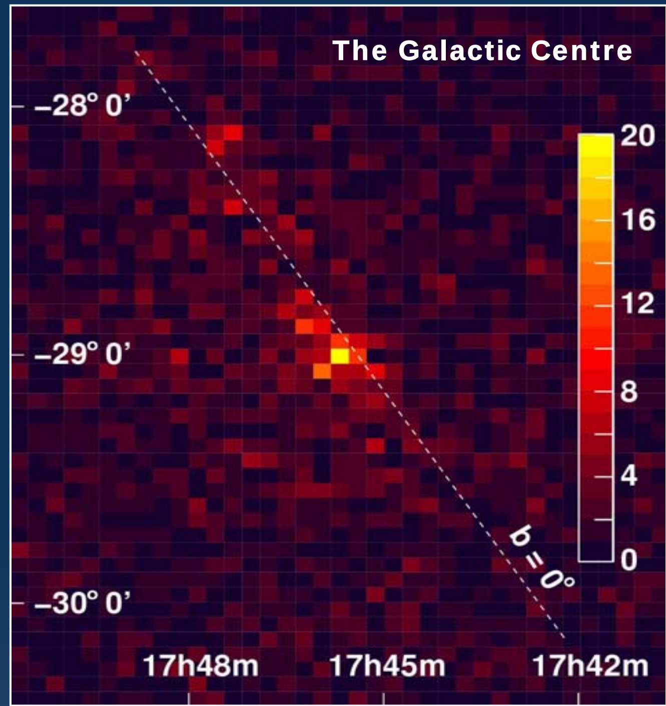
H.E.S.S. - High Energy Stereoscopic System

The New Window on the High-Energy Universe



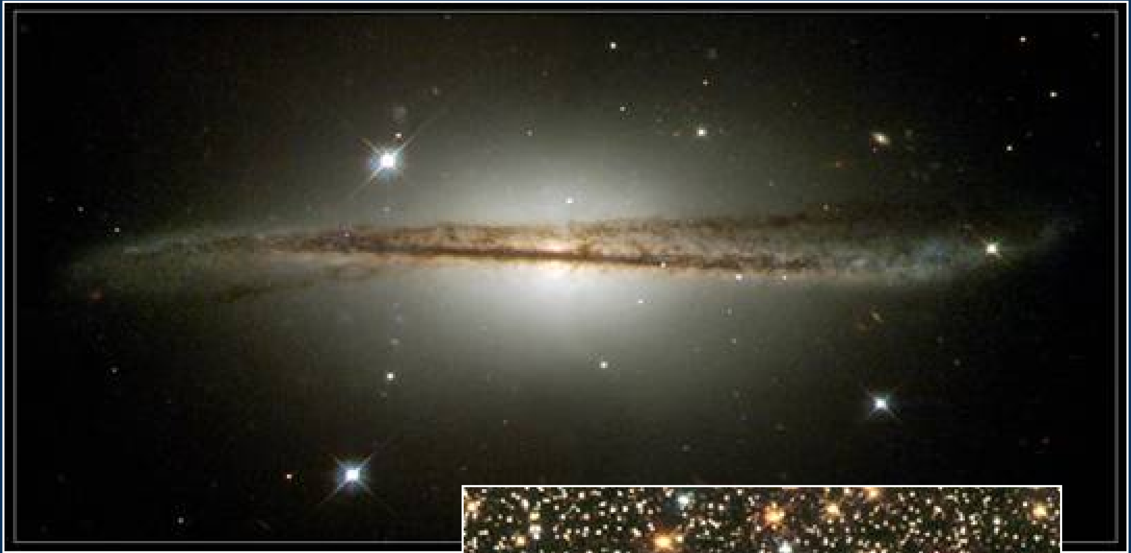
Inauguration of the High Energy Stereoscopic System
Windhoek/Goellschau, Namibia, September 28, 2004

H.E.S.S. - High Energy Stereoscopic System

Contents:

Imaging the Universe

Most of our knowledge about the universe comes from the observation of electromagnetic radiation from heavenly objects – starlight is the most obvious example of this radiation. Even with the naked eye, it is hard not to be overwhelmed by the view of the starry sky on a clear dark night. Images generated by modern large optical telescopes combine fascinating beauty with an enormous wealth of information for scientists.

