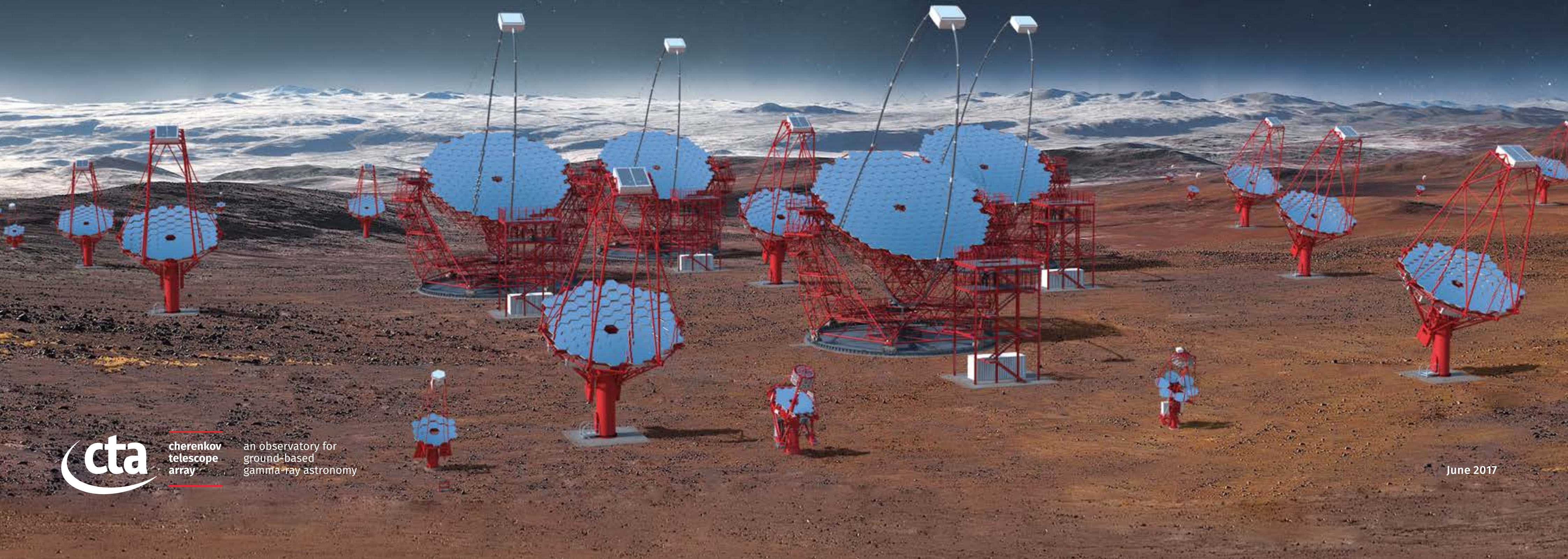
cherenkov telescope array

# Exploring the Universe at the Highest Energies



cherenkov telescope array

an observatory for ground-based gamma-ray astronomy

June 2017

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cover image credit:
Gabriel Pérez Diaz, IAC

# A High-Energy Evolution



High above the clouds, atop the rocky peaks of the island of La Palma and nestled in a valley of the great, desolate expanse of Chile's Atacama Desert, the foundations are being laid for the world's largest and most advanced ground-based observatory for gamma-ray detection.

Stargazers have long used these vantage points and others to marvel at the wonders of our Galaxy and beyond, working to unlock their mysteries and expand our understanding of the Universe. The Cherenkov Telescope Array (CTA) will push that perspective to reveal an entirely new and exciting view of the turbulent sky, revolutionizing what we know about the violent, high-energy Universe.

The current generation of ground-based gamma-ray detectors – the five H.E.S.S. telescopes located in Namibia, the two MAGIC telescopes in La Palma and the four VERITAS telescopes in Arizona – have been exploring the high-energy Universe since 2003, increasing the number of known gamma-ray-emitting celestial objects from 10 to more than 150. With more than 100 telescopes located in the northern and southern hemispheres, CTA will use its unprecedented accuracy and sensitivity to expand this register of known objects tenfold and to address some of the most perplexing questions in astrophysics. Not only will CTA break new ground in our understanding of the Universe, it will be the first of its kind to be open to the world-wide astronomical and particle physics communities as a resource for data from unique, very-high energy astronomical observations.

Unprecedented, powerful, accessible.
Let the next evolution begin...

image credit:
Panagiotis Papadopoulos

# The Light Hunters

The light you see from distant stars, planets and other celestial objects comes from just a small portion of the electromagnetic spectrum. Much more of the radiation is invisible to the human eye.

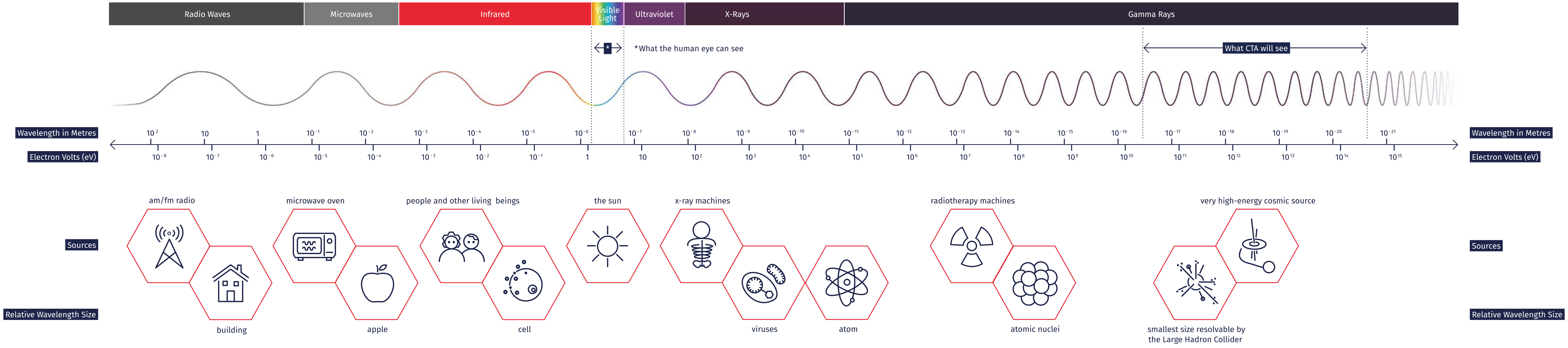
The full spectrum ranges from the low frequencies and long wavelengths of radio waves and microwaves to the mid-range frequencies found in infrared, optical (visible) and ultraviolet light to the very highest frequencies of X-rays and gamma rays. The frequency range of gamma rays is so vast that it does not even have a well-defined upper limit. In fact, the gamma rays CTA will detect are about 10 trillion times more energetic than visible light!

Optical telescopes have been capturing the visible light of the night sky since the early 17th century, putting the beauty of the Universe on display. To get a more complete picture of the phenomena and the physical mechanisms at work, scientists hunt with telescopes specially tuned to capture different frequencies of light. With its ability to view the highest-energy processes in the Universe, CTA will be a vital asset in improving our understanding of some of the most volatile and mysterious phenomena we know of or have yet to discover.

Imagine what these cosmic messengers will tell us...



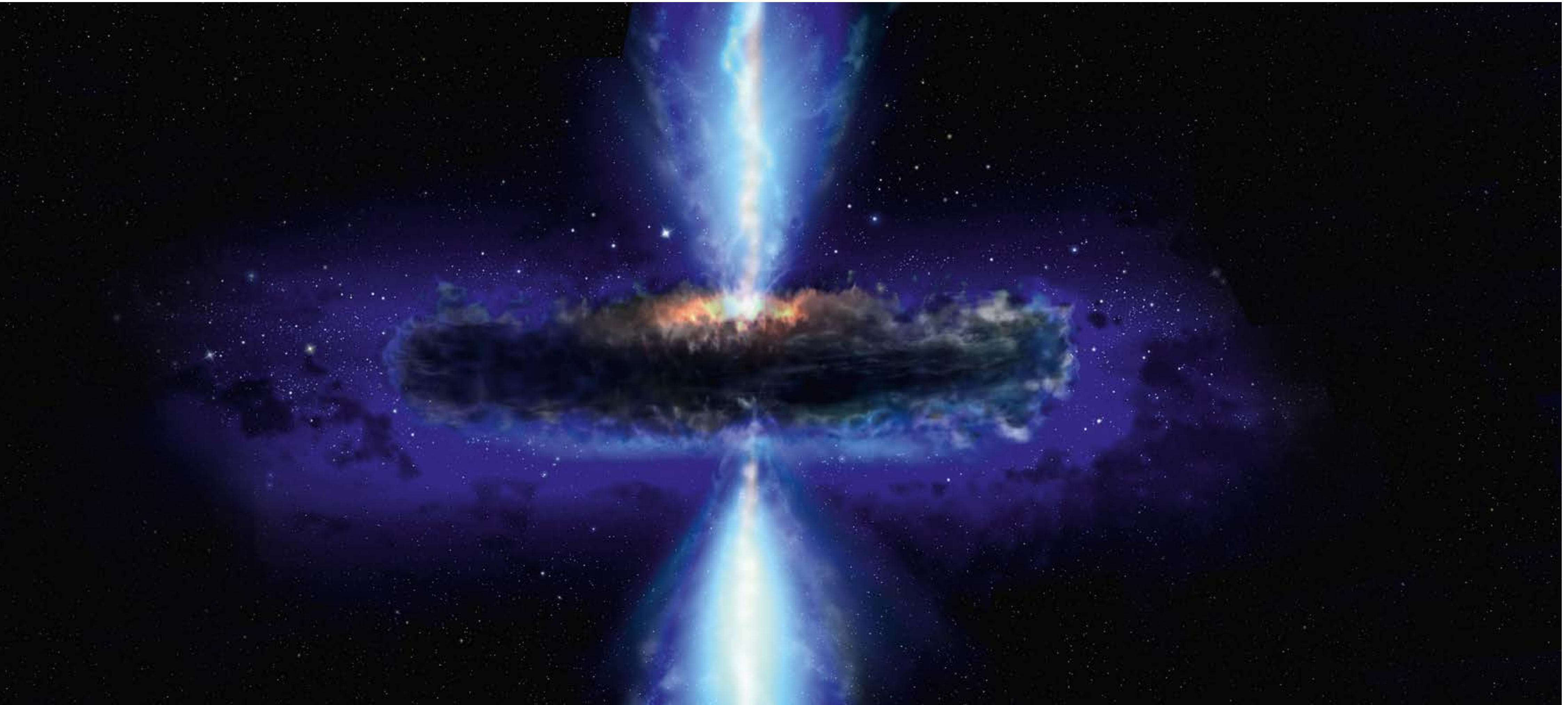
## The Electromagnetic Spectrum



# Birth of a Gamma Ray

At the heart of a galaxy billions of light years away, a supermassive black hole, having a mass a billion times that of the Sun, accumulates a very hot disk of material and gas. As the hot disk churns violently, it shines brighter than all the surrounding stars and discharges jets of highly energetic particles that travel beyond the bounds of its galaxy. It is in extreme environments like this where gamma rays are born.

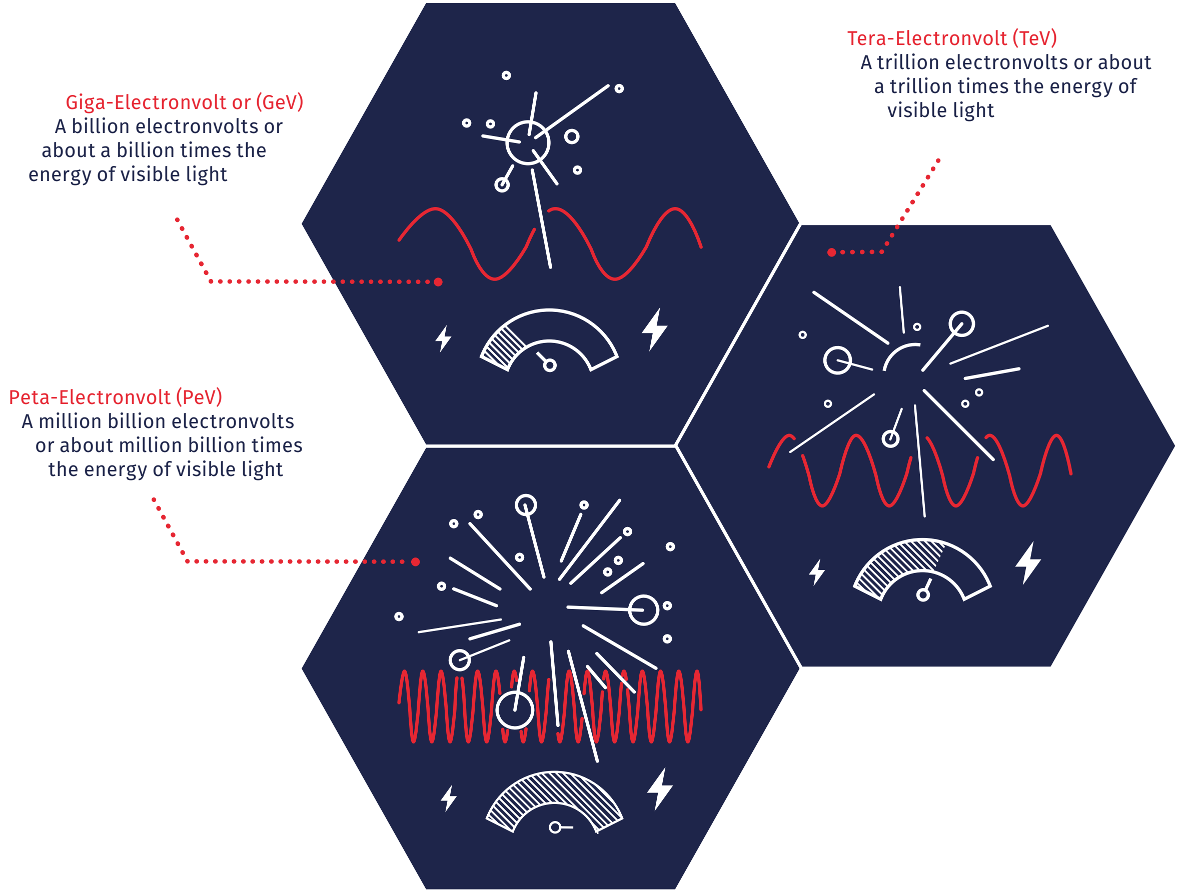
image credit:
ESA / NASA





However, no object, not even a supermassive black hole, produces gamma rays directly. Gamma rays are the product of subatomic particles (usually protons or electrons) that get accelerated in extreme environments typically associated with these violent events. Explosions, outbursts or powerful jets accelerate particles to nearly the speed of light. Gamma rays are produced when the particles collide with matter and radiation fields in or around the sources or in interstellar space. The gamma rays travel across the Universe to galaxies beyond, transporting with them the secrets of their birthplace.

