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on the cover

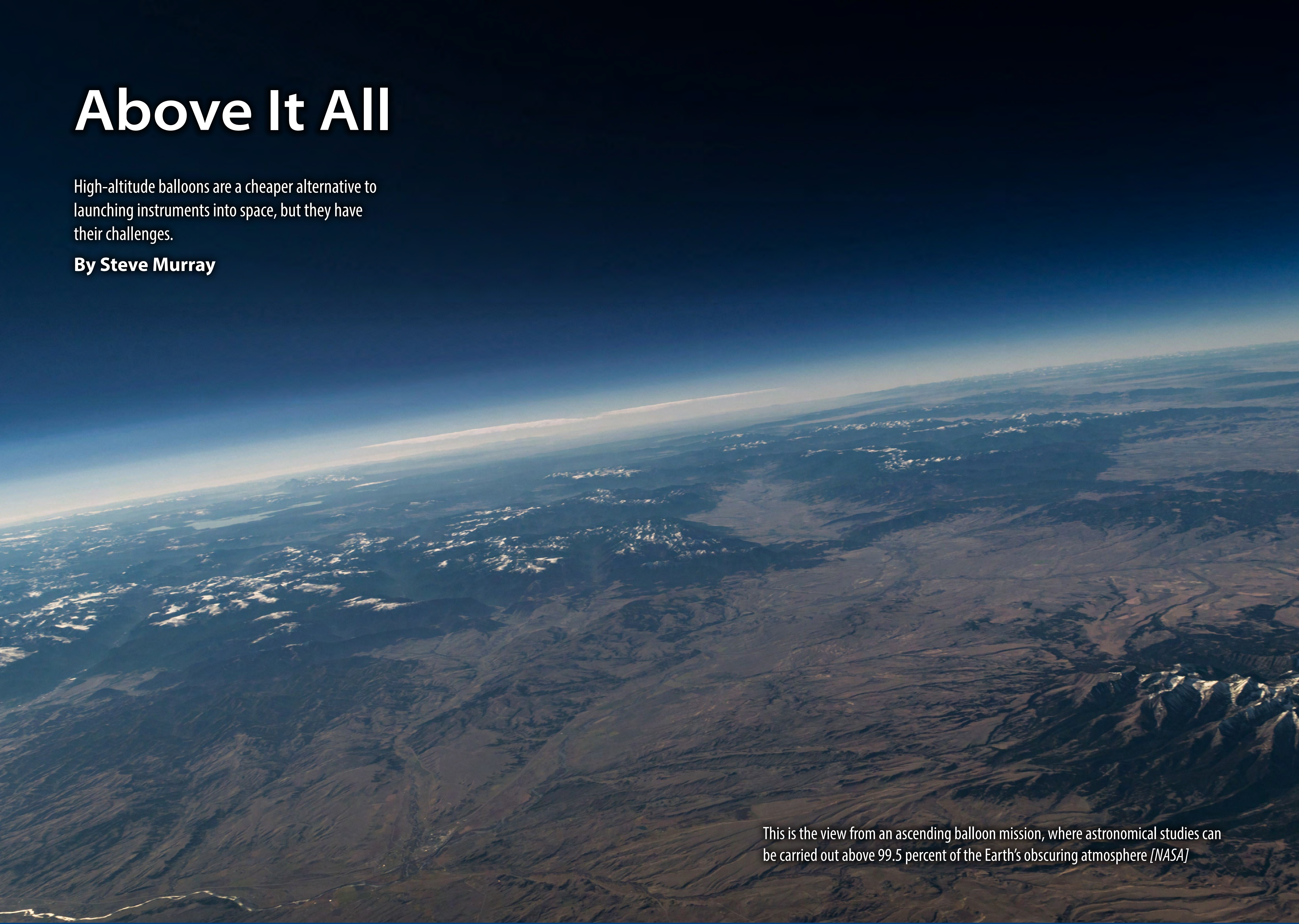
Front: Just before celebrating its 2,000th day (or "sol") on Mars, NASA's Mars rover Curiosity used a new drill method to produce a hole in a target named Lake Orcadie. More than a year ago, a motor problem curtailed the use of the drill, but engineers at NASA's Jet Propulsion Laboratory have managed to bypass the use of the drill stabilizers, allowing the drill bit to bore into rock samples once more. *Credit: NASA/JPL-Caletch/MSSS*

