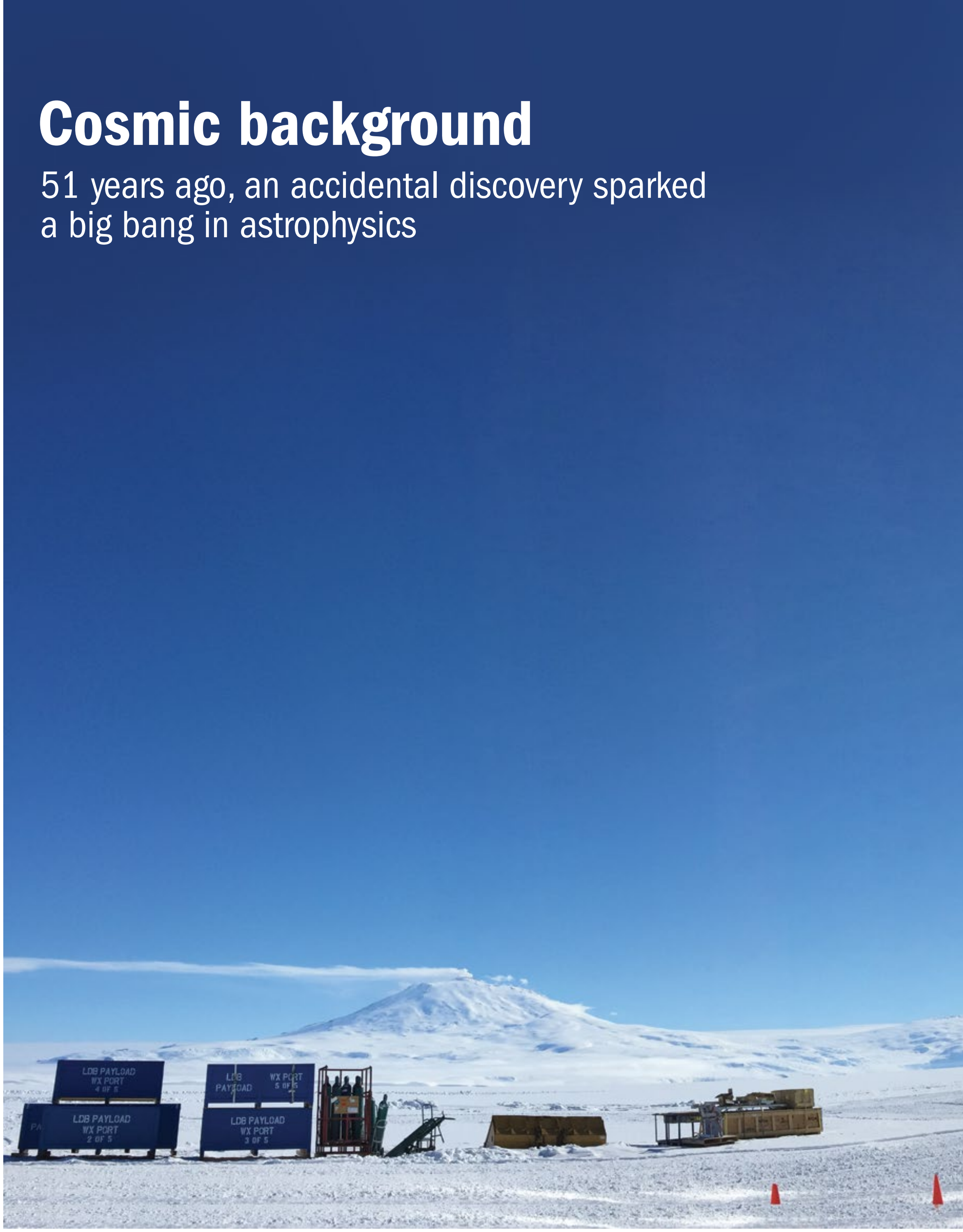
Cosmic background

51 years ago, an accidental discovery sparked a big bang in astrophysics



ON NEW YEAR'S DAY 2015, A BALLOON-BORNE SPACECRAFT ascended above Antarctica and snapped crisp photos of space, unobscured by the humidity of Earth's atmosphere. Meanwhile, a telescope located 4,000 miles to the north, in the desolate Chilean desert, scanned roughly half of the visible sky.

By air and by land, physicists have staked out the best vantage points on the globe, not for stargazing, but for peering between the stars at the thermal traces of the Big Bang.

Spread nearly evenly across the universe is a sea of invisible radiation called the Cosmic Microwave Background (CMB) that keeps space a chilly 2.7 degrees above absolute zero. The now-cold CMB, however, is a remnant of a much hotter, more violent cosmic epoch. About 13.8 billion years ago, immediately after the Big Bang, the universe was filled with a hot gas of ionized particles and radiation. As space expanded, the waves of radiation were stretched and diluted into their current low-energy state. The boiling plasma has since cooled and clumped into galaxies, stars, planets and human beings, all drifting through the faint afterimage of the first flash.