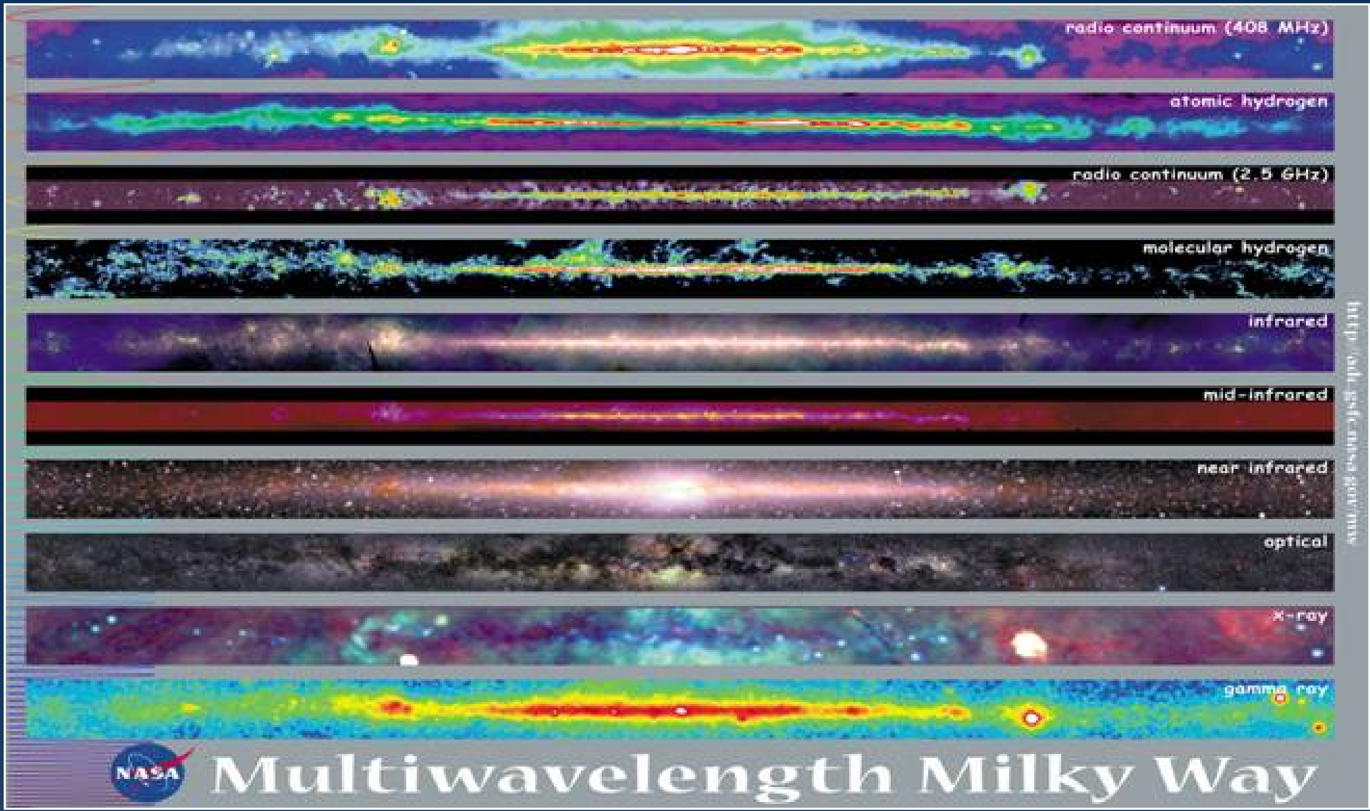


The warped spiral galaxy
ESO 510-13
(C. Conselice et al., Hubble Heritage Team, NASA)

The Sagittarius Star Cloud
(Hubble Heritage Team, AURA/STScU/NASA)

The Cone Nebula
(ACS Science and Engineering Team, NASA)

Exploring the Universe with H.E.S.S.



The ‘Multiwavelength Milky Way’ illustrates how different the Milky Way appears in different frequency bands. In visible light, the centre of our Galaxy is hidden by gas clouds. Both infrared radiation and gamma rays, on the other hand, penetrate these clouds and provide a view of the Galactic Centre. Infrared observations have revealed the existence of a large black hole at the core of the Galaxy, with a mass corresponding to a million solar masses. (NASA)

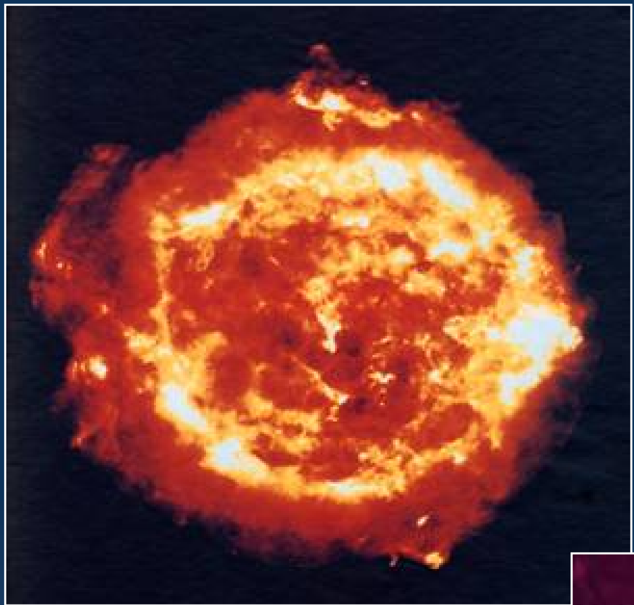
Different wavelength regimes

The visible starlight is only a tiny fraction of the spectrum of radiation incident upon the Earth. From red to blue, the spectrum of visible light covers one octave in frequency. The full spectrum, on the other hand, ranges over about 70 decades from below radio frequencies up to the gamma rays which the H.E.S.S. telescopes aim to study. Modern astrophysics explores all of this vast spectral range, trying to learn more about our stellar neighbourhood, about our own and distant galaxies, and about the Universe and its history.

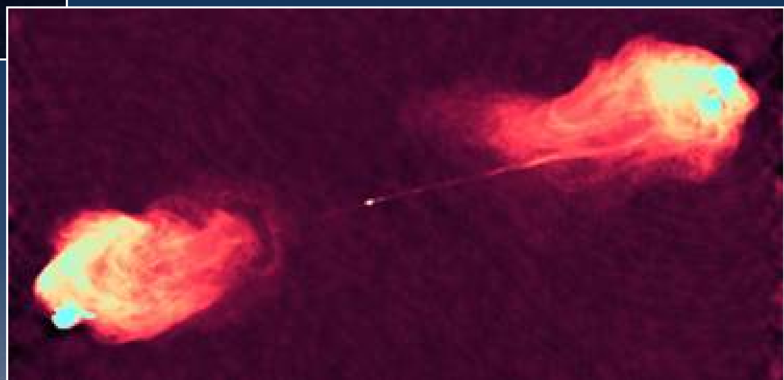
With the H.E.S.S. instrument, we aim to image the universe in the light of the highest-energy gamma rays, a regime about which very little is known.

Gamma Rays from the Cosmos

The Supernova Cassiopeia A exploded in 1680 A.D., sending a shock wave into space which by now has expanded to 15 light years. Particles crossing the shock wave can be accelerated to the highest energies (R.J. Tuffs, MPIK)



The Crab Nebula is the relic of a stellar explosion in the year 1054 A.D. It was the first strong source of very-high-energy gamma rays which was discovered in 1989 by the American Whipple Cherenkov telescope. (FORS Team, VLT, ESO)



The active galaxy Cygnus A – the small white spot at the centre – sends beams of matter across many hundreds of thousands of light years, generating turbulent 'plumes' when they are finally stopped, accelerating particles. (NRAO)

What is so interesting about gamma rays ?

High-energy gamma rays allow us to explore some of the most extreme, and most interesting objects in the Universe.

Most of the radiation we detect is thermal radiation, created by hot bodies such as our Sun. The hotter the source, the higher is the frequency of the radiation.

