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# Large Array of imaging atmospheric Cherenkov Telescopes (LACT): status and future plans

**Shoushan Zhang,[a,b,c,*] Yudong Wang,[a,c] Jiali Liu,[a,b,c] Shaohui Feng,[a,c] Mingjie Yang,[a,c] Lisi Geng[a,c] and Yong Zhang[a,c] for LACT group**

[a] *The Institute of High Energy Physics of the Chinese Academy of Sciences, YuQuan Road.19B, shijingshan district, Beijing, China*

[b] *University of Chinese Academy of Sciences, Department, YuQuan Road.19A, shijingshan district, Beijing, China*

[c] *TIANFU Cosmic Ray Research Center, Chengdu, Sichuan, China*

*E-mail:* zhangss@ihep.ac.cn

Recently, LHAASO has discovered more than 40 ultra-high-energy gamma-ray sources, opening a new window in ultra-high-energy gamma-ray astronomy. Notably, most of these sources exhibit extended characteristics that require telescopes with higher angular resolution and sensitivity to observe and study their morphology. Thus, we propose a new project: the Large Array of Imaging Atmospheric Cherenkov Telescopes (LACT). LACT is designed to consist of 32 telescopes, each achieving an angular resolution better than 0.05° above 10 TeV. These telescopes will be constructed within the LHAASO detector array, utilizing LHAASO unique muon detector array to provide superior gamma-proton discrimination at ultra-high energies. This will significantly enhance the detection sensitivity of gamma rays above 10 TeV, offering an unparalleled advantage over other IACT experiments globally. For gamma rays above 100TeV, the sensitivity of 500 hours of exposure on a single source is designed to match the sensitivity of one year of exposure to LHAASO. This capability will enable us to identify gamma-ray sources in PeVatrons and measure their morphology in detail, aiding in the understanding of gamma-ray emission mechanisms and the exploration of the origins of high-energy cosmic rays. Each LACT telescope has a field of view of 8° with a pixel size of 0.2°. This paper introduces the design concept, performance parameters, prototype development progress, and future construction plans for LACT.

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*Speaker





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## 1. Introduction

Since Austrian physicist Victor Hess discovered cosmic rays through balloon flight experiments in 1912, scientists have observed cosmic rays with energies exceeding $10^{20}$ electron volts. However, the origins and acceleration mechanisms of high-energy cosmic rays remain an unsolved mystery. During their propagation, charged cosmic rays are deflected by interstellar magnetic fields, making it difficult to directly trace their sources. Fortunately, cosmic rays interacting with the medium or photon fields within their sources can release gamma-ray photons. These gamma rays are not affected by magnetic fields, making them critical messengers in our quest to uncover the origins of cosmic rays.

The Large High Altitude Air Shower Observatory (LHAASO) [1], located in Haizi Mountain, Daocheng County, Sichuan Province, China, has discovered more than 40 ultra-high-energy gamma-ray sources [2, 3]. This discovery has opened a new window in ultra-high-energy gamma-ray astronomy, with the highest energy photon detected reaching up to 2 PeV [4]. Notably, most of these ultra-high-energy gamma-ray sources exhibit extended characteristics and are associated with celestial objects such as supernova remnants, pulsars, pulsar wind nebulae, young massive star clusters, and microquasars [2]. To deeply observe and study the morphology of these sources, precisely locate the radiation-emitting celestial bodies of ultra-high-energy gamma rays, and accurately analyze their radiation mechanisms, we need a telescope that combines high resolution and high sensitivity.

