Helium nuclei research advances our understanding of cosmic ray origin and propagation

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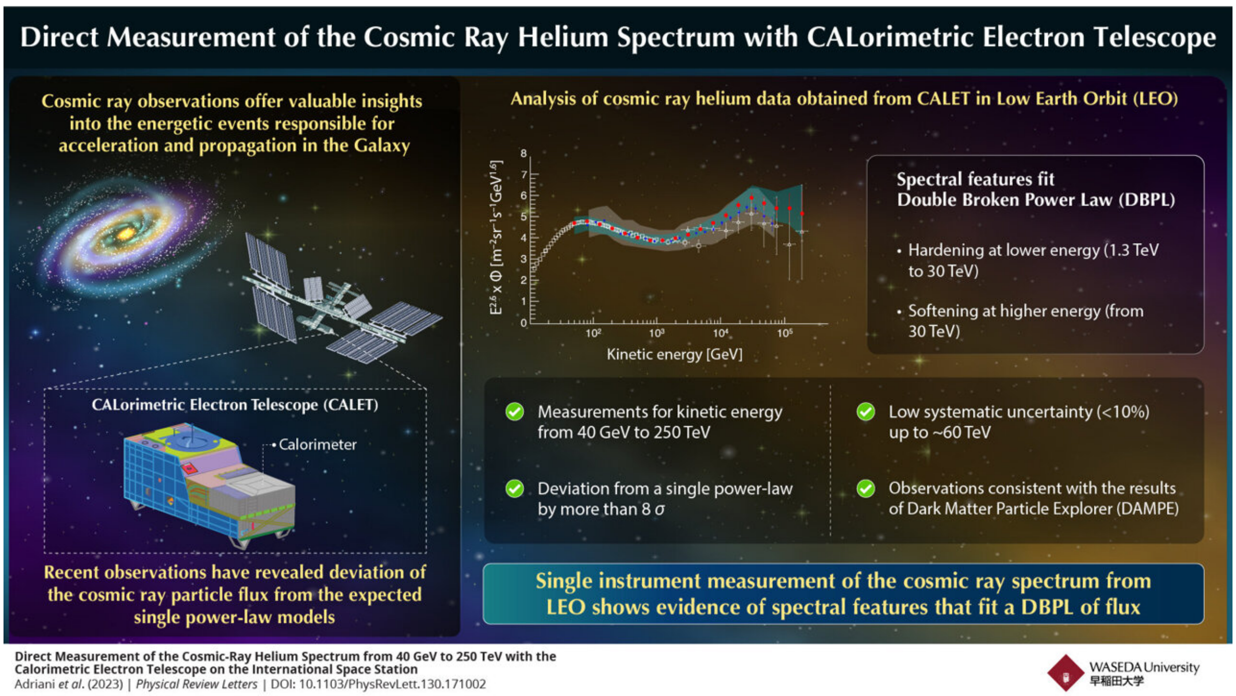

Cosmic ray helium particles were found to follow a Double Broken Power Law, with spectral hardening from 1.3 TeV and softening from 30 TeV. Credit: Waseda University

Much of our understanding of the universe and its mysterious phenomena is based on theoretical interpretations. In order to deepen the understanding of distant objects and energetic phenomena, astronomers are looking at cosmic rays, which are high-energy charged particles composed of protons, electrons, atomic nuclei, and other subatomic particles.

Such studies have revealed that cosmic rays contain all the elements known to us in the periodic table, suggesting that these elements originate from stars and high-energy events such as supernovae. Additionally, due to their charged nature, the path of cosmic rays through space is influenced by the magnetic fields of interstellar phenomena and objects.

Detailed observations of cosmic rays can, thus, not only shed light on the origins of these particles but also decode the existence of high-energy objects and phenomena such as supernova remnants, pulsars, and even dark matter. In an effort to better observe high-energy radiations, Japan, Italy, and USA collaboratively established the CALorimetric Electron Telescope (CALET) on the International Space Station in 2015.

In 2018, observations of the cosmic ray proton spectrum from 50 GeV to 10 TeV revealed that the particle flux of protons at high energies was significantly higher than expected. These results deviated from the conventional cosmic ray acceleration and propagation models that assume a "single power-law distribution," wherein the number of particles decrease with increasing energy.

Consequently, in a study published in 2022, the CALET team, including researchers from Waseda University, found cosmic ray protons in the energy range of 50 GeV to 60 TeV to follow a "Double Broken Power Law." This law assumes that the number of high-energy particles initially increase until 10 TeV (known as spectral hardening) and then decrease with an increase in energy (known as spectral softening).

Extending these observations further, the team has now found similar trends of spectral hardening and softening in the cosmic ray helium spectrum captured over a broad range of energy, from 40 GeV to 250 TeV.

The study, published in the journal *Physical Review Letters*, was led by Associate Professor Kazuyoshi Kobayashi from Waseda University, Japan, along with contributions from Professor Emeritus Shoji Torii, Principal Investigator of the CALET project, also affiliated with Waseda University, and Research Assistant Paolo Brogi from the University of Siena in Italy.

"CALET has successfully observed energy spectral structure of cosmic ray helium, especially spectral hardening starting from around 1.3 TeV, and the tendency of softening starting from around 30 TeV," says Kobayashi.

These observations are based on data collected by CALET aboard the International Space Station (ISS) between 2015 to 2022. Representing the largest energy range to date for cosmic helium nuclei particles, these observations provide additional evidence for deviation of the particle flux from the single power-law model. The researchers noticed that deviation from the expected power-law distribution was more than eight standard deviations away from the mean, indicating a very low probability of this deviation occurring by chance.

Notably, the initial spectral hardening observed in this data suggests that there may be unique sources or mechanisms that are responsible for accelerating and propagating the helium nuclei to high energies. The discovery of these spectral features is also supported by recent observations from the Dark Matter Particle Explorer, and questions our current understanding of the origin and nature of cosmic rays.

"These results would significantly contribute to the understanding of cosmic ray acceleration in the supernova remnant and propagation mechanism," says Torii.

These findings undoubtedly enhance our understanding of the universe. Even as we prepare for manned missions to the moon and Mars, the energy distribution of cosmic ray particles can also provide further insight into the radiation environment in space and its effects on astronauts.

More information: O. Adriani et al, Direct Measurement of the Cosmic-Ray Helium Spectrum from 40 GeV to 250 TeV with the Calorimetric Electron Telescope on the International Space Station, *Physical Review Letters* (2023). DOI: 10.1103/PhysRevLett.130.171002

Provided by Waseda University

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