In our own Galaxy, CTA will look for the remnants of supernova explosions, wind nebulae produced by rapidly spinning ultra-dense stars known as pulsars and for more normal stars in binary systems or in large clusters. Beyond our Galaxy, CTA will detect star-forming galaxies and galaxies with supermassive black holes at their centres (active galactic nuclei) and, possibly, whole clusters of galaxies. The gamma rays detected with CTA may also provide a direct signature of dark matter, evidence for deviations from Einstein's theory of special relativity and more definitive answers to the contents of cosmic voids.




Energies up to 300 TeV will push CTA beyond the edge of the known electromagnetic spectrum, providing a completely new view of the sky. The electronvolt (eV) is a unit of energy commonly used by scientists. The gamma rays CTA will detect have energies of billions to many trillions of electronvolts.

# Venturing Beyond the High-Energy Frontier

What if our ancestors never sailed beyond the horizon or failed to peer beyond the boundaries of our celestial neighbourhood? Without their courage to ask questions or challenge the known frontier, our understanding of our world and the Universe would be drastically stunted.

Ground-based gamma-ray astronomy is a young field with enormous scientific potential, as demonstrated by the current generation of instruments. With its superior performance, the prospects for CTA combine the in-depth understanding of known objects with the anticipated detection of new classes of gamma-ray emitters and a great potential for fundamentally new discoveries.

CTA will transform our understanding of the high-energy Universe by seeking to address a wide range of questions in astrophysics and fundamental physics.

These questions fall under three major study themes:

1. Understanding the origin and role of relativistic cosmic particles
2. Probing extreme environments
3. Exploring frontiers in physics

Learn more about CTA's study topics



## I. Understanding the Origin and Role of Relativistic Cosmic Particles

The Earth is constantly bombarded by cosmic rays, primarily in the form of high-energy protons and atomic nuclei; however, a full understanding of the source and production mechanisms for these cosmic rays has not been realized. The natural accelerators of cosmic rays within our own Galaxy are capable of accelerating subatomic particles to much higher energies than the Large Hadron Collider, the most powerful particle accelerator on Earth. However, as cosmic rays are electrically charged, their paths are scrambled in the magnetic fields between their sources and the Earth, making it nearly impossible to trace them back to their origin.

On the other hand, gamma rays – some of which are by-products of high-energy cosmic-ray acceleration – do not have an electric charge to deviate their path as they pass through magnetic fields. A direct path allows the gamma rays to transport images of their sources and the energetic particles that created them.

CTA's broad energy coverage and unprecedented angular resolution will enable us to look for the possible sources of cosmic rays within our own Galaxy and beyond and map the role they play in the feedback processes at work as stars form and galaxies evolve.

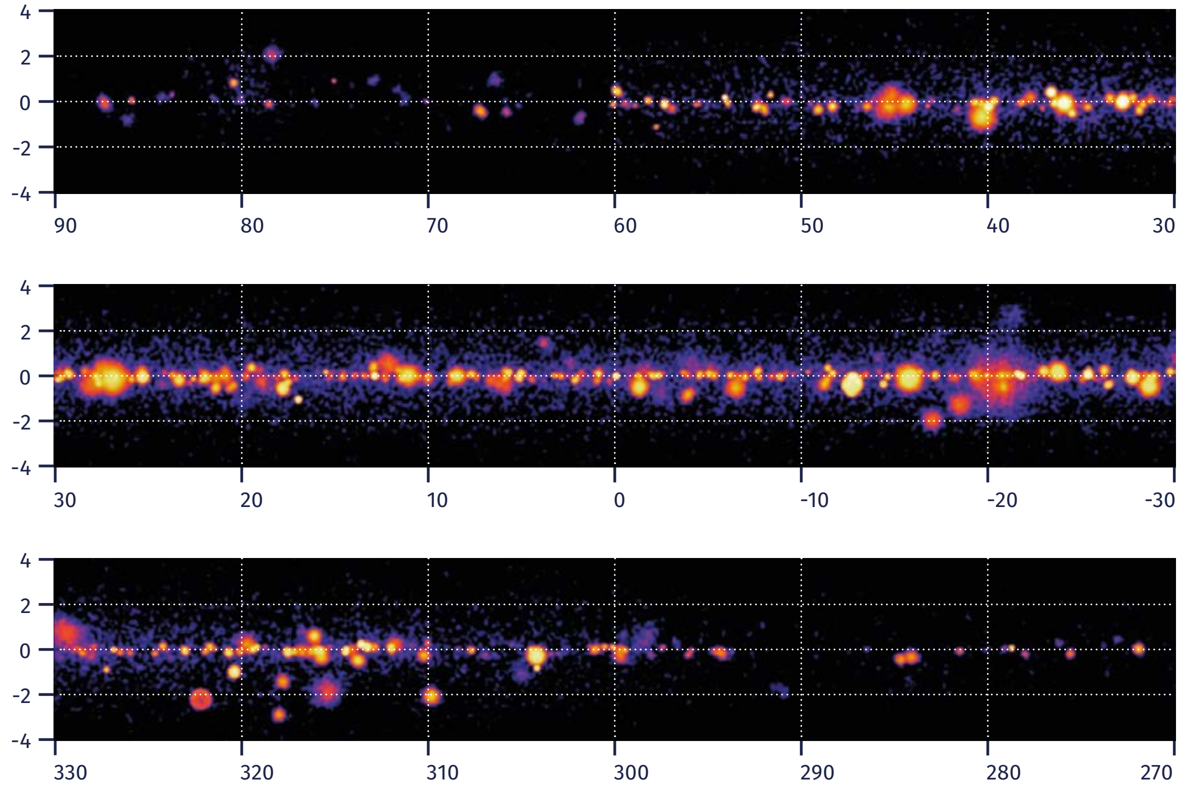
A field of view of 8 degrees will allow CTA to survey the sky quickly and measure very extended regions of gamma-ray emission.

### Target 1: The Galactic Plane – Surveying our Galaxy

The Milky Way is a spinning disc of about 200 billion stars that is about 90,000 light years across and 1,000 light years thick. The Galactic Plane is located at the midpoint of its thickness and is where the vast majority of stars live. CTA's survey of the Galactic Plane is expected to lead to the detection of more than 400 individual sources of gamma-ray emission, most of which have never been seen before in high-energy gamma rays. These discoveries will provide insights into the physics that accelerate particles to the highest energies and how these particles travel from their accelerating sites. Unveiling sources that are capable of accelerating particles to such high energies will be key to finally understanding the origin of the cosmic rays that permeate the Milky Way.

x = Longitude (deg)

y = Latitude (deg)



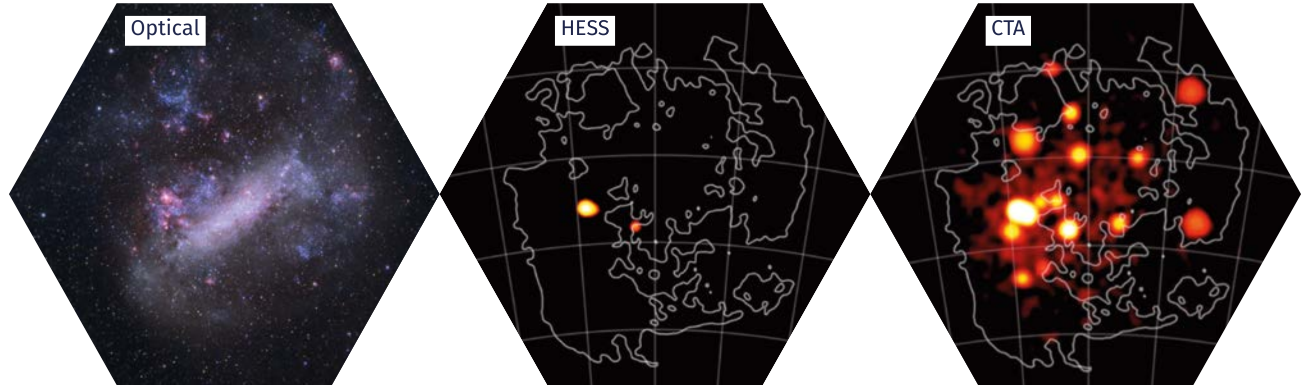

Left: A simulation of what CTA may observe during its Galactic Plane survey.

An angular resolution approaching one arcminute will allow CTA to resolve many cosmic sources to understand how ultra-relativistic particles are distributed in and around these celestial bodies.

image credit:
NASA / ESA / A. Fruchter / ERO

### Target 2: Large Magellanic Cloud – Our Vibrant Neighbour Galaxy

As a satellite of the Milky Way, the Large Magellanic Cloud (LMC) is one of the closest galaxies. It is a unique galaxy hosting a variety of exceptional objects, including star-forming regions, star clusters, pulsar wind nebulae and supernova remnants. CTA will observe the LMC for several of its science objectives, including to gain insight into the transport of cosmic rays on large scales — from their release into the interstellar medium to their escape from the galaxy.




A simulated comparison of CTA's survey of the LMC with current optical and H.E.S.S. images.

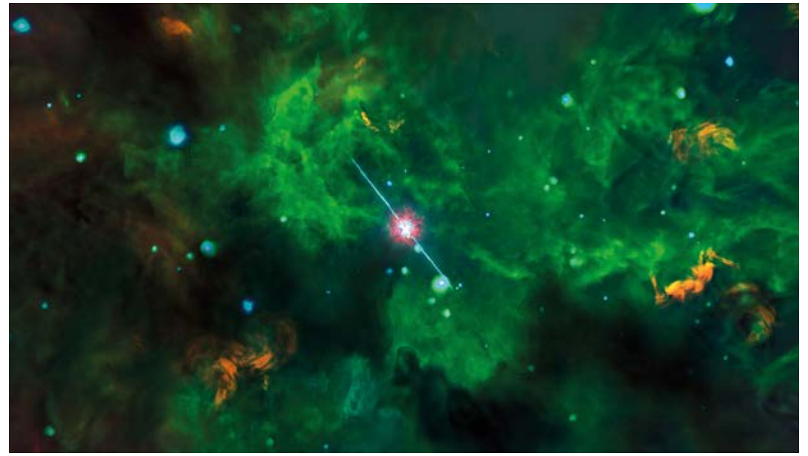
### Target 3: Galaxy Clusters – Bundles of Opportunity

Galaxy clusters typically host thousands of galaxies and are expected to contain cosmic rays accelerated by formation processes or the active galactic nuclei (AGN) found at some of the galaxy centres. It is believed cosmic rays play an important role in suppressing the cooling flows in galaxy clusters, but no proof of this exists. One of the galaxy clusters CTA will study is Hydra A, which has an AGN that ejects bubbles of hot material. Since cosmic rays are believed to be accelerated as a by-product of this process, gamma rays may be emitted as well. If CTA can detect these gamma rays, they could provide insight into cosmic ray acceleration at these sites and the role they potentially play in galaxy evolution and growth.



## II. Probing Extreme Environments

The gamma rays CTA will detect are at energies well beyond those of X-rays or even gamma rays detected by space instruments. As such, they encode information about the physical processes at work in some of the most energetic environments in the Universe. The black holes and neutron stars born when massive stars reach the end of their lives and explode are of particular interest. Gamma rays have been observed coming from jets of many black holes, although the exact mechanisms by which this emission process occurs are not fully understood. The capabilities of CTA will enable us to address these questions with an unprecedented level of accuracy.



### Target: Transients – Random Blasts Full of Information

The Universe hosts a diverse population of astrophysical objects that explode, flare up or intensify activity in dramatic and unpredictable fashion across the entire electromagnetic spectrum and over a broad range of timescales, spanning milliseconds to years. Collectively designated as "transients," many are known to be prominent emitters of high-energy gamma rays and are also likely sources of non-photonic, multi-messenger signals such as cosmic rays, neutrinos or gravitational waves. They are of great scientific interest, being associated with catastrophic events involving relativistic compact objects such as neutron stars and black holes that thrive in the most extreme physical conditions of our Universe. With its exceptional sensitivity to very-high energy (VHE) gamma rays, CTA has the potential to break new ground in explaining the physics of cosmic transients and discovering entirely new classes of transient sources.

