Eurocentric. The fieldwork sparked technological advances, but was tainted by racist 'science' and practice, from taking anthropometric measurements of Arctic peoples to erasing Nepalese Sherpas' contributions from papers.



Opium
John Halpern and David Blistein Hachette *(2019)*
Opium has been entwined with society for millennia. Here, psychiatrist John Halpern and writer David Blistein trace its path from Mesopotamia through ancient Egypt, Greece and Persia, finally reaching Britain and the United States by the nineteenth century. Both countries then fomented opium wars with China. By the twentieth century, US "drug hysteria and race-based enforcement" was rife, setting the stage for unwinnable drug wars. Now, the US opioid crisis is killing tens of thousands a year. It is time, the authors argue, to treat addiction as a curable illness — and learn the lessons of history.



The Artist in the Machine
Arthur I. Miller MIT Press *(2019)*
Can artificial intelligence (AI) attain the intellectual prowess of, say, astrophysicist Subrahmanyan Chandrasekhar? Arthur Miller probes that knotty question. Identifying seven hallmarks of creativity, he explores today's AI innovation landscape. Phillip Isola's app Pix2Pix 'translates' one image to another; Rebecca Fiebrink's Wekinator lets users make music with gestures; composer Eduardo Miranda plays duets with a slime-mould biocomputer. There are AI-scripted films, musicals, poetry — and, in Miller's view, many reasons to be cheerful about computational creativity, now and in the near future. **Barbara Kiser**

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framework of quantum mechanics inspire Carroll to call it the "courageous" approach. Don't worry about those extra worlds, he asserts — we can't see them, and if the many-worlds theory is true, we won't notice the difference. The many other worlds are parallel to our own, but so hidden from it that they "might as well be populated by ghosts".

BRANCHING CATS

For physicists, the theory is attractive because it explains many puzzles of quantum mechanics. With Erwin Schrödinger's thought experiment concerning a dead-and-alive cat, for instance, the cats simply branch into different worlds, leaving just one cat-in-a-box per world. Carroll also shows that the theory offers simpler explanations of certain complex phenomena, such as why black holes emit radiation. Furthermore, the theory might help to develop still-speculative ideas about conundrums such as how to combine quantum mechanics with relativity theory.

Something Deeply Hidden is aimed at non-scientists, with a sidelong glance at physicists still quarrelling over the meaning of quantum mechanics. Carroll brings the reader up to speed on the development of quantum physics from Max Planck to the present, and explains why it is so difficult to interpret, before expounding the many-worlds theory. Dead centre in the book is a "Socratic dialogue" about the theory's implications. This interlude, between a philosophically sensitive physicist and a scientifically alert philosopher, is designed to sweep away intuitive reservations that non-scientists might have.

Nevertheless, non-scientists might have lingering problems with Carroll's breezy, largely unexamined ideas about "reality". Like many physicists, he assumes that reality is whatever a scientific theory says it is. But what gives physicists a lock on this concept, and the right to say that the rest of us (not to mention, say, those in extreme situations such as refugees, soldiers and people who are terminally ill) are living through a less fundamental reality? Could it be that we have to follow Heisenberg's lead? That is, must we rely on tools for talking about the complexities of reality that philosophers have developed over millennia to explain why the fox has such a tough time reaching those grapes?

What a wacky idea. ■

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e-mail: robert.crease@stonybrook.edu

ASTROPHYSICS

Zwicky: new lens on an elusive astrophysicist

Jaco de Swart enjoys a biography of the scientist who pioneered findings on dark matter and supernovae.

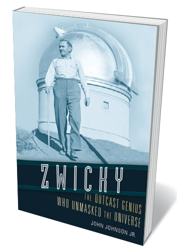
Fritz Zwicky advanced astronomy over much of the twentieth century, pioneering findings on constituents of the cosmos from supernovae and neutron stars to dark matter and compact galaxies. He worked at two of the world's most historically important observatories: Mount Wilson and Palomar in California. He was an early innovator in jet-engine design. Yet the Swiss astronomer is a somewhat elusive figure in the history of science. Science journalist John Johnson seeks to rectify that in his spirited biography, *Zwicky*.

As Johnson reveals, the very boldness and ingenuity of Zwicky's discoveries could work against him: many were viewed as unconventional, and were confirmed only years after he made them. Zwicky also had a reputation for abrasiveness. For instance, he reportedly called some of his colleagues at the California Institute of Technology (Caltech) in Pasadena "spherical bastards" (meaning, from whichever angle you looked at them). Johnson's book unravels these two sides of Zwicky — the brilliance and the ire — by framing him as an "outcast genius". But can this portrayal help to change perceptions of the prolific astrophysicist?

Zwicky trained in physics and mathematics at the Swiss Federal Institute of Technology in Zurich. In 1925, the Rockefeller Foundation in New York City offered him a fellowship to study the physics of crystals at Caltech with the Nobel-prizewinning experimental physicist Robert Millikan. Two years later, he shifted fields. He began to research galaxies at Mount Wilson alongside Edwin Hubble, the astronomer who would find evidence for the expansion of the Universe in 1929. Zwicky himself soon produced a series of intriguing theories and observations.

> **"Zwicky is celebrated mainly as the 'father of dark matter'."**

Zwicky is celebrated mainly as the 'father of dark matter'. In the early 1930s, while studying Hubble's observations of the Coma Cluster of galaxies, he noted an anomaly. According to the measure of visible mass, single galaxies were moving too fast for the cluster to remain bound together. Zwicky posited that an as-yet unobserved type of mass, *dunkle Materie* (dark matter) might explain it, and in 1933 he



Zwicky: The Outcast Genius Who Unmasked the Universe
JOHN JOHNSON
Harvard (2019)

presented his findings in the journal of the Swiss Physical Society. However, it took another three decades for the phenomenon to be observed widely. And only after Zwicky's death, in 1974, was dark matter accepted as part of the cosmological canon, through the work of radio astronomers, cosmologists and particle physicists.

Zwicky's star soon rose. In 1934, he and Walter Baade identified the existence of supernovae, the explosive final stage of a star's life. Zwicky posited that novae launched a sea of particles into space that might account for cosmic rays, the then-unexplained phenomenon observed by Nobel laureate Victor Hess in 1912, during experiments conducted in a balloon. When the theory was made public, Zwicky's career exploded, and he became "the darling of reporters everywhere", Johnson writes.

Johnson touches on many other examples of Zwicky's prescience during his Caltech years. Again with Baade in 1934, he predicted the existence of neutron stars, extremely dense bodies of neutrons left behind after a supernova. In 1937, he was the first to argue that galaxies, like stars, could act as gravitational lenses, bending light according to Albert Einstein's general theory of relativity. And in the 1940s, his search with Milton Humason for white dwarfs — another class of dense stellar remnants — gave early hints of the highly energetic outbursts that came to be known as quasars. Johnson tells the story well, but does not delve much into the science behind the insights.

As a scientist, Zwicky went his own way, tending to study phenomena outside trends in stellar astrophysics. His professional animosities, however, were actively divisive. Johnson notes that Zwicky despised what he saw as unoriginal "grey thinking" in fellow researchers. He called theoretical physicist Richard Feynman a "spiritual coward", and was contemptuous of astrophysicists who adhered to the theory of an

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