The Polish contribution to the Cherenkov Telescope Array

Hunting for the Highest Energies

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In the early 21st century, modern ground-based very-high-energy gamma-ray observatories have ushered in a new era of astronomy. The number of known gamma-ray sources increased from the handful detected prior to 2002 to more than 150 a decade later. Using three types of telescopes – small, medium, and large-sized – the CTA array will observe many new objects and phenomena. One of these instruments is being designed by Polish scientists and engineers

Gamma-ray sources may be of various types, such as blazars, remnants of supernova explosions, X-ray binary star systems, the center of the Milky Way galaxy, molecular clouds, radio galaxies, and starburst galaxies. Observations of very high-energy gamma-ray photons coming from such sources also allow us to address various fundamental questions of physics and cosmology, such as the properties of extragalactic background light, the nature of dark matter and the effects of quantum gravity that may lead to the Lorentz symmetry violation.

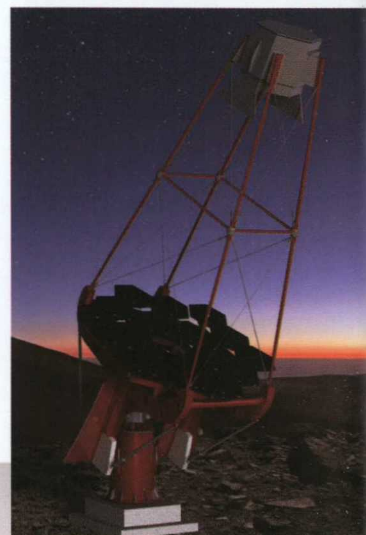
Cherenkov radiation

Modern gamma-ray astronomy instruments use gamma-ray photon detection method that involves imaging the short flashes of Cherenkov radiation produced by cascades of charged particles in the upper layers of the Earth's atmosphere. These flashes arise as a result of a gamma-ray particle colliding with air atoms. Using the stereoscopic technique, i.e. with a number of telescopes registering images of the same flash simultaneously, makes it possible to attain a detection sensitivity well beyond other observation methods, eliminating the background noise of cosmic rays and muons. We can also precisely identify which direction a given gamma-ray particle came in from, and what its energy was.

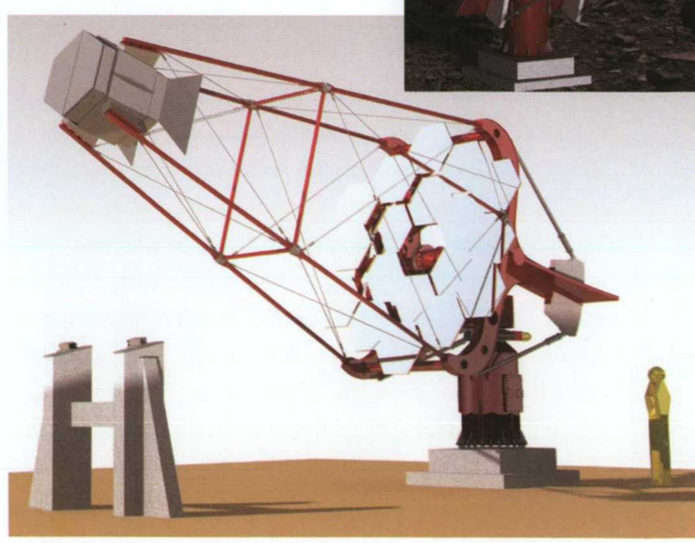
The ground-based gamma-ray observatories now in operation consist of 2 to 5 telescopes. Two 17-meter telescopes of the MAGIC observatory, thanks to their large mirror surfaces, are able to image the weak Cherenkov radiation flashes initiated by photons with lower energies, measured in the tens of gigaelectronvolts (GeV). The sensitivity of the array of four 12-meter telescopes of the H.E.S.S. and VERITAS observatories is highest for photons with energies on the order of teraelectronvolts (TeV). The H.E.S.S. observatory has also recently gained a fifth telescope (with the world's largest reflector diameter, 28 meters). The next generation of such projects will be the Cherenkov Telescope Array (CTA) observatory, soon slated to come online.

