New telescopes to study the aftermath of the Big Bang

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A photograph of a CMB-S4 detector wafer being prepared for testing in a cryostat at Lawrence Berkeley National Laboratory. Credit: Thor Swift/Lawrence Berkeley National Laboratory

Astronomers are currently pushing the frontiers of astronomy. At this very moment, observatories like the James Webb Space Telescope (JWST) are visualizing the earliest stars and galaxies in the universe, which formed during a period known as the "Cosmic Dark Ages." This period was previously inaccessible to telescopes because the universe was permeated by clouds of neutral hydrogen.

As a result, the only light is visible today as relic radiation from the Big Bang—the cosmic microwave background (CMB)—or as the 21 cm spectral line created by the reionization of hydrogen (aka the Hydrogen Line).

Now that the veil of the Dark Ages is being slowly pulled away, scientists are contemplating the next frontier in astronomy and cosmology by observing "primordial gravitational waves" created by the Big Bang. In recent news, it was announced that the National Science Foundation (NSF) had awarded $3.7 million to the University of Chicago, the first part of a grant that could reach up to $21.4 million. The purpose of this grant is to fund the development of next-generation telescopes that will map the CMB and the gravitational waves created in the immediate aftermath of the Big Bang.

Gravitational waves (GW), originally predicted by Einstein's theory of general relativity, are ripples in spacetime caused by the merger of massive objects—like black holes and neutron stars. Scientists have also theorized that there are GWs formed during the Big Bang that could still be visible today as vibrations in the background. In collaboration with the Lawrence Berkeley National Laboratory (LBNL), researchers from the CMB-S4 project University of Chicago seek to build telescopes and infrastructure in Antarctica and Chile to search for these waves.

The collaboration currently involves 450 scientists from more than 100 institutions in 20 countries. The entire project is proposed to be jointly funded by the NSG and the U.S. Department of Energy (DoE), with the NSF's portion being led by the University of Chicago, while Lawrence Berkeley National Laboratory will lead the DoE portion. The project is expected to cost a total of about $800 million and become operational by the early 2030s. In addition to searching for primordial GWs, these telescopes could also map the CMB in incredible detail and reveal how the universe has changed over time.

These telescopes could also help search for the elusive "dark universe" and validate our current cosmological models. John Carlstrom is the Subrahmanyan Chandrasekhar Distinguished Service Professor of Astronomy and Astrophysics and Physics at UChicago and the project scientist for CMB-S4. "With these telescopes, we will be testing our theory of how our entire universe came to be, but also looking at physics at the most extreme scales in a way we simply cannot do with particle physics experiments on Earth," he said in a UChicago News statement.

Because the CMB carries information about the birth of the universe, scientists have been mapping it for decades. These include space-based telescopes like the Soviet RELIKT-1, NASA's Cosmic Background Explorer (COBE), the Wilkinson Microwave Anisotropy Probe (WMAP), and the ESA's Planck satellite. These missions have measured small temperature anisotropies (fluctuation) in the CMB with increasing detail, providing hints about how the universe began. What is needed, however, are telescopes sensitive enough to answer the deeper cosmological questions, like whether the universe began with a burst of inflation.

To this end, the CMB-S4 will build incredibly complex instruments to map the first light of the universe from spacecraft and the ground. The array will include two new telescopes in the Chilean Atacama Plateau and nine smaller ones at the NSF's South Pole Station (SPS). The project will also rely on the South Pole Telescope, which has been operational at the SPS since 2007. Each site will play an essential role, with the telescopes in Chile conducting a wide survey of the sky to capture a more detailed picture of the CMB. Meanwhile, the telescopes at the NSF's South Pole Station would take a deep, continuous look at a smaller part of the sky.

The observations from Chile will help improve our understanding of the evolution and distribution of matter and look for relic light particles that may have existed in the early universe. Meanwhile, the telescopes in Antarctica will offer a unique look at the universe since it is here that the rest of the Earth spins around, permitting continuous observations of one section of the sky. Their combined efforts will allow astronomers to look for the ripples in spacetime that could only emerge from a space smaller than a subatomic particle suddenly expanding into a much larger volume.

Said Lawrence Berkeley National Laboratory physicist Jim Strait (the project director for CMB-S4), this is an ambitious but worthwhile goal. "In many ways, the theory of inflation looks good, but most of the experimental evidence is somewhat circumstantial," he said. "Finding primordial gravitational waves would be what some people have called 'the smoking gun' for inflation."

Since these ripples would interact with the CMB and leave a distinct (but extremely faint) signature, large-scale and continuous mapping of the CMB should provide indications of their existence. The CMB-S4 should also provide clues about the nature of dark matter and dark energy. Whereas the former is theorized to account for the majority of the mass in the universe (about 69%), the latter is responsible for its accelerating rate of expansion. Furthermore, mapping primordial gravitational waves would also help scientists find the connection between the forces of gravity and quantum mechanics.

Microwave detectors are already so sensitive that measurements are dominated by background noise and local interference. Therefore, the plan is to outfit the combined CMB-S4 experiment with nearly 500,000 superconducting detectors, more than all previous experiments combined, and to greatly increase the number of measurements to provide a precise measurement of the signal level and reduce the noise. The new grant from the NSF will help fund the design of the new telescopes and site infrastructure, which will be the most complex ever built.

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