Current Imaging Atmospheric Cherenkov Telescope (IACT) experiments, such as H.E.S.S. [5], VERITAS [6], and MAGIC [7], have sufficient angular resolution, but their detection sensitivity is still inadequate to observe ultra-high-energy gamma rays emitted by these sources. The next generation of IACT experiments, such as the Cherenkov Telescope Array Observatory (CTAO) [8], is expected to achieve sufficiently high angular resolution and sensitivity in the Southern Hemisphere. However, in the Northern Hemisphere, the detection sensitivity for ultra-high-energy gamma rays is much less than that of telescope arrays in the Southern Hemisphere. Therefore, in the Northern Hemisphere, we propose the next-generation IACT experiment, the Large Array of Imaging Atmospheric Cherenkov Telescope (LACT). The LACT project plans to deploy 32 telescopes and aims to achieve an angular resolution better than 0.05° for energies above 10 TeV. Additionally, it is designed to match the sensitivity of LHAASO around 100 TeV. These telescopes will be built within the LHAASO detector array, utilizing its muon detector array to provide excellent gamma-proton discrimination capabilities at ultra-high energies, thereby enhancing the detection sensitivity of gamma rays above 10 TeV—an unparalleled advantage over other IACT experiments. In the following sections, this paper will detail the design concept, performance parameters, prototype development progress, and future construction plans for LACT.

## 2. LACT

LACT comprises 32 Cherenkov telescopes, each with a field of view (FOV) of about 8° × 8° and a pixel size of about 0.19° × 0.19°. These telescopes are organized into eight groups within the LHAASO site, with each group containing four telescopes (Figure 1). Ideally, the four telescopes in each group are placed at the vertices of a square, with the square's side length adjustable between

120 m and 200 m to balance optimal angular resolution and detection threshold energy. The entire LHAASO detector array spans approximately 1.3 $km^2$. Within this area, detectors are systematically arranged: the Cherenkov detector array within a radius of 635 m, the muon array within a radius of 575 m, and the water Cherenkov detector array occupying 78,000 $m^2$ in between. This arrangement establishes clear site boundary conditions for the LACT array layout. When planning the LACT array, it is essential to consider these existing array layouts to prevent interference among detector components while maximizing detection efficiency. Considering terrain factors and potential obstructions from surrounding high ground during observations at large zenith angles, the spacing between adjacent telescopes within each group is flexibly adjusted between 120 m and 200 m. For large zenith angle events, the distance between the nearest two groups of telescopes should ideally range from 350 m to 600 m, with larger distances yielding better results. Additionally, it is crucial to ensure that all telescopes are within the LHAASO site to avoid additional land acquisition and installation costs while maximizing the use of muon information measured by the LHAASO muon detector array.

**Table 1:** Parameters of LACT.

| | |
|---|---|
| Required energy range | 1 TeV - 1PeV |
| Total number of telescopes of LACT | 32 |
| Optical design | Davies-Cotton |
| Reflector diameter | ~ 6 m |
| Focal length | ~ 8 m |
| Field of view | ~ 8° |
| Number of pixels in each camera | 1616 |
| Pixel size | ~ 0.19° |
| Photodetector type | SiPM |
| Pointing accuracy | ≤ 18 arcseconds |

Each telescope primarily consists of a Davies-Cotton reflective mirror system, a Silicon Photomultiplier (SiPM) camera, an alt-azimuth mount, readout electronics, a slow control system, a power supply system, a data acquisition system and a calibration system. The distance between the Davies-Cotton mirror system and the SiPM camera is approximately 8000 mm. When charged particles in an air shower produce Cherenkov light, these photons are collected by the Davies-Cotton system and precisely focused on the SiPM camera, forming Cherenkov event images. The SiPM camera converts photons into electronic signals, which are amplified, digitized, and trigger-discriminated by the readout electronics. Once triggered, the relevant data are rapidly transmitted to the data acquisition center at the Daocheng site via optical fibers. At the Daocheng data acquisition center, this data undergoes further processing and is stored on local hard drives to ensure security and traceability. Finally, these data are transmitted via optical fibers to the data processing center at the Institute of High Energy Physics for further in-depth analysis. The alt-azimuth mount not only supports the mirror system, camera, and other components as a whole, but also drives the telescope to rotate in both azimuth and elevation directions, enabling the telescope to accurately and real-time track and observe celestial sources.