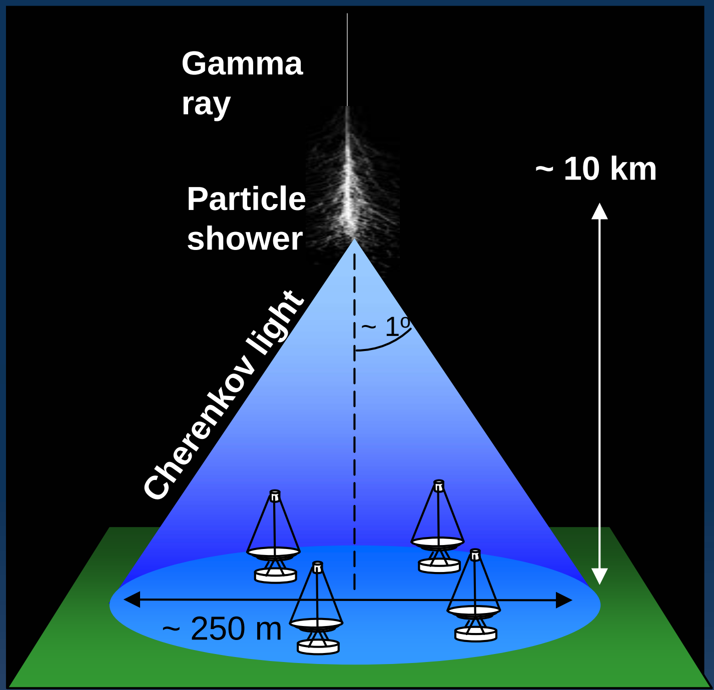
However, very basic considerations show that no material body can be hot enough to emit very-high-energy gamma rays; these must be generated in unusual, 'non-thermal' conditions. These occur in the aftermath of stellar explosions – supernovae – or in the vicinity of the giant black holes suspected to be at the cores of so-called active galaxies, which are continuously fed by stellar material from the surrounding galaxy.

Examples of such objects are shown on the left.

The H.E.S.S. telescopes teach us about the laws of nature under such extreme conditions.

Astronomy with Cherenkov Telescopes

The detection of high-energy gamma rays is not easy, since cosmic gamma rays interact with atoms in the Earth's atmosphere and are absorbed long before they reach the ground. They are therefore often studied with instruments on satellites orbiting the Earth, which detect the gamma rays before they enter the atmosphere. However, the most interesting very-high-energy gamma rays are so rare that it would take an impossibly large satellite to collect enough of them within a human being's lifetime.



The H.E.S.S. system uses four big telescopes, arranged in the corners of 120 m square, for best sensitivity.

The H.E.S.S. telescopes exploit the interactions of gamma rays in the atmosphere to detect them from the ground. When a gamma ray is absorbed, its energy is converted into secondary particles forming an 'air shower'. In this process, Cherenkov light is generated, a faint beam of blue light, which on the ground illuminates an area of about 250 m in diameter. The light flash is very short – it lasts only a few billionths of a second – and is far too faint to be detected by the human eye. However, a telescope with a large mirror to collect light and a light detector with a fast enough response can detect the Cherenkov light and 'see' the air shower generated by the high-energy gamma ray.

For a H.E.S.S. telescope, a gamma ray stopping in the atmosphere looks a bit like a meteor: an elongated track of light, which is basically a big pointer in the sky. However, from a single image one cannot tell exactly in which direction in space the track of a meteor or a gamma ray is pointing, and therefore one cannot locate the origin of the gamma ray.

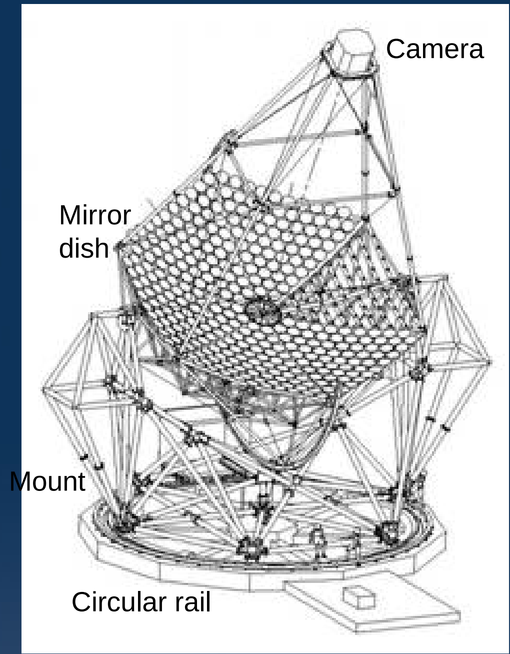
The solution is simple in principle, but quite complex once it comes down to the details: two images taken from different points provide a perception of space and depth. For humans, the 10 cm spacing of our eyes provides depth perception up to a distance of a few meters; in order to disentangle air showers at about 10 km height above the ground, one uses two (or more) telescopes spaced by about 100 m.

The H.E.S.S. Telescopes

Just like big optical telescopes, the H.E.S.S. Cherenkov telescopes consist of a *mirror* which focuses the incident light, and a light detector (the '*camera*') to record the images. A *mount* holds the *dish* which supports the tesselated *mirror* with its focal length of 15 m. The mount can be rotated on a big *circular rail*. Also the dish can be rotated, allowing the telescopes to point at stars and deep-sky objects, and to track them across the sky. The camera sits at the focal point of the mirror, supported by four camera masts.

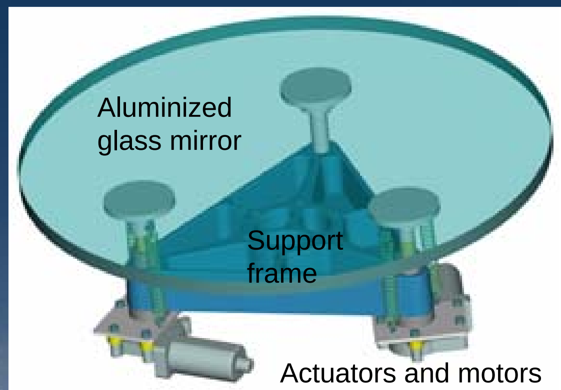
Mount and dish

Mount and dish are sturdy steel structures, designed for high rigidity. The steel structure which weighs 60 tones was designed by SBP, Stuttgart, Germany, and fabricated by NEC, Windhoek, Namibia based on production drawings from SCE, Windhoek. Computer-controlled drive systems steer the telescopes. It takes between one and three minutes to slew the telescope from the parking position to a sky object. A small optical guide telescope is attached to the telescope dish.



Mirrors

The diameter of the dish is more than 12 m, and the mirror area 107 m^2. Rather than using a single big mirror, which would both be very heavy and very costly, the mirror is composed of 380 round mirror tiles of 60 cm diameter. The mirrors consist of ground glass with an aluminized front surface. They were manufactured by companies in the Czech Republic and in Armenia; their production took about three years. Each individual mirror was checked in the laboratory for its optical quality. The 380 mirror tiles need to be aligned relative to each other with high precision. Each tile can be moved under remote control using two motor-driven actuators, which provide a precision of a few thousandth of a millimeter. To align the mirrors, the telescope is pointed at a star; a CCD camera in the center of the dish records the resulting image and moves the actuators for best image quality.



The H.E.S.S. Cameras

The cameras are the equivalent of a photographic film; they serve to record the short and faint light flashes generated by air showers. Electronic devices called photomultipliers are used to convert the light into electrical signals. The main difference to modern digital cameras is that the H.E.S.S. cameras allow much shorter exposure times, almost a million times faster. Each camera provides 960 image elements (pixels). The 960 pixels cover an area of about 1.4 m diameter – see the picture below – equivalent to a field of view of 5º on the sky (about 10 times the diameter of the moon).