Back: The Hubble Space Telescope has discovered the most distant (and therefore oldest) star ever seen—it formed only 4.4 billion years after the Big Bang. This is the field of Hubble's view through a massive galaxy cluster creating a gravitational lens, boosting the space telescope's magnifying strength. *Credit: NASA & ESA and P. Kelly (University of California, Berkeley)*

Above It All

High-altitude balloons are a cheaper alternative to launching instruments into space, but they have their challenges.

By Steve Murray



This is the view from an ascending balloon mission, where astronomical studies can be carried out above 99.5 percent of the Earth's obscuring atmosphere *[NASA]*

Earth's atmosphere is rarely a friend to astronomers.

The Primordial Inflation Polarization Explorer (PIPER) maps the entire sky for polarization patterns that could confirm inflation in the very early universe, but the atmosphere interferes with the weak signals that PIPER scientists are searching for.

The Super Trans-Iron Galactic Element Recorder (SuperTIGER) measures ultra-heavy cosmic ray nuclei to answer fundamental questions about the processes that generate them, but cosmic rays interact with atoms and molecules when they enter the atmosphere.

While many scientists rely on rocket-launched space probes to solve this problem, researchers for PIPER, SuperTIGER and other experiments have chosen high-performance balloons as a less expensive, less complex, and more expeditious route to the edge of space. Scientific balloons fill an important niche between ground-based observatories and full-on space missions and, as their capabilities improve, other science communities are beginning to pay attention.

"Almost Space"

Balloon systems carry science payloads of over 5,000 pounds (2,270 kilograms) to altitudes of 120,000 feet (36.6 kilometers) or better—above 99.5 percent of the atmosphere—and they can stay up for weeks with instruments that study the cosmos from gamma rays through infrared (IR) wavelengths. Balloons also make life simpler for design engineers, compared to the preparations required for space missions. Instruments don't have to fit into rocket nose cones, for example, and their trip aloft is much gentler. Payloads can be prepped and launched in as little as six months, compared to the years needed to flight-qualify space hardware. And most payloads are safely returned to earth after their missions are complete, where they can be refurbished, upgraded, and flown again.

An artist's impression of the Balloon Experimental Twin Telescope for Infrared Interferometry (BETTII), an example of a super-pressure balloon *[NASA]*

Although balloon programs are operated by many nations around the world, NASA runs one of the largest. The NASA Balloon Program Office is based at Wallops Island, Virginia, where it supports 10 to 15 flights each year. "We have a standard set of four zero-pressure balloon types," says Debbie Fairbrother, program office chief, "starting at 4 million cubic feet (113,300 cubic meters) and running up to 39 million cubic feet (1,104,000 cubic meters). These cover the majority of our missions."

Zero-pressure balloons are used for most conventional payloads. They're open at the bottom and are only partially filled with helium at launch. They expand as they climb to their designed float altitude, where they're at equilibrium with the surrounding air density. Zero-pressure balloons can carry large payloads, but when their gas cools after the sun sets, they can descend 30 to 50,000 feet (9 to 15 km).

Panorama of NASA Super-Pressure Balloon test from Wanaka, New Zealand *[NASA Balloon Program Office]*

Maintaining a consistent altitude over a multi-day mission means shedding 6 to 8 percent of their mass each day as ballast, which limits their flight duration. Launches from Antarctica are the exception because the sun shines continuously during polar summers; ballast needs are minimal and long flights are possible.

In contrast, super-pressure balloons are completely sealed. Day-night heating changes affect the balloon's internal pressure but not its volume, so it can float at the same density altitude throughout its mission. Super-pressure balloons typically carry lighter payloads at lower altitudes, but can offer the long durations required for some instruments.