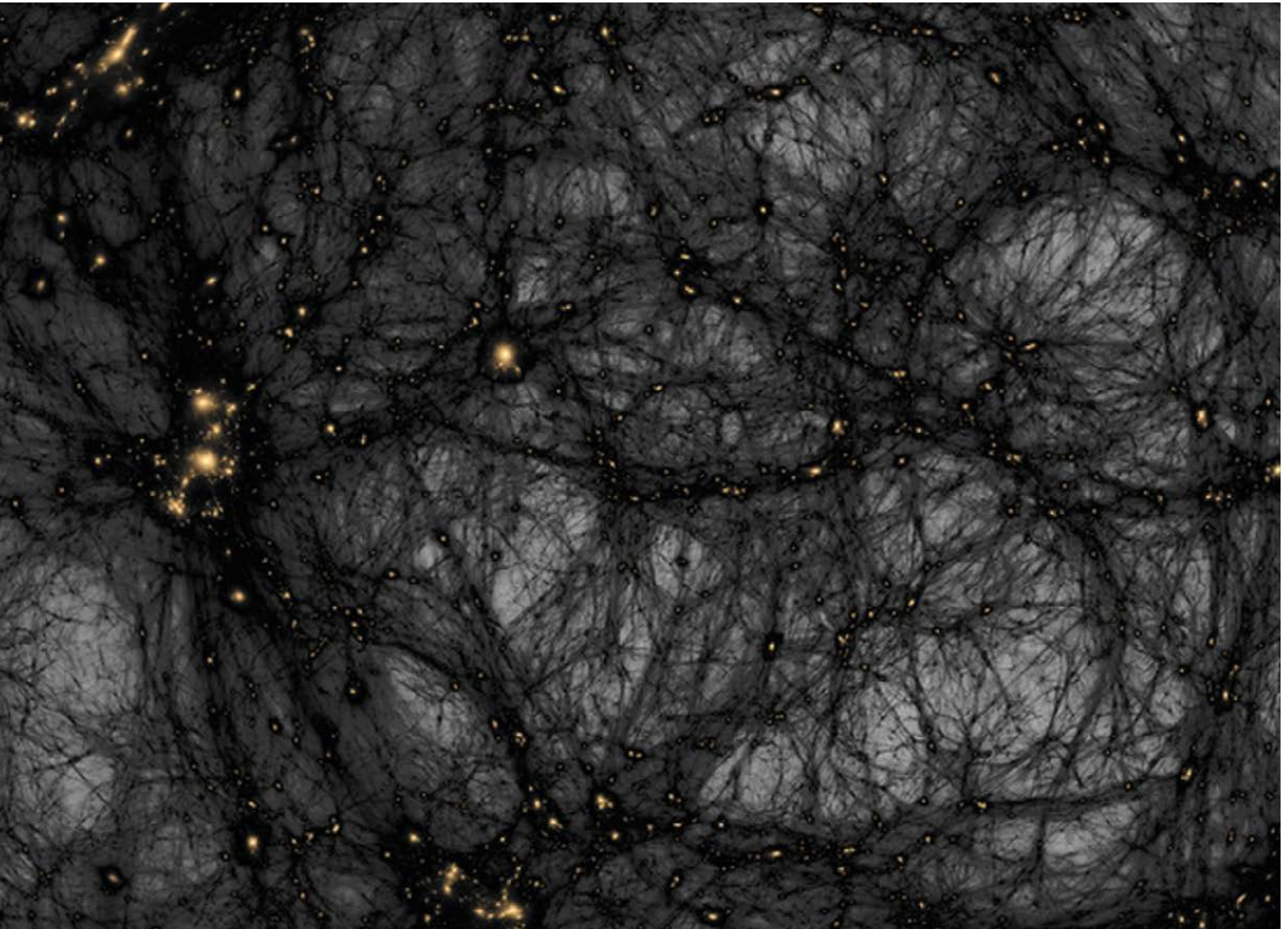
image credits:
NAOJ; NAOJ; ESO/A. Roquette;
ESO/L. Calçada

Accessing energies as low as 20 GeV will allow CTA to probe transient and time-variable gamma-ray phenomena in the very distant Universe with unprecedented precision.

## III. Exploring Frontiers in Physics

An energy resolution of 10 percent will improve CTA's ability to look for spectral features and lines associated with the annihilation of dark matter particles.

A major step forward in sensitivity and energy coverage brings discoveries in fundamental physics, or how the Universe behaves at its most basic level, well within CTA's reach. Specifically, CTA will seek to discover the nature and properties of dark matter, probe the existence of axion-like particles and test possible deviations from Einstein's theory of special relativity. Any of these discoveries would mean a revolution for particle physics and cosmology.

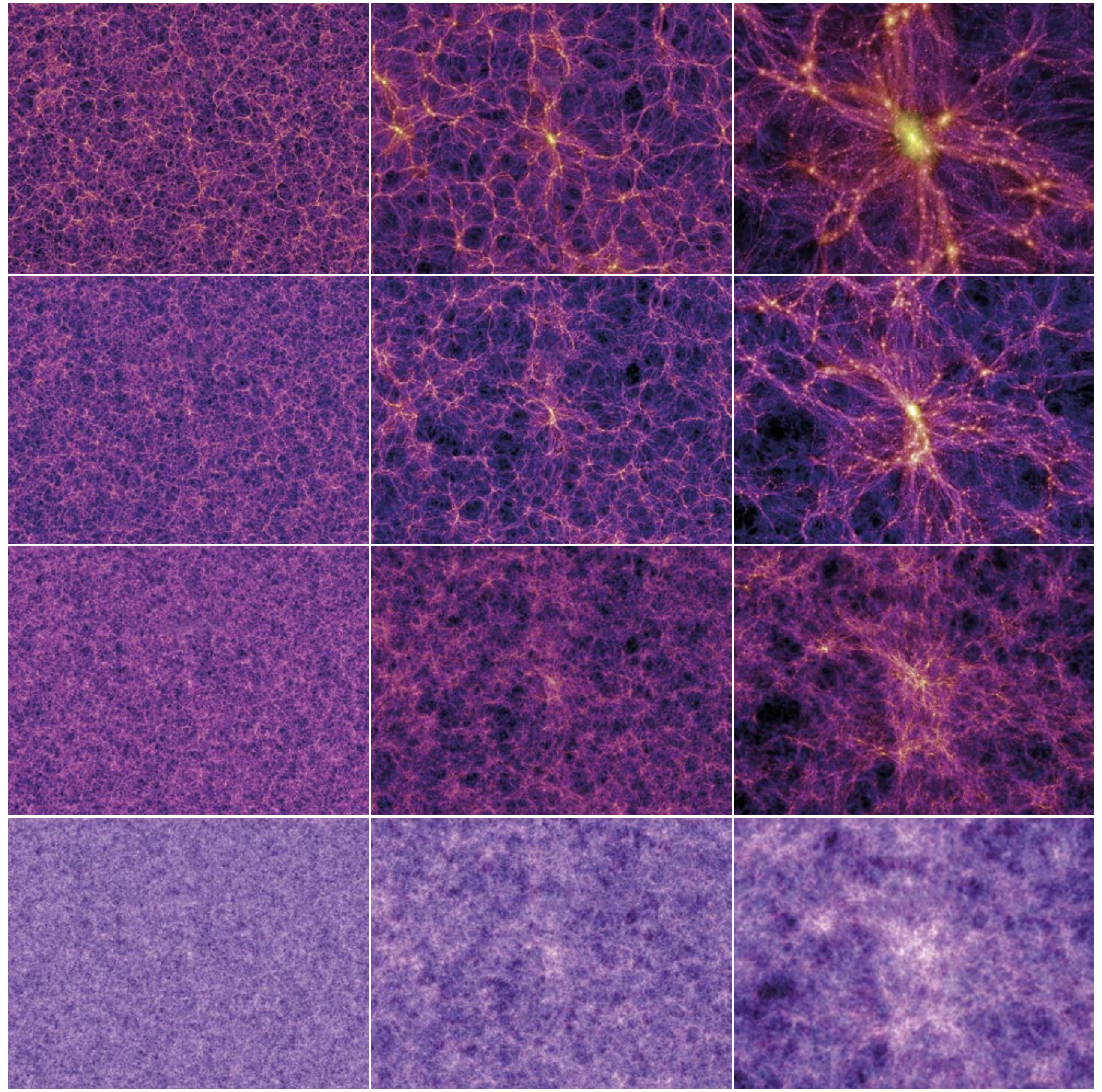


### Target 1: Dark Matter – One of Science's Greatest Mysteries

Dark matter is thought to account for a large part of the total mass of the Universe, but its nature remains one of the greatest mysteries in science. Dark matter manifests itself by its gravitational effects and seems to occur in far larger quantities than normal matter, but close to nothing is known about its nature. CTA will be a dark matter discovery instrument of unprecedented sensitivity and will potentially provide a tool to study the particle physics and astrophysical properties of the as-yet-unidentified dark matter particles. CTA will attempt to find dark matter by looking for the gamma rays produced when dark matter particles (believed to be weakly interacting massive particles, or WIMPs) annihilate one another when they interact. There is a well-motivated theory as to how often these annihilations happen and where to look for their signal – in places where the density of dark matter is very high (e.g. the centre of our own Galaxy). Current instruments are not sensitive enough to detect the signal predicted by models. CTA will reach this critical sensitivity and complement other searches using the Fermi satellite, the Large Hadron Collider and deep underground direct searches for WIMPs. Together, these instruments have a very good chance to solve the mystery of dark matter within a decade.

image credit:
American Museum of Natural History





### Target 2: The Voids Between Galaxies – Unexplored Regions of the Universe

Most of the Universe is very close to empty, with matter grouped into galaxy clusters, super-clusters and filaments, separated by huge voids. How empty these voids are is a matter of great debate, but it is believed they could contain relics of the earliest moments of the Universe. To probe these voids, CTA will be looking to a known ingredient in the space between galaxy clusters – the extragalactic background light (EBL). EBL represents the light emitted by all galaxies since the birth of the Universe and includes clues to the history of star formation. When gamma rays collide with photons of the EBL, they generate a specific spectral signature that can be measured. If the gamma rays interact, they generate cascades of secondary particles and additional lower-energy gamma rays. The distribution of these gamma rays are influenced by tiny magnetic fields that can be measured by CTA to gain insight into how the Universe was formed.

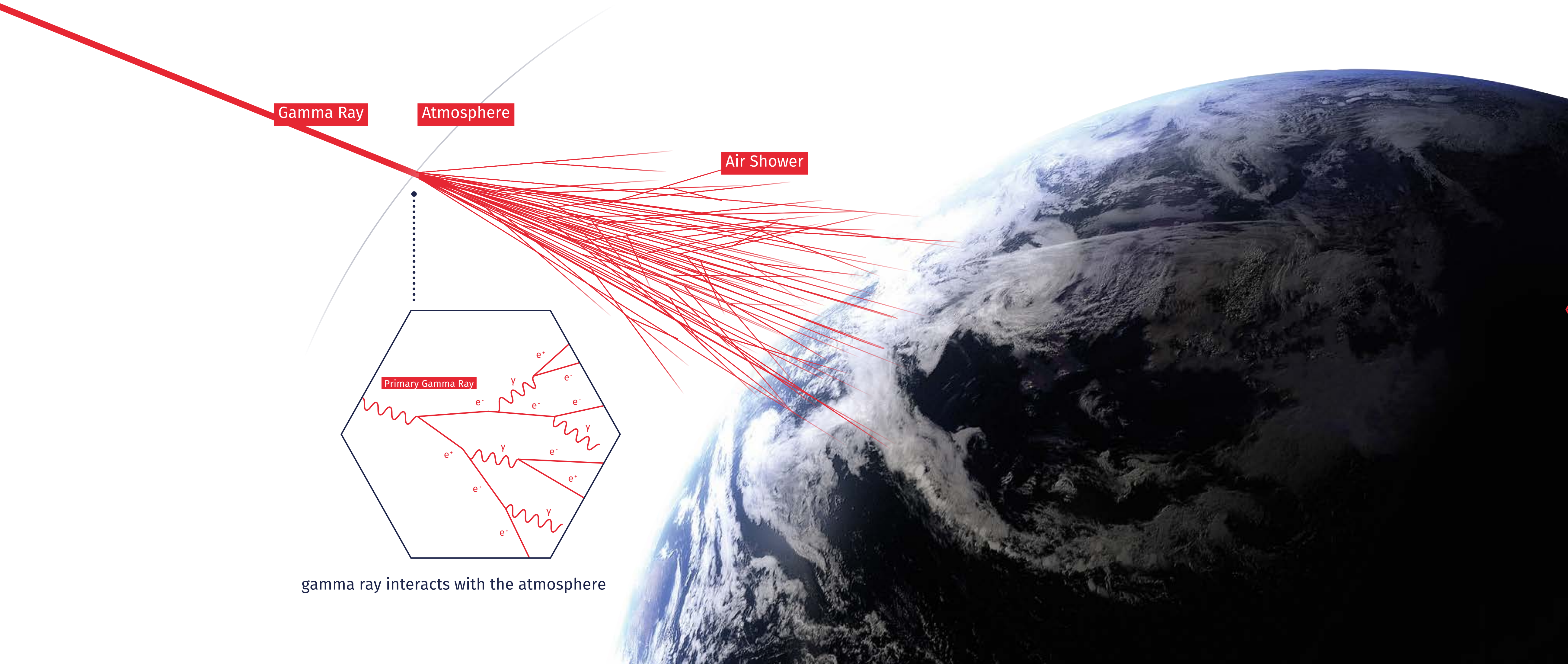
image credit:
Max Planck Institute for Astrophysics

# Gamma Ray Detection with Cherenkov Light

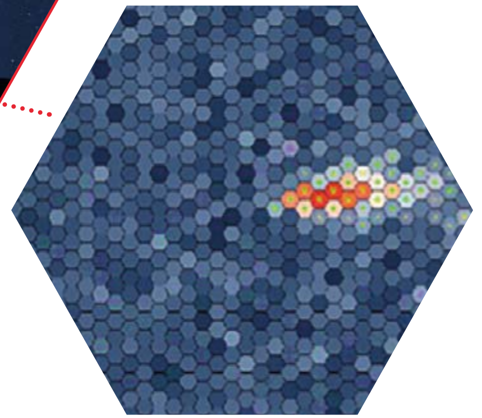
We know how gamma rays are born, but how will CTA detect them and decode the details of their origin? Interestingly, CTA will not detect gamma rays directly because they never actually make it to the Earth's surface.