To simplify construction and maintenance, the 960 light detectors are grouped into 60 'drawers' of 16 pixels each. Each drawer houses the photomultipliers and the electronics for signal processing. The drawers slide into the camera body; the rear section of the camera body contains power supplies and further digital processors. In total, the circuitry in the camera dissipates almost 5 kW of electrical power and almost 100 computer-controlled fans serve to control the air flow inside the camera.

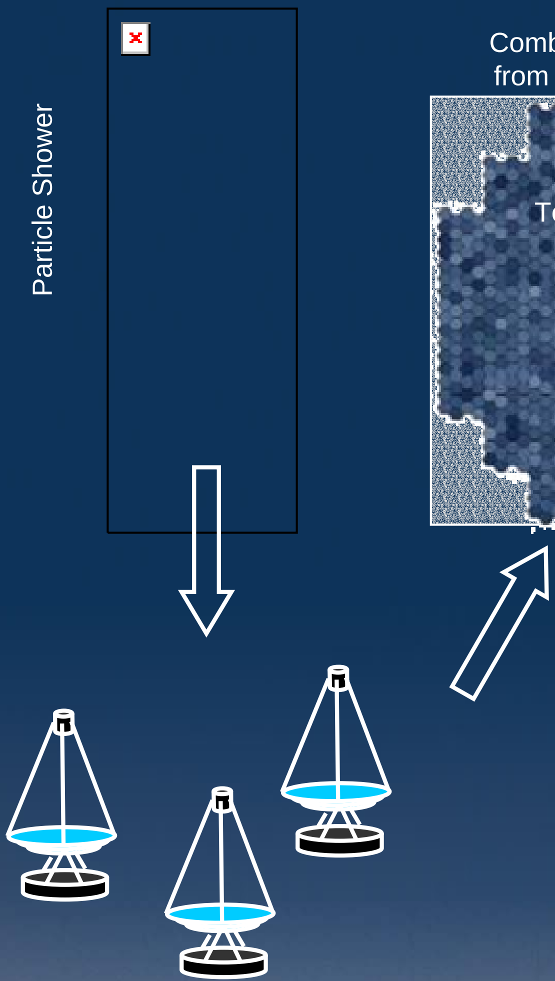
The electronics of each drawer samples and records the signal of the light detectors one billion times per second using custom-designed integrated circuits. A 'trigger' circuit checks the signals to see if they contain a good image of an air shower. If this happens, the data are saved and are sent via a fibre-optical link to the central recording station in the control building for further processing and analysis.

Observing with H.E.S.S.

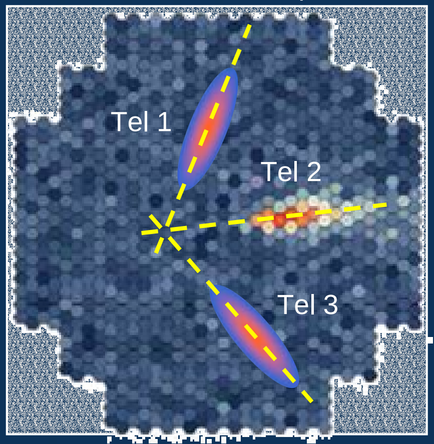
Since each high-energy gamma ray carries a large amount of energy – as much as 1000 billion quanta of normal visible light – they are produced at a much lower rate than starlight. To collect enough gamma rays to diagnose what is happening inside a cosmic particle accelerator, one needs to point the telescopes at this source for many hours; in extreme cases, data for one celestial object may be accumulated for many tens of hours. The H.E.S.S. telescopes are operated at night, if the moon is not visible (otherwise the sky is too bright to see the Cherenkov flashes), and will accumulate about 1000 hours of data each year. During a given night, the telescope may be pointed at up to a dozen different objects, as observation conditions are best near culmination.

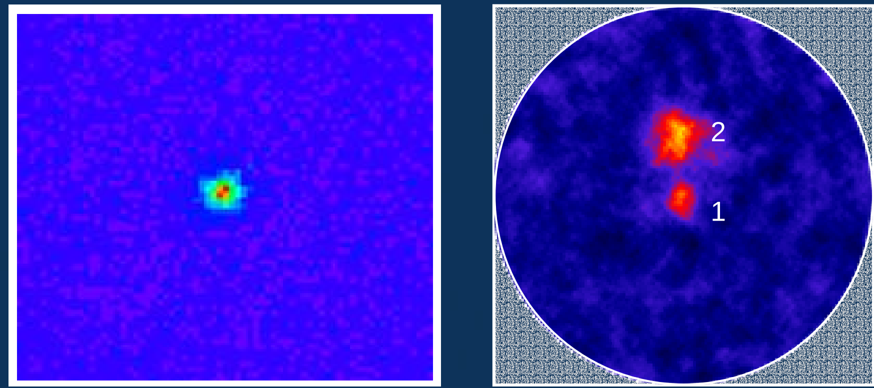
The control computers are able to steer the telescopes and to control data acquisition automatically throughout the night, slewing the telescopes from one object to the next according to a target list. However, a crew of two or three observers is present during observations, both to intervene in case of technical problems and to react in case of unexpected results. The observers usually come from the participating institutions; they come to the H.E.S.S. site for a full new-moon period of two to three weeks, and are assisted by local experts.

Images of the Sky with H.E.S.S.



Combination of images from three telescopes





Reconstructed sky map of gamma rays from the Crab Nebula, which appears as a point like source (left). The right panel shows a point like source of gamma rays (1) adjacent to a slightly extended source (2), at an angular distance of ~0.7 degrees.

Observing with the H.E.S.S. Cherenkov telescopes is quite different from observing with ‘normal’ optical telescopes. The images of *particle showers* (left panel) seen by the cameras are images of air showers, and not images of the gamma-ray sources in the sky. To generate a gamma-ray sky image, a computer program combines up to four images of the air shower and determines its direction, and also the amount of energy deposited in the atmosphere. The origin of the gamma ray is then plotted as point on a map of the sky. Many such points combined provide an image of the gamma-ray source, and one can determine the shape of the source, and the energy spectrum of the gamma rays (their ‘colour’). While a first ‘quick-look’ data analysis is carried out by the computers on the site, in most cases the final detailed analysis will be performed at one or more of the home institutions.

The History of H.E.S.S.