NASA provides researchers with the balloon and the helium, and operational support that includes integration, launch, recovery, tracking, and telemetry. During flight preparation, NASA also offers technical guidance and historical "lessons learned" about how to build up their instruments and support equipment into a payload. The agency has additional resources, such as tracking and pointing systems, but these are usually provided to researchers on a fee basis.

Vagabond Science

The Columbia Scientific Balloon Facility (CSBF) is NASA's main US launch site. It's located in Palestine, Texas with an outlying site in Ft. Sumner, New Mexico. Short duration missions, with about an 8-hour "float," can be launched from Palestine, but as cities like Dallas and Houston have grown, safe flight corridors have narrowed. The majority of current flights are therefore launched from Ft. Sumner, where prevailing winds carry payloads over more sparsely-populated terrain.

A NASA site at McMurdo Station in Antarctica is operated through the National Science Foundation (NSF). Launches here can stay aloft for a long time by taking advantage of winds that rotate around the South Pole. NASA can also access launch sites in other countries, depending on the latitudes and winds required by certain missions. "We go to the Swedish Space Agency's European Space Range (ESRANGE), for example," says Fairbrother, "and use their facilities outside of Kiruna. In New Zealand, we've been leasing a hangar at Queenstown Airport and a launch pad at the Wanaka Airport. We also have a launch facility in Alice Springs, Australia, although we haven't been there for several years."

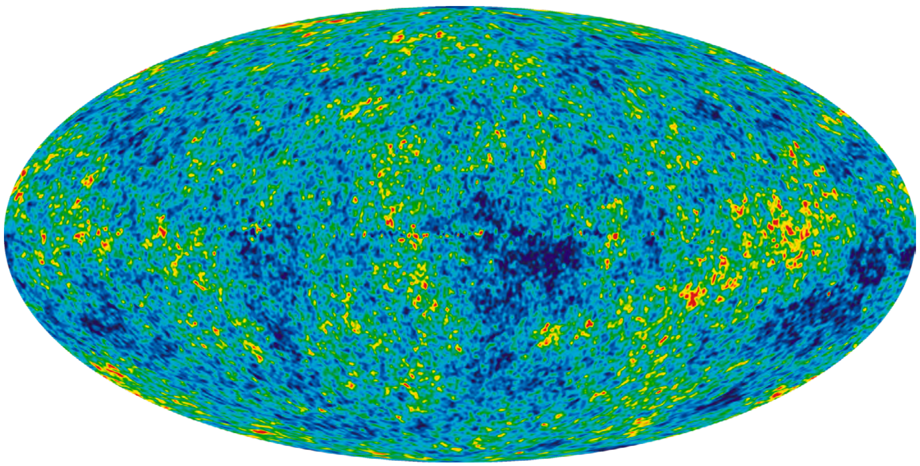
The balloon launch season follows a set pattern that begins in Palestine in late May, when winds blow to the west over unpopulated areas of Texas and Arizona. In mid-August, launch crews move to Ft. Sumner where flights can be safely terminated over Arizona. By late September, winds offer an interlude of slow speeds as they change direction, which allows balloons to linger near the launch site (and in radio contact) for 24 hours or more—a very desirable period for some science teams. When eastward winds pick up again by early October, launch crews move south to Antarctica and get ready for the December to February season at the South Pole. While some missions may also launch from Sweden or New Zealand in early spring, crews are back in Texas in May.

Looking to Confirm Inflation

The Primordial Inflation Polarization Explorer (PIPER) is a super-cooled telescope designed to detect faint remnants of heat radiation from the Big Bang. If, in fact, inflation describes the behavior of the very early universe, gravitational waves from this period should have left signatures in the form of unique polarization patterns in the cosmic microwave background (CMB). Al Kogut, of the NASA Goddard Space Flight Center (GSFC) is the principal investigator for the multi-institution project. "The search for this inflationary signal is one of the top goals in cosmology," says Kogut, "because it's telling us something about the start of space and time. The inflationary signal is coming from quantum mechanical gravity waves, so if we see it, it's also direct observational evidence that gravity obeys quantum mechanics."

