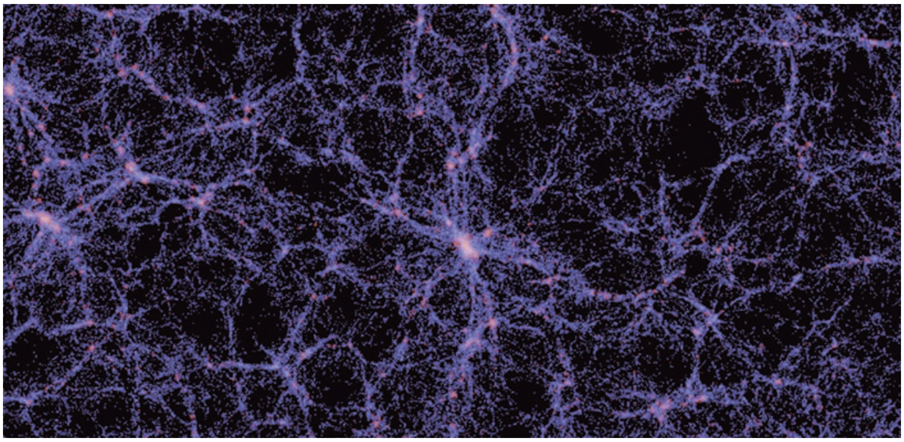


V. SPRINGEL, HITS, UNIV. HEIDELBERG

The cooling Universe enabled galaxies to form, as this simulation shows.

COSMOLOGY

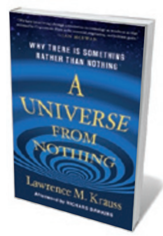
Plucked from the vacuum

A tale of multiverses, cosmic inflation and dark energy grips **Caleb Scharf**.

In less than 100 years, humanity has seen the predictions of fundamental physics converge with the observation of nature on cosmic scales. The result is an increasingly convincing picture that we, and the Universe as a whole, owe our existence to the instability of 'empty' space at a quantum level. Moreover, space and the laws of physics may be just one variant among many possible ways to assemble universes, separated by dimension or by scale.

How physicists came up with the current model of the cosmos is quite a story, and to tell it in his elegant *A Universe From Nothing*, physicist Lawrence Krauss walks a carefully laid path. The evolving Universe of finite age has pushed physicists to tackle ever more profound and challenging questions using some of the most innovative tools ever forged.

Krauss begins in 1916, when Albert Einstein fudged the field equations in his general theory of relativity to ensure that they modelled a static Universe. To do this he added a small constant repulsive force, equivalent to endowing empty space with energy. Within a few years, Edwin Hubble and other astronomers demonstrated that, in fact, the Universe is expanding and dynamic. Einstein removed the force from his equations. In the following decades came the recognition that most matter is dark and only weakly interacting, and that the observed cosmic mix of light elements, such as hydrogen, helium and lithium, is the result of primordial nucleosynthesis in the first minutes after the Big Bang, when newly stable protons and neutrons combined in a frenzy of nuclear fusion.



A Universe from Nothing: Why There is Something Rather Than Nothing
LAWRENCE M. KRAUSS
Free Press: 2012. 224 pp. $24.99, £17.99

Another milestone in the story is the measurement, in 1992, of hot and cold patches in the sea of microwave radiation that was scattered as the plasma of a 380,000-year-old Universe cooled enough to form atoms. These patterns reveal the seeds of galactic structures in today's Universe and offer striking confirmation of current cosmological theories. But just as all seemed to be fitting together well, astronomers turning their telescopes to distant, dimmed supernovae saw that the expansion of the space between the stars was accelerating rather than decelerating. Like Einstein, physicists are again stepping back to look for a way to tie the strands together.

Mathematical investigations of the atomic and subatomic world provide a plausible solution. The overall smoothness and geometrical regularity of the Universe could have resulted from its rapid inflation from quantum scales during its earliest stages. The later accelerating expansion might be driven by the 'dark energy' of the vacuum itself — a seething ocean of virtual particle pairs popping in and out of existence as a result of quantum uncertainty.

Furthermore, Krauss points out, our Universe seems to have a net gravitational energy that is suspiciously close to zero: its existence may 'cost' nothing, requiring no energy input. This raises the possibility of the ultimate free lunch — of a cosmos that is merely a piece of borrowed stuff, having appeared spontaneously, like a virtual particle, and been filled with matter and radiation simply as a consequence of the energy of empty space. Ours may be one of an infinite array of universe-like things, just one instance in a multiverse.

It would be easy for this remarkable story to revel in self-congratulation, but Krauss steers it soberly and with grace, taking time to let the reader digest the material. His discussion of the multiverse is a good example: he lays out the possibilities and scientific and philosophical implications without beating the drum for any one hypothesis. His asides on how he views each piece of science and its chances of being right are refreshingly honest.

He notes that a number of vital empirical discoveries are, ominously, missing from our cosmic model. Dark matter is one. Despite decades of astrophysical evidence for its presence, and plausible options for its origins, physicists still cannot say much about it. We don't know what this major mass component of the Universe is, which is a bit of a predicament. We even have difficulty accounting for every speck of normal matter in our local Universe. This does not mean that something is wrong with the current picture, but that we astronomers should be uncomfortable about embracing a phenomenon such as dark energy when we still have a mess to tidy up elsewhere.

Krauss eases such concerns by showing that the Universe's accelerating expansion fits astonishingly well with a host of its other characteristics. He shows how the theories of the physical sciences — from the subatomic to the cosmological — unite sublimely.

What does this mean for humanity? In a provocative afterword, evolutionary biologist and atheist Richard Dawkins writes that the apparent near-inevitability of something arising out of unstable nothingness, as described by Krauss, is devastating for theologians and creationists. Dawkins is right. But it is also invigorating for the rest of us, because in this nothingness there are many wonderful things to see and understand. ■

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