Building a major astrophysics experiment like H.E.S.S. is a long process from the idea to the first observations. As successor to the previous generation of experiments, namely CAT and HEGRA, the first idea of building such a telescope system was born in 1995, when these two experiments went into operation. Almost nine years later, in 2004, full operation of the new telescope system began.

1995 First idea to build a H.E.S.S. type experiment

1996 First design studies

1997 Official Letter of Intent for the H.E.S.S. experiment
- Constituting workshop on H.E.S.S.
- First visit to Namibia as potential site for the experiment

1998 Establishment of the HESS collaboration
- The Khomas Highland of Namibia prime candidate for the site
- Development work on telescope components
- Letter of support from the President of the Republic of Namibia

1999 Cooperation agreement between UNAM and MPIK
- Initiation of bidding process for the steel structures
- Start of construction of telescope components and cameras

2000 Exchange of diplomatic notes between Germany and Namibia concerning H.E.S.S.
- Namibian stamp showing H.E.S.S. Telescopes

- Start of construction of the steel structures in Namibia
- Completion of telescope foundations

2001 Steel structure of the first and second telescope on site
- Infastructure on site with workshops and residence building complete

2002 Start of operation of first telescope and astrophysical data taking
- Inauguration of the first telescope of H.E.S.S.

2003 Installation and commissioning of telescopes 2,3 and 4
- Initial stereoscopic observations with 2 and 3 telescopes
- Report of first physics results at international conferences

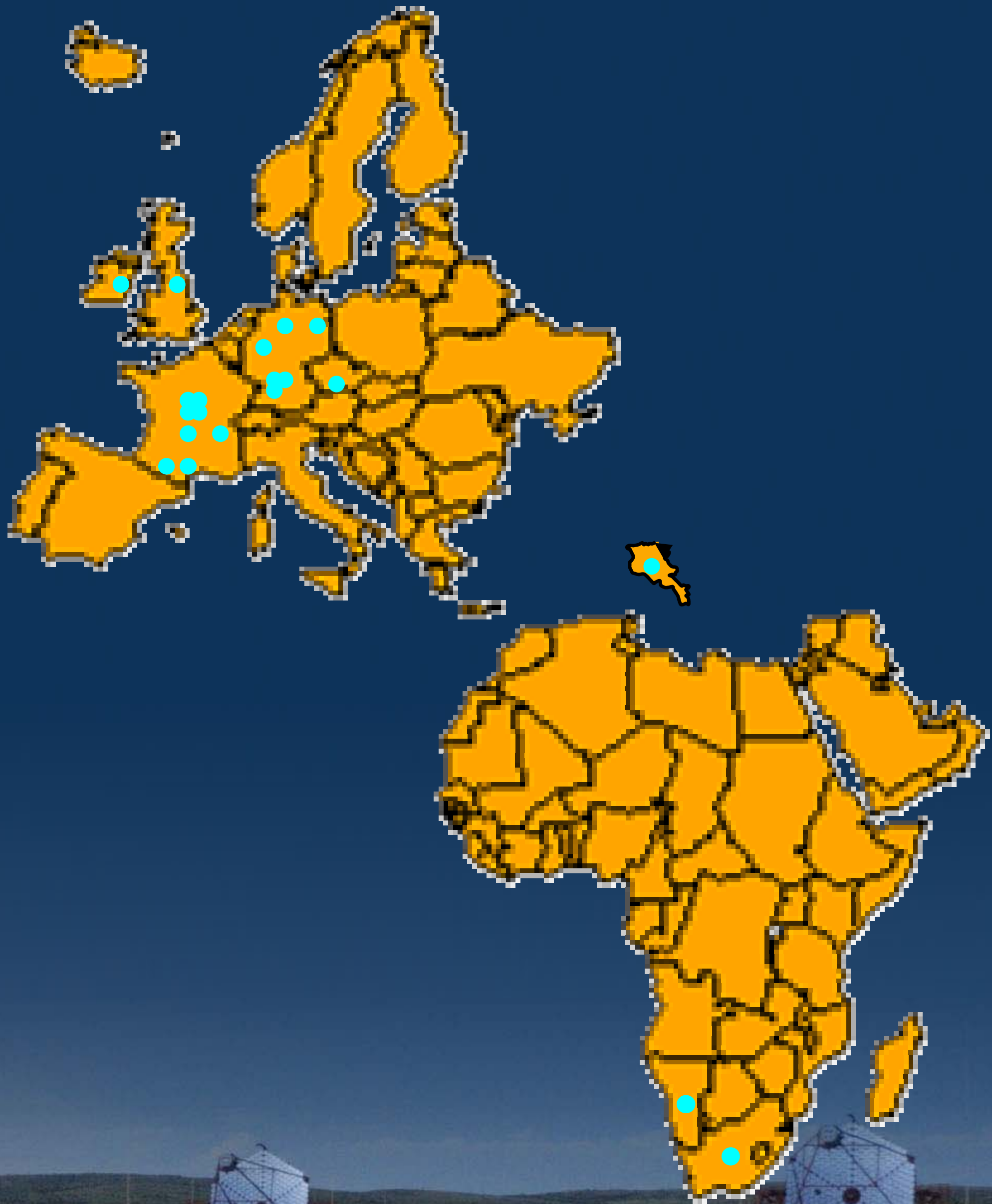
2004 Routine physics observations with H.E.S.S.
- First new gamma-ray sources detected with H.E.S.S.
- Official start of the H.E.S.S. Experiment (Phase I)

The H.E.S.S. Collaboration

H.E.S.S. : An international approach

The H.E.S.S. telescopes are built and operated by an international collaboration of about 100 scientists from eight different countries.
The participating institutes are:

Max-Planck-Institut für Kernphysik, Heidelberg, Germany
Humboldt Universität Berlin, Germany
Ruhr-Universität Bochum, Germany
Universität Hamburg, Germany
Landessternwarte Heidelberg, Germany
Laboratoire Leprince-Ringuet, Ecole polytechnique, Palaiseau, France
PCC/APC College de France, Université Paris VII, France
LPHNE, Universités Paris VI - VII, France
LAM, Université de Grenoble, France
GAM, Université Montpellier II, France
CESR, Toulouse, France
Sap, DAPNIA/CEA Saclay, France
Observatoire de Paris-Meudon, DAEC, France
Durham University, U.K.
Dublin Institute for Advanced Studies, Dublin, Ireland
Charles University, Prag, Czech Republic
Yerevan Physics Institute, Yerevan, Armenia
University of Namibia, Windhoek, Namibia
NW University, Potchefstroom, Republic of South Africa
LEA, supported by CNRS and MPG

