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EARTH • ENERGY • ENVIRONMENT

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Riding high:

Physics team seeks cosmic rays from subspace

The Extreme Universe Space Observatory - Super Pressure Balloon takes off from Wanaka, New Zealand on April 24, 2017.

Just as you can see a huge slice of a city from atop a mountain or skyscraper, you can see an enormous swath of earth from 110,000 feet in the air. That's 21 miles above sea level and more than three times the 30,000-foot altitude of a typical commercial airplane flight.

This grand view of the planet is why Mines Physics Professor Lawrence Wiencke and his colleague Angela Olinto, a physicist at the University of Chicago, wanted their cosmic ray detection equipment aboard a super pressure balloon launched by the National Aeronautics and Space Administration (NASA).

The project puts a ray detection device into suborbital space, where it will look for extreme energy cosmic rays, the highest-energy subatomic particles known to exist in the universe.

Institutions from 16 countries developed the technology for the detector, which headed skyward on the Extreme Universe Space Observatory – Super Pressure Balloon (EUSO-SPB) mission. The detector and the balloon gondola it rides in were assembled at Mines and launched from Wanaka, New Zealand, on April 24, 2017 (April 25 local time).

TWINKLE, TWINKLE LITTLE PARTICLE

The cosmic rays under investigation by the EUSO-SPB mission are subatomic particles moving at nearly the speed of light, and light is how the researchers intend to observe them.

Wiencke says Einstein's famous $E=mc^2$ equation comes into play: "This particle has so much kinetic energy that it can convert some of its energy into mass. By converting a lot of its kinetic energy into other particles, it creates a shower of particles that go through the atmosphere," he explains. The electrons in this air shower excite atmospheric nitrogen molecules, which then radiate fluorescent light. "The amount of light produced is proportionate to the energy of the original particle."

Just how much energy is packed into these particles? To answer that, Wiencke invites us to consider the piano. "The colors that you can see with your eyes represent about one octave of a piano," he says. "The total range in energy of radiation that's coming to us from the universe is not just one octave. It's not even one piano. It represents about

80 pianos, and these cosmic rays are up with the highest notes on the highest keyboard."

BUNDLE OF ENERGY

No source on Earth—or even within our own galaxy—could produce particles with this much energy, Wiencke says.

The unit measured is electron volts (eV), or the amount of energy gained by a proton or electron moving through a voltage difference of one volt. A molecule of oxygen in the air we breathe measures at 0.03 eV. A molecule at the temperature of the sun's surface has 0.5. Slap six zeros on the end of a 1, and you have 1 mega electron volt (MeV). The energy that a radioactive uranium 238 particle packs is 4.2 MeV.

Wiencke, however, isn't looking for particles that have eV measured with six zeros. He seeks particles energized in the range of 10^{18} electron volts (that's 1 followed by 18 zeros). Ultimately, he hopes to build a space-based detector that will find particles in the 10^{20} electron volt range.

"The energy scale is extremely high," Wiencke says. "We don't know where these particles are coming from or what's producing them," although he adds that there are multiple theories about acceleration sources.

A supernova, for instance, might do the job, but Wiencke says it would only push the energy up to about 10^{17} electron volts, and the particles he's looking for go beyond that. "It's almost certainly not a supernova that makes these things," he says.

Candidate objects that could provide the necessary acceleration include a class of galaxies that have a massive black hole within them emitting particles. They're called active galactic nuclei. Pulsars—spinning, magnetized neutron stars—are another possibility. Neutron stars form when giant stars die in supernovas and their cores collapse.