In optical design, we prefer the Davies-Cotton structure over the parabolic structure due to its superior optical imaging performance, which is comparable to that of a parabolic mirror, and

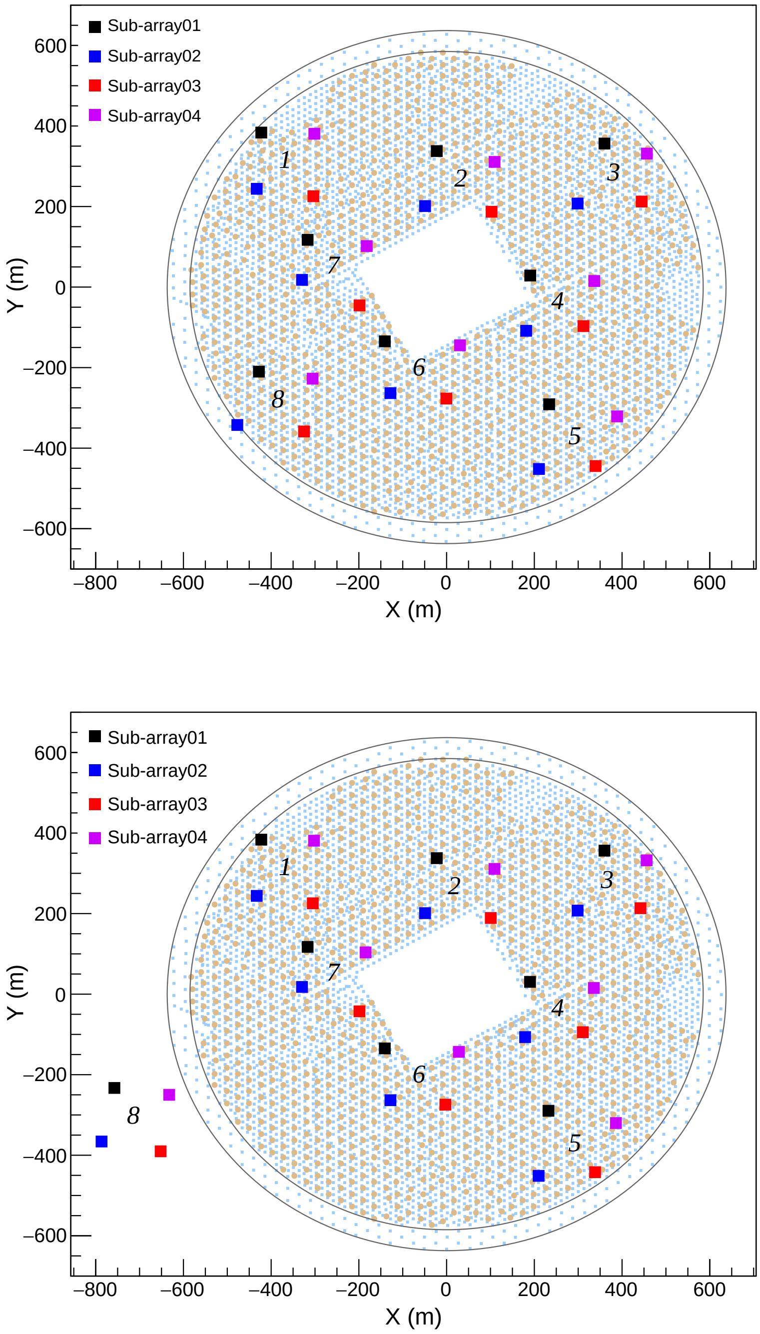


**Figure 1:** Two array layout schemes for LACT are under consideration. Each square represents a LACT telescope. Scheme 1 (up diagram) places all 32 telescopes within the LHAASO detector array. Scheme 2 (down diagram) is a variation of Scheme 1, with four telescopes (numbered 8) relocated outside the array, but still within the site designated by LHAASO. When all 32 telescopes are observing a single source, the differences in angular resolution and effective area performance between these two layouts can be ignored. However, it is necessary to compare the performance of these two layout schemes under large zenith angle observation mode and small zenith angle observation mode for sub-arrays. The optimization and research of these performance differences are ongoing. The largest ring is the boundary of the LHAASO scintillator detector array, and the slightly smaller ring is the boundary of the LHAASO muon detector array.

