WHAT DID SST-1M SEE?

Ultra-high-energy gamma rays are stopped by the Earth's atmosphere before they can reach the planet's surface. However, our atmosphere could also become a tool for detecting photons with energies in the teraelectronvolt range. By using instruments registering Cherenkov radiation, astronomers conduct observations of sources emitting ultra-high-energy photons with ground-based telescopes.

Asst. Prof. Alicja Wierzcholska

Institute of Nuclear Physics,
Kraków, Polish Academy of Sciences

Ultra-high energy gamma ray photons, with energies reaching tens of gigaelectronvolts (GeV), penetrate Earth's atmosphere where their main obstacles are oxygen and nitrogen molecules. Their collisions with these particles generate cascades of secondary particles known as air showers. Many of the secondary particles created through such collisions travel at velocities greater than the speed of light in the atmosphere. This results in the emission of Cherenkov radiation, presenting as a characteristic blue glow. Its flashes are too short-lived to be observed by the human eye. However, they are picked up by optical telescopes equipped with sensitive detectors.

Three eyes plus one

Three observatories are currently conducting observations of ultra-high-energy gamma rays: the High Ener-

Alicja Wierzcholska, PhD
works as Assistant Professor at the Laboratory of Gamma Ray Astrophysics at the PAS Institute of Nuclear Physics. She conducts observations of blazars, specializing in ultra-high-energy gamma rays. She is also a member of the High Energy Stereoscopic System (H.E.S.S.) and Cherenkov Telescope Array (CTA) Collaborations.
alicja.wierzcholska@ifj.edu.pl

Prototype of the SST-1M telescope with camera mounted at the PAS Institute of Nuclear Physics in Kraków. The telescope has a diameter of 4 m. It comprises 18 spherical mirrors. The focal length is 5.6 m and the field of vision is 9.1 degrees.

Who built the SST-1M?

It took a concerted effort of many people working at different institutions to create this unique camera. The mechanical structure of the SST-1M telescope and its drive was designed and made at the PAS Institute of Nuclear Physics in Kraków. The camera was made jointly by teams from the Jagiellonian University, the AGH University of Science and Technology and the PAS Institute of Nuclear Physics in Kraków, which designed the digital electronics for signal acquisition (DigiCam), and the University of Geneva which built the camera's photosensitive surface and mechanism with a cooling system. The PAS Nicolaus Copernicus Astronomical Centre in Warsaw and Toruń designed the computer system for recording data and a system for positioning the telescope, while the PAS Space Research Centre designed the mirror positioning system. The Czech team was responsible for building the optical system, including coating the reflective layers on the glass mirrors.

gy Stereoscopic System (H.E.S.S.) in Namibia, Major Atmospheric Gamma Imaging Cherenkov Telescopes (MAGIC) on La Palma, one of the Canary Islands, and the Very Energetic Radiation Imaging Telescope Array System (VERITAS) in Arizona in the United States. The observatories comprise between two and five Cherenkov telescopes.

Results obtained by H.E.S.S., MAGIC and VERITAS so far have been so groundbreaking that a decision was made to build another, even more powerful detector of ultra-high-energy gamma photons. Scientists and engineers from around the globe are working together to develop a huge, new-generation international Cherenkov Telescope Array (CTA). The observatory will consist of two arrays on the northern and southern hemispheres to cover the full energy range and conduct observations of the entire sky. The locations have been chosen as Chile and La Palma – sites best suited for astronomical observations.

CTA is designed to detect gamma rays using over a hundred Cherenkov telescopes of three types, varying by size: small-sized telescopes (SSTs) with a mirror diameter of 4 m, medium-sized telescopes (MSTs) with a diameter of 12 m, and large-sized telescopes (LSTs) with a diameter of 23 m. The different sized mirrors are used to conduct observations across a wide range of energies, from around 20 GeV to over 300 TeV. The largest telescopes detect rays with the lowest energy ranges, and the smallest detect the highest energies. Stereoscopic observations conducted by several telescopes should provide a very high detection sensitivity. It will also be possible to eliminate background events such as cosmic rays, and to precisely reconstruct the direction of arrival and energy of gamma photons.

However, this poses a major challenge, since the design of such telescopes will be very different from current designs. This is why members of the CTA consortium all over the globe are working on their projects, designs and prototypes to make sure they meet all the technical requirements.

Dewy-eyed

One of the prototypes of a small CTA telescope, known as SST-1M (single mirror), was developed at the Niewodniczański Institute of Nuclear Physics of the Polish Academy of Sciences. On 1 September 2017, the instrument registered light for the first time – it took its first ever "look" at the sky. This was the result of five years of intensive work on the construction of the telescope and its subsystems, including the mechanical structure, mirrors, and state-of-the-art cameras with a silicon photomultiplier and digital instruments for recording and processing data. The prototype was designed by a consortium of scientists and engineers from Poland, Switzerland and Czechia. The SST-1M project is coordinated by Prof. Teresa Montaruli from the University of Geneva, while the coordinator of the Polish section is Jacek Niemiec, PhD, from the PAS Institute of Nuclear Physics.

