The Very Energetic Radiation Imaging Telescope Array System

J. Kildea
Harvard-Smithsonian Center for Astrophysics

Summary

VERITAS (The Very Energetic Radiation Imaging Telescope Array System) is an **array of Imaging Atmospheric Cherenkov telescopes** that is used to measure the sky in very-high-energy gamma-rays.

VERITAS consists of **four 12-m diameter telescopes** at the basecamp of the Whipple Observatory in Arizona. Operating on clear moonless nights, **the four telescopes simultaneously image** brief flashes of blue light in the sky that are produced by the absorption of gamma-rays in the Earth's upper atmosphere. VERITAS scientists use these images to map the sky in very-high-energy gamma-rays.

The Purpose of VERITAS

VERITAS is designed to measure very-high-energy gamma-rays from extreme objects and processes in the Universe, such as Active Galaxies, Microquasars, Pulsar Wind Nebula, Supernova Remnants and Dark Matter.

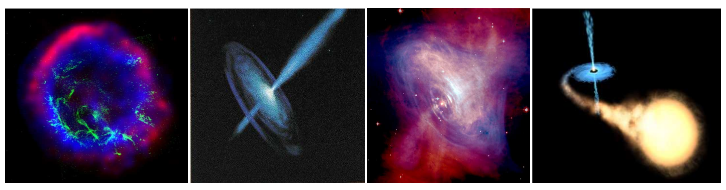

Figure 1: Images of extreme objects. From left to right: a Supernova Remnant, artist's impression of an Active Galaxy, a Pulsar Wind Nebula, and an artist's impression of a Microquasar.

The Imaging Atmospheric Cherenkov Technique

VERITAS **indirectly** detects cosmic gamma-rays using a technique known as the **Imaging Atmospheric Cherenkov Technique**.

Gamma-rays can only be measured indirectly from the Earth's surface since the atmosphere absorbs (and protects us from) them. When a gamma-ray is absorbed in the upper atmosphere a cascade of particles, known as an **air-shower**, is produced that falls towards the Earth's surface. The air-shower, in turn, produces a brief flash of blue light, known as **Cherenkov light**, that is detectable from the ground. It is this Cherenkov light that is measured using the Imaging Atmospheric Cherenkov Technique.

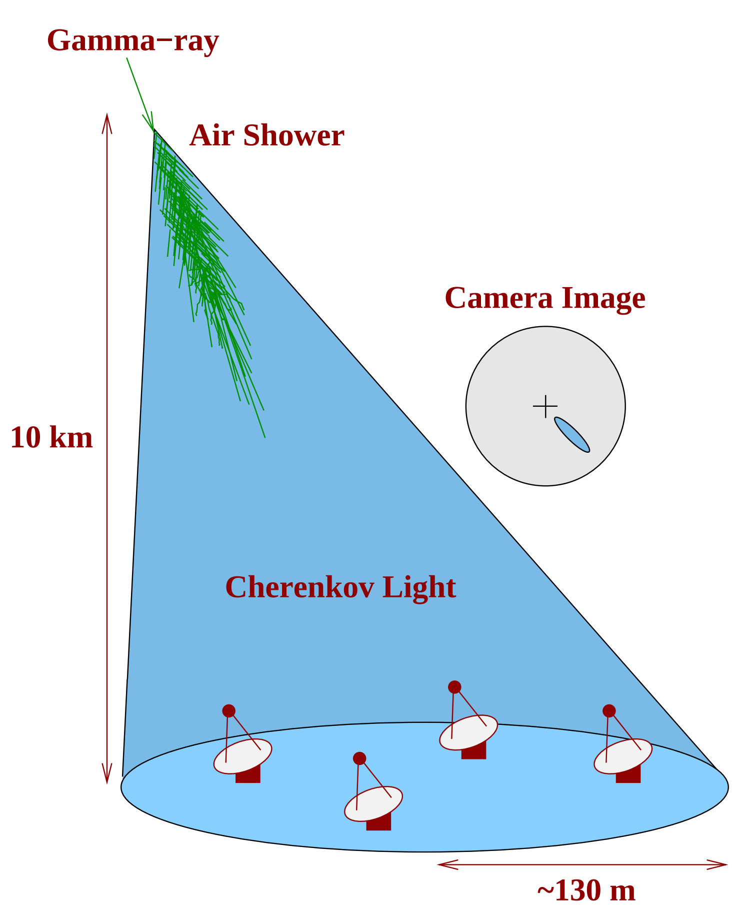

Figure 2: The Imaging Atmospheric Cherenkov Technique. When a gamma-ray is absorbed by the Earth's atmosphere it produces a shower of particles known as an "air-shower". The air-shower is detectable from the ground because of the blue Cherenkov light that it emits.