**Figure 2:** A prototype of LACT on LHAASO site for research and development.

the uniform radius of curvature of all spherical mirrors. This simplifies processing, installation, and debugging, thereby reducing production costs. The reflective focusing mirror system of the LACT telescope is composed of 54 hexagonal spherical mirror facets, each with a side length of 461.88 mm, following the Davies-Cotton design. The curvature radius (R) of the mirror facets is approximately 16 m, and all 54 mirrors are mounted on a spherical dish with a radius of ( $\frac{1}{2}$ R ). The diameter of the reflective focusing mirror system is about 6 m.

Another essential component of the telescope is the SiPM camera, which is composed of 1616 SiPM units arranged in a compact manner. Each SiPM unit includes a light funnel (Winston cone), a front-end amplifier board, and a voltage and temperature compensation circuit board to ensure accurate signal capture and efficient transmission. Notably, the unique design of the light funnel features an entrance area of 24.4 mm × 24.4 mm (pixel size is about 25.8 mm × 25.8 mm), and its exit area perfectly aligns with the SiPM's sensitive area (13 mm × 13 mm), significantly enhancing photon collection efficiency for each pixel. To further optimize the signal-to-noise ratio, an optical filter window with a high transmittance of up to 92% is installed in front of the SiPM camera, allowing only light with wavelengths from 280 nm to 550 nm to pass through, effectively filtering out long-wavelength background noise.

For signal readout, the output from the SiPM is initially matched by a front-end amplifier and then divided into two channels with high gain and low gain to maintain signal linearity across a wide dynamic range. These signals are subsequently converted from analog to digital using a 1 GS/s, 10-bit ADC and processed by a field-programmable gate array (FPGA). The FPGA executes complex trigger algorithms, data transmission, and buffering. This comprehensive series of signal processing steps ensures that the LACT telescope captures high-quality observational data.

## 3. Performance and Prototypes

We optimized the angular resolution, effective detection area, and detection sensitivity of LACT while taking into account the terrain of the LHAASO site and the layout of detectors. The array layout of LACT is illustrated in Figure 1. The observation modes of LACT are categorized into full array observation mode (32 telescopes pointing to the same celestial source) and sub array observation mode (8 telescopes pointing to one celestial source). The four sub arrays of LACT can simultaneously observe four celestial sources. When a gamma ray event is imaged and measured by at least two telescopes, the angular resolution can be better than 0.06° for energies above 50TeV and zenith angles greater than 50°. The effective detection area of each sub array can exceed 2.4 square kilometers. For zenith angles less than 50°, the angular resolution can be better than 0.07°, and the effective detection area can be greater than 1.3 square kilometers. The effective detection area of each sub array for gamma rays exceeds the area of LHAASO (1.3 square kilometers). In the full array observation mode, the angular resolution is approximately 0.06° for energies around 1TeV and better than 0.05° for energies beyond 10TeV, with an effective detection area exceeding 1.6 square kilometers.

LHAASO's muon detector array can significantly enhance the detection sensitivity of LACT for gamma photons, particularly for extended gamma ray celestial sources, by providing excellent gamma-proton discrimination capability [9]. The cosmic ray background is suppressed to less than one in ten thousand at around 100 TeV (Figure 3) [10]. The scintillation detector array and water Cherenkov detector array of LHAASO can provide the core position and shower direction for LACT, thereby enhancing its angular resolution and sensitivity.

Currently, two prototype LACT telescopes have been developed, one at the LHAASO site in Daocheng (Figure 2) and the other near the office building of the Tianfu Cosmic Ray Research Center (Figure 4), Chengdu, Sichuan. These prototypes aim to evaluate the performance of the telescope rotation system, the mirror system, and installation processes. Various types of reflective mirrors, such as all glass mirrors, aluminum honeycomb sandwich glass mirrors, and glass honeycomb sandwich glass mirrors, have been tested. The camera will use SiPM, and 18 SiPM cameras have been successfully developed for the LHAASO telescope [11, 12]. For LACT's SiPM camera, our self-developed 1GHz sampling rate ASIC chip will be considered to reduce power consumption and cost. In addition, the plan is to select SiPM with higher sensitivity to ultraviolet wavelengths. These experiments and developments are progressing smoothly.

