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Near-earth microquasar a source of powerful radiation

> *Modern astronomy has clung to the belief that the relativistic outflows or jets responsible for the existence of electromagnetic radiation of particularly high energies are located in the nuclei of active galaxies distant from Earth. However, a different picture of reality is emerging from the latest data from the HAWC observatory: also jets launched in astrophysical sources from our own intra-galactic 'backyard' turn out to be sources of gamma photons of extremely high energy.*

Electromagnetic radiation of extremely high energies is produced not only in the jets launched in active nuclei of distant galaxies, but also in jet-launching objects lying within the Milky Way, called microquasars. This latest finding by scientists from the international High-Altitude Water Cherenkov Gamma-Ray Observatory (HAWC) radically changes the previous understanding of the mechanisms responsible for the formation of ultra-high-energy cosmic radiation and in practice marks a revolution in its further study.

Since the discovery of cosmic radiation by Victor Hess in 1912, astronomers have believed that the celestial bodies responsible in our galaxy for the acceleration of these particles up to the highest energies are the remains of gigantic supernova explosions, called supernova remnants. However, a different picture is emerging from the latest data from the HAWC observatory: the sources of radiation of extremely high energies turn out to be microquasars. Astrophysicists from the Institute of Nuclear Physics of the Polish Academy of Sciences (IFJ PAN) in Cracow, co-financed by a grant from the National Science Centre, played a key role in the discovery.

The HAWC observatory was erected on the slope of the Sierra Negra volcano in Mexico with the aim of recording incoming particles and photons from space at particularly high energies. The facility consists of 300 steel water tanks equipped with photomultipliers sensitive to fleeting flashes of light, known as Cherenkov radiation. This appears in the tank when a particle travelling faster than the speed of light in water falls into it. Typically, the HAWC captures gamma photons with energies ranging from hundreds of gigaelectronvolts to hundreds of teraelectronvolts. These are energies up to a trillion times greater than the energy of visible light photons and over a dozen times greater than the energy of protons accelerated at the Large Hadronic Collider (LHC) accelerator.

The supermassive black holes within quasars, i.e. the active nuclei of some galaxies (objects with enormous masses, numbering in the hundreds of millions of solar masses) accelerate and absorb matter from the accretion disk that surrounds them. During this process, very narrow and very long streams of matter, called jets, are shot out from near the poles of the black hole, in both directions along its rotation axis. These move at velocities often close to the speed of light, resulting in shock waves – and it is there that photons of extremely high energies, reaching up to hundreds of teraelectronvolts, are produced.

Located in the nuclei of other galaxies, quasars are among objects that are very distant from us: the nearest (Markarian 231) is 600 million light years away from Earth. This is not the case for microquasars. These are compact binary systems, made up of a massive star and its matter-absorbing black hole, which emit jets with lengths of hundreds of light years. Several tens of such objects have so far been discovered in our galaxy alone.

“Photons detected from microquasars have usually much lower energies than those from the quasars. Usually, we are talking about values of the order of tens of gigaelectronvolts. Meanwhile, we have observed something quite incredible in the data recorded by the detectors of the HAWC observatory: photons coming from a microquasar lying in our galaxy and yet carrying energies tens of thousands of times higher than typical!” says Dr. Sabrina Casanova (IFJ PAN), who, together with Dr. Xiaojie Wang from Michigan Tech University and Dr. Dezhi Huang from University of Maryland were the first to observe the anomaly.

The source of photons with energies of up to 200 teraelectronvolts has been found to be the microquasar V4641 Sagittarii (V4641 Sgr). It lies in the background of the Sagittarius constellation, at a distance of about 20,000 light years from Earth. The main role here is played by a black hole with a mass of about six solar masses, pulling in matter from the stellar giant with a mass three times that of the Sun. The objects orbit around a common centre of mass, circling each other once in just under three days. Interestingly, the jet emitted by the V4641 Sgr system is directed towards the Solar System. In this configuration, an Earth-based observer has a relativistically distorted perception of the time of the matter at the beginning and end of the jet: its front begins to appear younger than it actually is. As a result, the jet seems to propagate through space at superluminal velocity, in the present case as much as nine times the speed of light.

“Significantly, the V4641 Sgr microquasar turns out not to be unique. Extremely energetic photons are meanwhile detected not only from this but also from other microquasars, detected by the LHAASO observatory. It therefore seems likely that microquasars significantly contribute to the cosmic ray radiation at the highest energies in our galaxy,” adds Dr. Casanova.

The latest discovery is of interest not only to cosmic ray scientists. It proves that at a relatively small distance from Earth, mechanisms of jet formation and production of ultra-energetic photons must be at work analogous to those in the nuclei of active, distant galaxies, scaled appropriately to the mass of the black hole. These processes in microquasars occur on a much more human-friendly timescale – over days, not hundreds of thousands or millions of years. Moreover, the photons emitted by microquasars do not have to make their way through the millions of light-years of the cosmic vacuum, where they can be scattered or absorbed during interactions with photons of the ubiquitous cosmic background radiation. All this means that astrophysicists have, for the first time, gained the ability to make comprehensive and virtually undisturbed observations of processes crucial to the evolution of galaxies.

The Henryk Niewodniczański Institute of Nuclear Physics (IFJ PAN) is currently one of the largest research institutes of the Polish Academy of Sciences. A wide range of research carried out at IFJ PAN covers basic and applied studies, from particle physics and astrophysics, through hadron physics, high-, medium-, and low-energy nuclear physics, condensed matter physics (including materials engineering), to various applications of nuclear physics in interdisciplinary research, covering medical physics, dosimetry, radiation and environmental biology, environmental protection, and other related disciplines. The average yearly publication output of IFJ PAN includes over 600 scientific papers in high-impact international journals. Each year the Institute hosts about 20 international and national scientific conferences. One of the most important facilities of the Institute is the Cyclotron Centre Bronowice (CCB), which is an infrastructure unique in Central Europe, serving as a clinical and research centre in the field of medical and nuclear physics. In addition, IFJ PAN runs four accredited research and measurement laboratories. IFJ PAN is a member of the Marian Smoluchowski Kraków Research Consortium: “Matter-Energy-Future”, which in the years 2012-2017 enjoyed the status of the Leading National Research Centre (KNOW) in physics. In 2017, the European Commission granted the Institute the HR Excellence in Research award. As a result of the categorization of the Ministry of Education and Science, the Institute has been classified into the A+ category (the highest scientific category in Poland) in the field of physical sciences.

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SCIENTIFIC PUBLICATIONS:

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LINKS:

http://www.ifj.edu.pl/
The website of the Institute of Nuclear Physics, Polish Academy of Sciences.

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Press releases of the Institute of Nuclear Physics, Polish Academy of Sciences.

IMAGES:

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Sources of high-energy cosmic rays in the vicinity of the microquasar V4641 Sag, on the left with energies above a teraelectronvolt, on the right – hundreds of teraelectronvolts. The location of the microquasar is marked with a yellow dot. (Source: IFJ PAN / HAWC)