The technique essentially involves taking an extremely-short-exposure (a few billionths of a second) photograph of the flash of Cherenkov light that is emitted by the upper atmosphere after a gamma-ray is absorbed by it.

By examining the image of the Cherenkov flash, VERITAS scientists can "reconstruct" information on the gamma-ray that entered the upper atmosphere. Such information includes the **direction** from which the gamma-ray originated and the **energy** of the gamma-ray. This information, helps us to better understand the astrophysical objects that produce gamma-rays.

The Stereoscopic Imaging Technique

Stereoscopically imaging a gamma-ray air-shower, using two or more telescopes, significantly improves the effectiveness of the Imaging Atmospheric Cherenkov Technique. Several images of the same air-shower, at the same time, provide a better measurement of the direction and energy of the gamma-ray than is provided by a single telescope.

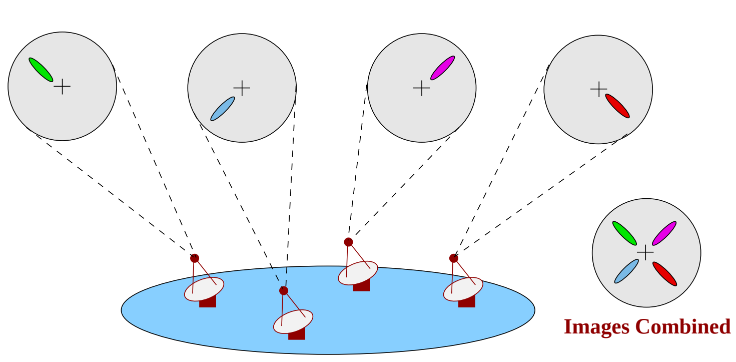

Figure 3: Stereoscopic imaging involves simultaneously observing the same air-shower with several telescopes. Combining the images from a number of telescopes provides more information regarding the gamma-ray that produced the air-shower. Each image points back to the direction from which the gamma-ray originated

The VERITAS Telescope Array

The VERITAS telescope array is located at the basecamp of the Whipple Observatory, near Mt. Hopkins in Southern Arizona.

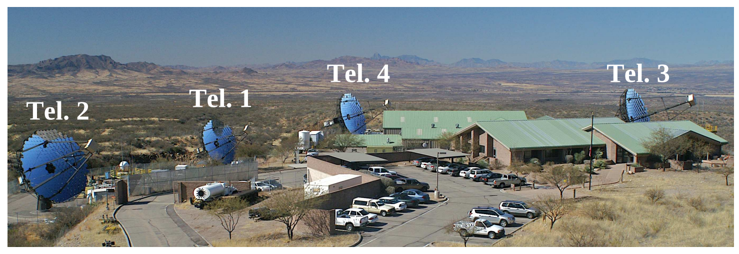

Figure 4: The VERITAS telescope array at the basecamp of the Whipple Observatory, Arizona. The four telescopes of the array are numbered in the order in which they were constructed.

The array comprises four identical telescopes with an average spacing between them of about 78 m. The telescopes are positioned so as to minimize inconvenience for day-to-day basecamp operations.

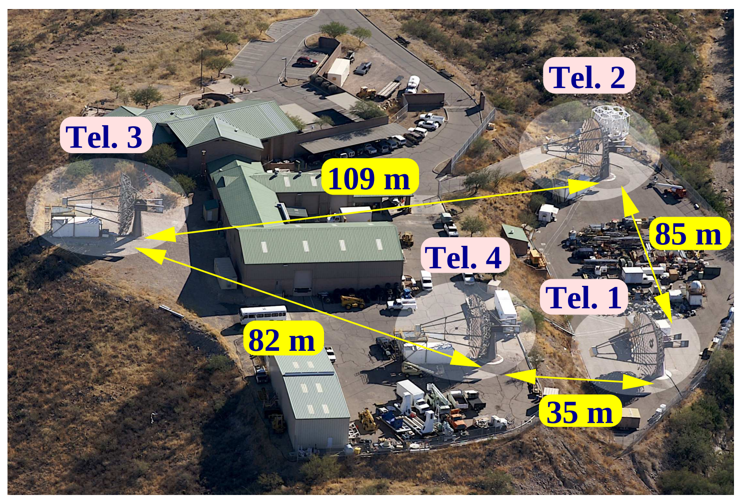

Figure 5: Bird's-eye view of the VERITAS telescopes at the basecamp of the Whipple Observatory. The distances between the telescopes are shown.

The VERITAS Telescopes

Each of the VERITAS telescopes are identical—12 m in diameter and composed of 345 aluminized, spherical, glass mirrors. The mirrors were manufactured by *Displays and Optical Technologies Inc.* in Texas and aluminized at the Whipple Observatory.

The reflecting dish of a VERITAS telescope is very large in order to maximize the amount of light that is reflected onto the camera. The larger the size of a telescope's primary mirror, the more light it can collect and hence the fainter the objects that it can see.