PIPER will map the entire sky at four different frequencies to distinguish between polarization due to very early gravitational waves and polarization due to interstellar dust. "Dust in our galaxy is at least 10 times brighter than the inflationary signal we're looking for," says Kogut, "and it could be hundreds of times brighter, so we measure the signal from galactic dust and subtract it out. The way you do that is by taking measurements at different wavelengths because the dust gets brighter at shorter wavelengths."

To achieve the required sensitivity, the telescope flies while immersed in a bucket of liquid helium the size of a hot tub that keeps its sensors close to absolute zero. PIPER missions need about 10 to 12 hours aloft for good data collection, so the team is up all night when the payload flies—and the team welcomes all the altitude that the balloon can give them. "The atmosphere generates noise," says Kogut, "and we're looking at very faint signals. The higher you are, the closer you are to having no atmospheric signal. The PIPER payload weighs 6,000 pounds (2,700 kg), however, so 120,000 feet (36.6 km) turns out to be as high as you can go with it."



Nine years of observations by NASA's Wilkinson Microwave Anisotropy Probe (WMAP) created this map of slight variations in temperature (anisotropies) in the CMB. By studying the slight polarization differences in this signal, balloon missions like PIPER could reveal new insights to the physics of the early universe *[NASA/WMAP Science Team]*

SuperTIGER is inflated and launched from McMurdo Station in Antarctica to take advantage of the winds that rotate around the South Pole *[Ryan Murphy, Washington University in St. Louis]*

PIPER researchers are expecting a busy balloon season; the telescope was launched once in late 2017 and is slated for three more flights in the summer and fall of 2018.

Looking for Cosmic Rays

The Super Trans-Iron Galactic Element Recorder (SuperTIGER) experiment measures rare heavy nuclei to better understand the origin of high-energy cosmic rays. During fusion, stars generate elements in their cores of increasing atomic number up to iron and then explode as supernovae. These violent events create a flood of neutrons that can yield new elements heavier than iron, and provide the energy to hurl these particles away as cosmic rays. Research suggests, however, that some or all of these neutron-rich particles are produced by neutron star mergers rather than supernovae. Measuring the distribution of high atomic number rays could resolve the issue.

Robert Binns, Research Professor of Physics at Washington University in Saint Louis, is the principal investigator for the project, a multi-institution collaboration that includes NASA. He's worked with Brian Rauch, Research Assistant Professor of Physics at Washington University, and a SuperTIGER collaborator since its earliest days. "We're studying heavy cosmic rays," says Binns, "which can interact with the atmosphere, so we need to get up as close to the top of the atmosphere as we possibly can."

When cosmic rays enter the Earth's atmosphere, they collide with molecules (primarily oxygen and nitrogen) and break into smaller particles. "We look to get close to 130,000 feet (39.6 km)," adds Brian Rauch. "That last 10,000 feet (3 km) makes a big difference in the cosmic ray flux we see."

SuperTIGER needs long flights, as well. Over 98 percent of cosmic ray particles are hydrogen nuclei, helium nuclei, protons and electrons. The team is looking for the heaviest and rarest particles in the slim remainder of this distribution, so more flight time means more data. "We need long durations for this experiment," says Binns, and "The circular wind patterns in Antarctica are the best way to get them."

The Antarctic vortex is a prevailing low pressure zone that rotates counter clockwise around the South Pole during the Antarctic summer. The wind pattern ranges about 1,200 miles (2,000 km) from the pole, extends up to the stratosphere, and provides a stable pattern that can confine a balloon within it. "When we flew in 2012," says Binns, "we got 55 days at float altitude, which is still a record for a heavy payload zero-pressure balloon. We don't use super-pressure balloons because they won't handle the 6,000 pound (2,720 kg) weight of our payload. Even if they did, they don't go high enough for us."