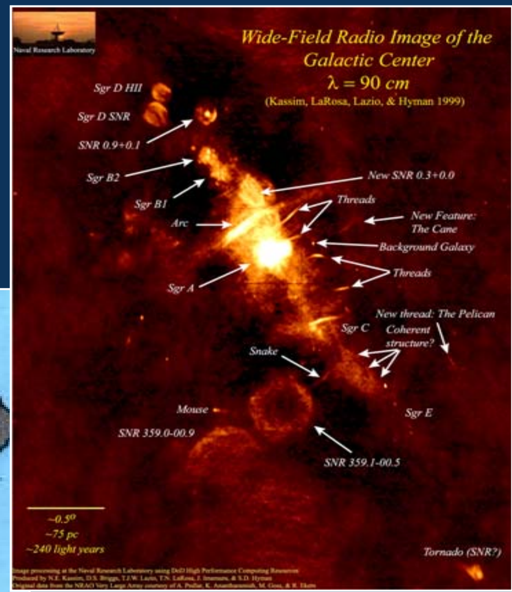


H.E.S.S. in Namibia

Why is H.E.S.S. located in Namibia ?

- The Gamsberg area has long been known for its excellent conditions for optical astronomy, with many clear nights and dark skies.
- A location in the Southern Hemisphere offers optimal viewing conditions for many objects in our Galaxy. In particular, the Galactic Centre is passing almost through the zenith.
- The mild climate allows the operation of the telescopes without protective enclosures.

A key component in the decision for the Gamsberg site was the participation of the University of Namibia and the very positive response of the Namibian government. Construction and operation of H.E.S.S. is defined and supported by an exchange of notes between the Namibian and German governments, and by cooperation agreements between the University of Namibia and H.E.S.S. institutes.



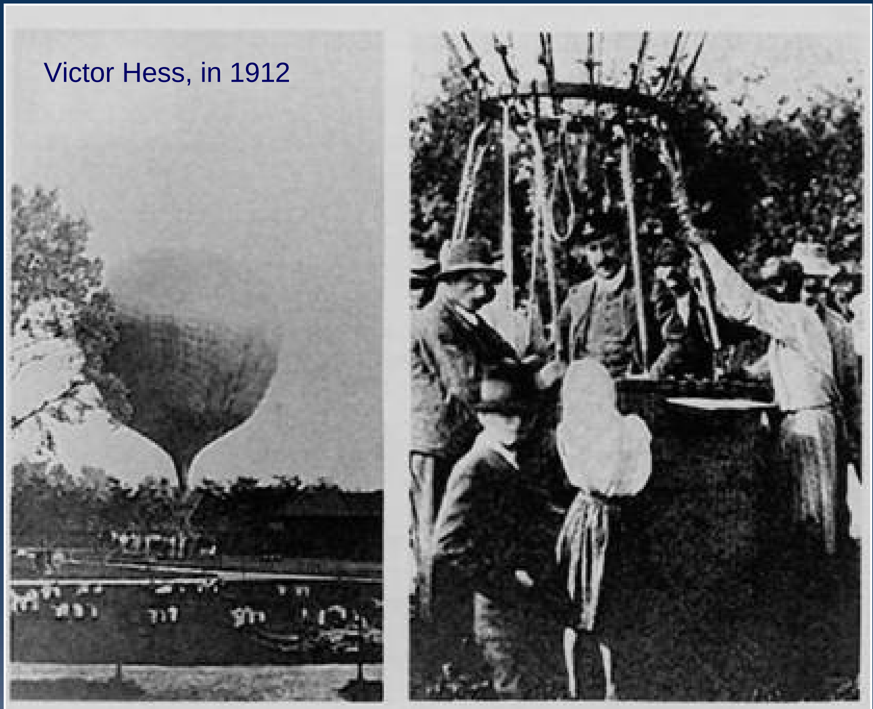
Education and training

H.E.S.S. provides an ideal training ground for students from Namibia and abroad, covering modern technology, techniques for data handling and data analysis, and cooperation in a multi-national enterprise.

What does *H.E.S.S.* stand for ?

H.E.S.S. is an acronym that stands for "High Energy Stereoscopic System" and characterizes the key features of the instrument.

At the same time, the name honours VICTOR F. HESS, the Austrian physicist, born in 1883, and emigrated to the United States in 1938. Hess, whose discovery of cosmic rays made him the co-recipient of the 1936 Nobel Prize in Physics, has in the course of more than fifty years made basic contributions to the understanding of radiation and its effects on the human body. In ten balloon ascents between 1911 and 1913, he detected ionizing radiation; from the observation that the intensity increased with height, he deduced that this radiation was incident from outer space. Cosmic rays and their sources have been the subjects of intense research since then.



Victor Hess, in 1912

Further information

More information about the H.E.S.S. project can be found on the H.E.S.S. web pages:

http://www.mpi-hd.mpg.de/HESS

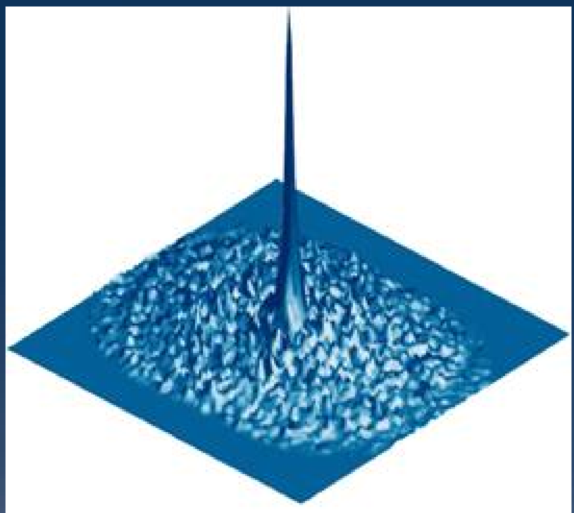
Other interesting resources on astrophysics include:

- http://antwrp.gsfc.nasa.gov/apod/ : each day a new astro image explained, plus a great library of past images
- http://heritage.stsci.edu/ : the Hubble heritage collection of the most fascinating images from the Hubble space telescope
- http://heasarc.gsfc.nasa.gov/ : the NASA pages on high-energy astrophysics
- http://www.stsci.edu/astroweb/astronomy.html : Astroweb - astronomy/astrophysics on the internet

First Science: The Performance of H.E.S.S.

One of the motivations for building the new experiment was to improve the sensitivity with respect to previous experiments by a factor of about 10 and at the same time to lower the energy threshold down to about 100 GeV.

In order to predict the performance of such an experiment and to optimize the design of the telescopes before they were built, extensive computer simulations were performed. The verification of the simulations can only be done after the experiment becomes operational, by comparing the predictions with measurements.