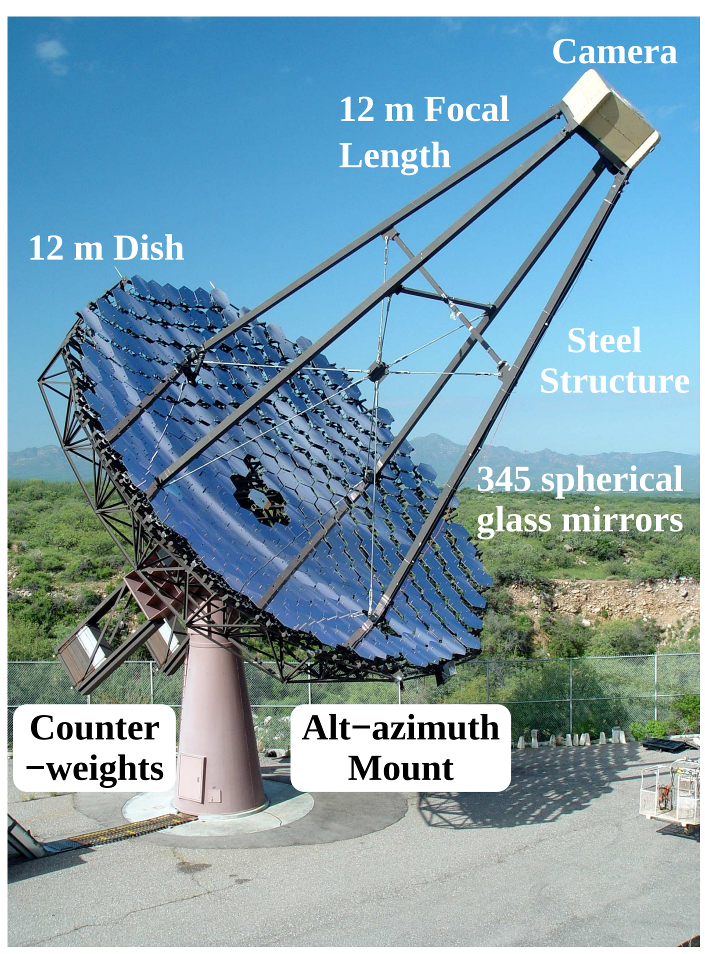

Figure 6: A VERITAS Telescope at the basecamp of the Whipple Observatory, Arizona.

The telescope structure is composed of tubular steel, with lead counter-weights at the back for balance. The steel structure was built by *Amber Steel* in Arizona. The mount is **alt-azimuth** and was manufactured by *RPM/PSI Inc.* in California.

Since the VERITAS telescopes are kept outdoors, they are exposed to the dust and dirt of the desert environment. To keep the mirrors clean they are washed once a month using high-pressure water. To maintain the reflectivity of the mirrors, they are monitored regularly and re-coated as necessary (typically, every 2 years or so).

VERITAS Observations

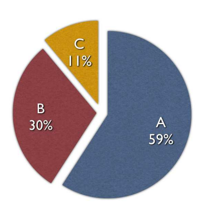

Figure 7: VERITAS weather during 2006/2007.

VERITAS observations are conducted on clear moonless nights. Approximately 800 hours of observations are recorded per year, amounting to about 5 TB of data. The VERITAS observers categorize the weather quality during observations as either A, B or C quality; for clear, mostly clear and partly cloudy weather, respectively. About 90% of VERITAS data is recorded in A or B weather.

The Davies-Cotton Telescope Design

The VERITAS telescopes conform to the **Davies-Cotton** design. This means that the spherical reflecting dish is composed of many smaller spherical mirrors, with the radius of curvature of each small mirror corresponding to twice the radius of curvature of the dish. When the small mirrors are correctly aligned, light that arrives parallel to the direction at which the telescope is pointing is focused onto the center of the camera, which are held securely at the center of the dish.

For the VERITAS telescopes the radius of curvature of the dish is 12 m. Each of the 345 mirrors that are mounted on the dish has a radius of curvature of 24 m.