The first observation, held on the night of 31 August 2017, was the culmination of four days of hard work by the Polish and Swiss teams, including mounting the camera on the telescope structure.

The researchers started by reviewing atmospheric conditions. Only then was the camera cover removed, revealing a huge silicon "eye" taking its first look at the world. Meanwhile, the team in Geneva programmed the instrument remotely to follow blazar 1ES 1959+650 – a source of ultra-high-energy gamma rays known to astronomers for around twenty years.

The telescope took just a few seconds to turn towards 1ES 1959+650 and start conducting measurements. The monitor screens followed the events, and 342 GB of data was collected in just 90 minutes. Not all events are gamma photon flashes; many signals are simply due to light pollution. The false positives will be eliminated during data processing and analysis.

The camera was checked a few days later since it had been exposed to very heavy rain, but it was shown to be sealed and secure. All this is just the first step towards the goal of creating a fully functional instrument. The telescope software will be modified such that it can distinguish between gamma ray photons and background cosmic radiation. The latter are responsible for around 100,000 more data points.

The atmospheric conditions in Kraków make it difficult to test the telescope camera, since they are completely different to those found in the Atacama Desert in Chile, which is likely the final destination of the instrument. The location in Chile is one of the driest places on Earth, while during tests in Kraków the humidity varied between 30% during the day and 95% at night, reaching the dew point at around 10°C. The working conditions of the camera were monitored very closely by pumping the instrument full of dry air to prevent damage to the delicate electronic subsystems.

The first light in the SST-1M telescope camera is an important step in constructing the prototype. Researchers were able to mount the camera on the telescope structure in just a few days by using a highly innovative installation method: the telescope structure was used as a crane lifting the camera from the transport crate and placing it on the assembly trolley. The process will be repeated during the final installation at CTA.

Alicja Wierzcholska
Photography by: Jacek Niemiec

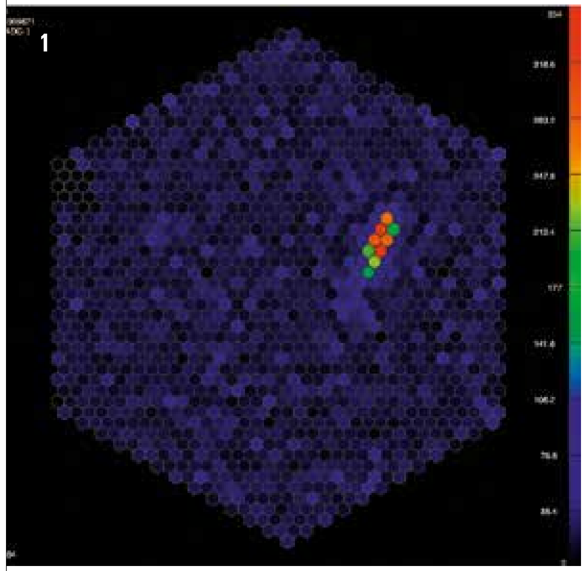

Fig. 1.
Typical elongated image of a Cherenkov glow of an air shower, most likely induced by gamma rays. The axis of the elongated image indicates the location of the source.

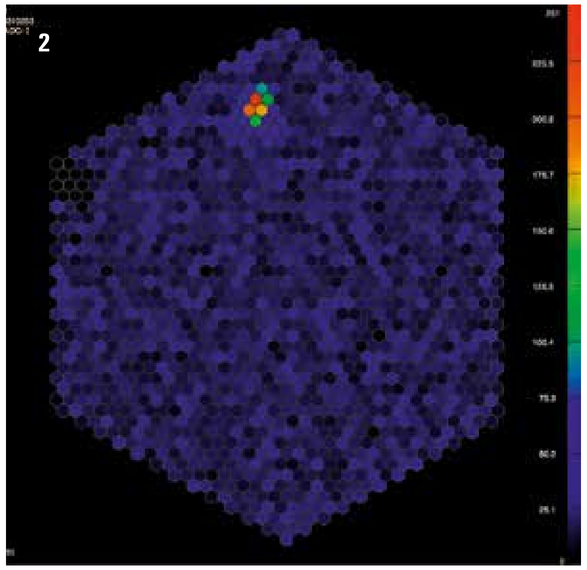

Fig. 2.
Typical blurred image of a cascade caused by cosmic radiation, most likely protons. The image is less regular than that obtained by a photon cascade.
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Camera of the SST-1M prototype telescope before sunrise and the closure of the cover.

Further reading:

Niemiec J. (2014). Hunting for the Highest Energies. *Academia 1 (41).*

http://www.isdc.unige.ch/~lyard/FirstLight/FirstLight_slowHD.mp4.