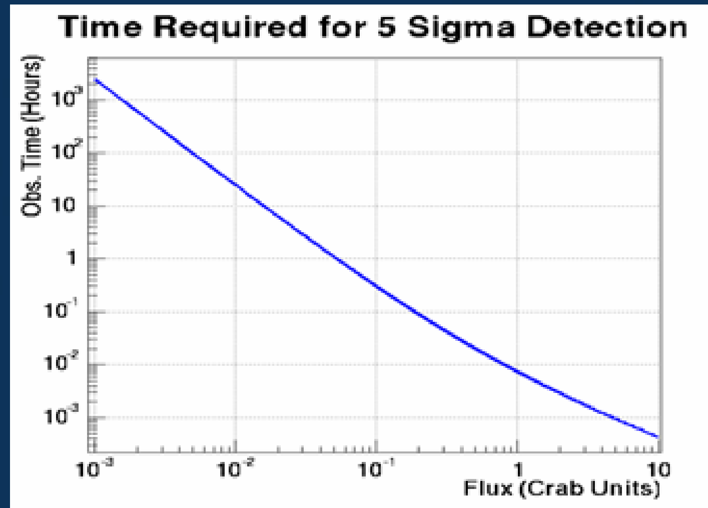
Sky map of reconstructed gamma rays from the Crab Nebula obtained with H.E.S.S. . By comparing the results with simulations the following performance parameters of H.E.S.S. could be confirmed, showing that H.E.S.S. has reached the design goals:

Energy threshold: 100 GeV

Energy resolution: ~ 15 %

Angular resolution: < 0.1 deg

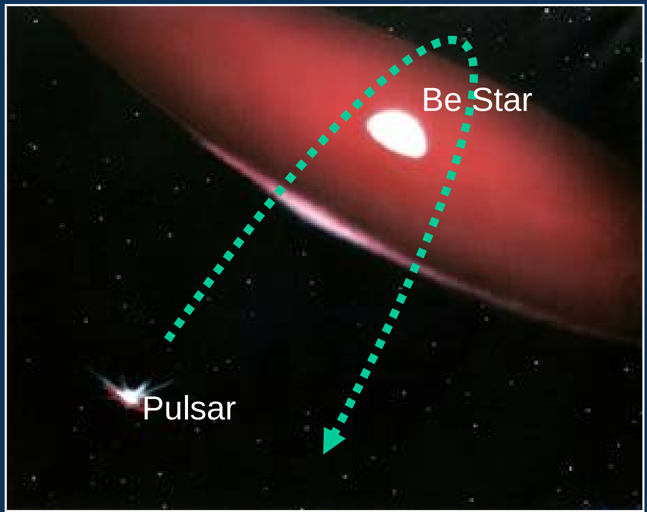
H.E.S.S detects sources 100 times faster than previous experiments



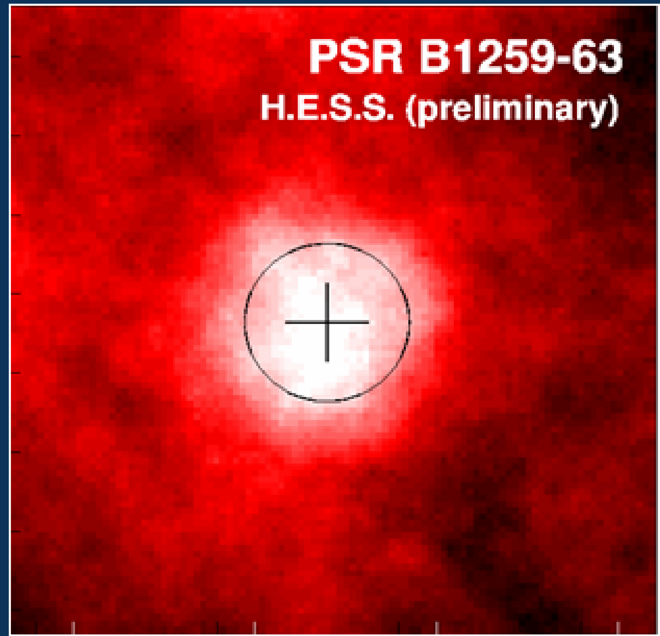
It is common practice in this field of astrophysics to express the sensitivity of an experiment, i.e. the capability to detect sources, in terms of the observation time needed to see a source of given strength. The strength of a source is typically expressed in units of the flux from the Crab Nebula ("Crab Units"). As we can see from the diagram, H.E.S.S. only needs about 30 seconds to detect a Crab like source. For weak sources H.E.S.S. needs a factor 100 less observation time than any previous experiment. This capability of H.E.S.S. to detect sources opens a new window on the high energy universe.

Gamma Rays from a Binary System

Binary system of a Be star and a pulsar



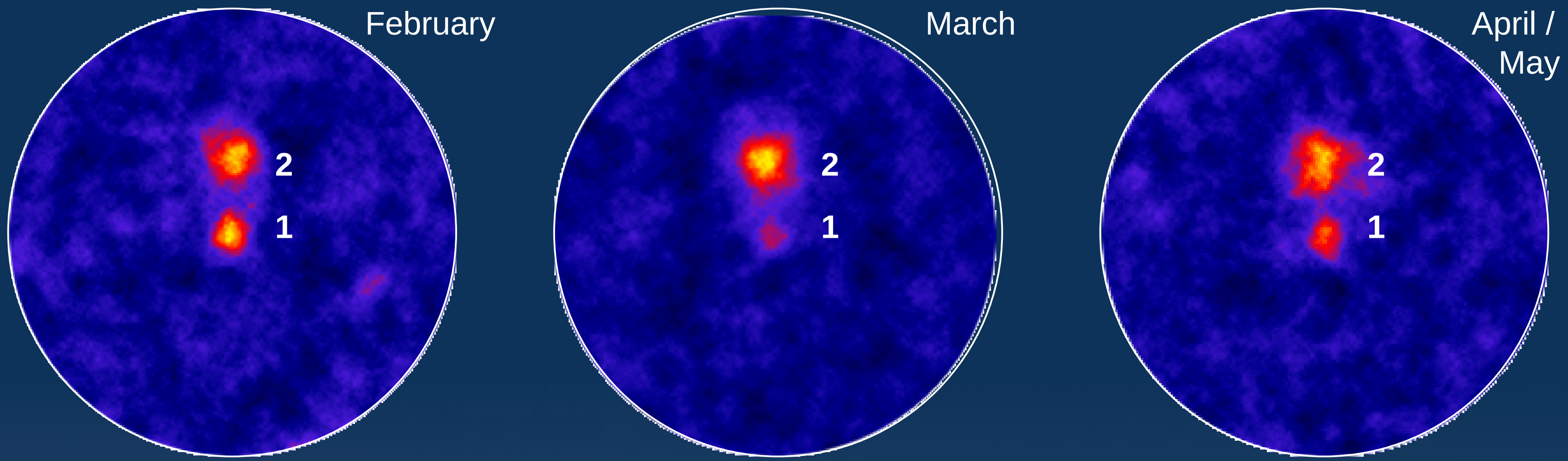
The millisecond pulsar PSR B1259-63 is one of only two pulsars, which are known to form a binary system. In the case of PSR B1259-63 the companion SS2883 is a very massive “Be” star, with a mass about 10 times as big as the mass of our sun and a diameter about 6 times larger. The Be star ejects material (gas) from its surface, which forms a large stellar disk in a plane around its equator. The millisecond pulsar orbits in a highly excentric orbit around the Be star, with a period of 3.5 years. At periastron, which is the closest point of approach between the pulsar and the Be star, the distance between the two objects is only about 20 times the diameter of the star. On its path around the Be star, the pulsar passes through the disk of material and intense interactions with material of the disk and with the stellar photon field are expected, which in turn should lead to the generation of high energy gamma rays.



