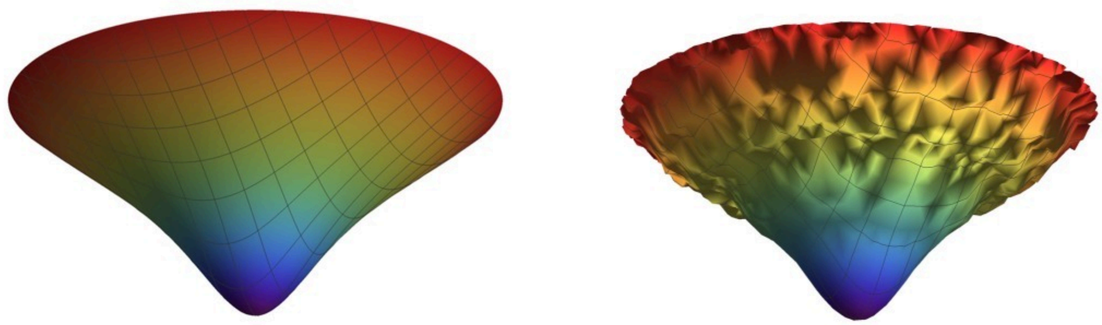
No Universe without Big Bang

June 15 2017



Credit: J.-L. Lehners (Max Planck Institute for Gravitational Physics)

According to Einstein's theory of relativity, the curvature of spacetime was infinite at the big bang. In fact, at this point all mathematical tools fail, and the theory breaks down. However, there remained the notion that perhaps the beginning of the universe could be treated in a simpler manner, and that the infinities of the big bang might be avoided. This has indeed been the hope expressed since the 1980s by the well-known cosmologists James Hartle and Stephen Hawking with their "no-boundary proposal", and by Alexander Vilenkin with his "tunnelling proposal". Now scientists at the Max Planck Institute for Gravitational Physics (Albert Einstein Institute/AEI) in Potsdam and at the Perimeter Institute in Canada have been able to use better mathematical methods to show that these ideas cannot work. The big bang, in its complicated glory, retains all its mystery.

One of the principal goals of cosmology is to understand the beginning of our universe. Data from the Planck satellite mission shows that 13.8 billion years ago the universe consisted of a hot and dense soup of particles. Since then the universe has been expanding. This is the main tenet of the hot big bang theory, but the theory fails to describe the very first stages themselves, as the conditions were too extreme. Indeed, as we approach the big bang, the energy density and the curvature grow until we reach the point where they become infinite.

As an alternative, the "no-boundary" and "tunneling" proposals assume that the tiny early universe arose by quantum tunnelling from nothing, and subsequently grew into the large universe that we see. The curvature of spacetime would have been large, but finite in this beginning stage, and the geometry would have been smooth - without boundary (see Fig. 1, left panel). This initial configuration would replace the standard big bang. However, for a long time the true consequences of this hypothesis remained unclear. Now, with the help of better mathematical methods, Jean-Luc Lehners, group leader at the AEI, and his colleagues Job Feldbrugge and Neil Turok at Perimeter Institute, managed to define the 35 year old theories in a precise manner for the first time, and to calculate their implications. The result of these investigations is that these alternatives to the big bang are no true alternatives. As a result of Heisenberg's uncertainty relation, these models do not only imply that smooth universes can tunnel out of nothing, but also irregular universes. In fact, the more irregular and crumpled they are, the more likely (see Fig. 1, right panel). "Hence the "no-boundary proposal" does not imply a large universe like the one we live in, but rather tiny curved universes that would collapse immediately", says Jean-Luc Lehners, who leads the "theoretical cosmology" group at the AEI.

Hence one cannot circumvent the big bang so easily. Lehners and his colleagues are now trying to figure out what mechanism could have kept those large quantum fluctuations in check under the most extreme circumstances, allowing our large universe to unfold.

More information: Job Feldbrugge et al. Lorentzian quantum cosmology, *Physical Review D* (2017). DOI: 10.1103/PhysRevD.95.103508