The prediction, discovery and study of the CMB 50 years ago comprise a story that is deeply intertwined with several generations of faculty at the Princeton physics department. The story continues today as University researchers probe the microwave background with

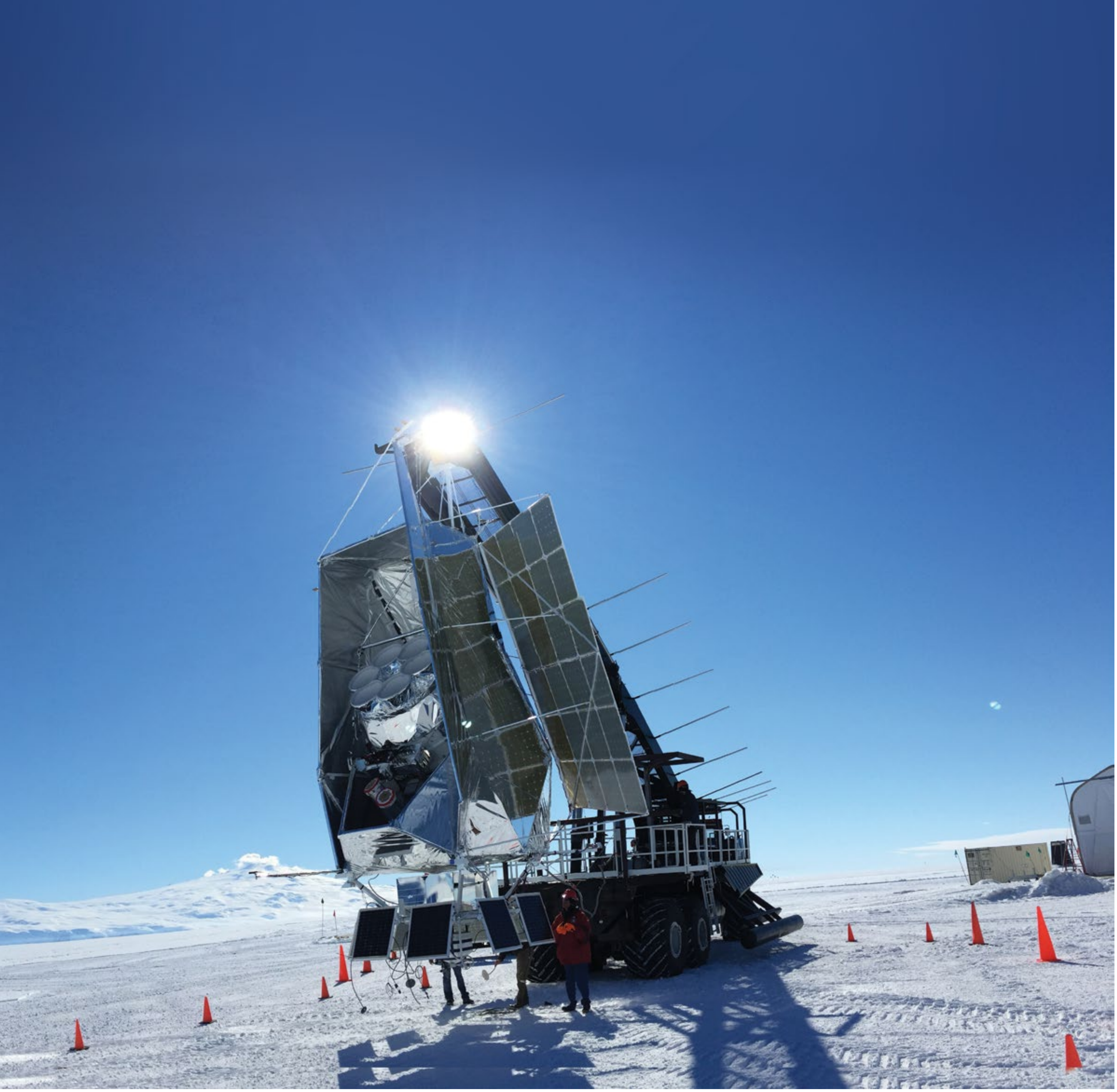


PHOTO BY ZIGMUND KERMISH

the goal of understanding the past and future of our cosmos.

The discovery of the background radiation was a serendipitous one. In 1964, Bell Laboratories technicians Robert Wilson and Arno Penzias racked their brains for an explanation of the noisy signal recorded by their radio antenna. When it turned out that the "noise" was actually radiation from the CMB, the two engineers found themselves unexpectedly pulled into the growing field of modern cosmology. The detection of the CMB earned them the Nobel Prize.

Yet the discovery wouldn't have been possible without the work of physicists at Princeton, 40 miles down the road from Bell Labs. Back then, the branch of science known as cosmology was ignored by most serious researchers. The physics community viewed the origin and development of the universe as dead-end topics, yet a few at Princeton had dared to tackle it.