After their long journey from their sources, the gamma rays interact with the atmosphere, producing cascades of subatomic particles also known as air showers. Nothing can travel faster than the speed of light in a vacuum. However, in air, a very energetic charged particle can travel faster than light, whose speed is reduced by the index of refraction of the air. Thus, very-high energy particles in the atmosphere can create a cone of blue "Cherenkov light" (discovered by Russian physicist Pavel Cherenkov in 1934) similar to the sonic boom created by an aircraft exceeding the speed of sound. Although the light is spread over a large area (250 m in diameter), the cascade only lasts a few billionths of a second. It is too faint to be detected by the human eye but not too faint for CTA's telescopes with their large light-collecting mirrors and sensitive light sensors. When the Cherenkov light reaches CTA's telescopes, the mirrors will reflect the light so the cameras can capture the event. The cameras will be sensitive to these faint flashes and use extremely fast detectors to capture the light and then convert it into an electrical signal that is digitised and transmitted to record the image of the light.




gamma ray interacts with the atmosphere

10 nanosecond snapshot

Learn how CTA works

# Two Eyes on the Turbulent Universe

Capturing the particle showers from a gamma ray that hits the Earth's atmosphere is like the classic scenario of "looking for a needle in the haystack."

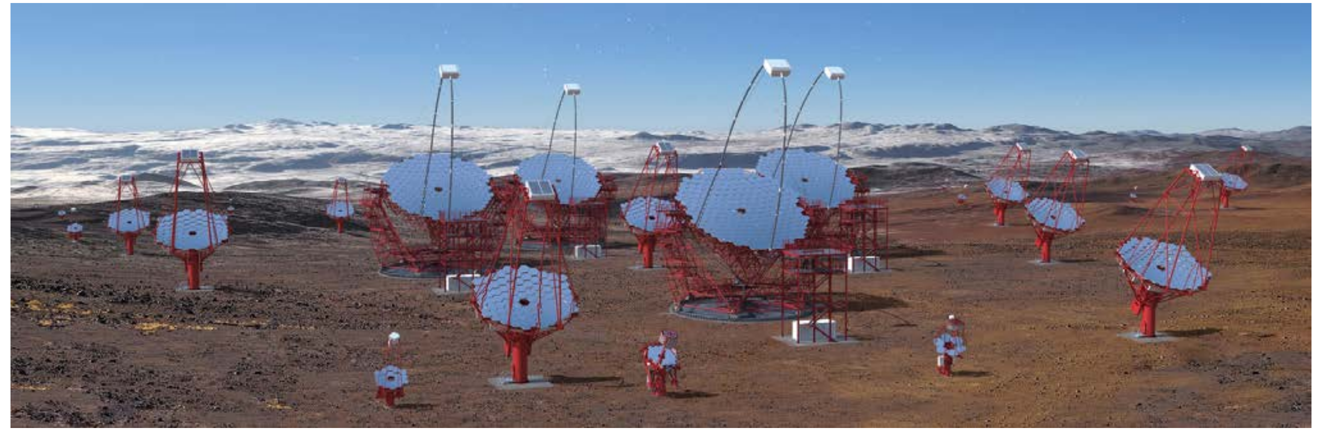


image credit:
Gabriel Pérez Diaz, IAC

In fact, the expectation for the rate of gamma rays is only one per metre squared per year from a bright source, or one per metre squared per century from a faint source. To improve its ability to detect gamma rays, CTA will split more than 100 telescopes between two array locations – one in the northern hemisphere and one in the southern hemisphere to explore the entire sky.

### Northern Hemisphere Site

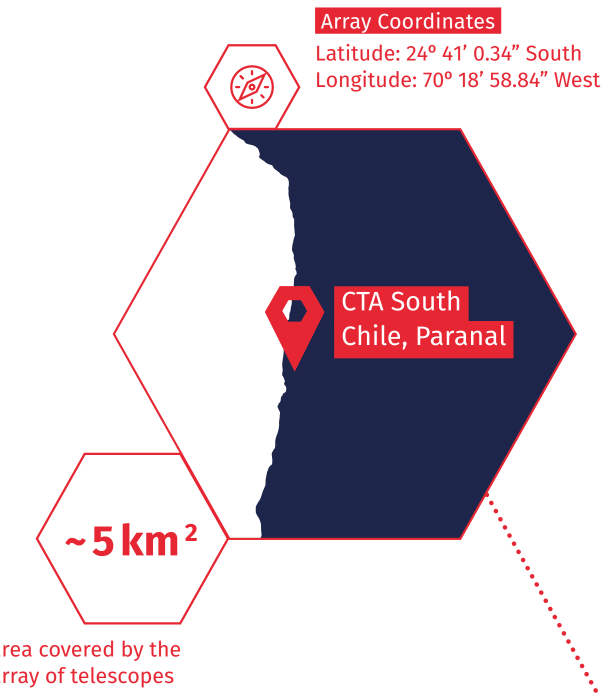
CTA's northern hemisphere site is located on the existing site of the Instituto de Astrofisica de Canarias' (IAC's) Observatorio del Roque de los Muchachos on the island of La Palma, a Spanish island in the Canary Islands. At 2,200 metres altitude and nestled on a plateau below the rim of an extinct volcanic crater, the site currently hosts the two MAGIC Cherenkov telescopes. The northern hemisphere array will be composed of 19 telescopes and will focus on CTA's low- and mid-energy ranges from 20 GeV to 20 TeV.

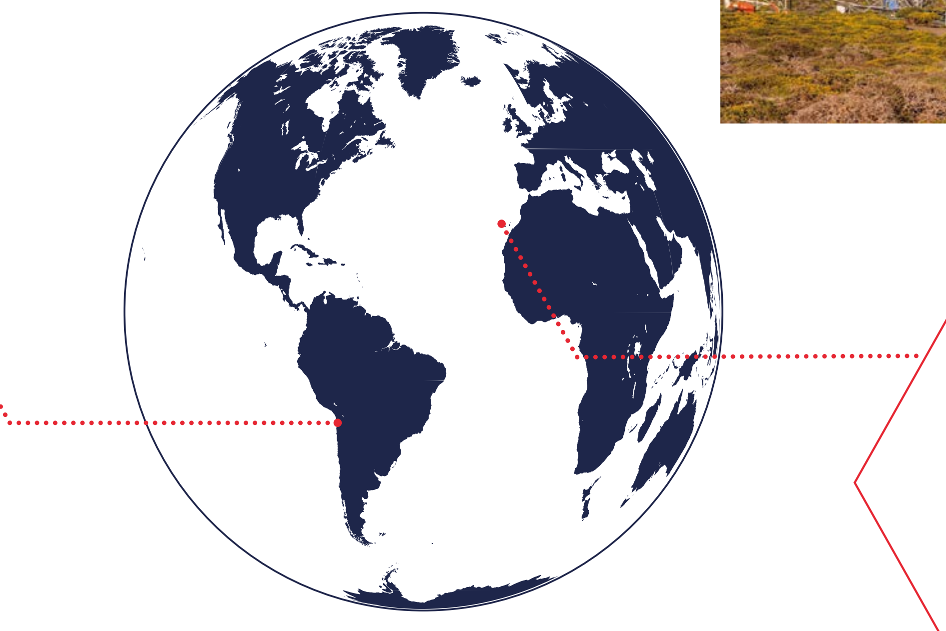
### Southern Hemisphere Site

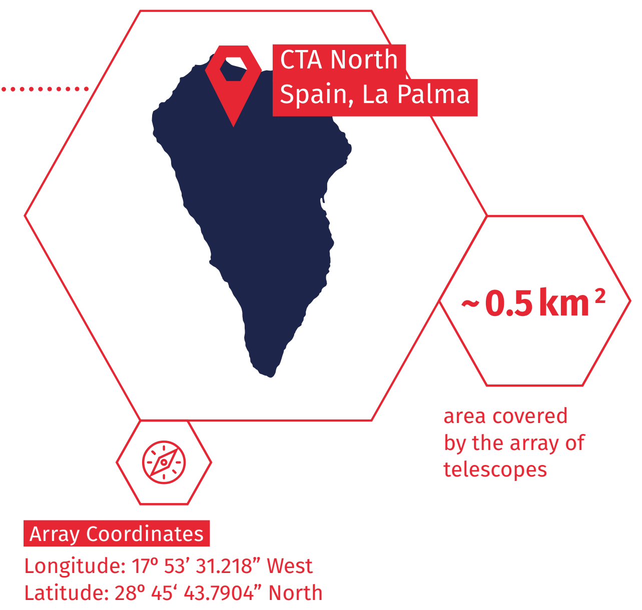
The southern hemisphere site is less than 10 km southeast of the European Southern Observatory's (ESO's) existing Paranal Observatory in the Atacama Desert in Chile, which is considered one of the driest and most isolated regions on earth – a dark paradise for stargazers. The southern hemisphere array will span the entire energy range of CTA, covering gamma-ray energies from 20 GeV to more than 300 TeV with 99 telescopes spread over 4 square kilometres.

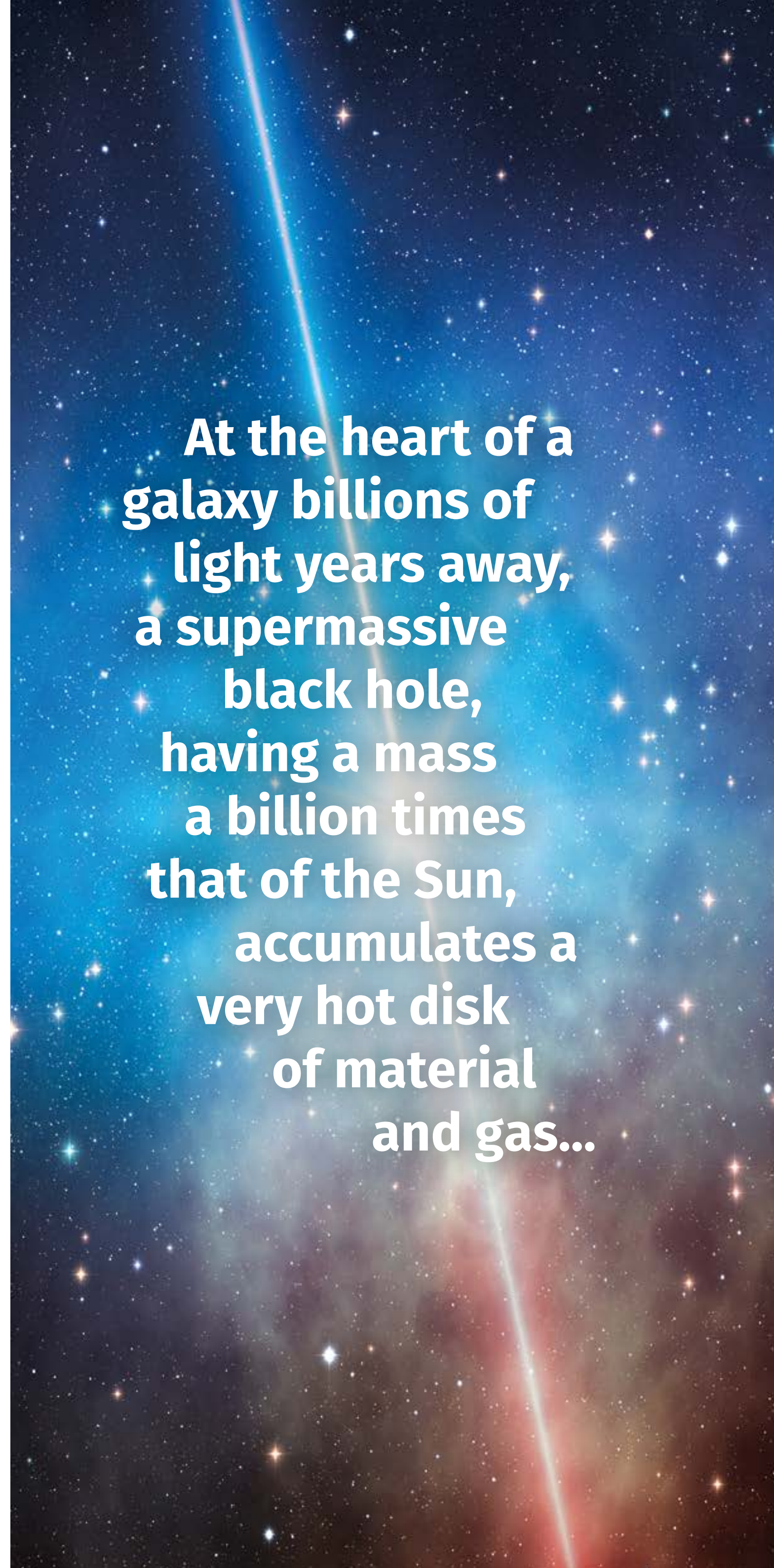
## The Array Locations








from emission to discovery
cherenkov telescope array
Emission
Supermassive Black Hole
Accretion Disc
Shock
Particle Acceleration
X-Rays
Radio Waves
1 Billion Years Later
High-Energy Gamma Ray
Air Shower
Earth's Atmosphere
Primary γ
Gamma Ray Interacts with the Atmosphere
Cherenkov Effect
CTA North
CTA South
La Palma
(LST, MST)
Chile
(LST, MST, SST)
Detection
Medium-Sized Telescope (MST)
Small-Sized Telescope (SST)
Camera
Mirror
Large-Sized Telescope (LST)
Data
Data Processing, Archiving and Access
10 nanosecond snapshot
Light Bounces off Mirror and Captured by Camera
On-Site Storage
Real-Time Analysis
Processing
Alert
Alert
Off-Site Archive
Observation Scheduling + Telescope Control
Other Observations
Scientists / Users
Discovery
Time [min]
Shower Reconstruction
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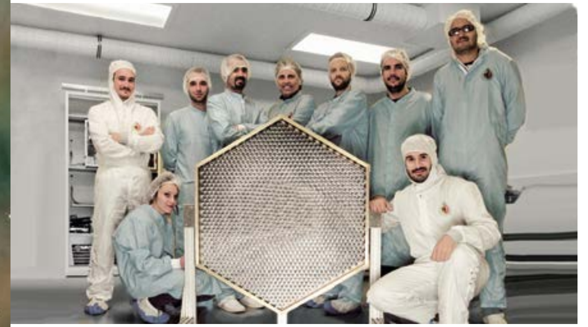
cherenkov telescope array

# Unprecedented Powerful Accessible



## CTA technologies in development around the world...



# Building the Next Generation High-Energy Discovery Machine



The current generation of ground-based detectors have cracked the door open to the high-energy Universe, giving us a glimpse of what there is to see.