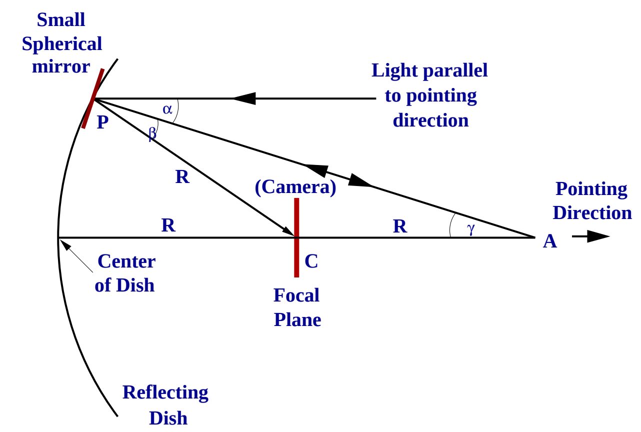

Figure 8: The Davies-Cotton telescope design. Side view of the telescope in the daytime position. The radius of curvature of the dish (R) is half the radius of curvature of the individual spherical mirrors mounted on it (2R). When correctly aligned, the triangle PAC is isosceles and light arriving parallel to the pointing direction is focused onto the center of the focal plane. The law of reflection is satisfied, since $\alpha = \beta$. Light that originates at point A is reflected back to that point. Alignment of the mirrors is carried out at point A by directing a laser at each mirror individually and adjusting the mirror's position until the laser beam returns to point A.

Each of the 345 mirrors that comprise a VERITAS telescope are mounted on the telescope structure at three points. The mirror positions are adjustable from the front for easy access. Alignment of the mirrors is undertaken several times a year. It involves directing a laser, mounted at the "Alignment Point" at each mirror individually. By adjusting a mirror until the reflected laser beam returns to the Alignment Point, the mirror may be brought into correct alignment.

The VERITAS Cameras and Electronics

The VERITAS cameras are housed in a secure steel box at the focal plane of each telescope. Each camera is identical and is composed of 499 pixels. In order to detect the very brief flash of Cherenkov light, sensitive light detectors called **photomultiplier tubes**, are used. Each pixel is made up of one photomultiplier tube.

Small light-reflectors, called **lightcones**, placed in front of the photomultiplier tubes, reflect light that would otherwise fall into the empty space between pixels, into the photomultiplier tubes. In this way the light that is imaged by the VERITAS cameras is maximized.

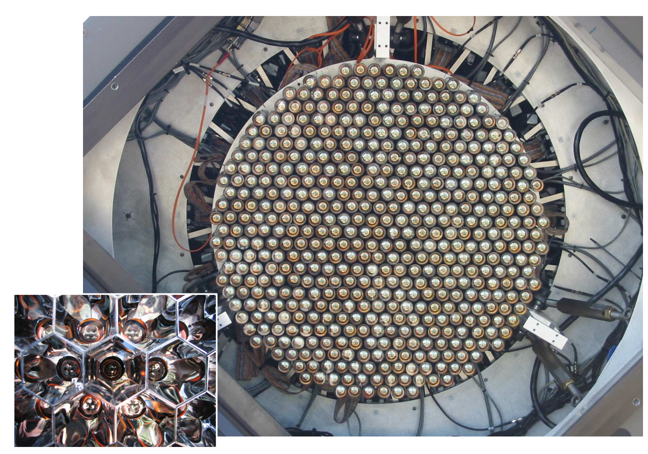

Figure 9: One of the VERITAS telescope cameras shown without lightcones. Inset: a close-up photo of several lightcones in front of their photomultiplier tubes.

Although the number of pixels in the VERITAS camera may seem small compared to a personal digital camera, it is more than adequate to obtain a crude (but very useful) image of the Cherenkov light from an air-shower. VERITAS scientists use the crude images of many hundreds of air-showers to build up accurate information about gamma-ray emitting astrophysical objects.

The electronics used to record the light registered by each camera pixel are housed in a trailer adjacent to each telescope. A central control trailer is used by VERITAS astronomers to control observing operations each night that data is taken.

VERITAS Data Analysis

Analysis of VERITAS data involves examining the air-shower images recorded by each telescope and combining them to obtain the direction-of-origin of each gamma-ray on the sky. VERITAS typically records 9,000 air-shower images per minute, the vast majority of which are not due to gamma-rays but rather background cosmic rays. After data analysis, approximately 20 true gamma-ray air-shower images per minute remain.

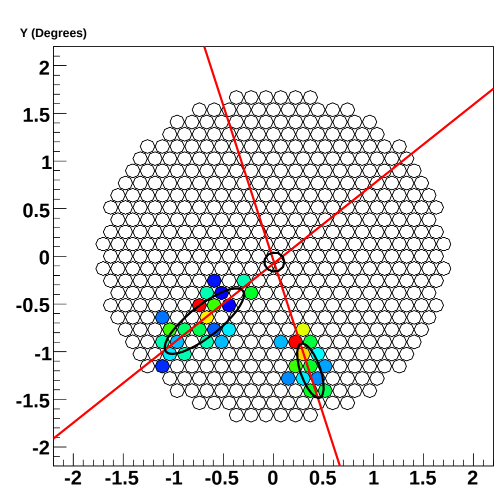

Figure 10: Reconstruction of the point-of-origin of a gamma-ray air-shower. The simultaneously-recorded images from two telescopes are combined. The intersection of their major axes represents the direction-of-origin of the gamma-ray on the sky.