First observations of PSR B1259 have been performed with H.E.S.S. from February until May, 2004. A clear gamma-ray signal was found after a few hours of observation time. Since the distance of the binary system is about 4900 light years, the emission of gamma rays appears to be point-like within the angular resolution of the H.E.S.S. telescope system. This detection at energies above 200 GeV is the first discovery of a binary system with a pulsar, emitting high energy gamma rays.

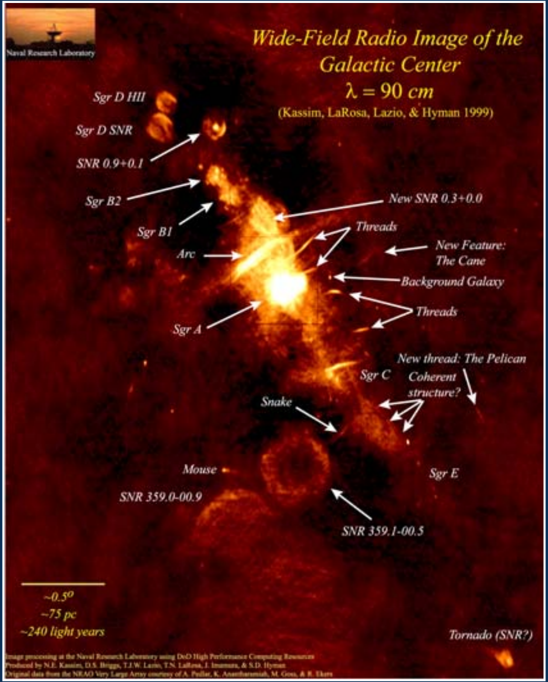
A Mystery Source of Gamma Rays

Cherenkov telescopes do pointed observations, targeting at individual objects from which one hopes to detect gamma-ray emission. The H.E.S.S. stereoscopic system provides a field of view with a diameter of about 4 degrees on the sky. This means that whenever a strong enough source of high energy gamma rays is within this field of view, gamma rays can be detected, even if it was not the primary target of the observation.



The three figures above show the sky maps in gamma rays of the region around the binary system PSRB1259-63 which was the target for observations during February to May 2004. The signal from the binary system with its varying intensity is seen in the centre of the field of view (spot 1). However, during all observations a second “hot spot” (spot 2) was apparent, which can be attributed to another new, yet unknown source of high energy gamma rays. Detailed investigations of the emission characteristics of the hot spot have shown, that the source has a constant emission intensity and is extended with a diameter of about 0.2 degrees. So far, no counterpart has been found in any other energy range, which makes this “hot spot” the first unidentified TeV source discovered by the H.E.S.S. experiment.

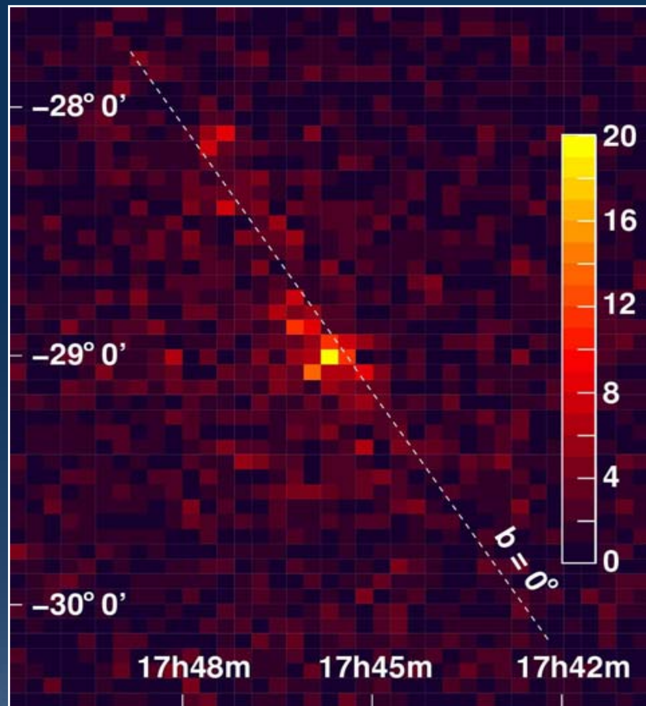
The Galactic Centre



One of the most exciting regions in the sky is the central part of our Galaxy. Within a few parsecs around the Galactic Centre there is a real “playground” for astrophysicists, consisting of a large number of young, massive and evolved stars, of diffuse hot gas and ionized gas streams, several powerful supernova remnants and finally even a supermassive black hole with a mass of about 2.6 million times that of our Sun. Quite a number of possible sources of high energy gamma rays are located within this small volume. This includes the hypothetical gamma-ray emission from Dark Matter particles concentrated in this region.

Radio Image of the Centre of our Galaxy (NRAO/VLA)

Gamma-ray image of the Galactic Centre region, obtained with two H.E.S.S. telescopes during commissioning



The possibility of observing the Galactic Centre under optimum conditions was one of the reasons for building the H.E.S.S. experiment in the Southern Hemisphere in Namibia. First observations were performed in 2003 during the construction of the telescope system. A strong high energy gamma-ray signal from the region of Sgr A* was detected. Due to the very good source localization of H.E.S.S., the position of the signal could be determined with an accuracy of about 30 arcseconds. Within this accuracy the origin of the gamma-ray signal is consistent with the position of Sgr A*, the very centre of our Galaxy. Further observations will be performed with the full system of H.E.S.S. phase I.

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