At the time, P. James Peebles was a physics postdoctoral researcher at Princeton. "When I started working in this field, everyone was saying, 'There's no evidence. Why are you studying this?'" said Peebles, who today is the Albert Einstein Professor of Science, Emeritus. Instead, the mainstream focus was particle physics, which studies the subatomic particles that make up the universe.

Two Princeton professors, John Wheeler and Peebles' mentor, Robert Dicke, decided that research on the cosmic scale should not be neglected. Since 1915, when Einstein developed

A team of researchers from Princeton and collaborating institutions prepare to launch a balloon-borne spacecraft, known as SPIDER, in Antarctica on New Year's Day 2015. The instrument captured images of space to look for evidence of how the early universe evolved.

the theory of general relativity to explain the behavior of large objects in space, hardly any further research had been done on gravity or the structure of the universe. This was due in part to respect for Einstein's picture of the cosmos, and in part to the difficulty of devising fruitful experiments. "In the mid-1950s, Bob started a serious program of laboratory and extraterrestrial tests for general relativity," said Peebles. "John started a school for the theoretical study of the subject. These changes marked a renaissance."

While everyone else was thinking small, Dicke and Wheeler were thinking big. More specifically, Dicke was thinking about the Big Bang, a concept that dated back to the 1920s, when it was first observed that the universe is expanding. Yet extrapolating the current expansion back in time to a tiny, hot, dense state from which it all began was not a widely accepted leap. Peebles said: "Until the '60s, the evidence that this is what happened was minimal. It was still just an idea, popular in some circles, detested in others."

Dicke took the Big Bang theory from guesswork firmly into the realm of empirical physics when he proposed the CMB as evidence for a hot, dense beginning. Peebles recalls how Dicke almost casually set the course for his career and that of his peers: "He persuaded Dave Wilkinson and Peter Roll [Princeton physics faculty members] to build a device called a Dicke radiometer to look for this radiation, and he told me with a wave of his hand, 'Why don't you go think about the theory.' And I've been doing it ever since."

By 1970, the scientific community had accepted that the CMB had the properties that made it undeniable evidence for the Big Bang. Physicists then shifted their attention to more detailed scrutiny of the remnant radiation as a way of deepening our understanding of the birth of the universe, its expansion and its fate.

One area of scrutiny is whether the universe went through a period of rapid expansion, or inflation, after the Big Bang. To look for signs of inflation and to map the CMB in our region of space, NASA in partnership with Princeton and other universities launched the Wilkinson Microwave Anisotropy Probe (WMAP) satellite, named postmortem in honor of Wilkinson's contribution to experimental cosmology.

The inflationary model predicts a particular pattern to the fluctuations of the CMB. When WMAP released its first set of results in 2003, they neatly matched the predictions of inflation. Among the many Princeton researchers who played significant roles in WMAP were Lyman Page, the James S. McDonnell Distinguished University Professor in Physics; Norman Jarosik, senior research physicist; and David Spergel, the Charles A. Young Professor of Astronomy on the Class of 1897 Foundation. Thanks to WMAP, Spergel said, "We have a coherent cosmological model that fits all the data."

Since then, several other projects, including most recently the European Space Agency's Planck space telescope, have mapped the CMB and provided evidence for inflation. But scientists are looking for additional evidence in the form of long undulations — called gravitational waves — stretching across the fabric of space. The remnants of these waves could be detected as a faint pattern in the CMB known as B-mode polarization. A reported detection of gravitational waves earlier this year from another project, BICEP2, created a stir in the astrophysics community but turned out to be an artifact of interstellar dust.

Detecting the remnants of gravitational waves is one of the goals of the Atacama Cosmology Telescope (ACT), an international project funded by the National Science Foundation and led by Princeton's Suzanne Staggs, the Henry DeWolf Smyth Professor of Physics. The team includes Page, Spergel and many colleagues at collaborating institutions.

The data collected during the flight of the balloon-borne SPIDER mission in Antarctica — funded by NASA, the National Science Foundation, the David and Lucile Packard Foundation, and the Natural Sciences and Engineering Research Council of Canada; and led by Assistant Professor of Physics William Jones — could also reveal evidence of these waves in the CMB.

The search for gravitational waves is just one of the ways in which the CMB provides opportunities for studying the early universe. The ACT collaboration is also looking for evidence of dark energy, a mysterious force that is speeding up the expansion of the universe, and answers to even bigger questions about the cosmological model. It is clear that the CMB is an important tool for the foreseeable future of cosmology. However faint, it illuminates the distant past, which in turn illuminates the future.
–By Takim Williams

David Wilkinson and Peter Roll used this experimental setup on the roof of Guyot Hall, which housed the Department of Geology (now Geosciences), to search for the CMB, at Bob Dicke's suggestion. Wilkinson is holding a screwdriver, and Roll is almost obscured by the instrument. Photo by Robert Matthews circa 1964-65.