

A View of Inflation—Eternally Going on Somewhere in the Multiverse

Our Cosmic Habitat

► Martin Rees
Princeton U. Press, Princeton, N.J., 2001. \$22.50 (205 pp.). ISBN 0-691-08926-4

Reviewed by Michael S. Turner

Astronomy is in the midst of an explosive period of discovery and deepening understanding, made possible by new technology and new ideas. Just 100 years ago the universe was dated by astronomers to be 30 million years old and consisted of our galaxy, with only a million of its 100 billion stars observed. The Solar System was known to have only 7 planets, and the workings of stellar furnaces were a mystery. The largest telescope was a 40-inch refractor that used photographic plates to capture 1% of the incident cosmic light.

Today, the largest optical telescope is 400 inches in diameter and charge-coupled devices capture nearly 100% of the incident light. Our eyes on the universe span from radio to TeV gamma rays and also include cosmic rays with energies up to 10^{21} eV, MeV neutrinos from the Sun and a supernova, and, possibly soon, gravity waves. The Sloan Digital Sky Survey has cataloged close to 100 million galaxies, including four quasars whose light was emitted when the universe was less than one-seventh its present size and less than a billion years old. Four independent methods peg the age of the universe at 14 ± 1 billion years. Known extrasolar planets outnumber the planets in our own solar system by 10 to 1.

In short, science can now tell the story of the universe from quark soup to the emergence of life on the third rock from the Sun. And no one is more capable of doing so than Sir Martin Rees, leading British astrophysicist and Astronomer Royal. He is articulate, witty, and authoritative, and he has the intellectual breadth to cover this enormous range in space, time, and subject matter.

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In 2000, Rees delivered the first series of Scribner Lectures at Princeton University; they are the substance of his most recent book, *Our Cosmic Habitat*. The book's style is less formal than the usual popular science book, but I think it works very well, for the generalist and even for the specialist.

The title of the prologue is the question raised by Einstein, "Could God have made the world any differently?" It sets the stage. This question, which in Einstein's time was certainly outside the realm of science, may now be within its purview. What makes this so, according to Rees, is the concept of the multiverse: a universe consisting of infinitely many causally distinct regions.

To prepare for the multiverse, Rees takes the reader on a wonderful tour of our universe, from its Big-Bang beginning to stars, planets, and life; he always clearly differentiates what we know with reasonable confidence from current fad and wild speculation.

In the final part of the book, Rees turns to the multiverse, which has its origins in inflationary universe theory. According to inflation, all that we see today traces back to a small bit of the pre-inflationary universe that underwent a burst of exponential expansion. Alex Vilenkin, Andrei Linde, and others have shown that inflation is eternal—if it ever occurred, it is occurring now, it occurred in the past, and it will occur in the future. Different inflationary bubbles are causally distinct, which leads to a multiverse structure for the universe. If true, that is a realization as profound as Copernicus's banishing of Earth from the center of the universe.

But here many cosmologists (including me) get conflicted. As profound as the multiverse concept may be, if it isn't testable, it isn't science. Although we are well on our way to testing the idea that our portion of the universe originated from a burst of inflationary expansion, the multiverse seems beyond the reach of similar direct testing, because, according to our current understanding, the different bubbles cannot communicate. However, Rees argues that the multiverse may even be testable now—I leave readers of the

book to decide whether or not his arguments are persuasive.

What Rees finds so attractive about the multiverse is that it gets at Einstein's question, or at least Rees's reformulation of it. In a previous successful book, *Just Six Numbers* (Basic Books, 2000), Rees identified a set of six numbers that had to be "just so" in order to result in a universe like ours. (The six numbers include the level of primeval lumpiness in the dark matter, the weakness of gravity, the binding energy of atoms, the amount of ordinary matter, and the strength of the weak forces.) Rees's version of Einstein's question is then, Could these six numbers have been chosen differently?

Marrying the multiverse to modern ideas in particle physics leads to the possibility of finding in the different bubbles, different local "bylaws" such as the local values for Rees's six numbers, the suite of stable particles, and even numbers of large dimensions. The existence of our universe comes not from any special choice but from the large number of tries. Fortunately, one can only imagine Einstein's reaction, as Rees has taken dice rolling to a new cosmic level.

Our Cosmic Habitat is science writing at its best: An eminent and articulate scientist writes about the frontiers of research and is not afraid to give his own perspective on the most thought-provoking questions. Whether or not his views on the multiverse hold up is irrelevant; he has taken his readers from quark soup to life on Earth, stimulating them in the process to think about one of the truly big questions.

Bioinformatics: The Machine Learning Approach

► Pierre Baldi and Søren Brunak
MIT Press, Cambridge, Mass., 2nd ed., 2001 [1998]. \$49.95 (452 pp.). ISBN 0-262-02506-X

Bioinformatics is an amorphous discipline that could be described as "biologically inspired computer science." But bioinformatics also draws ideas