A prototype (Figure 4) located at the Tianfu Cosmic Ray Research Center has preliminarily verified the optical performance of LACT by observing the spot imaging of Jupiter (with a visual magnitude of about -2.9) on the focal plane. Almost all photons reflected by Jupiter through the telescope mirror system are focused within a square frame with a side length of 20mm, which is smaller than the pixel size (25.8mm × 25.8mm) and better than the design specifications (the proportion of photons within 25.8 mm × 25.8 mm > 80%).

## 4. Summary and future plan

LACT is the next generation IACT, with plans to build 32 telescopes at the LHAASO site. The LHAASO muon array can provide excellent ggamma-proton discrimination, significantly improving the sensitivity of LACT. The angular resolution of LACT above 10 TeV is better than 0.05 °, and the gamma ray detection sensitivity at around 100 TeV for 500 hours is almost equivalent to the sensitivity of LHAASO within one year. This enables the identification of PeVatron gamma ray sources and detailed measurements of their morphology, which helps to understand the mechanisms behind PeVatron gamma ray emission and explore the origins of high-energy cosmic rays.

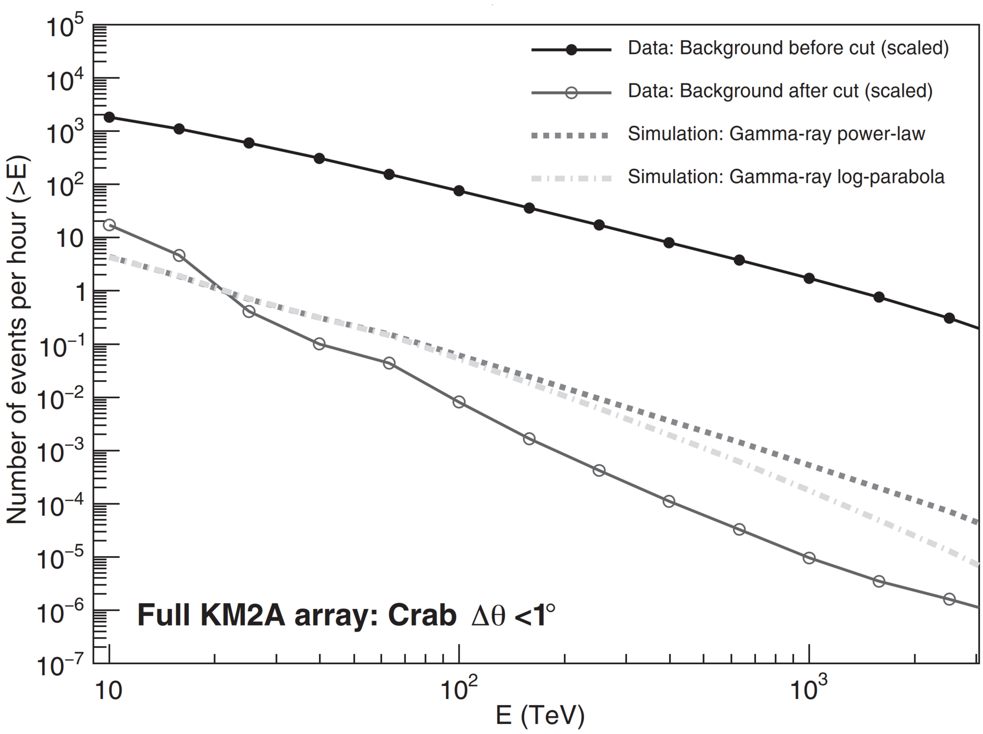


**Figure 3:** The detection rates of gamma rays from the Crab and the cosmic ray background events above the shower energy E by the 1-km2 array within a 1° cone centered at the Crab direction as detected by LHAASO [10]. As the LACT is situated at the LHAASO site, the LHAASO muon array can offer excellent gamma-hadron discrimination. The cosmic ray background is suppressed to less than one in ten thousand at around 100 TeV. Consequently, the sensitivity of the LACT can be significantly enhanced.

The development technology scheme of the LACT detector is currently undergoing iterative optimization, and the performance of the LACT array is still undergoing further in-depth research. The prototype of the LACT will be put into operation in 2025, with 8 telescopes scheduled to be put into operation in 2026. It is anticipated that a total of 32 telescopes will be completed by 2028.