But with CTA, the hope is that the door will be pushed wide open to reveal an entirely new view of the Universe. This will be no small feat; scientists and engineers around the world have been working for more than a decade to plan CTA and build the next-generation discovery machine. How will they do it? Simply put, by pooling their knowledge and resources to build the most advanced Cherenkov telescopes ever constructed and by building more of them than ever before.

The project to build CTA is well on its way to construction: as of early 2017, working prototypes exist for all but the largest telescope design and site infrastructure work is underway in preparation for the first pre-production telescopes on site.

Three classes of telescope are required to cover the full CTA energy range (20 GeV to 300 TeV). For its core energy range (100 GeV to 10 TeV), CTA is planning 40 Medium-Sized Telescopes distributed over both array sites. Eight Large-Sized Telescopes and 70 Small-Sized Telescopes are planned to extend the energy range below 100 GeV and above 10 TeV, respectively. The telescopes are arranged within the arrays based on their different energy domains. Low-energy gamma-ray events (best detected by larger mirrors) happen more frequently, requiring a small number of LSTs in close proximity, while the high-energy events (most economically detected by smaller mirrors) are extremely rare, requiring a large number of SSTs spread out over several kilometres. The MSTs' broad energy range cover the middle of CTA's energy range.

CTA's three classes of telescope will provide broad energy coverage from billions to trillions times the energy of visible light (20 GeV to 300 TeV).

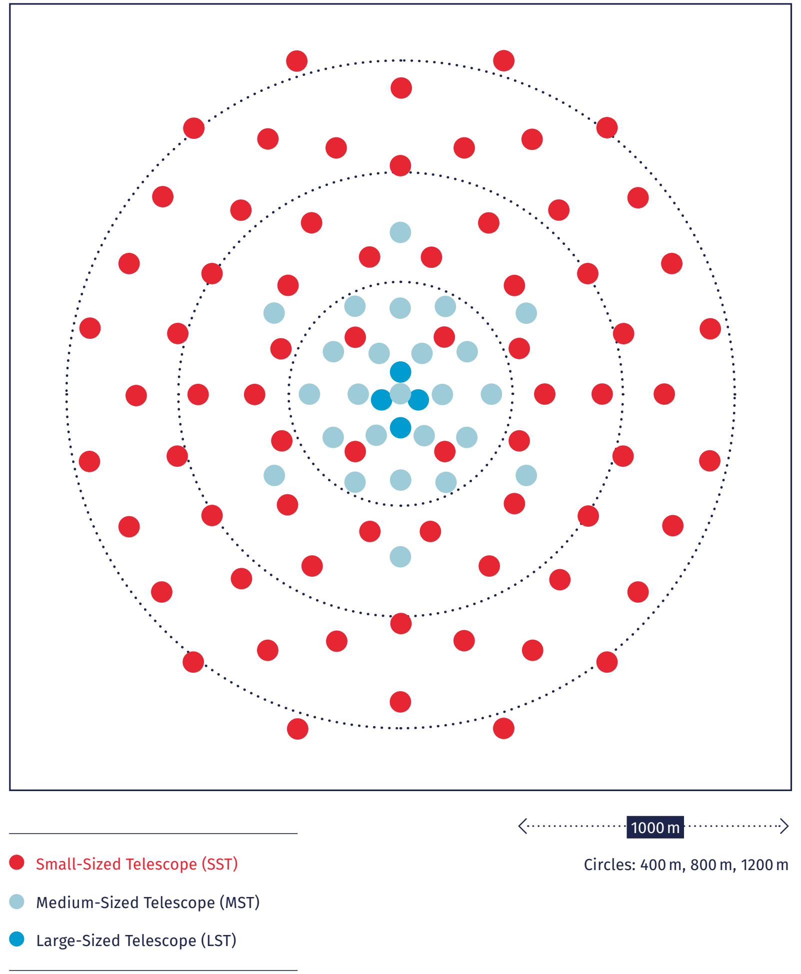
Learn more about the project

# Small-Sized Telescope

The Small-Sized Telescopes (SSTs) will outnumber all the other telescopes and will be spread out over several square kilometres in the southern hemisphere array.

CTA will use more than 7,000 highly-reflective mirror facets (90 cm to 2 m diameter) to focus light into the telescopes' cameras.

**Southern Hemisphere Array** 70 SSTs




This is because VHE gamma-ray showers produce a large amount of Cherenkov light, and the SSTs are sensitive to the highest energy gamma rays. SST mirrors will be about 4 m in diameter and will have a wide field of view of 9 degrees. Three different SST implementations are being prototyped and tested – one single-mirror design and two dual-mirror designs.

The SST-1M is a single-mirror design with a 4 m diameter (focal length of 5.6 m) reflector that uses hexagonal mirror facets. The SST-1M project teams are in Czech Republic, Ireland, Poland and Switzerland. A prototype of the telescope is being tested in Krakow, Poland.

The SST-2M ASTRI design is a dual-mirror Schwarzschild-Couder configuration. The 4.3 m diameter primary mirror is segmented into hexagonal facets and the 1.8 m secondary mirror is monolithic. Teams in Italy, Brazil and South Africa are contributing to ASTRI. In 2016, the ASTRI prototype in Serra La Nave, Italy, demonstrated the viability of the Schwarzschild-Couder design for the first time since its initial conception in 1905 and detected its first Cherenkov light in 2017.

SST-2M GCT is also a dual-mirror design. The optics are very similar to those of the SST-2M ASTRI, but the GCT emphasizes a low-mass design. The 4 m diameter primary and the 2 m secondary mirrors are each divided into six petal-shaped segments, and a fold-up shelter will protect the telescope when it is not observing. The GCT is being built by teams in Australia, France, Germany, Japan, the Netherlands and the United Kingdom. While undergoing testing in Meudon, France in 2015, the GCT prototype was the first CTA prototype to detect Cherenkov light.

## SST Main Parameters

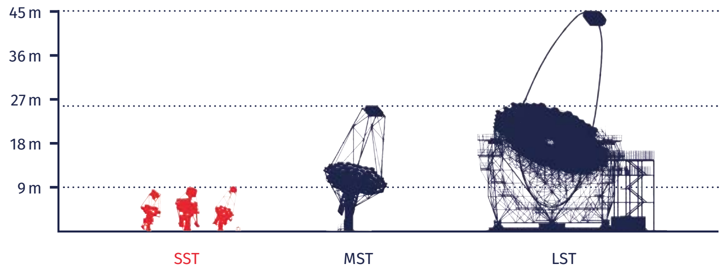
| Energy Range | 1-300 TeV | | |
|---|---|---|---|

| Mechanical and Optical Parameters | ASTRI | GCT | SST-1M |
|---|---|---|---|
| Dish Shape | 2-Mirror Schwarzschild-Couder | 2-Mirror Schwarzschild-Couder | Davies Cotton |
| Dish Diameter | 4.3 m | 4 m | 4 m |
| Focal Length | 2.15 m | 2.28 m | 5.60 m |
| Total Weight | 19 tons | 7.8 tons | 8.6 tons |

| Camera Parameters | | | |
|---|---|---|---|
| Type of Sensors | Silicon Photomultipliers | Silicon Photomultipliers | Silicon Photomultipliers |
| Number of Pixels | 2368 | 2048 | 1296 |
| Field of View | 10° | 9.2° | 9° |

(Numbers are estimations.)

## Proportions






# Medium-Sized Telescope

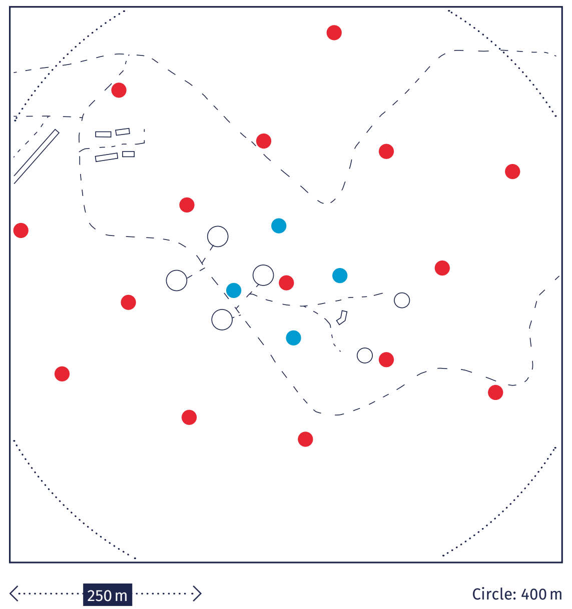
At the centre of both arrays (25 in the southern hemisphere and 15 in the northern hemisphere) and scattered just beyond the LSTs, CTA's "workhorses", the Medium-Sized Telescopes (MSTs), will be tasked to cover the middle of CTA's energy range.

MST mirrors will be 12 m in diameter and will have two different camera designs. Their wide field of view of 8 degrees will enable the MSTs to take rapid surveys of the gamma-ray sky.

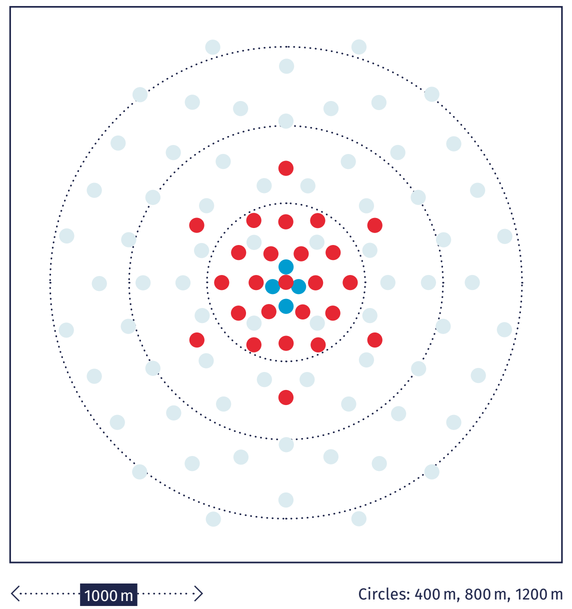
The MSTs are being designed and built by an international collaboration of institutes and universities from Austria, Germany, France, Brazil, Poland, Spain, Switzerland and Italy. An MST prototype was deployed in Berlin in 2012 and is currently undergoing performance testing.

A dual-mirrored version of the MST, the Schwarzschild-Couder Telescope (SCT), is proposed as an alternative type of medium telescope. The SCT's two-mirror optical system is designed to better focus the light for greater imaging detail and improved detection of faint sources. In collaboration with the SST-2M and MST groups and institutes in Germany, Italy, Japan and Mexico, institutes in the United States have been the pioneers of the SCT design since 2006. A prototype of the SCT is under construction at the Whipple Observatory in Arizona.

**Northern Hemisphere Array** 15 MSTs




**Southern Hemisphere Array** 25 MSTs



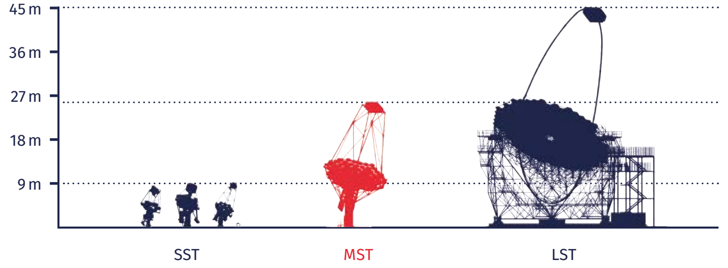

- Small-Sized Telescope (SST)
- Medium-Sized Telescope (MST)
- Large-Sized Telescope (LST)