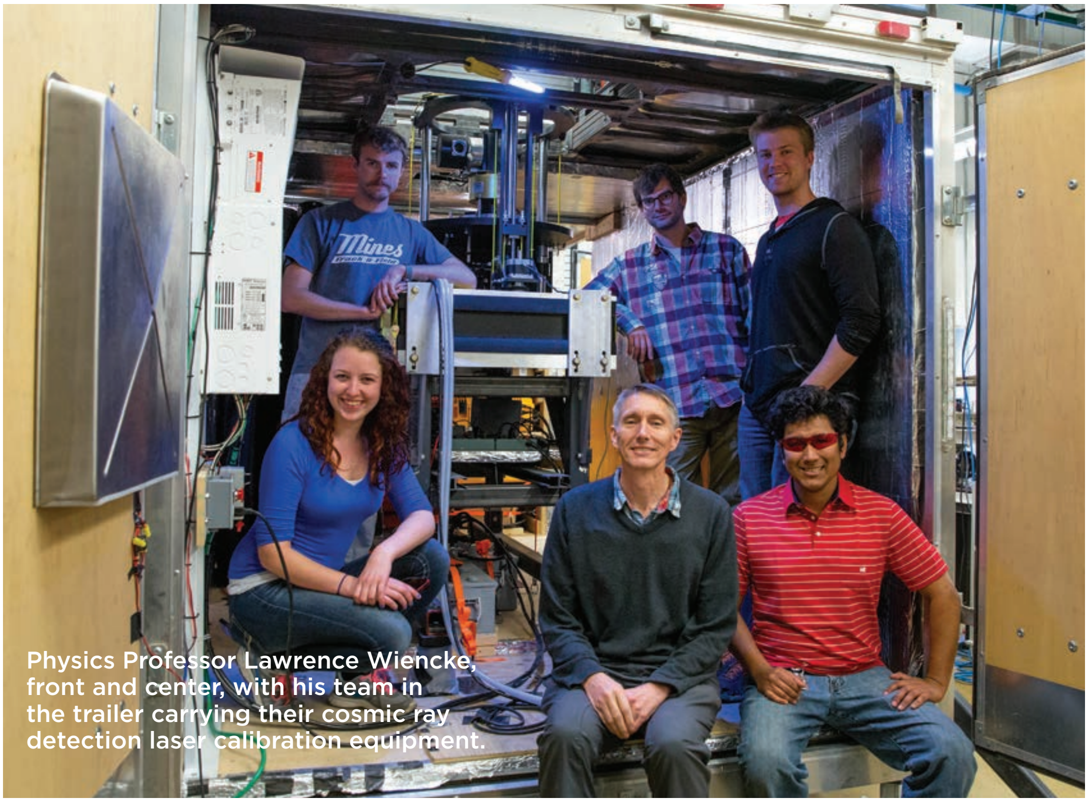
"The object can be very small but, in that case, you need a very strong magnetic field. Or, it can have weaker magnetic fields and be much larger," Wiencke explains. To put this into perspective, he points to the Large Hadron Collider (LHC), the largest particle accelerator on Earth. It's a 17-mile ring of superconducting magnets plus accelerating structures built in to boost the energy of the particles along their way. "If you wanted to accelerate particles to the energies that we're looking at, the LHC would need to be about the size of the orbit of Mercury."

EVENT OF THE CENTURY

The particles under study may be energetic, but they're also quite rare. The rate at which they reach Earth is somewhere on the order of less than one particle per square kilometer per century.

According to Simon Bacholle, a postdoctoral research fellow with Wiencke in the Physics Department, this rarity contributes to the mystery of their origin. By searching for the particles from near space, the research team raises its chances of seeing them. "If we can detect them, we can become

Flight path of the EUSO-SPB.



Physics Professor Lawrence Wiencke, front and center, with his team in the trailer carrying their cosmic ray detection laser calibration equipment.

more aware from which direction they come and then we can maybe—hopefully—identify what kind of source they came from," he says.

It is Bacholle's role to coordinate operation of the EUSO equipment. "We can't steer the flight, but we can control how our detector operates," he explains. "It has to be monitored 24/7."

The equipment looking for the particles includes an ultraviolet camera that takes 400,000 pictures per second. "This device, when it's running, consumes about 75 watts," explains William Finch, adjunct faculty in mechanical engineering and the man who designed the equipment Mines attached to NASA's super pressure balloon. "The balloon flies a large solar panel array and has 10 lead-acid batteries—essentially car batteries" to maintain power supply, he explains.

KEEPING IT COZY

It was Finch's job to design the gondola so that it would hold both the optical equipment and the batteries, a task he had well under control until the research team came to him one day and, as he puts it, said, "You know, we found out that these batteries are happier when they're a little bit warmer."

