MSU astrophysicists test Einstein's theory of relativity with extreme astronomy

The High-Altitude Water Cherenkov (HAWC) gamma ray observatory, located in the volcanic mountains of central Mexico (more than 13,500 feet above sea level), observes astrophysical sources emitting light at very high energies (gamma rays), higher energies than produced by any accelerator on Earth. Its large water tanks contain sensitive light detectors which measure showers of particles produced by the high energy gamma rays striking the atmosphere, more than 10 miles above the observatory.

Using the capabilities of HAWC, scientists can collect and analyze HAWC data to detect new sources of very high-energy gamma-ray showers that have never been detected before.

Sometimes in science, things that don't occur can be as interesting as those that do. Much of modern physics is founded on Einstein's special relativity, but physicists have also considered possible models in which it is subtly violated at very high energies. To constrain such theoretical ideas, it is important to test the observational consequences of such exotic theories.

If special relativity were violated at high energy, strange things could happen; gamma rays might travel faster or slower than lower energy light. Or high energy gamma rays could turn into lower energy particles and thus never reach Earth.

In a recent study, published in in the March 30th issue of *Physical Review Letters*, MSU Department of Physics and Astronomy Professor Jim Linnemann and his now former graduate student Sam Marinelli tested this theory by working on machine learning algorithms to take the patterns observed by the HAWC detectors and translate them into surprisingly accurate estimates–within 30 percent– of the energy of the gamma rays initiating the particle showers.

Linnemann, Marinelli and another Physics and Astronomy graduate student, Joe Lundeen, then scanned three year's data for the rare [one or two a month] gamma rays above 100 TeV coming from four astrophysical sources and turned them into a test of Einstein's special relativity. The sources are likely associated with neutron stars in our galaxy, fast-spinning magnetized leftovers from supernovae.

"The fact that HAWC saw such high energy photons, higher than those analyzed before, raises the minimum energy scale at which such violations of special relativity could take place by a factor of more than one hundred," Linnemann said.

"The higher the gamma ray energy observed, the better the limits placed on nonstandard behavior," HAWC collaborator Humberto Martinez-Huerta added.

Overall, the data indicate that the gamma-ray energy spectra of the sources continue normally at least out to 285 TeV (TeV is a unit of energy: T = 10^12; an eV is the energy a single electron gets in a 1-volt battery). Such gamma rays carry about 100 trillion times the energy of visible light coming from the Sun. The HAWC observatory is one of the most sensitive in the world in the energy range above 100 TeV.

"HAWC will nearly double this data sample in the coming years and detect further high-energy sources which we can add to the analysis," Linnemann said. "Improvements to the HAWC detector and analysis under way will allow us to further sharpen these results."

Linnemann and his team also worked with HAWC colleagues Humberto Martinez of Sao Paulo, Brazil, and Pat Harding of Los Alamos National Laboratory on the analysis.

The HAWC team is an international collaboration between more than 30 institutions in the United States, Mexico, Europe, Asia and South America. HAWC was built with the support of the National Science Foundation, the U.S. Department of Energy and El Consejo Nacional de Ciencia y Tecnología in Mexico.

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Banner image: The HAWC Observatory's large water tanks—300 in total— (pictured above) contain sensitive light detectors which measure showers of particles produced by the high energy gamma rays striking the atmosphere, more than 10 miles above the observatory. Credit: Jordan Goodman

Photo caption: MSU astrophysicist Jim Linnemann and his research team are testing Einstein's special relativity by working on machine learning algorithms to take the patterns observed by the HAWC detectors and translate them into surprisingly accurate estimates of the energy of gamma rays initiating particle showers. Courtesy photo

Photo caption: The all-sky distribution in the relative intensity of 10 TeV cosmic rays observed by the HAWC and IceCube Observatories. The red color indicates an excess of cosmic rays with respect to the mean flux, and blue indicates a deficit. On the left, the white arrow indicates the direction of motion of the solar system through the local interstellar medium. The black lines indicate the local interstellar magnetic field outside the heliosphere. The right plot shows the opposite side of the sky. Credit: Savannah Guthrie, WIPAC