### MST Main Parameters

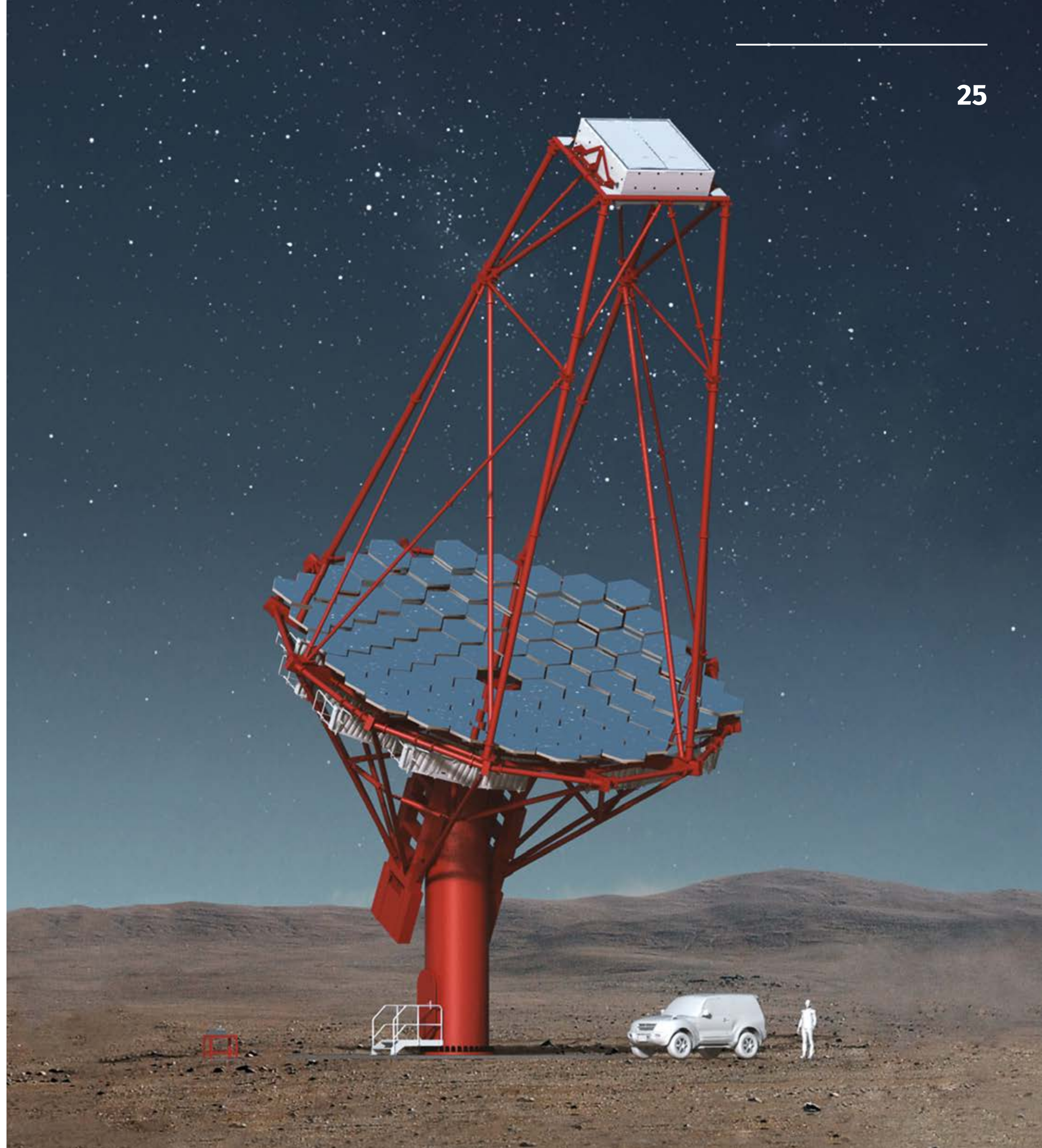
| | | |
|---|---|---|
| Energy Range | 100 GeV - 10 TeV | |
| **Mechanical and Optical Parameters** | | |
| Dish Shape | Modified Davies Cotton | |
| Dish Diameter | 12 m | |
| Focal Length | 16 m | |
| Total Weight | 82 tons | |
| **Camera Parameters** | **FlashCAM** | **NectarCAM** |
| Type of Sensors | Photomultiplier Tubes | Photomultiplier Tubes |
| Number of Pixels | 1758 | 1855 |
| Field of View | 7.7° | 8° |

(Numbers are estimations.)

### Proportions





# Large-Sized Telescope

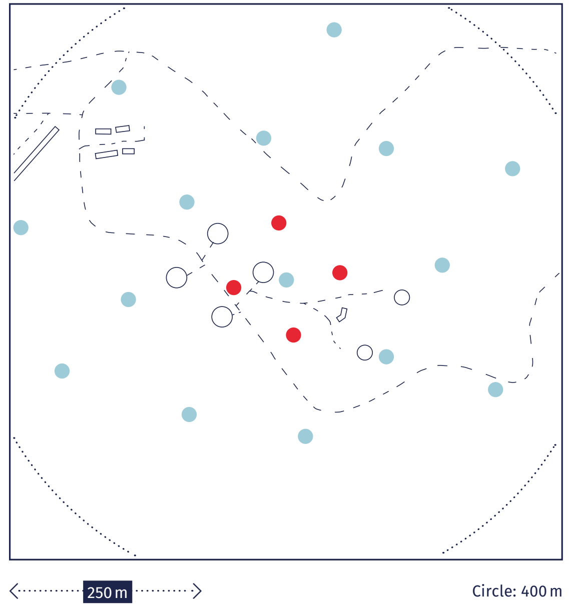
At the centre of both the northern and southern hemisphere arrays, a cluster of four Large-Sized Telescopes (LSTs) looms.

Standing tall at 45 m and weighing in at about 100 tonnes, the LSTs are CTA's biggest telescopes. Why so big? Because gamma rays with low energies produce small showers with a low amount of Cherenkov light, telescopes with large mirrors are required to capture them.

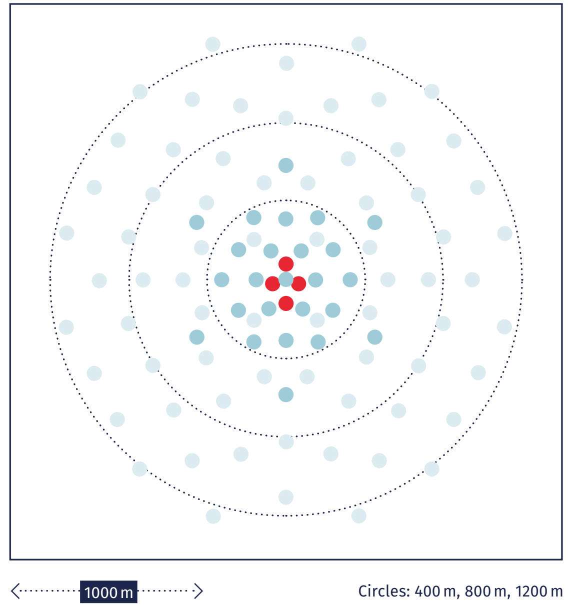
LST mirrors will be 23 m in diameter and parabolic in shape, and the cameras will have a field of view of 4.5 degrees. But looks can be deceiving – these massive telescopes also must be very nimble to capture brief, low-energy gamma-ray signals. The plan is for the LSTs to be able to re-position to a new target in the sky within 20 seconds.

More than 100 scientists and engineers from Brazil, Croatia, France, Germany, India, Italy, Japan, Spain and Sweden are working together to design and build the LSTs. An LST prototype is being constructed on CTA's site on the island of La Palma and is scheduled to be completed in 2018.

### Northern Hemisphere Array 4 LSTs




### Southern Hemisphere Array 4 LSTs



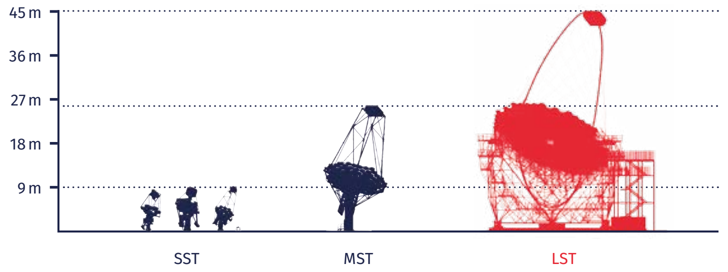

- Small-Sized Telescope (SST)
- Medium-Sized Telescope (MST)
- Large-Sized Telescope (LST)

## LST Main Parameters

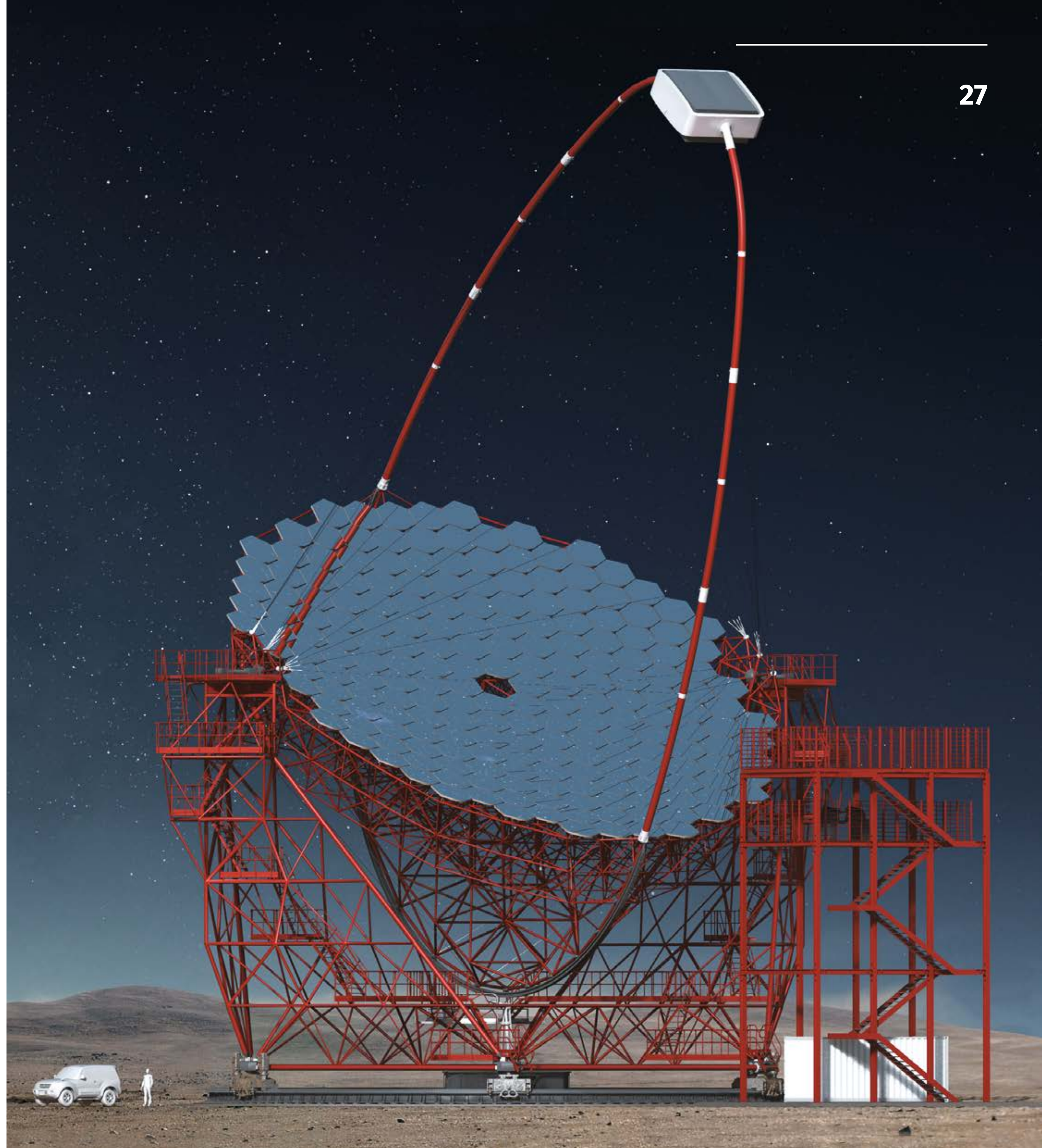
| | |
|---|---|
| Energy Range | 20 - 200 GeV |
| **Mechanical and Optical Parameters** | |
| Dish Shape | Parabolic |
| Dish Diameter | 23 m |
| Focal Length | 28 m |
| Total Weight | 103 tons |
| **Camera Parameters** | |
| Type of Sensors | Photomultiplier Tubes |
| Number of Pixels | 1855 |
| Field of View | 4.5 ° |

(Numbers are estimations.)

## Proportions





# Measuring the Light with CTA Cameras

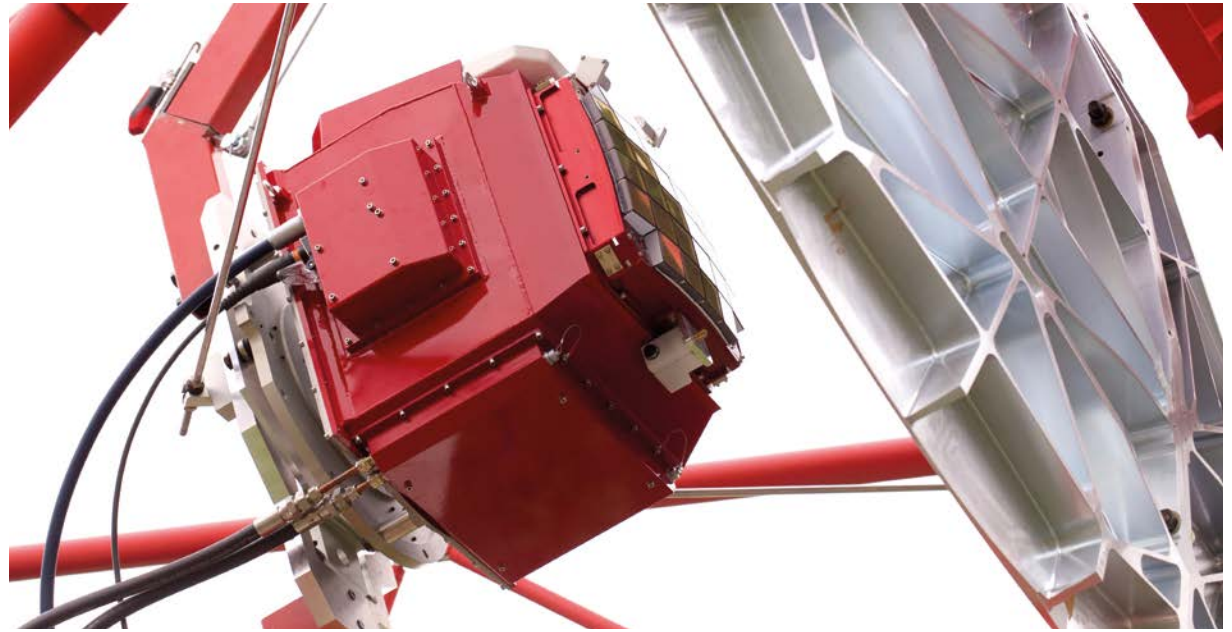
When a gamma-ray initiates an air shower, the resulting faint blue-ultraviolet Cherenkov light will last only a few billionths of a second.