The CTA Consortium

The CTA Consortium, which emerged out of an initiative of the research communities engaged in the H.E.S.S. and MAGIC projects, now embraces more than 1,200 collaborating scientists and engineers from 28 countries of the world. Plans call for two observatories, one in the northern hemisphere, the other in the southern, putting the whole sky within the observation range. All told, observations will be performed by more than 150 Cherenkov telescopes. To cover a broad range of energies, from around 20 GeV to more than



Design of the small Cherenkov telescope



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Prototype of the mechanical structure for the small CTA telescope

300 TeV, three types of telescopes will be built: small (with 4-meter dishes), medium-sized (12m), and large (23m).

Among the main partners of the international CTA Consortium is a Polish team; in collaboration with Switzerland we have taken on the responsibility for designing the small-size telescope and developing a prototype. The Polish Consortium of the CTA Project has been operating since May 2009 and draws together more than 70 people from nine research institutions. The project has been listed on the European roadmap for research infrastructure (ESFRI), on the world roadmaps ASPERA and ASTRONET, and also on the Polish Roadmap for Research Infrastructure drawn up by the Polish Ministry of Science and Education.

The array of small-size telescopes will be imaging gamma-ray photons with energies reaching 300 TeV. The detection of particles with such high energies using Cherenkov telescopes is currently impossible, yet studying this energy range is very important - for instance, for our understanding of the mechanisms by which cosmic-ray particles become accelerated.

Our small telescope

The design of the mechanical structure and drive system of the small-size Cherenkov telescope was developed by a team from the Niewodniczański Institute of Nuclear Physics, Polish Academy of Sciences, in Kraków. The telescope uses a Davies-Cotton optics, which means that a spherical dish with a radius of curvature equal to the focal length of the telescope is constructed out of a mosaic of spherical mirrors with a focal length equal to the reflector's radius of curvature. Such a design offers a cost-effective way to eliminate optical aberrations.

The telescope has a focal length of 5.6 meters, a reflector radius of 4 meters, and 18 hexagonal mirrors, and it will be equipped with an innovative, fully digital camera comprised of 1296 silicon photomultipliers. The camera's field of view is 9 degrees, at least twice that of the instruments currently being used. The image of a particle shower initiated by a high-energy particle will therefore fit fully within the camera. Based on the shape of the image, it will be easy to distinguish a photon from a hadron. It will also be possible to survey the sky more rapidly.

The movement of the telescope around the azimuth and the elevation axes is realized by two independent drive systems consisting of a slew-drive transmission equipped with two motors and a roller-bearing. The mechanical structure of the telescope is mainly built of commercially available steel profiles and sheets, which significantly helps to lower costs.

On 29 November 2013, a prototype mechanical structure of the small-size CTA telescope was assembled at the Niewodniczański Institute of Nuclear Physics (PAS) in Kraków, by the personnel of the company Ponar Sp. z o.o. from Żywiec. A control cabinet containing the electronics for the drive system was also built by engineers from our institute. The prototype is now equipped with the drive control and safety system. Several tests have been also performed. They have confirmed the results of our computer modellings, showing that the maximum deformations of the mirror dish with respect to the camera are well within the constraints set by the CTA specifications. Dynamic analysis has also shown that the telescope structure is resistant to hurricane-force winds of 200 km/h and strong earthquakes. But before the planned test observations of the Crab Nebula (the standard candle of gamma-ray astronomy) can begin, the telescope will still have to be equipped with mirrors, camera, etc. The inauguration ceremony for the prototype structure of our small-size telescope took place on 2 June 2014. The fully equipped telescope, ready for test observations, should be finished by summer 2015. ■

Further reading:

Acharya et al. (2013). Introducing the CTA concept. *Astroparticle Physics, 43*, 3.