Hunting for Dark Matter: The First Direct Detection of a Break in the Teraelectronvolt Cosmic-ray Spectrum of Electrons and Positrons

By SONG Jianlan (Staff Reporter)

An artistic illustration of DAMPE, the DArk Matter Particle Explorer, also known as "*Wukong*." (Credit: DAMPE collaboration)

The initial findings of the mission of the Dark Matter Particle Explorer (DAMPE) – nicknamed "*Wukong*" after the monkey king, the hero in the Chinese tale *Journey to the West* – have been listed sixth among China's 2018 "Annual Top 10 Science Advances" based on their contribution to the international effort to search for dark matter and explore the high-energy window of the universe.

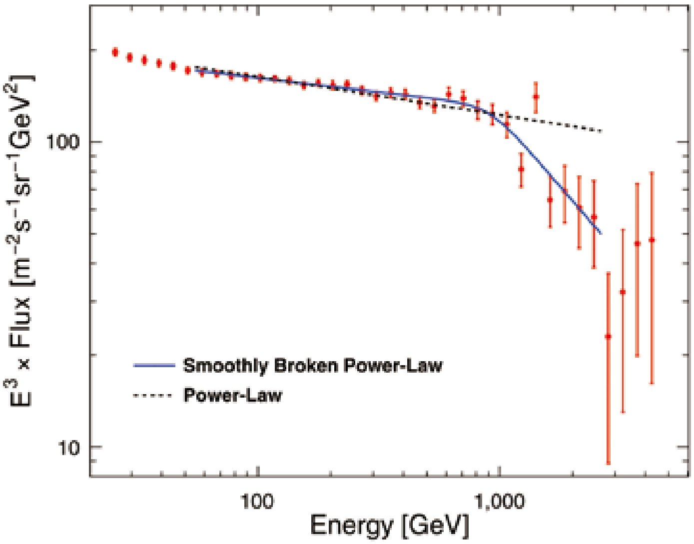
Physicists around the world have long been searching for the "missing mass" in the cosmos, the hypothetical matter without which many observed astronomical phenomena could not be explained using current theories. It is named "dark" because it does not give off any electromagnetic radiation and hence cannot be "seen" by conventional astronomical instruments.

Many theories have been proposed to predict the properties and derivative behaviors of this invisible matter. Among the prevailing ones is the "weakly interacting massive particle" (WIMP) model, which describes this elusive existence as a type of unusual particles that only interact with each other through gravity and some undefined interactions as weak as or even weaker than the canonical weak nuclear force, namely the intra-nuclear interaction responsible for nuclear fission or radioactive decays of atoms. This low-profile nature makes it very hard to detect, if it really exists; so far, no experiment has succeeded in identifying its whereabouts.

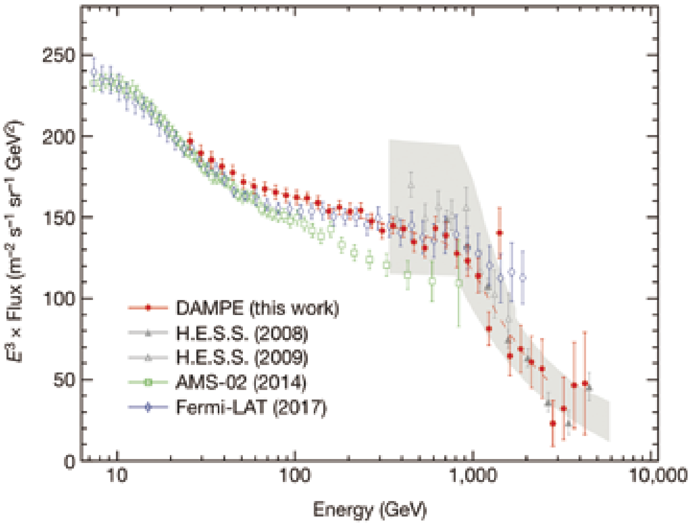
According to the WIMP model, such particles might collide with each other (though very scarcely). Once this happens, they would annihilate and give off high-energy gamma-rays as well as other ordinary particles and anti-particles, such as electrons and positrons. At last falling into the secular world in the form of ordinary matter, the remnants from the annihilation can be picked up by refined astronomical instruments. Hence, from these offspring particles human beings can catch a glimpse of their father particles indirectly.

Thus has DAMPE been built and sent into a sun-synchronous orbit, as a new international effort initiated by CAS scientists. Led by Prof. CHANG Jin from **the Purple Mountain Observatory (PMO)**, CAS, the DAMPE international collaboration developed the detector to measure cosmic-ray electrons and positrons (CREs) in space and scrutinize every anomaly in the spectrum, in the hope of finding the traces presumably left behind by the hypothetical particles.

In comparison with other dark matter detectors such as the AMS-02 and Fermi-LAT missions, DAMPE offers a wider energy coverage and better ability to discern TeV CREs from other much more abundant particles (mainly



The CRE spectrum measured by DAMPE in the energy range from 25 GeV to 4.6 TeV. Of note, the data in the energy range between 55 GeV and 2.63 TeV strongly prefers a broken smooth power-law model over a single power-law model. (Image by the DAMPE collaboration, from the *Nature* paper)



The CRE spectrum measured by DAMPE in comparison with other published measurements. (Image by the DAMPE collaboration, from the *Nature* paper) protons), hence producing broader and "cleaner" spectra. In particular, it can give more details in higher energy ranges, due to its unprecedentedly high-energy resolution and low background contamination.

Based on the data from the satellite's first 530-day observation, the consortium reported their first finding in *Nature* in late Dec 2017: the accurate measurement of the CRE spectrum in the energy range from 25 GeV to 4.6 TeV. As analyzed by the team, the spectrum in the energy range of 55 GeV–2.63 TeV strongly prefers a smoothly broken power-law model over a single power-law model. This structure might have been the traces from some nearby fresh signal sources, as speculated by some physicists, based on the fact that ordinary astrophysics generally predicts a power-law model.

The results immediately caught the eye of the whole physics community and evoked a wave of renewed enthusiasm about the search for dark matter. Particularly, the refined spectral structure at energies of ~0.9 TeV and beyond, including a potential sharp "spike" at around 1.4 TeV, greatly interested physicists. This spike, indicating a gathering of CREs at this particular energy, together with the fast declining fluxes (the break) at around 0.9 TeV, aroused heated discussions on the nature of the astronomical events that could have given off the recorded signals. Proposed possible sources include nearby dark matter halos, among others.

Before DAMPE, the High Energy Stereoscopic System (H.E.S.S.), a system of Imaging Atmospheric Cherenkov Telescopes (IACT), indirectly detected from the ground a vague break at energies around 1 TeV. However, the H.E.S.S. observation is subject to a large systematic error and covers a smaller energy range, which threw the indirectly observed break to uncertainty. Now, the direct detection by DAMPE has confirmed the former's indirect hint with much higher precision and established the spectral break unambiguously.

The team cautioned that more data are definitely required to explain the spectral structure between 1 and 2 TeV energies. For now, however, the first results from DAMPE have inspired further search for dark matter. Prof. Lars Bergstrom, Member of the Royal Swedish Academy of Sciences, confirmed that this is the first direct detection of a break in this energy range; and Prof. Marc Kamionkowski from Johns Hopkins University, USA listed this among his picks of the most exciting science advances of the year.

References

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2. J. Chang, *et al.*, The DArk Matter Particle Explorer Mission. *Astroparticle Physics* 95, 6-24 (Published: October 01, 2017). doi: 10.1016/j.astropartphys.2017.08.005.