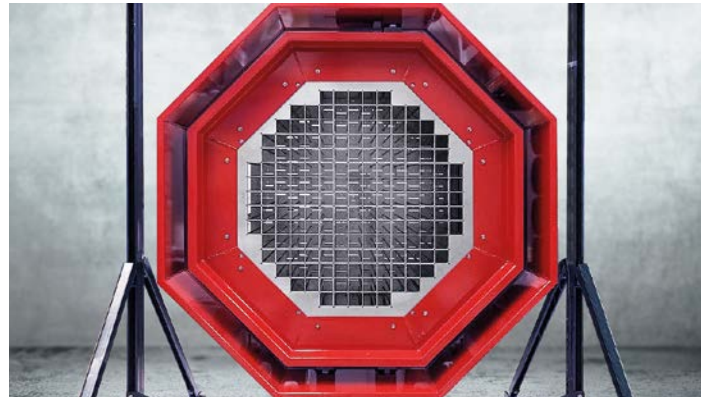
CTA's cameras will use both photomultiplier tubes (PMTs) and silicon photo multipliers (SiPMs) for a total of more than 200,000 ultra-fast light-sensitive pixels.

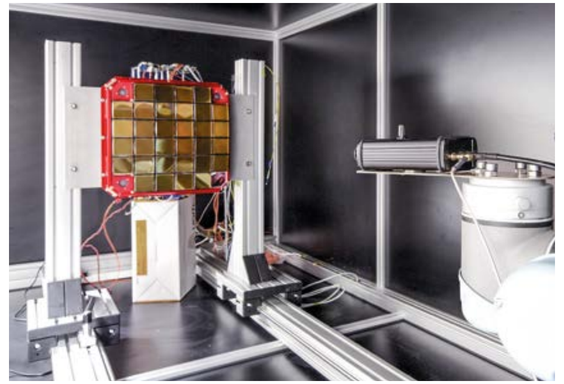
The mirrors of CTA's telescopes will be tasked with capturing the flash, but measuring the light will be the role of the cameras. While the camera designs are slightly different for each telescope type, they all are driven by the faint light yield and short duration of the Cherenkov light flash.

To detect the short flashes of light produced by cosmic rays and gamma rays as they hit the earth's atmosphere, the telescopes' cameras must be about a million times faster than a digital camera. To do this, they will use high-speed digitisation and triggering technology capable of recording shower images at a rate of one billion frames per second and sensitive enough to resolve single photons.

Depending on the camera, photomultiplier tubes (PMTs) or silicon photomultipliers (SiPMs) will convert the light into an electrical signal that is then digitised and transmitted to record the image of the cascade. SiPMs can operate during high levels of moonlight, improving CTA's efficiency in collecting Cherenkov light during moonlight conditions. Both sensors will be more efficient and advanced than what is used in current generation instruments.









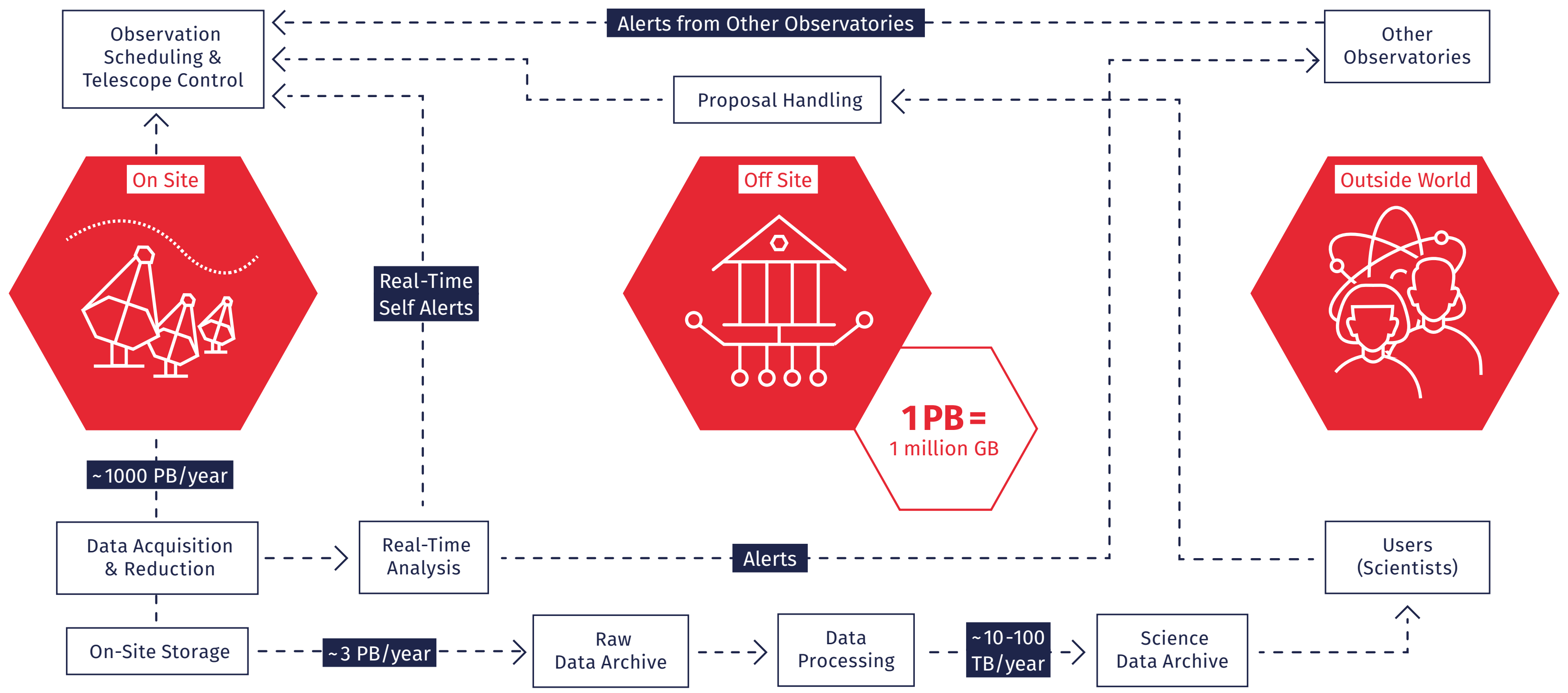
# From Data to Discovery

Once the telescopes record the Cherenkov images of a cascade, any undesirable "noise" in the image will be suppressed to reduce its size before it is analysed in real time.

If any of the real-time analysis reveals an unexpected gamma-ray signal, alerts will be generated to adapt the CTA observing schedule and to notify other observatories. This instant alert system will help to ensure CTA and its partners do not miss significant cosmic events. Processed images will then be transmitted to central computing facilities for further processing and to be archived.

The calibrated image data will be used to reconstruct the properties of individual gamma rays. The energy and arrival direction of the gamma rays will be provided to science users of the Observatory and used to make spectra, lightcurves and images of astro-physical objects. The CTA Science Data Management Centre (SDMC), to be located on the DESY campus in Zeuthen, Germany, will coordinate the processing and long-term preservation of the data, in addition to providing the data, tools and support to the scientific users of the facility.

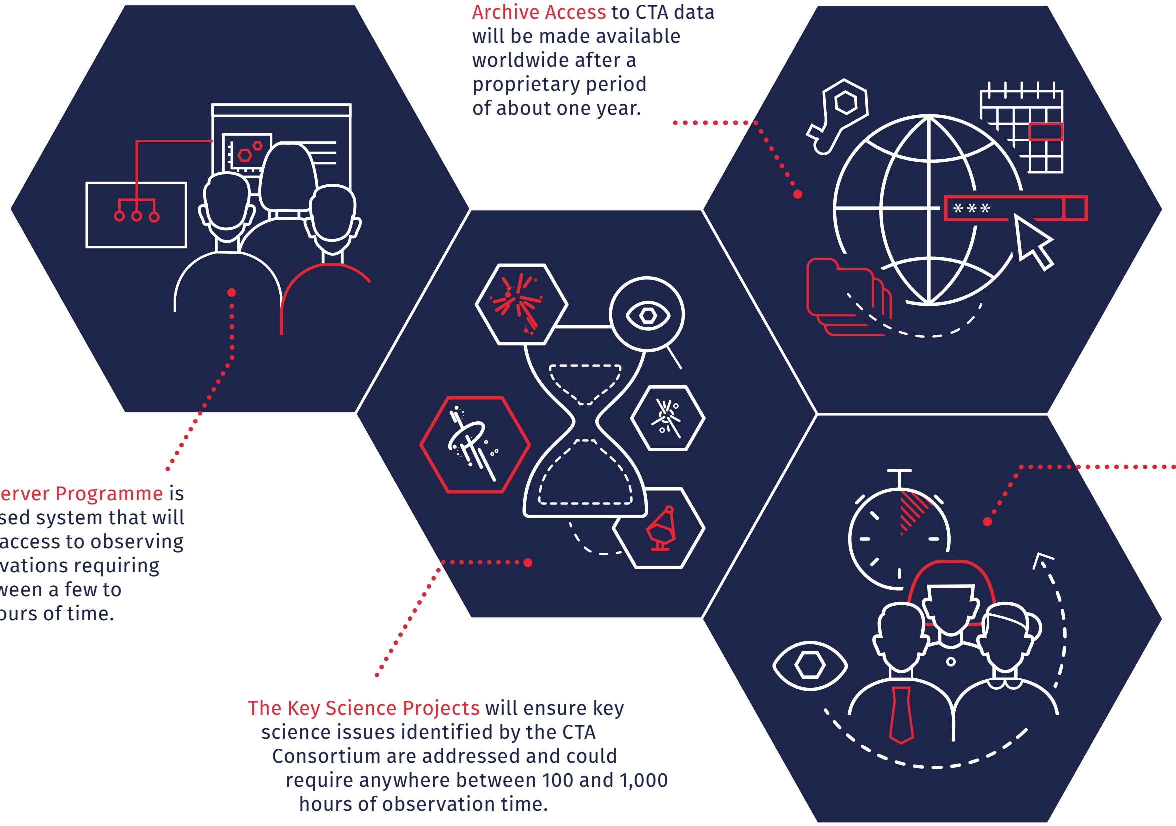
CTA is a BIG DATA project. The Observatory is expected to generate approximately 100 petabytes (PB) of data by 2030.



# Observatory Operations

CTA will be the first ground-based gamma-ray observatory open to the world-wide astronomical and particle physics communities as a facility devoted to high-energy astronomy.

The CTA Headquarters, located on the INAF campus in Bologna, Italy, will be the central office responsible for the overall administration of Observatory operations. Observations will be carried out by operators, and then the data will be calibrated, reduced and, together with analysis tools, made available to the principal investigator in common astrophysics data formats. After a proprietary period of time, data will be made openly available through the CTA data archive. CTA observation time and data products will be provided to users through several different modes:



Archive Access to CTA data will be made available worldwide after a proprietary period of about one year.

The Director's Discretionary Time will represent a small fraction of observation time that will be used for, e.g., unanticipated targets of opportunities or outstanding proposals from non-member countries.

The Guest Observer Programme is a proposal-based system that will provide users access to observing time for observations requiring anywhere between a few to hundreds of hours of time.

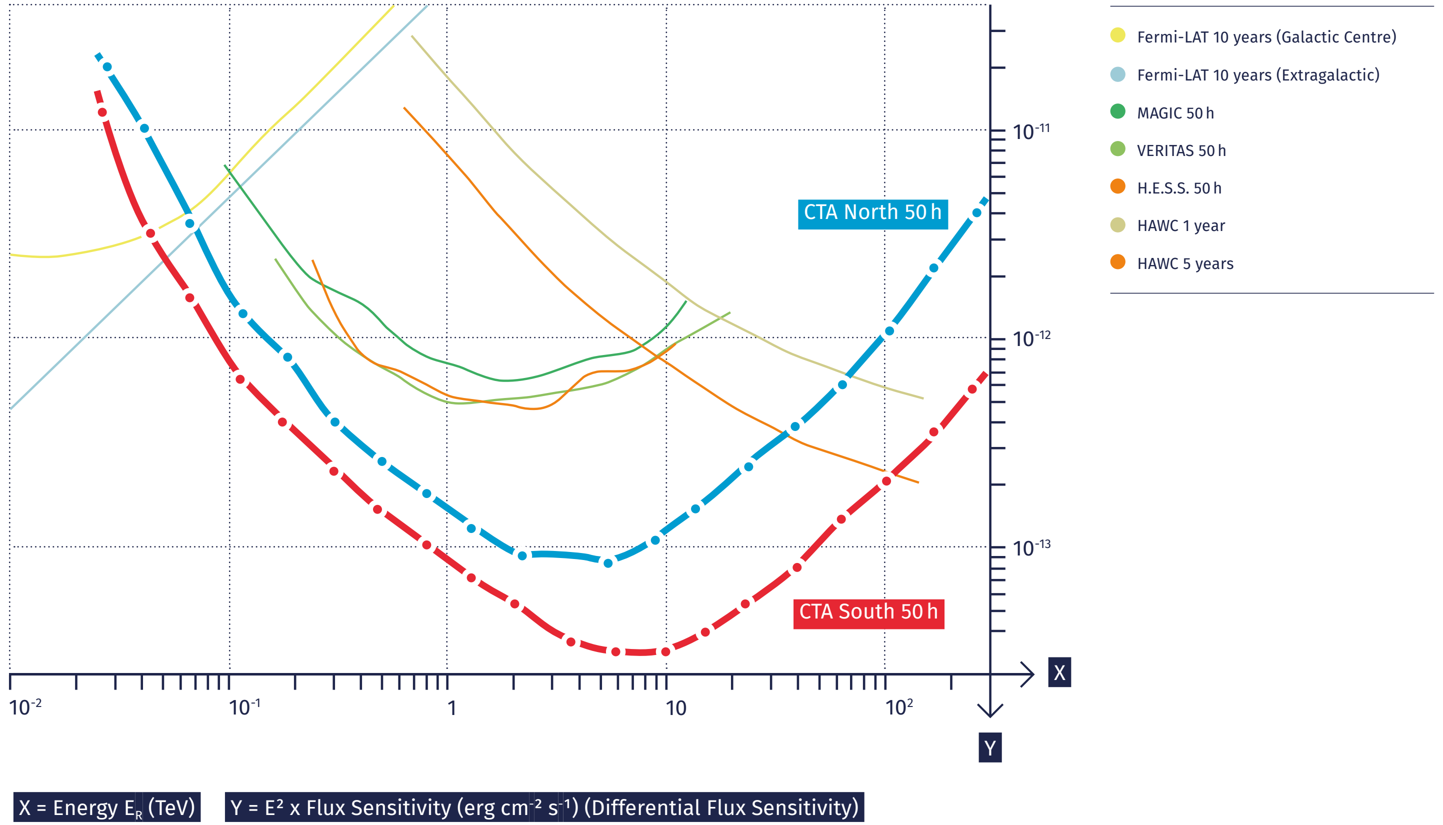
The Key Science Projects will ensure key science issues identified by the CTA Consortium are addressed and could require anywhere between 100 and 1,000 hours of observation time.



