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Scientists discover the highest energy gamma rays ever seen from a pulsar

The H.E.S.S. observatory records 20 TeV photons from the Vela pulsar

Scientists using the H.E.S.S. observatory in Namibia have detected the highest energy gamma rays ever recorded from a dead star called a pulsar. The energy of these gamma rays clocked in at 20 teraelectronvolts, or about ten trillion times the energy of visible light. This observation is hard to reconcile with the theory of the production of such pulsed gamma rays, as the international team reports in the journal Nature Astronomy.

Pulsars are the left-over remnants of stars that spectacularly exploded in a supernova. The explosions leave behind a tiny dead star with a diameter of just about 20 kilometers, rotating extremely fast and endowed with an enormous magnetic field. *"These dead stars are almost entirely made up of neutrons and are incredibly dense: a teaspoon of their material has a mass of more than five billion tones, or about 900 times the mass of the Great Pyramid of Giza,"* explains H.E.S.S. scientist Dr. Emma de Oña Wilhelmi, a co-author of the publication working at Deutsches Elektronen-Synchrotron (DESY) in Germany.

Pulsars emit rotating beams of electromagnetic radiation, somewhat like cosmic lighthouses. If their beam sweeps across our solar system, we see flashes of radiation at regular time intervals. These flashes, also called pulses of radiation, can be searched for in different energy bands of the electromagnetic spectrum. Scientists think that the source of this radiation are fast electrons that travel from the pulsar's surface to the very end of its magnetosphere. The magnetosphere is made up of plasma and electromagnetic fields that surround and co-rotate with the star. "*On their outward journey, the electrons acquire energy and release it in the form of the observed radiation beams,"* says Prof. Bronek Rudak from the Nicolaus Copernicus Astronomical Center (CAMK PAN) in Poland, also a co-author.

The Vela pulsar, located in the Southern sky in the constellation Vela (sail of the ship), is the brightest pulsar in the radio band of the electromagnetic spectrum and the brightest persistent source of cosmic gamma rays in the gigaelectronvolts (GeV) range. It rotates about eleven times per second. However, above a few GeV, its radiation ends abruptly, presumably because the electrons reach the end of the pulsar's magnetosphere and escape from it.

But this is not the end of the story: using deep observations with H.E.S.S., a new radiation component at even higher energies has now been discovered, with energies of up to tens of teraelectronvolts (TeV). *"That is about 10,000 times more energetic than all radiation ever detected before from this object,"* says co-author Prof. Christo Venter from the North-West University in South Africa. This very high-energy component appears at the same phase intervals as the one observed in the GeV range. However, to attain these energies, the electrons might have to travel even farther than the magnetosphere, yet the rotational emission pattern needs to remain intact.

"This result challenges our previous knowledge of pulsars and requires a rethinking of how these natural accelerators work," says Dr. Arache Djannati-Ataï from the Astroparticle & Cosmology (APC) laboratory in France, who led the research. *"The traditional scheme according to which particles are accelerated along magnetic field lines within or slightly outside the*

magnetosphere cannot sufficiently explain our observations. Perhaps we are witnessing the acceleration of particles through the so-called magnetic reconnection process beyond the light cylinder, which still somehow preserves the rotational pattern? But even this scenario faces difficulties to explain how such extreme radiation is produced."

Whatever the explanation is, in addition to its other remarkable qualities, the Vela pulsar now officially holds the record as the pulsar with the highest-energy gamma rays discovered to date. *"This discovery opens a new observation window for detection of other pulsars in the range of tens of teraelectronvolts with current and upcoming more sensitive gamma-ray telescopes, hence paving the way for a better understanding of the extreme acceleration processes in highly magnetised astrophysical objects,"* says Dr. Djannati-Ataï.

The High Energy Stereoscopy System (H.E.S.S.) is an array of five imaging atmospheric Cherenkov telescopes for studying cosmic gamma rays. The observatory is operated through an international collaboration. The telescopes are located in Namibia, near the Gamsberg mountain, in a region known for its excellent conditions for astronomy. Four H.E.S.S. telescopes started operation in 2002/2003, the much larger fifth telescope known as H.E.S.S. II is operational since July 2012 and extends the energy coverage towards lower energies, as well as further improving sensitivity. More than 230 researchers from 41 institutes in 15 different countries are involved in H.E.S.S.

The H.E.S.S. team comprises scientists from five Polish institutions: the Nicolaus Copernicus Astronomical Center Polish Academy of Sciences in Warsaw, the Astronomical Observatory of the Jagiellonian University in Krakow, the Henryk Niewodniczański Institute of Nuclear Physics Polish Academy of Sciences in Krakow, the Astronomical Observatory of the University of Warsaw, and the Institute of Astronomy at Nicolaus Copernicus University in Toruń. The role of the national project coordinator is held by Prof. Dr. hab. Rafał Moderski from the Nicolaus Copernicus Astronomical Center Polish Academy of Sciences. At the Institute of Nuclear Physics Polish Academy of Sciences, the H.E.S.S. project involves Dr. hab. Sabrina Casanova, Prof. Dr. hab. Jacek Niemiec, and Dr. hab. Alicja Wierzcholska.

Reference:

"Discovery of a Radiation Component from the Vela Pulsar Reaching 20 Teraelectronvolts";
The H.E.S.S. collaboration; Nature Astronomy, 2023;
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Public access link to the full online version of the article: https://rdcu.be/dnO0T

Link to the popular science material on YouTube: https://www.youtube.com/watch?v=bPZkSDBtQms

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Images:

IFJ231006b_fot01s.jpg **HR:** http://press.ifj.edu.pl/news/2023/10/06/IFJ231006b_fot01.jpg
The researchers think that infrared light particles (photons) from the poles of the pulsar are boosted to gamma-ray energies (blue) by fast electrons. (Credit: Science Communication Lab for DESY).