A SuperTIGER hang test is carried out despite the inclement Antarctica weather *[Ryan Murphy, Washington University in St. Louis]*

The brief summer season at McMurdo gives a special urgency to data collection, as payload recovery might not happen. Although the SuperTIGER instrument carries onboard data storage drives, the team relies strongly on real-time telemetry systems. "The reason it's important to get as much telemetry data down as we can," says Binns, "is because quite often these payloads are not recovered in the year that they fly. You never know if recovery crews will be able to get out to where the payload comes down and retrieve the data disks. I'd say it's a 50-50 proposition."

Antarctica is a big place. Fickle weather and distances to a balloon termination site can force recovery crews to wait for better conditions. Researchers could have to wait a year or more to get their payload and data. "If your flight terminates near the end of January, there's virtually no possibility for a recovery that season unless it happens to come down very, very close to McMurdo," says Binns. "In 2012, our flight came down something like 1,000 miles (1,600 km) from the station!"

Things Happen

Although delays and failures happen with most research programs, scientific ballooning can present some unique challenges. They're rarely as serious or costly as a failed rocket launch, but they're no less frustrating to the scientists who experience them.

"We're looking for a total of eight science flights for PIPER over the next several years," says Kogut, "which could be an aggressive launch schedule. It depends on how lucky we are with landings and launch conditions. The balloons we're using are extremely large—about the size of a football stadium—and they take an hour or more to inflate, so you need dead flat calm during that process. Sometimes the winds start blowing, though, and they don't stop for a month.

"The last couple of seasons, we haven't had much success getting payloads off the ground. The weather has not been cooperating with us. A bunch of payloads, including ours, sat around for about a month and then had to go back home without flying."

SuperTIGER had an especially bad season last year, and never got the conditions needed to launch from McMurdo. "You need winds to be within a certain velocity range," says Rauch. "You need a vertical profile of winds, and you need them to stay stable over a couple of hours. We went out 16 times to check on conditions. Winds would keep changing direction. We started like December 8th or 9th, and we continued to mid-January before they called it."

"I don't think there's ever been a season this bad," adds Binns. "To my knowledge, there's never been a year where there wasn't a single launch opportunity—until now."

SuperTIGER is currently stored in a payload building at McMurdo Station, waiting for another season to fly, but that opportunity isn't guaranteed. "We're expecting company," says Rauch. "We're not the only payload down there." NASA will conduct a new annual selection cycle and the team doesn't know yet how that will turn out. "At least we have squatters' rights," says Binns.

Thinner and Higher

Balloon technology is continually evolving to meet the increased performance demands of scientists. "I have scientists who want to fly even higher than we can currently go," says Fairbrother, "so we're also testing a zero-pressure balloon that's called the 'Big 60.' It's made of extremely thin film and I think we could get close to 158,000 feet (48 km) with it. When I mention it at meetings, some of the scientists' eyes bug out.

"We're also testing a new 18.8 million cubic foot (532,500 cubic meter) super-pressure balloon that's slated to fill a mid-range 'sweet spot' that the science community wants: a 5,000 pound (2,270 kg) payload carried at 110,000 feet. We've flown it four times now."

Victor F. Hess was awarded the Nobel Prize in Physics in 1936 for his discovery of cosmic rays during balloon-bourne experiments in 1911 and 1912 *[VF Hess Society]*

Progress like this is also attracting new astronomers, interested in space access alternatives for their own research needs. "Our planetary work is coming along," says Fairbrother. "The NASA Planetary Division is typically focused on spacecraft and hasn't realized the capability that balloon platforms offer. You can get some long observation times on a planetary body at such a lower cost that you would on a spacecraft. So they're interested and they're watching."

A 1912 balloon flight to study radiation climbed to only 16,000 feet (4.9 km), but it was enough to give science its first evidence of cosmic rays. Since then, balloons have carried many more instruments to 10 times that altitude, enabling new studies at the edge of space. It's been a productive century. ✪

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