# Performance Expectations

With a sensitivity as low as 20 GeV and as high as 300 TeV, pushing CTA beyond the edge of the known electromagnetic spectrum, CTA is expected to provide a completely new view of the sky.

To calculate CTA's baseline performance, computer models are used to simulate the sequence of events from the development of the particle cascade in the atmosphere and the propagation of Cherenkov light to the capture and focus of the light by the telescopes' mirrors and the electronic processing of the data. The result is performance expectations that include a tenfold improvement in sensitivity over current instruments, making CTA the most sensitive instrument at energies beyond the X-ray regime.




The figure left compares the estimated performance of CTA with a selection of existing gamma-ray instruments. The flux level shows how CTA's arrays in the northern hemisphere (CTA North) and and southern hemisphere (CTA South) will be able to make significant measurements in each independent energy bin (five per decade) in 50 hours of observations.

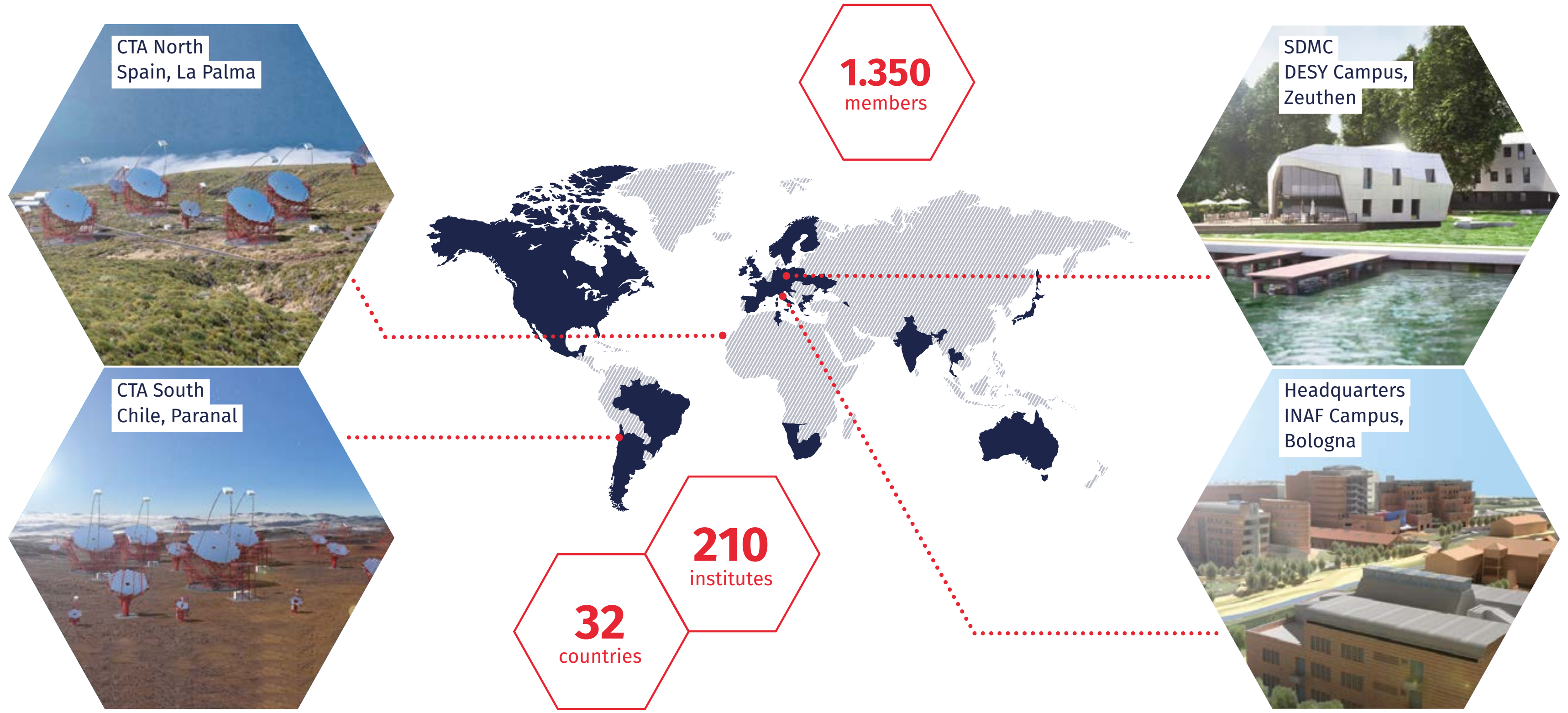
Learn more about CTA's performance expectations

## A Global Collaboration

From its base in Europe to the Americas, Asia, Africa and Australia, the CTA collaboration spans the globe.

The CTA Consortium, established in 2008, includes 1.350 members from 210 institutes in 32 countries and continues to grow as the excitement for CTA's prospective discoveries builds. The group of scientists and engineers are engaged in the scientific and technical development of CTA.

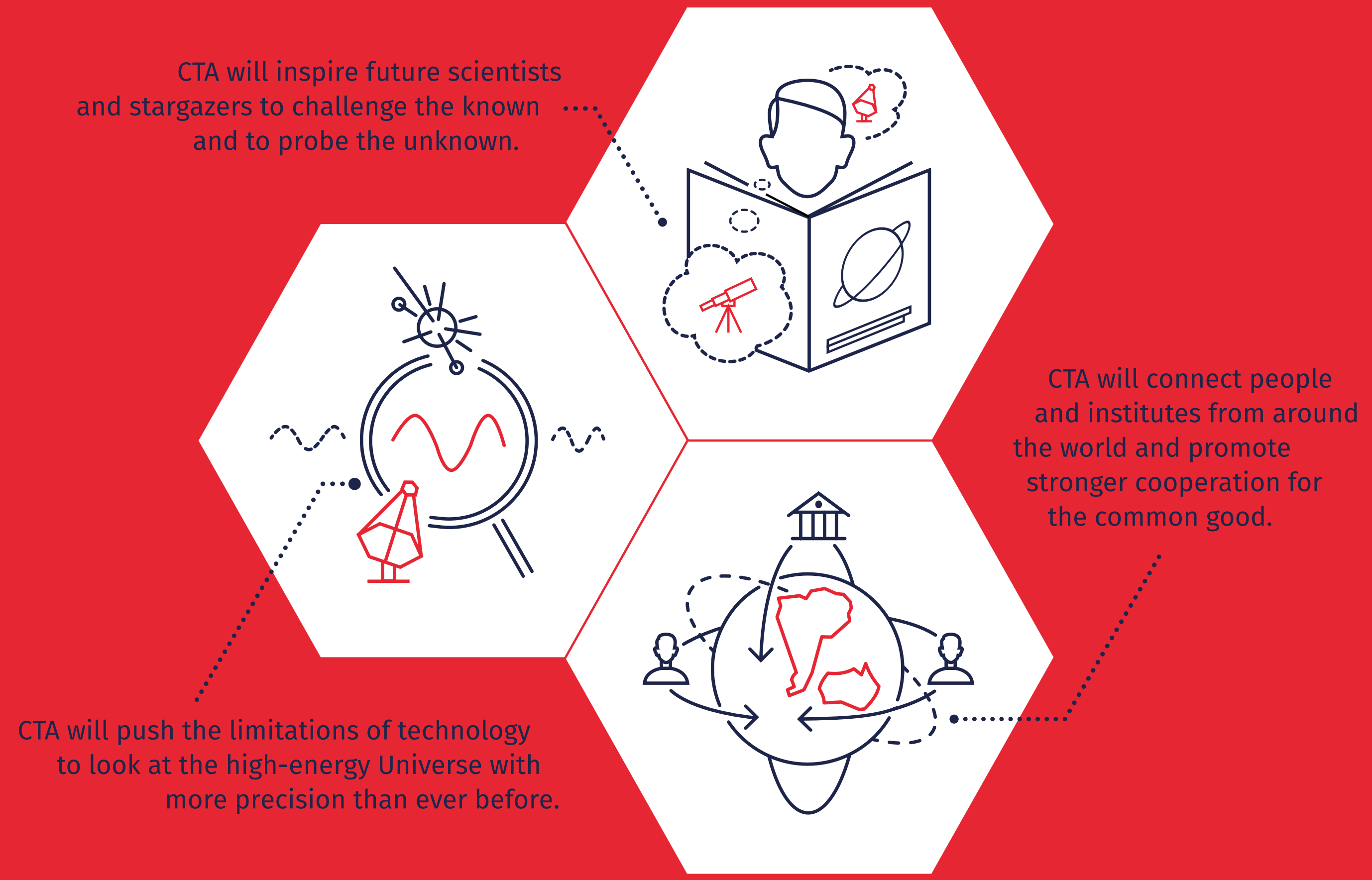
The CTAO gGmbH, and its Project Office, manages the construction project and implementation of CTA and is governed by a council of shareholders and associate members from 11 countries (as of May 2017).






## For the Benefit of All

CTA will venture beyond the high-energy frontier, seeking to expand our knowledge of the Universe for the benefit of all. But CTA is more than a tool for science – its value goes far beyond its potential for discovery.



## Built on International Support

CTA's ongoing success would not be possible without worldwide financial support from a mounting number of agencies and organizations. CTA receives array components as in-kind contributions from the CTA Consortium members funded by the shareholders and associate members of the CTAO gGmbH.
In addition, the project and this work have been financed by:

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The European Union's Horizon 2020 research and innovation programs under agreement No 676134.

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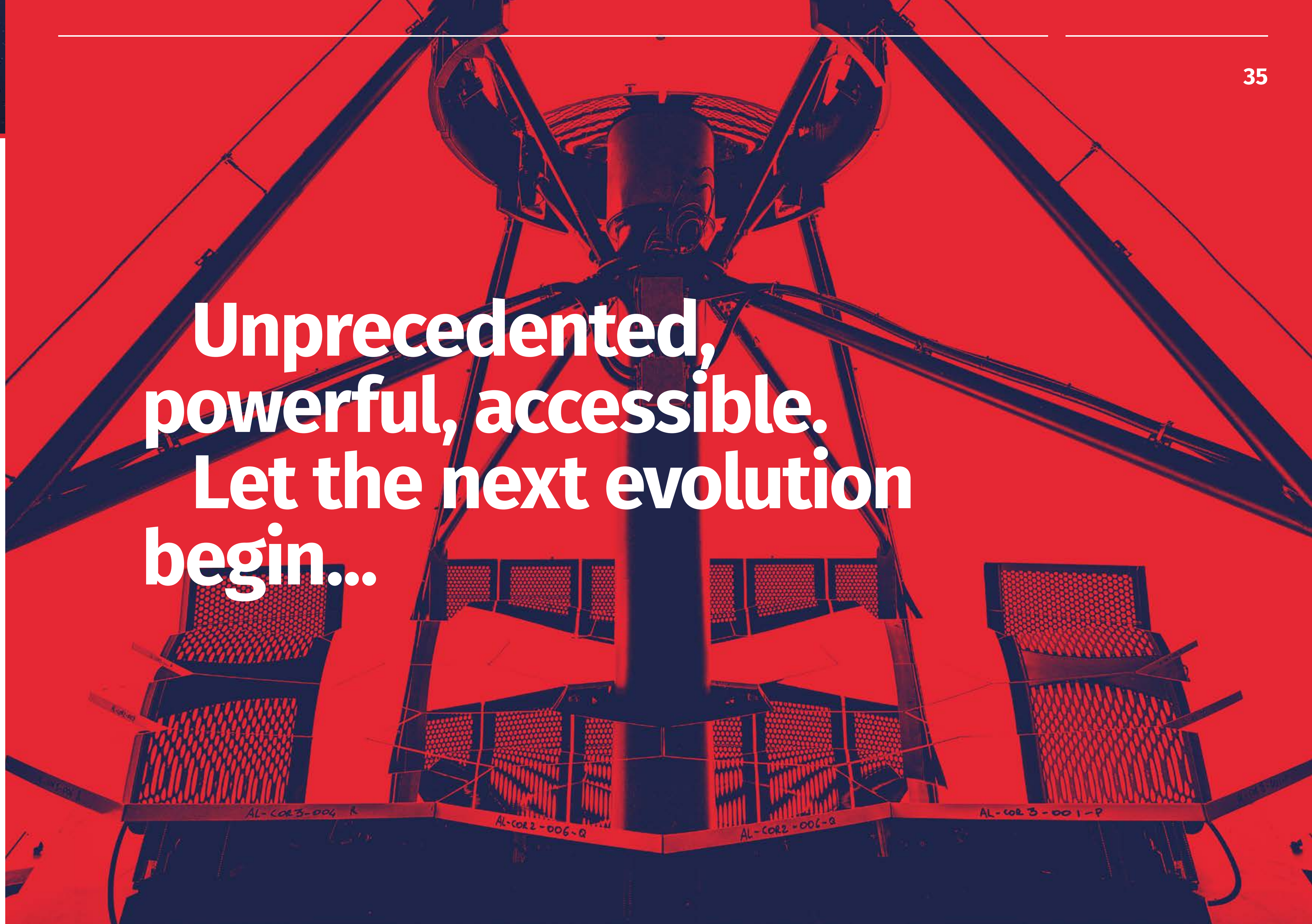
Learn more about the CTA Funding Agencies and Organisations
www.cta-observatory.org/about/funding-sources





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cherenkov telescope array

an observatory for ground-based gamma-ray astronomy