It's hard to stay warm in the stratosphere, where temperatures drop to -40 degrees on both the Celsius and Fahrenheit scales. At such chilly temps, batteries lose efficiency, which would leave the mission at risk.

"It was my job to cram 400 pounds of batteries inside this precision optical device and capture some of the waste heat from the electronics to keep those batteries warm and happy," Finch says.

He also worked with the Columbia Scientific Balloon Facility, a NASA organization, to get the EUSO equipment certified for flight. "I did a lot of analysis that showed our design would handle all the cyclones and not get pulled apart during launch or recovery," Finch says.

IF YOU BUILD IT, THEY WILL COME

Among those who constructed Finch's designs was Mines undergraduate Rachel Gregg, who is working on a combined bachelor's and master's degree in engineering physics. The project relates to her senior design class, she says. As part of her class deliverables, she wrote a manual on constructing the equipment as well as a comprehensive blog.

Gregg's role in the mission reflects her love of the hands-on building process, something first sparked when she helped her grandfather build birdhouses. For the EUSO mission, Gregg spent the better part of her fall semester fitting in hours of construction work alongside both staff and other student workers, and she remembers several visitors from the community and NASA coming to see their progress. When they'd ask what her role was, she'd explain that she was the main undergrad mechanic. "They were surprised—shocked—to realize that I welded that. I built that," she recalls. Gregg and her teammates built the equipment quickly, too. Asked what the biggest challenge was on this project, Gregg joined Finch in saying the compressed timeline—a little more than a year—was tough to meet.

Another person pressed into fast service was Johannes Eser, a Mines doctoral candidate whose job it is to run the lasers the team will use to calibrate the detection device.

"I helped build and test two roving laser systems," he explains, adding that the lasers simulate the cosmic ray air showers, allowing the team to "make sure the detector actually sees tracks that are moving at the speed of light."

Equipment that will detect the subatomic particles in cosmic rays is unloaded at Wanaka Airport in New Zealand.

With his first laser system, Eser flew in a helicopter beneath a stratospheric balloon launched for a one-night flight from Timmons, Canada, in 2014. The second system was used to test and calibrate the EUSO-SPB detector against a dark, starry Utah sky in September 2016. That laser also attended the actual EUSO balloon launch, as Eser was in a plane below the balloon, once again validating the equipment.

UP, UP AND AWAY

NASA's high-pressure balloon carrying the detector is made with plastic as thin as a sandwich bag. Because the balloon contains no open ducts, helium doesn't escape once the vehicle is inflated. The balloon could conceivably fly for as long as 100 days, and that's the goal. So far, such balloons have achieved a 54-day flight record. In contrast, non-super-pressurized balloon flights average two days or less.

Inflated, the EUSO balloon measures some 150 meters in diameter—approximately the same size as a football stadium. To launch this beast, the team must have precisely the right weather conditions, a circumstance that had evaded the researchers from the time the launch window opened in late March. After seven attempts that were aborted due to unfavorable weather, the EUSO-SPB launched from Wanaka Airport the afternoon of April 24, 2017. The 10,000 pounds of balloon, parachute and payload rose nearly straight up and reached an altitude of 109,000 feet about three hours later.

Unfortunately, the balloon developed a leak a few days after launch; the flight was terminated by NASA controllers on May 7 after 12 days and four hours in the stratosphere, with the entire flight train splashing into the Pacific Ocean.

"Although this early termination is not what we had hoped for, we did operate the instrument successfully for 11 nights and we downloaded some 60 GB of data to analyze," Wiencke said. "We are in contact with NASA and planning for another payload and flight."

It will take the team some time to sort through its data, and Wiencke remains positive. "We have a good chance to see a cosmic ray or two, and perhaps something unexpected from this pioneering mission."

Aloft, the balloon provides a wide field of view, big enough that the team can "see hundreds of square kilometers of the atmosphere," Wiencke says. He adds that if the experiment shows promise, "it paves the way for a much larger experiment that would be higher up in space, perhaps aboard the International Space Station or a free-flying satellite."

BY BETSY LOEFF