## 5. Acknowledgements

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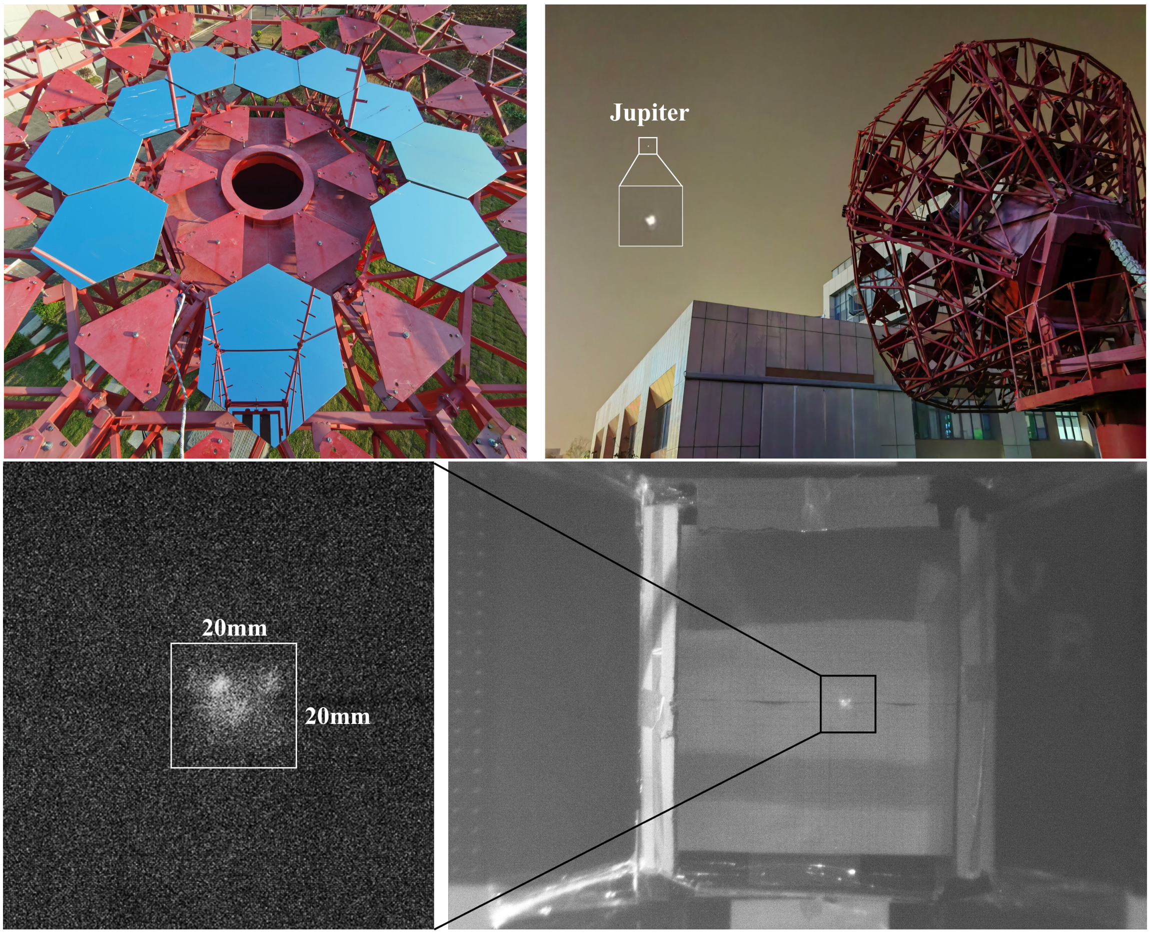


**Figure 4:** A prototype of LACT installed at the Tianfu Cosmic Ray Research Center, with 10 mirror facets installed on the telescope. It observed the spot imaging of Jupiter (with a visual magnitude of approximately -2.9) on the focal plane, with almost all photons focused within a square frame with a side length of 20mm, which is smaller than the pixel size (25.8m × 25.8mm) and better than our design requirements.

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